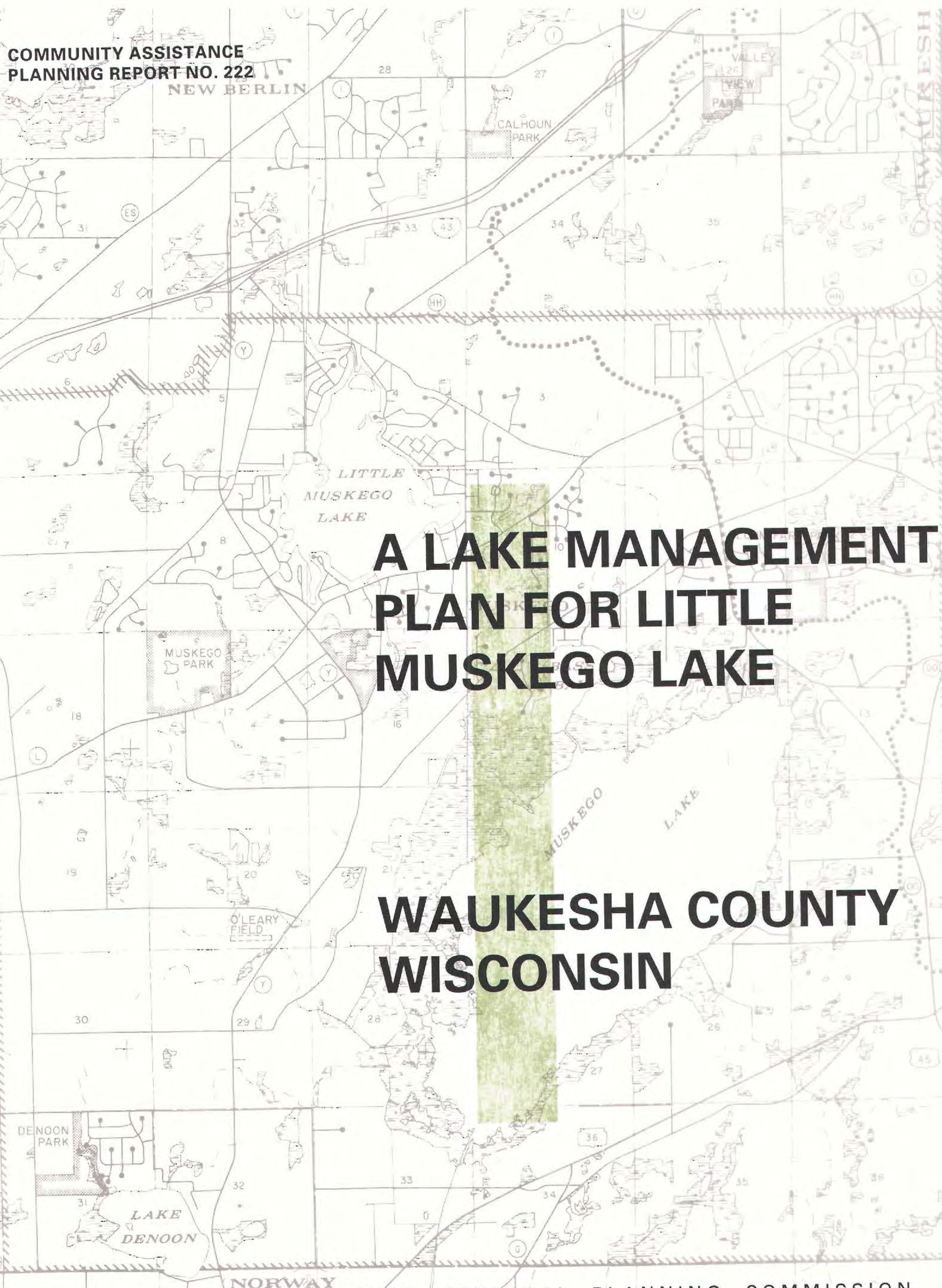
COMMUNITY ASSISTANCE
PLANNING REPORT NO. 222

A LAKE MANAGEMENT PLAN FOR LITTLE MUSKEGO LAKE

WAUKESHA COUNTY WISCONSIN



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NUMBER 222

A LAKE MANAGEMENT PLAN FOR LITTLE MUSKEGO LAKE
WAUKESHA COUNTY, WISCONSIN

Prepared by the

Southeastern Wisconsin Regional Planning Commission
P. O. Box 1607
Old Courthouse
916 N. East Avenue
Waukesha, Wisconsin 53187-1607

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June 1996

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June 27, 1996

TO: All Units and Agencies of Government and Citizen Groups Involved in Water Quality and Water Use Management of Little Muskego Lake

Over the past approximately 10 years, agencies such as U. S. Geologic Survey and the Southeastern Wisconsin Regional Planning Commission, at the request of the Little Muskego Lake Management District, have been conducting lake management-related data collection and analysis efforts. These efforts have now been integrated into a lake management plan for Little Muskego Lake, which plan is intended to address the water quality, recreational use, and natural resource problems of the Lake. The preparation of the plan was a cooperative effort by the City of Muskego, the Little Muskego Lake Management District, the Little Muskego Lake Association, Inc., the U. S. Geological Survey, the Wisconsin Department of Natural Resources, and the Southeastern Wisconsin Regional Planning Commission.

This report documents the recommended lake management plan. The report describes the physical and biological properties of Little Muskego Lake and its watershed; the quality of the Lake waters and the factors affecting that quality, including land use and management practices; the recreational use of the Lake; and the shoreline conditions around the Lake and sets forth recommended management measures.

The plan presented in this report is intended to provide a guide to the making of development decisions concerning the wise use and management of Little Muskego Lake as an aesthetic and recreational asset of immeasurable value. Accordingly, adoption of the plan presented herein by all concerned water use management agencies is urged. The Regional Planning Commission stands ready to assist the various units and agencies of government concerned in adopting and carrying out over time the plan recommendations.

Respectfully submitted,

Kurt W. Bauer
Executive Director

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Chapter I

INTRODUCTION

The 101 major inland lakes within Southeastern Wisconsin constitute one of the most valuable natural resources of the Region. Concern over the deteriorating condition and increasing use of these lakes for recreational purposes led the State Legislature, in 1974, to enact legislation enabling lake-area residents and others to form inland lake protection and rehabilitation districts. The purpose of these special-purpose units of local government is to carry out programs that will protect and rehabilitate the valuable natural resources represented by the lakes.

Little Muskego Lake, a 506-acre through-flow lake, is one of these resources, located on a tributary of the Fox River in U. S. Public Land Survey Sections 4, 8, and 9, Township 5 North, Range 20 East, City of Muskego, Waukesha County. Entirely within the City of Muskego, Little Muskego Lake is subject to the effects of continued urbanization within the watershed and to a heightened demand for water-based recreation. Realization that increased development and demands on lake use could cause problems in terms of deteriorating water quality and degradation of the overall lake ecosystem led to the formation of the Little Muskego Lake Management District by the City of Muskego in 1974.

Planning efforts relating to Little Muskego Lake have included the preparation of a regional water quality management plan,[1] a subsequent nonpoint pollution abatement plan for the Muskego–Wind Lakes watershed,[2] and a stormwater management plan for the City of Muskego.[3] These plans identified surface water quality problems within the Region and the Fox River watershed, identified the major sources of pollution, and provided recommendations for abating those sources to achieve specified water use objectives and attendant water quality standards. One of the recommendations set forth in the regional plan was that there be a reduction of about 50 percent in the urban and 75 percent in the rural nonpoint source pollutant loadings to Little Muskego Lake in order to improve water quality conditions. The Wisconsin Department of Natural Resources (DNR) initiated a nonpoint source pollution abatement priority watershed planning program for the Muskego–Wind Lakes watershed in 1993. That program provided more specific recommendations for achieving the planned nonpoint source pollutant loading reductions to Little Muskego Lake, which were consistent with the recommendations set forth in the regional water quality management plan. The priority watershed plan completion made State funds available to landowners and municipalities to install and maintain nonpoint source pollution abatement measures and practices in portions of the watershed—including Little Muskego Lake—where major nonpoint pollution sources had been identified. The project implementation period for this program is scheduled to end in 2002. An important element of this implementation was the completion of the above-referenced stormwater management plan for the City of Muskego, the essential elements of which include ongoing enforcement of the City's construction erosion control ordinance, promulgation of ordinances requiring stormwater management measures, development of a stormwater management master plan for the City, and formulation of a funding mechanism for the construction and maintenance of stormwater management measures. However, control of nonpoint pollution sources in the watershed is only one part of a comprehensive water quality management effort for the Lake; in-lake management measures are also considered to be important for water quality management in Little Muskego Lake.

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[1]*SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000, Vol. 2, Alternative Plans, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, February 1979; and SEWRPC Memorandum Report No. 93, A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, March 1995.*

[2]*DNR Publication No. WR-340-93, A Nonpoint Source Control Plan for the Muskego-Wind Lakes Priority Watershed Project, Wisconsin Department of Natural Resources, Madison, Wisconsin, October 1993.*

[3]*City of Muskego: Phase 1 Stormwater Management Plan, Rust Environment & Infrastructure, Milwaukee, Wisconsin, April 1995.*

Prior to and following the designation of the Muskego–Wind Lakes watershed as a priority lakes watershed, the Little Muskego Lake Management District undertook a complementary program of research to evaluate water quality conditions and identify specific management measures needed to improve the water quality and recreational use potential of Little Muskego Lake. This program involved a cooperative effort between the U. S. Geological Survey (USGS), the City of Muskego, the DNR, the Southeastern Wisconsin Regional Planning Commission, the Little Muskego Lake Management District, and the Little Muskego Lake Association, Inc. The results of the hydrologic and water quality monitoring program, conducted by the USGS from October 1986 through September 1993 in order to determine the existing water budget and water quality of the Lake, and to quantify pollutant loadings to the Lake, were available for use in the preparation of this plan, as were the findings of watershed, aquatic plant, and sediment surveys conducted by private consultants under contract to the Little Muskego Lake Association, and the stormwater management plan prepared by private consultants under contract to the City of Muskego. This plan also incorporates pertinent data collected, and recommendations made, under the above-referenced Muskego–Wind Lakes priority watershed plan and in the Wind Lake management plan published in 1991 by the Regional Planning Commission.[4] In addition, this plan incorporates fishery data and recommendations provided by the DNR staff specifically for the Little Muskego Lake management plan.

The primary objectives which this plan is intended to achieve are 1) reduction in sediment loading to the Lake and control of sediments within its basin; 2) reduction in contaminant loadings to the Lake and control of nutrients, oxygen-consuming substances, and salts within its basin; 3) maintenance of a healthy aquatic ecosystem and reduction in the severity of nuisance resulting from recurring excessive aquatic macrophyte and algal growths; 4) development of the lakeshore and watershed in such a way as to contribute to the maintenance of a healthy aquatic community; 5) promotion of public awareness of the Lake as an aquatic ecosystem; and 6) improvement of the aesthetic characteristics of the Lake and enhancement of opportunities for water-based recreational activities. These objectives are intended to complement broader City objectives relating to enhancement of the economic development potential of the area and the quality of life in Muskego. Particularly important in this respect is the enhancement of the central business district of the City, the setting for which is provided by Little Muskego Lake. This plan should serve as a practical guide over time for achieving these objectives in a technically sound manner.

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[4]*SEWRPC Community Assistance Planning Report No. 198, A Management Plan for Wind Lake, Racine County, Wisconsin, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, December 1991.*

Chapter II

PHYSICAL DESCRIPTION

INTRODUCTION

The physical characteristics of a lake and its watershed are primary determinants of the water quality conditions in the lake. Such characteristics as watershed topography, lake morphometry, and local hydrology ultimately influence water quality conditions and the composition of plant and fish communities within the lake; therefore, these characteristics must be considered in any sound lake management planning process. Accordingly, this chapter provides pertinent information on the physical characteristics of Little Muskego Lake, its watershed, and the climate and hydrology of the Little Muskego Lake study area. Subsequent chapters deal with the chemical and biological environments of the Lake.

LAKE BASIN

Little Muskego Lake is a flow-through lake with extensive shallow margins and a single deep basin. Little Muskego Lake has a surface area of 506 acres. The Lake has been modified in both area and depth by a dam, originally constructed in 1838 at the outlet and rebuilt several times since, most recently in 1974 and 1995; this dam raised the original water level by approximately eight feet.[1] At the time of the 1995 rebuilding, the dam spillway was modified to allow the Lake to be drawn down at a rate of one inch per hour. The original basin of Little Muskego Lake was formed as the Michigan and Green Bay Lobes of the continental glacier retreated from Southeastern Wisconsin approximately 12,500 years ago, during the late Wisconsin stage of glaciation. The Lake, like many others in the Region, lies in a depressed area of this interlobate, or "kettle moraine," area that is characterized by unconsolidated glacial sediments consisting predominantly of silty-clay till and sandy outwash deposits. These glacial sediments, ranging in thickness from 100 to 200 feet, are underlain by Silurian dolomite and are overlain by organic deposits formed after glaciation.

Jewel Creek provides the major inflow to the Lake and enters via Linnie Lac from the north. The Creek exhibits continuous flow and has a resident fish population. As already noted, outflow from the Lake is controlled by a dam and a fixed-height overflow structure, both located on the southern side of Little Muskego Lake just upstream of CTH L. The dam overflow discharges to the south through a concrete culvert into Muskego Creek and thence into Big Muskego Lake, which is located south and east of CTH J. Big Muskego Lake discharges via the Muskego Canal to Wind Lake and ultimately, via the Wind Lake Drainage Canal, to the Fox River at the Village of Rochester in Racine County, about 10.4 stream miles downstream from the Little Muskego Lake outlet.

Of the approximately 101 major lakes in the seven-county Southeastern Wisconsin Region, Little Muskego Lake ranks in the upper third in terms of its surface area. Basic hydrographic and morphometric data on the Lake are presented in Table 1. About 31 percent of the Lake's area is less than four feet deep, 32 percent is between four and eight feet deep, 6 percent is between eight and 12 feet deep, 5 percent is between 12 and 20 feet deep, and 26 percent is deeper than 20 feet. The mean depth is 14 feet, and the maximum depth is 65 feet. Little Muskego Lake is 1.32 miles long, north to south, and 1.04 miles wide at its widest point. The shoreline length is 7.1 miles; and the shoreline development factor is about 1.4, indicating that the shoreline is fairly regular and about one-third longer than the shoreline of a circular lake of the same area. The Lake has a volume of approximately 7,170 acre-feet. The bathymetry of the Lake is illustrated in Map 1.

Lake Bottom Substrate

Lake bottom sediment types were surveyed in 1967 by a professional engineer, Mr. Casimir Kendziorski, Jr.; and more recently, in part, by Midwest Engineering Services, Inc.[2] The findings of these surveys

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[1]*Wisconsin Department of Natural Resources, Environmental Impact Statement: Proposed Little Muskego Lake Rehabilitation Project, DNR, Madison, Wisconsin, January 1980.*

[2]*Casey Kendziorski, Jr., P.E., Feasibility Report, Removal of Sediment and Muck from Little Muskego Lake, Milwaukee, Wisconsin, December 1967; Midwest Engineering Services, Inc., Project Report No. 7-31010-2, Lake Sediment Exploration and Analysis: Little Muskego Lake, Muskego, Wisconsin, Waukesha, Wisconsin, May 1993.*

are summarized on Map 2. Virtually all of the bottom is covered by muck; sand or silty sand was found only in isolated areas of the bottom sampled: along the southern shoreline and in the north central portion of the main lake basin. The depths of the soft sediments ranged from two feet in the eastern embayment to more than 12 feet in some of the muck areas in the main lake basin.

Shoreline Conditions

Erosion of shorelines results in the loss of riparian land, damage to shoreland infrastructure, and interference with access and lake use. Such erosion is usually caused by wind-wave erosion, ice movement, or motorized boat traffic. A survey conducted by Regional Planning Commission staff during the summer of 1993 identified shoreland protection structures around the Little Muskego Lake shoreline. Some 46 bulkheads, vertical walls; 23 revetments, sloping stone walls; and 10 beaches were recorded, in addition to 48 areas where riprap had been used to stabilize the shoreline, as shown on Map 3. Most bulkheads were of concrete or wooden construction, although some appeared to have been grouted revetments given the size of the stone used. Most were in a good state of repair, although a few minor problems were observed. Commonly observed problems included cracking and collapse of the structures, possibly due to toe scouring associated with water level variations and wind-wave and ice action along the shoreline. Nearly all of the shoreland of Little Muskego Lake have been provided with some form of shoreline protection, although most of the inlet area and islands were unprotected except for extensive growths of aquatic vegetation as described in Chapter V. Few erosional sites were noted.

WATERSHED CHARACTERISTICS

The Little Muskego Lake direct drainage area shown on Map 4, defined for the purposes of this plan as the area which drains directly to the Lake and indirectly to the Lake via the portion of Jewel Creek downstream of the Linnie Lac inlet, is 2,214 acres, or 3.5 square miles. Because Jewel Creek provides the only inflow to Little Muskego Lake and because of its importance to the hydrology and water quality of the Lake, the area drained by Jewel Creek directly upstream of Little Muskego Lake but below the Linnie Lac inlet has been included in this area, as shown on Map 4. The total drainage area, including the entire area upstream of Muskego Lake drained by Jewel Creek, is 7,537 acres, or 11.8 square miles, and is shown on Map 5. Little Muskego Lake has a watershed-to-lake ratio of 14.5 to 1.

Table 1

HYDROGRAPHY AND MORPHOMETRY OF LITTLE MUSKEGO LAKE: 1993

Parameter	Measurement
Size	
Lake Surface Area	506 acres
Total Drainage Area	7,537 acres
Direct Drainage Area	2,214 acres
Volume	7,170 acre-feet
Residence Time[a] (1986-93 USGS study period)	0.9 year
Shape	
Maximum Length of Lake	1.3 miles
Length of Shoreline	7.1 miles
Maximum Width of Lake	1.0 mile
Shoreline Development Factor[b]	1.4
Depth	
Percentage of Surface Area	
Less than Three Feet	27 percent
Three to 20 Feet	47 percent
Greater than 20 Feet	26 percent
Mean Depth	14 feet
Maximum Depth	65 feet

[a] *Residence time: time required for a volume equivalent to full volume replacement by inflowing waters to enter a lake.*

[b] *Shoreline development factor: ratio of shoreline length to that of a circular lake of the same area.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

The hydrology of Little Muskego Lake has been extensively modified by the construction of the Linnie Lac impoundment upstream of Little Muskego Lake, and the construction of the dam at the Lake's outlet to the Muskego Canal and Big Muskego Lake. Map 6 reproduces the original 1836 plat of the U. S. Public Land Survey for the Little Muskego Lake area. A comparison of the present surface area of Little Muskego Lake, about 506 acres as shown on Map 4, with the surface area of the Lake in 1836, about 231 acres as shown on Map 6, graphically indicates the extent to which the Lake's area has expanded since the creek was dammed in 1838. According to newspaper accounts, when the first European settlers arrived in the area that is now the City of Muskego, the Lake was surrounded on the west and north by swamp through which the Muskego Creek, now known as Jewel Creek, meandered as it flowed generally

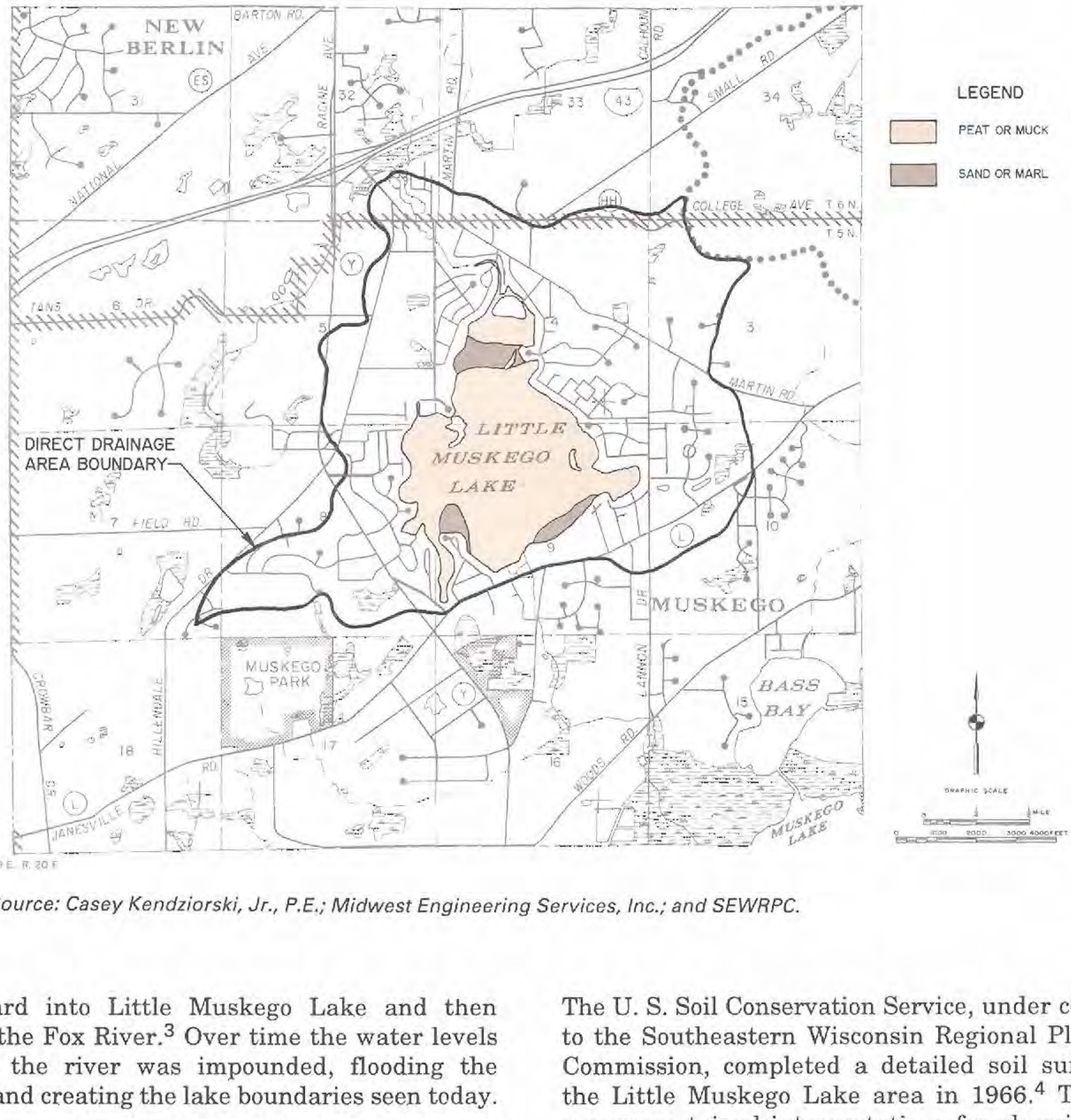
Map 1

BATHYMETRIC MAP OF LITTLE MUSKEGO LAKE

Source: SEWRPC.

Map 2

BOTTOM SUBSTRATE IN LITTLE MUSKEGO LAKE: 1993



Source: Casey Kendziorski, Jr., P.E.; Midwest Engineering Services, Inc.; and SEWRPC.

southward into Little Muskego Lake and then toward the Fox River.[3] Over time the water levels rose as the river was impounded, flooding the swamp and creating the lake boundaries seen today.

Soil Types and Conditions

Soil type, land slope, and land use and management practices are among the more important factors determining lake water quality conditions. Soil type, land slope, and vegetative cover are also important factors affecting the rate, amount, and quality of stormwater runoff. The soil texture and the shape and stability of aggregates of soil particles, expressed as soil structure, influence the permeability, infiltration rate, and erodibility of soils. The land slope is also an important determinant of stormwater runoff rates and of susceptibility to erosion.

The U. S. Soil Conservation Service, under contract to the Southeastern Wisconsin Regional Planning Commission, completed a detailed soil survey of the Little Muskego Lake area in 1966.[4] The soil survey contained interpretations for planning and engineering applications and for agricultural applications. Using the regional soil survey, an assessment was made of hydrologic characteristics of the soils in the drainage area of Little Muskego Lake.

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[3]*The Democrat, March 17, 1888; Waukesha Freeman, February 5, 1891.*

[4]*See SEWRPC Planning Report No. 8, The Soils of Southeastern Wisconsin, June 1966.*

Map 3

SHORELINE CONDITIONS ON LITTLE MUSKEGO LAKE: 1993

LEGEND

- BEACH
- RIPRAP
- NATURAL
- BULKHEAD
- REVETMENT

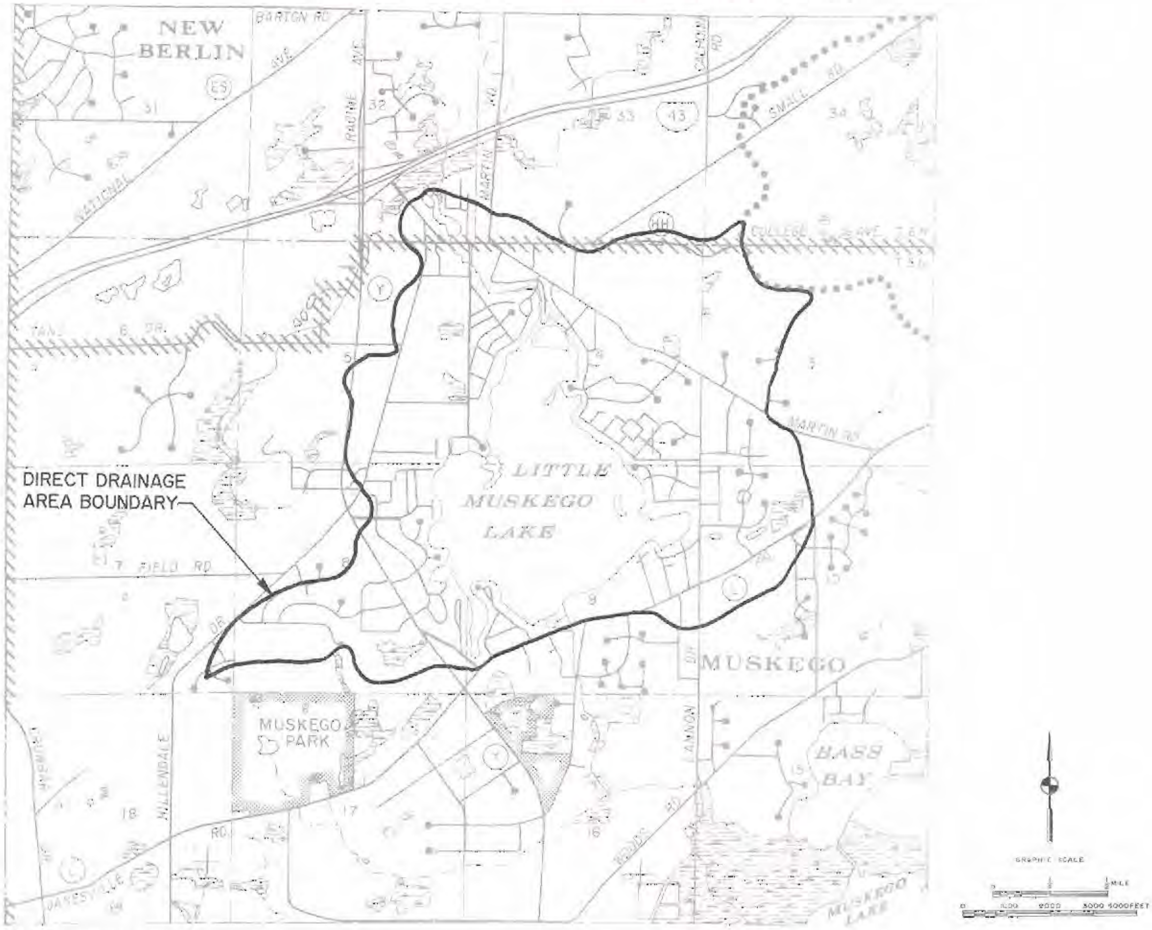
GRAPHIC SCALE

0 400 800 1200 FEET

Source: SEWRPC.

Map 4

LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA



Source: SEWRPC.

The suitability of the soils for urban residential development was assessed using three common development scenarios: development with conventional onsite sewage disposal systems (septic tank systems), alternative onsite sewage disposal systems, and public sanitary sewers.

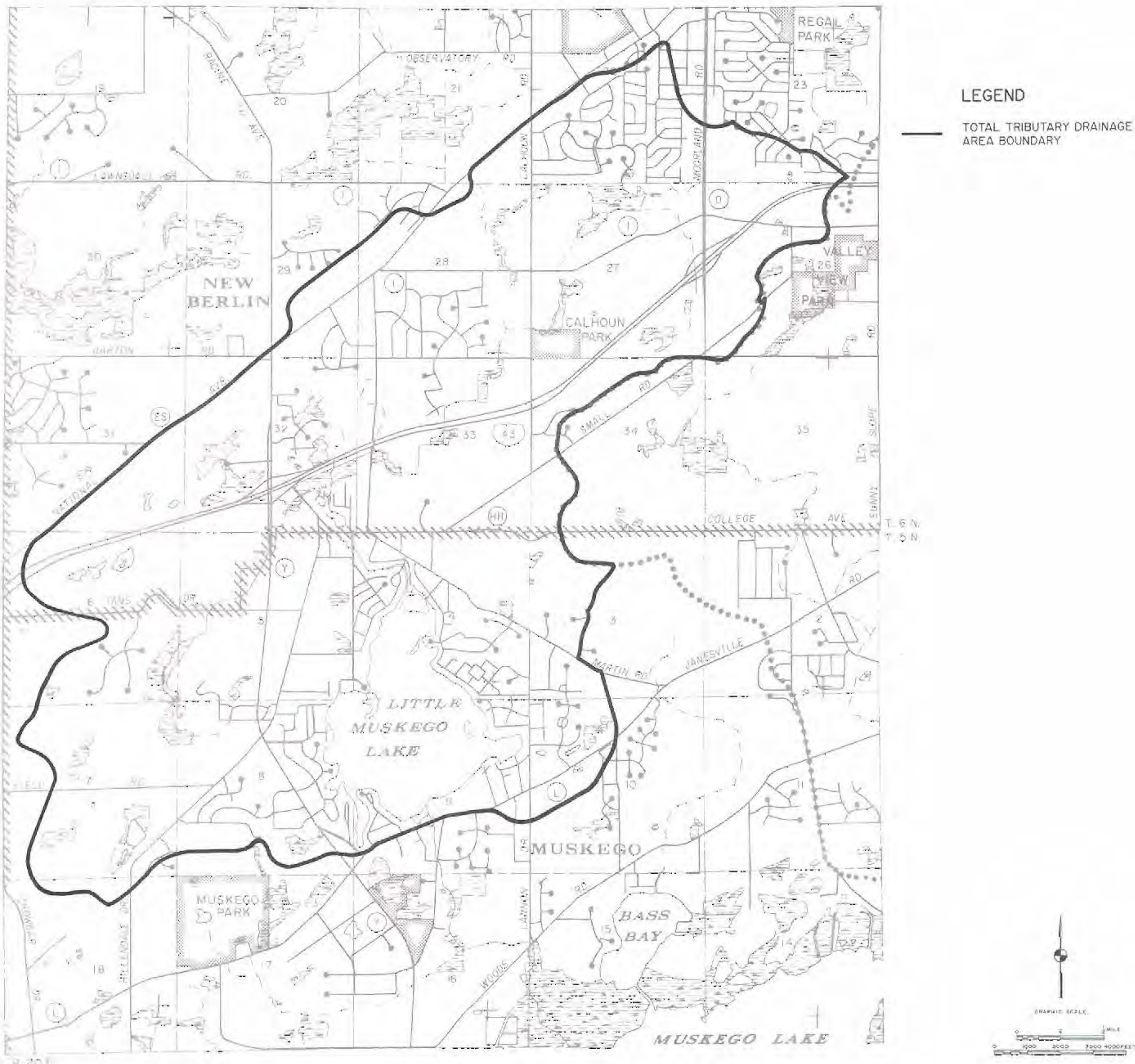
Soils within the study area of Little Muskego Lake were categorized into four main hydrologic soil groups and an "other" category, as indicated in Table 2. The areal extent of these soils and their locations within the watershed are shown on Map 7. The relative proportions of the Little Muskego Lake study area covered by each of the hydrologic soils groups are as follows: Group A, excessively drained soils, 0 percent; Group B, well-drained soils, about 4 percent; Group C, poorly drained soils, about 63 percent; Group D, very poorly drained soils, about 10 percent; and "other," which includes such disturbed lands as fill areas and quarries, about 1 percent. Surface water accounts for the remaining 22 percent of the study area.

As noted above, the soils within the Little Muskego Lake study area were classified with respect to suitability for urban residential development by the U. S. Soil Conservation Service. The classification system used for onsite sewage disposal was developed under the Regional Planning Commission's most recent land use planning program[5] and was

[5]*SEWRPC Planning Report No. 40, A Regional Land Use Plan for Southeastern Wisconsin: 2010, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, January 1992.*

Map 5

TOTAL TRIBUTARY DRAINAGE AREA TO LITTLE MUSKEGO LAKE

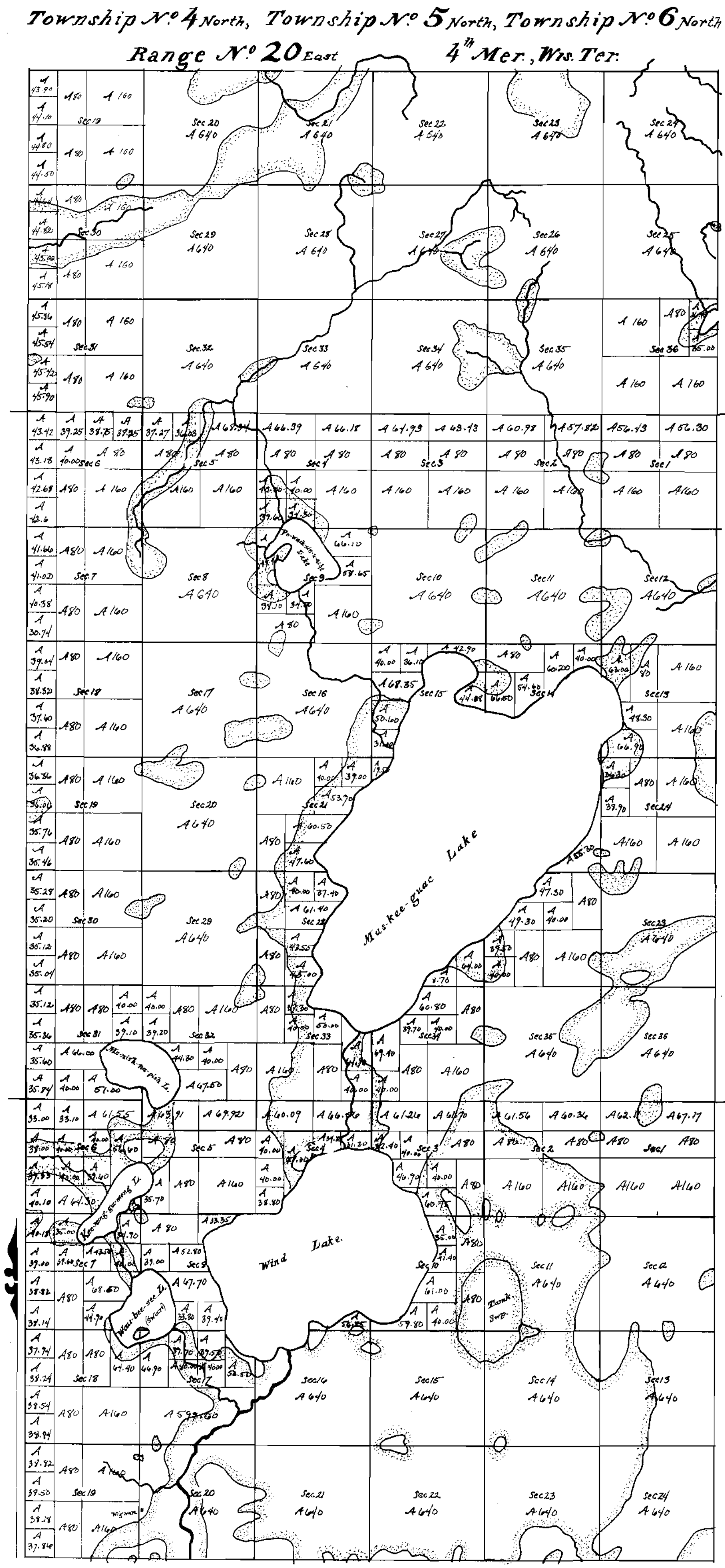


Source: SEWRPC.

based upon soil characteristics set forth in the detailed soil surveys and upon the field experience of County and State technicians responsible for overseeing the location and design of such disposal systems. The classifications reflect the current soil and site specifications set forth in Chapter ILHR 83 of the Wisconsin Administrative Code. With respect to urban residential development utilizing conventional onsite sewage disposal systems, as shown on Map 8, less than 1 percent of the Little Muskego Lake study area is covered by soils suitable for such development and about 72 percent by soils

Map 6

ORIGINAL U. S. PUBLIC LAND SURVEY MAP FOR THE LITTLE MUSKEGO LAKE AREA: 1836



Source: U. S. Public Land Survey and SEWRPC.

Table 2

GENERAL HYDROLOGIC SOIL TYPES IN THE LITTLE MUSKEGO LAKE STUDY AREA

Group	Soil Characteristics	Study Area Extent (acres)	Percent of Total
A	Excessively drained to somewhat excessively drained; very rapid to rapid permeability; low shrink-swell potential	0	0
B	Well drained to moderately well drained; texture intermediate between coarse and fine; moderately rapid to moderate permeability; low to moderate shrink-swell potential	76	4
C	Somewhat poorly drained to poorly drained; high water table for part or most of year; mottling, suggesting poor aeration and lack of drainage, generally present in A to C horizons	1,406	63
D	Very poorly drained; high water table for most of year; organic or clay soils; clay soils having high shrink-swell potential	228	10
Other	Hydrologic soil group not determined	24	1
- -	Water	480	22
- -	Total	2,214	100

Source: SEWRPC.

unsuitable for such development. The soil suitability could not be determined for about 5 percent of the direct drainage area, and about 1 percent could not be classified.

Using alternative onsite sewage disposal systems, such as mound systems, as shown on Map 9, yields additional land for urban residential development utilizing onsite sewage disposal systems; about 16 percent of the Little Muskego Lake study area is covered by soils suitable for such development and about 36 percent by soils unsuitable for such development. Soil suitability could not be determined for about 25 percent of the land in the direct drainage area, and about 1 percent could not be classified.

Soil limitations for residential development utilizing sanitary sewer service are shown on Map 10. About 41 percent of the Little Muskego Lake study area is covered by soils suitable for such development and about 36 percent by soils unsuitable for such development. Soil suitability could not be determined for the remaining 1 percent of the drainage area not covered by surface water. Most urban development within the Little Muskego Lake study area is currently served by public sanitary sewers.

The existing 1990 sanitary sewer service areas for the Little Muskego Lake area, and those proposed for the year 2010 in the adopted regional water quality management plan, are delineated on Map 11. The regional plan calls for virtually all of the direct drainage area to be served by sanitary sewers by the year 2010.[6]

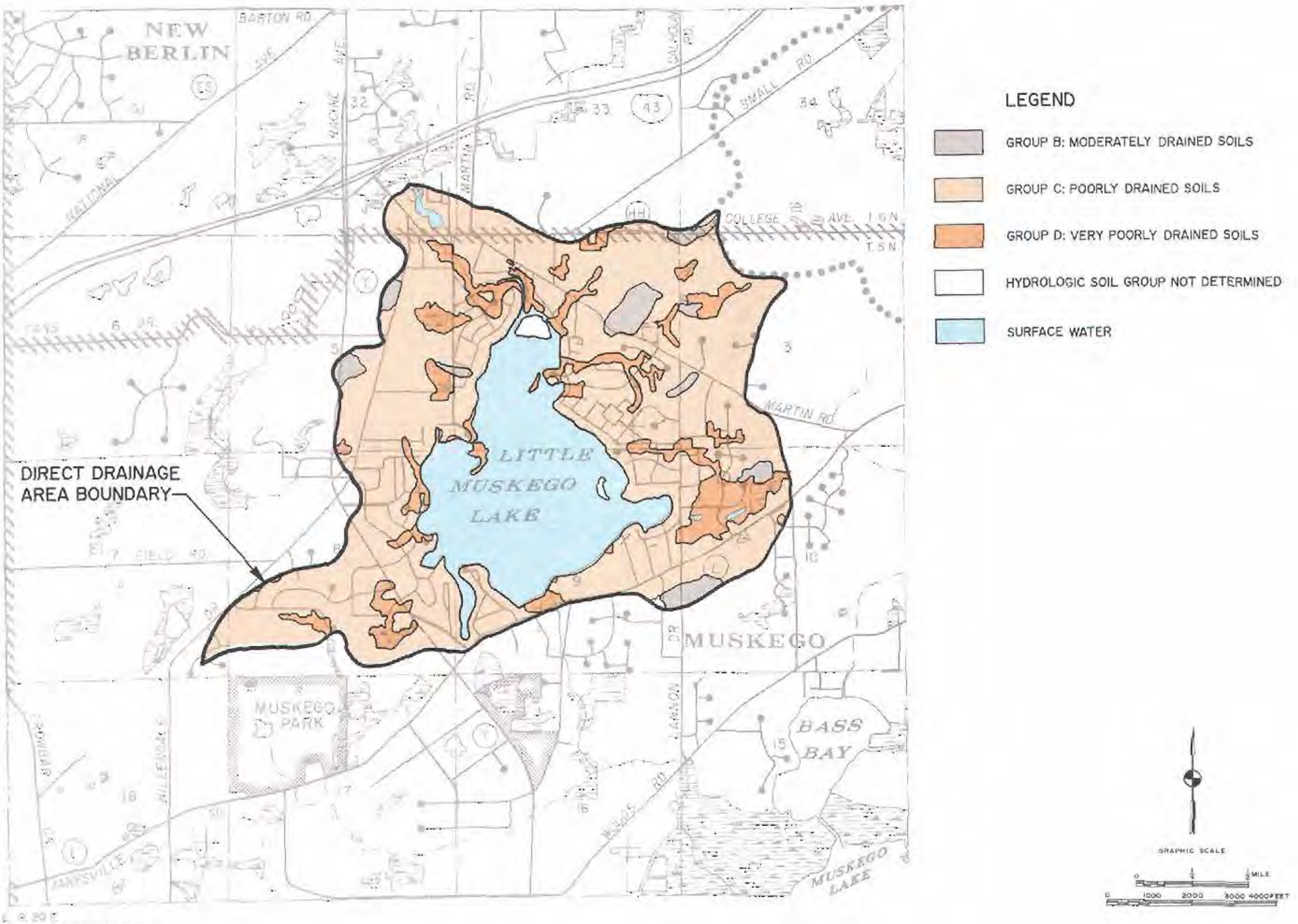
Climate and Hydrology

Climatologic and hydrologic data were collected during a recent study; the monitoring stations are shown on Map 12. Long-term average monthly air temperature and precipitation values for the Little Muskego Lake area are set forth in Table 3. In addition, Table 3 provides monthly air temperature and precipitation data from the period during which lake hydrology and water quality data were obtained for use in this report. Table 3 also provides runoff data for both periods, the long-term and

[6]*SEWRPC Community Assistance Planning Report No. 64 (2nd Edition), Sanitary Sewer Service Area for the City of Muskego, Waukesha County, Wisconsin, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, March 1986.*

Map 7

HYDROLOGIC SOIL GROUPS WITHIN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA



Source: SEWRPC.

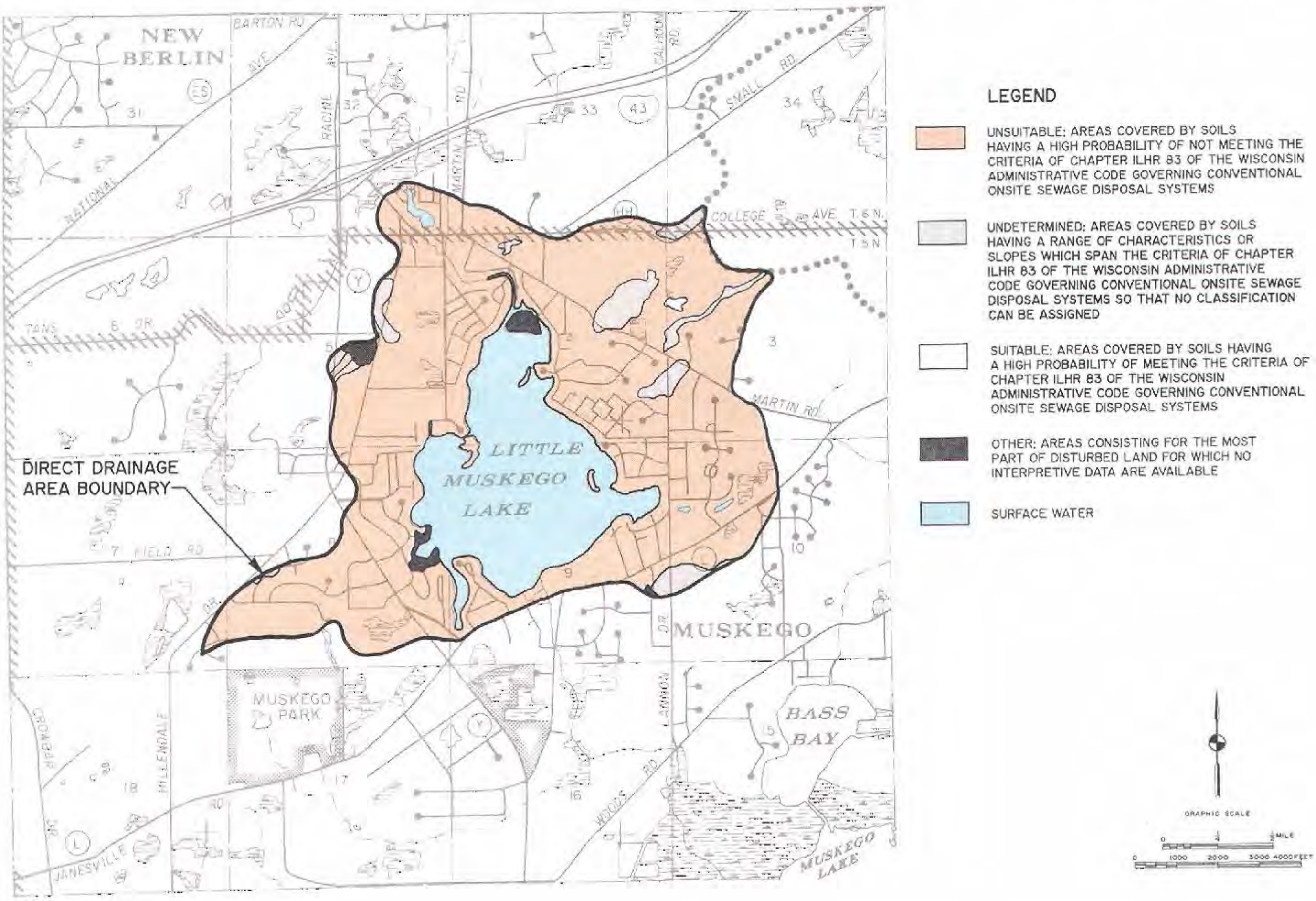
study periods, derived from U. S. Geological Survey (USGS) flow records for the Fox River at the City of Waukesha in Waukesha County. Supplemental data for the 1988 and 1989 water years were obtained from Muskego Creek below Big Muskego Lake downstream of the study area. Changes in lake storage at Little Muskego Lake were estimated from lake level data recorded by the USGS at the Little Muskego Lake dam.

The mean summer and winter temperatures of 64.1°F and 32.3°F, respectively, at Burlington are similar to those of other recording locations in Southeastern Wisconsin. Mean total annual precipitation at Burlington is 33.48 inches. More than one-half of the normal yearly precipitation falls during the growing season, from May to September. Runoff rates are generally low during this period because evapotranspiration rates are high, vegetation cover is abundant, and soils are not frozen. Normally, less than 15 percent of the summer precipitation is expressed as surface runoff, but intense summer storms occasionally produce high runoff. Peak runoff usually occurs during winter and early spring, when about 30 percent of the annual precipitation, in the form of snowmelt and rain, falls on frozen ground.

As Table 3 shows, the 1989 water year, the period from October 1988 through September 1989, had 2.33 inches more precipitation, or about 7 percent more, than the long-term annual average at Burlington. September, the wettest month, had 7.82 inches of precipitation, or 4.76 inches more than normal; while February, the driest month, had 0.48 inches of precipitation, or 0.60 inch less than

Map 8

SUITABILITY OF SOILS WITHIN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA FOR CONVENTIONAL ONSITE SEWAGE DISPOSAL SYSTEMS UNDER CURRENT ADMINISTRATIVE RULES



Source: SEWRPC.

normal. The 1989 water year restored lake levels to full supply after a lack of precipitation during the previous water year had caused declines in lake levels throughout the Muskego-Wind Lakes chain of between 1.5 and 3.0 feet.

Groundwater levels were not measured during this study. Information on groundwater flows was abstracted from the groundwater maps. The slope of the water table indicates that groundwater flowed toward the Lake from the northeast and northwest during the entire study period. Little Muskego Lake appeared to act as a recharge area for groundwater flows that leave the Lake in a southeasterly direction toward Big Muskego Lake.

Based on available data, an annual water budget for Little Muskego Lake was estimated and is set forth in Figure 1.[7] During the period from October 1986 through September 1989, an estimated 8,365 acre-feet of water entered the Lake per annum. Jewel Creek is estimated to have contributed over 70 percent of the known inflow, the major part of which occurred during the months of March, April, and May. The remainder of the known inflow came from surface runoff draining directly to the Lake, direct precipitation on the Lake, and groundwater.

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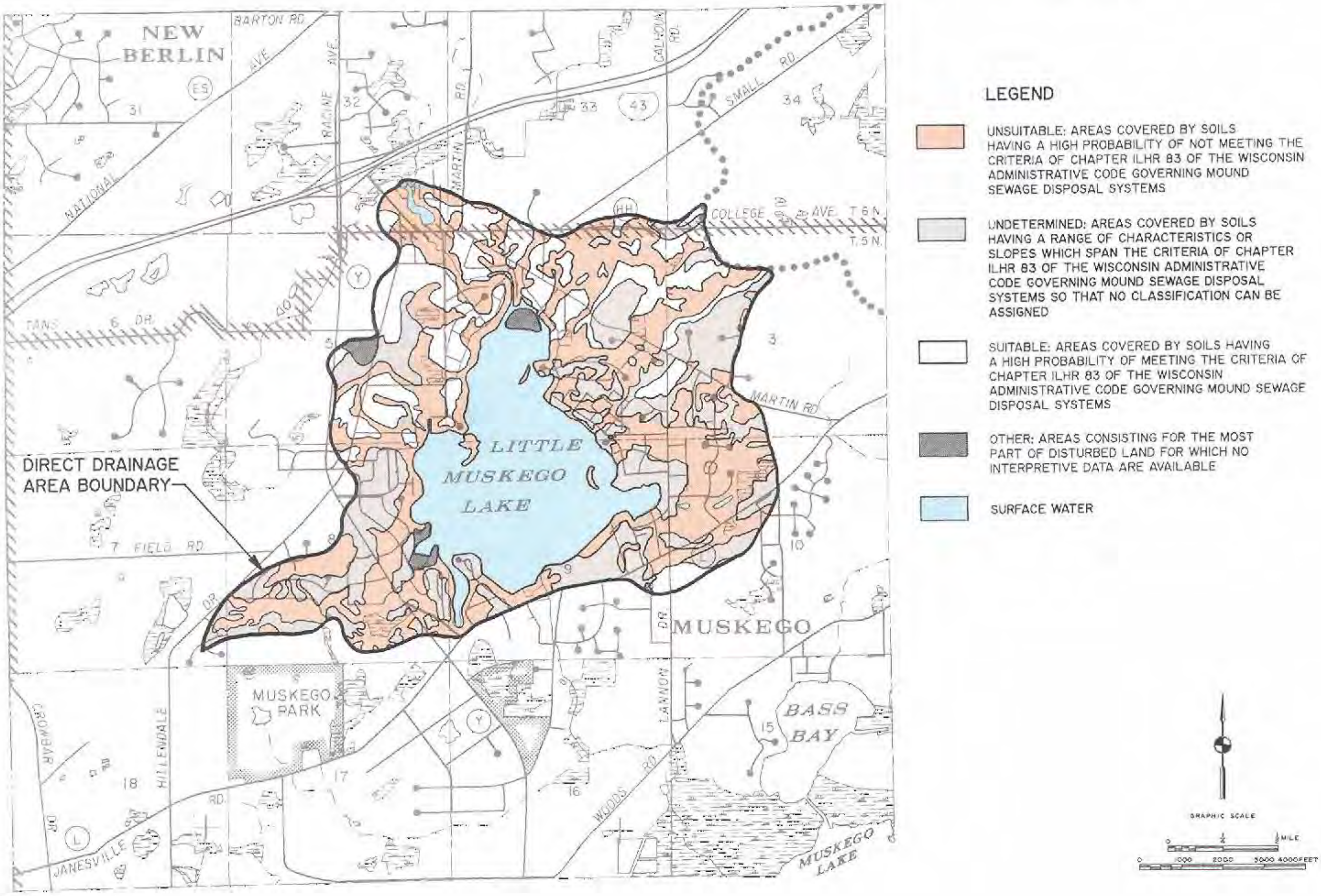
[7]*Stephen J. Field, USGS Water Resources Investigations Report No. 91-4107, Hydrology and Water Quality of Wind Lake in Southeastern Wisconsin, U. S. Geological Survey, Madison, Wisconsin, 1993.*

Map 9

SUITABILITY OF SOILS WITHIN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA FOR MOUND SEWAGE DISPOSAL SYSTEMS UNDER CURRENT ADMINISTRATIVE RULES



Source: SEWRPC.

An estimated 6,814 acre-feet of water per year was lost from the Lake via the outlet and evaporation from the surface during the period from 1986 to 1989. The net gain of water resulted in an average annual variation in the Lake's surface level of about 1.34 feet during this five-year period. This change in storage is consistent with the annual over-winter drawdown of Little Muskego Lake of about 1.5 feet.

During the study period, the hydraulic residence time, or the time required for a volume equivalent to the full volume of a lake to enter its basin, was about 0.9 year, which approximates the long-term water residence time of the Lake as estimated by the DNR.[8] The values calculated during the study period ranged from a low of 0.5 year for the 1993 water year to a high of 1.4 years during the 1989 water year, reflecting the effects of the Midwest drought of that year. In comparison, the long-term average hydraulic residence time for downstream Big Muskego Lake was 0.5 year; for Wind Lake, it was also 0.5 year. The hydraulic residence time is important in determining the expected response time of the Lake to increased or decreased nutrient and pollutant loadings. The smaller the lake volume or greater the rate of inflow, the shorter the hydraulic residence time will be. The longer

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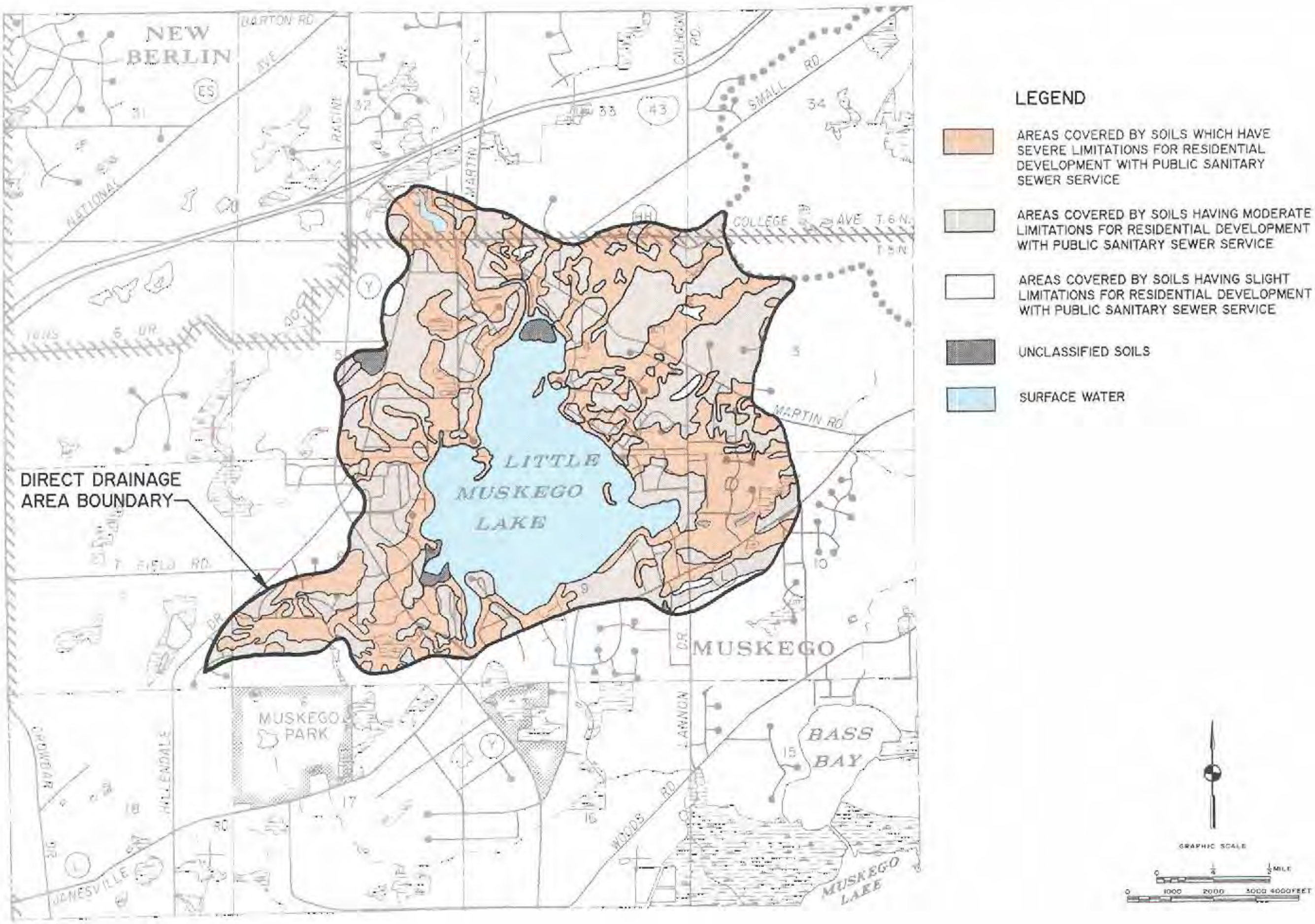
[8]*Wisconsin Department of Natural Resources,* *__Muskego–Wind Lakes Priority Watershed Project Water Resources Appraisal Report__, DNR, Madison, Wisconsin, April 1994.*

Map 10

SUITABILITY OF SOILS WITHIN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA FOR RESIDENTIAL DEVELOPMENT WITH PUBLIC SANITARY SEWER SERVICE



Source: SEWRPC.

residence time for Little Muskego Lake implies that the water quality of the Lake will be less of a direct reflection of the quality of the influent Jewel Creek and will develop more of a lacustrine character.

SUMMARY

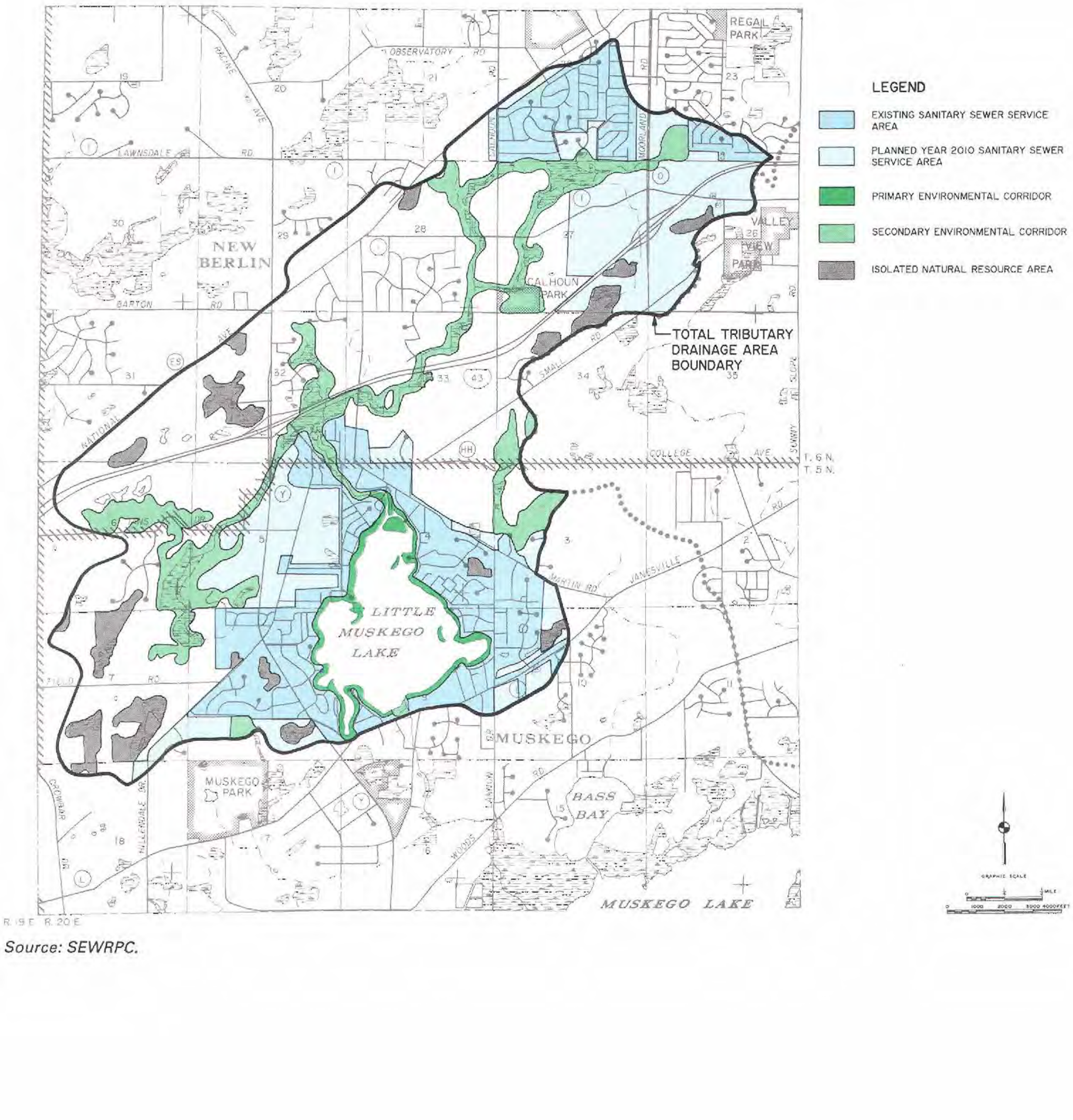
This chapter has presented an inventory of the physical characteristics of Little Muskego Lake and its drainage area. Proper consideration of alternative measures which affect the hydrology or water quality of Little Muskego Lake require such a characterization of lake basin morphometry, the surface water drainage pattern, and the climate and hydrology of the drainage area.

Little Muskego Lake is a 506-acre through-flow lake. The Lake has a mean depth of 14 feet and a maximum depth of 65 feet. Muck and clay cover virtually all of the lake bottom. The Little Muskego Lake study area, equal to the direct drainage area, covers about 2,214 acres, and the total drainage area to Little Muskego Lake covers about 7,537 acres.

The climate and hydrology of Little Muskego Lake were observed by the U. S. Geological Survey from October 1986 through September 1992. Long-term annual average precipitation for 1951 through 1980 was 33.48 inches, measured at the Burlington weather station. Of the total water input to Little Muskego Lake over this period, an estimated

Map 11

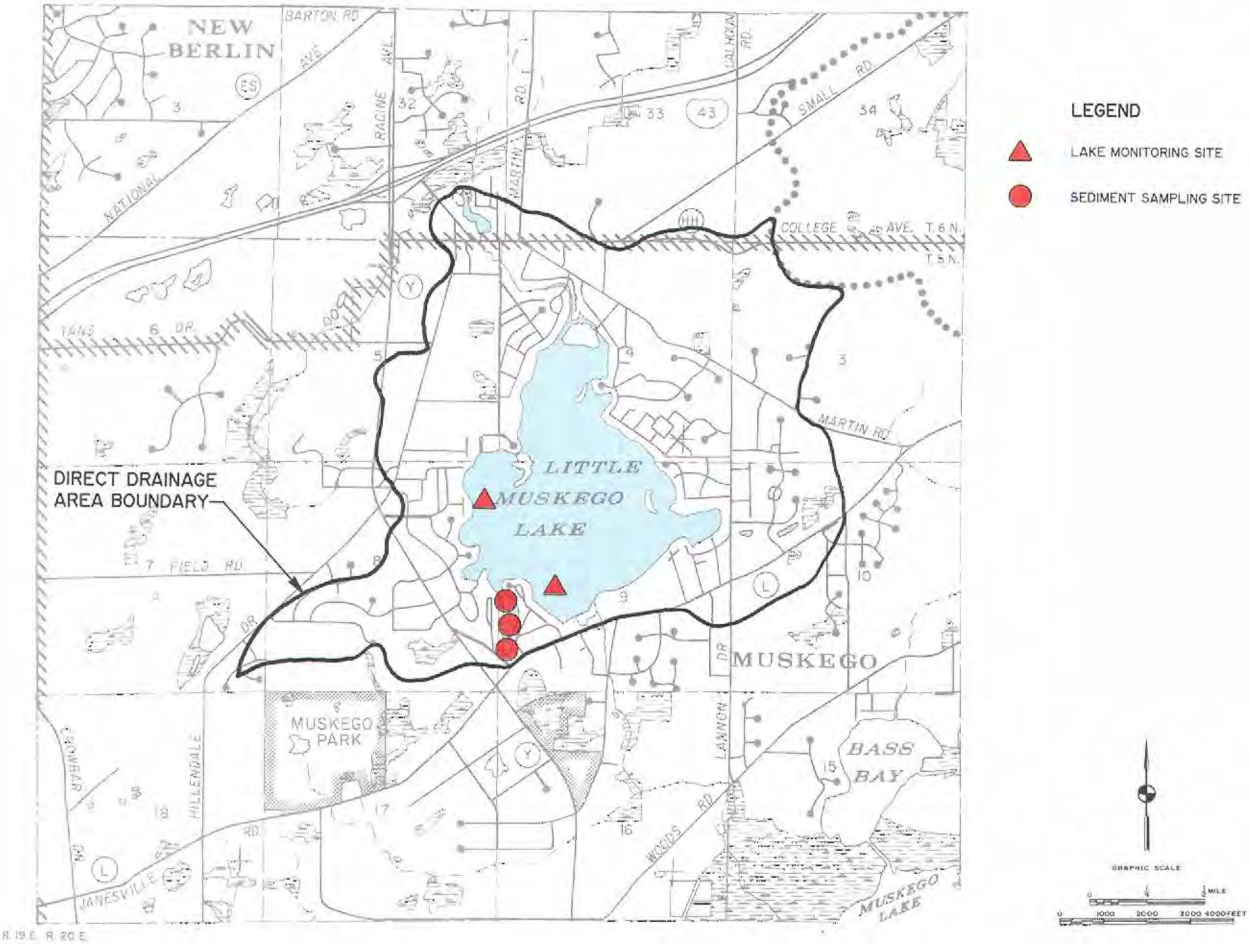
EXISTING AND PLANNED SANITARY SEWER SERVICE AREAS WITHIN THE TOTAL TRIBUTARY DRAINAGE AREA OF LITTLE MUSKEGO LAKE



Source: SEWRPC.

Map 12

LOCATION OF MONITORING STATIONS WITHIN THE LITTLE MUSKEGO LAKE STUDY AREA: 1986-1995



Source: SEWRPC.

8,365 acre-feet, Jewel Creek contributed an estimated 70 percent; direct precipitation, groundwater inflows, and shoreline drainage contributed the remaining 30 percent. Of the total water output from Little Muskego Lake, an estimated 6,814 acre-feet, most was discharged from the Little Muskego Lake outlet to Muskego Creek and the downstream Big Muskego Lake, while about 18 percent was estimated to have evaporated from the Lake's surface. In addition, about 1,500 acre-feet is lost annually through the outlet dam during the annual winter take drawdown.

Little Muskego Lake typically has a moderately long residence time of about 0.9 year, indicating that the water quality of the Lake will be less of a direct reflection of the quality of the influent Jewel Creek, and that the Lake will develop a more lacustrine character than will other lakes having shorter water residence times.

Table 3

LONG-TERM AND 1989 STUDY YEAR CLIMATOLOGICAL DATA FOR THE LITTLE MUSKEGO LAKE AREA

	Long-Term Average Values (1951-1980)												
Climatological Data	October	November	December	January	February	March	April	May	June	July	August	September	Annual
Mean Air Temperature, °F (Burlington)	50.4	36.9	22.2	17.4	21.6	32.0	45.8	56.7	66.3	71.1	69.2	57.0	45.6
Mean Precipitation, Inches (Burlington)	2.44	2.21	1.70	1.44	1.08	2.44	3.46	2.96	4.52	4.41	3.76	3.06	33.48
Mean Runoff, Inches (Fox River at Waukesha)	0.30	0.70	0.46	0.47	0.41	1.22	0.87	0.52	0.58	0.89	1.09	0.98	8.49

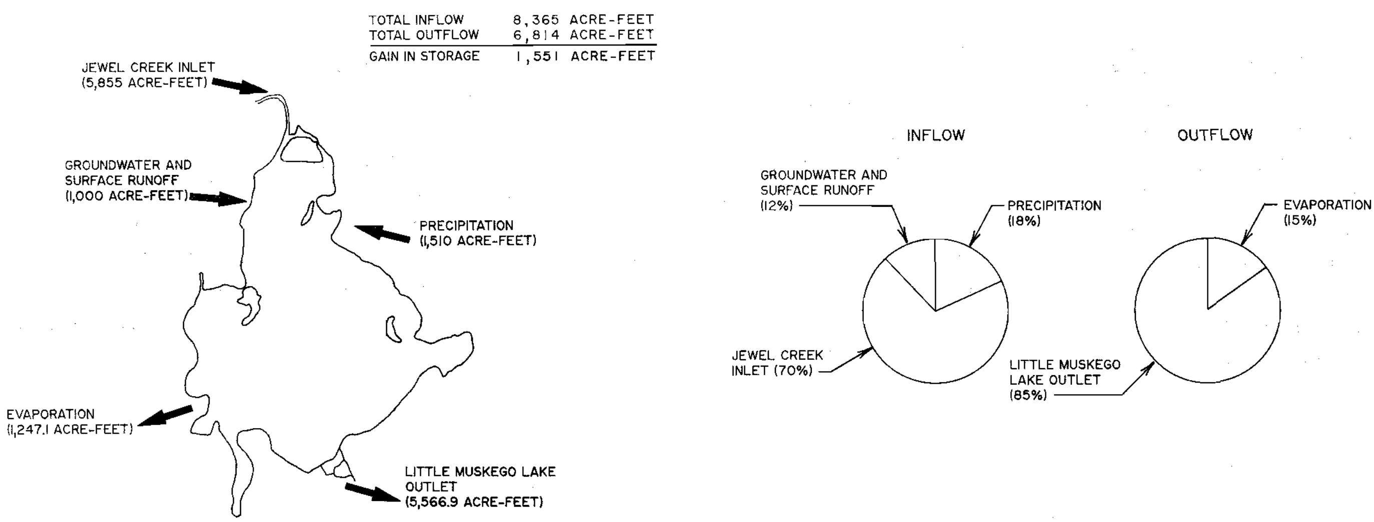
	1989 Study Year Values												
	1988			1989									
Climatological Data	October	November	December	January	February	March	April	May	June	July	August	September	Annual
Mean Air Temperature, °F (Burlington)	45.3	41.3	- -[a]	30.0	18.5	31.5	44.0	56.3	66.8	71.9	- -[a]	- -[a]	46.1
Departure from Long-Term Mean Air Temperature, °F	-5.1	4.4	- -	12.6	-3.1	-0.5	-1.8	-0.4	0.5	0.8	- -	- -	0.6
Precipitation, Inches (Wind Lake)	3.15	4.70	1.52	0.68	0.48	2.69	1.15	1.32	1.64	7.70	2.96	7.82	35.81
Departure from Long-Term Mean Precipitation, Inches	0.71	2.49	-0.18	-0.76	-0.6	0.25	-2.31	-1.64	-2.88	3.29	-0.80	4.76	2.33
Runoff, Inches (Fox River at Waukesha)	0.30	0.68	0.46	0.48	0.37	1.22	0.84	0.52	0.56	0.89	1.09	0.94	8.35
Departure from Long-Term Mean Runoff, Inches	0.00	-0.02	0.00	0.01	-0.04	0.00	-0.03	0.00	-0.02	0.00	0.00	-0.04	-0.14

[a] *Data not reported; monthly average was used to calculate annual temperature.*

Source: National Oceanic and Atmospheric Administration, U. S. Geological Survey, and SEWRPC.

Figure 1

HYDROLOGIC BUDGET FOR LITTLE MUSKEGO LAKE[a]



Source: U. S. Geological Survey and SEWRPC.

Chapter III

HISTORICAL, EXISTING, AND PLANNED LAND USE AND POPULATION

INTRODUCTION

Water pollution problems, and the ultimate solutions to these problems, are primarily a function of the human activities within the drainage area of a water body, and of the ability of the underlying natural resource base to sustain those activities. This is especially true in an area directly tributary to a lake because lakes are highly susceptible to water quality degradation attendant to human activities in their immediate drainage areas, there being no intermediate stream segments to attenuate pollutant loads. Human activities in a watershed may result in both point and nonpoint sources of water pollution. Point source pollution typically relates to sewage treatment plant and industrial waste outfalls; nonpoint source pollution, to stormwater runoff. Nonpoint source pollution, with attendant lake degradation, is as likely to interfere with desired water uses as is pollution from point sources, and is often more difficult and costly to correct. Accordingly, the population and employment levels and attendant land uses in the direct drainage area of a lake are important considerations in lake water quality management.

Civil Divisions

The areal extent and functional responsibilities of civil divisions and special-purpose units of government are important factors which must be considered in any water quality management planning effort, since these local units of government provide the basic structure of the decision-making framework within which environmental problems must be addressed. Superimposed on the Little Muskego Lake drainage area are the local civil division boundaries, as shown on Map 13. The drainage area tributary to Little Muskego Lake includes portions of the Cities of New Berlin and Muskego. The area and proportion of the total drainage area lying within each jurisdiction concerned, as of 1990, are set forth in Table 4.

Population

As indicated in Table 5, the resident population of the Little Muskego Lake study area increased fairly steadily between 1963 and 1980, then leveled off during the next decade, although further growth in population is anticipated during the planning period. The 1990 resident population of the direct drainage area of Little Muskego Lake, estimated at 5,839 persons, was about 18 percent higher than the estimated 1970 population, and about one-tenth of 1 percent higher than the 1980 population. Population forecasts prepared by the Regional Planning Commission on the basis of a normative regional land use plan indicate, as shown in Table 5, that the population of the drainage area directly tributary to Little Muskego Lake may be expected to increase to about 7,164 persons by the year 2010. A comparison of historic, existing, and forecast population levels for the drainage area directly tributary to Little Muskego Lake, for Waukesha County, and for the Southeastern Wisconsin Region is set forth in Figure 2. The resident population in the Little Muskego Lake study area since 1970 has increased at a slightly more rapid rate than has the County population, and at a much more rapid rate than has the regional population. This population growth may be expected to place a continued and increasing stress on the natural resource base of the Little Muskego Lake drainage area. As the resident populations of the study area, of the County, and of the Region continue to grow and change, water resource demands and use conflicts may be expected to increase.

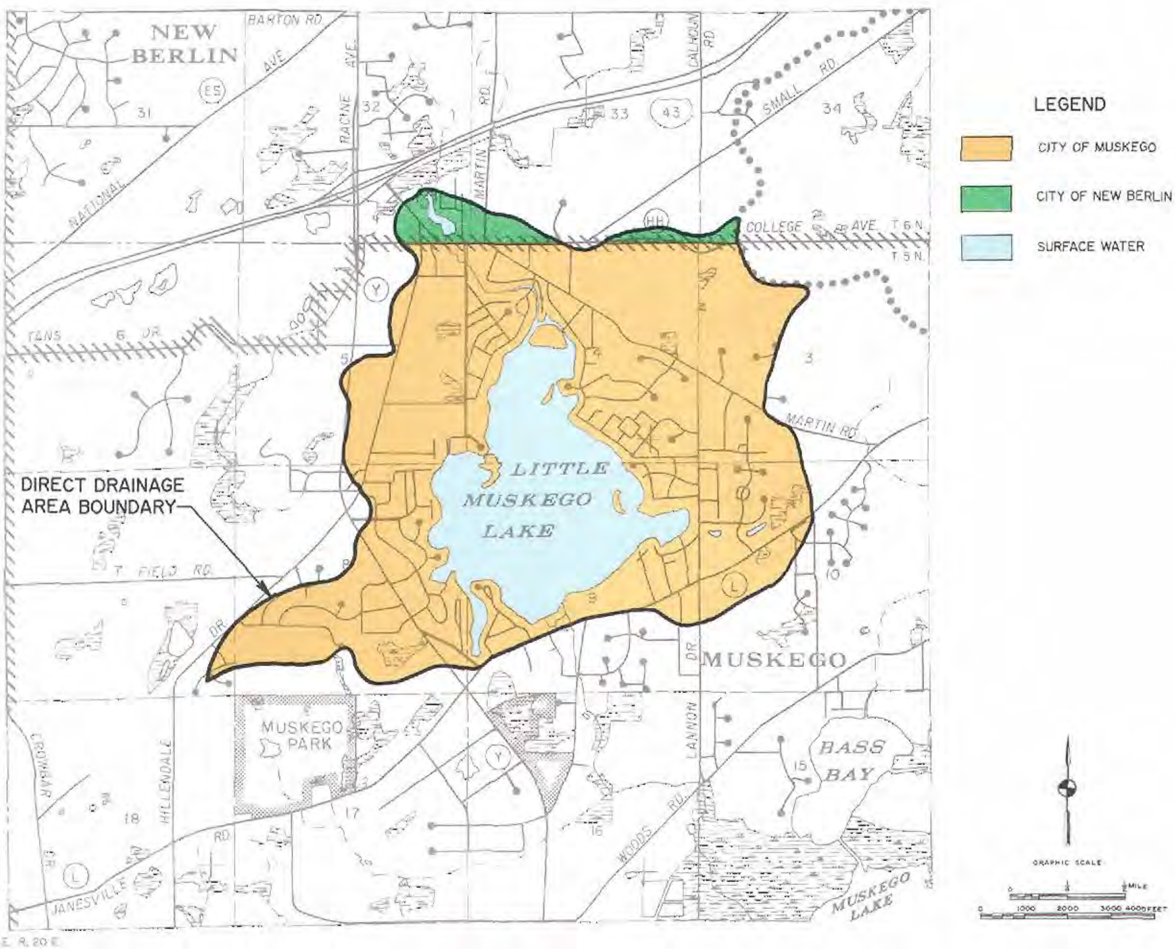
Land Use

The type, intensity, and spatial distribution of the various land uses within the Little Muskego Lake study area are important determinants of lake water quality. The existing land use pattern can best be understood in the context of the historical development of the area. The movement of European settlers into the Southeastern Wisconsin Region began about 1830. Completion within Southeastern Wisconsin of the U. S. Public Land Survey in 1836 and the subsequent sale of public lands in Wisconsin brought a rapid influx of settlers into the area. Map 6 in Chapter II shows the original plat of the U. S. Public Land Survey for the Little Muskego Lake area.

Map 14 and Table 6 indicate the historical urban growth pattern in the direct drainage area of Little Muskego Lake since 1880. Significant urban development began in the Little Muskego Lake area after the Civil War, with a further period of rapid

Map 13

CIVIL DIVISION BOUNDARIES IN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA



Source: SEWRPC.

increase in urban land use development occurring after the Second World War, between 1950 and 1963. The rate of urban development in the direct drainage area after 1985 has decreased in comparison to previous years, and few changes have occurred in the last decade.

The existing land use patterns in the Little Muskego Lake study area, as of 1990, are shown on Map 15 and quantified in Table 7. As indicated in Table 7, about 1,119 acres, or about 51 percent of the direct drainage area, were in urban land uses, with the dominant urban land use being residential, encompassing 840 acres, or about 75 percent of the area in urban use. As of 1990, about 1,095 acres, or about 49 percent of the Little Muskego Lake study area, were still in rural land use. About 437 acres, or about 40 percent of the rural area, were in agricultural land uses. Woodlands, wetlands, and surface water, including the surface area of Little Muskego Lake, accounted for approximately 643 acres, or about 59 percent of the area in rural use. Extractive operations comprised the remaining 1 percent of the area under rural land use.

The estimated 1,325 new residents who may be expected in the study area between 1990 and 2010 will require an increase in the land area devoted to urban use. The year 2010 land use plan adopted by the Regional Planning Commission, as set forth on Map 16 and quantified in Table 8, recommends that most new residential development in the Little Muskego Lake study area occur at medium densities. Compared to the existing 1990 land use pat-

Table 4

AREAL EXTENT OF CIVIL DIVISIONS IN THE LITTLE MUSKEGO LAKE TOTAL TRIBUTARY DRAINAGE AREA: 1990

Civil Division	Civil Division Area within Drainage Area (acres)	Percent of Drainage Area within Civil Division	Percent of Civil Division within Drainage Area
City of Muskego	3,393	45	15
City of New Berlin	4,144	55	18
Total	7,537	100	- -

Source: SEWRPC.

Table 5

HISTORIC AND FORECAST RESIDENT POPULATION LEVELS IN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA: 1963-2010[a]

Year	Number of Households	Number of Residents
1963	937	3,483
1970	1,211	4,947
1980	1,737	5,833
1990	1,935	5,839
2010[b]	2,380	7,164

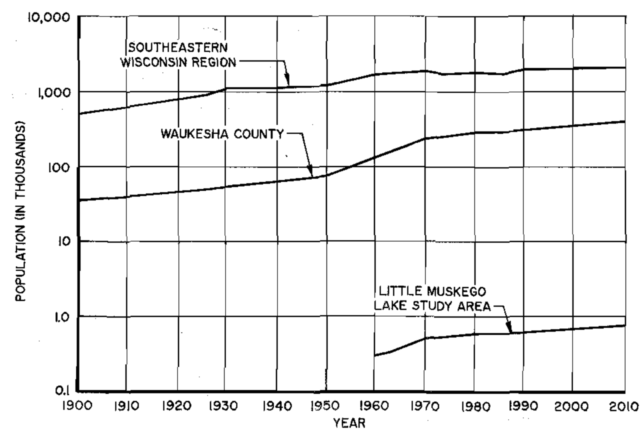
[a]*Study area approximated using whole U. S. Public Land Survey one-quarter sections.*

[b]*Year 2010 data are presented for the recommended land use plan as set forth in the year 2010 regional land use plan.*

Source: U. S. Bureau of the Census and SEWRPC.

Figure 2

COMPARISON OF HISTORIC, EXISTING, AND FORECAST POPULATION TRENDS FOR THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA, WAUKESHA COUNTY, AND THE SOUTHEASTERN WISCONSIN REGION



Source: SEWRPC.

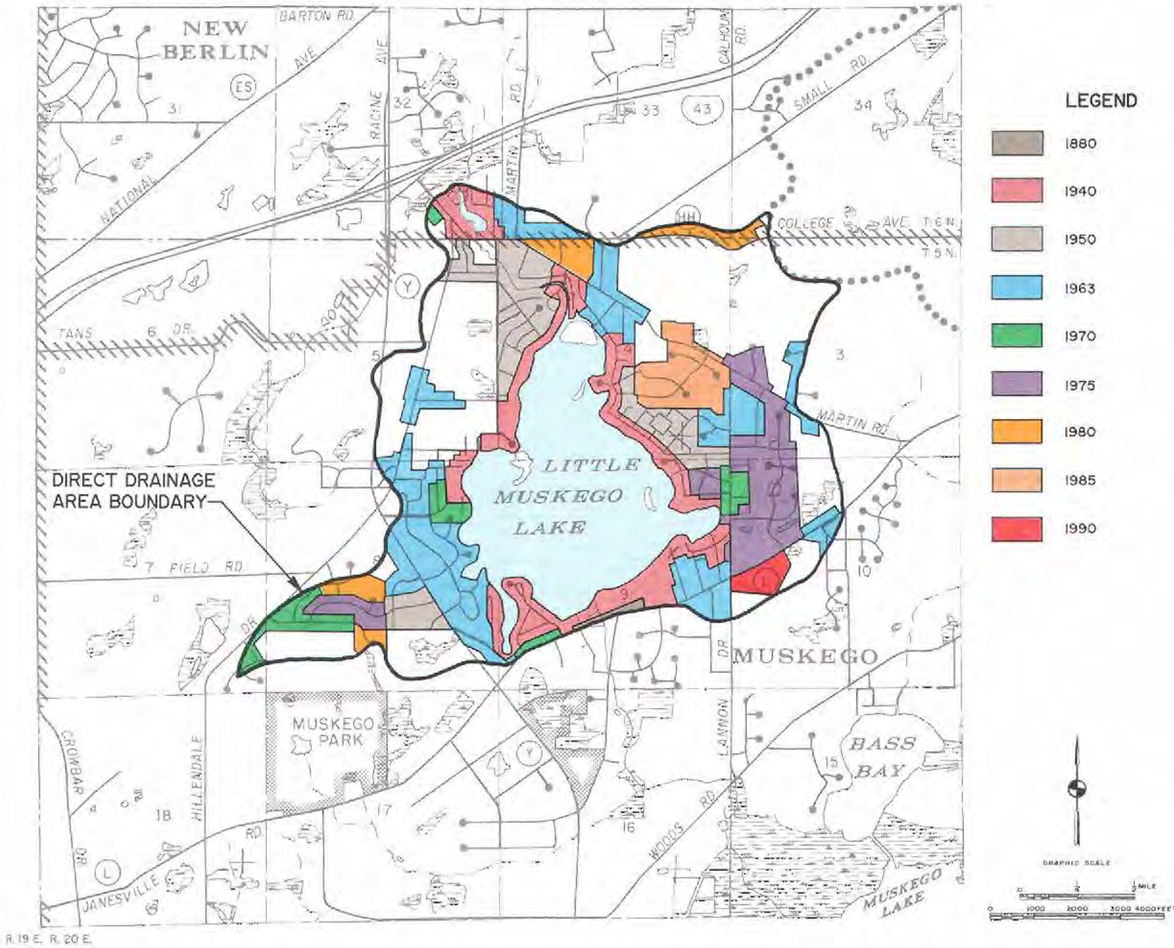
tern, an 18 percent increase in urban land uses, largely reflecting the increase in residential land uses, is envisioned to occur by the design year of the plan. Certain lands which encompass the immediate shorelands of Little Muskego Lake have been designated in the adopted regional land use plan as primary environmental corridor, and are recommended to be kept in essentially natural, open uses. There were no lands designated in the adopted regional land use plan as prime agricultural land in this urbanized watershed.

On a larger scale, existing and planned land uses within the Little Muskego Lake watershed, which includes the Jewel Creek basin upstream of the Little Muskego Lake outlet, are shown on Maps 15 and 16 and quantified in Tables 7 and 8. Generally, the anticipated changes in land uses within this watershed are less pronounced but parallel the expected changes in the Little Muskego Lake study area. The largest single development planned as of 1995 is the proposed Westridge Business Park at IH 43 and Moorland Road in the City of New Berlin, a portion of which drains to Jewel Creek.

Qualitatively, the greatest changes in land use in the Little Muskego Lake direct drainage and total tributary drainage areas are in the amounts of land allocated for residential use. Residential lands are expected to increase substantially in

Map 14

HISTORIC URBAN GROWTH IN THE DIRECT DRAINAGE AREA OF LITTLE MUSKEGO LAKE: 1880-1990



Source: SEWRPC.

extent, primarily at the expense of formerly unused and open lands. Interestingly, woodlands and wetlands are expected to be little affected by the continued growth of the residential areas, if the recommendations to protect the environmental corridors are fully implemented. Significant growth is also expected in the transportation sector, primarily in support of the expanding residential land use sector. Planning and controlling this urban growth in the Little Muskego Lake study area and watershed present a major challenge in protecting the water quality of Little Muskego Lake.

EXISTING ZONING REGULATIONS

The comprehensive zoning ordinance represents one of the most important tools available to local units of government in directing the proper use of lands within their areas of jurisdiction. The Little Muskego Lake total tributary drainage area includes portions of the City of Muskego and City of New Berlin. The Cities each administer their own zoning regulations. A summary of the zoning districts available for use in the civil divisions concerned, and the extent of the land placed in each of the zoning districts in 1990 is shown on Map 17.

Concerns have been expressed over the need to protect the lakeshore from overly intensive land use. These concerns have arisen in light of infilling and densification, such as the process of replacing low-density residential development with higher-density urban development, sometimes in the form of condominium development. Such redevelopment of the lakefront and direct drainage area can be undesirable from the point of view of water quality protection; densification generally results in a greater area of impervious surface, increased runoff, and increased nonpoint source pollutant loading on the Lake as described in Chapter IV. Both Cities have recently updated their general zoning ordinances. These ordinances provide for protection of wetlands, floodplains, and primary environmental corridors. The zoning ordinance of the City of Muskego appears to be reasonable with regard to lakeshore development and protection. The City of Muskego has promulgated a shoreland overlay district applicable to all shorelands within the City for this purpose.[1] The potential for rezoning to allow for higher density and different land uses on the lakeshore and in the direct drainage area should be carefully reviewed with regard to potential impacts on lake water quality and recreational uses.

Other pertinent regulations include wetland and shoreland protection ordinances. In accordance with Chapter NR 117 of the Wisconsin Administrative Code, cities and villages are required to protect shoreland-wetland areas following the receipt of final State wetland inventory maps from the Wisconsin Department of Natural Resources. Shoreland-wetlands are defined in Chapter NR 117 as wetlands five acres or larger located in shoreland areas within 300 feet of a stream and 1,000 feet of a lake, or to the landward side of the floodplain, whichever is greater. Both Cities received final State wetland inventory maps in 1986 and subsequently adopted ordinances.

SUMMARY

Current population growth forecasts suggest that the number of people within the Little Muskego Lake study area will continue to increase. Initially, the urban growth was centered around Little Muskego Lake and along CTH L, with relatively little areal expansion until the suburban growth in the post-World War II period (see Table 6). This suburban growth is expected to continue, albeit at a slower rate, into the foreseeable future. Residential land uses supported by commercial developments are anticipated to increase in extent by the year 2010 in the Little Muskego Lake study area and in the watershed as a whole as the City of Muskego and City of New Berlin absorb an expected 1,500 new residents during this period. Woodlands and wetlands, however, are expected to remain relatively stable at about 112 acres and 47 acres, respectively, in the study area, and about 558 acres and 338 acres, respectively, in the watershed. The situation of these wetlands and woodlands, and water bodies, in the environmental corridors delineated by the Regional Planning Commission would appear to underlie this apparent stability[2] (see Table 8). The adoption of shoreland zoning regulations, in association with sound urban planning principles, should continue to guide this development along the lines of minimal environmental impact (see Chapter VII).

Table 6

EXTENT OF HISTORIC URBAN GROWTH IN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA: SELECTED YEARS, 1880-1990

Year	New Urban Development[a] Occurring since Previous Selected Year	Cumulative Extent of Urban Development (acres)
1880	--	6
1940	220	226
1950	174	400
1963	314	714
1970	70	784
1975	161	945
1980	58	1,003
1985	70	1,073
1990	16	1,089

[a]Urban development, as defined for the purposes of this discussion, includes those areas within which houses or other buildings have been constructed in relatively compact groups, thereby indicating a concentration of urban land uses. Scattered residential developments were not considered in this analysis.

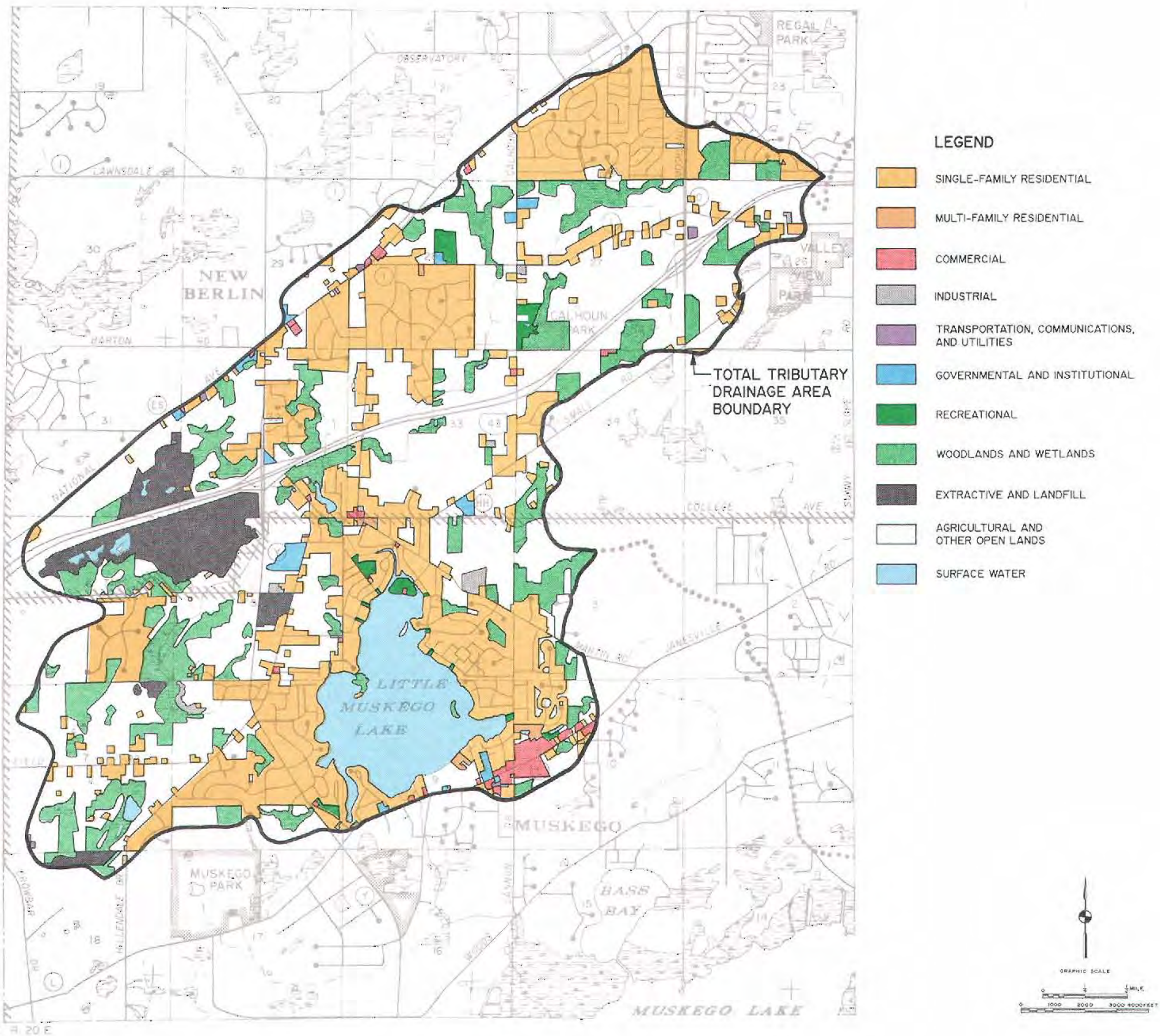
Source: U. S. Bureau of the Census and SEWRPC.

[1]*City of Muskego, Zoning Ordinance, City of Muskego, Waukesha County, Wisconsin: Planning for Balance, October 1993.*

[2]*SEWRPC Planning Report No. 27, A Regional Park and Open Space Plan for Southeastern Wisconsin: 2000, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, November 1977; B. P. Rubin and G. H. Emmerich, "Refining the Delineation of Environmental Corridors in Southeastern Wisconsin," SEWRPC Technical Record, Vol. 4, No. 2, March 1981, pp. 1-22.*

Map 15

EXISTING LAND USES WITHIN THE TOTAL TRIBUTARY DRAINAGE AREA OF LITTLE MUSKEGO LAKE: 1990



Source: SEWRPC.

Table 7

EXISTING LAND USES WITHIN THE LITTLE MUSKEGO LAKE DIRECT AND TOTAL TRIBUTARY DRAINAGE AREAS: 1990

Land Use Category	Direct Drainage Area			Total Tributary Drainage Area		
	Acres	Percent of Major Category	Percent of Drainage Area	Acres	Percent of Major Category	Percent of Drainage Area
Urban						
Residential	840	75	38	1,962	69	26
Commercial	47	4	2	58	2	1
Industrial	11	1	1	25	1	1
Governmental and Institutional	19	2	1	51	2	1
Transportation, Communication, and Utilities	182	16	8	709	24	9
Recreational	20	2	1	49	2	1
Subtotal	1,119	100	51	2,854	100	39
Rural						
Agricultural	437	40	19	2,973	63	39
Woodlands	112	10	5	558	12	7
Wetlands	47	4	2	338	7	4
Water	484	44	22	505	11	7
Other	15	2	1	309	7	4
Subtotal	1,095	100	49	4,683	100	61
Total	2,214	- -	100	7,537	- -	100

Source: SEWRPC.

Table 8

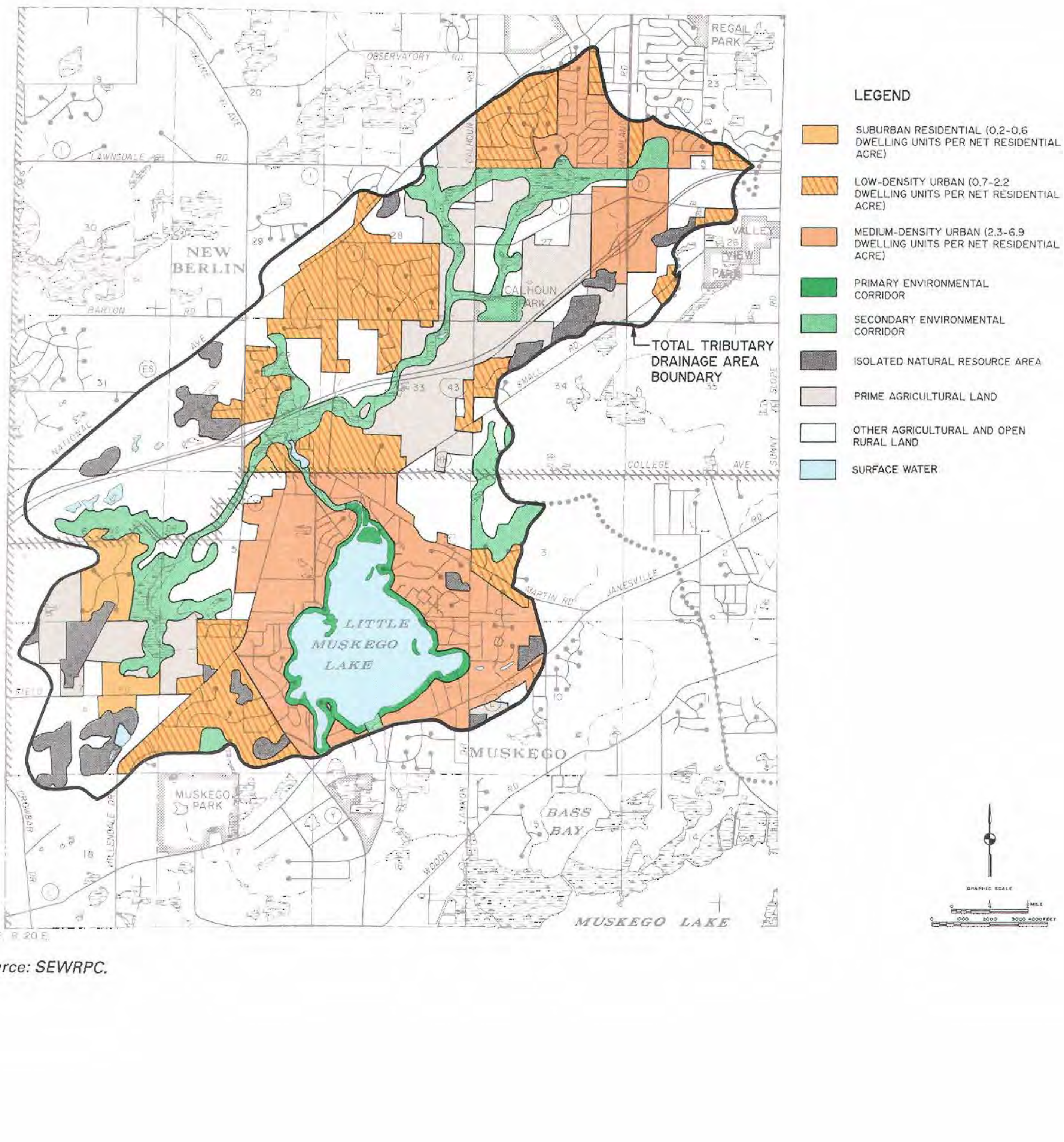
PLANNED YEAR 2010 LAND USES WITHIN THE LITTLE MUSKEGO LAKE DIRECT AND TOTAL TRIBUTARY DRAINAGE AREAS

Land Use Category	Direct Drainage Area			Total Tributary Drainage Area		
	Acres	Percent of Major Category	Percent of Drainage Area	Acres	Percent of Major Category	Percent of Drainage Area
Urban						
Residential	976	74	44	2,280	68	30
Commercial	69	5	3	84	2	1
Industrial	29	2	1	65	2	1
Governmental and Institutional	20	2	1	56	2	1
Transportation, Communication, and Utilities	205	15	9	801	24	10
Recreational	21	2	1	51	2	1
Subtotal	1,320	100	59	3,337	100	44
Rural						
Agricultural	236	26	11	2,490	59	33
Woodlands	112	13	5	558	13	7
Wetlands	47	5	2	338	8	5
Water	484	54	22	505	12	7
Other	15	2	1	309	8	4
Subtotal	894	100	41	4,200	100	56
Total	2,214	- -	100	7,537	- -	100

Source: SEWRPC.

Map 16

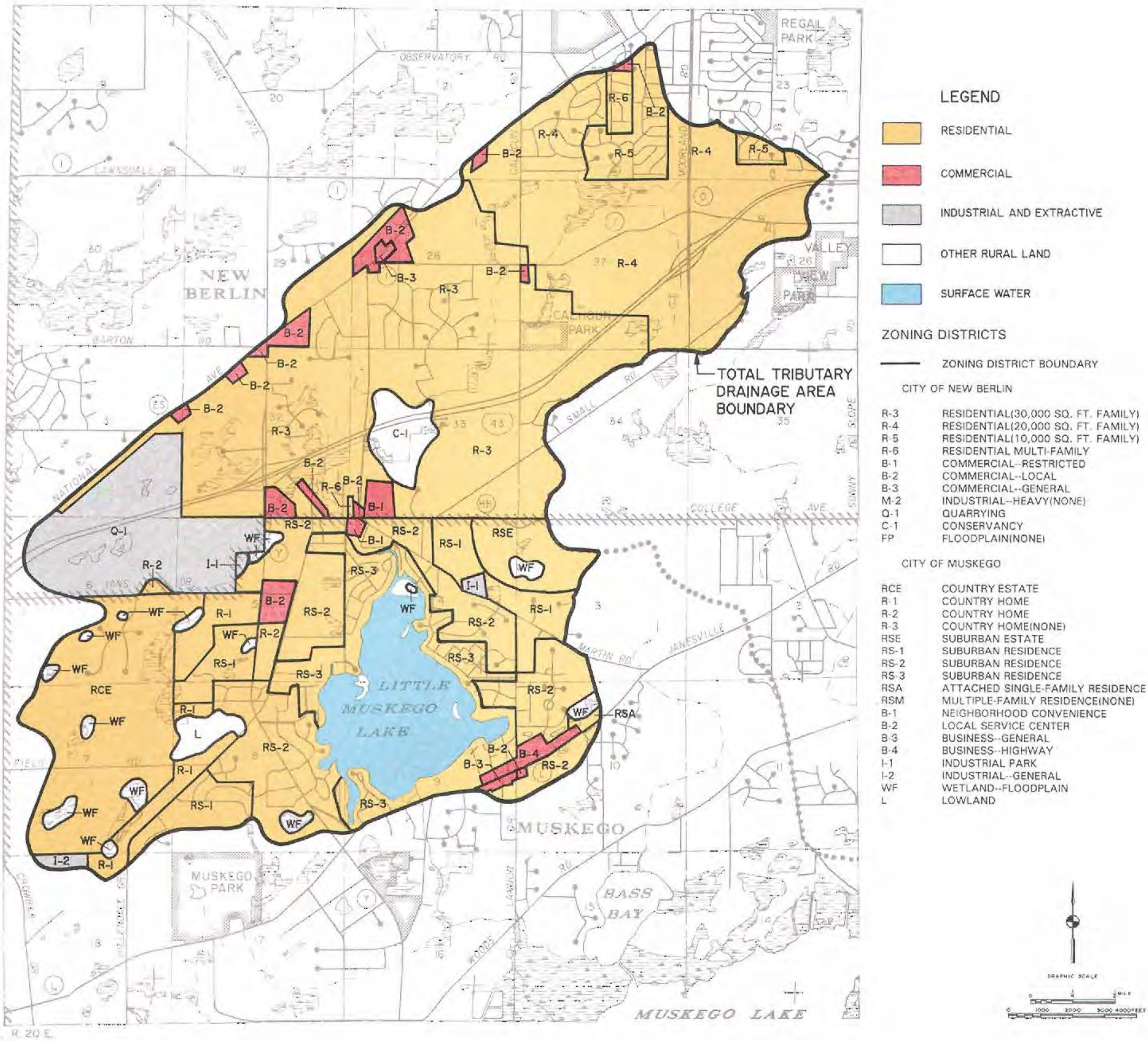
PLANNED LAND USES WITHIN THE TOTAL TRIBUTARY DRAINAGE AREA OF LITTLE MUSKEGO LAKE: 2010



Source: SEWRPC.

Map 17

EXISTING ZONING DISTRICTS WITHIN THE TOTAL TRIBUTARY DRAINAGE AREA OF LITTLE MUSKEGO LAKE: 1990



Source: SEWRPC.

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Chapter IV

WATER QUALITY

HISTORICAL BACKGROUND

While data on the water quality of Little Muskego Lake collected prior to the 1986 U. S. Geological Survey (USGS) study were collated for use in this study, the findings reported herein are largely founded on data collected since 1986. The earliest definitive information on water quality conditions in Little Muskego Lake was collected by R. J. Poff and C. W. Threinen in the early 1960s.[1] Other sources of information on the historical water quality conditions in Little Muskego Lake included the results of a monitoring study conducted from 1973 to 1975 by the Wisconsin Department of Natural Resources (DNR). Those data indicated that Little Muskego Lake had relatively good water quality at the times of those studies and that there was little evidence of pollution or excessive fertilization.

More recently, however, residents of the Little Muskego Lake area have expressed concerns about deteriorating water quality conditions; by the 1980s, the Lake was being described as eutrophic or nutrient enriched. In 1986, the Little Muskego Lake Management District concluded that it was necessary to take action to limit the extent of perceived water quality degradation taking place in the Lake. In response to citizen concerns, the District purchased and installed a Clean-Flo Laboratories continuous laminar flow inversion aeration system in the main lake basin. The stated goals of installing this system were 1) to remove muck and deepen the Lake, 2) to control aquatic plant growth, 3) to improve water clarity, and 4) to improve fish growth.[2] The aeration system was operated by the District during open-water periods between the time of its purchase in 1987 and the autumn of 1991. The system has not been operated subsequently, pending the completion of an assessment of its efficacy.

As a condition of the DNR permit that allowed the District to install this system, issued under authority granted the Department in Chapter 30 of the Wisconsin Statutes, a water quality study was initiated to provide background information on the Lake and permit assessment of the efficacy of the aeration system in meeting the above-mentioned goals. A comprehensive water quality monitoring program was developed by the District in cooperation with the USGS, whose staff, with local assistance provided by the Little Muskego Lake Management District, then conducted that water quality monitoring program for Little Muskego Lake from October 1986 through September 1993. This program involved the determination of physical, chemical, and biological characteristics of the Lake's water, including dissolved oxygen concentration and water temperature profiles, pH, specific conductance, water clarity, and nutrient and chlorophyll-a concentrations. In addition to these data, the USGS collected information on the Lake's surface level and on the basic hydrology of the Lake.

The in-lake water quality monitoring investigations were cost-shared between the State and local community under the Lake Management Planning Grant Program provided for in Chapter NR 119 of the Wisconsin Administrative Code. The data obtained through these investigations have been used in the development of this lake management plan, which also has been funded in part through the NR 119 program.

EXISTING WATER QUALITY CONDITIONS

The data collected during the study period from 1986 through 1993 were used to determine water quality conditions in the Lake and to characterize the suitability of the Lake for recreational use and the support of fish and aquatic life. Water quality samples were taken from the main basin of the Lake approximately every two weeks from February 1987 through October 1992, and approximately monthly during the rest of the study period. The findings are summarized in Tables 9 and 10 and are discussed below. The primary sampling station was located at

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[1] *R. J. Poff and C. W. Threinen, Surface Water Resources of Waukesha County, Wisconsin Conservation Department, Madison, Wisconsin, 1963.*

[2] *Wisconsin Department of Natural Resources, Environmental Assessment for the Proposed Clean-Flo Multiple Inversion Aeration System, 1986, cited in Muskego-Wind Lakes Priority Watershed Project Water Resource Appraisal, DNR, Milwaukee, Wisconsin, April 1994.*

Table 9

SEASONAL WATER QUALITY CONDITIONS IN LITTLE MUSKEGO LAKE: FALL 1986 THROUGH FALL 1993

	Fall (mid-September to mid-December)		Winter (mid-December to mid-March)		Spring (mid-March to mid-June)		Summer (mid-June to mid-September)	
Parameter[a]	Shallow[b]	Deep[c]	Shallow[b]	Deep[c]	Shallow[b]	Deep[c]	Shallow[b]	Deep[c]
Temperature (°F)								
Range	42.0-69.0	42.0-68.5	34.0-40.5	36.5-38.5	41.0-72.5	40.0-54.0	67.0-81.5	45.5-72.0
Mean[d]	59.0(14)	55.0(14)	36.5(8)	37.0(8)	58.0(26)	47.0(25)	75.0(39)	60.0(39)
Specific Conductance (μS/cm)								
Range	596-643	599-740	575-723	700-795	612-714	576-721	520-718	533-691
Mean[d]	618(14)	646(14)	648(8)	746(8)	657(21)	667(21)	644(42)	635(41)
pH (standard units)								
Range	7.9-8.7	7.2-8.5	6.9-9.2	7.5-8.6	7.6-8.8	7.4-8.7	8.1-8.8	6.9-8.2
Mean[d]	8.4(12)	8.0(12)	8.3(8)	7.8(8)	8.4(26)	7.9(26)	8.4(39)	7.4(39)
Dissolved Oxygen								
Range	6.0-12.1	0.0-11.3	10.9-19.7	0.8-11.6	0.1-13.1	0.0-12.3	4.6-13.4	0.0-6.8
Mean[d]	8.9(12)	5.5(12)	14.1(8)	6.4(8)	10.3(26)	4.1(26)	8.4(39)	0.5(39)
Total Phosphorus								
Range	0.013-0.063	0.030-0.350	0.003-0.050	0.063-0.175	0.002-0.043	0.002-0.218	0.002-0.156	0.004-0.816
Mean[d]	0.040(14)	0.126(14)	0.016(6)	0.096(6)	0.006(26)	0.046(26)	0.008(38)	0.179(38)
Orthophosphorus								
Range	0.002-0.022	0.005-0.330	0.001-0.018	0.041-0.175	0.002-0.011	0.001-0.218	0.002-0.057	0.004-0.816
Mean[d]	0.007(16)	0.097(16)	0.006(6)	0.079(6)	0.004(23)	0.049(23)	0.007(37)	0.180(37)
Chlorophyll-a (μg/l)								
Range	8.0-53.0	--	4.0-42.0	--	5.0-29.0	--	4.0-81.0	--
Mean[d]	24.6(14)	--	15.3(7)	--	13.7(26)	--	28.1(38)	--
Secchi-Disk Transparency (feet)								
Range	2.6-8.5	--	1.3-12.5	--	2.9-9.2	--	2.3-11.5	--
Mean[d]	4.9(13)	--	7.9(7)	--	5.1(25)	--	4.4(39)	--

[a]Milligrams per liter unless otherwise indicated.

[b]Depth of sample approximately 1.5 feet.

[c]Depth of sample greater than 60 feet.

[d]Number of samples in parentheses.

Source: U. S. Geological Survey and SEWRPC.

Table 10

LITTLE MUSKEGO LAKE WATER QUALITY DATA: APRIL 1987 THROUGH APRIL 1993

	April 7, 1987		April 13, 1988		April 11, 1989		April 5, 1990		April 9, 1991		April 8, 1992		April 26, 1993	
Parameter[a]	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep	Shallow	Deep
Depth of Sample (feet)	3.0	63.5	1.5	34.0	1.5	67.0	1.5	65	3.0	55.0	1.5	60	1.5	66
Specific Conductance (μS/cm)	620	628	648	650	665	670	646	646	670	676	673	677	628	645
pH (standard units)	8.4	8.4	8.4	8.3	7.6	8.0	8.0	8.4	8.3	7.9	8.4	8.7	8.3	8.0
Water Temperature (°F)	43.3	41.9	50.9	49.1	41.0	40.1	41.9	41.4	53.1	45.0	46.4	41.0	50.0	42.8
Color (platinum-cobalt scale)	9	6	15	15	10	15	15	20	10	10	15	15	15	15
Turbidity (nephelo-metric turbidity units)	1.2	1.6	3.2	7.7	2.1	2.8	2.2	2.4	2.8	1.7	1.7	2.5	6.9	3.3
Secchi-Disk Transparency (feet)	4.9	--	3.0	--	4.9	--	4.6	--	3.6	--	4.3	--	--	--
Dissolved Oxygen	12.4	11.8	12.5	11.2	12.8	10.7	12.3	12.3	10.8	7.9	13.0	11.8	11.7	10.1
Hardness, as $CaCO_3$	184	181	260	260	250	250	260	260	260	270	270	270	240	240
Calcium	56	55	51	51	46	45	48	49	53	54	54	53	51	50
Magnesium	35	35	31	31	34	33	34	34	32	33	34	34	28	29
Sodium	33	33	32	32	38	37	40	40	37	38	39	39	37	39
Potassium	2.5	2.5	2.5	2.5	2.2	2.2	2.7	2.6	2.4	2.5	2.0	2.0	2.0	2.0
Alkalinity, as $CaCO_3$	224	224	210	212	197	200	193	194	214	214	210	210	190	190
Sulfate	42	42	39	39	43	43	39	39	41	42	42	42	33	34
Fluoride	--	--	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.1
Chloride	61	62	61	60	72	73	74	74	71	72	75	75	71	75
Silica	1.1	1.2	3.7	3.7	1.6	1.6	3.2	3.2	1.6	4.1	0.8	0.2	2.3	2.7
Dissolved Solids	367	364	372	372	372	372	376	376	380	378	396	398	352	356
Nitrate and Nitrite	0.20	0.20	0.28	0.28	0.26	0.26	0.30	0.30	0.36	0.32	0.32	0.33	0.50	0.47
Ammonia Nitrogen	0.04	0.04	0.02	0.02	0.05	0.06	0.18	0.17	0.02	0.09	0.01	0.03	0.01	0.11
Total Nitrogen, Including Organic	1.1	1.2	0.8	1.0	0.8	0.7	0.9	1.0	0.8	0.7	0.6	0.6	0.6	0.5
Total Phosphorus	0.043	0.040	0.041	0.046	0.033	0.030	0.044	0.041	0.027	0.024	0.019	0.019	0.035	0.026
Orthophosphorus	0.003	0.001	0.005	0.005	0.003	0.003	0.003	0.004	0.004	0.005	0.003	--	0.002	0.004
Iron (μg/l)	7	4	100	100	50	50	50	50	50	50	50	80	50	50
Manganese (μg/l)	2	1	40	40	40	40	40	40	40	40	40	40	40	40
Chlorophyll-a (μg/l)	10	--	29	--	16	--	25	--	16	--	13	--	18	--

[a]Milligrams per liter unless otherwise indicated.

Source: U. S. Geological Survey and SEWRPC.

Table 11

WATER QUALITY CONDITIONS AT SPRING TURNOVER FOR LITTLE MUSKEGO LAKE, BIG MUSKEGO LAKE, AND WIND LAKE IN THE MIDDLE FOX RIVER WATERSHED: APRIL 1989

Parameter[a]	Little Muskego Lake at 1.5-Foot Depth April 11, 1989	Little Muskego Lake at 67-Foot Depth April 11, 1989	Big Muskego Lake at 0.5-Foot Depth April 12, 1989	Big Muskego Lake at 2.5-Foot Depth April 12, 1989	Wind Lake at 1.5-Foot Depth April 11, 1989	Wind Lake at 50-Foot Depth April 11, 1989
Water Temperature (°F)	41	40	42	42	42	40
Dissolved Oxygen	12.8	10.7	13.6	13.7	12.9	13.1
Specific Conductance (μS/cm)	665	670	545	545	591	586
Dissolved Solids	372	372	318	320	360	356
Alkalinity, as $CaCO_3$	197	200	156	155	172	173
Hardness, as $CaCO_3$	250	250	230	220	250	250
pH (standard units)	7.6	8.0	7.9	8.1	7.2	8.1
Secchi-Disk Transparency (feet)	4.9	--	1.3	--	3.9	--
Color (platinum-cobalt scale)	10	15	40	40	30	30
Turbidity (nephelo-metric turbidity units)	2.1	2.8	12	--	3.0	3.2
Chlorophyll-a (μg/l)	16	--	31	--	25	--
Nitrate and Nitrite	0.26	0.26	0.41	0.40	0.40	0.41
Ammonia Nitrogen	0.05	0.06	0.04	0.04	0.14	0.13
Total Nitrogen, Including Organic	0.8	0.7	1.5	1.6	1.5	1.5
Orthophosphorus	0.003	0.003	0.005	0.005	0.005	0.005
Total Phosphorus	0.033	0.030	--	0.069	0.056	0.051
Calcium	46	45	44	41	48	49
Magnesium	34	33	23	28	32	32
Sodium	38	37	23	23	26	27
Potassium	2.2	2.2	2.6	2.6	3.0	3.2
Sulfate	43	43	58	58	62	62
Chloride	72	73	46	45	49	49
Silica	1.60	1.60	<0.20	<0.20	0.30	0.30
Iron (μg/l)	<50	<50	<50	<50	<50	<50
Manganese (μg/l)	<40	<40	<40	<40	<40	<40

[a]*Milligrams per liter unless otherwise indicated.*

Source: U. S. Geological Survey and SEWRPC.

the deepest point in the Lake, as shown on Map 13 in Chapter III. Comparable data collected between 1985 and 1989 by the USGS for Wind Lake are listed in Table 11 and indicate that the water quality of Little Muskego Lake is similar to that of Wind Lake. More detailed information on these water quality data, including locations and procedures, may be found in reports published by the USGS.[3]

Thermal Stratification

Thermal and dissolved oxygen profiles for Little Muskego Lake are shown in Figure 3. Water temperature ranged from 34.0°F during the winter to 81.5°F during the summer. Complete mixing of the Lake was restricted by thermal stratification in the summer and by ice cover in the winter. Thermal stratification is the result of differential heating of lake water and the resulting water temperature-density relationships. Water is unique among liquids because it reaches its maximum density, or weight per unit of volume, at about 39.2°F. The development of thermal stratification begins in early summer, reaches its maximum in late summer, and disappears in the fall, as illustrated diagrammatically in Figure 4. Stratification may also occur in winter under ice cover.

As summer begins, the lake waters absorb solar energy at the surface. Wind action and, to some extent, internal heat-transfer mechanisms transmit this energy to the underlying portions of the water body. As the upper layer of water is heated by solar energy, a density barrier begins to form between the warmer surface water and the lower, heavier, colder water, as illustrated by the June, July, and August profiles in Figure 3. This barrier is marked by a

[3]*U. S. Geological Survey, Hydrology and Water Quality of Wind Lake in Southeastern Wisconsin, Water Resources Investigations Report No. 91-4107, USGS, Madison, Wisconsin, 1993. See also the annual water resources data reports published in the USGS Water-Data Report series for Wisconsin.*

Figure 3

TEMPERATURE AND DISSOLVED OXYGEN PROFILES FOR LITTLE MUSKEGO LAKE: 1987-1993

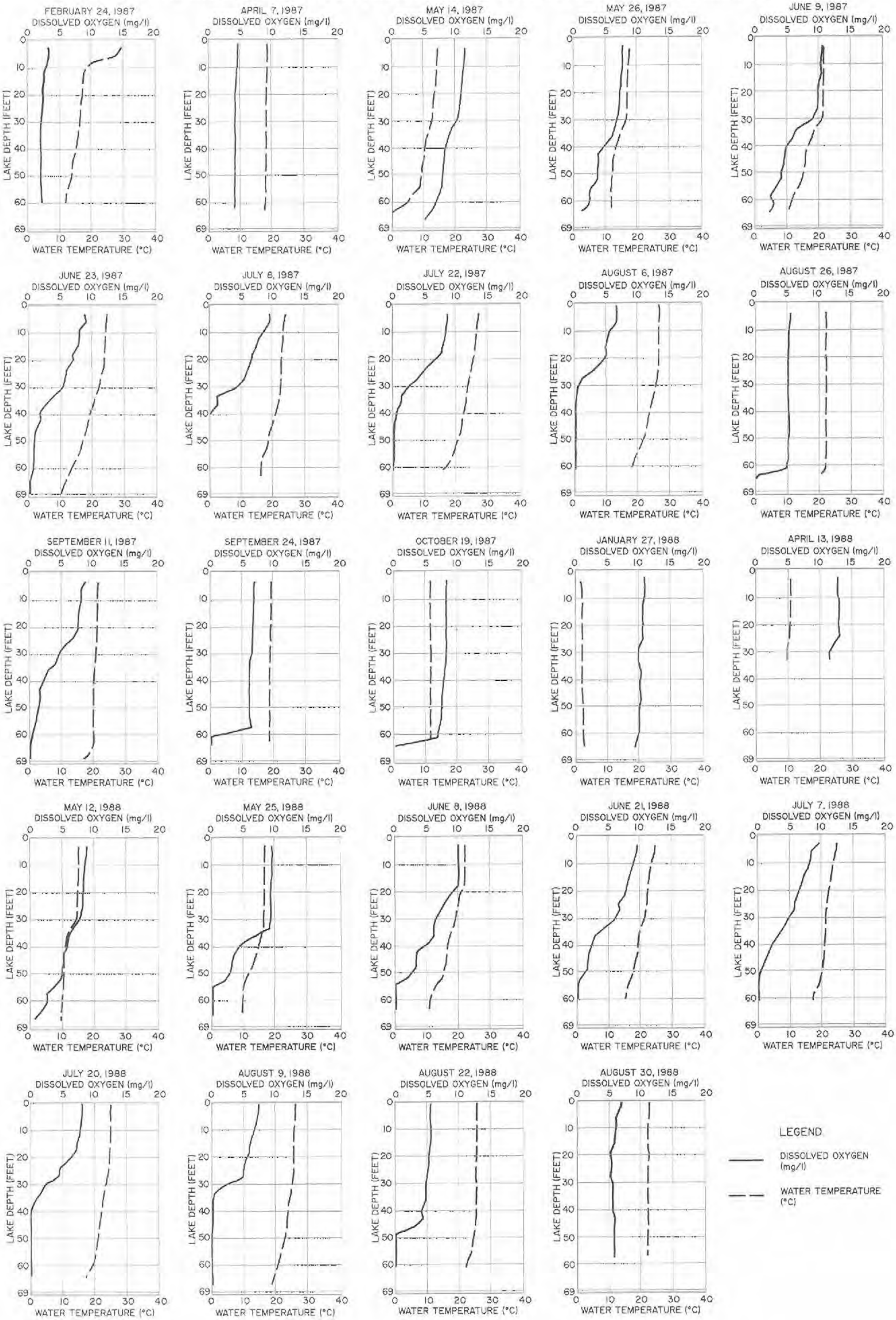


Figure 3 (continued)

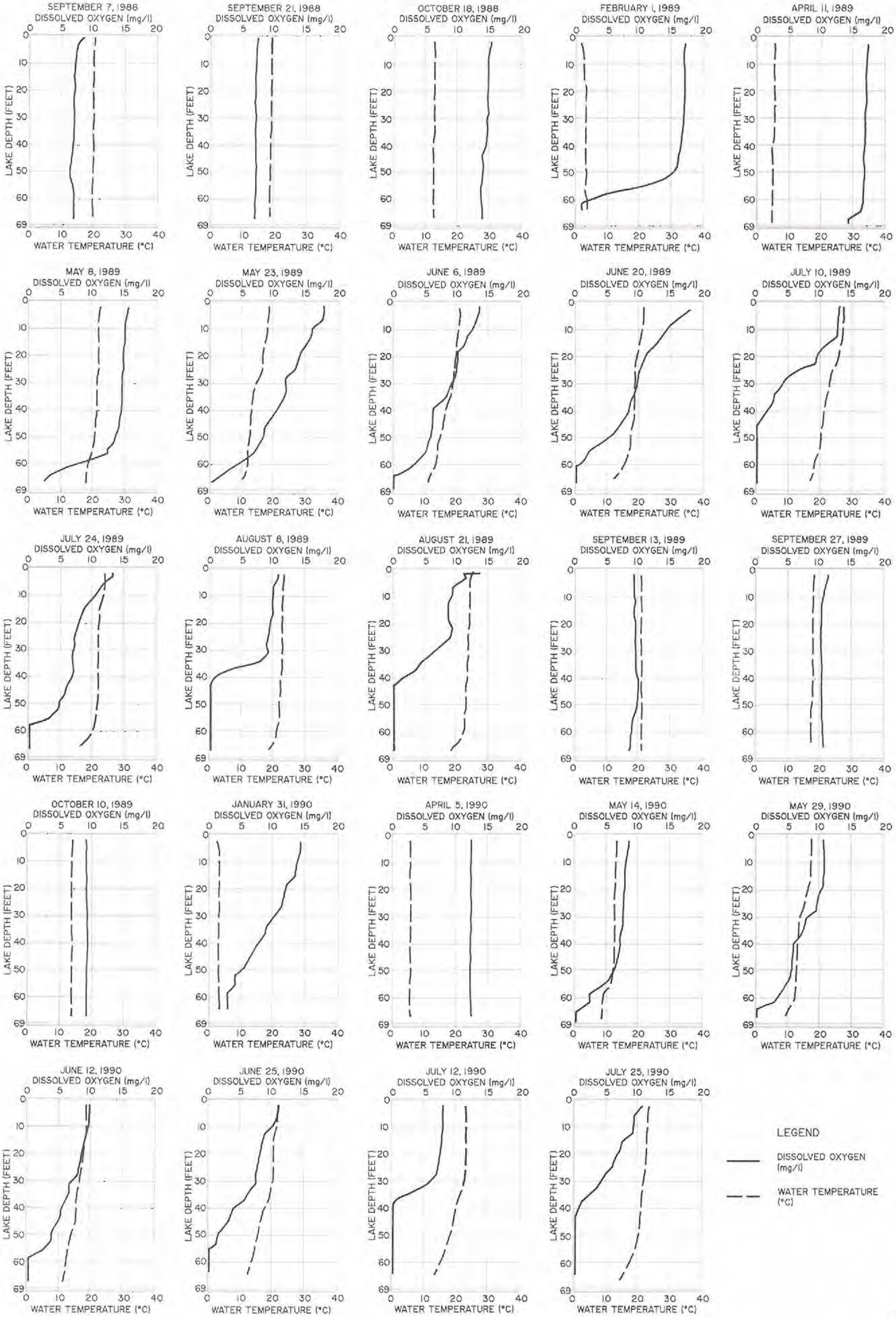


Figure 3 (continued)

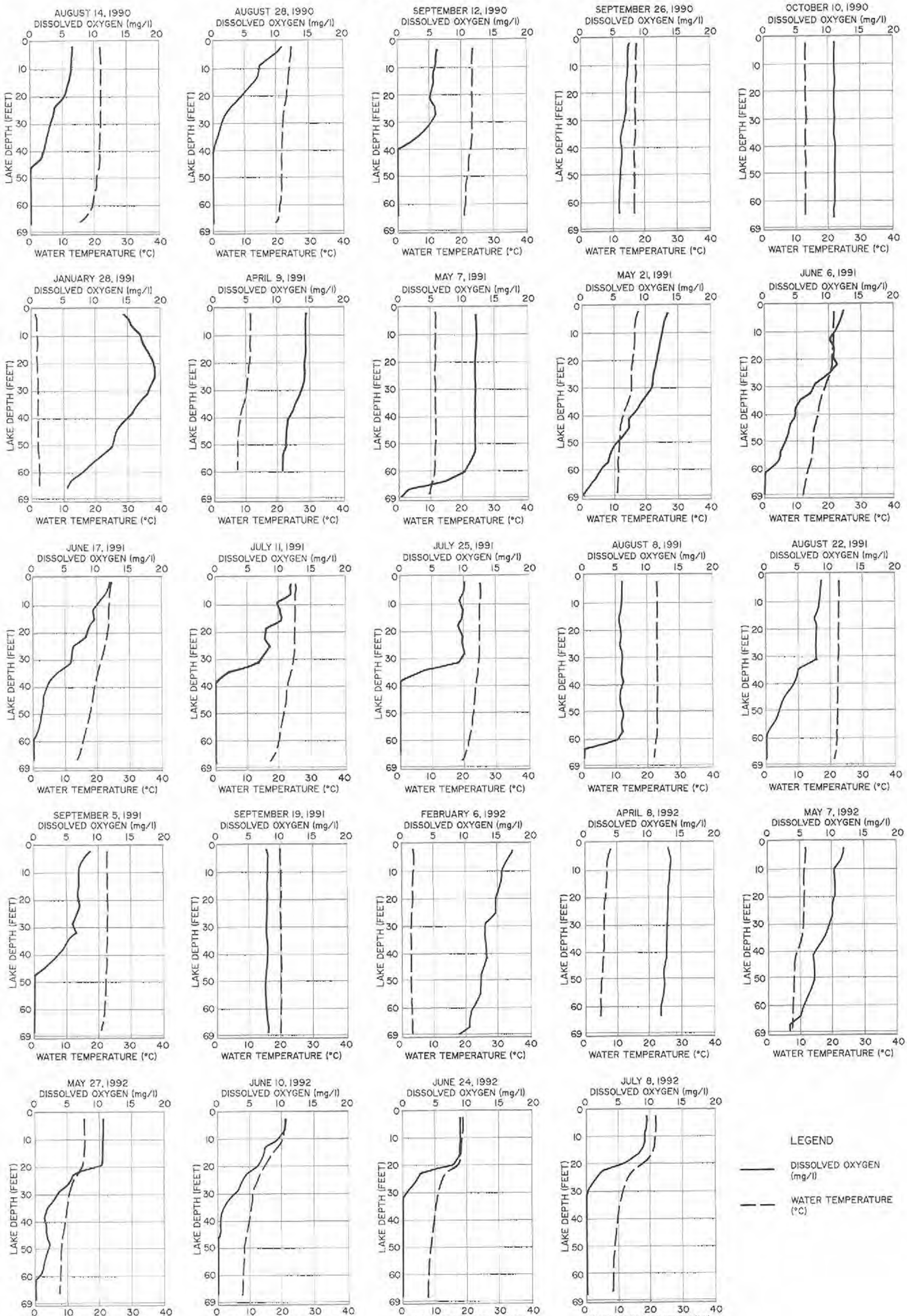
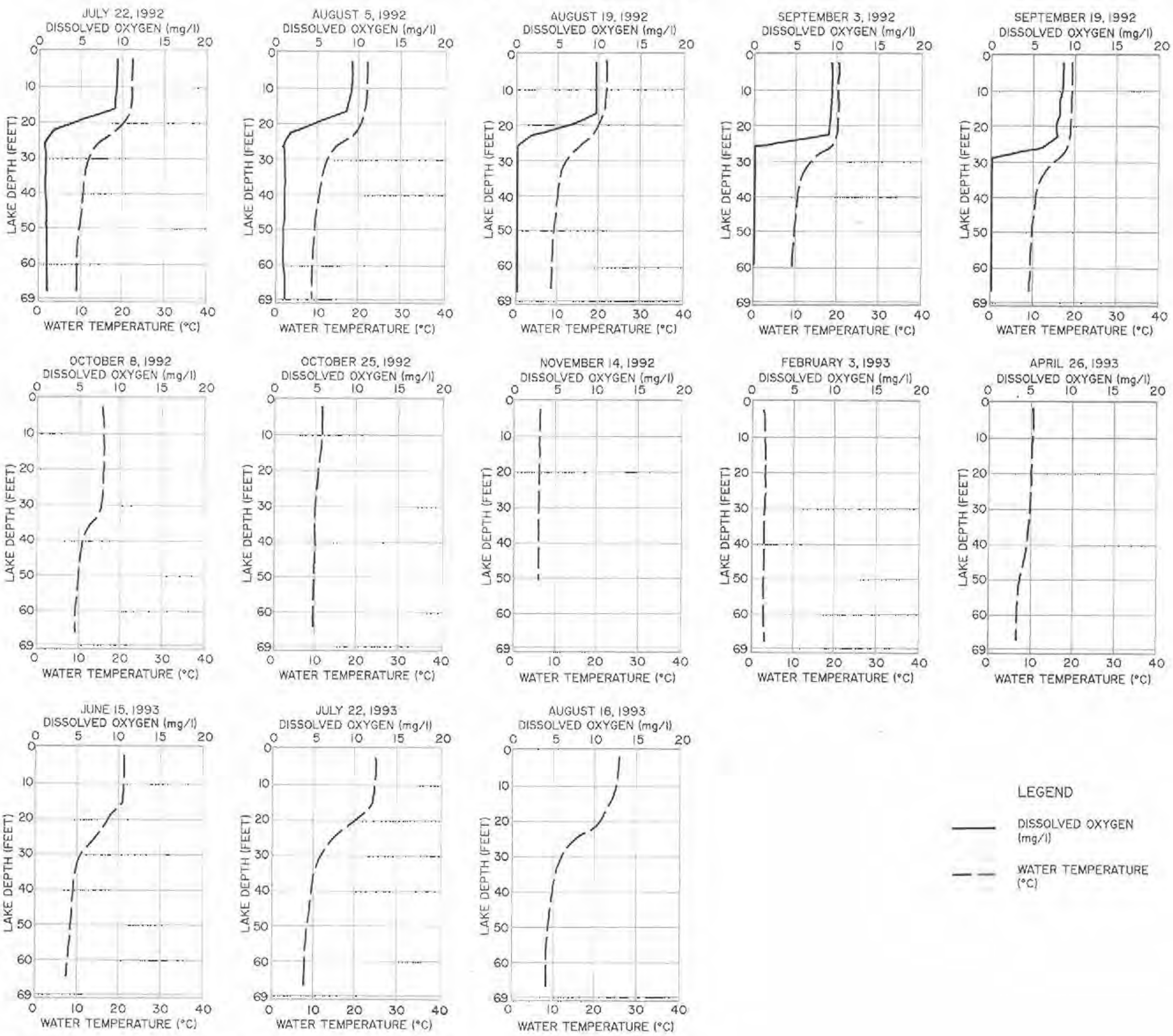


Figure 3 (continued)



Source: U. S. Geological Survey and SEWRPC.

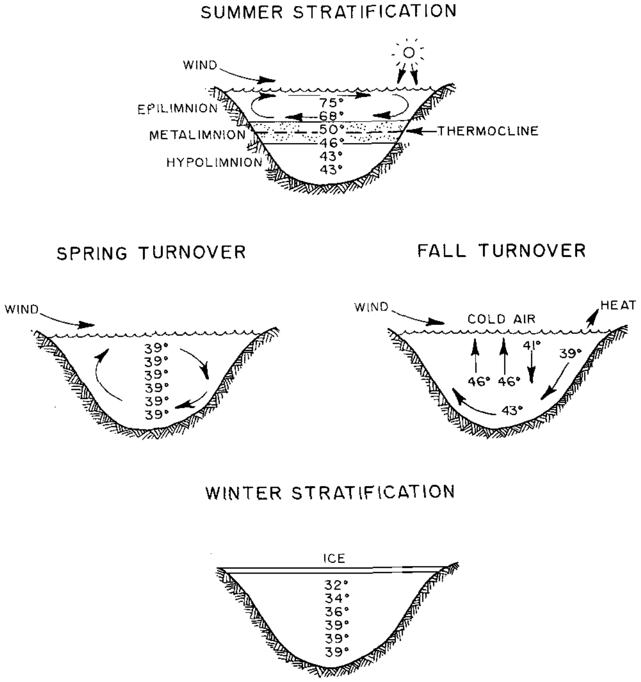
sharp temperature gradient known as the "thermocline" and is characterized by an approximately 1°F-to-2°F drop in temperature per three feet of depth that separates the warmer, lighter upper layer of water, called the "epilimnion," from the lower layer, called the "hypolimnion." Although this barrier is readily crossed by fish when sufficient oxygen exists, it essentially prohibits the exchange of water between the two layers. This condition, which is discussed further in this report, has a great impact on both the chemistry and biology of a lake, illustrated diagrammatically in Figure 5, which are also commonly stratified as a result.

The autumnal mixing period occurs when air temperatures cool the surface water and wind action results in the erosion of the thermocline: as the surface water cools, it becomes heavier, sinking and displacing the now relatively warm water below. The colder water sinks and mixes under wind action until the entire column of water is of uniform temperature. This process is known as "fall turnover."

When the water temperature drops to the point of maximum water density, 39.2°F, the waters at the lake surface become more dense than the now warmer bottom waters of the lake, which rise to the surface. Eventually, the water column is cooled to the point at which the surface of the water, cooled to 32°F and now lighter than the bottom waters, which remain close to 39°F, becomes ice and covers the surface of the lake, isolating it from the atmosphere for a period of up to four months, as illus-

Figure 4

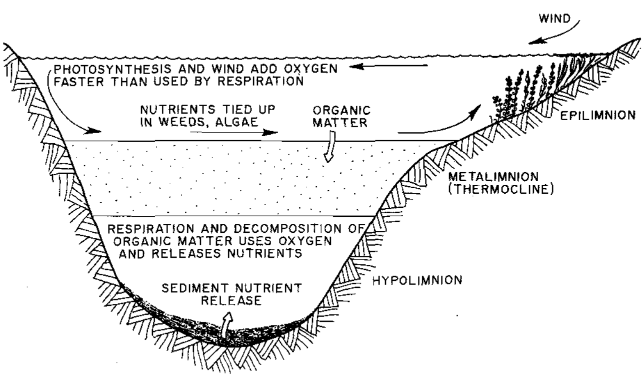
THERMAL STRATIFICATION OF LAKES



Source: University of Wisconsin–Extension and SEWRPC.

Figure 5

LAKE PROCESSES DURING SUMMER STRATIFICATION



Source: University of Wisconsin–Extension and SEWRPC.

trated by the February profiles in Figure 3. This winter stratification occurs as the colder, lighter water and ice remain at the surface, now separated from the warmer, heavier water near the bottom of the lake. During the study period, ice cover on Little Muskego Lake existed from January 16, 1987, through February 24, 1987. In subsequent years, the USGS records indicate that the Lake was ice-covered during the period from January through early February.

Spring brings a reversal of this process. As the ice thaws and the upper layer of water warms, it again becomes more dense and begins to approach the temperature of the warmer, deeper water until the entire water column reaches the same temperature. This process is referred to as "spring turnover" and usually occurs within weeks after the ice goes out, as illustrated by the April profiles in Figure 3. After spring turnover, the water at the surface again warms and becomes lighter, so that it floats above the colder, deeper water. Wind and resulting waves carry some of the energy of the warmer, lighter water to lower depths, but only to a limited extent. Thus begins the formation of the thermocline and another period of summer thermal stratification.

Dissolved Oxygen

Dissolved oxygen levels are one of the most critical factors affecting the living organisms of a lake ecosystem. As shown in Figure 3, dissolved oxygen levels were generally highest at the surface of Little Muskego Lake, which experienced an interchange between the water and the atmosphere, stirring by wind action, and production of oxygen by plant photosynthesis. Dissolved oxygen levels were lowest on the bottom of the Lake, where decomposer organisms and chemical oxidation processes, collectively known as biochemical oxygen demand, utilized oxygen in the decay process.

When any lake becomes thermally stratified as described above, the surface supply of dissolved oxygen to the hypolimnion is cut off. Gradually, if insufficient dissolved oxygen exists to meet the total demands from the bottom-dwelling aquatic life and decaying material, the dissolved oxygen levels in the bottom waters may be reduced to zero, a condition known as "anoxia" or "anaerobiasis."

The hypolimnion of Little Muskego Lake becomes anoxic during summer stratification. During the study period from 1986 through 1993, dissolved oxygen concentrations at the bottom of the Lake fell to zero by late May to mid-June. In some years—1987 through 1991, for example—dissolved oxygen concentrations dropped below 5 milligrams per liter (mg/l), or the minimum level necessary to support many species of fish, at a depth of approximately 45 to 55 feet, with concentrations decreasing to zero at about 60 feet. In more recent years, 1992 and 1993, the depth at which the dissolved oxygen concentration reached 5 mg/l was about 20 feet. By late July to early August, the dissolved oxygen concentration was generally zero from the bottom of the Lake to about 30 to 40 feet below the surface.

Fall turnover, between September and October in most years, naturally restores the supply of oxygen to the bottom waters, although hypolimnetic anoxia can be reestablished during the period of winter thermal stratification. Winter anoxia is more common during years of heavy snowfall, when snow covers the ice, reducing the degree of light penetration and reducing algal photosynthesis that takes place under the ice. In Little Muskego Lake, however, dissolved oxygen levels at depths of less than 50 feet were found to be adequate for the support of fish throughout the winter. It should be noted that the aeration system discussed earlier did not operate during the winter months. At the end of winter, dissolved oxygen concentrations in the bottom waters of the Lake are restored during the period of spring turnover, which generally occurs between March and May.

Hypolimnetic anoxia is common in many of the lakes in Southeastern Wisconsin during summer stratification. The depleted oxygen levels in the hypolimnion cause fish to move upward, nearer to the surface of the lake, where higher dissolved oxygen concentrations exist. This migration, when combined with temperature, can select against some fish species who prefer the cooler water temperatures that generally prevail in the lower portions of the lake. When there is insufficient oxygen at these depths, the fishes are susceptible to summer-kills or, alternatively, are driven into the warmer portions of the lake, where their condition and competitive success may be severely impaired.

In other lakes in the Region, hypolimnetic anoxia can also occur during winter stratification. Under these conditions, anoxia contributes to winter-kill of fishes.

In addition to these biological consequences of anaerobiasis, the lack of dissolved oxygen at depth can enhance development of chemoclines, or chemical gradients, with an inverse relationship to the dissolved oxygen concentration. For example, the sediment-water exchange of such elements as phosphorus, iron, and manganese is increased under anaerobic conditions, resulting in higher hypolimnetic concentrations of these elements. Under anaerobic conditions, iron and manganese change oxidation state, enabling the release of phosphorus from the former iron and manganese complexes to which they were bound under aerobic conditions. This internal loading can affect water quality significantly if these nutrients and salts are mixed into the epilimnion, especially during early summer, when these nutrients can become available for algal or plant growth.

Specific Conductance

Specific conductance is an indicator of the concentration of dissolved solids in the water; as the amount of dissolved solids increases, the specific conductance increases. Conductivity, pH profiles, and Secchi-disk transparency readings for Little Muskego Lake are shown in Figure 6. During winter and summer thermal stratification, specific conductance increases at the lake bottom as a result of an accumulation of dissolved materials in the hypolimnion, referred to above as "internal loading." This phenomenon was more noticeable in Little Muskego Lake during winter stratification than during the summer, and more pronounced after late May 1992 than previously. The relationship between these observations and the operation of the aeration system is discussed below. As shown in Table 9, the specific conductance of Little Muskego Lake during the spring turnovers of 1987 to 1993 ranged from 576 to 721 microSiemens per centimeter (μS/cm) at 25°C, which is within the normal range for lakes in Southeastern Wisconsin.[4]

Chloride

Chloride concentrations ranged from 60 to 75 mg/l during the spring turnovers of 1987 through 1993. As shown in Table 11, these values are somewhat greater than those found in other area lakes. The most important anthropogenic source of chlorides is believed to be street deicing salts.

Alkalinity and Hardness

Alkalinity is an index of the buffering capacity of a lake, or the capacity of a lake to absorb and neutralize acids. The alkalinity of a lake depends on the levels of bicarbonate, carbonate, and hydroxide ions present in the water. Lakes in Southeastern Wisconsin typically have a high alkalinity because of the types of soil covering, and the bedrock underlying, the watersheds. In contrast, water hardness

[4] *R. A. Lillie and J. W. Mason, Limnological Characteristics of Wisconsin Lakes, Technical Bulletin No. 138, Wisconsin Department of Natural Resources, Madison, Wisconsin, 1983.*

Figure 6

SPECIFIC CONDUCTANCE AND pH PROFILES FOR LITTLE MUSKEGO LAKE: 1987-1993

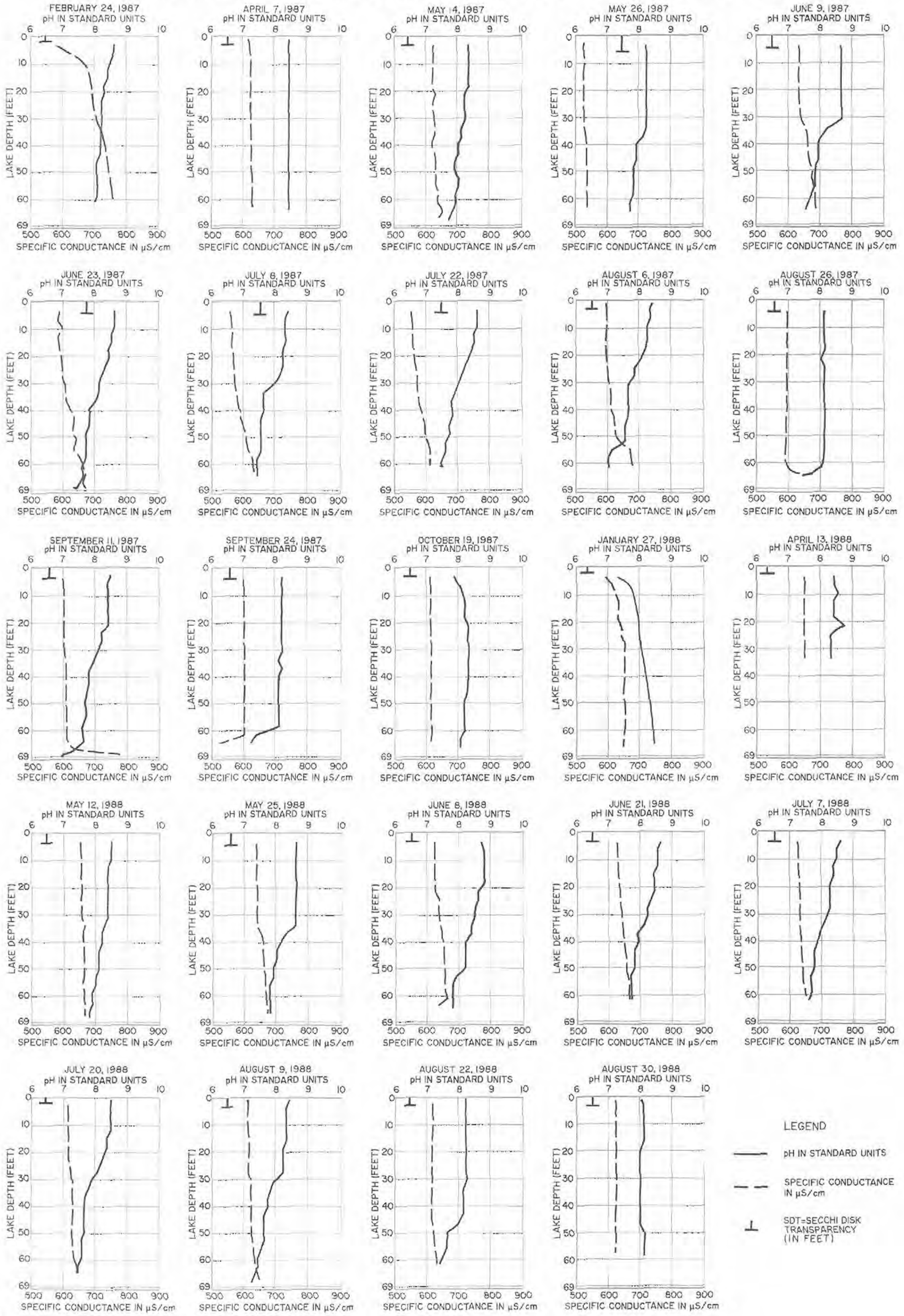


Figure 6 (continued)

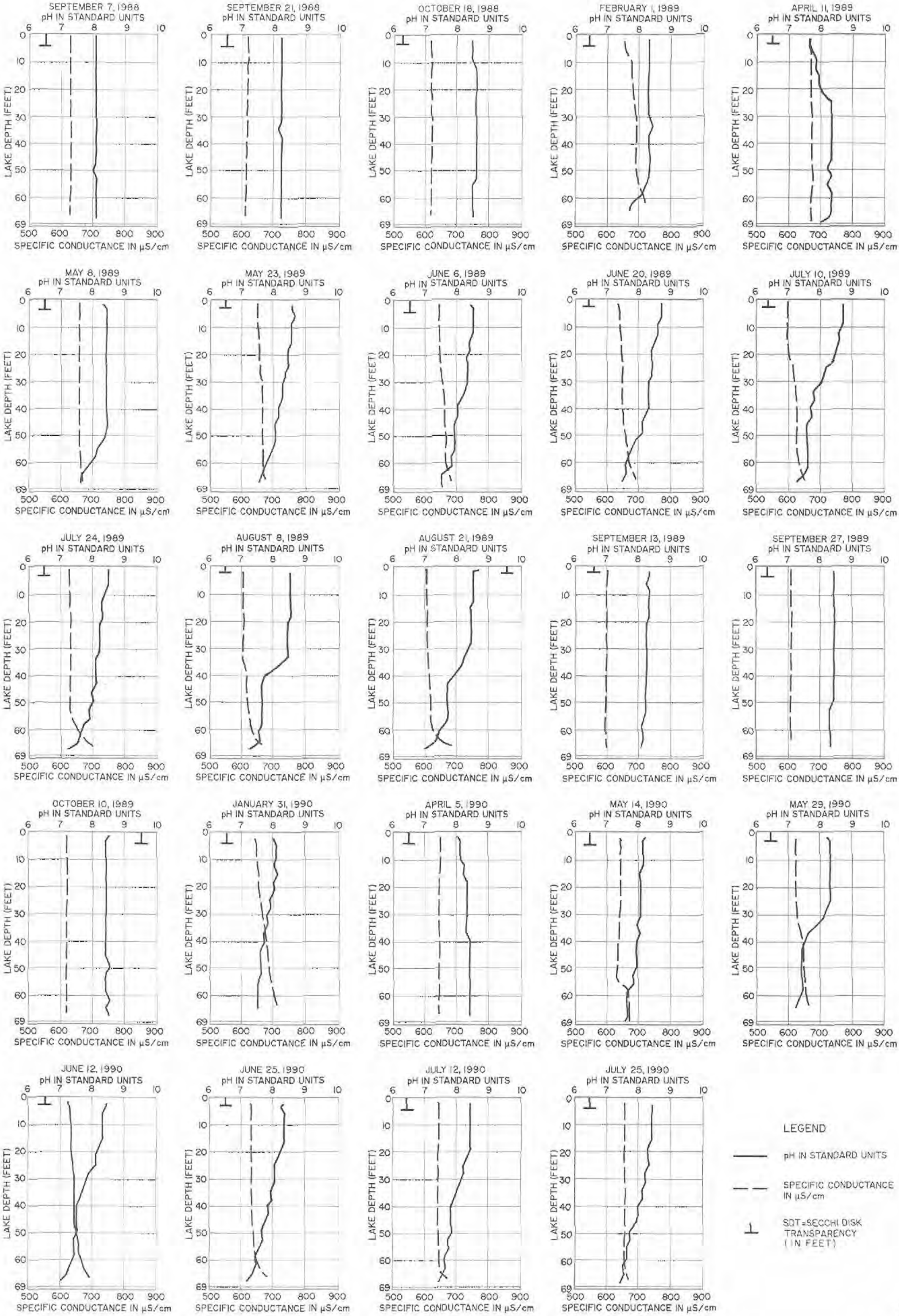


Figure 6 (continued)

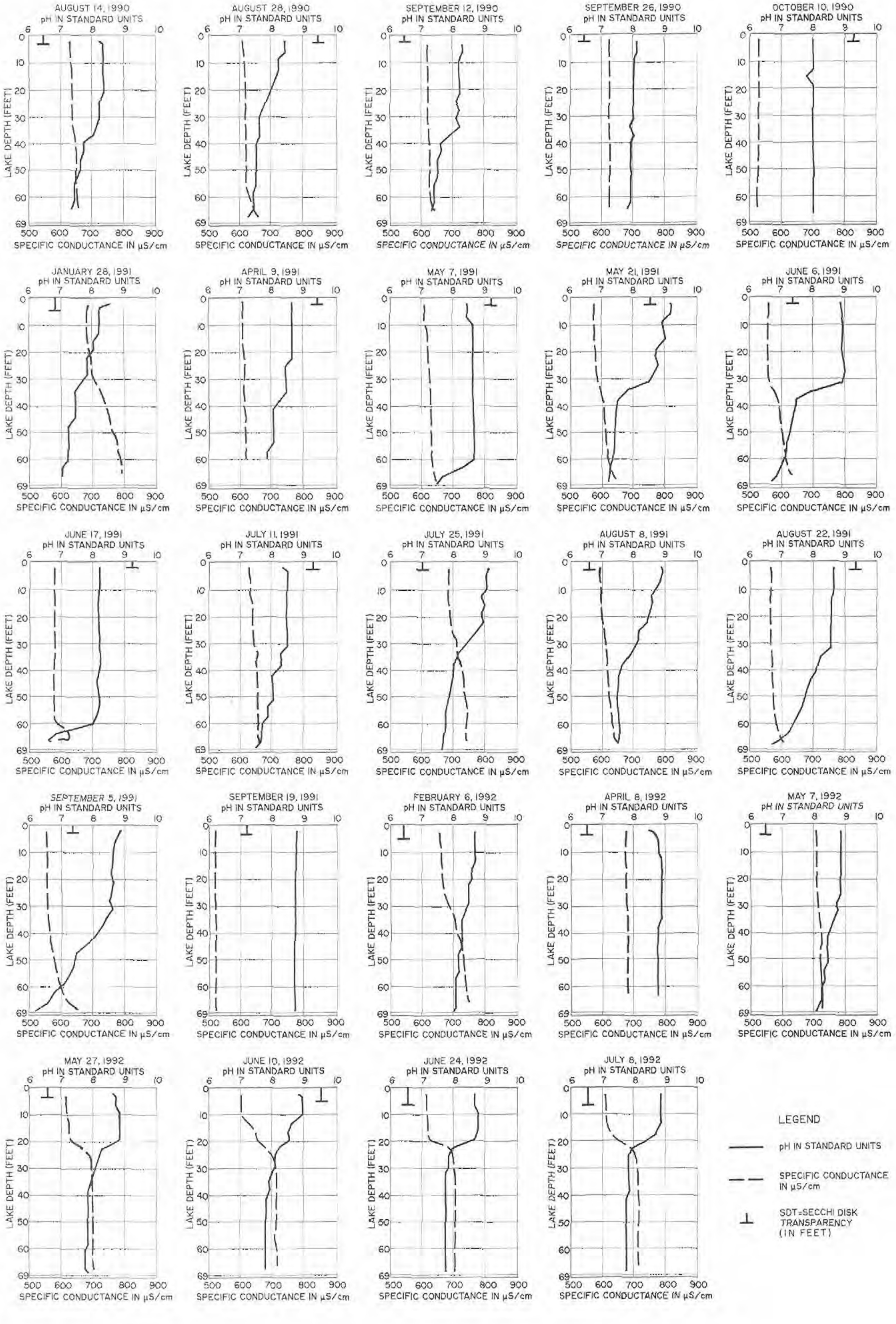
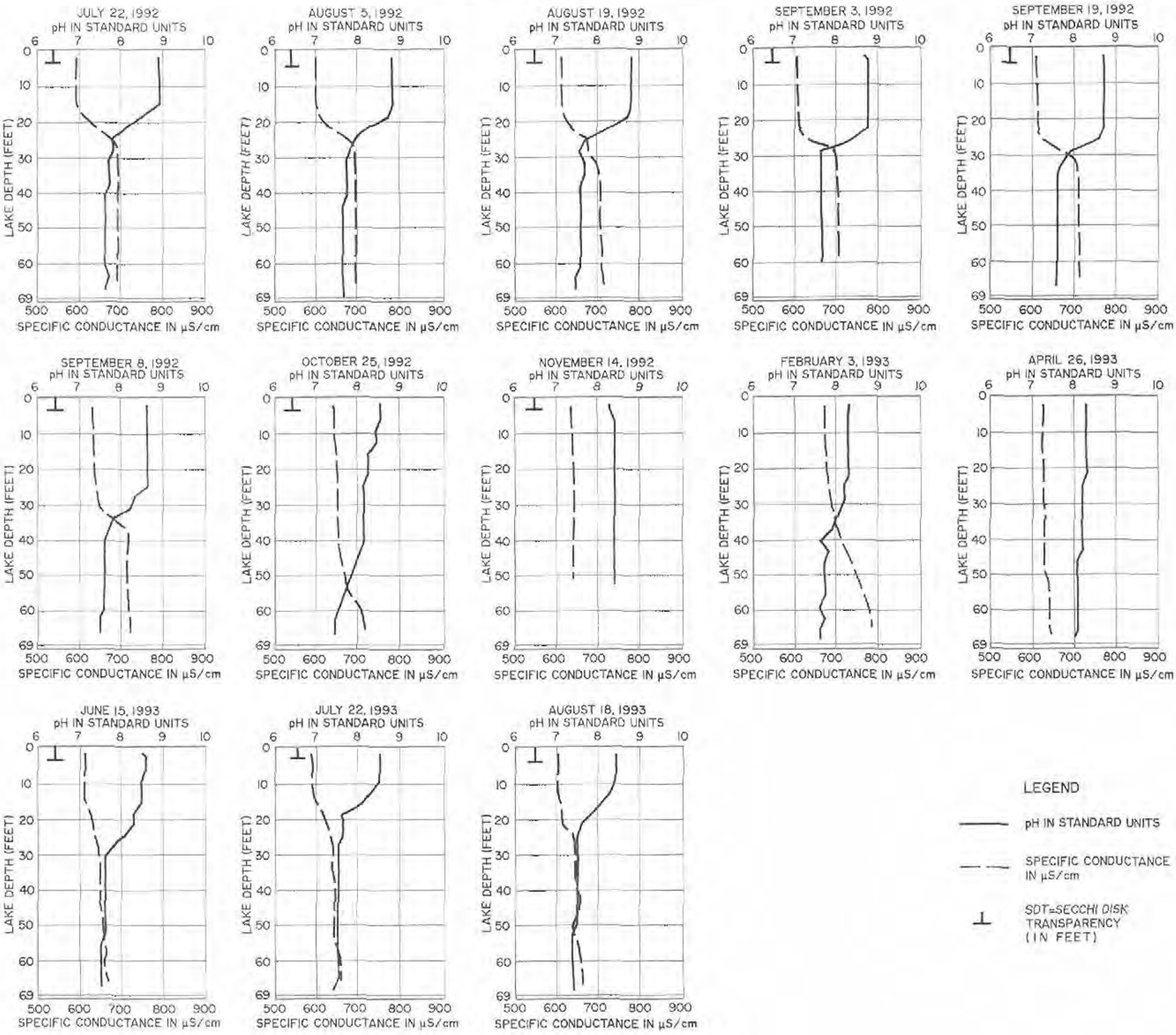


Figure 6 (continued)



Source: U. S. Geological Survey and SEWRPC.

is a measure of the multivalent metallic ions, such as calcium and magnesium, present in the lake. Hardness is usually reported as an equivalent concentration of calcium carbonate ($CaCO_3$). When these measures are applied to the study lake, Little Muskego Lake can be described as a hard-water alkaline lake.

During the spring turnovers of 1987 through 1993, alkalinity averaged about 206 mg/l, while hardness averaged about 247 mg/l, as listed in Table 10. These values are within the normal range for lakes in Southeastern Wisconsin.[5]

Hydrogen Ion Concentration (pH)

The pH is a logarithmic measure of hydrogen ion concentration on a scale of 0 to 14 standard units, with 7 indicating neutrality. A pH above 7 indicates basic (or alkaline) water, a pH below 7 indicates acidic water. In Little Muskego Lake, the pH was found to range between 6.9 and 9.2 standard units, as shown in Table 9. Since Little Muskego Lake has a high alkalinity, or buffering capacity, the pH generally does not fluctuate below 7, and the Lake is not susceptible to the harmful effects of acidic precipitation. In general, pH declined with depth, exhibiting an inverse relationship to conductivity, as shown in Figure 6. As noted in terms of electrical conductance, the pH gradient became more pronounced after spring 1992.

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[5]*Ibid.*

Water Clarity

Water clarity, or transparency, gives an indication of overall water quality; clarity may decrease because of high concentrations of suspended materials, such as algae, zooplankton, and inorganic solids; or because of high concentrations of dissolved organic substances, such as water-coloring compounds. Water clarity is measured with a Secchi disk, a black-and-white, eight-inch-diameter disk, which is lowered into the water until a depth is reached at which the disk is no longer visible. This depth is known as the "Secchi-disk reading." These readings form an integral part of the DNR Self-Help Monitoring Program, in which a citizen volunteer monitor is enrolled as part of the District's water quality monitoring effort, as discussed in Chapter VIII.

Water clarity generally varies throughout the year as algal populations increase and decrease, and as the amount of inorganic suspended materials and humic coloration varies, in response to changes in weather conditions and nutrient loadings. These same factors make Secchi-disk readings vary from year to year as well. Secchi-disk readings for Little Muskego Lake were always greater than one foot; during much of the study period, they were greater than 5.5 feet. Greatest water clarity was observed during winter, and least clarity, on average, during summer. Clarity appears to have increased during recent years, 1992 and 1993, in comparison to the earlier years of the study; summer transparencies during the period from 1987 to 1991 averaged 3.6 feet, in contrast to average transparencies of 7.5 feet recorded more recently. These values are indicative of an average water quality, compared to other lakes in Southeastern Wisconsin.[6]

Chlorophyll-a

Chlorophyll-a is the major photosynthetic (green) pigment in algae. The amount of chlorophyll-a present in the water is an indication of biomass or amount of algae in the water. Chlorophyll-a concentrations in Little Muskego Lake ranged from a low of 4 micrograms per liter (μg/l) in June 1992, to a high of 81 μg/l in June 1989. These values, although within the range of chlorophyll-a concentrations recorded in other lakes in the Region,[7] are high and indicate poor water quality.

[6] *Ibid.*

[7] *Ibid.*

Nutrient Characteristics

Aquatic plants and algae require such nutrients as phosphorus, nitrogen, carbon, calcium, chloride, iron, magnesium, sulfur, and silica for growth. In hard-water alkaline lakes, most of these nutrients are generally found in concentrations which exceed the needs of growing plants. However, in lakes where the supply of one or more of these nutrients is limited, plant growth is limited by the amount of that nutrient available. Two of the most important nutrients, in this respect, are phosphorus and nitrogen.

The ratio of total nitrogen to total phosphorus in lake water, or the N:P ratio, can indicate which nutrient is likely to be limiting plant growth. Where the N:P ratio is greater than 14 to 1, a lake is probably phosphorus-limited, while a ratio of less than 10 to 1 indicates that nitrogen is probably the limiting nutrient.[8] As shown in Table 12, the N:P ratios in spring turnover samples collected from Little Muskego Lake during the study period were generally greater than 20 to 1. This indicates that plant production was most likely consistently limited by phosphorus. Other factors, such as light, turbulence, and through flow, may also limit plant growth; these are further discussed below.

Both total phosphorus and soluble phosphorus concentrations were measured for Little Muskego Lake. Soluble phosphorus, being dissolved in the water column, is readily available for plant growth. However, its concentration can vary widely over short periods of time as plants take up and release this nutrient. Therefore, total phosphorus is usually considered a better indicator of nutrient status. Total phosphorus includes the phosphorus contained in plant and animal fragments suspended in the lake water, phosphorus bound to sediment particles, and phosphorus dissolved in the water column.

The Southeastern Wisconsin Regional Planning Commission recommends that total phosphorus concentrations in lakes not exceed 0.020 mg/l during spring turnover in order to prevent nuisance algal and aquatic plant growths. During the study years, the total phosphorus concentrations at spring turn-

[8] *M. O. Alum, R. E. Gessner, and J. H. Gokstatter, An Evaluation of the National Eutrophication Data, U. S. Environmental Protection Agency Working Paper No. 900, Corvallis, Oregon, 1977.*

Table 12

NITROGEN-TO-PHOSPHORUS RATIOS FOR LITTLE MUSKEGO LAKE: 1987-1993

Date	Nutrient Levels		
	Nitrogen (mg/l)	Phosphorus (mg/l)	N:P Ratio
April 7, 1987	1.3	0.043	30.2
April 13, 1988	0.8	0.041	19.5
April 11, 1989	0.8	0.033	24.2
April 5, 1990	0.9	0.044	20.5
April 9, 1991	0.8	0.030	26.7
April 8, 1992	0.9	0.019	47.4
April 26, 1993	1.1	0.035	31.4

Source: U. S. Geological Survey and SEWRPC.

over in Little Muskego Lake were generally greater than 0.030 mg/l, as shown in Table 10. Throughout the study period, total phosphorus in the surface waters of Little Muskego Lake averaged 0.034 mg/l. In the hypolimnion, or bottom waters, of Little Muskego Lake, total phosphorus concentrations were generally higher, ranging from 0.002 to 0.816 mg/l, as shown in Tables 9 and 10. The average bottom-water total phosphorus concentration during the study period was 0.112 mg/l.

When aquatic organisms die, they usually sink to the bottom of the lake, where they are decomposed. Phosphorus from these organisms is stored in the bottom sediments. Because phosphorus is not highly soluble in water, it readily forms insoluble precipitates with calcium, iron, and aluminum under aerobic conditions and accumulates predominantly in the lake sediments, although some may be rereleased into the water column. However, when the bottom waters become depleted of oxygen during stratification, certain chemical changes occur, especially the change in the oxidation state of iron from the insoluble Fe^{3+} state to the more soluble Fe^{2+} state. The effect of these chemical changes is that phosphorus becomes soluble and is more readily released from the sediments. This process also occurs under aerobic conditions, but generally at a slower rate. As the water begins to mix again during spring or fall turnover, this phosphorus can be mixed throughout the lake and may be available for algal growth. If the turnover event is slow, over several weeks, this hypolimnetic phosphorus may be readsorbed by the iron and precipitate back to the sediment. If the process is more rapid, hours to days, some of this phosphorus is circulated into the upper waters of the lake, generally in a bioavailable form, where it can be taken up very rapidly by algae.

The data from 1987 through 1993 indicated potential for considerable internal loading of phosphorus from the bottom sediments of Little Muskego Lake. Such releases tended to occur primarily during the anaerobic periods of summer and winter stratification. The dissolved phosphorus concentrations in the bottom waters during the summer anoxic periods ranged from 0.004 to 0.816 mg/l, as shown in Table 9; during winter stratification, the concentrations ranged from 0.063 to 0.175 mg/l. The limited volume of the hypolimnion during the period from 1987 to 1992 probably made the contribution of phosphorus from the anoxic area of Little Muskego Lake negligible in terms of the total phosphorus load. In more recent years, however, the larger hypolimnion volume could potentially contribute significant quantities of phosphorus to the surface waters of the Lake during rapid mixing events, such as during severe summer thunderstorms which occasionally pass through this area.

EFFECTS OF AERATION

Observed Effects

The Little Muskego Lake Management District purchased and installed a Clean-Flo Laboratories continuous laminar flow inversion aeration system during 1987. As previously noted, the purpose of this system was primarily fourfold: 1) to remove muck, 2) to control aquatic plants, 3) to improve water clarity, and 4) to improve the lake fishery. Aeration, or the process of injecting air into the hypolimnion, primarily during periods of stratification, using a system of mechanical air compressors and diffuser piping, is intended to counteract the tendency of a lake to stratify and develop hypolimnetic anoxia. Aeration acts directly on the effects of biochemical oxygen demand in the bottom waters of the lake by supplementing the quantity of available oxygen, and is considered most important during periods when the hypolimnion is isolated from the atmosphere. This is in contrast to whole-lake circulation, whereby air is pumped into the hypolimnion with the intent of preventing stratification from taking place, with the further intent of keeping the lake well-mixed all year round.

The effects of hypolimnetic aeration on Little Muskego Lake are shown in Figures 3 and 6. As noted, for the summer observations recorded prior to May 1992, the depth of the oxycline, or depth at which the oxygen concentration turned sharply toward zero, was between approximately 50 and 60 feet, with anoxia occurring at about 60 feet. In light of these data, the aeration system at Little Muskego Lake appeared to be able to modify significantly the thermal structure of the Lake's water column. However, it appeared unable to satisfy the oxygen demand completely in the lowest portion of the hypolimnion. This condition is entirely consistent with the highly organic nature of the lake-bottom sediments noted by both Kendziorski[9] and Midwest Engineering Services.[10]

Contrasting these data with data recorded after 1991, when the aeration system was shut down, clearly shows the degree of thermal and chemical modification that was achieved in the Lake with the aeration system.[11] For example, the presence of distinct thermal and chemical—oxygen, pH, and conductivity—gradients in the water column can be noted during the period from May 27, 1992, through October 8, 1992, which gradients recurred during June, July, and August 1993. Data from Tables 9 and 10 show other, less obvious effects as well. Examination of these data suggests the following findings, which are considered to be preliminary because of the relatively short period of record available following aeration shutdown:

1. Surface phosphorus concentrations decreased after the aeration system was shut down. The water column mixing, encouraged by the breakdown of the thermal gradient by the aeration system, more readily transported this element throughout the water column. As shown in Figure 7, water quality indicators, including total phosphorus concentrations, are indicative of impaired water quality during the summer months when the aeration system was operating, but suggest improved water quality after the system was shut down. Total phosphorus concentrations in the surface waters of Little Muskego Lake decreased from an average of 0.04 mg/l during the summers of 1987 through 1991, to an average of less than 0.02 mg/l during the summers of 1992 through 1994, as shown in Figure 7. Evidence from the scientific literature clearly shows that sediment-water exchange of phosphorus takes place under both aerobic and anaerobic conditions, although the process occurs at a faster rate under anaerobic conditions.[12] Anaerobic conditions existed at the sediment-water interface in Little Muskego Lake throughout the study period. Total phosphorus concentrations in the anaerobic zone of the Lake averaged about 0.22 mg/l between 1987 and 1991, decreasing slightly to about 0.19 mg/l subsequently. Because of the much-reduced volume of the hypolimnion during the period when the aerator was operating, the phosphorus that had accumulated in the bottom waters of the Lake was potentially more susceptible to mixing into the aerobic portion of the Lake than under usual conditions. The mixing that was occurring above the anaerobic layer encouraged diffusive trans-

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[9] *Casey Kendziorski, Jr., P.E., Feasibility Report, Removal of Sediment and Muck from Little Muskego Lake, Milwaukee, Wisconsin, December 1967.*

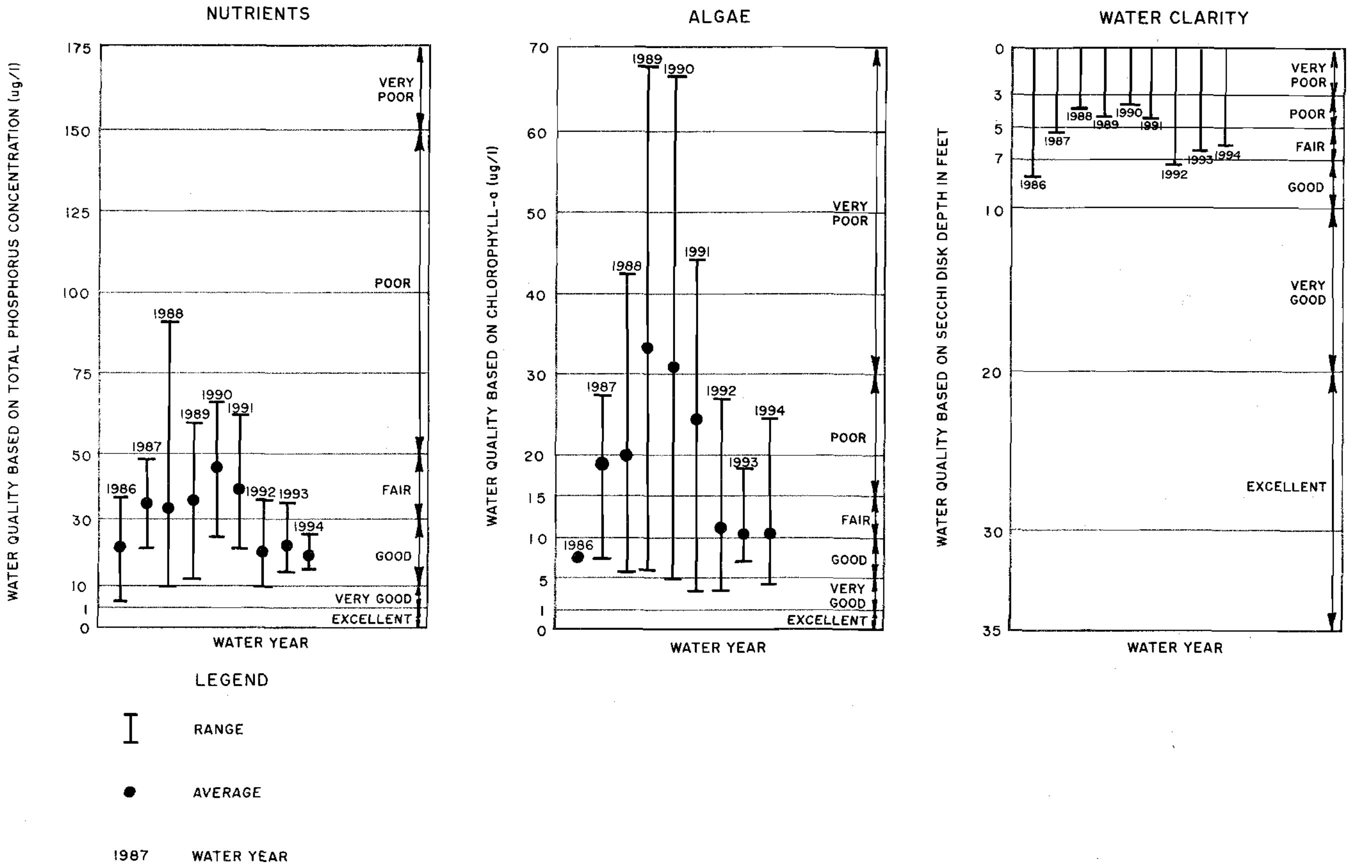
[10] *Midwest Engineering Services, Inc., Project Report No. 7-31010-2, Lake Sediment Exploration and Analysis: Little Muskego Lake, Muskego, Wisconsin, Waukesha, Wisconsin, May 1993.*

[11] *All data used in this analysis were published in Madison, Wisconsin, by the U. S. Geological Survey in the water resources data reports for water years 1987 through 1994. See USGS Water-Data Report WI-87-1, Water Resources Data—Wisconsin, Water Year 1987, 1988, p. 272; USGS Water-Data Report WI-88-1, Water Resources Data—Wisconsin, Water Year 1988, 1989, p. 307; USGS Water-Data Report WI-89-1, Water Resources Data—Wisconsin, Water Year 1989, 1990, p. 330; USGS Water-Data Report WI-90-1, Water Resources Data—Wisconsin, Water Year 1990, 1991, p. 498; USGS Water-Data Report WI-91-1, Water Resources Data—Wisconsin, Water Year 1991, 1992, p. 510; USGS Water-Data Report WI-92-1, Water Resources Data—Wisconsin, Water Year 1992, 1993, p. 450; USGS Water-Data Report WI-93-2, Water Resources Data—Wisconsin, Water Year 1993, Vol. 2, Upper Mississippi River Basin, 1994, p. 341; USGS Water-Data Report WI-94-2, Water Resources Data—Wisconsin, Water Year 1994, Vol. 2, Upper Mississippi River Basin, 1995, p. 315.*

[12] *See B. Bostrom, J. M. Andersen, S. Fleischer, and M. Jansson, "Exchange of Phosphorus across the Sediment-Water Interface," in G. Persson and M. Jansson (eds.), Phosphorus in Freshwater Ecosystems, Kluwer Academic Publishers, Boston, 1988.*

Figure 7

LITTLE MUSKEGO LAKE PRIMARY WATER QUALITY INDICATORS: 1986-1994



Source: U. S. Geological Survey and SEWRPC.

port of the nutrient into the water column by continually eroding the chemical gradient at this interface and preventing the development of a larger and more stable buffer, such as was formed by the larger hypolimnion in more recent years. This response is illustrated by the slightly higher concentration of total phosphorus observed during the period of aerator operation than subsequently, and is typical of the responses observed elsewhere.[13]

2. Secchi-disk transparencies increased after the aeration system was shut down. In most northern temperate lakes, the greatest contributor to loss of transparency is organic particulate matter in the water column, specifically the presence of phytoplankton or algae. The amount of algae has been shown to be proportional to the amount of phosphorus available in these lakes.[14] Given the higher surface-water phosphorus concentration observed during the period from 1987 through 1991, a more abundant growth of planktonic algae would also be anticipated, reducing water clarity. This is clearly shown in Figure 7 in the average summer chlorophyll-a concentration of 33.5 $\mu g/l$ and Secchi-disk transparency of about five feet recorded

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[13]*Wisconsin Department of Natural Resources, Technical Bulletin No. 75, Survey of Lake Rehabilitation Techniques and Experiences, DNR, Madison, Wisconsin, 1974, pp. 18-19.*

[14]*Organization for Economic Cooperation and Development, Eutrophication of Waters: Monitoring, Assessment and Control, Paris, 1982.*

during 1987 through 1991. A decrease in the amount of phosphorus available to these algae, as was observed during the period since 1991, had the opposite consequence. Summer average chlorophyll-a concentrations decreased to about 8 μg/l, and Secchi-disk transparency increased to over seven feet.

3. Hypolimnetic temperatures decreased after the aeration system was shut down. Another common consequence of aeration, due to the reduced level of thermal stratification, is that heat transfer by mixing processes is enhanced and the temperature of the lake becomes more uniform.[15] While surface heating still takes place, more of this heat is transferred downward to the lower levels of the lake. Such transference can be seen in Figure 3 between 1987 and 1991, when bottom-water temperatures ranged from about 50°F to 72°F; this temperature range is in contrast to the temperatures recorded subsequently, which ranged from 40°F to 45.5°F, with similar surface temperatures during both periods.

4. Hypolimnetic oxygen concentrations decreased after the aeration system was shut down. An obvious consequence of the cessation of aeration is a return to more extensive hypolimnetic anoxia. As has been noted, the oxycline moved upward in the water column from between 50- and 60-foot depth to about 20 feet after the aeration system had been shut down. As the sources of the oxygen demand, such as decomposing plants and fishes, remain in the Lake, it can be expected that the cessation of aeration would lead to a resumption of the previously prevailing situation, in which dissolved oxygen trapped in the hypolimnion of the Lake following the onset of stratification had been rapidly exhausted. This was indeed the case, as comparison of the data gathered during 1992 and 1993 with those gathered between 1987 and 1991 reveals.

5. Hypolimnetic pH decreased after the aeration system was shut down. As the artificial supply of air to satisfy the high oxygen demand in the bottom waters of Little Muskego Lake was terminated by the shutdown of the aeration system, the demand for oxygen in these waters had to be met from within the mass of oxygen present in the volume of water trapped by density in the lower portion of the water column prior to the formation of the thermocline. Initially, this demand is met by the dissolved oxygen remaining in the water immediately following the onset of stratification. Once this source of oxygen is exhausted, bacteria are expected to begin to strip the surplus oxygen molecules off such common aqueous constructs as carbonate, nitrate, and sulphate, and replace them with hydrogen molecules, creating methane, ammonia, and hydrogen sulphide. This process results in a reduced pH.[16] The data given in Figure 6 clearly demonstrate this pH reduction during periods of anoxia. During July 1993, for example, when dissolved oxygen concentrations dropped to zero at a depth of about 15 feet, the pH of the water decreased by about one pH unit, from about 8.5 to about 7.5, as shown in Figures 3 and 6. Similar responses are also present in previous years. A further consequence of this reduction in pH, as has been noted above, is an increased propensity for iron- and manganese-bound phosphorus to be released. This phenomenon is reflected in Figure 6 by the concomitant increase in conductivity observed in the anoxic zone of the Lake below the thermocline.

6. Hypolimnetic conductivity increased after the aeration system was shut down. As iron and other salts ionize and dissociate in the hypolimnion in response to the biochemical oxygen demand and decreased pH, the amount of dissolved material in solution increases, driving up the specific conductance of the bottom waters of the Lake, as shown in Figure 6. For example, the data for July 1993 show an increase in conductivity of about 50 μS/cm below 15 feet in depth, coincident with both the one-unit pH decrease and the onset of anoxia illustrated in Figure 3. Both increased conductivity in the bottom waters and a lowered pH level are characteristic of enriched lakes in the Region.

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[15] *Wisconsin Department of Natural Resources, Technical Bulletin No. 75, op. cit.*

[16] *See W. Stumm and J. J. Morgan, Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters, Wiley-Interscience, New York, 1970.*

In addition to the preliminary findings which have been based upon the available data, the following additional considerations related to eliminating the aeration system have been hypothesized which are not based upon direct-measurement data:

1. Changes in hypolimnetic phosphorus loading rates: While direct measurements of the rate of hypolimnetic phosphorus release were not obtained during the study period, this response may be estimated by calculating the mass of phosphorus present in the surface and bottom waters of the Lake both during and after aerator operation. Assuming an average depth to the summer oxycline of about 55 feet during the period of aeration, and average total phosphorus concentrations of 0.22 mg/l in the hypolimnion and 0.04 mg/l in the epilimnion, as given above, the mass of total phosphorus present in each of these layers can be calculated as approximately 120 pounds and 760 pounds, respectively. After termination of aeration, the average depth to the summer oxycline decreased to about 20 feet, and average total phosphorus concentrations decreased to 0.19 mg/l in the hypolimnion and 0.02 mg/l in the epilimnion, as given above. The total mass of phosphorus in each of these layers can be calculated as 1,140 pounds and 230 pounds, respectively. In effect, aeration appears to have significantly suppressed hypolimnetic phosphorus release but provided substantially more phosphorus to the surface waters of the Lake. This is consistent with evidence from other lake systems, and with the chlorophyll-a and conductivity data set forth above for Little Muskego Lake. Overall, therefore, aeration achieved an estimated reduction in mass of total phosphorus in the Lake of about 490 pounds, which, when compared to the total phosphorus load to the Lake from external sources, achieved an approximate reduction of between 8 percent and 10 percent of the load.[17] This conclusion is consistent with that drawn by the DNR.[18]

2. Changes in phytoplankton species composition: The generally improved water clarity observed after the shutdown of the aerator may be obscured in the future, as part of the loss of transparency experienced in enriched water bodies can be ascribed not only to algal abundance, as measured by chlorophyll-a, but also to the type of algae present in the lake. Under the more turbulent conditions extant when the aeration system was operating, these algae would probably have been green algae or diatoms, which affect transparency less than do the scum-forming, buoyant blue-green algae that would be likely to be present during the summer season.[19,20] Should blue-green algae assume a dominant role in Little Muskego Lake, water transparency could be reduced despite the reduction in phosphorus concentrations.[21] The shift

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[17]*The total phosphorus load to Little Muskego Lake has been estimated to be about 4,940 pounds by the DNR, as set forth in Wisconsin Department of Natural Resources Publication No. WR-340-93, A Nonpoint Source Control Plan for the Muskego-Wind Lakes Priority Watershed Project, Milwaukee, Wisconsin, October 1993; and about 6,180 pounds by the Little Muskego Lake Association, as set forth in Little Muskego Lake Association Inc., Little Muskego Lake: Watershed Inventory, Muskego, Wisconsin, November 1994.*

[18]*D. R. Helsel, Muskego-Wind Lakes Priority Watershed Project Water Resources Appraisal: Final Report, Wisconsin Department of Natural Resources, Milwaukee, Wisconsin, April 1994.*

[19]*Green algae and diatoms appear to be more transparent than blue-green algae because they tend to be more evenly distributed throughout the water column; lacking the buoyancy mechanism of the blue-green algae, the green algae and diatoms tend to sink unless suspended by turbulence in the water column, thus becoming relatively evenly distributed. Blue-green algae, in contrast, use their buoyancy mechanism to remain near the water surface, forming scums, which are less transparent to the casual observer. Professor Robert G. Wetzel provides a detailed explanation of this effect in his text, Limnology, published by W. B. Saunders Company, Philadelphia, in 1975.*

[20]*See also G. J. Kohler, Factors Affecting Phytoplankton Species Composition, Dominance and Succession in Shallow, Hypereutrophic Big Muskego Lake, M.Sc. thesis, University of Wisconsin– Milwaukee, 1982. This publication described the common algal seasonality in southeastern Wisconsin based on observations in neighboring Big Muskego Lake.*

[21]*Wisconsin Department of Natural Resources, Technical Bulletin No. 75, op. cit.*

to blue-green algal dominance would be encouraged by a high phosphorus concentration and a low nitrogen-to-phosphorus ratio, both of which are presently less than favorable.[22] Unfortunately, no data on the algal species composition were available to permit examination of this hypothesis.

General Conclusions

As to whether this aeration system achieved the objectives set for it at the time of its installation—the removal of muck, the control of aquatic plants, the improvement of water clarity, and the improvement of the lake fishery—only the second objective, the improvement of water clarity, can be quantitatively assessed from the foregoing data. The data presented in Figures 6 and 7 clearly show that, as Secchi-disk transparencies improved after the system was shut down, the system did not meet this objective. However, as outlined in the foregoing discussion, transparency is one of the more problematical parameters to predict; therefore, other indicators should be used to assess the overall performance of the aeration system. In this regard, a more qualitative assessment of the efficacy of the aeration system in reducing the mass of muck in the Lake can be made.

It was alleged that, at the time of installation, hypolimnetic aeration would counteract the effects of lowered dissolved oxygen levels in the bottom waters of the Lake and hasten the decomposition and oxidation of the organic matter comprising the Little Muskego Lake sediments. To do so effectively, it may be assumed that the sediment surface must be oxidized or subjected to the influence of aerobic waters at the sediment-water interface. The system appeared unable to maintain an aerobic layer at this interface in Little Muskego Lake, as has been noted above and shown in Figure 3. The calculated mass of total phosphorus in the hypolimnion, and in the Lake as a whole, indicates that the aeration system did achieve a degree of reduction in the mass of phosphorus; however, in the absence of appropriate data, it is not possible to ascribe this diminution to enhanced rates of decomposition and oxidation of organic matter in the sediments.[23]

The Little Muskego Lake Management District Board of Commissioners noted that citizen perceptions of the efficiency of the aeration system varied.[24] Some citizens purportedly observed improvements in the water quality and fishery of the Lake that are somewhat at variance with the above-cited data. Reasons offered by the Commissioners for these varying perceptions included the following: 1) the fact that the observed water clarity may reflect factors other than the operation of the aerator, including sampling during, or shortly after, periods of heavy Lake recreational usage or storm events; 2) an observed migration of muck and silt from the littoral zone, up to 10 feet from the shoreline; and 3) uncertainties relating to the sampling methodologies, especially those employed in the fisheries surveys, as set forth in Chapter V, and the sampling protocols concerning the period over which the water quality studies were conducted by the USGS relative to inter-annual variability typically observed in the Lake. As previously noted, the analyses conducted by Regional Planning Commission staff and set forth herein were based on data provided by the USGS and DNR; thus, it was not possible for the Commission staff to exercise control over the methodological aspects of the study. Nevertheless, examination of these data would suggest a consistency in results, consistent with limnological theory that implies little influence of these uncertainties on the net result of analyses over the study period, especially with regard to the water quality data. The fisheries data presented in Chapter V are subject to a greater degree of uncertainty, which is due to the absence of data from the period of aerator operation. It appears that data obtained during the period of aerator operation are as likely to have been collected on or shortly after a heavy recreational-use period or storm event as are the data obtained during the post-aeration period. For example, Figure 3 shows that samples were taken approximately the same number of days after

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[22]*See the article by Dr. Val H. Smith, "Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue-Green Algae in Lakes," which appeared in* Science, *Vol. 221, pp. 669-70.*

[23]*Indeed, as set forth above, the diminution in the mass of total phosphorus in the Lake appears to be the result of 1) the redistribution of phosphorus within the water column—more of the mass was present within the aerobic epilimnion of the Lake, and 2) the reduction in volume of the hypolimnion due to the action of the aerator.*

[24]*Little Muskego Lake Management District Board of Commissioners meeting, December 1995.*

Table 13

CONCENTRATIONS OF SYNTHETIC ORGANIC CHEMICALS, METALS, AND NUTRIENTS IN SEDIMENTS IN LITTLE MUSKEGO LAKE: 1993

Parameter	Sediment Sample Analytical Results (ppm)				
	Sample 5 (HA-5)	Sample 6 (HA-6)	Sample 7 (HA-6)	DNR Guideline[a]	
				LEL	SEL
Ammonia Nitrogen	180	110	120	75	- -
Total Kjedal Nitrogen	1,600	1,500	1,300	- -	- -
Nitrate Nitrogen	<20	<20	<20	- -	- -
Nitrite Nitrogen	<20	<20	<20	- -	- -
Oil and Grease	9.9	30	<2	1,000	- -
Total Phosphorus	230	240	120	- -	- -
Arsenic	6.6	9.6	5.1	6	85
Cadmium	0.75	0.52	0.43	1.1	9
Copper	17	15	8.3	25	390
Lead	21	19	20	31	250
Nickel	8.2	6.7	5.6	31	75
Zinc	72	51	37	120	820
Total Organic Carbon	18,000	23,000	20,000	- -	- -
4,4-DDE	<0.08	<0.008	<0.008	0.005	1
4,4-DDT	<0.08	<0.008	<0.008	0.008	3.6
Chlordane	<0.4	<0.04	<0.04	0.007	0.3
Toxaphene	<4	<0.4	<0.4	- -	- -
Lindane	<0.08	<0.008	<0.008	- -	- -
Heptachlor	<0.08	<0.008	<0.008	- -	- -
Endrin	<0.08	<0.008	<0.008	- -	- -
Aldrin	<0.08	<0.008	<0.008	0.002	0.4
Dieldrin	<0.08	<0.008	<0.008	- -	- -

[a]"LEL" = Lowest Effect Level; "SEL" = Severe Effect Level.

Source: Midwest Engineering Services, Inc.; and SEWRPC.

the Independence Day and Labor Day holidays each year between 1987 and 1993. Notwithstanding, it is conceivable that the Lake had not fully reached a state of equilibrium with respect to aerated conditions during the years when the aerator operated. While this is unlikely, given the summer-only period of operation and the consistency of the data set forth in Figure 7, this issue cannot be resolved without further information. Similarly, the issue of sediment migration cannot be resolved on the basis of the available data.

Chapter V includes a discussion of system performance with regard to the control of aquatic plants or the improvement of the lake fisheries.

CHARACTERISTICS OF BOTTOM SEDIMENTS

Analyses of sediment cores from within Moonlight and Kingston Bays on the southwestern shore of the Lake were conducted to characterize the levels of nutrients, metals, and organic chemicals. Analyses followed the requirements of the pre-dredging protocol set forth in Section NR 347.06 of the Wisconsin Administrative Code. Map 12 in Chapter II shows the sampling locations, and Table 13 lists the concentrations at the referenced locations.

According to a U. S. Environmental Protection Agency (EPA) classification system for sediments, phosphorus concentrations greater than 650 milligrams per kilogram (mg/kg) are indicative of "heavily polluted" lakes.[25] In Little Muskego Lake, the sediment phosphorus concentration was less than this value, ranging from 120 mg/kg to 240

[25]*U. S. Environmental Protection Agency, Guidelines for the Pollutional Classification of Great Lakes Harbor Sediment, Washington, D. C., 1977.*

mg/kg.[26] However, data provided by Kendziorski in a 1967 report would suggest a potentially higher concentration.[27] Converting the values set forth in the 1967 report, between 18 pounds and 29 pounds of phosphorus per acre, to the volumetric basis used by the EPA and Midwest Engineering Services, using a published sediment density of 2.5,[28] results in a range of sediment phosphorus concentrations between 720 mg/kg and 1,280 mg/kg. However, as the 1967 report did not indicate from which of the nine sampling sites the three sediment chemistry samples were obtained, these estimates cannot be related to the more recent measurements.

The data presented in Table 13 suggest that levels of organic biocides are below the levels of detection. Metal concentrations—concentrations of arsenic, cadmium, copper, lead, nickel, and zinc—are within the ranges reported by Forstner and Whitman for unpolluted sediments in lakes[29] and within proposed DNR guidelines for uncontaminated sediments,[30] with the exception of arsenic, which exceeded the proposed DNR Lowest Effect Level (LEL) in two of the three samples. This elevated arsenic concentration probably reflects the use in the Lake of sodium arsenite as an aquatic herbicide between 1950 and 1969, as described in Chapter V of this report.

POLLUTION LOADINGS AND SOURCES

Currently, there are no known point source discharges of pollutants to Little Muskego Lake or to the surface waters tributary to Little Muskego Lake. Nonpoint sources of water pollution include urban sources, such as runoff from residential, commercial, industrial, transportation, construction, and recreational activities; and rural sources, such as runoff from extractive operations, agriculture, and woodlands. In order to estimate the amount of pollution contributed by these sources to Little Muskego Lake, and eventually to downstream Big Muskego and Wind Lakes, annual loading budgets for phosphorus and sediment were developed for rural areas of the watershed, and for phosphorus, sediment, and zinc for the urban areas of the watershed. Nine subareas were delineated within the total tributary drainage area to Little Muskego Lake for this purpose, as shown on Map 18. Input loads from the rural areas were calculated by the DNR[31] and by the Little Muskego Lake Association[32] using the Wisconsin Nonpoint Source Model (WIN), and for the urban areas by the Little Muskego Lake Association using a unit area loading analytical approach. The pollutant loadings estimates are discussed below.

Rural Sources of Nonpoint Pollutants

Agricultural cropland in the Little Muskego Lake drainage area was identified using the Commission's one-inch-equals-400-feet-scale 1990 aerial photographs, and inventoried on site during 1991 and 1992 by the Little Muskego Lake Association as part of a watershed inventory project completed as a prior phase of this lake management planning program, funded in part through a Chapter NR 119 Lake Management Planning Grant.[33] For each of the 368 agricultural fields surveyed, the soil type,

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[26]*Midwest Engineering Services, Inc., Lake Sediment Exploration and Analysis: Little Muskego Lake, Muskego, Wisconsin, Waukesha, Wisconsin, May 1993.*

[27]*Casey Kendziorski, Jr., Removal of Sediment and Muck from Little Muskego Lake, op. cit.*

[28]*David N. Edgington, Evaluation of the Magnitude of Sediment Erosion from the Lake Forest Development and Its Effect on Little Muskego Lake–Kingston and Moonlight Bays, Milwaukee, Wisconsin, June 1994.*

[29]*United Nations Educational Scientific and Cultural Organization, World Health Organization, and United Nations Environment Programme, Deborah V. Chapman (ed.), Water Quality Assessments: A Guide to the Use of Biota, Sediments and Water in Environmental Monitoring, Chapman & Hall, New York, 1992.*

[30]*Wisconsin Department of Natural Resources, draft, Inventory of Statewide Contaminated Sediment Sites and Development of a Prioritization System, Madison, Wisconsin, June 1994.*

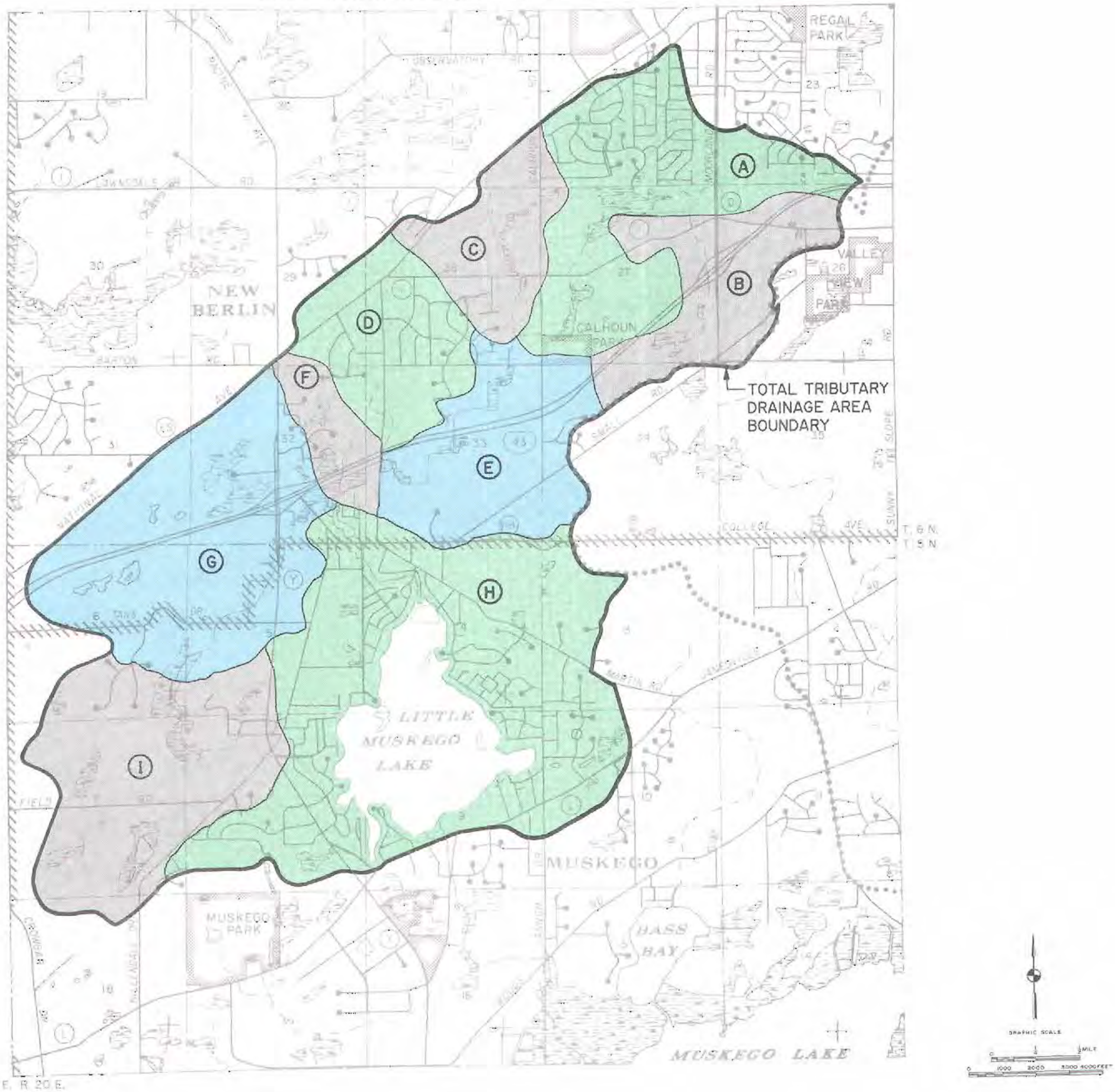
[31]*K. Baun and S. Snowdon, The Wisconsin Nonpoint (WIN) Model, Version 2.2, Wisconsin Department of Natural Resources, Madison, Wisconsin, 1988; see also DNR Publication No. WR-340-93, op. cit.*

[32]*Little Muskego Lake Association, Inc., op. cit.*

[33]*Ibid.*

Map 18

SUBBASINS DRAINING TO LITTLE MUSKEGO LAKE



Source: SEWRPC.

slope, slope length, cropping regime or other agricultural use, crop rotation, type of tillage, applicable conservation practices, distance from the watercourse or water body, and presence and severity of any gully erosion were noted. On the basis of these data, annual average contributions of sediment and phosphorus from croplands in the Little Muskego Lake watershed were calculated at about 1,034 tons of sediment and about 4,375 pounds of phosphorus. These loads were generated from 131 fields covering 1,503 acres, or about 20 percent of the Little Muskego Lake total tributary drainage area. The largest portion of these loads, set forth in Table 14, was generated from fields located in the City of New Berlin, within subbasins A and B, 335 tons of sediment and 1,416 pounds of phosphorus; subbasin C, 127 tons of sediment and 537 pounds of phosphorus; and

Table 14

ANNUAL SEDIMENT AND PHOSPHORUS DELIVERY FROM SHEET AND RILL EROSION ON CROPLAND IN THE LITTLE MUSKEGO LAKE TOTAL TRIBUTARY DRAINAGE AREA

Subbasin	Number of Fields Exporting Sediment	Acres	Annual Delivery	
			Sediment (tons)	Phosphorus (pounds)
A and B	31	417	334.71	1,416
C	10	149	127.24	537
D	9	124	99.66	422
E	19	224	202.05	855
F	5	20	16.21	69
G and I	39	383	57.47	243
H	18	186	197.04	833
Total	131	1,503	1,034.38	4,375

Source: Little Muskego Lake Association, Inc.; and SEWRPC.

subbasin E, 202 tons of sediment and 855 pounds of phosphorus. These subbasins, shown on Map 18, were characterized by annual cropping, primarily of beans and corn, and by soils having low infiltration rates, as shown in part on Map 7 in Chapter II for the direct drainage area of Little Muskego Lake. The next greatest mass of pollutants was the estimated 197 tons of sediment and 833 pounds of phosphorus from within the direct tributary drainage area to Little Muskego Lake, subbasin H, located almost entirely within the City of Muskego, as shown on Map 18.

In addition to these sources, the Little Muskego Lake Association identified 13 actively eroding gullies within the watershed, totaling about 5,000 feet in linear extent.[34] About 270 tons of sediment were calculated as being generated from this source. Eroding stream banks generated another 200 tons of sediment. These gullies and eroding stream banks were generally located within subbasins E and H. Further, phosphorus totaling about 380 pounds was calculated as being generated from two livestock operations situated in subbasins E, G, and I within the Cities of New Berlin and Muskego.

Urban Sources of Nonpoint Pollutants

Urban lands were identified on the Commission's one-inch-equals-400-feet-scale 1990 aerial photographs, and inventoried on site during 1991 and 1992 by the Little Muskego Lake Association as part of the aforementioned watershed inventory project.[35] Unit area loading data for Southeastern Wisconsin were used to generate watershed-specific loads of sediment, phosphorus, and zinc to Little Muskego Lake. Total annual loads for these contaminants were calculated to be about 1,208 tons of sediment, about 1,808 pounds of phosphorus, and about 1,287 pounds of zinc. Subbasin H, riparian to Little Muskego Lake, generated the largest part of the sediment and phosphorus loads, as shown in Table 15.

Lands under construction generated the largest fraction of the sediment load, accounting for about 490 tons of sediment from within subbasin H and about 685 tons of sediment from the total tributary drainage area. Subbasin H generated about 72 percent of the construction-related sediment load, and construction about 57 percent of the total sediment load, to Little Muskego Lake. Urban residential uses contributed the next highest proportion of the sediment load to Little Muskego Lake, generating about 248 tons, or about 21 percent of the total sediment load.

Urban residential lands generated the largest percentage of the total phosphorus load to Little

[34] *Ibid.*

[35] *Ibid.*

Table 15

LAND USE AND ESTIMATED POLLUTANT LOADING CHARACTERISTICS OF IMPORTANT URBAN SUBBASINS IN THE LITTLE MUSKEGO LAKE WATERSHED

Subbasin	Sediment						Phosphorus					
	Residential (tons per year)	Commercial and Institutional (tons per year)	Industrial (tons per year)	Land under Construction (tons per year)	Freeways (tons per year)	Total (tons per year)	Residential (pounds per year)	Commercial and Institutional (pounds per year)	Industrial (pounds per year)	Land under Construction (pounds per year)	Freeways (pounds per year)	Total (pounds per year)
A and B	65	10	4	55	17	151	342.0	30.0	13.5	--	35.1	420.6
C	11	17	2	30	--	60	57.5	51.0	6.0	--	--	114.5
D	32	5	--	25	--	62	168.5	16.5	--	--	--	185.0
E	18	24	18	10	8	78	96.5	70.5	54.0	--	16.2	237.2
F	5	4	--	--	--	9	29.0	13.5	--	--	--	42.5
G and I	31	3	6	75	11	126	166.0	9.0	19.5	--	21.6	21.6
H	86	41	5	490	--	622	453.0	124.5	15.0	--	--	592.5
Total	248	104	35	685	36	1,208	1,312.5	315.0	108.0	--	72.9	1,808.4

Source: Little Muskego Lake Association, Inc.; and SEWRPC.

Table 16

ANNUAL POLLUTANT DELIVERY FROM URBAN LAND IN THE LITTLE MUSKEGO LAKE WATERSHED

Pollutant	Pounds per Year				
	Residential	Commercial and Institutional	Industrial	Freeways	Total
Phosphorus	1,312	315	108	73	1,808
Zinc	525	441	151	170	1,287

Source: Little Muskego Lake Association, Inc.; and SEWRPC.

Muskego Lake, contributing about 73 percent, or about 1,313 pounds of phosphorus, with about 35 percent of this load being generated from the lands riparian to the Lake in subbasin H, as set forth in Table 15. Residential, commercial, and transportation-related land use activities generated about 90 percent of the zinc load to the Lake, as set forth in Table 16. Zinc is used as an indicator representative of the metals and other pollutants generated primarily from urban sources.

Phosphorus Loads

Between 5,000 and 6,000 pounds of phosphorus is calculated to enter Little Muskego Lake annually.[36] Jewel Creek is the major source of phosphorus, contributing 88 percent of this load, followed by runoff from areas in the City of Muskego draining directly to the Lake or to other, minor tributaries (11 percent) and atmospheric depositions on the Lake's surface (1 percent). Phosphorus loads are expected to increase by about 19 percent as a result of new development in the direct drainage area of Little Muskego Lake. Of the total phosphorus load to the Lake from external sources, about 71 percent is generated from rural lands within the watershed, and about 29 percent from urban lands.

In addition to the external phosphorus load, the DNR has estimated that an additional 930 pounds of phosphorus could be expected to be added to the

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[36]*Phosphorus loadings to Little Muskego Lake were estimated using a variety of means: about 4,940 pounds of phosphorus was estimated by the Wisconsin Department of Natural Resources on the basis of the WIN model, as set forth in DNR Publication No. WR-340-93, op. cit.; about 5,500 pounds of phosphorus was estimated, also by the DNR, on the basis of the WINHUSLE model, as set forth in the DNR water resource appraisal report, op. cit.; and about 6,179 pounds of phosphorus was estimated by the Little Muskego Lake Association on the basis of the WIN model and UAL analysis, as set forth in the Little Muskego Lake Association watershed inventory report, op. cit.*

Lake's water column as the result of internal loading during periods of stratification.[37] This estimate is of the same order as the difference, calculated by SEWRPC staff and set forth above, between the masses of in-lake hypolimnetic total phosphorus during operation of the aerator, when internal loading was suppressed to a degree, and subsequently, when internal loading was unimpeded. As noted above, the effect of this internal loading can be seen in the elevated hypolimnetic phosphorus concentrations recorded in Tables 9 and 10.

Approximately 47 percent of the total external phosphorus load, or about 2,900 pounds, was used by the biomass within the Lake or deposited in the sediments, resulting in a net transport of phosphorus to Big Muskego Lake of about 3,300 pounds, or about 53 percent of the total phosphorus load to Little Muskego Lake.

Sediment Loads

Bottom sediment conditions have an important effect on the condition of a lake. As sediment is deposited, valuable benthic habitats are buried, macrophyte-prone substrates are increased, fish spawning areas are covered, and aesthetic nuisances develop. Sediment particles also act as transport mechanisms for other substances, such as phosphorus, nitrogen, organic materials, pesticides, and heavy metals.

The annual sediment load to Little Muskego Lake was calculated to have been 5,224,000 pounds; see Table 17. About 58 percent of the sediment load came from Jewel Creek, and approximately 42 percent was contributed by runoff from areas in the City of Muskego which drain directly to the Lake or to minor tributaries of the Lake. New development in the Little Muskego Lake direct drainage area is expected to increase the sediment loads to the Lake by about 17 percent.

Zinc Loads

In contrast to the foregoing, the zinc loading to Little Muskego Lake was dominated by runoff from the urban areas. Zinc is used in this analysis as an indicator of metals and other pollutants contributed primarily by urban sources. Of the 1,287 pounds of zinc calculated to enter Little Muskego Lake annually, about 53 percent was contributed through urban runoff from lands in the City of Muskego draining directly to the Lake or to minor tributaries; about 34 percent was generated from land uses tributary to Jewel Creek. The zinc load is also forecast to increase as a result of land use changes within the Little Muskego Lake direct drainage area. Most of the zinc can be expected to be retained in the Lake's sediments.

Table 17

ANNUAL SEDIMENT AND PHOSPHORUS LOADS TO LITTLE MUSKEGO LAKE FROM THE WATERSHED

Sediment Load	
Land Use	Sediment Delivery (tons per year)
Agricultural, Sheet and Rill	1,034
Agricultural, Gully Erosion	270
Streambank	200
Established Urban Areas	423
Land under Construction	685
Total	2,612

Phosphorus Load	
Land Use	Phosphorus Load (pounds per year)
Agricultural Land	4,375
Streambank	- -
Established Urban Areas	1,808
Land under Construction	- -
Total	6,179

Source: Little Muskego Lake Association, Inc.; and SEWRPC.

Onsite Sewage Disposal

As of 1985, approximately 4,750 persons, or 81 percent of the population in the direct drainage area of Little Muskego Lake, were served by a public sanitary sewer system which collects and then conveys sewage to the Milwaukee Metropolitan Sewerage District sewerage system for treatment. The remainder of the residents in the direct drainage area utilized onsite disposal systems. Onsite sewage disposal systems are designed to remove phosphorus by adsorption to soil in a drain field. Removal capacity decreases with increasing soil particle size, and all soils have a fixed absorptive capacity that could eventually become exhausted. Onsite sewage disposal systems include conventional septic tank systems; septic systems with seepage pit disposal systems; septic tanks with alternative distribution systems, such as ground

[37]*Wisconsin Department of Natural Resources, Muskego–Wind Lakes Priority Watershed Project Water Resources Appraisal, op. cit.*

pressurized systems; seepage pits; mound systems; and holding tanks. Holding tanks store wastewater temporarily until it is pumped and conveyed by tanker truck to a sewage treatment plant, storage lagoon, or land disposal site.

Provided that onsite systems are located, installed, used, and maintained properly, the system should operate with few problems for periods of about 20 years. Failure of a septic tank system occurs when the soil surrounding the seepage area will no longer accept or properly stabilize the septic tank effluent. Further, not all residential areas within the Little Muskego Lake direct drainage area served by septic tanks are located in areas covered by soils suitable for septic tank use as shown on Map 8, and septic system failure may result from improper location, poor installation, or inadequate maintenance. While many older systems met Wisconsin Administrative Code requirements when installed, these requirements have changed over the years, with the effect that many older systems no longer conform to present practices. Also, some installations designed for vacation use are now in year-round use and are potentially subject to overloading. The precise identification of potential septic tank problems will require a sanitary survey.

The regional water quality management plan recommends that all new development, as well as a portion of the currently unsewered lands, in the area tributary to Little Muskego Lake be provided with public sanitary sewerage.[38] Installation of sanitary sewers serving about 2,000 additional persons within the Little Muskego Lake study area by the year 2010 may be expected to reduce the number of existing onsite sewage disposal systems, leaving about 400 persons continuing to be served by onsite systems in the study area, primarily in isolated enclaves of urban development in the southern portions of the City of New Berlin. These will remain on soils limited for such use and will need to be maintained properly so as to minimize potential adverse environmental impacts on surface- and groundwater quality in the direct drainage area.

RATING OF TROPHIC CONDITION

Lakes are commonly classified according to their degree of nutrient enrichment, or trophic status. The ability of a lake to support a variety of recreational activities and healthy fish and aquatic life communities is often correlated to the degree of nutrient enrichment that has occurred. Three terms are usually used to describe the trophic status of a lake: oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes are nutrient-poor lakes. These lakes characteristically support relatively few aquatic plants and often do not contain productive fisheries. Because of the naturally fertile soils and the intensive land use practices employed in the State, there are relatively few oligotrophic lakes in Southeastern Wisconsin. Mesotrophic lakes are moderately fertile lakes that support abundant aquatic plant growths and may support productive fisheries. Nuisance growths of algae and aquatic plants are usually not exhibited by mesotrophic lakes. Many of the cleaner lakes in Southeastern Wisconsin are classified as mesotrophic. Eutrophic lakes are nutrient-rich lakes. These lakes are often characterized by excessive growths of aquatic weeds and may experience frequent algal blooms. Many eutrophic lakes support very productive fisheries. In shallow eutrophic lakes, fish winterkills may also be common. Many of the more polluted lakes in Southeastern Wisconsin are classified as eutrophic. A fourth descriptor, hypertrophic, is applied to the most severely enriched lakes.

Several numerical scales, based on one or more water quality parameters, have been developed to define the trophic condition of a lake. Because trophic state is actually a continuum from very nutrient-poor to very nutrient-rich, a numerical scale is useful for comparing lakes and for evaluating trends in water quality conditions. Care must be taken, however, so that the particular scale used is appropriate for the lake to which it is applied. In this case, two indices are commonly used; namely, the Vollenweider-OECD open-boundary trophic classification system,[39] and the Carlson

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[38]*SEWRPC Memorandum Report No. 93,* A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report, *Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, March 1995.*

[39]*Organization for Economic Cooperation and Development (OECD),* Eutrophication of Waters: Monitoring, Assessment and Control, *Paris, 1982; S.-O. Ryding and W. Rast,* The Control of Eutrophication in Lakes and Reservoirs, *UNESCO/MAB Series 1, Parthenon Press, 1989; and H. Olem and G. Flock,* The Lake and Reservoir Restoration Guidance Manual, *2nd Edition, U. S. Environmental Protection Agency Report No. EPA-440/4-90-006, Office of Water (WH-553), Washington, D. C., 1990.*

Trophic State Index (TSI).[40] The Carlson Index has recently been supplemented by the more appropriate Wisconsin Trophic State Index developed by the DNR to account for the peculiar characteristics of Wisconsin lakes, generally related to their higher levels of dissolved—humic—color.[41]

Vollenweider-OECD Trophic Classification System

The European Organization for Economic Cooperation Development (OECD) investigated numerous lakes and reservoirs from around the world, with the majority of their approximately 750 lakes being in Europe and North America, and developed a number of empirical relationships among chlorophyll-a, Secchi-disk transparency, phosphorus, nitrogen, primary productivity, and trophic state. The result was both a set of predictive models and a set of trophic boundary descriptors. Applying the latter to the Little Muskego Lake data given in Table 10 results in the Lake's being classified as having a 10 percent probability of being oligotrophic, a 60 percent probability of being mesotrophic, and a 30 percent probability of being eutrophic, on the basis of the total phosphorus concentration, as shown in Figure 8. When chlorophyll-a concentration is used, the Lake has a 55 percent probability of being eutrophic, a 38 percent probability of being hypertrophic, and a 7 percent probability of being mesotrophic. The Secchi-disk-based classification yields a similar result, 47 percent probabilities of being eutrophic and of being hypertrophic, and a 6 percent probability of being mesotrophic, also as shown in Figure 8. Thus, Little Muskego Lake should be classified as a eutrophic lake, or a lake with water quality that would be considered impaired for many uses.

Trophic State Index

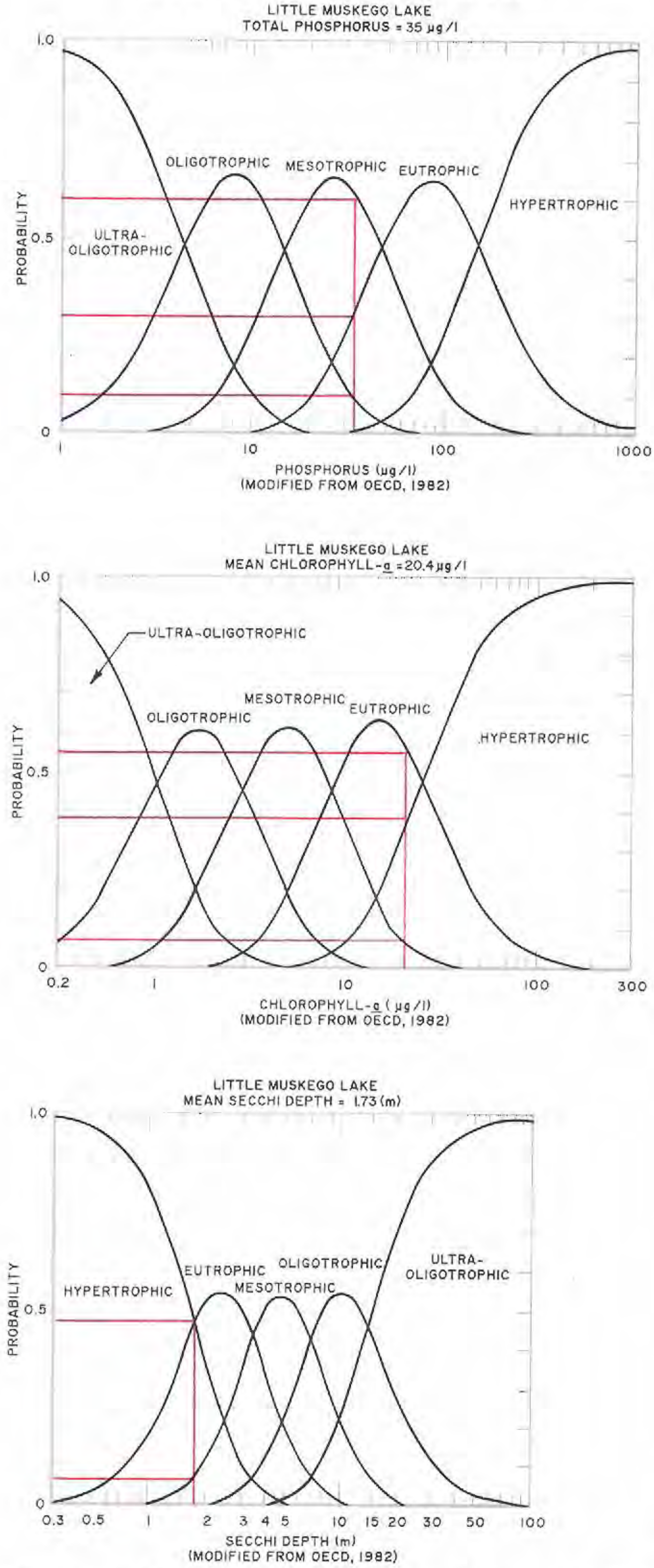
The Trophic State Index (TSI) assigns a numerical trophic condition rating based on Secchi-disk transparency and total phosphorus and chlorophyll-a concentrations. The original index developed by Carlson has been modified for Wisconsin lakes by

[40] *R. E. Carlson, "A Trophic State Index for Lakes," Limnology and Oceanography, Vol. 22, No. 2, 1977.*

[41] *R. A. Lillie, S. Graham, and P. Rasmussen, "Trophic State Index Equations and Regional Predictive Equations for Wisconsin Lakes," Research Management Findings, No. 35, Wisconsin Department of Natural Resources Publication No. RS-735-93, Madison, Wisconsin, 1993.*

Figure 8

TROPHIC STATE CLASSIFICATION OF LITTLE MUSKEGO LAKE BASED ON THE VOLLENWEIDER MODEL



Source: S.-O. Ryding and W. Rast, The Control of Eutrophication of Lakes and Reservoirs, Vol. 1, 1989; U. S. Geological Survey; and SEWRPC.

the DNR using data on 184 lakes throughout the State.[42] The Trophic State Index ratings for Little Muskego Lake ranged from 40 to 75 over the study period, as shown in Figure 9. The Wisconsin Trophic State Index (WTSI) varied similarly as a function of sampling date. Based on these TSI ratings also, Little Muskego Lake may be classified as eutrophic.

SUMMARY

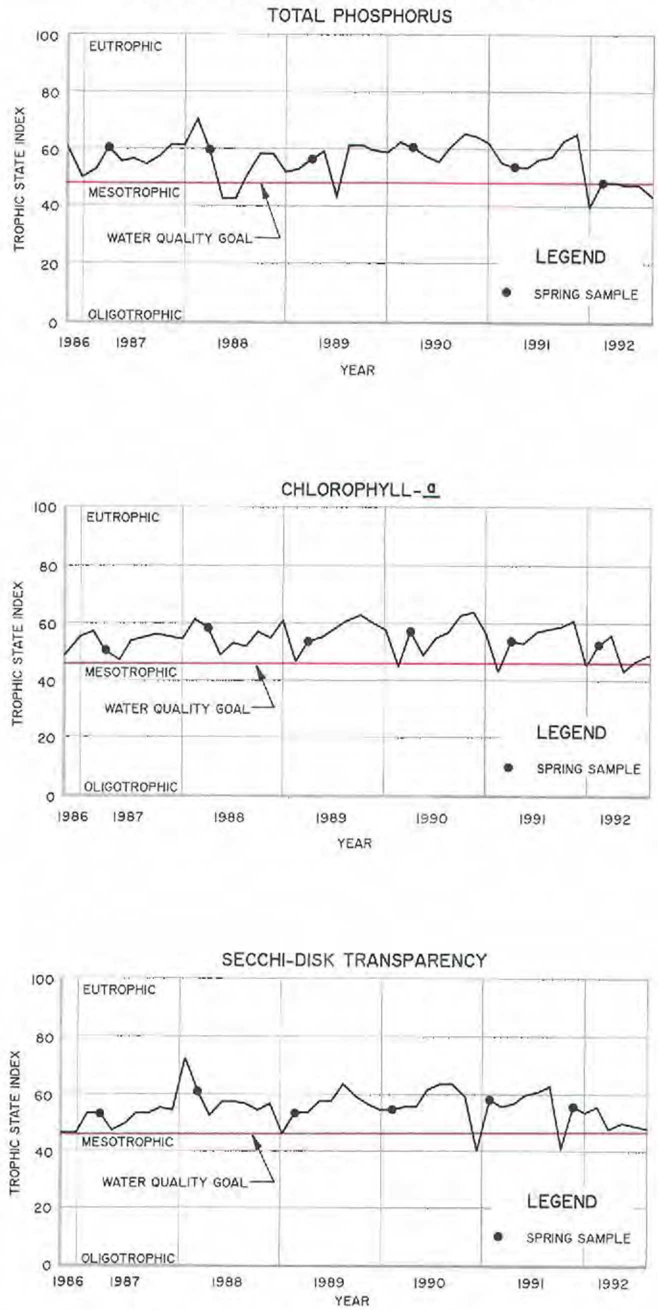
Little Muskego Lake is an enriched hard-water, alkaline lake that has been subjected to relatively high levels of pollution. Physical and chemical parameters measured during the study period indicated that the water quality is within the "fair to poor" range, compared to other regional lakes. Total phosphorus levels were found to be above the level considered to cause nuisance algal and aquatic plant growths. During summer stratification, the water below a depth of 25 feet became devoid of oxygen, while the upper waters remained well oxygenated and supported a healthy fish population; see Chapter V. Winterkill was not a problem in Little Muskego Lake; dissolved oxygen levels were found to be adequate for the support of fish throughout the winter at depths above 40 feet. Internal releases of phosphorus from the bottom sediments were observed in Little Muskego Lake.

There were no known point sources of pollutants in the Little Muskego Lake watershed. Nonpoint sources of pollution included stormwater runoff from urban and rural areas. Suspended solids, phosphorus, and zinc loadings from the urban areas in the watershed were estimated using the Wisconsin Nonpoint Source Model and were found to be highest in the downtown commercial areas and new residential areas bordering the Lake. Unit area loading data indicated that runoff from residential and rural areas was the largest external source of sediment and phosphorus; runoff from urban areas was the largest external source of zinc and lead. Zinc, in particular, was included in the modeling study as a surrogate value for total metals of urban origin.

In 1992, the total phosphorus load to Little Muskego Lake was estimated to be about 6,200 pounds. Jewel Creek contributed the largest amount of phosphorus, 88 percent of the load. A further 930 pounds of phosphorus was estimated to be added to the water column through internal loading from the lake sediments, particularly under stratified conditions. On the basis of the Vollenweider phos-

Figure 9

TROPHIC STATE INDICES FOR LITTLE MUSKEGO LAKE: 1986-1992



Source: U. S. Geological Survey, Wisconsin Department of Natural Resources, and SEWRPC.

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[42]*Ibid.*

phorus loading model and the Trophic State Index ratings calculated from Little Muskego Lake data for 1986 through 1994, Little Muskego Lake may be classified as a eutrophic lake.

In general, the water quality data and the classification systems used indicate that Little Muskego Lake has fair to poor water quality. Important water quality considerations to be discussed further in subsequent sections of this report are the potential impacts of Jewel Creek and of direct shoreline drainage on water quality conditions, and alternatives for protecting Little Muskego Lake from problems that may arise from these sources. In addition, lake management actions that will maintain or reduce other pollution sources are also to be considered.

Chapter V

AQUATIC BIOTA, ECOLOGICALLY VALUABLE AREAS, AND RECREATIONAL ACTIVITIES

INTRODUCTION

Little Muskego Lake is an important natural resource for the City of Muskego. The Lake, its biota, and the adjacent park and residential lands combine to contribute to the quality of life in the City and its environs. The Lake also directly impacts the economy of the City, in part because of its proximity to the central business district. Such natural resource features as lakes and wetlands, however, when located in urban settings, are typically subject to great stresses. Pollutant discharges, common forms of stress to aquatic systems, may result in the deterioration of these natural resource features.

For this reason, the formulation of sound management strategies must be based on a thorough knowledge of the pertinent characteristics of the individual resource features. Accordingly, this chapter provides information concerning the natural resource features of the Little Muskego Lake watershed, including data on primary environmental corridors, wetlands, aquatic macrophytes, fish, and wildlife. In addition, recreational activities relating to the use of these natural resource features are described.

AQUATIC PLANTS

Aquatic plants include larger plants, or macrophytes, and microscopic algae, or phytoplankton. These are the primary producers of a lake and form an integral part of the aquatic food web. They convert inorganic nutrients in the water and sediments into organic compounds which are directly available as food for other aquatic organisms. In this process, known as photosynthesis, plants utilize energy from sunlight and release the oxygen required by other aquatic life forms.

Aquatic Macrophytes

Aquatic macrophytes are an important factor in the ecology of Southeastern Wisconsin lakes. They can be either beneficial or a nuisance, depending on their distribution and abundance and the activities taking place on the water body. Macrophytes are usually an asset because they provide food and habitat for fish and other aquatic life, produce oxygen, and may remove nutrients and pollutants from the water that could otherwise cause algal blooms or other problems. Aquatic plants become a nuisance when their presence reaches densities that interfere with swimming and boating and the normal functioning of a lake ecosystem. Many factors, including lake configuration, depth, water clarity, nutrient availability, bottom substrate, wave action, and types of fish populations present, determine the distribution and abundance of aquatic macrophytes in a lake. Some nonnative plant species, lacking natural controls, may be especially favored by the habitats available in this Region and can exhibit explosive growths to the detriment not only of lake users but also of indigenous aquatic life and native plant species.

To document the types and relative abundances of aquatic macrophytes in Little Muskego Lake, an aquatic plant survey was conducted by the Wisconsin Department of Natural Resources (DNR) during July 1992.[1] The aquatic plant survey was designed to determine species composition. A further survey of aquatic plant community distributions in Little Muskego Lake was conducted by Commission staff in July 1994.

Eleven species of aquatic macrophytes were identified and are listed in Table 18. Map 19 shows the distribution of common species during the July 1994 survey. Aquatic macrophytes occurred throughout Little Muskego Lake, although diversity was greatest in the vicinity of the eastern and western shorelines, as shown on Map 19. The most diverse growths occurred adjacent to the main lake basin.

Chara was the most abundant aquatic plant, occurring in three of the four environmentally sensitive areas identified by the DNR. It dominated the macrophyte community at two of these areas, including the largest area along the eastern shoreline. Eurasian water milfoil (Myriophyllum spica-

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[1]*Wisconsin Department of Natural Resources, Aquatic Plant Management Sensitive Area Designation for Little Muskego Lake, Waukesha County, Wisconsin, July 1992.*

tum) was also abundant, occurring at all four areas. It was the dominant species in one area on the western shore, but was abundant in all four areas. Coontail (Ceratophyllum demersum) occurred at only one site on the northeastern lakeshore. Wild celery (Vallisneria americana) and several species of pondweeds (Potamogeton spp.) also occurred in Little Muskego Lake. The pondweeds occurred throughout the Lake and were most abundant in the fourth area. White water lilies were common in the shallow water of two areas, one on each shore. Cattails and bulrushes dominated the emergent flora along the shores of the Lake.

In general, Little Muskego Lake supported a healthy and diverse aquatic macrophyte community. Such species as milfoil and coontail had a tendency to form dense mats that may interfere with boat traffic; harvesting has been necessary in selected areas to ameliorate the adverse effects of excessive macrophyte growth.

Table 18

LITTLE MUSKEGO LAKE MACROPHYTE SURVEY RESULTS: 1992

Scientific Name	Common Name
Submerged Plants	
Ceratophyllum demersum	Coontail
Chara spp.	Muskgrass
Myriophyllum spicatum	Eurasian water milfoil
Najas spp.	Naiads
Nitella sp.	Muskgrass
Potamogeton crispus	Curly-leaved pondweed
P. richardsonii	Richardson's pondweed
P. zosteriformis	Flat-stemmed pondweed
Vallisneria americana	Eelgrass or wild celery
Floating Plants	
Nymphaea tuberosa	White water lily
Emergent Plants	
Typha spp.	Cattail
Scirpus spp.	Bulrush
Cyperaceae	Sedges

Source: Wisconsin Department of Natural Resources and SEWRPC.

Phytoplankton

Phytoplankton, or algae, are small, generally microscopic plants that are found in all lakes and streams. They occur in a wide variety of forms, in single cells or colonies, and can be either attached or free floating. Phytoplankton abundance varies seasonally with fluctuations in solar irradiance, turbulence due to prevailing winds, and nutrient availability. In lakes with high nutrient levels, heavy growths of phytoplankton, or algal blooms, may occur.

Algal blooms have occurred on Little Muskego Lake, as indicated by the chlorophyll-a concentrations in excess of 20 micrograms per litre shown in Table 9, but have not been considered a major problem. Therefore, identification and quantification of those algae present within the Lake were not included as part of the post-1986 U. S. Geological Survey (USGS) surveys or in the 1992 DNR survey.

Aquatic Plant Management

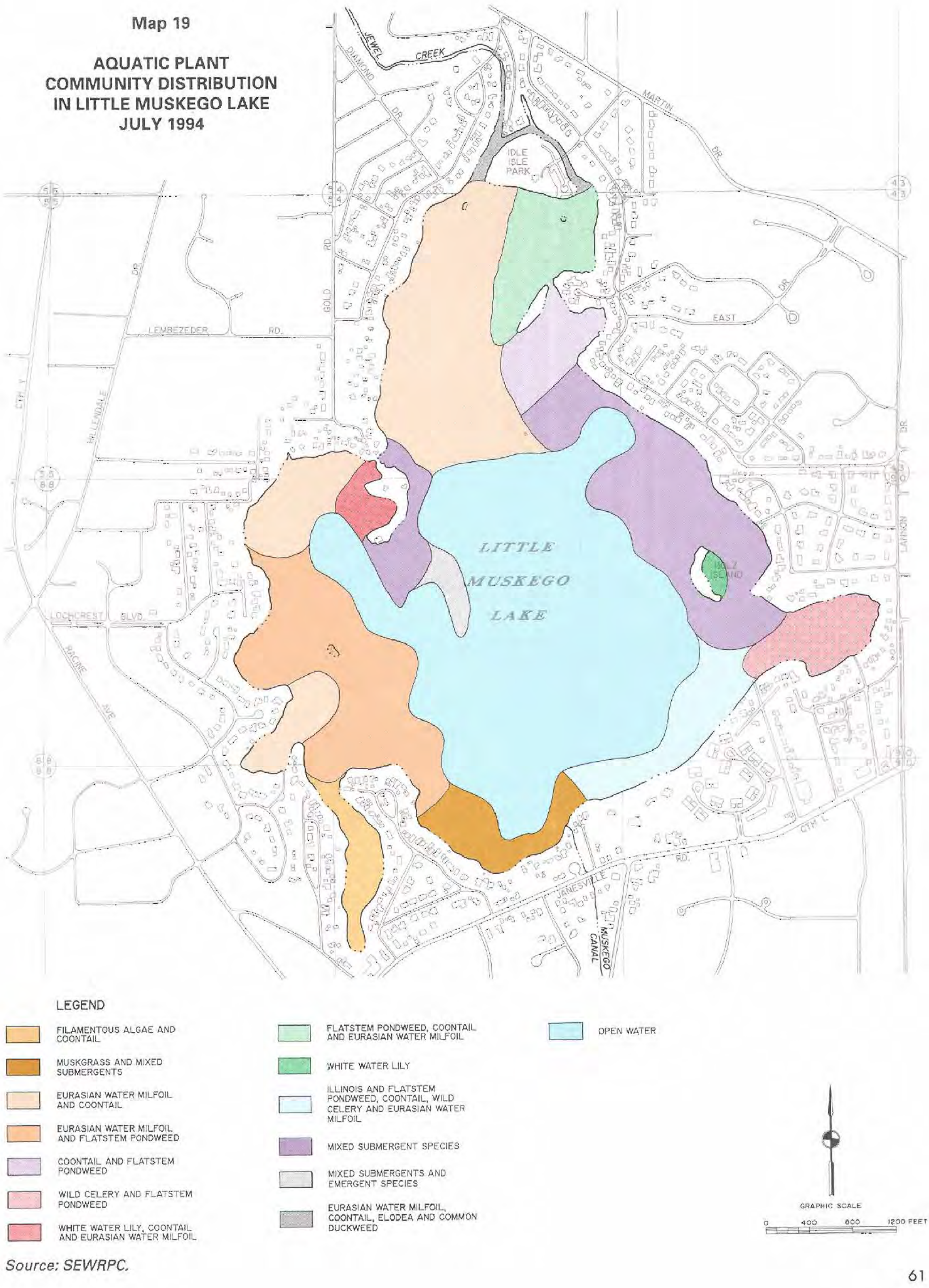
Records of aquatic plant management efforts on Wisconsin lakes were not maintained by the DNR prior to 1950. Therefore, while previous interventions are likely, the first recorded efforts to manage the aquatic plants in Little Muskego Lake took place in 1950. Aquatic plant management activities in Little Muskego Lake can be categorized as macrophyte harvesting, chemical macrophyte control, and chemical algae control.

Perceived excessive macrophyte growth on Little Muskego Lake has historically resulted in a control program that used both harvesting and chemicals. Under the existing macrophyte control program, the Little Muskego Lake Management District harvests macrophytes with an Aquarius Systems H-420 harvester. Since chemical herbicides are generally applied to Little Muskego Lake in early summer, harvesting is initiated only after the macrophytes become reestablished, usually in mid- to late July. Typically, only the macrophytes growing along the shoreline of the Lake are cut, although excessive macrophyte growths occur in other shallow portions of the Lake away from the shoreline. These are occasionally cut to improve navigation and enhance swimming opportunities. It was estimated that approximately 2.3 million pounds of macrophytes were harvested from Little Muskego Lake in 1993, or about one-half of the approximately 4.8 million pounds harvested in 1992, at a cost to the District of approximately $20,000 for 1993. No permit is currently required to cut vegetation in lakes mechanically, although the harvested plant material must be removed from the water.

Since 1941, the use of chemicals to control aquatic plants has been regulated in Wisconsin. In 1926, sodium arsenite, an agricultural herbicide, was first applied to lakes in the Madison area; by the 1930s, sodium arsenite was widely used throughout the

Map 19

AQUATIC PLANT COMMUNITY DISTRIBUTION IN LITTLE MUSKEGO LAKE JULY 1994



Source: SEWRPC.

State for aquatic plant control. No other chemicals were applied in significant amounts to control macrophytes until recent years, when a number of organic chemical herbicides have come into general use. The amounts of sodium arsenite applied to the 12 lakes receiving the largest amounts of sodium arsenite in Southeastern Wisconsin, including Little Muskego Lake, are shown in Table 19.

Sodium arsenite was usually sprayed onto the lake surface within an area extending as far as 200 feet from the shoreline. Treatment typically occurred between mid-June and mid-July. The amount of sodium arsenite used was calculated to result in a concentration of about 10 milligrams per liter (mg/l) sodium arsenite (about 5 mg/l arsenic) in the treated lake water. The sodium arsenite typically remained in the water column for less than 120 days. Although the arsenic residue was naturally converted from a highly toxic form to a less toxic and less biologically active form, much of the arsenic residue was deposited in the lake sediments.

When it became apparent that arsenic was accumulating in the sediments of treated lakes, the use of sodium arsenite was discontinued in the State of Wisconsin in 1969. The applications and accumulations of arsenic were found to present potential health hazards to both humans and aquatic life. In drinking water supplies, arsenic was suspected of being carcinogenic and, under certain conditions, has leached into and contaminated groundwaters, especially in sandy soils that serve as a source of drinking water in some communities. The U. S. Environmental Protection Agency (EPA)-recommended drinking water standard for arsenic is a maximum level of 0.05 mg/l.

During anaerobic conditions, arsenic may be released from the bottom sediments to the water column above. In this way, some arsenic probably continues to be removed from Little Muskego Lake and enters Big Muskego Lake through the outlet. However, the arsenic-laden sediments are continually being covered by new sediments; thus, the level of arsenic in the water and in the surface sediments may be expected to decrease with passage of time. There is some evidence that the arsenic-laden sediments in Little Muskego Lake have been covered by such additional debris which has entered the Lake and do not appear to be releasing arsenic into the water column. No significant increase in dissolved arsenic concentration in the hypolimnion of Little Muskego Lake was reported by the USGS during its water quality monitoring studies, although sediment arsenic concentrations measured by Midwest Engineering Services during 1993, and shown in Table 13, exceeded the Lowest Effect Level (LEL) guidelines proposed by the DNR at two of three stations sampled.[2]

As shown in Table 20, the aquatic herbicides Diquat, Aquathol, Hydrothol, and 2,4-D have also been applied to Little Muskego Lake to control aquatic macrophyte growth since 1980. Diquat, Aquathol, and Hydrothol are contact herbicides and kill plant parts exposed to the active ingredient. Diquat use is restricted to the control of duckweed (Lemna sp.), milfoil (Myriophyllum spp.), and waterweed (Elodea sp.). However, this herbicide is nonselective and will kill many other aquatic

Table 19

LAKES RECEIVING THE 12 LARGEST AMOUNTS OF SODIUM ARSENITE IN WISCONSIN FOR AQUATIC MACROPHYTE CONTROL: 1950-1969

Lake	County	Amount of Sodium Arsenite (pounds)
Pewaukee	Waukesha	312,908
Okauchee	Waukesha	181,580
Big Cedar	Washington	179,164
Pine	Waukesha	129,337
Fowler	Waukesha	87,456[a]
Nagawicka	Waukesha	87,214
Lac La Belle	Waukesha	77,858
Onalaska	La Crosse	64,676
Shangrila (Benet)	Kenosha	59,020
Browns	Racine	56,600
Whitewater	Walworth	55,920
Little Muskego	Waukesha	47,096
Total	--	1,338,829[b]

[a]*Includes applications of sodium arsenite to the Oconomowoc River near Fowler Lake.*

[b]*The 1,338,829 pounds of sodium arsenite applied to these lakes constitutes 62 percent of the total amount of sodium arsenite applied to a total of 167 lakes and streams in Wisconsin from 1950 to 1969.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

[2]*Wisconsin Department of Natural Resources, Inventory of Statewide Contaminated Sediment Sites and Development of a Prioritization System, draft, June 1994.*

Table 20

CHEMICAL CONTROL OF AQUATIC PLANTS IN LITTLE MUSKEGO LAKE: 1950-1994

Year	Macrophyte Control									Algae Control	
	Diquat (gallons)	Aquathol-K		2,4-D		Hydrothol (gallons)	Endothol (pounds)	Silvex (pounds)	Sodium Arsenite (pounds)	Cutrine Plus	
		Gallons	Pounds	Gallons	Pounds					Gallons	Pounds
1950	--	--	--	--	--	--	--	--	4,600	--	--
1951[a]	--	--	--	--	--	--	--	--	--	--	--
1952	--	--	--	--	--	--	--	--	1,000	--	--
1953	--	--	--	--	--	--	--	--	2,000	--	--
1954	--	--	--	--	--	--	--	--	600	--	--
1955	--	--	--	--	--	--	--	--	4,640	--	--
1956	--	--	--	--	--	--	--	--	4,120	--	--
1957	--	--	--	--	--	--	--	--	3,200	--	--
1958	--	--	--	--	--	--	--	--	3,112	--	200
1959	--	--	--	--	20	--	--	--	3,104	--	--
1960	--	--	--	--	--	--	0.36	0.5	2,860	--	--
1961	--	--	--	--	--	--	--	--	2,980	--	--
1962	--	--	--	--	--	--	--	--	1,080	--	--
1963	--	--	--	--	--	--	--	--	3,360	--	--
1964	--	--	--	--	--	--	--	--	3,060	--	--
1965	--	--	--	--	--	--	4.60	--	1,620	--	--
1966	--	--	--	--	--	--	--	--	4,140	--	--
1967	--	--	--	--	--	--	--	--	1,620	--	--
1968	--	--	--	--	--	--	--	--	--	--	--
1969	--	--	--	--	--	--	--	--	--	--	--
1970	5.0	7.00	--	--	--	--	--	--	--	--	50
1971[a]	--	--	--	--	--	--	--	--	--	--	--
1972[a]	--	--	--	--	--	--	--	--	--	--	--
1973[a]	--	--	--	--	--	--	--	--	--	--	--
1974[a]	--	--	--	--	--	--	--	--	--	--	--
1975	--	--	--	--	--	--	--	--	--	160.0	--
1976[b]	--	--	--	--	--	--	--	--	--	--	--
1977[a]	--	--	--	--	--	--	--	--	--	--	--
1978	--	--	--	--	20	--	--	--	--	--	--
1979	--	7.00	--	165.5	--	--	--	--	--	83.5	--
1980	--	36.00	--	129.0	--	8.5	--	--	--	49.0	35
1981	--	49.00	--	167.0	--	--	--	--	--	52.5	--
1982	--	119.00	--	63.0	--	--	--	--	--	72.0	--
1983[b]	--	--	--	--	--	--	--	--	--	--	--
1984	--	61.00	40	120.5	40	--	--	--	--	123.5	80
1985	--	27.00	--	86.0	--	--	--	--	--	88.5	--
1986	2.0	43.00	--	31.0	27	--	--	--	--	22.0	25
1987	50.5	10.00	--	--	--	--	--	--	--	101.0	--
1988	--	61.50	--	89.0	--	--	--	--	--	41.0	--
1989	11.0	90.40	--	17.5	--	--	--	--	--	68.5	--
1990	6.0	25.00	--	--	--	--	--	--	--	68.0	--
1991	--	--	18	--	--	--	--	--	--	--	--
1992	35.0	36.25	--	--	--	--	--	--	--	35.0	--
1993	29.0	27.00	--	--	--	--	--	--	--	52.5	--
1994	19.0	21.50	--	--	--	--	--	--	--	13.5	--

[a]*No chemicals named were applied during the year listed.*

[b]*No records were available for the year listed.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

plants, such as pondweeds (Potamogeton spp.), bladderwort (Utricularia sp.), and naiads (Najas spp.). Aquathol and Hydrothol kill primarily pondweeds but do not control such nuisance species as Eurasian water milfoil (Myriophyllum spicatum). The herbicide 2,4-D is a systemic herbicide which is absorbed by the leaves and translocated to other parts of the plant; it is more selective than the other herbicides listed above and is generally used to control Eurasian water milfoil. However, it will also kill more valuable species, such as water lilies (Nymphaea sp. and Nuphar sp.). The present restrictions on water use following application of these herbicides are given in Table 21.

At present, the Little Muskego Lake Management District holds State permits required under Chapter NR 107 of the Wisconsin Administrative Code for chemical treatment of aquatic plants. Chemicals are applied annually on a contractual basis by a local applicator. As previously noted, herbicide application usually takes place in late spring or early summer, with a second treatment of a smaller area, if necessary, in late July or early August. Map 20 shows the areal extent of that portion of Little Muskego Lake to which chemicals have been applied during the period of record. All chemicals for aquatic plant control used today are approved by the U. S. EPA and the Wisconsin DNR and are registered in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act as amended in 1972.

In addition to the chemical herbicides used to control large aquatic plants, algicides have also been applied to Little Muskego Lake. As shown in Table 20, Cutrine Plus has been applied to Little Muskego Lake on occasion since 1980, primarily to control the macroscopic alga, Chara. Like arsenic, copper, the active ingredient in many algicides including Cutrine Plus, may accumulate in the bottom sediments. Excessive levels of copper have been found to be toxic to fish and benthic organisms but, generally, not to humans. Restrictions on water use following application of Cutrine Plus are also given in Table 21.

AQUATIC ANIMALS

Aquatic animals include microscopic zooplankton; benthic, or bottom-dwelling, invertebrates; fish and reptiles; amphibians; mammals; and waterfowl that inhabit the Lake and its shorelands. These make up the primary and secondary consumers of the food web.

Table 21

PRESENT RESTRICTIONS ON WATER USE FOLLOWING APPLICATION OF THE MAJOR AQUATIC HERBICIDES[a]

	Days After Application			
Use	Cutrine Plus	Diquat	Hydrothol and Aquathol	2,4-D
Drinking	0	14	7-14	--[b]
Fishing	0	14	3	0
Swimming	0	1	--	0
Irrigation	0	14	7-14	--[b]

[a] *The U. S. Environmental Protection Agency has indicated that, if these restrictions are observed, pesticide residues in water, irrigated crops, or fish will not pose an unacceptable risk to humans and other organisms using or living in the treatment zone.*

[b] *Products containing 2,4-D are not to be applied to waters used for irrigation, animal consumption, drinking, or domestic uses, such as cooking and watering vegetation.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Zooplankton

Zooplankton are minute, free-floating animals inhabiting the same environment as phytoplankton. Zooplankton are primary consumers in the aquatic food chain, feeding to a large extent on such phytoplankton as green algae and diatoms. The zooplankton, in turn, are preyed upon by fish, particularly the larvae and fry of bluegills, pumpkinseeds, sunfish, and largemouth bass. While the zooplankton population is an indicator of the trophic status of a lake and of the diversity of aquatic habitat, zooplankton were not sampled during the U. S. Geological Survey inventory; no information on the species composition or relative abundance is available for Little Muskego Lake. However, given the composition and condition of the fish community in Little Muskego Lake, it may be assumed that the zooplankton population is sufficiently robust and diverse to support a relatively healthy fishery.

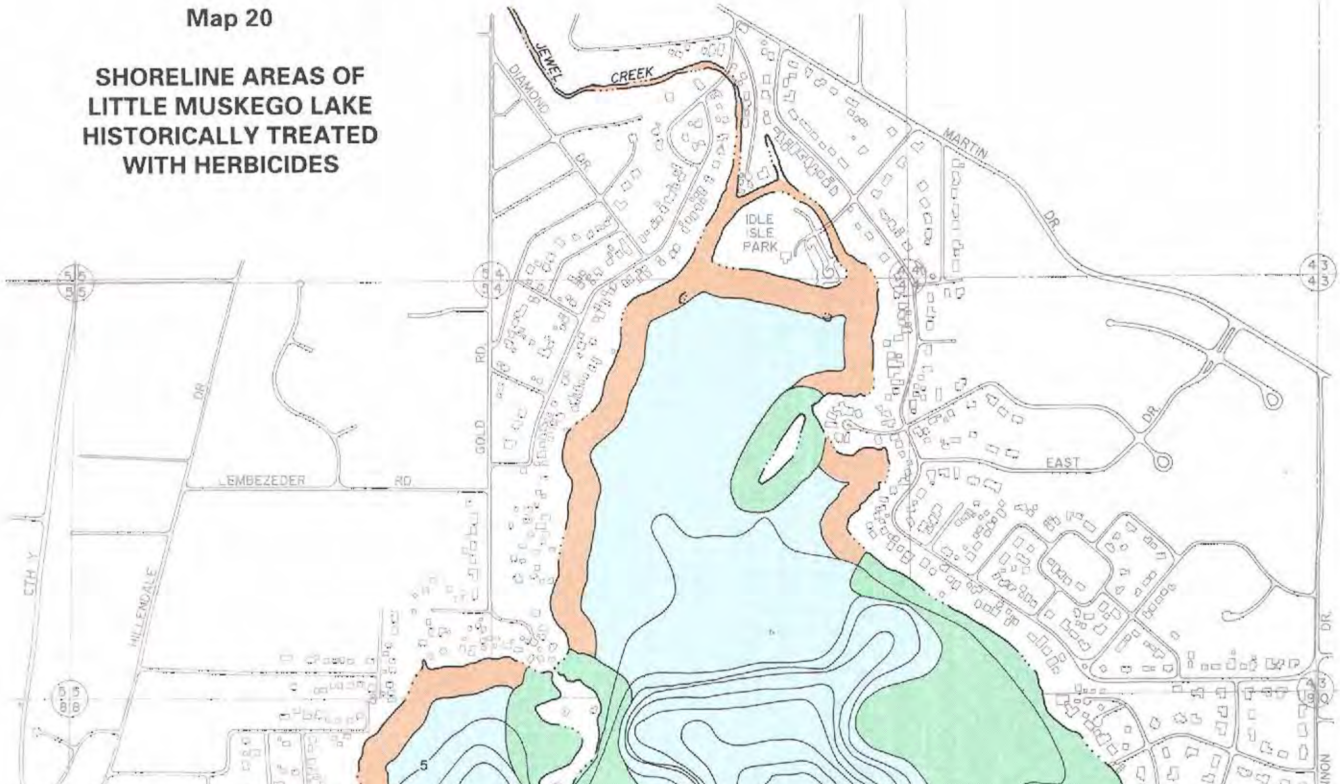
Fish of Little Muskego Lake

Little Muskego Lake supports a moderately diverse, but relatively unstudied, fish community. A Wisconsin DNR fish survey conducted in 1992 recorded the presence of 14 species of fish representing four families, as shown in Table 22.

The predator fishes highest in the food web in Little Muskego Lake include northern pike, walleyed pike, and largemouth bass. These species are car-

Map 20

SHORELINE AREAS OF LITTLE MUSKEGO LAKE HISTORICALLY TREATED WITH HERBICIDES



LEGEND

WATER DEPTH CONTOUR (DEPTH IN FEET)

SIGNIFICANT AREAS TO WHICH CHEMICALS HAVE BEEN APPLIED

ENVIRONMENTALLY SENSITIVE AREAS WITH NO CHEMICAL APPLICATIONS SINCE 1992

SIGNIFICANT AREAS WITH NO CHEMICAL APPLICATIONS

OPEN WATER

GRAPHIC SCALE 0 400 800 1200 FEET

Source: Little Muskego Lake Management District, Wisconsin Department of Natural Resources, and SEWRPC.

Table 22

SPECIES OF FISH IDENTIFIED DURING THE LITTLE MUSKEGO LAKE FISH SURVEY: 1992

Angling Type	Common Name	Family Name	Genus and Species Name
Sport Fish	Walleyed Pike	Percidae	Stizostedion vitreum
	Northern Pike	Salmonidae	Esox lucius
	Largemouth Bass	Centrarchidae	Micropterus salmoides
Panfish	Yellow Perch	Percidae	Perca flavescens
	Bluegill	Centrarchidae	Lepomis macrochirus
	Pumpkinseed	Centrarchidae	Lepomis gibbosus
	Green Sunfish	Centrarchidae	Lepomis cyanellus
	Black Crappie	Centrarchidae	Ambloplites rupestris
	Warmouth	Centrarchidae	Lepomis gulosus
	Golden Shiner	Centrarchidae	Notemigonus crysoleucas
	Black Bullhead	Ictaluridae	Ictalurus melas
	Yellow Bullhead	Ictaluridae	Ictalurus natalis
	White Sucker	Catostomidae	Catostomus commersoni
Rough Fish	Carp	Cyprinidae	Cyprinus carpio

Source: Wisconsin Department of Natural Resources and SEWRPC.

nivorous, feeding primarily on other fish, crayfish, and frogs. These predator fishes are among the largest and most prized game fish sought by Little Muskego Lake anglers. As shown in Table 23, the Wisconsin DNR currently stocks the Lake to supplement the natural fishery.

"Panfish" is a common term applied to a broad group of smaller fish with a short and usually broad shape. Panfish species present in Little Muskego Lake include bluegills, pumpkinseeds, green sunfish, black crappies, white suckers, golden shiners, yellow perch, and bullheads. The habitats of panfish vary widely among the different species, but their cropping of the plentiful supply of insects and plants, coupled with prolific breeding rates, leads to large populations with a rapid turnover. Many regional lakes have stunted, or slow-growing, panfish populations because their numbers are not controlled by predator fishes.[3] Panfish frequently feed on the fry of predator fish and, if the panfish population is overabundant, they may quickly deplete the predator fry population.

[3] *Personal communication, Dr. Ron Crunkilton, University of Wisconsin-Stevens Point College of Natural Resources, 1992.*

Table 23

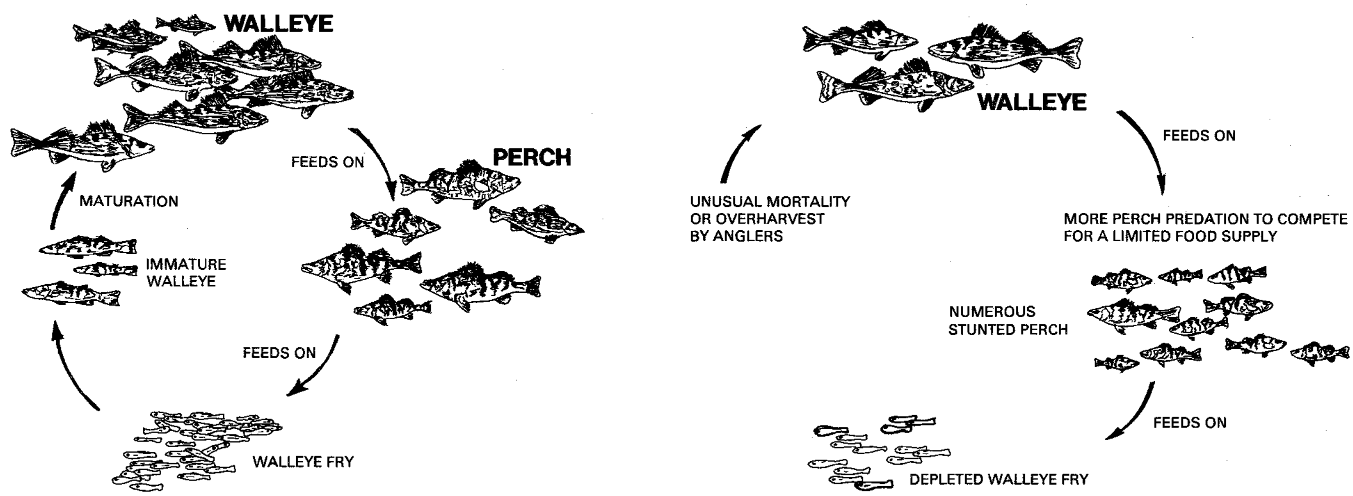
LITTLE MUSKEGO LAKE FISH STOCKING RECORD

Species	Year Stocked	Number Stocked
Northern Pike	1973	1,154,500 fry
	1974	500,000 fry
	1974	1,000 yearlings
	1975	6,400,000 fry
	1975	1,520 yearlings
	1976	495,000 fry
	1976	1,000 yearlings
	1986	2,000 fingerlings
	1991	2,000 fingerlings
	1992	2,000 fingerlings
	1993	2,300 fingerlings
Fathead Minnow	1973	60 gallons
Walleye	1973	2,499,000 fry
	1973	31,440 fingerlings
	1974	46,875 fingerlings
	1975	1,000,000 fry
	1975	22,500 fingerlings
	1976	50,000 fingerlings
	1977	15,275 fingerlings
	1984	460,000 fry
	1990	275,000 fingerlings
	1991	12,330 fingerlings
Largemouth Bass	1973	120,500 fry
	1973	311,675 fingerlings
	1974	57,500 fingerlings

Source: Wisconsin Department of Natural Resources and SEWRPC.

Figure 10

THE PREDATOR-PREY RELATIONSHIP



Source: Wisconsin Department of Natural Resources, Bureau of Fisheries Management; and SEWRPC.

Figure 10 illustrates the importance of a balanced predator-prey relationship, using walleyed pike and perch as an example.

"Rough fish" is a broad term applied to species, such as carp, that do not readily bite on hook and line, but feed on game fish, destroy habitat needed by more desirable species, and have a poor eating quality because of numerous bones or undesirable flavors. Carp dominated the Lake during the 1960s, when water clarity was minimal and game fish populations had been depleted. Since that time, game fish populations have been largely restored through the extensive stocking program undertaken by the DNR, as shown in Table 23, although carp remain in the Lake and are subjected to an annual "Carp-Out" sponsored by the Little Muskego Lake Association. For these reasons, it is believed that the Little Muskego Lake fish composition has changed significantly since 1960.[4]

The Lake is currently managed for the production of bluegills, largemouth bass, and northern pike. It is assumed that an over-harvest of largemouth bass, northern pike, and larger bluegills may have contributed to an unbalanced, slow-growing panfish population because of a lack of predation. In order to enhance and maintain sport fishing opportunities for anglers using Little Muskego Lake, the Wisconsin DNR has stocked the Lake with walleyed and northern pike, as shown in Table 23. The Department plans to continue to stock Little Muskego Lake with pike annually, depending on their availability from the Department's fish hatcheries.

Other Wildlife

Although a quantitative field inventory of amphibians, reptiles, birds, and mammals was not conducted as a part of the Little Muskego Lake study, a field survey was undertaken by the DNR during July 1992. In addition, the inventory procedures used involved compiling wildlife inventory data lists of those amphibians, reptiles, birds, and mammals known to exist, or to have existed, at Little Muskego Lake and in Waukesha County; associating these lists with the historic and remaining habitat areas as inventoried; and projecting the appropriate amphibian, reptile, bird, and mammal species into the Little Muskego Lake area. The net result of the application of this technique is a determination of those species which were once

[4]*Personal communication, Edward R. Schumacher, Fish Manager, Wisconsin Department of Natural Resources, 1994.*

present in the drainage area, those species which are still expected to be present under currently prevailing conditions, and those species which could be expected to be lost or gained as a result of continued urbanization within the area.

Amphibians and Reptiles: Although often unseen and unheard by humans, amphibians and reptiles are vital components of the ecosystem in an environmental unit like the Little Muskego Lake drainage area. Examples of amphibians native to the area include frogs, toads, and salamanders. Turtles and snakes are examples of reptiles common to the Little Muskego Lake area. Table 24 presents a summary of the 11 amphibian and 13 reptile species normally expected to be present in the Little Muskego Lake area under present conditions and identifies those species most sensitive to urbanization.

Most amphibians and reptiles have definite habitat requirements which are adversely affected by advancing urban development and by certain agricultural land management practices. One of the major detrimental factors affecting the maintenance of amphibians in a changing environment is the destruction of breeding ponds. Frogs and salamanders often return to the same breeding site each year, continuing this behavior even if the breeding pond is not there and they cannot breed. If an area is being filled and developed, some ponds must be selectively retained if the amphibian populations are to be maintained. Toads are something of an exception among amphibians in this respect, in that they better adapt to the changes in environment which normally accompany urbanization.

Another major consideration in the preservation of both amphibians and reptiles is the maintenance of migration routes. Many species annually traverse distances of a mile or more from wintering sites to breeding sites to summer foraging grounds. The same pathways are used each year, and, if these species are to be maintained in an area, these pathways must be preserved. Protection of environmental corridors can assist materially in this respect.

Certain amphibians and reptiles are particularly susceptible to changes in food sources brought about by urbanization. The eastern milk snake, for example, is very likely to be lost from the area over time because of a reduction in the number of rodents, its normal prey.

Birds: A large number of birds, ranging in size from large game birds to small songbirds, are found in the Little Muskego Lake area. Table 25 lists those birds that normally occur in the drainage area. Each bird is classified as to whether it breeds within the area, visits the area only during the annual migration periods, or visits the area only on rare occasions.

Game birds which are found in the Little Muskego Lake drainage area include pheasants, partridges, woodcocks, snipe, dabbling ducks, diving ducks, and geese. Pheasants and partridges are upland game birds and provide some opportunities for hunting. Although the drainage area lies within the Mississippi flyway, opportunities for waterfowl hunting are now extremely constrained because of habitat deterioration and urbanization. The fall pheasant population within the drainage area is irregularly distributed, but fair populations live in the larger habitat areas. Winter flocks require good cover interspersed with fields containing waste grain, such as corn, from farming operations. Supplemental feeding of such flocks will greatly aid in their survival during severe winters. However, such predators as fox and coyote can greatly impact the pheasant and other ground-nesting bird populations.

The Little Muskego Lake drainage area supports a significant population of waterfowl, including mallards and teals. Larger numbers move through the drainage area during migrations, when most of the regional species may also be present. Other species of water-based birds within the area include herons, sandpipers, gulls, plovers, and terns. Most of the waterfowl, shorebirds, and wading birds may be expected to appear in, and adjacent to, Little Muskego Lake. In fact, downstream Big Muskego Lake is well known as a waterfowl hunting area.[5]

Because of the mixture of lowland and upland woodlots, wetlands, and agricultural lands still present in the area, along with the favorable summer cli-

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[5]*SEWRPC Memorandum Report No. 94, A Recommended Public Boating Access and Waterway Protection Plan for Big Muskego Lake, Waukesha County, Wisconsin, draft, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, July 1994.*

Table 24

AMPHIBIANS AND REPTILES LIKELY TO OCCUR IN THE LITTLE MUSKEGO LAKE AREA

Scientific (family) and Common Name	Species Reduced or Dispersed with Full Area Urbanization	Species Lost with Full Area Urbanization
Amphibians		
<u>Necturides</u>		
Mudpuppy	X	- -
<u>Ambystomatidae</u>		
Blue-Spotted Salamander	- -	X
Eastern Tiger Salamander	X	- -
<u>Salamandridae</u>		
Central Newt	X	- -
<u>Bufonidae</u>		
American Toad	X	- -
<u>Hylidae</u>		
Northern Spring Peeper	- -	X
Eastern Gray Tree Frog	- -	X
Western Chorus Frog	X	- -
<u>Ranidae</u>		
Bull Frog	- -	X
Green Frog	X	- -
Northern Leopard Frog	- -	X
Reptiles		
<u>Chelydridae</u>		
Common Snapping Turtle	X	- -
<u>Kinosternidae</u>		
Musk Turtle (Stinkpot)	X	- -
<u>Emydidae</u>		
Painted Turtle	X	- -
Blanding's Turtle[a]	- -	X
<u>Trionychidae</u>		
Eastern Spiny Softshell Turtle	X	- -
<u>Colubridae</u>		
Eastern Hognose Snake	X	- -
Smooth Green Snake	X	- -
Northern Water Snake	X	- -
Northern Brown Snake	X	- -
Red-Bellied Snake	X	- -
Eastern Garter Snake	X	- -
Butler's Garter Snake	X	- -
Eastern Milk Snake	- -	X

[a]*Identified as threatened in Wisconsin.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

mate, the area supports many other species of birds. Hawks and owls function as major rodent predators within the ecosystem. Swallows, whip-poorwills, woodpeckers, nuthatches, flycatchers, and several other species serve as major insect predators. In addition to their ecological roles, such birds as robins, red-winged blackbirds, orioles, cardinals, kingfishers, and mourning doves serve as subjects for bird watchers and photographers.

Not all birds are viewed as an asset from an ecological, economic, or social point of view. With the advance of urbanization and, therefore, the loss of natural habitat, conditions have become less

Table 25

BIRDS LIKELY TO OCCUR IN THE LITTLE MUSKEGO LAKE AREA

Scientific (family) and Common Name	Breeding	Wintering	Migrant
<u>Podicipedidae</u>			
Pied-Billed Grebe	--	--	X
<u>Ardeidae</u>			
American Bittern	--	--	X
Least Bittern	--	--	X
Great Blue Heron	--	--	X
Green-Backed Heron[a]	X?	--	X
Black-Crowned Night Heron	--	--	R
Yellow-Crowned Night Heron	--	--	R
<u>Anatidae</u>			
Tundra Swan	--	--	R
Canada Goose	--	--	X
Wood Duck[a]	X	--	X
Green-Winged Teal	--	--	X
American Black Duck	--	X	X
Gadwall	--	--	X
Mallard[b]	X	X	X
Northern Pintail	--	--	X
Blue-Winged Teal[a]	X	--	X
Northern Shoveler	--	--	X
American Widgeon	--	--	X
Redhead	--	--	X
Ring-Necked Duck	--	--	X
Canvasback	--	--	X
Lesser Scaup	--	--	X
Common Goldeneye	--	--	X
Bufflehead	--	--	X
Hooded Merganser	--	--	X
Common Merganser	--	--	X
<u>Cathartidae</u>			
Turkey Vulture	--	--	X
<u>Accipitridae</u>			
Osprey	--	--	R(E)
Bald Eagle	--	--	R(E)
Northern Harrier	--	--	R
Sharp-Shinned Hawk	--	--	X
Cooper's Hawk	--	--	X(T)
Northern Goshawk	--	--	R
Red-Shouldered Hawk	--	--	R(T)
Broad-Winged Hawk	--	--	X
Red-Tailed Hawk[a]	X	X	X
Rough-Legged Hawk	--	X	X
<u>Falconidae</u>			
American Kestrel[b]	X	X	X
Merlin	--	--	R
Peregrine Falcon	--	--	R(E)
<u>Phasianidae</u>			
Ring-Necked Pheasant[b] (introduced)	X	X	NA
<u>Rallidae</u>			
Virginia Rail[a]	R	--	X
Sora[a]	R	--	X
Common Moorhen	--	--	X
American Coot	R	--	X
<u>Gruidae</u>			
Sandhill Crane	--	--	R

Table 25 (continued)

Scientific (family) and Common Name	Breeding	Wintering	Migrant
Charadriidae			
Semipalmated Plover	--	--	X
Killdeer[b]	X	--	X
Scolopacidae			
Greater Yellowlegs	--	--	X
Lesser Yellowlegs	--	--	X
Solitary Sandpiper	--	--	X
Spotted Sandpiper[b]	X	--	X
Semipalmated Sandpiper	--	--	X
Pectoral Sandpiper	--	--	X
Dunlin	--	--	X
Common Snipe	R	R	X
American Woodcock[a]	X	--	X
Wilson's Phalarope	--	--	X
Laridae			
Ring-Billed Gull	--	X	X
Herring Gull	--	X	X
Caspian Tern	--	--	R
Common Tern	--	--	R(E)
Forster's Tern	--	--	R(E)
Black Tern	--	--	R
Columbidae			
Rock Dove	X	X	NA
Mourning Dove	X	X	X
Cuculidae			
Black-Billed Cuckoo[a]	X	--	X
Yellow-Billed Cuckoo[a]	--	--	X
Stirigidae			
Eastern Screech Owl[b]	X	X	NA
Great Horned Owl[a]	X	X	NA
Snowy Owl	--	R	R
Long-Eared Owl	--	R	R
Short-Eared Owl	--	--	R
Northern Saw-Whet Owl	--	--	X
Common Barn Owl	--	--	R(E)
Caprimulgidae			
Common Nighthawk	X	--	X
Whippoorwill	--	--	X
Apodidae			
Chimney Swift	X	--	X
Trochilidae			
Ruby-Throated Hummingbird	X	--	X
Alcedinidae			
Belted Kingfisher[b]	X	--	X
Picidae			
Red-Headed Woodpecker[b]	X	R	X
Red-Bellied Woodpecker[b]	R	X	NA
Yellow-Bellied Sapsucker	--	R	X
Downy Woodpecker[b]	X	X	NA
Hairy Woodpecker[b]	X	X	NA
Northern Flicker[b]	X	R	X
Tyrannidae			
Olive-Sided Flycatcher	--	--	X
Eastern Wood-Ewee[b]	R?	--	X
Yellow-Bellied Flycatcher	--	--	X
Acadian Flycatcher	--	--	X
Alder Flycatcher	--	--	X

Table 25 (continued)

Scientific (family) and Common Name	Breeding	Wintering	Migrant
Tyrannidae (continued)			
Willow Flycatcher[a]	X	- -	X
Least Flycatcher	- -	- -	X
Eastern Phoebe[a]	X	- -	X
Great Crested Flycatcher[b]	X	- -	X
Eastern Kingbird[b]	X	- -	X
Alaudidae			
Horned Lark[a]	- -	X	X
Hirundinidae			
Purple Martin[b]	X	- -	X
Tree Swallow[b]	X	- -	X
Northern Rough-Winged Swallow	R?	- -	X
Bank Swallow[a]	R?	- -	X
Cliff Swallow[a]	X	- -	X
Barn Swallow[a]	X	- -	X
Corvidae			
Blue Jay	X	X	X
American Crow	X	X	X
Paridae			
Black-Capped Chickadee[b]	X	X	X
Tufted Titmouse	R?	R	NA
Sittidae			
Red-Breasted Nuthatch	- -	R	X
White-Breasted Nuthatch	R	X	NA
Certhiidae			
Brown Creeper	- -	X	X
Troglodytidae			
Carolina Wren	- -	- -	R
House Wren	X	- -	X
Winter Wren	- -	- -	X
Sedge Wren[a]	R	- -	X
Marsh Wren[a]	R	- -	X
Musicapidae			
Golden-Crowned Kinglet	- -	X?	X
Ruby-Crowned Kinglet	- -	- -	X
Blue-Gray Gnatcatcher[a]	R	- -	X
Eastern Bluebird[a]	R	- -	X
Veery[a]	R?	- -	X
Gray-Cheeked Thrush	- -	- -	X
Swainson's Thrush	- -	- -	X
Hermit Thrush	- -	- -	X
Wood Thrush[b]	R?	- -	X
American Robin	X	X	X
Mimidae			
Gray Catbird	X	- -	X
Northern Mockingbird	- -	R	R
Brown Thrasher[b]	X	- -	X
Motacillidae			
Water Pipit	- -	- -	X
Bombycillidae			
Bohemian Waxwing	- -	R	- -
Cedar Waxwing	X	X	X
Laniidae			
Northern Shrike	- -	R	X
Sturnidae			
European Starling	X	X	X

Table 25 (continued)

Scientific (family) and Common Name	Breeding	Wintering	Migrant
Vireonidae			
White-Eyed Vireo	--	--	R?
Solitary Vireo	--	--	X
Yellow-Throated Vireo[a]	--	--	X
Warbling Vireo	X	--	X
Philadelphia Vireo	--	--	X
Red-Eyed Vireo[b]	R?	--	X
Emberizidae			
Blue-Winged Warbler[a]	R	--	X
Golden-Winged Warbler	--	--	X
Tennessee Warbler	--	--	X
Orange-Crowned Warbler	--	--	X
Nashville Warbler	--	--	X
Northern Parula	--	--	X
Yellow Warbler[b]	X	--	X
Chestnut-Sided Warbler[a]	R?	--	X
Magnolia Warbler	--	--	X
Cape May Warbler	--	--	X
Black-Throated Blue Warbler	--	--	X
Yellow-Rumped Warbler	--	--	X
Black-Throated Green Warbler	--	--	X
Blackburnian Warbler	--	--	X
Pine Warbler	--	--	X
Palm Warbler	--	--	X
Bay-Breasted Warbler	--	--	X
Blackpoll Warbler	--	--	X
Cerulean Warbler	--	--	X
Black-and-White Warbler[a]	R?	--	X
American Redstart[a]	R?	--	X
Prothonotary Warbler	--	--	R
Ovenbird[a]	R	--	X
Northern Water Thrush	--	--	X
Louisiana Water Thrush	--	--	R
Kentucky Warbler	--	--	R
Connecticut Warbler	--	--	X
Mourning Warbler[a]	R	--	X
Common Yellowthroat[b]	X	--	X
Hooded Warbler	--	--	X
Wilson's Warbler	--	--	X
Canada Warbler[a]	R?	--	X
Yellow-Breasted Chat	--	--	R
Scarlet Tanager[a]	--	--	X
Northern Cardinal	X	X	NA
Rose-Breasted Grosbeak[b]	X	--	X
Indigo Bunting[b]	X	--	X
Dickcissel	--	--	R
Rufous-Sided Towhee[a]	X?	--	X
American Tree Sparrow	--	X	X
Chipping Sparrow	X	--	X
Clay-Colored Sparrow	--	--	X
Field Sparrow[a]	X	--	X
Vesper Sparrow[a]	--	--	X
Savannah Sparrow[a]	X	--	X
Grasshopper Sparrow	--	--	X
Henslow's Sparrow[a]	X?	--	X
LeConte's Sparrow	--	--	R
Fox Sparrow	--	R	X

Table 25 (continued)

Scientific (family) and Common Name	Breeding	Wintering	Migrant
Emberizidae (continued)			
Song Sparrow[b]	X	R	X
Lincoln's Sparrow	- -	- -	X
Swamp Sparrow[a]	X	R	X
White-Throated Sparrow	- -	R	X
White-Crowned Sparrow	- -	- -	X
Harris' Sparrow	- -	- -	R
Dark-Eyed Junco	- -	X	X
Lapland Longspur	- -	R?	X
Snow Bunting	- -	R?	X
Bobolink[a]	R?	- -	X
Red-Winged Blackbird[b]	X	X	X
Eastern Meadowlark[a]	X	R	X
Western Meadowlark[a]	R?	- -	X
Yellow-Headed Blackbird	- -	- -	X
Rusty Blackbird	- -	R	X
Brewer's Blackbird	- -	- -	X
Common Grackle	X	X	X
Brown-Headed Cowbird[b]	X	X	X
Orchard Oriole	R	- -	R
Northern Oriole	X	- -	X
Fringillidae			
Pine Grosbeak	- -	R	- -
Purple Finch	- -	X	X
Red Crossbill	- -	R?	R
White-Winged Crossbill	- -	R	R
Common Redpoll	- -	X	X
Pine Siskin	- -	X	X
American Goldfinch	X	X	X
Evening Grosbeak	- -	R	X
Ploceidae			
House Sparrow	X	X	NA

NOTE: Breeding—Nesting species (nonnesting species present in summer are not included)
Wintering—Present January-February
Migrant—Transient spring, fall, or both

X - present, not rare
R - rare
V - vagrant (not regularly occurring in Southeastern Wisconsin)
NA - not applicable
(T) - threatened species in Wisconsin
(E) - endangered species in Wisconsin (bald eagle also U. S. threatened, peregrine falcon also U. S. endangered)
? - seasonal status uncertain

[a]*Species lost as breeding birds with full watershed urbanization.*

[b]*Species reduced in numbers as breeding birds with full watershed urbanization.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

compatible with the more desirable bird species. English sparrows, starlings, grackles, and pigeons have replaced more desirable birds in certain areas because of their greater tolerance for urban conditions. The red-winged blackbird, in particular, has been impacted by urbanization as wetland areas, particularly cattail marshes, are drained or filled.

Mammals: A variety of mammals, ranging in size from large animals like the northern white-tailed deer to small animals like the cinereous shrew, are found in the Little Muskego Lake area. Table 26 lists 35 mammals whose ranges are known to extend into the area.

The larger mammals that are still fairly common in the less densely populated areas of the drainage area include white-tailed deer, cottontail rabbits, gray squirrels, fox squirrels, muskrats, minks, weasels, raccoons, red foxes, skunks, and opossums. The first four are often considered game mammals, while the rest are classified as furbearing mammals. White-tailed deer are generally restricted to the larger wooded areas, the open meadows and croplands adjacent to the woodlots, and the shrub swamps. Human and deer populations living in close proximity are incompatible. When deer wander, or are forced, into residential, commercial, or industrial areas, they typically exhibit extreme panic, running wildly and presenting a threat to people, property, and themselves. Foraging deer sometimes cause damage to gardens, ornamental trees, croplands, and orchards. Deer-automobile collisions often occur on the fringes of urban areas, while hunters stalking the animals in urbanizing areas create yet another hazard in such fringe areas.

Cottontail rabbits are abundant throughout the drainage area, even in urbanized areas. Rabbit hunting is possible in some areas, although many people enjoy simply observing the activities of this mammal. Gray squirrels and fox squirrels also abound in the area. The gray squirrel is found primarily in woodlots and wooded residential areas, while the fox squirrel is found in some of the more open woods and countryside. Both require trees of some maturity because natural cavities in such trees are needed both for the rearing of young and for winter protection.

Muskrats and cottontail rabbits are probably the most abundant and widely distributed fur-bearing mammals in and near the area. Muskrats may be attracted to any significant water area, including Little Muskego Lake, wetlands, small ponds, creeks, and drainage ditches, all of which may provide suitable habitat. The familiar muskrat house contributes a certain amount of interest to the landscape and is often used by other wildlife. Waterfowl may make use of the houses for nesting, and minks and raccoons occasionally use muskrat houses as dens. Preservation and improvement of muskrat habitat could, therefore, benefit waterfowl, mink, and raccoon.

Table 26

MAMMALS OF THE LITTLE MUSKEGO LAKE AREA

<u>Didelphidae</u>
Common Opossum
<u>Soricidae</u>
Cinereous Shrew
Short-Tailed Shrew
<u>Vespertilionidae</u>
Little Brown Bat
Silver-Haired Bat
Georgian Bat
Big Brown Bat
Red Bat
Hoary Bat
<u>Leporidae</u>
Mearns's Cottontail Rabbit
<u>Sciuridae</u>
Woodchuck
Striped Ground Squirrel
Eastern Chipmunk
Gray Squirrel
Fox Squirrel
<u>Castoridae</u>
Beaver
<u>Cricetidae</u>
Woodland Deer Mouse
Prairie Deer Mouse
Northern White-Footed Mouse
Meadow Vole
Muskrat
<u>Muridae</u>
Norway Rat
House Mouse
<u>Zapodidae</u>
Hudsonian Meadow Jumping Mouse
<u>Canidae</u>
Coyote
Red Fox
Gray Fox
<u>Procyonidae</u>
Raccoon
<u>Mustelidae</u>
Short-Tailed Weasel
Long-Tailed Weasel
Mink
American Badger (occasional visitor to the drainage basin)
Northern Plains Skunk
Otter (occasional visitor)
<u>Cervidae</u>
White-Tailed Deer

Source: H. T. Jackson, <u>Mammals of Wisconsin</u>, 1961; Wisconsin Department of Natural Resources; and SEWRPC.

The raccoon is associated with the woodland areas. Much of the raccoon's food, however, is water-based, so it makes considerable, if transient, use of lakeshore, stream, and wetland areas. Scavenging raccoons can become pests in the wooded residential environments of the urban fringe.

The red fox is more characteristic of mixed habitat and farmland areas. Most people are tolerant of the fox because of its aesthetic appeal, while others, less well informed, consider it a threat to other wildlife.

Skunks and opossums are common furbearers in this area. Both of these mammals inhabit woodland areas bordering farmlands and urban fringes and venture into wetlands in search of food. Skunks and opossums tend to become inactive in cold weather, although neither is a true hibernator.

Small mammals fairly common in the area include the short-tailed shrew, striped ground squirrel or gopher, meadow vole, white-footed mouse, and little brown bat. These small mammals, with the exception of the bats, are commonly associated with meadows, fence rows, and utility and transportation rights-of-way. People view their importance differently, depending on whether they consider these mammals to be insect predators and food sources for larger mammals and such raptors as hawks and owls, or to be pests in croplands, gardens, and lawns.

Bats, despite their appearance and nocturnal habits, have a very positive impact on the urban environment in that they are major insect predators, often consuming one-third of their weight in insects in one night. With the destruction of woodland and wetland habitats through urban development, the more adaptable species of these flying mammals may relocate within areas of urban development, where they are viewed either as a boon or as a pest.

The complete spectrum of wildlife species originally native to Waukesha County has, along with its habitat, undergone significant change in terms of diversity and population sizes since the European settlement of the area. This change is a direct result of the conversion of land by the settlers from its natural state to agricultural and urban uses, beginning with the clearing of the forest and prairies and the draining of wetlands, and ending with the development of extensive urban areas. Successive cultural uses and attendant management practices, both rural and urban, have been superimposed on the land use changes and have also affected the wildlife and wildlife habitat. In agricultural areas, these cultural management practices include draining land by ditching and tiling, and the expanding use of fertilizers, herbicides, and pesticides. In urban areas, cultural management practices that affect wildlife and their habitat include the use of fertilizers, herbicides, and pesticides; road salting; heavy motor vehicle traffic that produces disruptive noise levels and air pollution; and the introduction of domestic pets.

WILDLIFE HABITAT AND RESOURCES

Wildlife habitat areas remaining in the Region were inventoried by the Wisconsin DNR and the Southeastern Wisconsin Regional Planning Commission in 1985. The five major criteria used to determine the value of these wildlife habitat areas are listed below:

1. Diversity
   An area must maintain a high but balanced diversity of species for a temperate climate, balanced in such a way that the proper predatory-prey (consumer-food) relationships can occur. In addition, a reproductive interdependence must exist.

2. Territorial Requirements
   The maintenance of proper spatial relationships among species, allowing for a certain minimum population level, can occur only if the territorial requirements of each major species within a particular habitat are met.

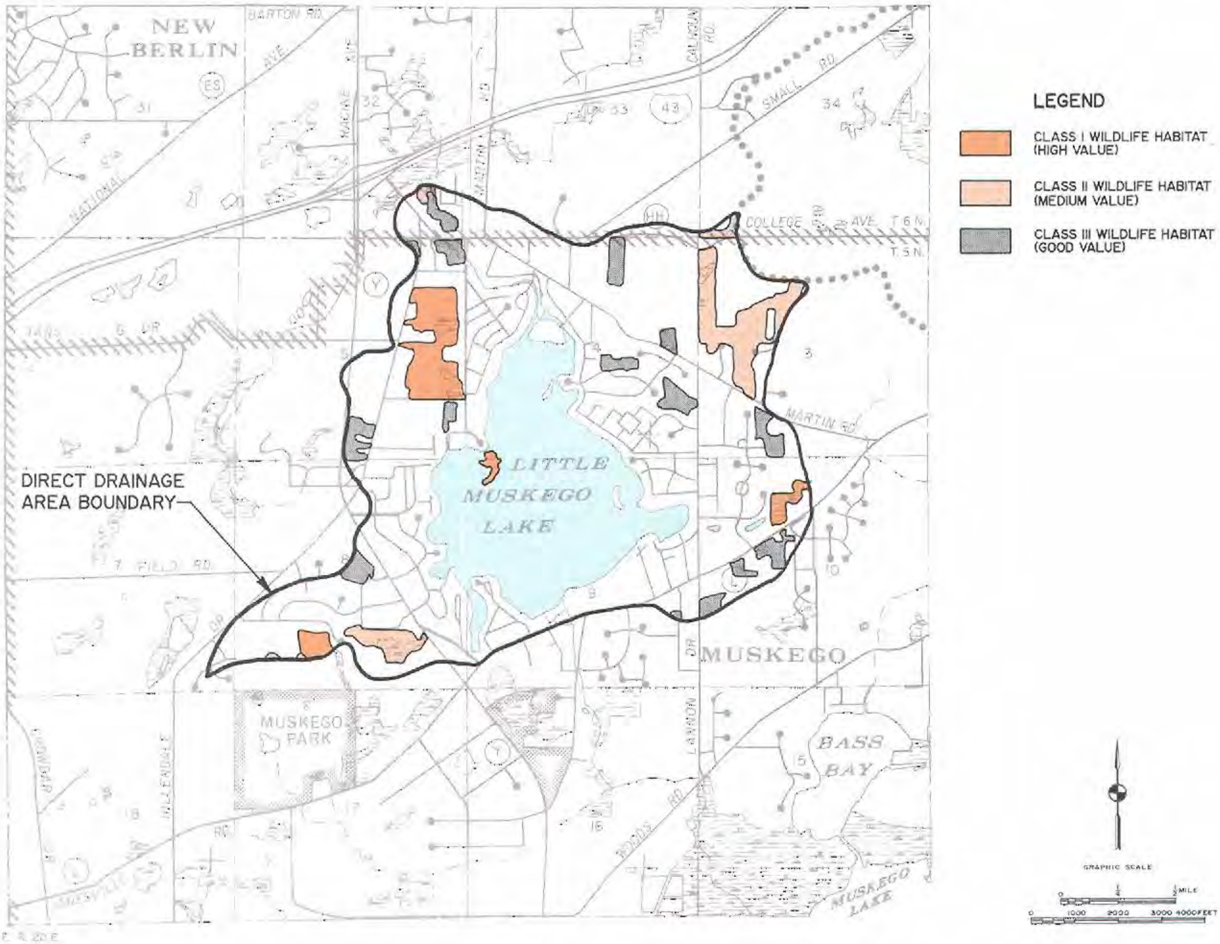
3. Vegetative Composition and Structure
   The composition and structure of vegetation must be such that the required levels for nesting, travel routes, concealment, and protection from weather are met for each of the major species.

4. Location with Respect to Other Wildlife Habitat Areas
   It is very desirable that a wildlife habitat maintain proximity to other wildlife habitat areas.

5. Disturbance
   Minimum levels of disturbance from human activities are necessary, other than those activities of a wildlife management nature.

Map 21

WILDLIFE HABITAT AREAS WITHIN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA



Source: SEWRPC.

On the basis of these five criteria, the wildlife habitat areas in the Little Muskego Lake study area were categorized as either Class I, High-Value; Class II, Medium-Value; or Class III, Good-Value, habitat areas. Class I wildlife habitat areas contain a good diversity of wildlife, are adequate in size to meet all of the habitat requirements for the species concerned, are generally located in proximity to other wildlife habitat areas, and meet all five criteria listed above. Class II wildlife habitat areas generally fail to meet one of the five criteria in the preceding list for a high-value wildlife habitat. However, they do retain a good plant and animal diversity. Class III wildlife habitat areas are remnant in nature in that they generally fail to meet two or more of the five criteria for a high-value wildlife habitat; nevertheless, these areas may be important if they provide corridors linking nearby wildlife habitat areas of higher value, or if they provide the only available range in an area.

As shown on Map 21, approximately 264 acres, or 12 percent of the direct drainage area to Little Muskego Lake, were identified as wildlife habitat. About 84 acres, or 4 percent of the direct drainage area, were classified as Class I habitat; 89.5 acres, or 4 percent of the direct drainage area, were classified as Class II habitat; and 90.5 acres, or 4 percent of the direct drainage area, were classified as Class III habitat.

WETLANDS

Wetlands are defined by the U. S. Army Corps of Engineers, the U. S. Environmental Protection Agency, and the Regional Planning Commission as areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. The Wisconsin DNR defines wetlands as areas where water is at, near, or above the land surface long enough to be capable of supporting aquatic or hydrophytic vegetation and which have soils indicative of wet conditions. The U. S. Natural Resource Conservation Service (NRCS), formerly the U. S. Soil Conservation Service, defines wetlands as areas having a predominance of hydric soils and that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances do support, a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions. The Corps and EPA definition used by the Commission is less inclusive than the NRCS definition in that the Corps and EPA definition requires that the site actually support wetland vegetation under normal conditions, while the NRCS definition only requires that conditions be such that the site be capable of supporting such plants, regardless of whether such plants are actually present on the site. The State definition, as actually applied, is more inclusive than the NRCS definition in that the Department includes as wetland soils some that do not show hydric field characteristics, a condition which may occur in some floodplain areas. It should be noted that, as a practical matter, the DNR and Regional Planning Commission definitions and delineation procedures will be consistent in the majority of situations. Wetlands in Southeastern Wisconsin are classified predominantly as deep marsh, shallow marsh, southern sedge meadow, fresh (wet) meadow, shrub carr, alder thickets, low prairie, fens, bogs, wet-mesic and southern wet-mesic hardwood forests, and conifer swamp.

Wetlands form an important part of the landscape in and adjacent to Little Muskego Lake in that they perform an important set of natural functions that make them ecologically and environmentally invaluable resources. These functions may be summarized as follows:

1. Wetlands affect the quality of water. The aquatic plants which grow in wetlands change inorganic nutrients, such as phosphorus and nitrogen, into organic material, storing it in their leaves and in peat. In addition, the stems, leaves, and roots of these plants slow the flow of water through the wetlands, allowing silt and other sediments, with their attached nutrients and other water pollutants, to settle out; thus, the plants help to protect downstream or offshore resources from siltation and pollution.

2. Wetlands influence the quantity of water. Wetlands provide water during periods of drought and hold it back during periods of wet weather, thereby stabilizing streamflows and controlling downstream flooding. At a depth of 12 inches, one acre of marsh is capable of holding more than 300,000 gallons of water, helping to protect downstream areas from flooding.

3. Wetlands located along the shorelines of lakes and streams help protect those shorelines from erosion.

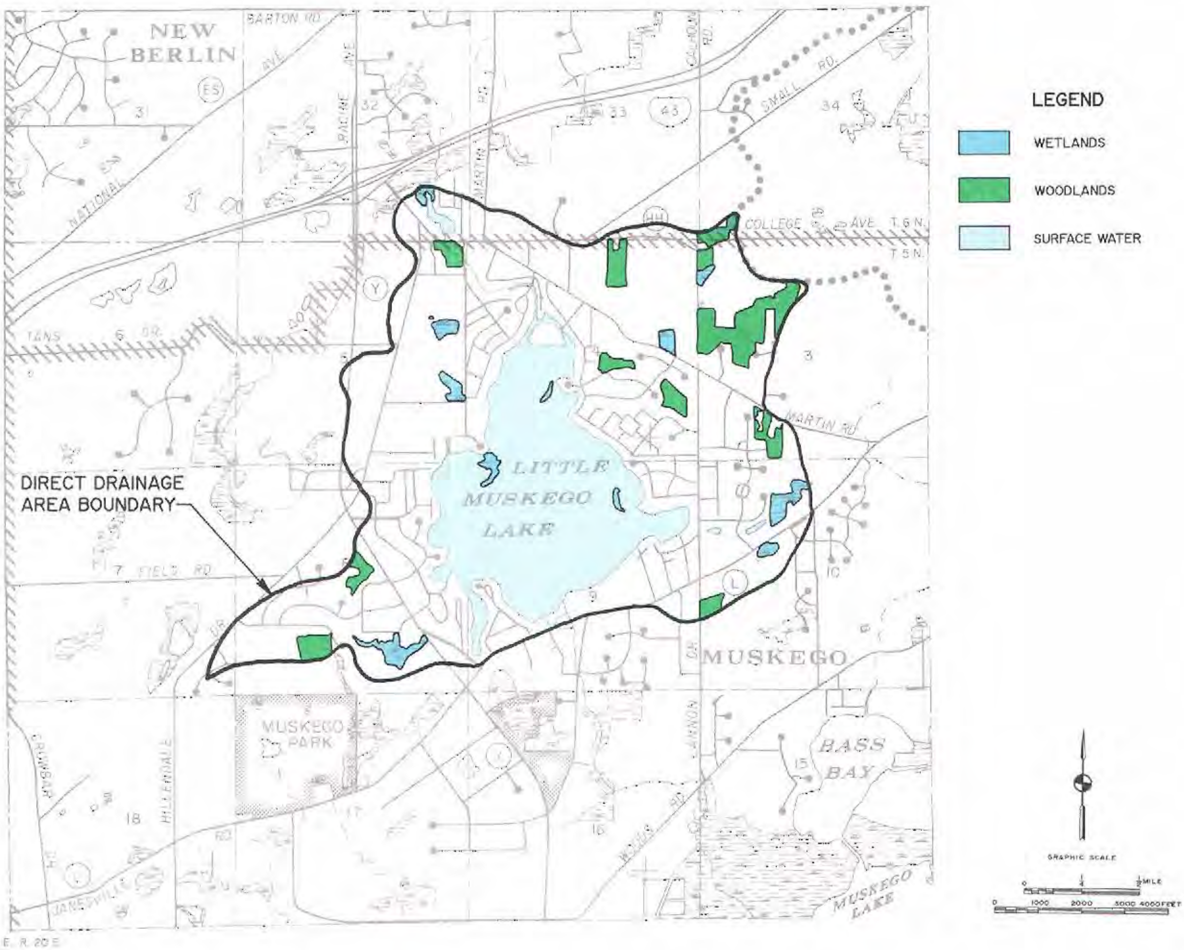
4. Wetlands may serve as groundwater discharge and recharge areas.

5. Wetlands are important resources for overall ecological health and diversity, providing essential breeding and feeding grounds, shelter, and escape cover for many forms of fish and wildlife. The water present in a wetland is attractive to upland birds and other animals, giving wetlands economic, recreational, research, and educational values. Wetlands support such activities as hunting, trapping, and fishing, and add aesthetic value to the community.

Wetlands constitute a constraint on residential, commercial, and industrial development. Generally, this constraint is due to the high soil compressibility and instability, high water table, low load-bearing capacity, and high shrink-swell potential of wetland soils, and, in some cases, to the potential for flooding. In addition, metal conduits placed in some types of wetland soils may be subject to rapid corrosion. These constraints, if ignored, may result in flooding, wet basements and excessive operation of sump pumps, unstable foundations, failing pavements, broken sewer and water lines, and excessive infiltration of clear water into sanitary sewerage systems. In addition, significant onsite preparation and maintenance costs are associated with the development of wetlands, particularly as they relate to roads, foundations, and public utilities.

Map 22

EXISTING WETLANDS IN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA



Source: SEWRPC.

The Commission wetland inventory, shown on Map 22, is maintained as part of the Commission's regional land use inventory, which is updated every five years. In 1990, wetlands covered about 47 acres, or 2 percent, of the Little Muskego Lake direct drainage area. This distribution should remain relatively constant, as shown in Tables 7 and 8 in Chapter III, if regional plan recommendations are followed.

WOODLANDS

Woodlands are defined by the Regional Planning Commission as those areas containing a minimum of 17 trees per acre with a diameter of at least four inches at breast height (4.5 feet above the ground).[6] The woodlands are classified as dry, dry-mesic, mesic, wet-mesic, wet hardwood, and conifer swamp forests. The last three are also considered wetlands and as such have been discussed above. In the Little Muskego Lake direct drainage area, shown on Map 22, approximately 112 acres of woodland were inventoried in 1990. These woodlands covered about 5 percent of the study area. The major tree species include the black willow (Salix nigra), cottonwood (Populus deltoides), green ash (Fraxinus pennsylvanica), silver maple

[6]*SEWRPC Technical Record, Vol. 4, No. 2, March 1981.*

(Acer saccharinum), American elm (Ulmus americana), basswood (Tilia americana), northern red oak (Quercus borealis), and shagbark hickory (Carya ovata). Some isolated stands of tamarack (Larix laricina) also exist in the drainage area, together with such other upland species as the white oak (Quercus alba), burr oak (Quercus macrocarpa), black cherry (Prunus serotina), American beech (Fagus grandifolia), and paper birch (Betula papyrifera).

Woodland acreage should remain stable in the Little Muskego Lake direct drainage area for the foreseeable future if the regional plan recommendations are followed.

ENVIRONMENTAL CORRIDORS

The Environmental Corridor Concept

One of the most important tasks undertaken by the Regional Planning Commission in its work program was the identification and delineation of those areas of the Region having concentrations of natural, recreational, historic, aesthetic, and scenic resources which should be preserved and protected in order to maintain the overall quality of the environment. Such areas normally include one or more of the following seven elements of the natural resource base, which are essential to the maintenance of both the ecological balance and the natural beauty of the Region: 1) lakes, rivers, and streams and the associated undeveloped shorelands and floodlands; 2) wetlands; 3) woodlands; 4) prairies; 5) wildlife habitat areas; 6) wet, poorly drained, and organic soils; and 7) rugged terrain and high-relief topography. While the foregoing seven elements constitute integral parts of the natural resource base, there are five additional elements which, although not a part of the natural resource base per se, are closely related to, or centered on, that base and, therefore, are important considerations in identifying and delineating areas with scenic, recreational, and educational value. These additional elements are 1) existing outdoor recreation sites; 2) potential outdoor recreation and related open space sites; 3) historic, archaeological, and other cultural sites; 4) significant scenic areas and vistas; and 5) natural and scientific areas.

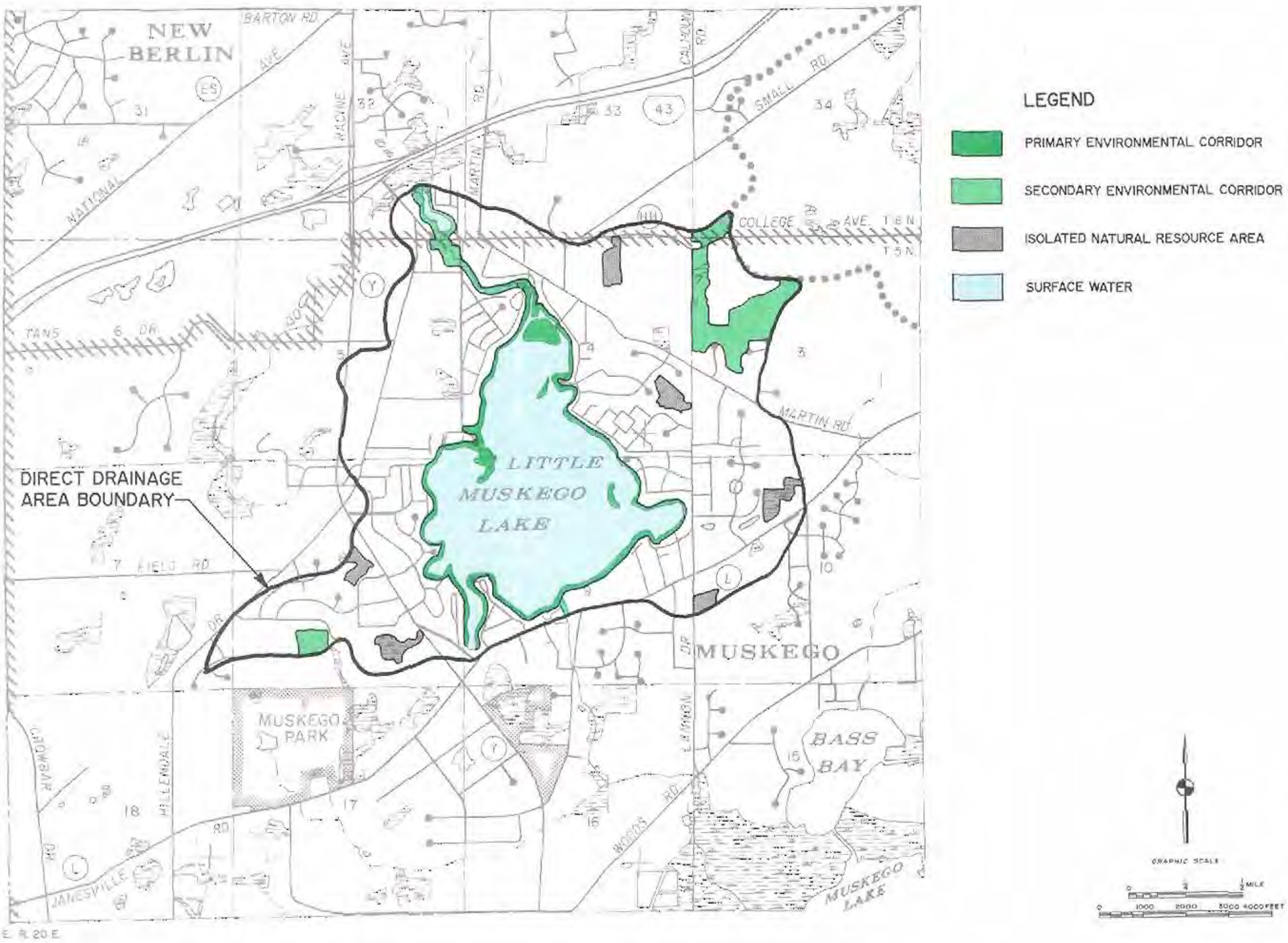
The delineation of these 12 natural resource and natural resource-related elements on a map results in an essentially linear pattern of relatively narrow, elongated areas which have been termed "environmental corridors" by the Commission. Primary environmental corridors include a wide variety of the above-mentioned important resource and resource-related elements and are, by definition, at least 400 acres in size, two miles in length, and 200 feet in width. The primary environmental corridors identified in the Little Muskego Lake study area are contiguous with environmental corridors and isolated natural resource areas lying within the Muskego River watershed and, consequently, meet these size and natural resource element criteria.

It is important to note here that, because of the many interlocking and interacting relationships between living organisms and their environment, the destruction or deterioration of one element of the total environment may lead to a chain reaction of deterioration and destruction. The drainage of wetlands, for example, may have far-reaching effects, since such drainage may destroy fish spawning grounds, wildlife habitat, groundwater recharge areas, and natural filtration and floodwater storage areas in interconnected lake and stream ecosystems. The resulting deterioration of surface water quality may, in turn, lead to a deterioration of the quality of the groundwater which serves as a source of domestic, municipal, and industrial water supplies and provides a basis for low flows in rivers and streams. Similarly, the destruction of woodland cover, which may have taken a century or more to develop, may result in soil erosion and stream siltation, and in more rapid runoff and increased flooding, as well as in the destruction of wildlife habitat. Although the effects of any one of these environmental changes may not in and of itself be overwhelming, the combined effects may lead eventually to the deterioration of the underlying and supporting natural resource base, and of the overall quality of the environment for life. The need to protect and preserve the remaining environmental corridors within the Little Muskego Lake direct drainage area thus becomes apparent and critical.

Environmental corridors were first identified within the Region in 1963 as part of the original regional land use planning effort of the Commission and were subsequently refined under the Commission watershed studies and regional park and open space planning programs. The environmental corridors in Southeastern Wisconsin generally lie along major stream valleys and around major lakes, and contain almost all the remaining high-value woodlands, wetlands, and wildlife habitat areas, and all the major bodies of surface water and related undeveloped floodlands and shorelands.

Map 23

ENVIRONMENTALLY VALUABLE AREAS IN THE LITTLE MUSKEGO LAKE DIRECT DRAINAGE AREA



Source: SEWRPC.

Environmental Corridors in the Little Muskego Lake Drainage Area

Environmental corridors in the Little Muskego Lake study area are shown on Map 23. About 69 acres, or 3 percent of the study area, are identified as primary environmental corridor. This area consists almost completely of the shorelands of Little Muskego Lake itself, little of which is presently in public ownership. A further 100 acres, or about 5 percent of the study area, are classed as secondary environmental corridor, while 46 acres, or about 2 percent, are isolated natural resource areas located within the study area.

Environmental corridors may be subject to urban encroachment because of their desirable natural resource amenities. Unplanned or poorly planned intrusion of urban development into these corridors not only tends to destroy the very resources and related amenities sought by the development, but also tends to create severe environmental and developmental problems as well. These problems include, among others, water pollution, flooding, wet basements, failing foundations for roads and other structures, and excessive infiltration of clear water into sanitary sewerage systems. The preservation of undeveloped corridors is one of the major ways in which the water quality can be protected and perhaps improved at relatively little additional cost to the taxpayers of the area. However, the lack of such undeveloped areas in the Little Muskego Lake study area precludes such action.

Nevertheless, in the Little Muskego Lake study area, the river banks and lakeshores located within the environmental corridors are immediate candidates for protection even though privately owned; as noted, few of these areas are in public ownership, although there are 20 public access sites on the lakeshore. Of the areas not already publicly owned, the remaining areas of natural shoreline, shown on Map 3, are perhaps the most sensitive areas in need of greatest protection. Of these, the islands along the perimeter of the main lake basin, one of which—Holz Island—is publicly owned, are both valuable habitat areas and most susceptible to erosion, and could immediately benefit from habitat stabilization actions. These actions are discussed in Chapters VII and VIII.

RECREATIONAL USES

Existing Public Parks and Recreational Facilities

Little Muskego Lake, lying in the center of an urban area, provides an ideal setting for the provision of parks and open space sites and facilities. There are 20 publicly owned parks and lake access sites along the Little Muskego Lake shoreline, including Idle Isle at the northern end of the Lake, the public boat launch at the southeastern end of the Lake, and 18 walk-in access sites situated around the southern half of the water body. These sites, shown on Map 24, comprise about 14 acres. In addition, 11 privately-owned sites, comprising a further seven acres in areal extent, exist around the lakeshore. Together, these 31 sites represent about 1 percent of the Little Muskego Lake study area. Existing recreational facilities in the vicinity of Little Muskego Lake, including Jensen Park, which is situated off the lakeshore, are shown on Map 24 and listed in Table 27.

Idle Isle is a popular seven-acre park on the northern shore of Little Muskego Lake in the north-central portion of the City of Muskego. Existing facilities include a beach, picnic area, playground, and shoreline fishing area. The Park Drive Access is a one-acre lake-access site on the southern shore of Little Muskego Lake near the central portion of the City, providing a boat-launching area and service area for the Lake District's aquatic plant harvester.

Water-based outdoor recreational activities on Little Muskego Lake include boating, fishing, swimming, and other active and passive recreational pursuits. Because of its size, Little Muskego Lake receives a significant amount of powerboat and sailboat use, and many of these craft were moored along the shore as of 1995, as shown in Table 29 in Chapter VI. A boat survey conducted on July 18, 1994, indicated that about 30 watercraft of all descriptions were in use on the Lake at that time. It is estimated that about two boats per riparian property owner are available for use on the Lake. The Water Bugs Ski Team, based at Idle Isle Park, makes use of Little Muskego Lake for routine practices and occasional shows.

Seasonal community and private events and activities take advantage of the aesthetic qualities of the Lake, including the annual City of Muskego Community Festival, and Little Muskego Lake Association Lakefest. Ice fishing is a popular winter pastime on Little Muskego Lake.

It is important to note that the provision of park and open space sites in the Little Muskego Lake study area should be guided, to a large extent, by the recommendations contained in the City of Muskego park and open space plan.[7] The purpose of that plan is to guide the preservation, acquisition, and development of land for park, outdoor recreation, and related open space purposes and to protect and enhance the underlying and sustaining natural resource base of the City. With respect to the Little Muskego Lake direct drainage area, including the lands along Jewel Creek and the shoreline of Little Muskego Lake, the plan recommends the maintenance of existing park and open space sites in the area. In addition, the plan recommends that the undeveloped lands in the primary environmental corridor around Little Muskego Lake be retained and maintained as natural, open space.

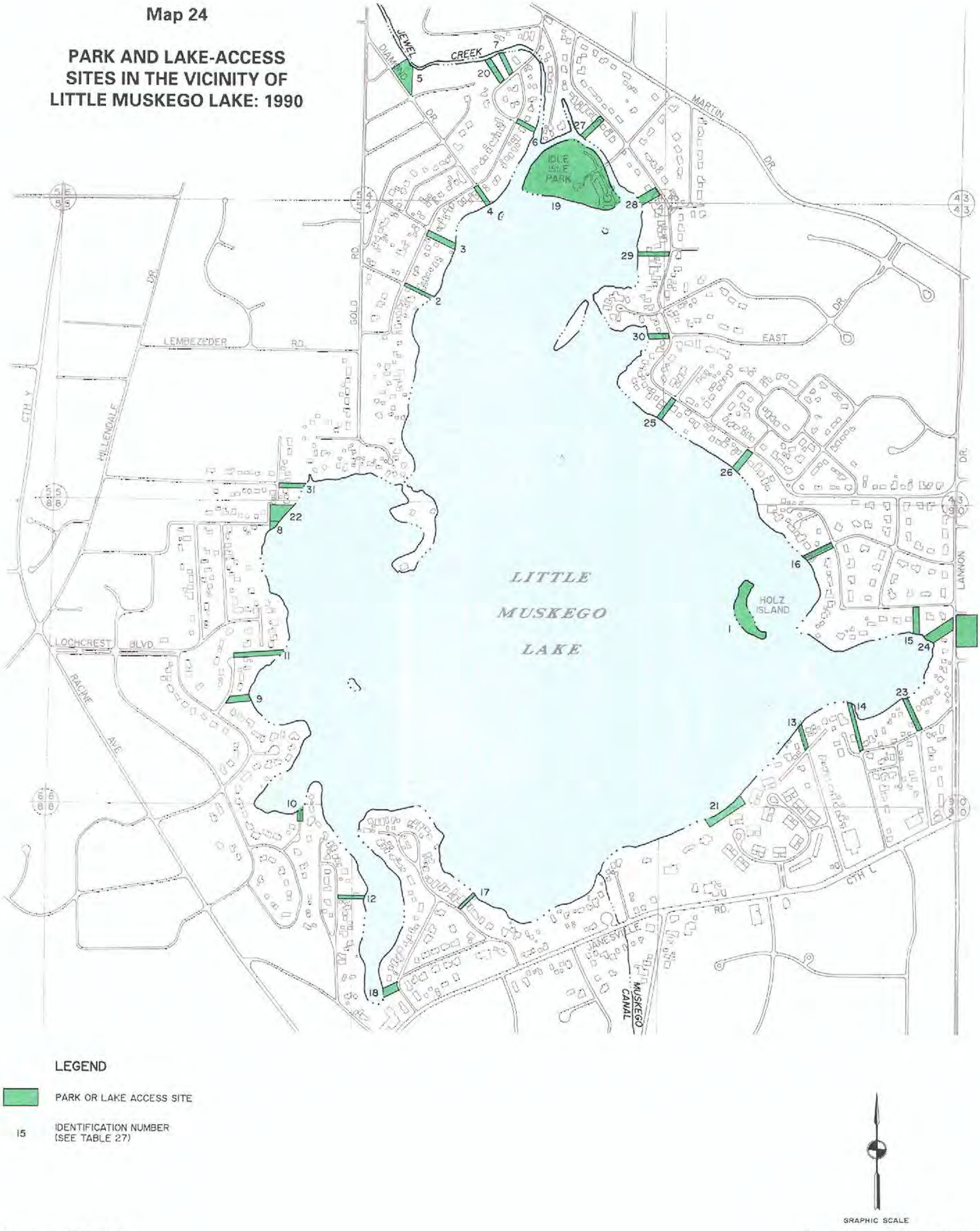
Wisconsin Department of Natural Resources Recreational Rating

A recreational rating technique has been developed by the Wisconsin DNR to characterize the recreational value of inland lakes. As shown in Table 28, Little Muskego Lake received 42 out of the possible 72 points, indicating that moderately diverse recreational opportunities are provided by the Lake. Favorable features include the healthy fishery and boating opportunities provided. In contrast, unfavorable features include relatively poor water quality and aquatic macrophyte growth. In general,

[7]*SEWRPC Community Assistance Planning Report No. 202, A Park and Open Space Plan for the City of Muskego, Waukesha County, Wisconsin, Southeastern Wisconsin Regional Planning Commission, Waukesha, Wisconsin, January 1992.*

Map 24

PARK AND LAKE-ACCESS SITES IN THE VICINITY OF LITTLE MUSKEGO LAKE: 1990



Source: SEWRPC.

Table 27

PARK AND LAKE-ACCESS SITES IN THE VICINITY OF LITTLE MUSKEGO LAKE: 1990

Number on Map 24	Site Name	Ownership	Acreage
	Public		
1	Holz Island	City of Muskego	2
- -	Lake-Access Sites	City of Muskego	12
2	No. 1 Pearl Drive		
3	No. 2 Emerald Drive		
4	No. 3 Diamond Drive		
5	No. 4 Jensen Park		
6	No. 5 Ruby Drive A		
7	No. 6 Ruby Drive B		
8	No. 7 Hillview Drive		
9	No. 8 Shore Drive		
10	No. 9 Oak Court		
11	No. 10 Lockcrest Boulevard		
12	No. 11 Oak Grove		
13	No. 12 Park Avenue		
14	No. 13 Michi Drive		
15	No. 14 Shubring Drive		
16	No. 15 Pleasant View Drive		
17	No. 16 Kingston Drive		
18	No. 17 Cook Drive		
19	No. 18 Idle Isle Park		
20	No. 19 Ruby Drive C		
- -	Subtotal—20 Sites	- -	14
	Nonpublic		
21	Bay Breeze Condominiums	Private	1
22	Hillview Association Access	Private	1
23	Krogman's Access Lot No. 1	Private	- -[a]
24	Lakeview Tavern	Private	2
- -	Muskego Shores Access Lots	Private	1
25	Lot No. 1		
26	Lot No. 2		
- -	Oak Ridge Access Lots	Private	1
27	Lot No. 1		
28	Lot No. 2		
29	Lot No. 3		
30	Lot No. 4		
31	Wentland Drive Access Lot	Private	- -[a]
- -	Subtotal—11 Sites	- -	6
- -	Total—31 Sites	- -	20

[a] *Less than one-half acre.*

Source: Muskego Parks and Recreation Board and SEWRPC.

Little Muskego Lake provides good opportunities for a variety of outdoor recreational activities, particularly boating, fishing, swimming, and aesthetic enjoyment. The natural resource features associated with Little Muskego Lake provide an aesthetically pleasing setting for an attractive urban environment which encourages public participation in outdoor recreation activities. In order to ensure that Little Muskego Lake will continue to provide such recreational opportunities, the resource values of the Lake must be protected.

SUMMARY

Little Muskego Lake is an urban lake situated adjacent to the downtown area of the City of

Table 28

RECREATIONAL RATING OF LITTLE MUSKEGO LAKE: 1991

Space			Total Area: 506 acres Total Shore Length: 7.1 miles Ratio of Total Area to Total Shore Length: 0.11					
Quality (18 maximum points for each item)								
Fish:								
___	9	High production	X	6	Medium production	___	3	Low production
___	9	No problems	X	6	Modest problems, such as infrequent winterkill, small rough fish problems	___	3	Frequent and overbearing problems, such as winterkill, carp, excessive fertility
Swimming:								
___	6	Extensive sand or gravel substrate (75 percent or more)	___	4	Moderate sand or gravel substrate (25 to 50 percent)	X	2	Minor sand or gravel substrate (less than 25 percent)
___	6	Clean water	___	4	Moderately clean water	X	2	Turbid or darkly stained water
___	6	No algae or weed problems	___	4	Moderate algae or weed problems	X	2	Frequent or severe algae or weed problems
Boating:								
___	6	Adequate water depths (75 percent of basin more than five feet deep)	X	4	Marginally adequate water depths (50 to 75 percent of basin more than five feet deep)	___	2	Inadequate depths (less than 50 percent of basin more than five feet deep)
___	6	Adequate size for extended boating (more than 1,000 acres)	X	4	Adequate size for some boating (200 to 1,000 acres)	___	2	Limit of boating challenge and space (less than 200 acres)
___	6	Good water quality	X	4	Some inhibiting factors, such as weedy bays, algae blooms, etc.	___	2	Overwhelming inhibiting factors, such as weed beds throughout
Aesthetics:								
___	6	Existence of 25 percent or more wild shore	X	4	Less than 25 percent wild shore	___	2	No wild shore
___	6	Varied landscape	X	4	Moderately varied	___	2	Unvaried landscape
___	6	Few such nuisances as excessive algae, carp, etc.	X	4	Moderate nuisance conditions	___	2	High nuisance condition
Total Quality Rating			42 out of a possible 72					

Source: Wisconsin Department of Natural Resources and SEWRPC.

Muskego. While the Lake has many of the features of a typical urban lake, including hardened shorelines, encircling development, and heavy recreational use pressures, it has avoided some of the more severe water quality and environmental impacts characteristic of this type of water body.

The Lake does suffer from an excessive abundance of aquatic plants, predominantly the nuisance species Chara, Myriophyllum (milfoil), and Ceratophyllum (coontail). These aquatic plants have historically been managed using a combination of chemical and mechanical control. Chemical controls, previously effected with sodium arsenite and more recently with Cutrine Plus and the synthetic organic herbicides Diquat, Aquathol, and 2,4-D (see Table 20), are applied in late spring, with a possible follow-up treatment in late summer.

Mechanical harvesting is carried out with an Aquarius H-420 harvester.

The Lake supports a vigorous, well-balanced fish community, including sport fish, panfish, and rough fish that are heavily sought by anglers. Walleyed pike and northern pike are stocked by the Wisconsin DNR.

Other aquatic life and wildlife in the direct drainage area of the Lake include such amphibians and reptiles as frogs, toads, turtles, and snakes; birds, including migratory waterfowl, raptors, and songbirds; and small and large mammals, including mice, rabbits, squirrels, foxes, skunks, and deer. While many of the wetland habitats frequented by many of these animals are expected to remain intact, some of the woodlands that house much of the terrestrial fauna are potential sites for further urban residential and recreational development; see Tables 7 and 8 in Chapter III of this report. Nevertheless, the Little Muskego Lake direct drainage area provides an adequate refuge for a healthy and diverse fauna.

The incorporation of much of the shoreland into the primary environmental corridor and the adoption of a park and open space plan by the City of Muskego have done much to preserve and maintain the relatively high-quality environment at Little Muskego Lake. Given the present use of the Idle Isle Park and other City amenities surrounding Little Muskego Lake, any additions to the public open space system are likely to be well used, especially for such passive pursuits as picnicking, playing, walking, and scenic viewing. Fishing is also a popular pastime at Little Muskego Lake, reinforcing the relatively high score which the Lake received during a recent Wisconsin DNR recreational rating exercise; see Table 28.

Chapter VI

CURRENT WATER USES AND WATER USE OBJECTIVES

INTRODUCTION

Nearly all major lakes in this Region serve multiple purposes, ranging from recreation to stormwater discharge outlets. Recreational uses range from such noncontact, passive recreation as picnicking and walking along the shoreline, to such full-contact, active recreation as swimming and water-skiing. Water use objectives and supporting water quality standards have been adopted by the Southeastern Wisconsin Regional Planning Commission as set forth in the adopted regional water quality management plan[1] for all major lakes and streams in the Region. The current water uses, as well as the water use objectives and supporting water quality standards for Little Muskego Lake, are discussed in this chapter.

WATER USES

Chapter V of this report presented information on the uses of Little Muskego Lake. Boating, swimming, and fishing are the predominant uses of Little Muskego Lake itself, according to surveys conducted in 1994 and 1995. In addition, biking and walking in the areas adjacent to the Lake were noted to be significant. While numerous boats were observed using Little Muskego Lake during the user surveys, many more craft were either moored or trailered on the shore. In 1995, a total of 645 such vessels were observed, most of which were either powerboats or pontoon boats, as shown in Table 29. The scope of uses engaged in on Little Muskego Lake is sufficiently broad to be consistent with the recommended use objectives of full recreational use and the support of a healthy warmwater sport fishery as set forth in the regional water quality management plan.[2]

WATER USE OBJECTIVES

As noted, the regional water quality management plan established recreational and warmwater fisheries objectives for Little Muskego Lake. The analyses set forth in Chapters III through V of this report indicate that the natural resource base is generally supportive of such objectives, although both the Commission[3] and DNR[4] note that remedial measures will be required if the Lake is to fully meet these objectives. In addition, to determine the community's desires as to the utility of Little Muskego Lake, Commission staff conducted several discussion sessions with the Lake District Commissioners and members of the public during 1993,[5] and conducted a number of recreational use counts during the summers of 1993 through 1995.

The recommended full recreational use objective provides for full body contact and is supported by responses given both by the Lake District Commissioners and by members of the public to questions asked of them by Commission staff during February and April 1993. Respondents suggested that swimming was an important recreational pastime at Little Muskego Lake that was being threatened by the presence of "muck," turbidity, and aquatic plant growth. It was primarily for this reason that "muck" was ranked as the most significant concern facing Little Muskego Lake. In addition, field observations of the several beaches along the Little Muskego

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[1]*SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000, Vol. 1, Inventory Findings, September 1978; Vol. 2, Alternative Plans, February 1979; Vol. 3, Recommended Plan, June 1979.*

[2]*Ibid., Vol. 2, Map 1, p. 14.*

[3]*Ibid., Vol. 2, pp. 449-52.*

[4]*DNR Publication No. WR-340-93, A Nonpoint Source Control Plan for the Muskego–Wind Lakes Priority Watershed Project, Wisconsin Department of Natural Resources, Madison, Wisconsin, October 1993.*

[5]*SEWRPC Staff Memorandum, "Summary of First Meeting to Establish a Lake Management Planning Strategy for Little Muskego Lake, Waukesha County, Wisconsin," March 1993; SEWRPC Staff Memorandum, "Summary of Written Comments Submitted at Second Meeting to Establish a Lake Management Planning Strategy for Little Muskego Lake, Waukesha County, Wisconsin," April 1993; SEWRPC Staff Memorandum, "Possible Management Options Applicable to Little Muskego Lake," February 1994.*

Table 29

WATERCRAFT ON AND AROUND LITTLE MUSKEGO LAKE: 1995

Type of Watercraft	In Operation	Moored (on water)	Trailered (on land)	Total Craft
Canoes and Rowing Boats	0	8	37	45
Paddleboats	0	33	26	59
Sailboats	0	13	14	27
Fishing Boats (powered)	5	74	75	154
Speedboats	2	104	67	173
Pontoon Boats	3	147	13	163
Jet Skis (personal watercraft)	0	18	6	24
Total Craft	10	397	238	645

Source: SEWRPC.

Lake shore by Commission staff during 1994 confirmed the desire of the community to engage in full-contact recreational pursuits. Swimming and waterskiing were popular activities, particularly at Idle Isle Park, where numerous swimmers and skiers were observed during the field survey conducted during the summer of 1994.

The recommended warmwater sport fishery objective is supported in Little Muskego Lake by a sport fishery based largely on pike, bass, and panfish. These fishes have traditionally been sought-after fishes in Little Muskego Lake; bass and panfish were noted as being common, and pike, both northern and walleyed, as being present. Unfortunately, the reproductive capability of pike and bass is limited in Little Muskego Lake by the paucity of appropriate habitat within the lake basin. This lack of habitat was highlighted in the public surveys conducted by Commission staff during 1993. In responses to the survey questions, "habitat loss" ranked immediately after "muck" and "contamination" as one of the major problems facing Little Muskego Lake.

WATER QUALITY STANDARDS

The water quality standards supporting the warmwater fishery and full recreational use objectives, established for planning purposes in the regional water quality management plan, are set forth in Table 30. These standards are similar to those set forth in Chapters NR 102 and NR 104 of the Wisconsin Administrative Code, but were refined for planning purposes in terms of their application. Standards are recommended for temperature, pH, dissolved oxygen, fecal coliform, and total phosphorus. These standards apply to the epilimnion of the lakes and to streams. The total phosphorus standard applies to spring turnover concentrations measured in the surface waters. Such contaminants as oil; debris; scum; odor-, taste-, and color-producing substances; and toxins are not permitted in concentrations harmful to the aquatic life as set forth in Chapter NR 102 of the Wisconsin Administrative Code.

The adoption of these standards is intended to specify conditions in the waterways concerned that would assist in the abatement of excessive macrophyte and algal growths and promote all forms of recreational use, including angling, in these waters.

SUMMARY

Little Muskego Lake is a multiple-purpose lake serving many recreational and aesthetic users. About 650 boats of all descriptions are kept on or around the Lake, and the Lake is a popular angling venue. During summer field surveys, many people were observed using the Lake for fishing, swimming and wading, waterskiing, and boating. Therefore, the recommended standards for full recreational use and a warmwater fishery are consistent with present activities. The achievement of these objectives requires management interventions aimed at controlling sediment and nutrient loading, algal and plant growth responses, and habitat degradation in the Lake. These actions will form the basis for the management plan hereafter recommended.

Table 30

RECOMMENDED WATER QUALITY STANDARDS TO SUPPORT RECREATIONAL AND WARMWATER FISH AND AQUATIC LIFE USE

Water Quality Parameter	Water Quality Standard
Maximum Temperature	89°F[a,b]
pH Range	6.0-9.0 standard units
Minimum Dissolved Oxygen	5.0 mg/l[b]
Maximum Fecal Coliform	200/400 MFFCC/100 ml[c]
Maximum Total Phosphorus	0.02 mg/l[d]
Other	- -[e,f]

[a]There shall be no temperature changes that may adversely affect aquatic life. Natural daily and seasonal temperature fluctuations shall be maintained. The maximum temperature rise at the edge of the mixing zone above the existing natural temperature shall not exceed 3°F for lakes.

[b]Dissolved oxygen and temperature standards apply to the epilimnion of stratified lakes and to the unstratified lakes; the dissolved oxygen standard does not apply to the hypolimnion of stratified inland lakes. Trends in the period of anaerobic conditions in the hypolimnion of stratified inland lakes should be considered important to the maintenance of water quality, however.

[c]The membrane filter fecal coliform count per 100 milliliters (MFFCC/100 ml) shall not exceed a monthly geometric mean of 200 per 100 ml based on not less than five samples per month, nor a level of 400 per 100 ml in more than 10 percent of all samples during any month.

[d]This standard for lakes applies only to total phosphorus concentrations measured during spring when maximum mixing is under way.

[e]All waters shall meet the following minimum standards at all times and under all flow conditions: Substances that will cause objectionable deposits on the shore or in the bed of any body of water shall not be present in such amounts as to interfere with public rights in waters of the State. Floating or submerged debris, oil, scum, or other material shall not be present in such amounts as to interfere with public rights in the waters of the State. Materials producing color, odor, taste, or unsightliness shall not be present in amounts which are acutely harmful to animal, plant, or aquatic life.

[f]Unauthorized concentrations of substances are not permitted that alone or in combination with other material present are toxic to fish or other aquatic life. Standards for toxic substances are set forth in Chapter NR 105 of the Wisconsin Administrative Code.

Source: SEWRPC.

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Chapter VII

ALTERNATIVE WATER QUALITY MANAGEMENT MEASURES

INTRODUCTION

Potential measures for the management of Little Muskego Lake include watershed management measures, such as local land use planning and zoning, nonpoint source pollution control measures, and in-lake rehabilitation techniques. Land use planning and zoning can serve to protect the Lake by promoting and maintaining a sound land use pattern in the tributary drainage area, protecting groundwater recharge areas, and helping to reduce nonpoint pollutant runoff into the Lake. Nonpoint source pollution control measures can serve to reduce pollutants in runoff discharged to the Lake by direct overland drainage, by drainage through natural or human-made channels or piped systems, and by groundwater inflow. In-lake rehabilitation techniques can treat directly identified problems of water quality and lake use constraints.

In addition to undertaking a land use planning and management program for the area draining directly to Little Muskego Lake, it is recommended that the local authorities and Lake District participate in implementation of measures recommended in the adopted regional water quality management plan and in the Muskego-Wind Lakes nonpoint source priority watershed program for the total drainage area tributary to Little Muskego Lake. Any pollution abatement practices adopted in that total tributary area will also benefit the downstream lakes, including Big Muskego and Wind Lakes, in addition to providing direct benefit to Little Muskego Lake.

LAND USE AND ZONING REGULATION ALTERNATIVES

A basic element of any water quality management effort for any lake, including Little Muskego Lake, is the promotion of sound land use and management in the tributary watershed. The type and location of future urban and rural land uses in the watershed will determine, to a large extent, the character, magnitude, and distribution of nonpoint sources of pollution; the practicality of, as well as the need for, various forms of land management; and, to some degree, the water quality of the Lake.

Existing 1990 and planned year 2010 land use patterns and existing zoning regulations in the tributary drainage area to Little Muskego Lake are described in Chapter III. The major land use changes noted in Chapter III are expected to be in the form of residential, commercial, and recreational developments, with an attendant decline in agricultural and other open lands. Increases in urban lands and impervious surface will increase runoff and will increase some pollutant loadings unless mitigative measures are taken. Additional urban development or redevelopment in the tributary drainage area may also increase recreational-use pressures on the Lake. Generally, the shoreline of Little Muskego Lake is fully developed. However, some redevelopment and limited infilling may occur. Land use redevelopment proposals around the shoreline of Little Muskego Lake must be carefully evaluated for potential impacts on the Lake.

It is anticipated that all new development in the Little Muskego Lake tributary drainage area will be served by public sanitary sewerage systems. In addition, some of the existing onsite sewage disposal systems remaining in the area tributary to Little Muskego Lake may be expected to be abandoned as expansion of the existing public sanitary sewerage system occurs.

The basis for the recommended year 2010 land use plan year 2010 for the Little Muskego Lake tributary drainage area, as presented in Chapter III, is the regional land use plan prepared and adopted by the Regional Planning Commission. That recommended land use plan is shown in graphic summary form on Map 16 and proposes that additional urban land use development occur at medium and low densities in the area tributary to Little Muskego Lake. Such urban uses should be permitted to occur, however, only in those portions of the drainage area which can be readily served by centralized sanitary sewerage facilities, which are covered by soils suitable for the intended use, which are not subject to such special hazards as flooding, and which are not environmentally sensitive, that is, are not encompassed within Regional Planning the year 2010, urban development in the total drainage area tributary to Little Muskego Lake may be expected to increase from about 2,854 acres to about 3,337 acres, or by about 17 percent over the 1990 level of urban development. The developed area as envisioned in the plan totals about one-half of the area zoned for urban development under existing zoning ordinances. Under the existing zoning ordinances about 6,385 acres, or about 85 percent, of the drainage area tributary to Little Muskego Lake are available for urban development. Therefore, the existing ordinances encourage within the drainage area the diffusion of urban development that conflicts with the recommendations of the adopted regional land use plan and with sound water quality management practice. In order to prevent undesirable urban development in the direct drainage area and in the total drainage area tributary to the Lake, it will be necessary for the responsible public officials in the two major civil divisions to review critically the individual zoning maps for the Little Muskego Lake direct and total drainage areas and amend the zoning ordinances so as to protect and enhance the existing natural resource base of the drainage areas. Preservation and enhancement of natural areas within the drainage basins will serve to protect, and ultimately to improve, the water quality of the Lake.

ALTERNATIVE MEASURES FOR NONPOINT SOURCE POLLUTION CONTROL

Watershed management measures may be used to reduce nonpoint source pollutant loadings from such rural sources as runoff from cropland and pastureland and from livestock wastes; from such urban sources as runoff from residential, commercial, industrial, transportation, and recreational land uses; and from construction activities. The alternative, watershed-based nonpoint source pollution control measures considered in this report are based upon the recommendations set forth in the regional water quality management plan,[1] in the Muskego-Wind Lakes priority watershed plan,[2] and in the Waukesha County soil erosion control plan;[3] and upon information presented by the U. S. Environmental Protection Agency.[4]

An inventory and analysis of nonpoint pollution sources in the urban and rural areas of the drainage basins concerned are presented in Chapter IV. That inventory identified sources of urban and rural nonpoint pollution and determined the relative contribution of each source under the then current 1990 and future year 2010 land use conditions so that control measures could be developed. Pollution sources identified within the drainage area tributary to Little Muskego Lake included upland agricultural and open land runoff, streambank and lakeshore erosion, urban runoff, and construction site erosion.

Appendix B presents a list of alternative management options that could be considered for use within the drainage areas tributary to Little Muskego Lake to reduce loadings from nonpoint sources of pollution. Information on the cost and effectiveness of the measures is also presented in Appendix B.

Rural Nonpoint Source Controls

Upland erosion from agricultural and other rural lands is a major contributor of sediment and phosphorus to streams in the tributary drainage area to Little Muskego Lake. Sediment and phosphorus runoff loadings were quantified for all the rural lands. These data and the water use objectives and supporting standards presented in Chapter VI were utilized in determining the pollutant load percentage reduction that should be achieved in the

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[1]*SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin—2000, Volume One, Inventory Findings, 1978; Volume Two, Alternative Plans, 1979; and Volume Three, Recommended Plan, 1979. See also SEWRPC Memorandum Report No. 93, A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report, March 1995.*

[2]*Wisconsin Department of Natural Resources, A Nonpoint Source Control Plan for the Muskego-Wind Lakes Priority Watershed Project, Publication No. WR-340-93, October 1993.*

[3]*SEWRPC Community Assistance Planning Report No. 159, Waukesha County Agricultural Soil Erosion Control Plan, June 1988.*

[4]*U. S. Environmental Protection Agency, Report No. EPA-440/4-90-006, The Lake and Reservoir Restoration Guidance Manual, Second Edition, August 1990; and its technical supplement, U. S. Environmental Protection Agency, Report No. EPA-841/R-93-002, Fish and Fisheries Management in Lakes and Reservoirs: Technical Supplement to the Lake and Reservoirs Restoration Guidance Manual, May 1993.*

Little Muskego Lake tributary drainage area, the types of practices needed, and the extent of the areas to which the practices were to be applied.

On the basis of 1990 land use conditions, the sediment loading from the tributary drainage areas of Little Muskego Lake totaled about 2,612 tons per year from the erosion of rural lands. Approximately 67 percent of this erosion came from lands with annual soil losses of over three tons per acre. Such losses exceed the target level of agricultural erosion control of three tons per acre per year, recommended in the Waukesha County agricultural soil erosion control plan. The regional water quality management plan recommends a reduction of about 75 percent in nonpoint source pollution loadings from rural sources in the tributary area to Little Muskego Lake.

Based upon a review of the data on the nonpoint source control measures set forth in Appendix B, and the aforementioned nonpoint source control priority watershed and the county soil erosion control plans, practices to control rural nonpoint sources of pollution considered viable in the Little Muskego Lake tributary drainage areas include conservation tillage, contouring, contour strip-cropping, changes in crop rotations, grassing of waterways, cover cropping, and developing and protecting permanent vegetative cover.

Detailed farm conservation plans should be prepared to identify specific erosion control practices for individual farm units. Generally prepared with the assistance of the U. S. Natural Resources Conservation Service or County Land Conservation Department staff, such plans identify desirable tillage practices, cropping patterns, and rotation cycles, considering the specific topography, hydrology, and soil characteristics of the farm; identify the specific resources available to the farm operator; and articulate the farm operator's objectives as owner and manager of the land.

Urban Nonpoint Source Controls

Urban nonpoint source pollution can vary directly with the degree of land disturbance. Developing areas can generate significantly higher pollutant loadings than do similar established areas. Developing areas include a wide array of situations, including urban renewal projects, individual site development within the existing urban area, and new land subdivision development. Established urban areas include lands in existing residential, commercial, industrial, transportation, and open space uses. In addition to contributing sediments and nutrients to Little Muskego Lake, as do rural sources, urban sources also contribute toxic substances, especially such metals as lead, cadmium, copper, and zinc. Within the drainage area directly tributary to Little Muskego Lake, urban nonpoint sources are particularly important because most of the urban land is located immediately adjacent to the Lake. As documented in Chapter IV, about 1,208 tons of suspended solids, or about 46 percent of the total suspended solids loading to Little Muskego Lake, are delivered by urban lands within the study area. Additionally, about 1,808 pounds of phosphorus, or 29 percent of the total loading, are contributed by urban areas.

The regional water quality management plan recommends that the nonpoint source pollutant loadings from the urban areas tributary to Little Muskego Lake be reduced by about 50 percent in addition to reductions from urban construction erosion control, onsite sewage disposal system management, and streambank and lakebank erosion control measures; thus, providing a total reduction in nonpoint source pollutant loadings of about 60 percent.

The plan for the Little Muskego, Big Muskego, and Wind Lake priority watershed project established pollutant reduction goals of 55 percent for sediment and 60 percent for phosphorus. The plan, however, established no specific reduction goal for metals and other toxic materials from urban runoff. However, the plan indicated that controls of these materials would be achieved by the practices needed to meet reductions for sediment and phosphorus. The loading reductions set forth in the priority watershed plan were based upon analytical work conducted by the Wisconsin Department of Natural Resources staff for Big Muskego and Little Muskego Lakes and upon modeling work conducted by the Regional Planning Commission for Wind Lake. The nonpoint source pollutant reduction goals set forth in the Little Muskego, Big Muskego, and Wind Lakes priority watershed project are similar to those established in the regional water quality management plan.

In addition to these regional and subregional plans, a stormwater management plan for the portion of the City of Muskego draining to Big and Little Muskego Lakes has been prepared as Phase 1 of a comprehensive stormwater management plan for the City.[5] A stormwater management plan for the Westridge Business Park located in the southern portion of the City of New Berlin draining to Little Muskego Lake has also been prepared.[6]

Developed Areas: Based upon a review of the regional, subregional, and local plans noted above, and the data on nonpoint source pollution abatement measures set forth in Appendix B, urban nonpoint source pollution control practices, which are considered applicable for use in the area tributary to Little Muskego Lake include street cleaning, grassed swales, stormwater detention, streambank erosion control, and good urban housekeeping practices.

Generally, the application of low-cost urban housekeeping practices may be expected to reduce nonpoint source loadings from urban lands by about 25 percent. Public education programs can be developed to encourage good urban housekeeping practices, to promote the selection of building and construction materials which reduce the runoff contribution of metals and other toxic pollutants, and to promote the acceptance and understanding of the proposed pollution abatement measures and the importance of lake water quality protection. Urban housekeeping practices and source controls include restricted use of fertilizers and pesticides, improved pet waste and litter control, proper disposal of motor vehicle fluids, improved yard waste management, and reduced use of street deicing salt. Particular attention should be given to reducing pollutant loadings from high pollutant loading areas, such as commercial and industrial sites, parking lots, and material storage areas. To the extent practicable, parking lot stormwater runoff should be diverted to areas covered by pervious soils and appropriate vegetation, rather than being directly discharged to impervious surfaces and storm sewers. Material storage areas may be enclosed or periodically cleaned, and diversion of stormwater away from these sites may further reduce pollutant loadings. It is estimated that implementation of good urban housekeeping practices and the use of grassed swales in selected areas may reduce the phosphorus pollutant loading to Little Muskego Lake by about 5 to 10 percent.

Proper design and application of urban nonpoint source control measures, such as grassed swales and detention basins, requires the preparation of a detailed stormwater management system plan that addresses stormwater drainage problems and controls nonpoint sources of pollution. Currently, the measures specifically recommended in the afore-referenced local stormwater management plans include continued street sweeping. Routine street sweeping on a twice-monthly basis between April and November of each year is recommended for all industrial, commercial and multi-family residential areas of the City where curb-and-gutter drainage is provided. In addition, existing and new storm sewer catch basins are recommended to be cleaned twice yearly, in spring and autumn. The City of Muskego Stormwater Management Plan further recommends the diversion of stormwater runoff from roofs and parking areas to grassed swales as an element of stormwater management for all future developments.

Nonstructural measures recommended to be implemented in the Phase 1 stormwater management plan include the enforcement of the City's construction erosion control ordinance, as described below. It is recommended that the City schedule and sponsor one or more workshops with local industries to discuss the specific requirements for industrial compliance with the Chapter NR 216 stormwater management requirements. Similar workshops related to City public works operations, combined with an environmental audit of practices, are recommended to be convened for City staff. In parallel with these efforts, the plan recommends that information be presented to householders within the City to inform the public of sound urban household practices which will reduce nonpoint source pollutant loadings.

Structural measures recommended in the Phase 1 stormwater management plan include the construction and maintenance of 12 new stormwater detention basins and the retro-fitting of four existing basins at an estimated capital cost of about $535,000. A combination of wet and dry detention basins is recommended in the plan.

Completion of the subsequent phases of the stormwater management planning effort is also recommended. These phases are recommended to include provisions for the protection, enhancement, and rehabilitation of wetlands within the Lake watersheds of the City, both to prevent future deterioration and to preserve environmental corridors and the natural resource base. This would also include

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[5]*Rust Environment & Infrastructure, City of Muskego: Phase 1 Stormwater Management Plan, April 1995.*

[6]*Ruekert & Mielke, Inc., Westridge Stormwater Management Plan, August 1995.*

protection and stabilization of eroding streambanks throughout the City. The estimated capital cost of these measures is about $155,000.

Developing Areas: Developing areas can generate significantly higher pollutant loadings than established areas of similar size. Developing areas include a wide array of activities, including urban renewal projects, individual site development within the existing urban area, and new land subdivision development.

Construction sites, especially, can be expected to produce suspended solids and phosphorus at rates several times higher than rates for established urban land uses. About 685 tons, or 26 percent of the sediment load, and 128 pounds, or one percent of the phosphorus load, to Little Muskego Lake are anticipated to originate in newly urbanizing lands. Control of sediment loss from construction sites is required in terms of the provisions of construction erosion control ordinances, based on the model ordinance developed by the Wisconsin League of Municipalities and Wisconsin Department of Natural Resources,[7] and adopted by the Cities of Muskego and New Berlin and by Waukesha County. These controls are temporary measures taken to reduce pollutant loadings from construction sites during stormwater runoff events. Construction erosion controls may be expected to reduce pollutant loadings from construction sites by about 75 percent. Such controls are important pollution control measures in order to prevent localized short-term loadings of phosphorus and sediment from the study area and the upstream tributary area. The control measures include such revegetation practices as temporary seeding, mulching, and sodding; and such runoff control measures as filter fabric fences, straw bale barriers, storm sewer inlet protection devices, diversion swales, sediment traps, and sedimentation basins. As noted above, development by the City of Muskego of policies and procedures relating to the implementation and enforcement of these practices in developing areas is recommended in the Phase 1 stormwater management plan for the City.

[7]*Wisconsin League of Municipalities and Wisconsin Department of Natural Resources, Wisconsin Construction Site Best Management Practices Handbook, 1989.*

IN-LAKE MANAGEMENT

The reduction of external nutrient loadings to Little Muskego Lake by the measures described above should help to prevent deterioration of its water quality conditions, but may not eliminate existing water quality and lake-use problems. In mesotrophic and eutrophic lakes, particularly in the presence of anaerobic conditions in the hypolimnion as occur in Little Muskego Lake during the summer, significant amounts of phosphorus can be released from the existing sediments to the overlying water column. Consequently, the water quality improvements expected from a reduced nutrient input may be inhibited. Because of this and because of other characteristics of the Lake, such as abundant macrophyte growth, which can result in restricted water use potential, the application of in-lake rehabilitation techniques should be considered.

The applicability of specific in-lake rehabilitation techniques is highly dependent on lake characteristics. The success of any lake rehabilitation technique can seldom be guaranteed since the technology is still in the early stages of development. Because of the relatively high cost of applying most techniques, a cautious approach to implementing in-lake rehabilitation techniques is generally recommended. Certain in-lake rehabilitation techniques should be applied only to lakes in which 1) nutrient inputs have been reduced below the critical level; 2) there is a high probability of success in applications of the particular technology to lakes of similar size, shape, and quality; and 3) the possibility of adverse environmental impacts is minimal. Finally, it should be noted that some in-lake rehabilitation techniques require the issuance of permits from appropriate State and Federal agencies prior to implementation.

Alternative lake rehabilitation measures include in-lake water quality, water level, aquatic plant, and fishery management measures. Each of these groups of management measures, together with the attendant costs, are described below.

Water Quality Management Measures

This group of in-lake management practices includes a variety of measures designed to directly modify the magnitude of either a water quality determinant or biological response, although specific measures aimed at managing aquatic plants and fishes are detailed separately below. Options considered under this heading include the aeration and nutrient inactivation measures recommended for further consideration in the regional water quality management plan.[8] The Little Muskego Lake Management District operated an experimental aeration system in the Lake between 1986 and 1990, as discussed in Chapter IV.

Dilution and Flushing: Dilution is a restoration measure which reduces the impact of contamination by blending contaminated waters with less contaminated waters, or using less contaminated waters to flush the contaminated waters out of the lake basin. Costs are extremely variable and depend upon the availability and location of a suitable source of flushing or dilution water. Where pumping is required, this technique can be very costly. Effectiveness also varies directly with the quality of the dilution and flushing water quality. Impacts can include over-topping of, and damage to, control structures—hydraulic over-loading—and transferral of the problem contaminants downstream. Use of this technique in Little Muskego Lake is limited by the lack of an upstream water source of better quality than currently exists in the Lake. Linnie Lac, the upstream water body, is also an enriched lake ecosystem and is of limited volume.[9] For these reasons, use of this technique is not recommended.

Phosphorus Precipitation and Inactivation: Nutrient inactivation is a restoration measure that is designed to limit the biological availability of phosphorus by chemically binding the element in the lake sediments using a variety of divalent or trivalent cations, or highly positively charged elements. Aluminum sulphate (alum), ferric chloride, and ferric sulphate are commonly used cation sources. The use of these techniques to remove phosphorus from nutrient-rich lake waters is an extension of common water supply and wastewater treatment processes. Costs depend on the lake volume and type and dosage of chemical used, with alum costing about $150 per ton; 100 tons can treat a lake of about 40 acres. Effectiveness depends in part on the ability of the alum flocculent to form a stable "blanket" on the lakebed—to wit, on flushing time, turbulence, lake water acidity (pH), and rate of continued sedimentation. Impacts can include the release of toxic quantities of free aluminum into the water. Improved water clarity can also encourage the spread of rooted aquatic plants.

Liming, or the use of calcium carbonate to precipitate nutrients and contaminants, is a restoration measure identical to that described above for phosphorus precipitation and inactivation. In addition to such use, lime also offers the benefit of neutralizing acidic compounds. Costs associated with the application of lime are similar to those cited for the other cationic compounds. Effectiveness and potential impacts are also similar.

Alum, or one of the other compounds, is typically applied to a lake surface over the deeper parts of the lake in a liquid form, resulting in the formation of a precipitate. In the case of alum, the precipitate is aluminum hydroxide. Aluminum hydroxide has a high capacity to absorb phosphorus and make it unavailable to plants and algae. It is also relatively inexpensive, and any free aluminum that might result has a relatively low toxicity to most forms of aquatic life. The aluminum hydroxide not only removes available phosphorus rapidly from the water column but, at the same time, prevents the release of phosphorus from the lake sediments, thus limiting the availability of the nutrient for the growth of planktonic plants. The floc absorbs phosphorus in the water column and forms a chemical and physical layer which retards the transfer of the nutrient from the sediments. When it is successful, results appear relatively quickly, and, if external sources of nutrients and in-lake turbulence are low, the effects are generally long-lasting.

The rate of application will depend on the compound used, the phosphorus concentration, and the buffering capacity of the lake. It is important that aluminum not be added in higher concentrations than the absorptive ability of the water—a function of the concentration of the multivalent anions—to prevent toxicity to aquatic organisms. Bench scale testing is necessary before alum or other compounds are used.

The application of alum to the hypolimnion of Little Muskego Lake, over the area shown on Map 25, would cost about $60,000 for each application, assuming a standard alum application rate of 15 milligrams per liter of water. The labor and equipment cost of the application is estimated at $12,000, resulting in a total cost for sediment alum application of about $72,000.

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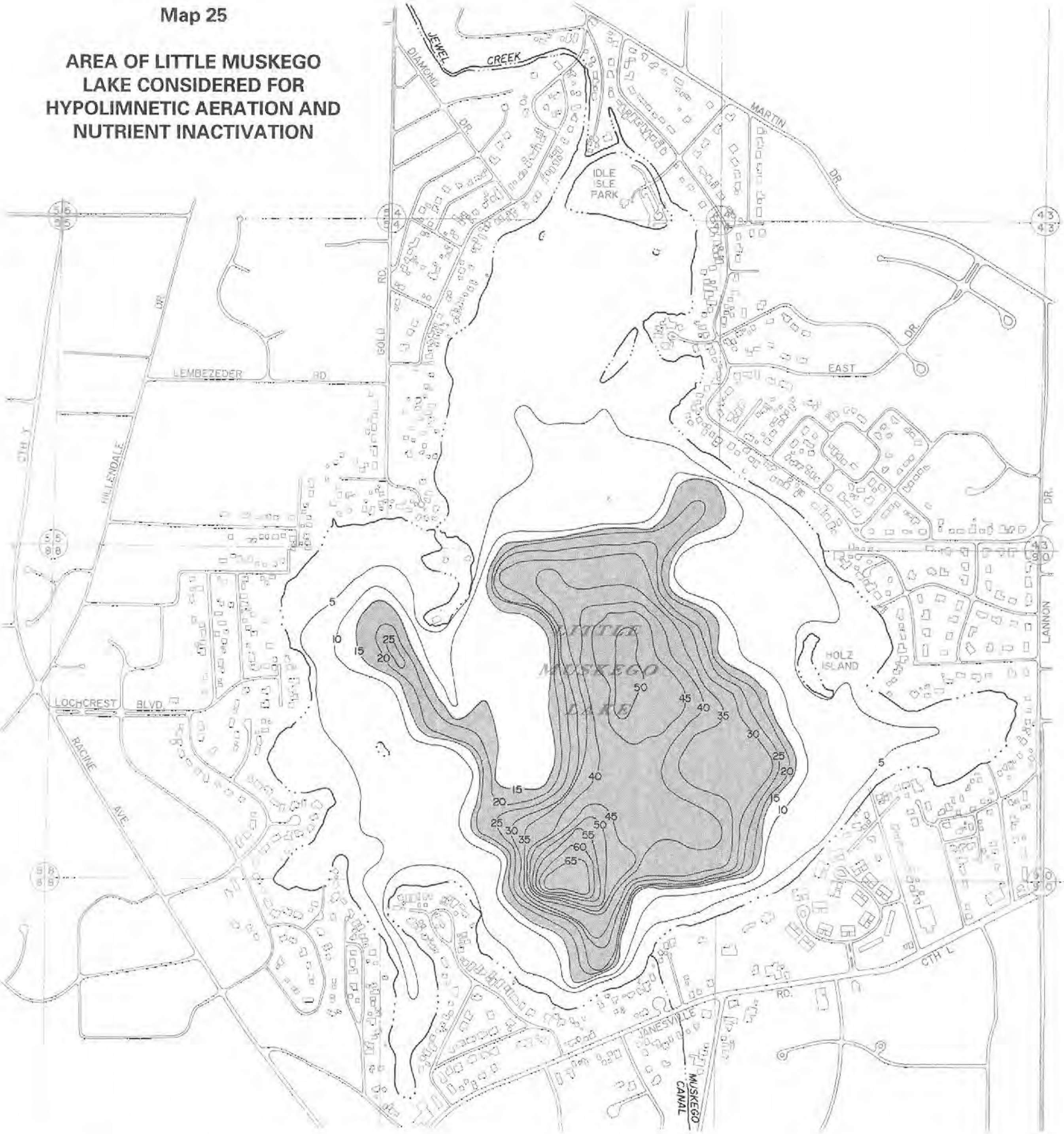
[8] *SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin—2000, Volume Two, Alternative Plans, 1979, pages 449-452.*

[9] *Aron & Associates, Linnie Lac, Waukesha County, Wisconsin, Planning Grant Findings, 1994.*

Map 25

AREA OF LITTLE MUSKEGO LAKE CONSIDERED FOR HYPOLIMNETIC AERATION AND NUTRIENT INACTIVATION



LEGEND

30 WATER DEPTH CONTOUR (DEPTH IN FEET)

AREA OF LAKE CONSIDERED FOR HYPOLIMNETIC AERATION AND NUTRIENT INACTIVATION

GRAPHIC SCALE

0 400 800 1200 FEET

Source: SEWRPC.

However, as stated in Chapter IV, the water quality of Little Muskego Lake is such that internal loading of phosphorus presently forms a relatively minor component, comprising less than 10 percent of the total phosphorus load to the Lake. Therefore, until the dominant external sources of the nutrient to the Lake are controlled by the watershed-based management practices set forth above, nutrient inactivation is not recommended for Little Muskego Lake.

Aeration and Destratification: Aeration, including hypolimnetic aeration and artificial circulation, is a management measure designed to partially or completely oxygenate the water column of a lake. Hypolimnetic aeration is the process of injecting oxygen into the water column, while artificial circulation is the process of destratifying and mixing the water column. The two processes are related in that compressed or pumped air is the medium used to inject oxygen or circulate the water. The principle applications of aeration in lake management include prevention of winter-kill of fish in shallow lakes and maintenance of a two-story fishery in deeper lakes.

Costs associated with the hardware required for an aeration system including piping and compressors, and operating costs tend to be high, ranging from $160 to $2,600 per acre per year. Effectiveness has been site and use dependent. Potential negative impacts include increased lake water temperatures—and more rapid heating and cooling, incidences of gas bubble disease in fish, and enhanced transfer of nutrients and algae throughout the water column. Algal growth may or may not be controlled depending on the species of algae present in the lake; generally, blue green algal blooms decrease in frequency while green algal and diatom growth may be stimulated.

To prevent the depletion of dissolved oxygen in the bottom waters of stratified lakes, mechanically induced circulation, or destratification, may be used.[10] Destratification of a lake eliminates the density differences in the water layers, thereby allowing for complete mixing of the well-oxygenated surface water with the oxygen-poor lower layers. Whole lake mixing may also reduce the rate of release of phosphorus from the sediments, while at the same time controlling some algal blooms by circulating the algae, such as blue green algae, out of the zone of light penetration. In addition to the possible decrease in algal biomass resulting from mixing-induced light limitation, destratification elevates epilimnetic carbon dioxide levels and may cause a sufficient drop in pH to shift dominance in the algal community from the nuisance blue-greens to a mixed assemblage of green algae and diatoms. This generally more edible plant resource, combined with an expansion of habitat, may lead to a more abundant zooplankton population consisting, in part, of large-bodied daphnids. Habitat expansion and shifts in community structure of benthic macroinvertebrates can also potentially increase the abundance and diversity of fish-food organisms. Surface water temperatures, which may be reduced by lake mixing, may allow for increased fish stocking.

An alternative to complete lake destratification would be hypolimnetic aeration, whereby oxygen is provided to the hypolimnion of a stratified lake without disrupting the stratification. The hypolimnion of Little Muskego Lake underlies about 132 acres, or about 26 percent of the lake surface area, as shown on Map 25. During part of the summer, the entire volume of water underlying this area has been found to be devoid of dissolved oxygen. Aeration of the hypolimnion increases the decomposition of organic matter and promotes sorption of phosphorus by the hydrous oxides of iron and manganese present in the lake bottom sediments. The result is that the concentration of phosphorus in the bottom waters may be substantially reduced and the oxygen levels and the habitat for fish and other aquatic life improved. Specifically, hypolimnetic aeration provides additional habitat for zooplankton, which can seek refuge from feeding fish during the day. These microcrustaceans then migrate towards the surface at night to graze on algae. Increased zooplankton grazing pressures can effectively reduce the numbers of certain species of algae.

Data from the U.S. Geological Survey presented in Chapter IV indicated that the operation of an aeration system in Little Muskego Lake during the periods of 1987 through 1991 was not successful in achieving the aforereferenced beneficial impacts. Water temperatures appeared to be higher and more constant throughout the water column during the period in which the aerator was operating. Algal growth, estimated by both chlorophyll-a and Secchi disc transparency, was increased and the water appeared more turbid. While much of the

[10]*Robert Pastorok, "Review of Aeration/Circulation for Lake Management," in U. S. Environmental Protection Agency, Restoration of Lakes and Inland Waters, EPA 440/5-81-010, 1981.*

hypolimnion was aerobic during the period of operation, the lower portion of the Lake still stratified, contributing to the continued sediment-water exchange of biologically-available phosphorus which was subsequently transported into the euphotic zone—or sunlit portion of the lake—where the nutrient stimulated algal growth.[11] A larger compressor and modified air delivery system, estimated at approximately double the capacity of the present system,[12] could potentially satisfy the total oxygen demand of the surfacial sediments, aerate the entire water column, and substantially reduce the internal phosphorus loading to the Lake; however, this would control less than 15 percent of the total nutrient load to the Lake as set forth in Chapter IV and would probably be subject ecological constraints, especially as they relate to fisheries management as discussed below.

While citizen perceptions varied, as reported in Chapter IV, evidence provided by the U.S. Geological Survey and the Wisconsin Department of Natural Resources would suggest that the fish species present in the Lake did not benefit from the added aerobic area of the water column. There may have been a reduced availability of prey organisms. These organisms, typically zooplankters, feed on algae which tend to accumulate at the thermocline or point in the water column where there is a significant change in temperature—and density—of the water. Removal of the thermocline as a result of aeration effectively dilutes the concentration of these organisms by providing a larger volume of water for the organisms to spread into and may, as has been noted, alter the species composition of the algae, which, in turn, affects their palatability and hence the grazing intensity exercised upon the algae by the zooplankton. The increased levels of chlorophyll observed during the period in which the aerator was operational might then reflect reduced zooplankton and fish predation as well as a species change and the effect of increased nutrient availability.

While it is unlikely that the effects of nonpoint source pollution control measures in the tributary drainage area to Little Muskego Lake will, for some years, if ever, substantially improve dissolved oxygen conditions in the hypolimnion, conditions are unlikely to deteriorate further. Thus, even though hypolimnetic aeration could be implemented before the control of nonpoint pollution sources in order to provide additional and more immediate improvement in the dissolved oxygen conditions in the bottom waters of the Lake, it would appear that the evidence to date does not support the use of an aeration system in Little Muskego Lake.

Nutrient Load Reduction: Nutrient diversion is a restoration measure which is designed to reduce the trophic state or degree of over-feeding of a waterbody and thereby control the growth response of the aquatic plants in the system. Control of nutrients in surface water runoff in the watershed is generally preferable to attempting such control within a lake. In-lake control of nutrients generally involves removal of sediments by dredging, encapsulation of nutrients by chemical binding, or creating an oxygen regime that limits the release of the contaminant. Hypolimnetic withdrawal or the removal of nutrient rich bottom waters from stratified lakes is a special case of flushing, while direct injection of nitrate into an anaerobic hypolimnion—the Riplox technique using a nitrogenous oxygen source—is a special case of aeration; both can also be used in reducing the internal nutrient supply to a lake.

Costs are generally high, involving an engineered design and usually some form of pumping or excavation. Effectiveness is variable. Potential negative impacts include the re-release of nutrients into the environment.

Water Level Management Measures

This group of in-lake management measures consists of actions designed to modify the depth of water in the waterbody. Generally, the objective of such manipulation is to enhance a particular class of recreational uses and/or to control the types and densities of organisms within a waterbody.

Drawdown: Water level management refers to a the manipulation of lake water levels, especially in

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[11]*R. E. Wedepohl, The Detrimental Effects on Water Quality Resulting from Aeration Induced, Partial Destratification at Little Muskego Lake, Wisconsin, poster paper presented to the North American Lake Management Society, November 1992.*

[12]*The detailed design of such a system, and further consideration of its positive and negative environmental impacts, is beyond the scope of this plan, but would be required for application for the Chapter 30, Stats., permit required for the installation and operation of such a system. Clean-Flo Laboratories, Inc., in litt., dated July 1, 1995, estimate the cost of the larger compressor and additional diffuser nozzles and piping at about $55,000, subject to development of a detailed plan.*

man-made lakes, in order to change or create specific types of habitat and thereby manage species composition within a waterbody. Water level management may be used to control aquatic plant growth and to manage fisheries. With regard to aquatic plant management, periodic drawdowns can reduce the growth of some shoreland plants by exposing the plants to climatic extremes, while the growth of others is unaffected or enhanced. Both desirable and undesirable plants are affected by such actions.

Costs are primarily associated with loss of use of the waterbody surface area during drawdown—provided there is a means of controlling water level in place, such as a dam or other outlet control structure. Effectiveness is variable, with the most significant side effect being the potential for increased plant growth. Drawdown can also affect lake fisheries both indirectly—by reducing the numbers of food organisms—and directly—by reducing available habitat and desiccating eggs and spawning habitat. In contrast, increasing water levels, especially during spring, can provide enhanced fish breeding habitat for some species such as pike and muskellunge, and increase the food supply for opportunistic feeders such as bass by providing access to terrestrial insects. Costs are primarily associated with loss of use. Effectiveness is better than for aquatic plant control, but the potential for side effects remains high given that undesirable fish species may also benefit from water level changes.

Sediment exposure and desiccation by means of lake drawdown has been used as a means of stabilizing bottom sediments, retarding nutrient release, reducing macrophyte growth, and reducing the volume of bottom sediments. During the period of drawdown, the exposed sediments are allowed to oxidize and consolidate. It is believed that by reducing the sediment oxygen demand and increasing the oxidation state of the surface layer of the sediments, drawdown may retard the subsequent movement of phosphorus from the sediments. Sediment exposure may also curb sediment nutrient release by physically stabilizing the upper flocculent (sediment-water interface) zone of the sediments which plays an important role in the exchange reaction and mixing of the sediments with the overlying water. Drawdown may thus deepen the lake by dewatering and compacting the bottom sediments. The amount of compaction depends upon the organic content of the sediment, the thickness of sediment exposed above the water table, and the timing and duration of the drawdown. Based on sediment types in Little Muskego Lake, it is estimated that a 30 to 50 percent reduction in volume of exposed sediments may be feasible.

Table 31

AQUATIC PLANTS CONTROLLED BY LAKE DRAWDOWN

Common Name	Scientific Name
Water Shield	Brasenia schreberi
Coontail	Ceratophyllum demersum
Stonewort	Chara sp.
Elodea	Elodea sp.
Milfoil	Myriophyllum sp.
American Lotus	Nelumbo lutea
Yellow Water Lily	Nuphar sp.
White Water Lily	Nymphaea odorata
White Water Lily	Nymphaea tuberosa
Clasping-Leaf Pondweed	Potamogeton robbinsii
Large-Leaf Pondweed	Potamogeton amplifolius
Swamp Fivefinger	Potentilla palustris
Arrowhead	Sagittaria heterophylla
Bladderwort	Utricularia vulgaris
Wild Celery	Vallisneria americana

Source: U. S. Environmental Protection Agency and SEWRPC.

Lake drawdown is an effective technique for the control of several nuisance macrophyte species. The objective is to retard macrophyte growth by destroying seeds and vegetative reproductive structures through exposure to drying or freezing conditions and by altering their substrate by dewatering and consolidating of sediments. Table 31 lists several species controlled by lake drawdown. This control generally lasts from one to two years. While drawdown can control the regrowth of several plants, it can also stimulate the growth of others, such as Bushy pondweed (Najas flexils), Flatstem pondweed (Potamogeton zosteriformis), and several sedges and shoreline species.

Possible improvements resulting from a lake drawdown include reduced turbidity from wind action, improved game fishing, an opportunity to collect fish more effectively in fish removal programs, an opportunity to improve docks and dams, and an opportunity to clean and repair shorelines and deepen areas using conventional earth-moving equipment. Depending on the timing and duration of the drawdown, drawbacks include loss of fish breeding habitat, loss of benthic food organisms, and disruption of waterfowl feeding and roosting patterns. Increased turbidity and unpleasant odors from rotting organic matter may occur during the period of the drawdown. Other adverse impacts of lake drawdown include algal blooms after reflooding, loss of use of the lake during the drawdown, changes in species composition, and a reduction in the density of benthic organisms following drawdown and reflooding. In some drawdown projects, it has been found that several years after reflooding, flocculent sediments began to reappear because of algae and macrophyte sedimentation. With the type of organic sediments in Little Muskego Lake, sedimentation of this type may take place. Therefore, to maintain the benefits of a drawdown project, the Lake may have to be drawn down every five to 10 years to recompact any new sediments.

The timing of a drawdown project is an important factor affecting the success of the project. Winter drawdowns have been employed successfully in several projects in Wisconsin.[13] The advantages of a winter drawdown are: 1) it would not interfere with summer boating, fishing, recreation, and irrigation activities, 2) the freezing and thawing of the sediments would facilitate dewatering, 3) the frozen sediment would provide a surface for access of earth-moving equipment, and 4) the freezing of the sediment would provide increased macrophyte mortality. The longer the sediments are exposed, the greater the benefit of the drawdown. Little Muskego Lake could be drained after Labor Day and left drained until March of the following year, allowing seven months of sediment exposure. With water from the spring snowmelt and spring rainstorms, the Lake would refill relatively quickly. The time for such filling to occur would have to be calculated using appropriate hydrologic analyses. A disadvantage of the over-winter drawdown is the increased potential for a fish winterkill due either to an oxygen deficit or to a whole lake freeze.

The water-control structure on Little Muskego Lake is a fixed-sill dam with an eight-foot head on the southern shore of the Lake. City officials have indicated that a drawdown of only between two and three feet could be obtained by opening the outlet control structure, which would not be enough to have an appreciable effect on reducing macrophyte growth. A total breaching of the dam would allow a drawdown of approximately eight feet, exposing about 60 percent of the lake bottom. Even this level of drawdown may not produce the amount of control that is desired. Added to this is the unpredictability of the results, the impairment of recreational uses, and the temporary nature of the beneficial effects of a drawdown. Thus, drawdown is not recommended for Little Muskego Lake.

Notwithstanding the foregoing, the present operating regime of the Little Muskego Lake dam includes an annual over-winter drawdown of approximately 1.5 feet. A drawdown of up to about 3 feet has been undertaken in recent years—1993-1995—to facilitate dredging and dam maintenance activities. This drawdown is undertaken for purposes of hydrological management—providing reserve hydraulic capacity in the impoundment to accommodate spring flood flows—and differs from that discussed above for this reason. While this operational strategy has some flood and erosion control benefits, adverse environmental consequences can result from 1) the retention of a significant proportion of the spring phosphorus and sediment loads to the Lake; 2) the erosional effects of ice-movement and water level changes on unprotected shorelines; and 3) the potential encouragement of undesirable aquatic plant species—such as cattail (Typha spp.) growth—that are generally viewed as obstructing lake access and recreational use of the Lake. It is recommended that the necessity for this practice be re-evaluated, and that consideration be given to discontinuing the practice on the basis of the strong likelihood of negative environmental consequences.

Dredging: Sediment removal is a restoration measure that carried out using a variety of techniques, both land-based and water-based, depending on the extent and nature of the sediment removal to be carried out. For large-scale applications, a barge-mounted hydraulic or cutter-head dredge is generally used, while for smaller-scale operations a mud-cat or drag-line bucket, shore-based system is typically employed. Both methods are expensive, especially if a suitable disposal site is not located close to the dredge site.

Costs may be expected to range from \$10 to \$15 per cubic yard, including disposal with sediment removal alone costing between \$3.00 and \$5.00 per cubic yard. Effectiveness varies with the effectiveness of watershed controls in reducing or minimizing the sediment source. Impacts relate to increased turbidity during the dredging operation, toxicity from dissolved constituents released from the lake sediments, and algal blooms. U. S. Army Corps of Engineers permits are required for use of this option.

[13]*Wisconsin Department of Natural Resources Technical Bulletin No. 75, Survey of Lake Rehabilitation Techniques and Experiences, 1974.*

Dredging is the only restoration technique that directly removes the accumulated products of degradation and sediment from a lake system and can return a lake to a younger "age." In the extreme, dredging can be used to construct a new lake on a site with a size and depth to suit the management objectives. Dredging has been used to increase water depth; remove toxic materials; decrease sediment oxygen demand, preventing fish winterkills and nutrient recycling; and decrease macrophyte growth. Because Little Muskego Lake is now 65 feet deep and does not experience winter dissolved oxygen problems, the main objective of a dredging program at Little Muskego Lake would be to reduce the size of the littoral zone, thereby reducing the areal extent of macrophyte growth. The theoretical maximum depth of macrophyte colonization in Little Muskego Lake, under present conditions of water clarity, is about nine feet. To reduce the extent of macrophyte growth, sections of the bottom would have to be deepened to 10 feet or more by dredging. Map 26 illustrates areas where possible future dredging may be needed in Little Muskego Lake. The solid shaded areas indicate maintenance dredging projects underway or permitted as of 1995.[14] A slope of four on one or less should be maintained to prevent slumping of the organic sediments and to ensure the safety of recreational users.

Dredging may have serious, though generally short-term, adverse effects on a lake. These adverse effects could include increased turbidity caused by sediment resuspension, oxygen depletion as organic sediments mix with the overlying water, water temperature alterations, and destruction of benthic habitats. There may also be impacts at upland disposal sites, such as odor problems, restricted use of the site, and disturbances associated with heavy truck traffic.

Dredging of lakebed material from navigable waters of the State requires a Wisconsin Department of Natural Resources Chapter 30.20 permit and a U. S. Army Corps of Engineers Chapter 404 permit. In addition, current solid waste disposal regulations define dredge material as a solid waste. Section NR 180.13 of the Wisconsin Administrative Code requires that any dredging project of over 3,000 cubic yards submit preliminary disposal plans to the Wisconsin Department of Natural Resources for review and potential solid waste licensing of the disposal site. Because of the large amounts of sodium arsenite that were applied to Little Muskego Lake in the 1950s and 1960s, as noted in Chapter V, sediment samples may need to be analyzed to determine the extent and severity of any residual arsenic contamination.

Dredging Little Muskego Lake could be accomplished with several different types of equipment, including a hydraulic cutterhead dredge mounted on a floating barge; or bulldozer and backhoe equipment if part of the Lake were drained; or a clamshell, or bucket, dragline dredge from the shoreline.

Hydraulic cutterhead dredging is the most commonly employed method in the United States. The dredge is typically a rotating auger or cutterhead on the end of a ladder that is lowered to the sediment-water interface. Sediment excavated by the cutterhead is pumped in a slurry of 10 to 20 percent solids by a centrifugal pump to the disposal site. This pumping usually limits the distance between the lake and disposal site to less than a mile, even using intermediate booster pumps. Because of the large volume of slurry produced, a relatively large disposal site would be required. Potential disposal sites are illustrated on Map 27. Water returned from the disposal site, whether returned to the lake or a stream, would have to meet effluent water quality standards of the State and would be subject to State permitting.

Draining the Lake and removing sediment with conventional earth-moving equipment has some advantages over hydraulic dredging since it would not require a large disposal or dewatering site in the immediate area. Draining is also more advantageous than dragline dredging because it would not require the removal of a large number of trees and would probably involve less disturbance of the shoreline to provide access for trucks and equipment. As noted above, a 36-inch lake drawdown has been used in recent years to provide an opportunity for the conduct of dredging and shoreline maintenance activities.

Shoreline dredging of Little Muskego Lake to remove and dispose of about 2,100,000 cubic yards of sediment would cost approximately $31.5 million. Although previously considered as a management option by the Wisconsin Department of

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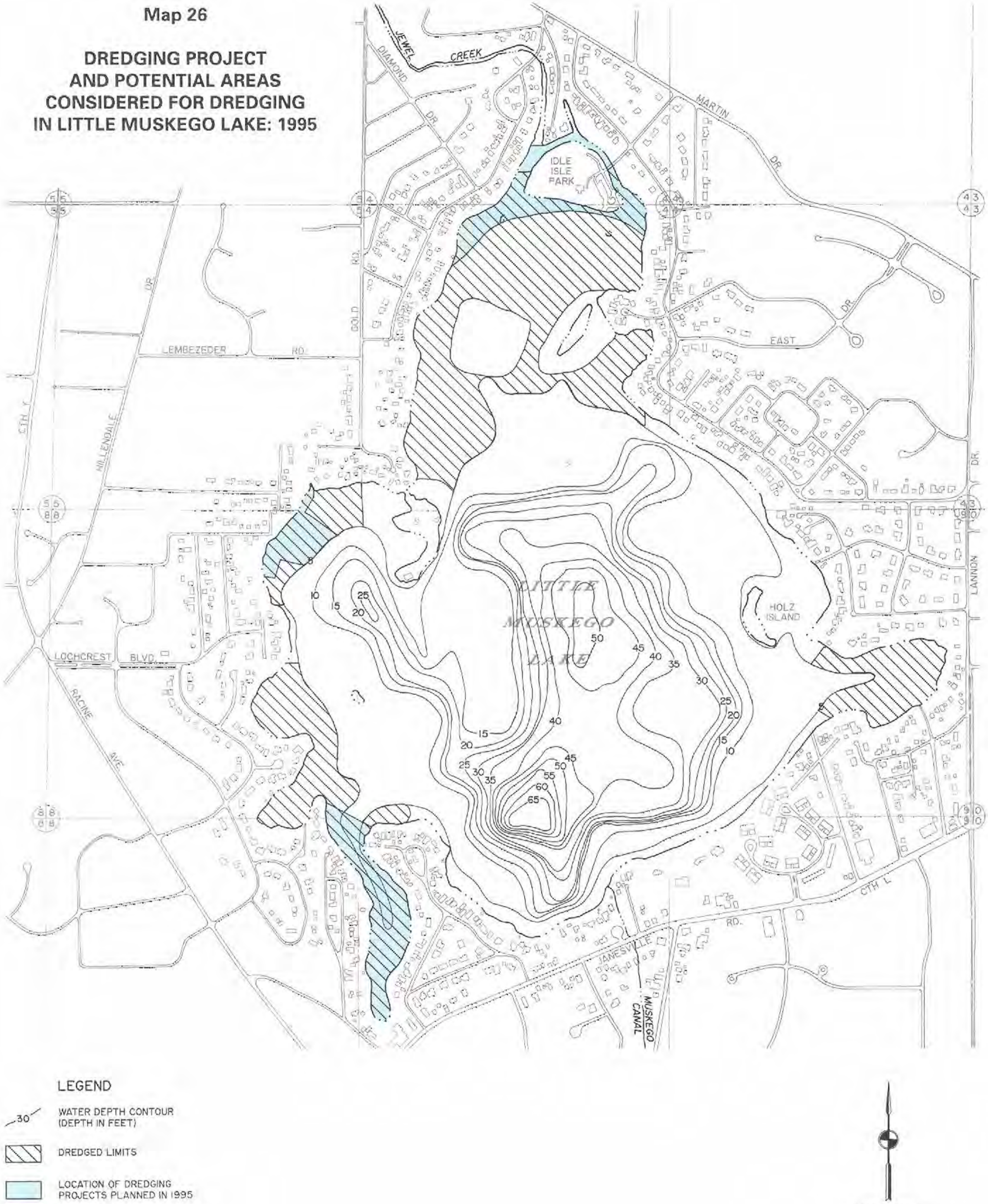
[14]*Little Muskego Lake Association, "Dredging Projects Begin,"* Lake Reflections, *January 1996.*

Map 26

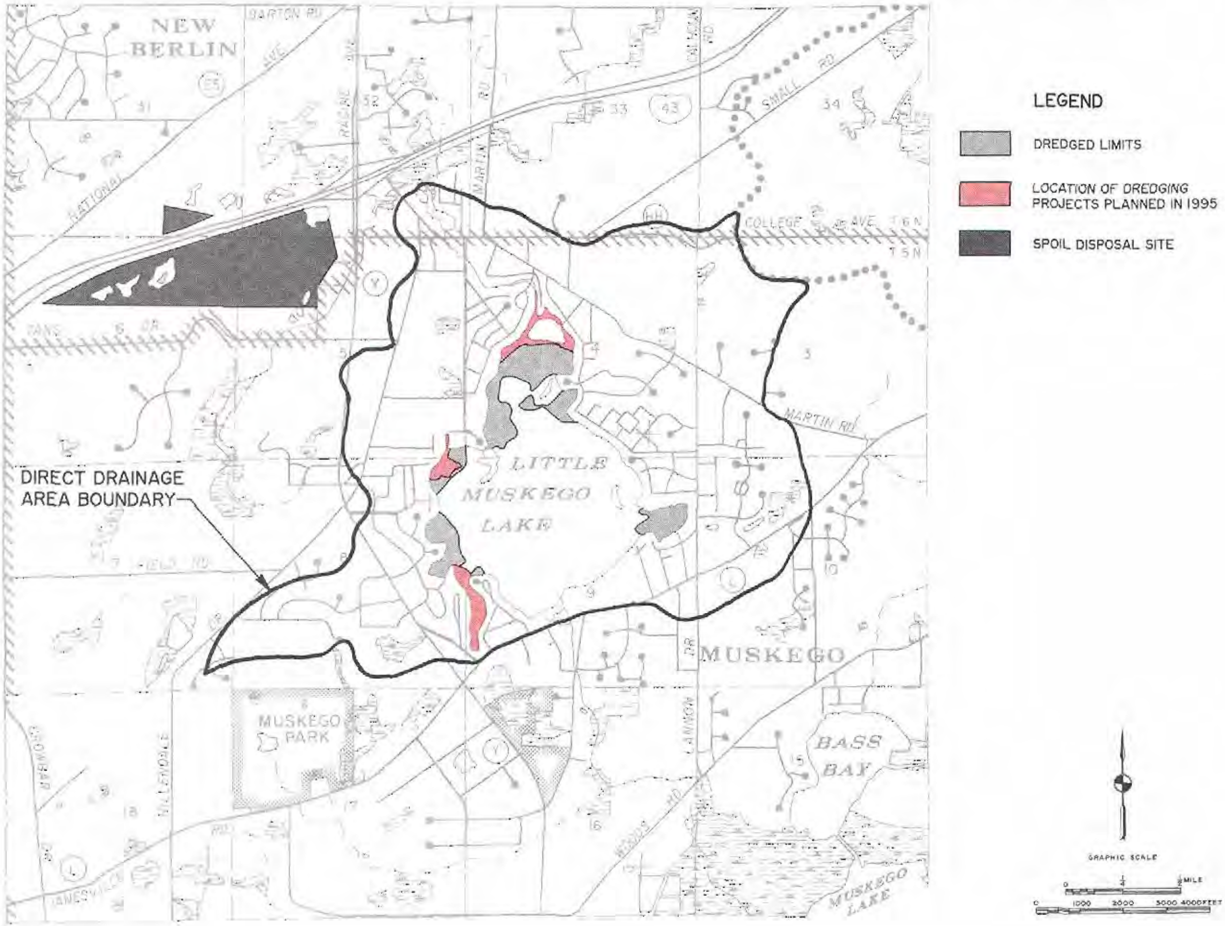
DREDGING PROJECT AND POTENTIAL AREAS CONSIDERED FOR DREDGING IN LITTLE MUSKEGO LAKE: 1995



Source: SEWRPC.

Map 27

LAKE AREAS CONSIDERED FOR SMALL-SCALE DREDGING PROJECTS AND POSSIBLE DREDGE SPOIL DISPOSAL SITES IN THE VICINITY OF LITTLE MUSKEGO LAKE



Source: SEWRPC.

Natural Resources,[15] the potential negative environmental effects of a large-scale lakewide dredging project and the high cost associated with dredge spoil disposal, indicates this option should be considered only on a limited basis for small-scale projects designed to improve hydraulic capacity or boating access, as shown on Map 26. The estimated cost of removing about 115,000 cubic yards of sediment at selected locations is about $1,000,000.[16]

<u>Aquatic Plant Management Measures</u>

Aquatic plant management refers to a group of management and restoration measures aimed at both removal of nuisance vegetation and manipulation of species composition in order to enhance and provide for recreational water use. Generally, aquatic plant management measures are classed into four groups: physical measures which include water level management and lake bottom covering; manual and mechanical removal measures which include harvesting and removal; chemical measures which include using aquatic herbicides; and biological controls which include the use of various organisms, including insects. Of these, physical, chemical, and biological measures are stringently regulated and require a State permit.

Costs range from minimal for manual removal of plants using rakes and hand-pulling to upwards

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[15]*Wisconsin Department of Natural Resources Environmental Impact Statement, <u>Proposed Little Muskego Lake Rehabilitation Project</u>, January 1980.*

[16]*Little Muskego Lake Association, "Five dredging projects to be completed in 1996," <u>Lake Reflections</u>, March 1996.*

of $75,000 for the purchase of a mechanical plant harvester—the operational costs for which can approach $10,000 to $20,000 per year depending on staffing and operating policies. Effectiveness is mixed. Harvesting is probably the measure best suited to large areas, while chemical controls may be best suited to use in confined areas and for initial control of invasive plants. Planting of native plant species is largely experimental in the Lake, but can be considered a specialized shoreland management zone at the water's edge. Physical controls and mechanical harvesting may have side effects in the expansion of plant habitat and the spread of reproductive vegetative fragments.

Aquatic Herbicides: Chemical treatment with aquatic herbicides is a short-term method of controlling heavy growths of aquatic macrophytes and algae. Chemicals are applied to the growing plants in either liquid or granular form. The advantages of using chemical herbicides to control aquatic macrophyte growth are the relatively low cost and the ease, speed, and convenience of application. However, the disadvantages associated with chemical control include the following:

1. Although the short-term, lethal effects of chemicals are relatively well known, potential long-term, sublethal effects, especially on fish, fish-food organisms, and humans, are relatively unknown.

2. The elimination of macrophytes eliminates their competition with algae for light and nutrients. Algal blooms may then develop unless steps are taken simultaneously to control the sources of nutrient input.

3. Since much of the dead plant materials is left to decay in the lake, nutrients contained in them are rapidly released into the water and fuel the growth of algae. The decomposition of the dead plant material also consumes dissolved oxygen and increases the potential for fish kills. Accretion of additional organic matter in the sediments as a result of decomposition also increases the organic content of the soils and predisposes the sediments toward reintroduction of other (or the same) nuisance plant species.

4. The elimination of macrophyte beds destroys important cover, food sources, and spawning areas for desirable fish species.

5. Adverse impacts on other aquatic organisms may be expected. At the concentrations used for macrophyte control, Diquat has been known to kill the zooplankton Daphnia and Hyalella, both important fish foods. Daphnia is the primary food for the young of nearly all fish species found in the Region's lakes.[17]

6. Areas must be treated again in the following season and weed beds may need to be treated more than once in a summer.

7. Many of the chemicals available are nonselective, often affecting nontarget, desirable species as well as the "weeds."

The advantages and disadvantages of chemical macrophyte control also apply to the chemical control of algae. Copper, the active ingredient in algicides, may accumulate in the bottom sediments, where excessive amounts are toxic to fish and benthic animals. Fortunately, copper is rapidly eliminated from human systems and few cases of copper sensitivity among humans are known.[18]

Costs of chemical treatments vary widely. Large, organized treatments are more efficient and tend to decrease unit costs for commercial applications compared to individual treatments. Other factors, such as the type of chemical used and the number of treatments needed, are also important. Estimated costs for lakes in Southeastern Wisconsin range from $240 to $480 per acre. Current treatment costs on Little Muskego Lake are approximately $8,000 per year. Chemical treatments must be permitted by the State under Chapter NR 107 of the Wisconsin Administrative Code. Because the demonstrated need to control aquatic plants in selected areas of Little Muskego Lake and the relatively low cost of chemical treatment and because current management decisions have indicated a need for some chemical treatment, chemical treatment is considered to be a viable management option to be considered further for Little Muskego Lake.

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[17] *P. A. Gilderhus, "Effects of Diquat on Bluegills and Their Food Organisms," The Progressive Fish-Culturist, Vol. 2, No. 9, 1967, pp. 67-74.*

[18] *J. A. Thornton, and W. Rast, "The Use of Copper and Copper Compounds as an Algicide," Copper Compounds Applications Handbook, H. W. Richardson, ed., Dekker, New York, 1997.*

Aquatic Plant Harvesting: Aquatic macrophytes are mechanically harvested with specialized equipment consisting of a cutting apparatus which cuts up to five feet below the water surface and a conveyor system which picks up the cut plants and hauls them to shore. Advantages of macrophyte harvesting include the following:

1. Harvesting removes the plants from the lake. The removal of this plant biomass decreases the rate of accumulation of organic sediment. A typical harvest of submerged macrophytes from eutrophic lakes in Southeastern Wisconsin can yield between 140 and 1,100 pounds of biomass per acre per year.[19]

2. Harvesting removes plant nutrients, including nitrogen and phosphorus, which would otherwise "refertilize" the lake as the plants decay. A typical harvest of submerged macrophytes from eutrophic lakes in Southeastern Wisconsin can remove between four and 34 pounds of nitrogen and 0.4 to 3.4 pounds of phosphorus per acre per year. In addition to the physical removal of nutrients, plant harvesting may reduce internal nutrient recycling. Several studies have shown that aquatic macrophytes can act as nutrient pumps, recycling nutrients from the bottom sediments into the water column. Ecosystem modeling results have indicated that a harvest of 50 percent of the macrophytes in Lake Wingra, Wisconsin, could reduce instantaneous phosphorus availability by about 30 percent, with a maximum reduction of 40 to 60 percent, depending on the season.[20]

3. Repeated macrophyte harvesting may reduce the regrowth of certain aquatic macrophytes. The regrowth of milfoil has been reported to have decreased as harvesting frequency was increased.[21]

4. Where dense growths of filamentous algae are closely associated with macrophyte stands, they may be harvested simultaneously.

5. The macrophyte stalks remaining after harvesting provide cover for fish and fish-food organisms, and stabilize the bottom sediment against wind erosion.

6. Selective macrophyte harvesting may reduce stunted populations of panfish in lakes where excessive cover has adversely influenced predator-prey relationships. By allowing an increase in predation on young panfish, both gamefish and the remaining panfish may show increased growth.[22]

7. The cut plant material can be used as mulch.

The disadvantages of macrophyte harvesting include the following:

1. Harvesting is most effective in water depths greater than two feet. Large harvesters cannot operate in shallow water or around docks and buoys.

2. The reduction in aquatic macrophytes by harvesting reduces their competition with algae for light and nutrients. Thus, algal blooms may develop.

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[19]*James E. Breck, Richard T. Prentki, and Orie L. Loucks, editors, Aquatic Plants, Lake Management, and Ecosystem Consequences of Lake Harvesting, Proceedings of Conference at Madison, Wisconsin, February 14-16, 1979.*

[20]*E. B. Welch, M. A. Perkins, K. Lynch, and P. Hufschmidt, "Internal Phosphorus Related to Rooted Macrophytes in a Shallow Lake," in James E. Breck et al., editors, 1979, pp. 81-99; G. B. Lie, "The Influence of Aquatic Macrophytes on the Chemical Cycles of the Littoral," op. cit., pp. 101-106; K. H. Landers, "Nutrient Release from Senescing Milfoil and Phytoplankton Response," op. cit., pp. 127-143; J.W. Barko and R.M. Smart, "The Role of Myriophyllum spicatum in the Mobilization of Sediment Phosphorus," op. cit., pp. 177-190; Orie L. Loucks and P. R. Weiler, "The Effects of Harvest Removal of Phosphorus on Remineralized P Sources in a Shallow Lake," op. cit., pp. 191-210.*

[21]*S. Nichols and G. Cottam, "Harvesting As A Control for Aquatic Plants," Water Resources Bulletin, Vol. 8, No. 6, December 1972, pp. 1,205-1,210; J. K. Neel, S. A. Peterson, and W. L. Smith, "Weed Harvest and Lake Nutrient Dynamics," EPA-660/3-73-001, 1973.*

[22]*James E. Breck, and J. F. Kitchell, "Effects of Macrophyte Harvesting on Simulated Predator-Prey Interactions," in James E. Breck et al., editors, 1979, pp. 211-228.*

3. Fish, especially young-of-the-year bluegills and largemouth bass, as well as fish-food organisms, are frequently caught in the harvester. As much as 5 percent of the juvenile fish population can be removed by harvesting. A Wisconsin Department of Natural Resources study found that four pounds of fish were removed per ton of plants harvested.[23]

4. The reduction in aquatic macrophyte biomass by harvesting or chemical control can reduce the diversity and productivity of macroinvertebrate fish-food organisms feeding on the epibiota.[24] Bluegills generally move into the shoreline area after sunset, where they consume these macroinvertebrates. After sunrise they migrate to open water, where they graze, primarily on zooplankton.[25] If harvesting or chemical control shifts the dominance of the littoral macroinvertebrate fauna to sediment dwellers, the macroinvertebrate component of the bluegill diet could be restricted. This would increase predation pressure on zooplankton and reduce the growth rate of the panfish; it could eventually lead to undesirable ramifications throughout the food web in a lake.

5. Macrophyte harvesting may influence the community structure of macrophytes by favoring such plants as milfoil (Myriophyllum sp.) that propagate from cut fractions. This may allow these plants to spread into new areas through the rerooting of the cut fractions.

6. The efficiency of macrophyte harvesting is greatly reduced around piers, rafts, and buoys because of the difficulty in maneuvering the harvesting equipment in those restricted areas. Manual methods have to be used in these areas.

7. High capital and labor costs are associated with harvesting programs. Macrophyte harvesting on Little Muskego Lake could be continued by the Little Muskego Lake Management District staff or be contracted to a private company. Based upon the number of acres cut in 1993, the estimated annual cost of harvesting by the District staff would be about $20,000; composed largely of staff costs and operating costs such as fuel, oil, and maintenance. The cost of a new replacement harvesting equipment, when needed, would be about $90,000.

A harvesting program should be designed to provide optimal benefits and minimal adverse impacts. Small fish are common in dense macrophyte beds, but larger fish, such as largemouth bass, do not utilize these dense beds.[26] Narrow channels may be harvested to provide navigational access and "cruising lanes" for predator fish to migrate into the macrophyte beds to feed on smaller fish. "Shared access" lanes may also be cut, allowing several residents to use the same lane. Increased use of these lanes should keep them open for longer periods than would be the case if a less directed harvesting program was followed. Because of the demonstrated need for control of aquatic plants in Little Muskego Lake and because the current lake management decisions have indicated a need for aquatic plant harvesting, harvesting is considered a viable management option to be considered further.

Manual Harvesting: Due to an inadequate depth of water it is not always possible for harvesters to reach the shoreline of every property. Another measure which could be considered is the purchase of a number of specially designed rakes which are designed specifically to manually remove aquatic plants from the shoreline area. The rakes could be made available for the riparian owners to use on a trial basis to test their operability before purchasing them. The advantage of the rake is that it is easy and quick to use, immediately removing the plants where as chemical treatment involves a waiting period. Using this method also removes the plants from the lake avoiding the accumulation of

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[23]*Wisconsin Department of Natural Resources, Environmental Assessment Aquatic Nuisance Control (NR 107) Program, 3rd Edition, 1990, 213 pp.*

[24]*James E. Breck, and J. F. Kitchell, "Effects of Macrophyte Harvesting on Simulated Predator-Prey Interactions," in James E. Breck et al., editors, 1979, pp. 211-228.*

[25]*Ibid.*

[26]*S. Nichols, "Mechanical and Habitat Manipulation for Aquatic Plant Management; A Review of Techniques," Wisconsin Department of Natural Resources Technical Bulletin No. 77, 1974.*

organic matter on the lake bottom adding to the nutrients which favor more plant growth. This method also gives the harvester more time to cover larger areas of the lake as maneuvering between the piers takes time and skill. In areas where mechanical harvesting is not practical, an option would be for shoreline cleanup crews to assist property owners.

Biological Controls: Another alternative approach to controlling nuisance weed conditions, in this particular case Eurasian water milfoil (EWM), is biological control. Classical biological control has been successfully used to control both weeds and herbivorous insects.[27] Recent documentation states that Euhrychiopsis lecontei, an aquatic weevil species, has the potential as a biological control agent for EWM. In 1989, the weevil was discovered during a study investigating a decline of EWM growth in a Vermont pond. Euhrychiopsis proved to have significant negative effects on EWM in the field and in the lab. The adult weevil feeds on the milfoil causing lesions which make the plant more susceptible to pathogens such as bacteria or fungi while the weevil larvae burrows in the stem of the plant causing enough tissue damage for the plant to lose buoyancy and collapse.[28] The few studies that have been done since that time have indicated the following potential advantages to use of this weevil as a means of EWM control:

1. Eurhychiopsis lecontei is known to cause fatal damage to the EWM plant and over a period of time has the potential to cause a decrease in the milfoil population.

2. Eurhychiopsis lecontei larvae are easy to produce.

3. Eurhychiopsis lecontei are not known to cause damage to existing native aquatic plants.

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[27]*C. B. Huffacker, D. L. Dahlsen, D. H. Janzen, and G. G. Kennedy, "Insect Influences in the Regulation of Plant Population and Communities," 1984, pp. 659-696; in C. B. Huffacker and R. L. Rabb, editors, Ecological Entomology, John Wiley, New York, New York, USA.*

[28]*Sally P. Sheldon, "The Potential for Biological Control of Eurasian Water Milfoil (Myriophyllum spicatum) 1990-1995 Final Report," Department of Biology Middlebury College, February 1995.*

The potential disadvantages of using Eurhychiopsis lecontei include:

1. The studies done on Euhrychiopsis are very recent and more tests are necessary to determine if there are significant adverse effects.

2. Since the upper portion of the EWM plant is preferred by the weevil, harvesting would have to be extremely limited or not used at all in conjunction with this type of aquatic plant management control.

Very few studies have been completed using Eurhychiopsis lecontei as a means of aquatic plant management control thus it is not practical to recommend this type of control on Little Muskego Lake at this time.

Lake Bottom Covering: Lake bottom covers and light screens provide limited control of rooted plants by creating a physical barrier which reduces or eliminates the sunlight available to the plants. They have been used to create swimming beaches on muddy shores, to improve the appearance of lakefront property, and to open channels for motorboating. Sand and gravel are usually readily available and relatively inexpensive to use as cover materials, but plants readily recolonize areas so covered in about a year. Synthetic material, such as polyethylene, polypropylene, fiberglass, and nylon, can provide relief from rooted plants for several years. The screens are flexible and can be anchored to the lakebed in spring or draped over plants in summer.

The advantages of bottom covers and screens are that control can be confined to specific areas, the covers and screens are usually unobtrusive and create no disturbance on shore, and the covers are relatively easy to install over small areas. The disadvantages of bottom covers and screens are that they do not reduce eutrophication of the lake, they are expensive, they are difficult to spread and anchor over large areas or obstructions, they can slip on steep grades or float to the surface after trapping gases beneath them, and they may be difficult to remove or relocate.

Screens and covers should not be used in areas of strong surfs, heavy angling, or shallow waters where motorboating occurs. They should also not be used where aquatic vegetation is desired for fish and wildlife habitat. To minimize interference with fish spawning, screens should be placed before or after spawning. A permit from the Wisconsin

Department of Natural Resources is required for use of sediment covers and light screens. Permits require inspection by the Department staff during the first two years, with subsequent permits issued for three-year periods.

The estimated cost of lake bottom covers that would control plant growth along a typical shoreline property, an area of about 700 square feet, ranges from $40 for burlap to $220 for aquascreen. Because of the limitations involved, lake bottom covers as a method to control aquatic plant growth are not recommended for Little Muskego Lake.

Public Information: Aquatic plant management usually centers on the eradication of nuisance aquatic plants for the improvement of recreational lake use. The majority of the public view all aquatic plants as "weeds" and residents often spend considerable time and money removing desirable plant species from a lake without considering their environmental impacts. Thus, public information is an important component of an aquatic plant management program and should include information and education on:

1. The types of aquatic plants in Little Muskego Lake and their value to water quality, fish, and wildlife.

2. The preservation of existing stands of desirable plant species.

3. The identification of nuisance species and the methods of preventing their spread.

4. Alternative methods for controlling existing nuisance plants including the positive and negative aspects of each method.

An organized aquatic plant identification and education day is one method of providing hands-on education to lake residents. Other sources of information and technical assistance include the Wisconsin Department of Natural Resources and the University of Wisconsin-Extension Service. The aquatic plant species list provided in Chapter V may serve as a checklist for individuals interested in identifying the plants near their residences. Residents can observe and record changes in the abundance and types of plants in their part of a lake on an annual basis.

Of the submerged floating and free-floating aquatic plant species found in Little Muskego Lake, Eurasian water milfoil is one of the few species likely to cause lake-use problems. As discussed in Chapter V, milfoil, like most aquatic plants, can reproduce from fragments and often forms dense beds. Residents should be encouraged to collect fragments that wash ashore after storms, from weekend boat traffic, and after harvesting. The plant fragments can be used as mulch on flower gardens or ornamental planting areas.

Milfoil and other aquatic plants can be transported between lakes as fragments on boats and boat trailers. To prevent unwanted introductions of plants into lakes, boaters should remove all plant fragments from their boats and trailers when exiting the lake. Providing the opportunity for the removal of plant fragments at the boat landing on Little Muskego Lake will remind boaters of this measure. Posters and pamphlets are available from the Wisconsin Department of Natural Resources and University of Wisconsin-Extension that provide information and illustrations of milfoil, discuss the importance of removing plant fragments from boats, and remind boaters of their duty in this regard.

Fish Management Measures

Little Muskego Lake provides a quality habitat for a healthy, warmwater fishery. Adequate water quality, dissolved oxygen levels, sand and gravel shorelines, and a moderate and diverse plant community contribute to the maintenance of a fish population that is dominated by desirable sport fish. Winterkills and the presence of rough fish are not problems.

Habitat Protection: Habitat protection refers to a range of conservation measures designed to maintain existing fish spawning habitat, including measures such as restricting recreational and other intrusions into gravel-bottomed shoreline areas during the spawning season—for bass this is spring, mid-April to mid-June. Use of natural vegetation in shoreland management zones and other "soft" shoreline protection options aid in habitat protection. Costs are generally low unless the habitat is already degraded. Ordinance modification might be required to impose boating restrictions or similar constraints on recreational use. Effectiveness is variable depending in part on community acceptance and enforcement. Generally, it is more effective to maintain a good habitat than to restore habitat after it is degraded.

Loss of habitat should be a primary concern of any fish management program. The environmentally valuable areas identified in Chapter V are the most important areas to be protected. Limiting or restricting power boats in these areas will prevent significant disturbance of fish nests and aquatic plant beds. Aquatic plant control should be avoided in these areas. Dredging, filling, and the construction of piers and docks should be discouraged in these areas.

Water level fluctuations can also alter fish habitat. The potential effects of any proposed perturbations in water levels on the fishery should be well-studied before considering implementation. Finally, the importance of maintaining good water quality cannot be overemphasized as a fish habitat protection measure. Because all of these alternatives are preventive in nature, no cost is associated with them.

Habitat Creation: In lakes where vegetation is lacking or where plant species diversity is low, artificial habitat may need to be developed. Northern pike artificial spawning habitat can be created by impounding small streams entering the lake.[29] Such impoundments usually have extensive shallows and marshy habitats that are prime northern pike habitat. Artificial walleyed pike spawning beds have been constructed from rocks and boulders, but the success has varied among lakes. In lakes that lack a healthy and diverse native aquatic plant community, transplant experiments have also been attempted to increase the available fish habitat.[30] As discussed in Chapter V, the results of the aquatic plant surveys of Little Muskego Lake indicate that there is insufficient habitat for a healthy fish community. Therefore, habitat creation programs are recommended for Little Muskego Lake.

Spawning habitat improvement and creation refers to a range of restoration measures designed to repair, replace or create additional habitat areas for fish in a lake. Where protection measures have not worked or have proven inadequate, improvement or creation of additional habitat may be warranted. Techniques to be considered include interception and diversion—see above—especially of turbid waters, shoreland management zones—see above, and flushing gravel beds or underwater springs to keep these areas free of silt prior to the spawning season. Water level control with reference to the fishery is also a recommended practice for spawning habitat improvement. In contrast, artificially creating spawning habitat by constructing rock reefs and gravel beds at depths of 1.5 to four feet for walleye spawning has been undertaken. In such cases, provision of additional structures for protection of juvenile fishes is usually a concurrent activity. Brush piles, cribs, stake beds, pipe pyramids and rubble piles can provide necessary cover and habitat for food organisms. Costs are generally modest. Effectiveness has been demonstrated but not well documented. Impacts are few, if any. State permits may be needed to employ this measure.

Modification of Species Composition: Species composition management refers to a group of conservation and restoration measures which include selective harvesting of undesirable fish species and stocking of desirable species designed to enhance the angling resource value of a lake. These measures include water level manipulation both to aid in the breeding of desirable species—for example, increasing water levels in spring to provide additional breeding habitat for pike—and to disadvantage undesirable species—for example, drawing a lake down to concentrate forage fish and increase predation success and also to strand juveniles and desiccate the eggs of undesirable species. Costs, as with water level management above, are primarily associated with loss of use; effectiveness is good but by no means certain; and side effects include collateral damage to desirable fish populations.

More extreme measures include fisherees, such as the annual Little Muskego Lake Carp-Out, that place a bounty on undesirable species—a means of increasing angling pressure, or selective cropping, of certain fishes, poisoning, and enhancement of predation by stocking. In lakes with an unbalanced fishery, dominated by carp and other rough fish, chemical eradication has been used to manage the fishery. The fish toxicant Rotenone is used to eradicate the existing fish population with the desired predator fish and panfish reintroduced. Lake drawdown is often used along with the chemical treatment. Drawdown will expose spawning areas and eggs and concentrate fish in shallow pools, thereby increasing their availability to anglers, commercial harvesters, or chemical

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[29]*G. C. Becker, Fishes of Wisconsin, The University of Wisconsin Press, Madison, Wisconsin, 1983.*

[30]*D. H. Les, G. Guntenspergen, J. Keough, and F. Stearns, "Feasibility of Increasing Native Aquatic Macrophytes in Lac La Belle and Okauchee Lakes, Wisconsin: Final Report on 1987 Field Study," unpublished report to the Wisconsin Department of Natural Resources, January 1988.*

eradication treatments. The newly created habitat will also benefit desired gamefish populations. Fish barriers are usually used to prevent reintroduction of undesirable species from up- or downstream. Chemical eradication is a drastic, costly measure and the end result may be highly unpredictable, although effectiveness is generally good. The estimated cost of a Rotenone treatment of Little Muskego Lake exceeds $50,000; most of this cost being for the chemical itself. Because the rough fish are not currently abundant, such extreme measures are not recommended for Little Muskego Lake where the fisheries value of the resource has been assessed as good to excellent.

The more common management measure is stocking of game fishes, with the mixture of species being determined by the stocking objectives, usually supplementing an existing population, maintaining a population that cannot reproduce itself, adding a new species to a vacant niche in the food web, replacing species lost due to a natural or human-made disaster, or establishing a fish population in a depopulated lake. Costs vary with species stocked and their relative availability, the numbers to be stocked and their year class or age, and the location and timing of the stocking. Effectiveness is variable, depending on the aforementioned factors, but can be good for many species. Impacts on other parts of the fish community are possible, especially if nonnative fish species are stocked, and other stresses may be imposed by an altered species composition or population structure.

Fish stocking is a management method used to supplement naturally reproducing species or to maintain populations of species with poor natural reproduction. Stocking of sport fish encourages angler use of a lake and can be used to maintain a balanced predator-prey relationship. Proper stocking of fish requires a thorough understanding of the existing fish population. Predator fish should not normally be stocked to control a panfish population that is already stunted. Once panfish become so abundant that the population is stunted, the number of predators required to control them is probably higher than the capacity of the lake in question for predators.[31] Overstocking or stocking when native predators are already present in adequate numbers may result in one or more of the following problems: 1) competition of stocked fish and native fish may force stocked fish out of a lake and into adjacent water bodies where their presence may be undesirable, 2) overcrowded fish populations may be more susceptible to bacterial, viral, and parasitic infections, and 3) overstocking may have an unfavorable effect on angling success.[32]

In Little Muskego Lake, stocking of northern and walleyed pike by the Wisconsin Department of Natural Resources is recommended to supplement the existing game fish populations. This may help prevent a stunted panfish population. Largemouth and smallmouth bass stocking is not normally needed where habitat conditions are favorable and is seldom successful where they are not.[33] The estimated annual cost of walleyed pike stocking is about $10,000, and of northern pike stocking is $1,600, based on current stocking programs.

Regulations and Public Information: To reduce the risk of overharvest, the Wisconsin Department of Natural Resources has placed restrictions on the number and size of certain fish species caught by anglers. The open season, size limits, and bag limits for the fish species of Little Muskego Lake are given in Table 32. These limits, together with the restoration of the thermocline following cessation of aeration, is thought to be primarily responsible for the resurgence in the Little Muskego Lake fishery. Enforcement of these regulations is critical to the success of any sound fish management program.

Shoreline Maintenance

Shoreline erosion was evident at scattered locations around Little Muskego Lake, although no serious problems were identified. Such erosion has been reported to be occurring since the turn of the century, and has been a notable feature of the Little Muskego Lake shoreline for many years. This phenomenon resulted in the armoring of the shore with stone before 1910 and is the basis for the almost completely armored shoreline of today. Shoreline erosion not only interferes with such activities as swimming, but also results in the retreat of the land by sloughing into the Lake, as much as one foot per year in some areas, and in the

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[31] *H. Snow, "Effects of Stocking Northern Pike in Murphy Flowage, Wisconsin," Wisconsin Department of Natural Resources Technical Bulletin No. 50, 1974, 25 pp.*

[32] *G. C. Becker, Fishes of Wisconsin, The University of Wisconsin Press, Madison, Wisconsin, 1983.*

[33] *Wisconsin Department of Natural Resources, Fish and Wildlife Comprehensive Plan, 1979.*

Table 32

1996-1997 OPEN SEASON, SIZE LIMITS, AND BAG LIMITS FOR FISH SPECIES IN LITTLE MUSKEGO LAKE

Species	Open Season	Daily Limit	Minimum Size
Northern Pike	May 4 to March 1	2	26 inches
Walleyed Pike	May 4 to March 1	5	15 inches
Largemouth Bass	May 4 to March 1	5	14 inches
Bluegill, Pumpkinseed (Sunfish), Crappie, and Yellow Perch	Open all year	50 in total	None
Bullhead	Open all year	None	None
Rough Fish	Open all year	None	None

[a]*The limits and sizes set forth in this table are for Little Muskego Lake. Daily limits and minimum sizes vary between lakes.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

deposition of sediment and nutrients into the Lake itself, which contributes to the formation of bottom sediments suitable for supporting excessive aquatic plant growth. It is estimated that, in an average year, 10 to 40 pounds of phosphorus, or about one percent of the total urban load from the study area, are contributed to Little Muskego Lake from shoreline erosion. This erosion may be attributed to the following factors:

1. Maintenance of lawns to the lake edge can increase the rate of shoreline erosion. The shallow root system of lawn grass fails to bind the soil in place sufficiently and allows undercutting and the filtering of sediment particles through the unstable shore slopes into the water. The lack of vegetation at the waterline serves as an indicator of active erosion.

2. Wave action is the primary direct cause of shoreline erosion when a lake is not ice-covered. Shoreline erosion by wave action is most evident along the eastern shoreline of lakes within Southeastern Wisconsin because of prevailing westerly winds. The waves undercut the exposed shoreline slopes, resulting in sloughing of the shore into the lake.

3. High lake levels may increase the shoreline erosion by exposing higher areas to direct wave action and by saturating normally unsaturated shoreline soils, thereby reducing the adhesiveness of the soil particles.

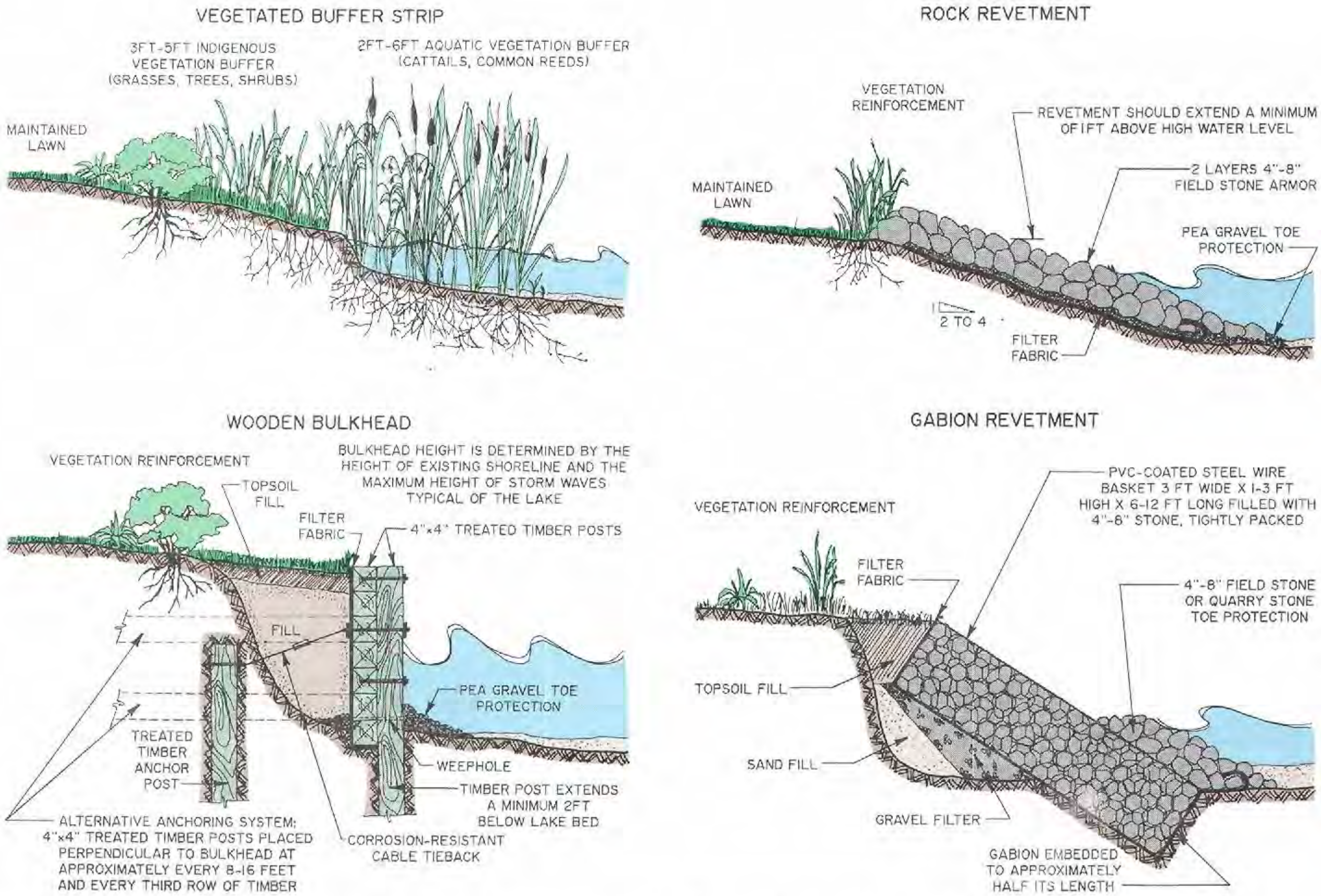
4. Ice action may be the single most important cause of shoreline erosion on Little Muskego Lake. Little Muskego Lake is normally covered by ice from about early December to late March. During this time, thermal expansion of the ice may force a layer of ice up onto the shore, while during spring breakup, windblown floating ice blocks and fragments can be forced onto the shore. Under high lake level conditions, freeze-thaw phenomena may also weaken submerged shore slopes. Together these ice-related activities physically scour the shoreline and prevent the establishment of a stable vegetative cover.

Four alternative shoreline erosion control techniques were considered: vegetative buffer strips, rock revetments, wooden bulkheads, and gabions. These alternatives considered were selected because they can be constructed, at least partially, by local residents; because most of the construction materials involved are readily available; because the technique would, in most cases, enable the continued use of the immediate shoreline; and because the measures are visually "natural" or "semi-natural" and should not significantly affect the aesthetic qualities of the lake shoreline.

The simplest, least costly, and most natural method of reducing shoreline erosion is the provision of a vegetative buffer strip immediately adjacent to the lake (Figure 11). This technique employs natural vegetation, rather than maintained lawns, within five to 10 feet of the lakeshore or the estab-

Figure 11

PLAN ALTERNATIVES FOR SHORELINE EROSION CONTROL



NOTE: Design specifications shown herein are for typical structures. The detailed design of shore protection measures must be based on detailed analysis of local conditions.

Source: SEWRPC.

lishment of emergent aquatic vegetation from two to six feet lakeward of the eroding shoreline. Aquatic species, such as cattails (Typha spp.) and common reed (Phragmites communis), may be suitable in the littoral areas along the eroding shores. Taller grasses invaded initially by weeds, and later by other species of grasses, forbs, and shrubs, should be encouraged on the shoreline. Some transplanting or seeding with carefully chosen indigenous plant types can decrease the time of this succession of plant species. Desirable plant species which may be expected and encouraged to invade the buffer strip, or which could be planted, include arrowhead (Sagittaria latifolia), cattail (Typha spp.), common reed (Phragmites communis), water plantain (Alisma plantago-aquatica), bur-reed (Sparganium eurycarpum), and blue flag (Iris versicolor) in the wetter areas; and jewelweed (Impatiens biflora), elderberry (Sambucus canadensis), giant goldenrod (Solidago gigantea), marsh aster (Aster simplex), red-stem aster (Aster puniceus), and white cedar (Thuja occidentalis) in the drier areas. In addition, trees and shrubs such as silver maple (Acer saccharinum), American elm (Ulmus americana), black willow (Salix nigra), and red-osier dogwood (Cornus stolonifera) could become established. These plants will develop a more extensive root system than the lawn grass and the above-ground portion of the plants will protect the soil against the erosive forces of rainfall and wave action. A narrow path to the lake can still be maintained as lake access for boating, swimming, fishing, and other activities. A vegetative buffer strip would also serve to trap nutrients and sediments washing into the lake via direct overland flow. This alternative would involve only minimal cost.

Rock revetments, or rip-rap, are a highly effective method of shoreline erosion control applicable to many types of erosion problems, especially in areas of low banks and shallow water. Some of these structures are already in place at Little Muskego Lake (see Map 3). The technique, as shown in Figure 11, involves the shaping of the shoreline slope, the placement of a porous filter material, such as sand, gravel, or pebbles, on the slope and the placement of rocks on top of the filter material to protect the slope against the actions of waves and ice. The advantages of a rock revetment are that the structure is highly flexible and not readily weakened by movements caused by settling or ice expansion, it can be constructed in stages, and it requires little or no maintenance. The disadvantages of a rock revetment are that it limits the use of the immediate shoreline in that the rough, irregular rock surfaces are unsuitable for walking; a relatively large amount of filter material and rocks needs to be transported to the lakeshore; and excavation and shaping of the shore slope may cause temporary disruptions and contribute sediment to the lake. Even if properly constructed, the revetment may fail because of washout of the filter material. A rock revetment constructed along a 300 foot shoreline by a private contractor would involve a total capital cost of about $7,500, or about $25 per linear foot. By providing labor and some materials, Little Muskego Lake residents could reduce this cost by up to 50 percent.

Wooden bulkheads, as shown in Figure 11, prevent the sliding of land or slope failure and provide protection against wave action and, to a lesser extent, ice action. A series of horizontal boards are bolted to a series of vertical posts sunk into the soil at the waterline. Alternatively, a close-set series of vertical poles three to six inches in diameter can be erected. A stone toe is usually provided on the lakeward side to protect against undercutting. A sunken cable tieback to an anchored "deadman" may be used to prevent the bulkhead from slipping towards the lake. Advantages of a wooden bulkhead are that it provides substantial protection and maintains the shoreline in a fixed position and that the materials are readily available. Bulkheads, depending on their type, may be considered less visually appealing than rock revetments; are less flexible and more susceptible to ice damage; and are considerably more difficult and expensive to repair than a rock revetment. A wooden bulkhead installed by a private contractor would involve a total capital cost of about $2,200, or about $7.50 per linear foot. As with rock revetments, the provision of labor and some materials by local residents could substantially reduce this cost.

A gabion is a steel wire-mesh basket filled with rock. Gabions are commercially available in a variety of sizes and are constructed and filled with rocks at the site of placement. A single gabion three feet high and three feet wide, sunk into the soil to about one-half its height, as shown in Figure 11, may be expected to protect the shoreline of Little Muskego Lake adequately. An underlying filter cloth prevents the erosion of finer particles below and behind the gabion, which could cause excessive movement and settling of the gabion. A rock toe may also be provided to prevent undercutting. The advantages of gabions are that they are flexible, relatively easy to construct, and are effective against ice movement. Gabions often become covered with vegetation, which adds to their visual appeal. The disadvantages of gabions are their relatively high cost, the potential for damage and breakage of the wire mesh basket, and the considerable excavation needed to implant them. Gabions installed by a private contractor along a 300-foot shoreline would cost about $10,800, or about $36 per linear foot. If labor and some materials could be provided by local residents, this cost could be substantially reduced.

Currently, about 28 percent of the shoreline of Little Muskego Lake is protected by some type of structural measure as shown on Map 3. Because of the extent of the system of shoreline armor already in place at Little Muskego Lake, armoring additional portions of unprotected shoreline in the main basin of the Lake would appear to be a viable option. If additional shore protection is installed, it is recommended that consideration be given to the visual aesthetics of blending various types of construction along the shore. This will not only enhance the visual appeal of the shoreline but minimize the edge effects that can occur as the result of two dissimilar abutting styles of construction. These boundaries can become points of weakness, susceptible to undercutting, overtopping or back erosion, which could undermine both sets of abutting structures. Vegetative buffer strips may be highly desirable in this lake.

Recreational Use Management and Environmentally Sensitive Area Protection

Measures are available to control lake and lake shoreland use. On land, shoreland zoning, requiring set backs and shoreland buffers can protect and preserve views both from the water and from the land, control development around a lake to minimize its environmental impacts and manage public and private access to a waterbody. On water, recreational use zoning can provide for safe and multi-purpose use of waterbody by various groups of lake users and protect environmentally sensitive areas in a lake. Use zoning can also take the form of allocating times of use, such as the annual fishing season established by the state. A key issue in zoning a waterbody for use is equity; the same rules must apply to both riparian owners and off-lake users. This condition is usually met in situations where use zoning is motivated by the protection of fish habitat, for example, as both on- and off-lake users would have use of an enhanced fishery. Costs are relatively low—associated with creating and posting the ordinance—and effectiveness can be good with regular and consistent enforcement. Costs increase for measures requiring bouyage.

Restrictive boating ordinances, that limit the time and area of use and the velocity of the boating traffic, in use on Little Muskego Lake to protect such recreational opportunities and a water safety patrol is operated by the City of Muskego Police Department. These same restrictions could be used to protect sensitive fish breeding areas or aquatic plant beds. Jet skiing and water skiing should be restricted to the northern portions of the main basin of Little Muskego Lake as part of zoning recreational use.

Public Information and Education Programs

Educational and informational brochures and pamphlets, of interest to homeowners and supportive of the recreational use and shoreland zoning regulations, are available from the University of Wisconsin-Extension and the Wisconsin Department of Natural Resources. These cover topics such as beneficial lawn care practices and household chemical use guidelines. These brochures could be provided to homeowners through local media, direct distribution or targeted library or civic center displays. The annual Community Festival, for example, could include a nature or environmental component similar to the historic tours offered during previous events. Such interventions could also rekindle public interest in the activities of the Little Muskego Lake Management District and Little Muskego Lake Association, Inc. Many of the foregoing ideas can be integrated into ongoing, larger-scale municipal activities, such as lakeside litter collections, which can reinforce anti-littering campaigns, recycling drives and similar pro-environment activities.

Finally, the participation of Little Muskego Lake in the Wisconsin Department of Natural Resources volunteer "Self-Help Monitoring" program, which involves citizens in taking Secchi disk transparency readings in the Lake at regular intervals, should be continued. Data gathered as part of this program should be presented by the volunteer at the annual meeting of the Lake District, where the citizen-monitors could be given some recognition for their work. The Lake Coordinator of the Wisconsin Department of Natural Resources Southeast District could assist in enlisting more volunteers in this program. The information gained at first hand by the public during participation in this program increases the credibility of the proposed changes in the nature and intensity of use to which the Lake is subjected.

SUMMARY

This chapter has described options that could be employed in managing the types of problems found to occur in Little Muskego Lake and which could, singly or in combination, assist in achieving and maintaining the water quality objectives set forth in Chapter VI. Selected characteristics of these measures are summarized in Table 33.

An evaluation of the potential management measures was carried out on the basis of the effectiveness of the measure for improving the Little Muskego Lake water quality and recreational use and on the basis of cost and technical feasibility of the measure. Those alternative measures eliminated from further consideration were: flushing and dilution, aeration and destratification, nutrient inactivation, drawdown, and bottom covering. The remaining measures are considered further for incorporation in the recommended lake management plan described in Chapter VIII.

Table 33

SELECTED CHARACTERISTICS OF ALTERNATIVE LAKE MANAGEMENT MEASURES FOR LITTLE MUSKEGO LAKE

Alternative Measure	Description	Estimated Costs: Capital	Estimated Costs: Operation and Maintenance	Considered Viable for Inclusion in Recommended Lake Management Plan
Sanitary Sewer Service	Provision of public sanitary sewerage system	- -	- -	Yes
Rural Nonpoint Source Pollutant Control	Conservation tillage, contour farming, contour strip cropping, crop rotation, grassed waterways, and pasture and streambank management	- -	- -	Yes
Urban Nonpoint Source Pollutant Control	Street cleaning	$ 120,000	$25 per mile; $25,000[a]	Yes
	Detention and infiltration basins	535,000[a]	Variable; $35,000[a]	Yes
Construction Erosion Control	Soil stabilization, surface roughening	$250 per acre	$250 per acre	Yes
Dilution-Flushing	Reduce contaminant concentrations in Lake	- -	- -	No
Nutrient-Toxicant Inactivation	Alum treatment	- -	$72,000	No
Aeration	Circulation of water column	$ 300,000	$160 to $2,600 per acre	No
Water Level Management	Drawdown	- -	- -	No
	Dredging	$1,000,000[b]	- -	Yes
Aquatic Plant Management	Herbicides	- -	$8,000	Yes
	Harvesting	$ 90,000	$20,000	Yes
	Sediment covering	- -	$40 to $220 per 700 square feet	- -
Fish Management	Habitat protection and shoreline maintenance	$7.50 to $36 per linear foot	- -	Yes
	Habitat creation	- -	- -	Yes
	Stocking	- -	$0.70 to $0.75 per fish	Yes
Recreational Use Zoning	Space and time zoning to maximize public safety	- -	- -	Yes
Educational Measures	Public information programming	- -	- -	Yes

[a]*Cost estimated from Phase 1 stormwater management plan, Rust Environment & Infrastructure, op. cit.*

[b]*Cost estimated from data supplied by the Little Muskego Lake Association, Lake Reflections, March 1996, op. cit.*

Source: SEWRPC.

Chapter VIII

RECOMMENDED MANAGEMENT PLAN FOR LITTLE MUSKEGO LAKE

INTRODUCTION

This chapter presents a recommended management plan, including attendant costs, for Little Muskego Lake. The plan is based upon analyses of the findings of land use, land and water management, and physical, biological, water quality, and pollution source inventories; planned land use and attendant population conditions; and an evaluation of the alternative lake management measures described in Chapter VII of this report. The recommended plan sets forth means for 1) achieving water quality conditions suitable for full-body contact recreational use and the maintenance of healthy communities of warmwater fish and other aquatic life; 2) reducing the severity of existing nuisance problems due to excessive macrophyte growth, which constrains or precludes desired water uses; 3) improving opportunities for water-based recreational activities; and 4) protecting environmentally sensitive areas. The recommended plan was selected from among the alternative measures described in Chapter VII, considering the degree to which the desired water use and related biological and recreational use objectives may be expected to be met by the alternative measures and considering the costs and feasibility of implementation.

Analyses of water quality and biological conditions indicate that the general water quality conditions of Little Muskego Lake are poor, and that water-based recreational uses are limited by nuisance growths of aquatic macrophytes and in some areas' sediments. Major in-lake water quality-related projects will be necessary to meet the water use, recreational, aquatic resource protection, and shore erosion control objectives. In addition to in-lake management measures, the recommended plan also sets forth recommendations for land use control and land management measures in the direct drainage area, and shore protection measures. These measures complement the land use controls and management measures recommended for the larger watershed in the adopted regional water quality management plan,[1] and nonpoint source control plan prepared under the Muskego-Wind Lakes priority watershed project.[2]

The recommended Little Muskego Lake management measures are graphically summarized on Map 28 and are listed in Table 34. It is recommended that the Little Muskego Lake Management District assume the lead in implementing the recommended measures.

LAND USE AND ZONING MEASURES

A fundamental element of a sound management plan and program for Little Muskego Lake is the proper development of the lands lying in the total drainage area tributary to the Lake and more especially in the drainage area directly tributary to Little Muskego Lake. The type and location of urban and rural land uses in the drainage area determines the character, magnitude, and distribution of nonpoint sources of pollution; the practicality of, as well as the need for, various land management measures; and, ultimately, the water quality of the lake.

The recommended land use plan for the drainage area directly tributary to Little Muskego Lake has a 2010 design year and is described in Chapter III. The content of, and framework for, the plan is the regional land use plan as prepared and adopted by the Regional Planning Commission. The recommended land use plan is shown in graphic summary form on Map 16 and recommends that additional urban land use development occur at low and medium densities in the drainage area directly tributary to Little Muskego Lake area. Such urban land use development should be allowed to occur, however, only in areas which can be readily served by centralized sanitary sewage facilities; which are covered by soils suitable for the intended use; which are not subject to special hazards, such as flooding; and which are not environmentally sensitive, that is, are not encompassed within the Regional Plan-

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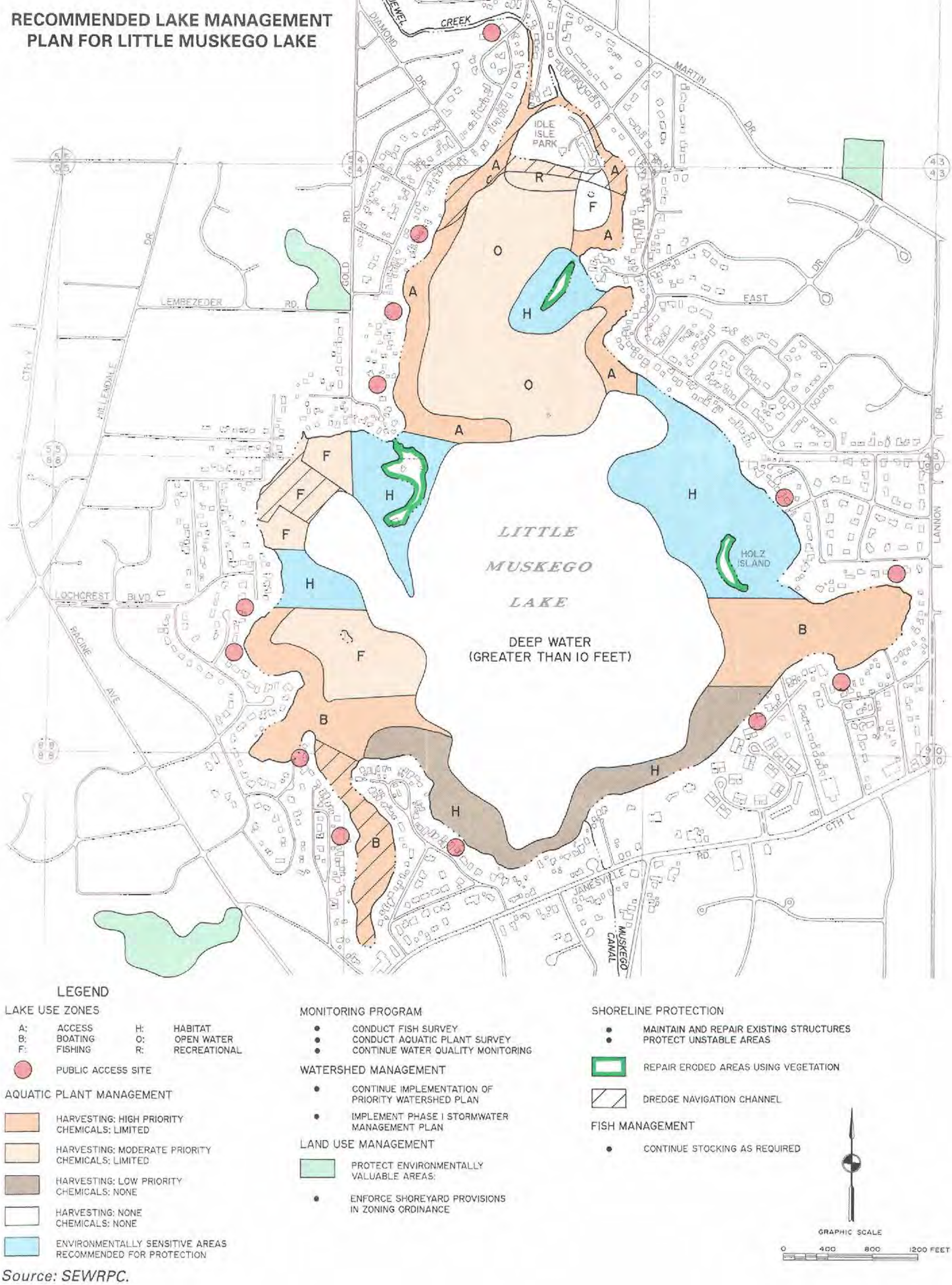
[1]*SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin: 2000, Vol. 3, Recommended Plan, June 1979.*

[2]*Wisconsin Department of Natural Resources Publication No. WR-340-93, A Nonpoint Source Control Plan for the Muskego-Wind Lakes Priority Watershed Project, October 1993.*

Map 28

RECOMMENDED LAKE MANAGEMENT PLAN FOR LITTLE MUSKEGO LAKE



Source: SEWRPC.

Table 34

RECOMMENDED MANAGEMENT PLAN ELEMENTS FOR LITTLE MUSKEGO LAKE

Plan Element	Subelement	Location	Management Measures
Land Use Management	Land use development planning	Entire watershed	Observe guidelines set forth in regional land use plan
	Density management	City	Maintain historic lake front residential dwelling densities to extent practicable
Watershed Land Management	Construction site erosion control	Entire watershed	Continue enforcement of existing ordinances
	Urban nonpoint source controls	Cities of New Berlin and Muskego	Continue implementation of the recommendations in the regional water quality management plan as refined in the Muskego-Wind Lakes Priority Watershed plan and in City of Muskego Stormwater Management Plan
	Rural nonpoint source controls	Cities of New Berlin and Muskego	Continue implementation of the recommendations of the regional water quality management plan as refined in the Muskego-Wind Lakes Priority Watershed plan
	Environmentally sensitive lands	City of Muskego	Restore and establish adequate protection of Jewel Creek inlet and islands and wetlands as appropriate; continue ongoing program of purchasing or otherwise protecting environmental corridor lands and other environmentally important lands in the watershed
Water Quality Management	Water quality monitoring	Entire Lake	Continue participation in DNR Self-Help Monitoring program supplemented by USGS monitoring
Aquatic Plant Management	Comprehensive plan revision	Entire Lake	Periodically update aquatic plant management plan
	Major channel harvesting	Zones A and B	Harvest aquatic plants as required
	Minor channel harvesting	Zones F, O, and R	Provide active recreational areas (Zones O and R); harvest fish lanes
	Chemical treatment	Zones A and B	Limited to control of milfoil growth around docks
Boating Access	Dredging	Limited localized areas of Lake shoreline	Small-scale dredging projects
Fish Management	Annual survey	Selected areas of Lake	Conduct fish survey to determine stocking needs; conduct periodic creel census
	Fish stocking	Entire Lake	Stock fish as required
Habitat Protection and Lake Use Management	Restrict boating	Zones F, R, and H	Establish "Slow-No-Wake" zones as shown on Map 28
	Restrict harvesting	Zones F and H	Restrict harvesting to access only as shown on Map 28
	Restrict chemical treatments	Zone A	Limit chemical treatments
		Zone B	Limit chemical treatments
		Zone F	Minimize chemical treatments and harvesting
		Zone H	Restrict chemical treatments and harvesting

Table 34 (continued)

Plan Element	Subelement	Location	Management Measures
Habitat Protection and Lake Use Management (continued)	Restrict chemical treatments	Zone O	Limit chemical treatments; harvest aquatic plants
		Zone R	Limit chemical treatments to vicinity of docks
Shoreland Protection	Maintain structures	Entire Lake	Maintain existing structures
	Install erosion protection	Islands	Install erosion control measures
Information and Education Program	Public information programming	Entire watershed	Continue public awareness and information programming

Source: SEWRPC.

ning Commission-delineated environmental corridors described in Chapter V.

Under the recommended plan, by the year 2010, urban development in the Little Muskego Lake area and in the drainage area directly tributary to the Lake may be expected to increase from 1,119 to about 1,320 acres, or by about 18 percent over the 1990 level of urban development. Within the total tributary drainage area to Little Muskego Lake, the area devoted to urban development is expected to increase from 2,854 acres in 1990 to about 3,337 acres in the year 2010, an increase of about 17 percent.

A land use issue which has the potential of affecting the Lake is the redevelopment of existing lakefront properties, replacing lower-density uses with higher-density, multi-family dwellings with increased roof areas, parking areas, and areas of other impervious surfaces. This has occurred at other lakes in Waukesha County. Replacement of a pervious land surface with an impervious surface may be expected to increase the rate at which stormwater enters the Lake and increases certain pollutant loading to the Lake. While these effects can be moderated to some extent through structural stormwater management measures, there is likely to be some residual adverse impact on the Lake from redevelopment involving higher-density land uses. For this reason, maintenance of the historic low- and medium-density shoreline development on Little Muskego Lake to the extent practical is recommended.

WATERSHED LAND MANAGEMENT MEASURES

The recommended watershed land management measures are specifically aimed at reducing the water quality impacts of nonpoint sources of pollution within the Little Muskego Lake watershed. These measures are set forth in the aforereferenced regional water quality management plan and the Muskego-Wind Lakes nonpoint source management plan. On the basis of a review of the sources of phosphorus loadings to Little Muskego Lake, as described in Chapters IV and VII, the only significant sources of phosphorus to the Lake from the study area subject to control are rural and urban nonpoint sources.

Appropriate nonpoint source pollution control measures include modified agricultural land management practices, construction site erosion control practices, and urban nonpoint source control and stormwater management practices. Technical and financial assistance from the State is available to help implement such practices. For example, funding is available for the institution and maintenance of management practices under the Chapter NR 120 Wisconsin Nonpoint Source Pollution Abatement Program Muskego-Wind Lakes Priority Watershed Project. The review and amendment of lake-related ordinances is an eligible cost-share expense under the Chapter NR 191 Lake Protection Grant Program. Both programs are administered by the Wisconsin Department of Natural Resources (DNR).

As noted in Chapter VII, nonpoint source control measures should be considered for the drainage areas directly tributary to Little Muskego Lake and within the Jewel Creek watershed, the upstream tributary watershed area. The regional water quality management plan recommended that a reduction of about 75 percent in rural and about 50 percent in urban nonpoint sources be achieved in the study area and in the upstream watershed. Similar loading reduction goals were identified in the nonpoint source pollution abatement program priority watershed plan. Nonpoint source pollution abatement controls in the study area are recommended to be achieved through a combination of rural agricultural nonpoint controls affecting construction erosion controls, and urban land runoff stormwater management. Implementation of these practices may be expected to result in a reduction of total phosphorus loadings to Little Muskego Lake of about 60 percent.

Rural Nonpoint Source Pollution Control

The implementation of nonpoint source pollution controls in rural areas requires the cooperative efforts of the Little Muskego Lake Management District, the Cities of Muskego and New Berlin, Waukesha County, and more particularly, the Waukesha County Land Conservation Committee. Additional technical assistance can be provided by the U. S. Department of Agriculture Natural Resources Conservation Service; the Wisconsin Department of Agriculture, Trade and Consumer Protection; and the University of Wisconsin-Extension (UWEX).

Highly localized, detailed, and site-specific measures are required in order to effectively reduce soil loss and contaminant runoff in rural areas. These measures are best defined and implemented at the local level through the preparation of detailed farm conservation plans. It is recommended that such plans be prepared for farms occupying a total of about 1,600 acres of rural land, as identified in the Muskego-Wind Lakes priority watershed plan and in the County soil erosion control plan as having estimated soil losses of greater than three tons per acre, per year.

Practices which are considered most applicable to the drainage area tributary to Little Muskego Lake include conservation tillage and pasture management and streambank erosion control. In addition, it is recommended that consideration be given to cropping patterns and crop rotation cycles, with attention to the specific topography, hydrology, and soil characteristics of each farm. Implementation of these measures should reduce phosphorus loading from agricultural lands by from 60 to 70 percent, and should reduce the total phosphorus loading to the Lake by about 45 percent. The cost of these measures will vary and will depend upon completion of detailed farm conservation plans. These costs may be expected to be incurred to a large extent for purposes of agricultural land erosion control in any case.

Construction Site Erosion Control

It is recommended that the City of Muskego continue its efforts to control soil erosion from construction activities. As noted in Chapter VII, the Cities of Muskego and New Berlin have adopted construction erosion control ordinances. The City ordinances are based on the model ordinance developed by the Wisconsin Department of Natural Resources in cooperation with the Wisconsin League of Municipalities. Such controls may include the use of silt fences, sedimentation basins, rapid revegetation of disturbed areas; the control of "tracking" from the site; and careful planning of the construction sequence to minimize the areas disturbed.

Construction site erosion controls are particularly important in minimizing the more severe localized short-term nutrient and sediment loadings to Little Muskego Lake that can result from uncontrolled construction sites. Such environmental damage was the central issue in the case of Little Muskego Lake Association, Inc., et al. v. Terra Development Corporation, et al. (1994), which case related to the impact of sediments transported from a residential development being constructed adjacent to CTH Y and CTH L in the City of Muskego on Kingston and Moonlight Bays of Little Muskego Lake.

The Little Muskego Lake Management District has worked with the City of New Berlin in the design of stormwater management measures and construction site erosion controls to be implemented at the Westridge Business Park development site, and has retained private consultants to review the proposed stormwater management measures.

In addition to these actions, the City of Muskego has recently initiated an erosion control hotline to facilitate dissemination of information on control practices and encourage reporting of ordinance violations so as to avoid serious sediment loading, wetland infilling or similar problems. The initial start-up cost of this telephone reporting system was $3,000, with annual operating costs in subsequent years expected to be about $900. Implementation of construction erosion control measures is expected to reduce the phosphorus loading from that source by about 75 percent, and the total phosphorus loading to the Lake by from 2 to 4 percent.

Urban Nonpoint Source Control

The development of urban nonpoint source pollution abatement measures should be the joint responsibility of the City of Muskego, the Little Muskego Lake District, and private property owners. Accordingly, it is recommended that the Little Muskego Lake Management District work with property owners to achieve good urban land management and good urban housekeeping practices. Such practices consist of limiting use of fertilizers and pesticides, controlling litter and pet waste, and managing leaf and yard waste. In this regard, it is recommended that the Little Muskego Lake Management District obtain and distribute fact sheets for residents describing specific residential land management practices that would be beneficial to the water quality of Little Muskego Lake. Several appropriate brochures are available from the Wisconsin DNR and the University of Wisconsin-Extension.

In addition, it is recommended that the City of Muskego continue to provide street sweeping, concentrated in the downtown areas, on an annual basis, including, in the City of Muskego, a citywide spring cleanup and fall leaf collection. It is further recommended that the Cities of Muskego and New Berlin take measures to reduce urban nonpoint sources of pollution. Specifically, urban nonpoint source pollution reduction measures should include maintenance of existing stormwater detention ponds located within the Lake Forest subdivision of the City of Muskego; maintenance of the stormwater detention ponds located in the Freedom Square subdivision of the City of Muskego; implementation of streambank erosion controls as recommended in the priority watershed plan; and construction of additional stormwater detention basins to a total of 13 acres of detention storage within the Cities of Muskego and New Berlin. The Little Muskego Lake District can also assist in taking measures to reduce urban nonpoint sources of pollution by encouraging good housekeeping practices among riparian residents. Specifically, urban nonpoint source reduction measures should include application of appropriate lawn and garden chemicals in correct dosages, usage of biodegradable substances, litter prevention and similar citizen-based measures. It is estimated that implementation of these measures would reduce the pollutant loadings from the urban areas by from 25 to 40 percent and would provide about a 10 percent reduction in the phosphorus loading to Little Muskego Lake. The capital cost of these structural facilities is estimated at about $535,000, with an annual operation and maintenance cost of about $30,000.

Environmentally Sensitive Land Protection Measures

The protection and preservation of the limited amount of environmental corridor in the vicinity of Little Muskego Lake is recommended as an important component of the recommended plan to protect the water quality of Little Muskego Lake. In this regard, implementation of the recommendations of the adopted park and open space plan for the City of Muskego would provide for the protection and preservation of these environmentally sensitive lands.[3]

IN-LAKE MANAGEMENT MEASURES

The recommended in-lake management measures for Little Muskego Lake are summarized in Table 34 and are graphically summarized on Map 28. The major plan elements include water quality monitoring, aquatic plant management, fishery management, habitat protection, shoreline protection, and recreational-use zoning.

Water Quality Monitoring

Continued water quality monitoring of Little Muskego Lake is recommended. Continued enrollment of one or more Lake Management District residents as Wisconsin Department of Natural Resources Self-help Monitoring Program volunteers is recommended. Such enrollment can be accomplished through the Southeast District Office of the Department at no cost to the Lake Management District. A firm commitment of time is required of the volunteers. In addition, participation in the expanded self-help monitoring program, measuring nutrients, chlorophyll-a, dissolved oxygen, pH, and temperature, is recommended. Such monitoring should be conducted in at least one location and at least four times per year. The City of Muskego, in conjunction with its public health maintenance responsibilities, should continue to monitor water clarity and bacterial levels at regular intervals to ensure compliance with full-contact recreational standards.

Aquatic Plant Monitoring and Management

A recommended aquatic macrophyte control plan consistent with Chapters NR 103 and NR 107 of the Wisconsin Administrative Code is included in Appendix A of this report. The plan recommends that continued aquatic macrophyte surveys be conducted at intervals of three to five years depending upon the observed degree of change in the aquatic

[3]*SEWRPC Community Assistance Planning Report No. 202, A Park and Open Space Plan for the City of Muskego, Waukesha County, Wisconsin, January 1992.*

plant communities. In addition, information on the aquatic plant control program should be recorded and should include descriptions of

1. Major areas of nuisance plant growth;

2. Areas harvested or chemically treated, or both;

3. Species harvested and amounts of plant material removed from lake; and

4. Species and approximate numbers of fish caught in the harvest.

A daily harvester log, containing this information, should be maintained as set out in the aquatic plant management plan. This information, in conjunction with the conduct of the recommended aquatic macrophyte surveys, will allow evaluation of the effectiveness of the aquatic plant control program and allow adjustments to be made in the program to maximize its benefit.

Modifications of the existing aquatic plant management program are recommended to enhance the use of the Lake while maintaining the quality and diversity of the biological communities. The following guidelines are recommended:

1. Mechanical harvesting is recommended as the primary management method.

2. Shared-access lanes rather than large areas should be harvested to minimize the potential detrimental effects on the fish and invertebrate communities. Directing boat traffic through these common lanes should delay the regrowth of vegetation in these areas.

3. Chemical herbicide use should be strictly limited to the absolute minimum required to control nuisance growth of nonindigenous species, such as Eurasian water milfoil. Only herbicides that selectively control milfoil, such as 2,4-D, should be used.

4. Chemical herbicide use should be restricted to those areas of nuisance aquatic macrophyte growth in shallow water near docks and other areas where mechanical harvesting is not feasible.

5. Chemical applications, if required, should be made shortly after mechanical harvesting to maximize effectiveness. The harvested plants will thus be chemical-free and suitable for use as mulch or for other uses.

6. Use of algicides, such as Cutrine Plus, are not recommended because there are no filamentous or planktonic algae problems in the Lake. Valuable macroscopic algae, such as Chara and Nitella, are killed by this chemical.

The recommended plan partitions Little Muskego Lake into zones for aquatic plant management, with control measures in each zone designed to optimize desired recreational opportunities and to protect the aquatic resources. The recommended aquatic plant control zones are shown on Map 28, and the controls recommended for each zone are described below.

1. Zone A, Access: This zone would provide narrow channels, approximately 10 to 15 feet wide, which would be harvested, to provide boating access to the main body of Little Muskego Lake. The total area recommended to be harvested for this purpose would total about 29 acres. No chemicals should be used.

2. Zone B, Boating: This zone is an important largemouth bass spawning area on a hard substrate. This zone would provide 10- to 15-foot-wide channels extending perpendicular to the shore to allow boat access to the central portion of the Lake. The area recommended to be harvested for this purpose would total about 67 acres. Chemical use, if required, would be restricted to pier and dock areas and would not extend more than 50 feet from the shore.

3. Zone F, Fishing: This zone would accommodate fishing from the shore. In this zone, approximately 10- to 15-foot-wide channels would be harvested perpendicular to the shore at about 100-foot intervals. The total area recommended to be harvested for this purpose would total about 40 acres. Chemical use, if required, would be restricted to nuisance milfoil control near the public access.

4. Zone H, Habitat: Portions of Little Muskego Lake should be preserved and protected as a high-quality habitat area. Accordingly, this zone and adjacent lands would be managed for fish habitat. No harvesting or in-lake chemical application would be conducted, except

that some herbicide application may be required for the control of Eurasian water milfoil. Debris and litter cleanup would be needed in some adjacent areas; the immediate shoreline would be preserved in natural, open uses to the extent possible. This zone would total about 112 acres.

5. Zone O, Open Water: This zone would consist of carefully selected areas of deeper water to provide a larger shared space for boating and fishing. Navigational channels, 30 feet in width, would be harvested. This zone would supplement those areas with a water depth greater than 20 feet which do not have excessive macrophyte growth. The area harvested would total about 65 acres. No chemicals should be used.

6. Zone R, Recreational: This zone would encompass the most heavily used areas of the shoreline. Nuisance aquatic macrophyte growth within 150 feet of shoreline would be harvested to provide maximum opportunities for boating, fishing, and swimming. Additional 30-foot-wide shared-access channels would extend to the center of the Lake. The area recommended to be harvested for this purpose would total about four acres. Harvesting should be concentrated in areas of abundant macrophyte growth. Patterns of harvesting will vary yearly dependent on macrophyte growth. Chemical use, if required, should be restricted to pier and dock areas and should not extend more than 50 feet from the shore.

Summary of Recommended Aquatic Plant Management Program: Under the recommended aquatic plant control program, about 200 acres of Lake surface area would be mechanically harvested. Some of these areas would be harvested more than once per year. Chemical applications would be restricted to the control of milfoil at the public boat launch and around docks and piers. The recommended program should not require an increase in the District's equipment or labor cost for aquatic plant control, although the eventual replacement of the harvester and other machinery may be required. Cost-share programs administered by the Wisconsin Waterways Commission may be available to offset up to 50 percent of the capital cost of new or used harvesting equipment purchased by State-approved organizations with aquatic plant management plans. The replacement cost of an aquatic plant harvester and ancillary equipment is estimated to be approximately $90,000 as set forth in Appendix A, with annual operating costs of about $12,000. In addition, it is recommended that an aquatic plant survey be conducted once every three to five years to determine changes in the aquatic plant community. Such surveys are estimated to cost $4,000, or about $20,000 over the 20-year planning period.

Boating Access

The use of dredging is recommended to be conducted only on a very limited, as-needed basis for small-scale projects where riparian or public boating access is inadequate. The associated environmental impacts of each of these small-scale projects should be identified and evaluated for severity on a case-by-case basis.

Large-scale dredging, which was proposed by the Lake District and discussed in the 1980 environmental impact statement,[4] is not recommended given the extremely high cost of such a project and the potential for negative environmental impacts when undertaken on the lake-wide scale. Rather, local maintenance or access dredging, such as is currently under way at Little Muskego Lake and shown on Map 26, is the preferred method, being site-specific, cost effective—the costs being incremental and applied as required for access and navigation purposes, and less environmentally damaging—aquatic life being able to take refuge in undisturbed portions of the Lake basin. Smaller-scale projects result in less environmental disturbance and are generally more cost-effective to undertake as share-based equipment can be used to remove the sediments in many instances. Also, the localized nature of the small-scale projects permits better containment of shoreland disturbances and more rapid restoration of lakeshore and littoral flora and fauna. Revegetation of the littoral area with native aquatic plants is recommended.

To prevent slumping or redeposition of sediments in the dredged access lanes, grading to a slope of four on one is recommended. Further maintenance of shoreline protection structures, as set forth below, or provision of naturally-vegetated shoreline buffer strips, illustrated in Figure 11, are recommended. Such actions will also contribute to the

[4]*Wisconsin Department of Natural Resources Environmental Impact Statement, Proposed Little Muskego Lake Rehabilitation Project, January 1980.*

maintenance of fish habitat, as described below, and will influence the composition of the aquatic plant communities.

Fish Monitoring and Management

The aquatic plant management strategy set forth above recognizes the importance of fishing as a recreational use of Little Muskego Lake. Integral to the aquatic plant management strategy is the protection and preservation of fish breeding habitat, especially in the area of the islands (Zone H) and along the western shore of the Lake (Zones B and F on Map 28). Any interventions in the inlet should be confined to the navigation access channel on the northern shore, shown as Zone A on Map 28.

Two specific actions by the Lake Management District are recommended with respect to fisheries management: conduct of a fishing survey and assessment angling pressures. The fishing survey should be conducted by the Wisconsin Department of Natural Resources at the request of the Lake Management District and would have several objectives:

1. To identify any changes in fish species composition that may have taken place in the Lake since the previous fishing surveys conducted in 1984 and 1993;

2. To relate any changes in fish populations, species composition, and condition factors to such known interventions as stocking programs, water pollution control activities, and aquatic plant management programs; and

3. To refine and update information on fish breeding areas, breeding success, and survival rates.

Additional information, such as obtaining confirmation of the lack of disturbance by rough fish populations, could also be obtained through such a survey.

The second action relative to a fishery management program is the assessment of angling pressures on the Lake. This program would

1. Provide information on the survival of walleyed and northern pike currently stocked into Little Muskego Lake (Table 23);

2. Provide data to determine the intensity of public use of the Little Muskego Lake fishery through creel surveys, citizen reporting activities, and evaluation of the fishery survey data; and

3. Provide data to assess the implications of a possible over-harvest of largemouth bass from the Lake.

This last action is recommended to be carried out by the Wisconsin Department of Natural Resources. Given the fishing pressures on the Lake, it would be useful to conduct a one-time analysis of fish tissues for metal and toxic contamination. This task could be included in the fish survey, when it would be possible to readily obtain representative samples from among the fish species collected during the survey. The cost of such a comprehensive fish survey is estimated to be $16,000. Stocking costs are dependent on the availability and types of fish stocked but can be expected to average about $12,000 annually.

Habitat Protection

Habitat protection measures recommended for Little Muskego Lake are, in part, provided for by the recommended aquatic plant management program activities. The aquatic plant management plan is designed to provide for such habitat protection measures as being aware of fish breeding areas and avoiding disturbances in these areas during spring and autumn; reducing the use of aquatic plant herbicides in these areas; and maintaining stands of native aquatic plants, especially in the inlet area.

In addition, it is recommended that environmentally sensitive lands, including wetlands along the lakeshore and the upstream tributary Jewel Creek be preserved and protected. In particular, this recommendation also extends to the maintenance of the islands located in the north, east, and west central portions of the lake basin, within the habitat areas, Zone H, as shown on Map 28. It is recommended that the island shorelines be stabilized with native aquatic plants so as to enhance the available habitat, and "Slow-No-Wake" restrictions imposed in their vicinities to minimize further erosion of their shorelines—as set forth below.

The accumulation of silt in the marginal areas of the Lake has caused concern among the lakeshore residents. The silt accumulates over the sand and gravel areas preferred for game fish spawning and can cause mortality of fish larvae by suffocation and burial. The use of such natural shoreland stabilization practices as vegetation, or the use of rock riprap, can mitigate the effects of shoreline erosion and should help to stabilize breeding habitat. In addition, the vegetation provides shelter for juvenile fishes and spawning substrate for fishes that deposit their eggs on plant material. Additional measures, such as placement of spawning cribs or similar artificial breeding substrate, do not appear to be warranted at present, but may be employed in the future after shorelines have been stabilized with natural vegetation, and as indicated by the results of the fish survey recommended to be conducted by the Wisconsin Department of Natural Resources.

Recreational Use Zoning

The principle actions required in terms of this task would include the imposition of "Slow-No-Wake" restrictions on those portions of the Lake bordering sensitive areas, such as Zone A, and where boating activities could be expected to come into conflict with other uses, such as angling in Zone F, swimming in Zone R, and habitat areas in Zone H. The boating regulation ordinance adopted by the City forms the legal basis necessary to carry out this action. Delegation of Lake safety patrol functions currently performed by the City of Muskego Police Department to the Lake District, pursuant to Section 33.22 of the Wisconsin Statutes, could be considered. Notwithstanding, continuing this patrol is strongly recommended. A Little Muskego Lake safety patrol operation is eligible for partial State cost-share funds under Section 30.77 of the Wisconsin Statutes. Such a patrol could function part time on Little Muskego Lake and part time on Big Muskego Lake.

Shoreline Protection

Most of the Little Muskego Lake shoreline is protected; however, areas of erosion have been identified along the island shores which require additional protection against wind, wave, and wake erosion. Various possible protection options have been outlined in Chapter VII to be considered by individual property owners with assistance in the form of education and information by the Lake District to repair or replace existing protection structures. The vegetated buffer strip method is recommended along the island shorelines and throughout the direct tributary drainage area in order to maintain habitat value and the natural ambience of the lake shore. Continued maintenance of existing revetments and bulkheads is also recommended. The cost of shoreline erosion control measures on Little Muskego Lake is estimated to be about $27,500.

PUBLIC INFORMATIONAL AND EDUCATIONAL PROGRAMS

It is recommended that the Lake Management District continue to assume the lead in the development of a public informational and educational program dealing with various lake management-related topics, including onsite sewage disposal system management, water quality management, land management, groundwater protection, aquatic plant management, fishery management, and recreational use. The District newsletter can provide an excellent medium for the conduct of such a program.

Educational and informational brochures and pamphlets, of interest to homeowners and supportive of the recreational use and shoreland zoning regulations, are available from the Wisconsin Department of Natural Resources and the University of Wisconsin-Extension. These should cover such topics as beneficial lawn care practices and household chemical use. Such brochures should be provided to homeowners through local media, direct distribution by the Lake Management District, or targeted library and civic center displays. Such distribution can also be integrated into ongoing, larger-scale activities, such as lakeside litter collection, which can reinforce anti-littering campaigns, recycling drives, and similar environmental protection activities.

PLAN IMPLEMENTATION AND COSTS

The actions recommended in this plan largely represent an extension of ongoing actions being carried out by the City of Muskego and the Little Muskego Lake Management District. The recommended plan introduces few new elements, although some of the plan recommendations represent refinements of current operations. This is particularly true in the case of the fisheries and aquatic plant management programs; the field surveys recommended in this plan will permit more efficient management of these resources.

Generally, fisheries and such aquatic plant management practices as stocking, harvesting, and public awareness campaigns currently implemented by the Lake District and City of Muskego are recommended to be continued with the refinements proposed herein. Some aspects of these programs lend themselves to citizen involvement through volunteer-based creel surveys, participation in the Wisconsin Department of Natural Resources Self-Help Monitoring Program, and identification with

Table 35

LOCAL GOVERNMENTAL MANAGEMENT AGENCY RESPONSIBILITIES FOR PLAN IMPLEMENTATION

Plan Element	Subelement	Agency: Waukesha County	Agency: Little Muskego Lake Management District	Agency: City of Muskego	Agency: City of New Berlin	Agency: Department of Natural Resources
Land Use Management	Development planning	--	--	X	X	--
	Density management	--	--	X	X	--
Watershed Land Management	Construction site erosion control	X	--	X	X	--
	Urban nonpoint source controls	X	X	X	X	--
	Rural nonpoint source controls	X	--	X	X	--
	Environmentally sensitive lands protection	--	X	X	X	--
Water Quality Management	Water quality monitoring	--	X	--	--	X
Aquatic Plant Management	Comprehensive plan revision	--	X	--	--	X[a]
	Major channel harvesting	--	X	--	--	--
	Minor channel harvesting	--	X	--	--	--
	Chemical treatment	--	X	--	--	X[b]
Boating Access	Dredging	--	X	--	--	X
Fish Management	Annual survey	--	X	--	--	X
	Fish stocking	--	X	--	--	X
Habitat Protection and Lake Use Management	Restrict boating	--	X	X	--	X[a]
	Restrict harvesting	--	X	--	--	--
	Restrict chemical treatments	--	X	--	--	X[b]
Shoreland Protection	Maintain structures	--	X[c]	X	--	--
	Install erosion protection	--	X[c]	X	--	X[b]
Information and Education Program	Public information programming	X[d]	X	X	X	X

[a]*The Wisconsin Department of Natural Resources reviews aquatic plant management plans, revisions thereof, and boating ordinances for compliance with State rules.*

[b]*This activity requires a Wisconsin Department of Natural Resources permit.*

[c]*Resident responsibility; the District can provide guidance, facilitate technical support, and potentially offer cost-sharing of expenses.*

[d]*County assistance is provided through the Land Conservation Division of the County Environmental Resources Department, and the University of Wisconsin-Extension.*

Source: SEWRPC.

Table 36

ESTIMATED COSTS OF RECOMMENDED LAKE MANAGEMENT MEASURES FOR LITTLE MUSKEGO LAKE

Plan Element	Subelement	Estimated Cost 1995-2010[a] Capital	Estimated Cost 1995-2010[a] Average Annual Operation and Maintenance	Potential Funding Sources[b]
Land Use Management	Development planning	- -[c]	- -[c]	DNR, County, City
	Density management	- -[c]	- -c	DNR, County, City
Watershed Land Management	Construction site erosion control	- -[d]	- -d	Private firms, individuals
	Urban nonpoint source controls	$ 635,000[e]	$55,000[e]	City of Muskego
	Rural nonpoint source controls	- -[e,f]	- -[e,f]	DNR, County
	Environmentally sensitive lands	- -[e]	- -[e]	DNR, City
Water Quality Management	Water quality monitoring	- -	$ 100[g]	DNR, District
Aquatic Plant Management	Comprehensive plan revision	$ 20,000[h]	- -	District
	Major and minor channel harvesting	$ 90,000[i]	$20,000	District, DNR, Waterways Commission
	Chemical treatment	- -	$ 8,000	District, DNR
Fish Management	Annual survey	$ 16,000	- -	DNR, District
	Fish stocking	- -	$12,000	DNR, District
Habitat Protection and Lake Use Management	Restrict boating	- -[c]	- -	DNR, City, District
	Restrict harvesting	- -	- -	District
	Restrict chemical treatments	- -	- -	DNR, District
Boating Access	Dredging	$1,000,000	- -	Private property owners
Shoreland Protection	Maintain structures	- -[c]	- -	Residents
	Install erosion protection	$ 27,000[c]	- -	District, City
Information and Education Program	Public information programming	- -	$ 1,000	City, District, UWEX, DNR

[a]*All costs expressed in June 1995 dollars.*

[b]*Unless otherwise specified, "DNR" is the Wisconsin Department of Natural Resources, "County" is Waukesha County, "City" is the City of Muskego, "District" is the Little Muskego Lake Protection and Rehabilitation District, and "UWEX" is the University of Wisconsin- Extension.*

[c]*Cost-share assistance may be available for ordinance review, revision, and writing under the NR 191 Lake Protection Grant Program.*

[d]*Cost varies with amount of land under development in any given year.*

[e]*Cost-share assistance may be available for watershed-based and in-lake best management practices, their repair or replacement under the NR 120 Wisconsin Nonpoint Source Pollution Abatement Program.*

[f]*Costs vary and will depend upon preparation of individual farm plans.*

[g]*The DNR Self-help Monitoring Program involves no cost but does entail a time commitment from the volunteer.*

[h]*Cost-share assistance may be available after July 1, 1995, under the revised NR 190--formerly NR 119--Lake Management Planning Grant Program.*

[i]*It is assumed that the existing harvester and ancillary equipment will be replaced during the planning period; cost-share assistance for harvester purchase may be available from the Wisconsin Waterways Commission Recreational Boating Facilities Grant Program.*

Source: SEWRPC.

environmentally sound owner-based land management attitudes. It is recommended that the Lake Management District assume the lead in the promotion of these citizen actions, with a view toward building community commitment and involvement. Assistance is generally available toward this end from such agencies as the Wisconsin Department of Natural Resources and the University of Wisconsin-Extension.

New work elements recommended in the plan include the periodic surveys indicated above. Some of the recommendations form part of ongoing operations or have been anticipated. For example, review and assessment of zoning ordinances and boating ordinances are ongoing activities. The conduct of fish and aquatic plant surveys, recommended in the plan, is designed to provide necessary information for the continued sound management of the Lake, while citizen-based volunteer monitoring programs will involve the public in a meaningful and constructive way in lake management.

The major cost relating to new elements herein recommended relates to the conduct of nonpoint source pollution abatement structural measures as set forth in the Muskego-Wind Lakes priority nonpoint pollution abatement priority watershed plan. Inclusion of the environmentally sensitive areas in the vicinity of Little Muskego Lake inlet area in some type of protection program is recommended. State cost-share opportunities may be available to obviate the funding burden associated with at least some of these expenditures.

The suggested lead agency or agencies for initiating program-related activities, by plan element, are set forth in Table 35 and the estimated costs of these elements, linked to possible funding sources where such are available, are summarized in Table 36.

The costs, expressed in 1995 dollars, of the recommended lake management measures in Little Muskego Lake, include a total capital cost in excess of $788,000 over a 20-year plan implementation period with an annual operations and maintenance cost of about $96,100. State programs that provide cost share money include 1) the Chapter NR50/51 Stewardship Grant Program; 2) the Chapter NR 120 Wisconsin Nonpoint Source Pollutant Abatement Program; and 3) the Chapter NR 191 Lake Protection Grant Program. The Wisconsin Department of Natural Resources also administers funds on behalf of the Wisconsin Waterways Commission, for recreational boating facilities development; and on behalf of the U. S. Fish and Wildlife Service, for sportfish restoration. Local units of government and private firms and individuals are also potential sources for funding.

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Chapter IX

SUMMARY

The management plan for Little Muskego Lake, as herein described, was prepared by the Southeastern Wisconsin Regional Planning Commission in cooperation with the Little Muskego Lake Management District, the City of Muskego, the Wisconsin Department of Natural Resources, and the U. S. Geological Survey. The planning effort included the design and conduct of a water quality sampling program and an aquatic plant survey for the Lake. Inventories and analyses were conducted of the existing and recommended future land use patterns within the watershed of the Lake, the associated pollutant loadings and sources, the physiography and natural resource base of the watershed, the recreational uses of the Lake, and the management practices employed, both on the Lake and in its watershed. Field studies associated with these activities were conducted between October 1986 through September 1994.

The objectives of this lake management plan are to provide for the protection and maintenance of good water quality conditions, for the enhancement of recreational opportunities, and for the maintenance of a healthy fishery and other aquatic resources. In order to meet these objectives the plan sets forth means for 1) providing water quality conditions suitable for full-body contact recreational use, and the maintenance of healthy communities of warmwater fish and other aquatic life; 2) reducing the severity of existing nuisance problems due to excessive macrophyte growth, which constrain or preclude desired water uses; 3) improving opportunities for water-based recreational activities; and 4) protecting environmentally sensitive areas.

Little Muskego Lake is a 506-acre impoundment on Jewel Creek downstream of Linnie Lac and upstream of Big Muskego and Wind Lakes. The Lake has extensive shallow margins and a single, deep basin. The Lake lies within U. S. Public Land Survey Sections 4, 8, and 9, Township 5 North, Range 20 East, City of Muskego, Waukesha County. The Lake, as it now exists, was created on the site of a natural waterbody in about 1838, when construction of a dam on Jewel Creek increased the water level of the Lake by about eight feet. The Lake has a maximum depth of 65 feet and a mean depth of 14 feet. Its direct drainage area, including the area draining to the wetland complex and the Jewel Creek between Linnie Lac and Little Muskego Lake, totals about 2,200 acres, or 3.5 square miles; while its total tributary drainage area, or watershed, encompasses about 7,500 acres, or 11.8 square miles.

Little Muskego Lake is an enriched hard-water, alkaline lake that has been subjected to relatively high levels of pollution. Physical and chemical parameters measured during the study period indicated that the water quality is within the "fair to poor" range. Total phosphorus levels were found to be above the level considered to cause nuisance algal and aquatic plant growths. During summer stratification, the water below a depth of 25 feet was found became devoid of oxygen, while the upper waters remained well oxygenated and supported a healthy fish population. Winterkill is typically not a problem in Little Muskego Lake because dissolved oxygen levels were found to be adequate for the support of fish throughout the winter at depths above 40 feet.

INVENTORY AND ANALYSIS FINDINGS

Population

- The resident population of the Little Muskego Lake direct drainage area has increased steadily since 1960. The 1990 resident population of the direct drainage area of Little Muskego Lake of approximately 5,840 persons was about 67 percent higher than the estimated 1963 population of about 3,490 persons.
- Population forecasts prepared by the Regional Planning Commission, on the basis of a normative regional land use plan, indicate that the population of the direct drainage area to Little Muskego Lake may be expected to increase to about 7,200 persons by the year 2010.

Land Use

- Urban land uses within the direct drainage area of Little Muskego Lake have increased from about 720 acres in 1963, to about 1,120 acres in 1990, or by about 55 percent. In 1990, about 51 percent of the direct drainage area of

Little Muskego Lake was in urban land uses, with the dominant urban land use being residential, encompassing 840 acres, or about 75 percent of the area in urban use. Within the total tributary drainage area of Little Muskego Lake, about 2,850 acres, or about 39 percent of the area, were in urban uses in 1990, with residential and transportation land uses encompassing about 1,960 acres, or 69 percent, and 710 acres, or about 25 percent, respectively, of the area in urban use.

- As of 1990, about 1,100 acres, or about 49 percent of the direct drainage area of Little Muskego Lake, were still in rural land use. About 440 acres, or about 40 percent of the rural area, were in agricultural land uses. Woodlands, wetlands, and surface water, including the surface area of Little Muskego Lake, accounted for approximately 640 acres, or about 59 percent of the area in rural use. Within the total tributary drainage area to Little Muskego Lake, about 4,700 acres, or about 61 percent, were in rural uses. About 2,970 acres, or 63 percent, of the rural lands were in agricultural uses.

- An increase of about 200 acres, or about 18 percent, in urban land uses within the direct drainage area of the Lake may be expected between 1990 and 2010. An increase of about 480 acres, or about 17 percent, in urban land uses may be expected in the total tributary drainage area by the design year 2010.

Water Budget

- During the period from October 1986 through September 1991, an estimated 8,400 acre-feet of water entered the Lake per year. Estimated inflow volumes ranged from approximately 5,150 acre-feet during the 1988-1989 water year, to 12,800 acre-feet during the 1992-1993 water year. Jewel Creek is estimated to contribute over 70 percent of the inflow to the Lake. The remainder of the inflow came from surface runoff draining directly to the Lake, direct precipitation on the Lake, and groundwater inflow.

- An estimated 6,800 acre-feet of water per year was lost from the Lake via the normal flow from the outlet and evaporation from the lake surface during the period from October 1986 through September 1991. An additional 2,000 acre-feet of water per year are removed during the annual winter drawdown.

Rural Sources of Nonpoint Pollutants

- The annual average loading of sediment and phosphorus from croplands in the area tributary to Little Muskego Lake was estimated to approximate 1,030 tons of sediment and about 4,400 pounds of phosphorus.

- About 270 tons of sediment were calculated as being generated annually from 13 actively eroding gullies within the watershed. Eroding streambanks generated another 200 tons of sediment.

Urban Sources of Nonpoint Pollutants

- The average annual nonpoint source contributions of sediment, phosphorus, and zinc from urban land uses in the total drainage area tributary to Little Muskego Lake were calculated to be about 1,110 tons of sediment; about 1,810 pounds of phosphorus; and about 1,240 pounds of zinc.

Water Quality

- Water quality data collected during the October 1986 through September 1994 study period indicate that the range of values for specific conductance, chloride, and alkalinity and hardness all fall within the normal range of lakes in Southeastern Wisconsin.

- Physical and chemical parameters measured on Little Muskego Lake during the 1986-through-1994 study period indicated that the water quality is considered fair based upon the phosphorus and water clarity readings, and poor based upon chlorophyll concentrations compared to other lakes in Southeastern Wisconsin.

- During the period from 1987 through 1991, the water quality of Little Muskego Lake was influenced by the operation, in the summer months, of an in-lake aeration system. During the period of operation of this system, surface water phosphorus concentrations increased; Secchi-disk transparencies decreased; bottom water temperatures increased; bottom water dissolved oxygen concentrations increased; bottom water pH values increased; and bottom water conductivity values decreased. Consequently, it was concluded that the aeration system did not meet its stated goals of removing muck, controlling aquatic plant growth, improving water clarity, and improving the fishery; and the system was abandoned in 1992.

Phosphorus Loads

- About 6,200 pounds of phosphorus is estimated to enter Little Muskego Lake annually, with Jewel Creek as the major source, contributing 88 percent of the loading; followed by runoff from areas draining directly to the Lake accounting for about 10 percent of the loading; and atmospheric deposition on the Lake surface accounting for the remainder of the loading.

- About 900 pounds of phosphorus is estimated to be added to the water column annually as internal loading from the lake sediments.

- Of the total external phosphorus loading to Little Muskego Lake, approximately 47 percent of the total phosphorus, or about 2,900 pounds, was used annually by the biomass within the Lake or deposited in sediments, resulting in a net transport of phosphorus out of Little Muskego Lake into Big Muskego Lake of about 3,300 pounds, or 53 percent of the total annual phosphorus load to Little Muskego Lake.

Sediment Loads

- The annual sediment loading to Little Muskego Lake was estimated to about 2,600 tons. About 58 percent of this loading entered the Lake via Jewel Creek, and approximately 42 percent was contributed by runoff from areas which drain directly to the Lake.

Sediment Quality

- Nearly all of the bottom of Little Muskego Lake is covered by muck, however, sand or silty sand was found in isolated areas of the bottom sampled in the eastern embayment and north-central portion of the main lake basin.

- According to a U. S. Environmental Protection Agency classification system for sediments, phosphorus concentrations greater than 650 milligrams per kilogram (mg/kg) are indicative of "heavily polluted" lakes. In Little Muskego Lake the sediment phosphorus concentration ranged from 120 to 240 mg/kg. Metal concentrations in the sediment were found to be generally within the range suggested by the Wisconsin Department of Natural Resources as indicative of uncontaminated sediment.

Natural Resource Base

- In 1990, high-value wildlife habitat, as shown on Map 21, covered approximately 84 acres, or about 4 percent of the direct drainage area of Little Muskego Lake.

- In 1990, wetlands areas, as shown on Map 22, covered about 47 acres, or about 2 percent of the direct drainage area of the Lake.

- Primary and secondary environmental corridors, as shown on Map 23, covered about 170 acres, or about 8 percent of the direct drainage area to Little Muskego Lake in addition to the entire lake area itself. These corridor areas include almost all the remaining high-value woodlands, wetlands, and wildlife habitat areas in and around Little Muskego Lake.

- Environmentally valuable areas in Little Muskego Lake providing aquatic habitat used for shelter, spawning, and feeding by aquatic animals include lake bottom and shoreline areas adjacent to wetlands and the three islands and surrounding areas.

Recreational Use

- Twenty publicly owned parks and lake access sites exist along the Little Muskego Lake shoreline, including Idle Isle Park boat launch at the northern end of the Lake and three other public boat launching sites located at Hillview Drive, Oak Court, and Pleasant View Drive; and 16 walk-in access sites situated around the waterbody.

- Eleven privately owned lake access sites also exist around the lakeshore.

- Water-based outdoor recreational activities on Little Muskego Lake include boating, fishing, swimming, and other active and passive recreational pursuits. Because of its size, Little Muskego Lake receives a significant amount of powerboat and sailboat use. Of the 650 watercraft observed to be in use or moored in the Lake or trailered on the shore in a survey conducted by Commission staff during the summer of 1995, about 50 percent were pontoon or powerboats, and about 25 percent were fishing boats. The remainder were canoes, sailboats, paddle boats, and jet skis.

- In a recreational rating technique developed by the Wisconsin Department of Natural Resources to characterize the recreational value of inland lakes, Little Muskego Lake received 42 out of the possible 72 points, indicating that moderately diverse recreational opportunities are provided by the Lake.

ALTERNATIVE LAKE MANAGEMENT MEASURES

Thirty alternative management techniques, including watershed, lake rehabilitation, and in-lake measures were evaluated based on effectiveness, cost, and technical feasibility as part of the planning effort. Those alternative measures eliminated from further consideration, after careful evaluation, included dilution and flushing, nutrient inactivation, aeration, nutrient load reduction, drawdown, biological controls, and lake bottom covering. The alternative measures which were incorporated into the recommended plan are described below.

THE RECOMMENDED PLAN

Analyses of water quality and biological conditions indicate that the general water quality conditions of Little Muskego Lake may be considered to range from fair to poor. Water-based recreational uses are limited by nuisance growths of aquatic macrophytes and in some areas by sediment deposition. Major in-lake water quality-related measures are recommended to meet full water use, recreational, aquatic resource protection, and shore erosion control objectives. In addition to in-lake management measures, the recommended plan also sets forth recommendations for land use control and land management measures in the drainage area tributary to the Lake.

The recommended Little Muskego Lake management measures are graphically summarized on Map 28 and are listed in Table 34. The recommended measures were developed within the framework of the adopted regional water quality management plan, and the nonpoint source control plan prepared under the Muskego-Wind Lakes priority watershed project. Those measures include:

For protection of the natural resource base:

1. The review and modification, as may be found necessary, of county and local zoning ordinances to preserve and enhance the existing natural resource base of the direct and tributary drainage areas to Little Muskego Lake, and the maintenance of the historic low- and medium-density shoreline development in Little Muskego Lake.

2. The preservation, protection, and enhancement in essentially natural open uses of all lands designated as primary environmental corridors.

For the protection and maintenance of water quality conditions:

1. Continued implementation of the nonpoint source controls recommended in the regional water quality management plan and the Muskego-Wind Lakes priority watershed plan for both urban and rural areas.

2. For rural areas, the implementation of land management measures. Such measures should be more specifically defined and implemented through the preparation of detailed farm conservation plans. It is recommended that such plans be prepared for farms occupying a total of about 1,600 acres of rural land, identified in the Muskego-Wind Lakes priority watershed plan and in the County soil erosion control plan as having estimated soil losses of greater than three tons per acre, per year. Implementation of these measures may be expected to reduce phosphorus loading from agricultural lands by 50 to 70 percent, and to reduce the total phosphorus loading to the Lake by about 45 percent.

3. For urban areas the adoption and implementation of good urban land management and urban housekeeping practices such as limiting use of fertilizers and pesticides, controlling litter and pet waste, and managing leaf and yard waste. In this regard, it is recommended that the Little Muskego Lake Management District utilize its newsletter to distribute fact sheets for residents describing specific residential land management practices that would be beneficial to the water quality of Little Muskego Lake. In addition, it is recommended that the City of Muskego continue to provide street sweeping on an annual basis and a fall leaf collection. It is further recommended that existing stormwater detention ponds be maintained; streambank erosion controls be carried out; and that additional stormwater detention basins be

constructed and maintained, all as identified in the City of Muskego stormwater management plan. It is estimated that implementation of these measures may be expected to reduce the pollutant loading from the urban areas by about 30 percent and to reduce the total phosphorus loading to the Lake by about 10 percent.

4. Continued enrollment of one or more Lake District electors in the Wisconsin Department of Natural Resources Self-Help Monitoring Program and participation in the expanded program offered by the Department. The City of Muskego should also continue to maintain the bacteriological monitoring program for the Lake.

5. The continued enforcement by the local units of government concerned of construction site erosion control ordinances in the entire tributary drainage area of the Lake.

For the enhancement of recreational opportunities through the reduction in severity of nuisances arising from recurring excessive algal and aquatic plant growths:

1. Adoption and maintenance of the modified aquatic plant management plan provided in Appendix A of this plan. Adoption of this plan would entail modification of the existing aquatic plant management practices by specifying mechanical harvesting as the primary management method, limiting the use of herbicides to the control of nonnative plants such as Eurasian water milfoil, and restricting herbicide use to shallow water areas near docks and areas where harvesting is not feasible. Chemical application, if required in selected areas, should occur in early summer followed by mechanical harvesting after macrophytes have become reestablished.

2. Adoption of lake use zoning, as summarized on Map 28, to provide for multiple-purpose recreational use of Little Muskego Lake. Zoning is recommended to provide for boating access from the northern shore of the inlet to the main lake basin, Zone A; boating access to and from the public launch sites and primary residential areas, Zone B; shore-based fishing from the northern parkway and western shores, Zone F; water-based recreation, including swimming, fishing, and boating along the eastern and southern shores, Zone R; deep-water recreational activities in the central portions of the Lake, Zone O; and habitat preservation within the eastern embayment and inlet, Zone H.

3. The dredging of selected nearshore areas where riparian or public boating access is inadequate.

For the protection and enhancement of fish and other aquatic resources, including wildlife habitat, woodlands, and wetlands:

1. Conduct a fish survey to assess changes in species composition of, and in angling-related pressures on, the fishery of the Lake since the previous fisheries survey conducted in 1969. Such a survey would provide information needed to better manage the ongoing fish stocking program for the Lake.

2. Through recreational use zoning and related activities for the protection of fish breeding areas and habitat including promulgation of modifications to the City zoning code, set forth above, minimize disturbances to lacustrine fish breeding areas during spring and autumn. Applying "slow-no-wake" restrictions applicable to Zone A and in those areas immediately adjacent to use zones where boating activities may be expected to interfere with other uses, such as adjacent to Zones F, R, and H, where boating may be expected to affect fishing, swimming, and habitat protection uses, would be useful.

3. Continued proper maintenance of the shoreline protection structures, including the repair and replacement of failed structures and the erection of suitable structures along eroding shorelines, as shown on Map 3.

For public information and education:

1. The continuation of the ongoing public informational and educational program directed toward comprehensive lake management through the use of newsletters and other media.

The recommended plan is based largely on existing and ongoing lake management measures being employed by the City of Muskego and the Little Muskego Lake Management District. These two public entities would retain primary responsibility for implementing this plan. Implementation of the plan would entail a capital expenditure of about $788,000 over the next 20 years and an annual operations and maintenance expenditure of about $96,100, as shown in Table 36, including existing expenditures.

Little Muskego Lake is a valuable natural resources in the Southeastern Wisconsin Region and a particularly valuable asset to the City of Muskego. The delicate, complex relationship between water quality conditions in Little Muskego Lake and the land uses within its tributary drainage area is likely to be subject to continuing pressures as demands for water-based recreation in the Lake and for urban development within its watershed resulting from increases in population, income, leisure, and individual mobility for the Region. To provide the water quality protection needed to maintain in Little Muskego Lake conditions conducive to meeting such pressures, it will be necessary to adopt and administer an effective program of lake management based upon comprehensive water quality management and related plans. This plan comprises an important element of such a program and is consistent with previously adopted comprehensive land use, water quality, recreation and open space, soil erosion control, and sanitary sewer service area plans for the Southeastern Wisconsin Region.

APPENDICES

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Appendix A

AN AQUATIC PLANT MANAGEMENT PLAN FOR LITTLE MUSKEGO LAKE, WAUKESHA COUNTY, WISCONSIN

INTRODUCTION

The aquatic plant management plan is an integral part of the Little Muskego Lake Management Plan, and represents an important element of the ongoing commitment of the City of Muskego, the Little Muskego Lake Association, Inc., and the Little Muskego Lake Management District to sound environmental management with respect to the Lake. The aquatic plant management portion of the lake management plan was prepared during 1994-95 by the Regional Planning Commission, and is based on field surveys conducted by the Department of Natural Resources (DNR) in 1992 and the Commission staff during 1994. This plan follows the format adopted by the DNR for aquatic plant management plans pursuant to Chapters NR 103 and NR 107 of the Wisconsin Administrative Code. Its scope is limited to those management measures which can be effective in the control of aquatic plant growth; those measures which can be readily undertaken by the City and Lake Management Association and District in concert with the riparian residents; and those measures which will directly affect the use of Little Muskego Lake.

This report is comprised of seven main sections: 1) a statement of planning goals and objectives; 2) a brief description of the Lake and its watershed; 3) a statement of the current use restrictions and the need for aquatic plant management in Little Muskego Lake; 4) an evaluation of alternative means of aquatic plant management and a selected plan; 5) a description of the recommended plan; 6) a description of the equipment needs for the selected plan; and 7) the recommended means of monitoring and evaluating the efficacy of the plan and equipment.

STATEMENT OF AQUATIC PLANT MANAGEMENT GOALS AND OBJECTIVES

The goals and objectives of the Little Muskego Lake Management District were developed in consultation with the City of Muskego. The goals and objectives are to:

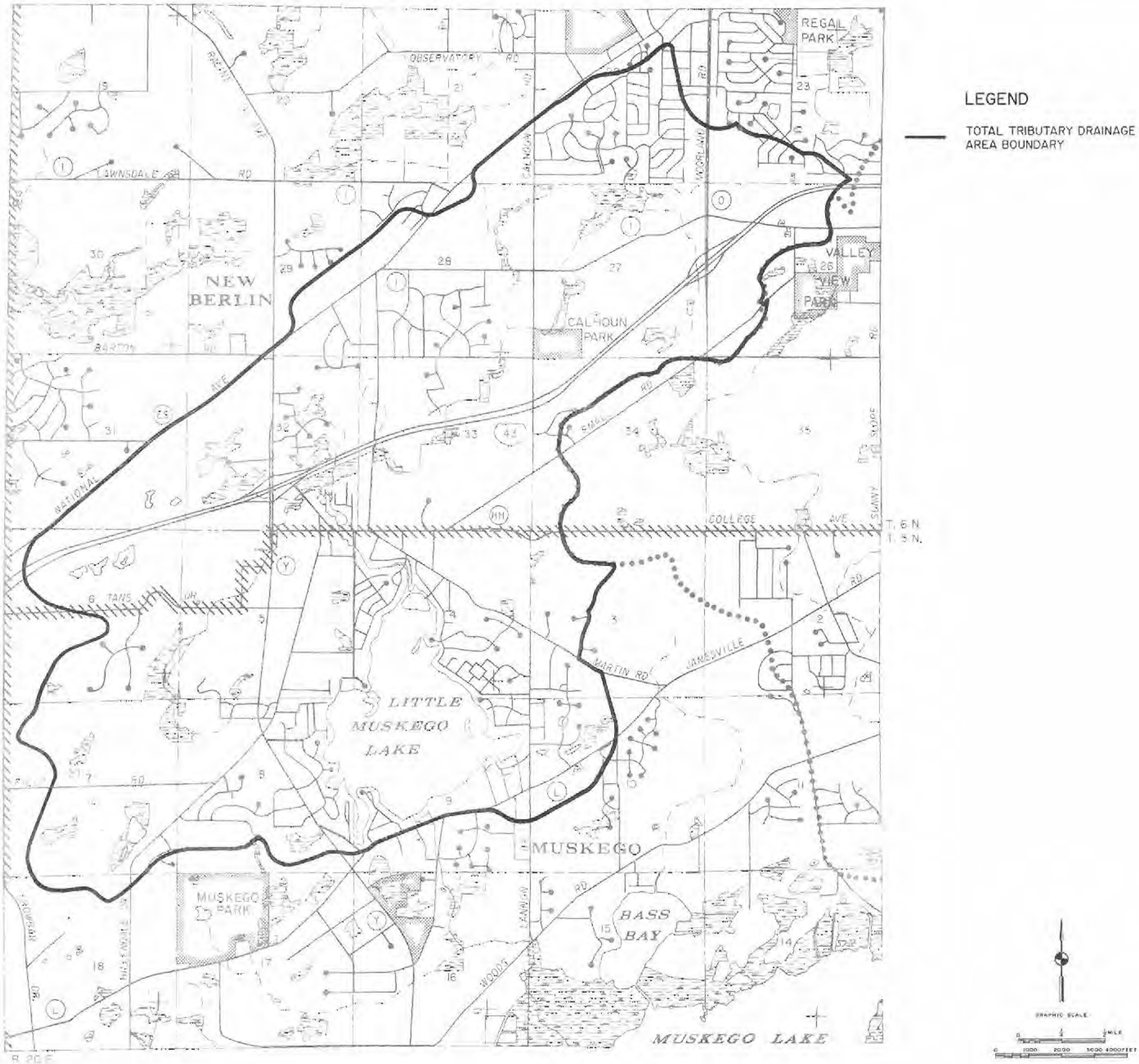
- Effectively control the quantity and density of aquatic plant growths in portions of Little Muskego Lake basin to better facilitate the conduct of water-related recreation, improve the aesthetic value of the resource to the community, and enhance the resource value of the waterbody;
- Protect and maintain public health, and promote public comfort, convenience, necessity and welfare, in concert with the natural resource, through the environmentally sound management of native vegetation, fishes and wildlife populations in and around Little Muskego Lake; and,
- Promote a quality, water-based experience for residents and visitors to Little Muskego Lake consistent with the policies and objectives of the Wisconsin Department of Natural Resources as set forth in the regional water quality management plan entitled, SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin—2000, adopted by the Regional Planning Commission on July 12, 1979.

LITTLE MUSKEGO LAKE AND ITS WATERSHED CHARACTERISTICS

Little Muskego Lake is a 506-acre through-flow lake located off a tributary of the Fox River. Jewel Creek provides the major inflow to Little Muskego Lake with the outflow being controlled by a dam, originally constructed in 1838, discharging into Muskego Creek and ultimately into Big Muskego Lake. Big Muskego Lake discharges to the Muskego Canal, which flows into Wind Lake and, finally, from the Wind Lake Drainage Canal into the Fox River within the town of Rochester in Racine County.

Map A-1

TOTAL TRIBUTARY DRAINAGE AREA TO LITTLE MUSKEGO LAKE



Source: SEWRPC.

Being located entirely within the City of Muskego, Little Muskego Lake has been subject to the continual consequences of urbanization. Concern over the increased development and demands on the Lake led to the formation of the Little Muskego Lake Management District in 1974.

The area considered as the direct drainage area of the Lake—that area which drains to Little Muskego Lake excluding the area that drains through any of the other major lakes—is about 2.3 square miles, and is situated wholly within Waukesha County. The total tributary drainage area, including the entire area upstream of Muskego Lake drained by Jewel Creek, is 8.4 square miles, as shown on Map A-1.

Table A-1

AQUATIC PLANT SPECIES PRESENT IN LITTLE MUSKEGO LAKE AND THEIR POSITIVE ECOLOGICAL SIGNIFICANCE

Aquatic Plant Species Present	Ecological Significance
Ceratophyllum demersum (coontail)	Provides good shelter for young fish, and supports insects valuable as food for fish and ducklings
Chara sp. (muskgrass)	Stabilizes bottom sediments; softens water by removing lime and carbon dioxide; provides cover for fish and food for waterfowl; and supports insects which are valuable as food for trout, bluegills, and smallmouth and largemouth bass
Chara vulgaris (muskgrass)	Excellent producer of fish food, especially for young trout, bluegills, small-mouth and largemouth bass; stabilizes bottom sediments; and has softening effect on the water by removing lime and carbon dioxide
Myriophyllum spicatum (Eurasian water milfoil)	None
Najas sp. (naiads)	Good producer of food and shelter for fish; stems, foliage, and seeds provide important food for ducks
Nymphaea tuberosa (white water lily)	Provides shade and shelter for fish; seeds eaten by wildfowl; rootstocks and stalks eaten by muskrats; roots eaten by beaver, deer, moose, and porcupine
Potamogeton crispus (curly-leaved red pondweed)	Provides good food and shelter, and shade for early-spawning fish
Potamogeton richardsonii (Richardson's pondweed)	Provides good food and cover and supports insects for fish
Potamogeton zosteriformis (flat-stemmed pondweed)	Provides food and shelter for fish
Vallisneria americana (eelgrass)	Provides good shade and shelter, supports insects, and is valuable fish food. Excellent food for wildfowl, attracts wildfowl and shore birds, and harbors minute animals

Source: Norman C. Fassett, A Manual of Aquatic Plants; Wisconsin Department of Natural Resources, Guide to Wisconsin Aquatic Plants; Floyd Swink and Gerould Wilhelm, Plants of the Chicago Region; and SEWRPC.

Land Use and Shoreline Development

Public and Private Access: As of 1990, there were eleven public access sites on Little Muskego Lake, all of which were located within the City of Muskego. The shoreland of Little Muskego Lake is used primarily for residential development. Nearly all of the shoreline around Little Muskego has some form of shoreline protection; a survey done in 1993 indicated 46 bulkheads, 23 revetments, and 10 beaches. The inlet and island areas of Little Muskego Lake, which do not have any structured shoreline protection, are somewhat protected by the aquatic plant vegetation.

Aquatic Plants, Distribution, and Management Areas

A 1994 macrophyte survey done by the Commission staff revealed macrophytes dispersed throughout Little Muskego Lake. The greatest diversity was found on the eastern and western shorelines; the most diverse growth occurred adjacent to the main lake basin. A species list, compiled from the results of this aquatic plant survey, is set forth in Table A-1. This survey identified 11 species of plants, many of which were common to abundant. Chara was found to be the most abundant species. Chara was found in three of the four environmentally sensitive areas identified by the DNR; it was the dominant species at two of these areas. Myriophyllum sp. was found to be present at all four sensitive areas in the Lake. Myriophyllum was the dominant species at one of the areas on the western shore, but was abundant at all four of the sites. Coontail (Ceratophyllum demersum) occurred at only one site located on the northeastern lakeshore. Wild celery

Table A-2

FISH SPECIES IDENTIFIED DURING THE LITTLE MUSKEGO LAKE FISH SURVEY: 1992

Angling Type	Common Name	Family Name	Genus and Species Name
Sport Fish	Walleyed Pike	Percidae	Stizostedion vitreum
	Northern Pike	Salmonidae	Esox lucius
	Largemouth Bass	Centrarchidae	Micropterus salmoides
Panfish	Yellow Perch	Percidae	Perca flavescens
	Bluegill	Centrarchidae	Lepomis macrochirus
	Pumpkinseed	Centrarchidae	Lepomis gibbosus
	Green Sunfish	Centrarchidae	Lepomis cyanellus
	Black Crappie	Centrarchidae	Ambloplites rupestris
	Warmouth	Centrarchidae	Lepomis gulosus
	Golden Shiner	Centrarchidae	Notemigonus crysoleucas
	Black Bullhead	Ictaluridae	Ictalurus melas
	Yellow Bullhead	Ictaluridae	Ictalurus natalis
	White Sucker	Catostomidae	Catostomus commersoni
Rough Fish	Carp	Cyprinidae	Cyprinus carpio

Source: Wisconsin Department of Natural Resources and SEWRPC.

(Vallisneria americana) and various species of pondweeds occurred throughout the Little Muskego Lake with pondweeds being most abundant at site four. Whitewater lilies were common in the shallow water of two sites, one on each shore. Cattails and bulrush dominated the emergent flora along the shores of the Lake.

Overall, Little Muskego Lake supports a healthy and diverse aquatic plant population. Species such as milfoil and coontail tend to form dense mats interfering with recreational and aesthetic uses, but for the most part appear to be kept under control through the harvesting program. Areas where the various plant communities were found are shown on Map A-2.

Fisheries, Wildlife, and Waterfowl

Little Muskego Lake supports a moderately diverse fish community, as set forth in Table A-2. The top predator fishes in the Lake include northern pike, walleyed pike and largemouth bass. Panfish species present in the Lake include bluegills, pumpkinseeds, green sunfish, black crappies, white suckers, golden shiners, yellow perch, and bullheads.

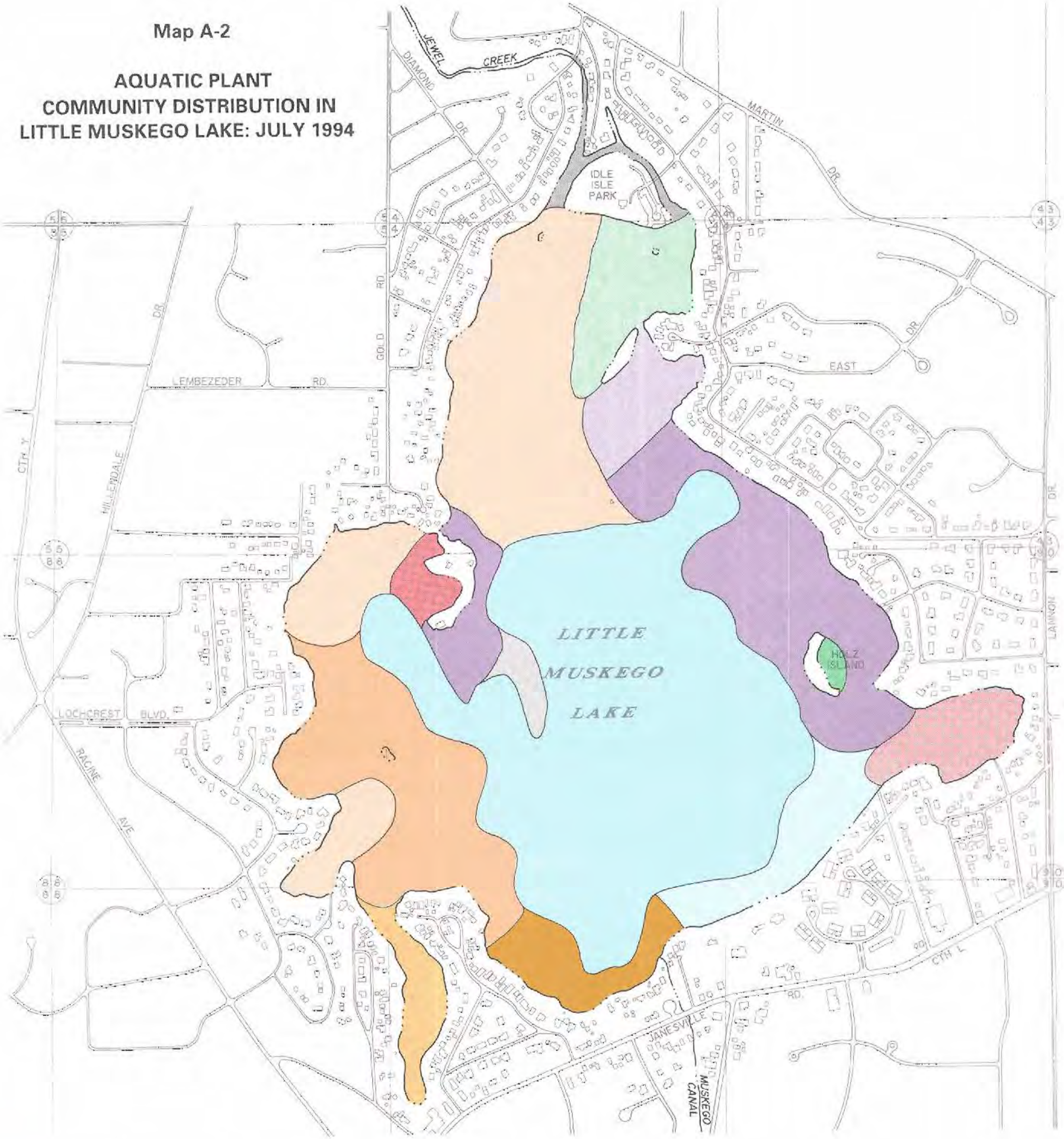
Given the urban nature of the shorelands, only small animals and limited numbers of waterfowl generally inhabit these areas. Muskrats and cottontail rabbits are probably the most abundant and widely distributed fur-bearing mammals in and near the area. Larger mammals, such as the whitetail deer are generally restricted to the larger wooded areas and the open meadows. The Little Muskego drainage area supports a significant population of waterfowl including mallards and teals. Migrating season moves larger numbers and types of waterfowl through the drainage are when most of the regional species may also be present.

Recreation

Recreational Uses: Little Muskego Lake is a multi-purpose waterbody serving all forms of recreation, including boating, swimming, and year around fishing. Being in the center of an urban area makes Little Muskego Lake an ideal setting for parks and open space sites and facilities. There are 20 publicly owned parks and lake access sites along the Little Muskego Lake shoreline, two boat launches and 18 walk-ins. Because of its size, Little Muskego Lake receives a significant amount of powerboat and sailboat use. A boat survey conducted on July 18, 1994, indicated that about 30 watercraft of all descriptions were in use on the

Map A-2

AQUATIC PLANT COMMUNITY DISTRIBUTION IN LITTLE MUSKEGO LAKE: JULY 1994



LEGEND

- FILAMENTOUS ALGAE AND COONTAIL
- MUSKGRASS AND MIXED SUBMERGENTS
- EURASIAN WATER MILFOIL AND COONTAIL
- EURASIAN WATER MILFOIL AND FLATSTEM PONDWEED
- COONTAIL AND FLATSTEM PONDWEED
- WILD CELERY AND FLATSTEM PONDWEED
- WHITE WATER LILY, COONTAIL AND EURASIAN WATER MILFOIL
- FLATSTEM PONDWEED, COONTAIL AND EURASIAN WATER MILFOIL
- WHITE WATER LILY
- ILLINOIS AND FLATSTEM PONDWEED, COONTAIL, WILD CELERY AND EURASIAN WATER MILFOIL
- MIXED SUBMERGENT SPECIES
- MIXED SUBMERGENTS AND EMERGENT SPECIES
- EURASIAN WATER MILFOIL, COONTAIL, ELODEA AND COMMON DUCKWEED
- OPEN WATER

GRAPHIC SCALE
0 400 800 1200 FEET

Source: SEWRPC.

Lake at that time. The "Waterbugs" Waterski Club, based at Idle Isle Park, makes use of Little Muskego Lake for routine practices and occasional shows.

USE RESTRICTIONS IMPOSED BY AQUATIC PLANTS

An aquatic plant distribution survey done by Commission staff in 1994 indicated heavy plant growth in all but the middle of the main lake basin. Up to 75 percent of the water surface area is affected by abundant aquatic plant growth that restricts any sort of boating traffic to a small area of open water at the center of the waterbody. In particular, excessive plant growth in the riparian zone makes access to the open water difficult without some sort of plant control strategy.

PAST AND PRESENT AQUATIC PLANT MANAGEMENT PRACTICES

A DNR-approved aquatic plant control program has been undertaken on Little Muskego Lake since the 1950s, when records of such control programs began to be kept by the DNR. However, aquatic plant control programs on Little Muskego Lake probably pre-date the DNR record-keeping system by several decades. This program initially involved the chemical treatment of aquatic plant growths with sodium arsenite. Little Muskego Lake has the somewhat dubious distinction of being one of the 10 most heavily dosed waterbodies in Wisconsin, receiving more than 20 tons of sodium arsenite during the 20-year period from 1950 to 1969. Applications of sodium arsenite were discontinued in 1969 after arsenic accumulations were found in the lake sediments and concerns were expressed over possible human health impacts. No health impacts, however, have been recorded. Subsequently, recent (annual) chemical treatments have made use of more specific, systemic herbicides such as 2,4-D as set forth in Table A-3. All chemical treatments on Little Muskego Lake are applied by state-licensed applicators and conform to the requirements of the DNR Chapter NR 107, *Aquatic Plant Management*, permit held by the Little Muskego Lake Management District. Chemical applications are normally made in late spring/early summer (May) as the plants begin to grow, with occasional follow-up treatments being applied in mid-summer (July).

Harvesting has been used in concert with an annual herbicide treatment to control aquatic plant growth in Little Muskego Lake. The Little Muskego Lake Management District has purchased and operates an Aquarius System H-420 harvester on the Lake. Past procedures have been to initiate harvesting after the plants have become reestablished following the chemical applications.

This dual control program has been viewed favorably by the public, although some concerns continue to be expressed on both sides of the issue. Nevertheless, it is a goal of the management plan for Little Muskego Lake that aquatic herbicide use be minimized, synchronized with the aquatic plant harvesting operation to maximize its impact, and applied primarily in the nearshore areas to control nuisance plants such as milfoil (which is difficult to control in any other way).

ALTERNATIVE METHODS FOR AQUATIC PLANT CONTROL

Background

Various aquatic plant management techniques—manual, mechanical, physical, and chemical—are potentially viable on Little Muskego Lake.[1] Consideration has been given to each of these techniques. A number of these methods have been employed with varying success on Little Muskego Lake in the past.

Physical Controls

Physical methods, such as drawdown, are not feasible due to the heavy recreational demands placed on the Lake throughout the year. Although an eight-foot drawdown could be achieved by removal of the dam at the Lake's outlet to Big Muskego Lake, the impact upon recreation and the uncertainty surrounding its effects, combined with the limited duration of such effectiveness, necessitating frequent repeat treatments, makes this type of control expensive and problematical, and, hence, not feasible for use on Little Muskego Lake.

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[1] *The various methods referred to in the text are described in more detail in U. S. Environmental Protection Agency Report No. EPA-440/4-90-006, The Lake and Reservoir Restoration Guidance Manual, August 1990.*

Table A-3

CHEMICAL CONTROL OF AQUATIC PLANTS IN LITTLE MUSKEGO LAKE: 1980-1994

Year	Macrophyte Control									Algae Control	
	Diquat (gallons)	Aquathol-K		2,4-D		Hydrothol (gallons)	Endothol (pounds)	Silvex (pounds)	Sodium Arsenite (pounds)	Cutrine Plus	
		Gallons	Pounds	Gallons	Pounds					Gallons	Pounds
1950	--	--	--	--	--	--	--	--	4,600	--	--
1951[a]	--	--	--	--	--	--	--	--	--	--	--
1952	--	--	--	--	--	--	--	--	1,000	--	--
1953	--	--	--	--	--	--	--	--	2,000	--	--
1954	--	--	--	--	--	--	--	--	600	--	--
1955	--	--	--	--	--	--	--	--	4,640	--	--
1956	--	--	--	--	--	--	--	--	4,120	--	--
1957	--	--	--	--	--	--	--	--	3,200	--	--
1958	--	--	--	--	--	--	--	--	3,112	--	200
1959	--	--	--	--	20	--	--	--	3,104	--	--
1960	--	--	--	--	--	--	0.36	0.5	2,860	--	--
1961	--	--	--	--	--	--	--	--	2,980	--	--
1962	--	--	--	--	--	--	--	--	1,080	--	--
1963	--	--	--	--	--	--	--	--	3,360	--	--
1964	--	--	--	--	--	--	--	--	3,060	--	--
1965	--	--	--	--	--	--	4.60	--	1,620	--	--
1966	--	--	--	--	--	--	--	--	4,140	--	--
1967	--	--	--	--	--	--	--	--	1,620	--	--
1968	--	--	--	--	--	--	--	--	--	--	--
1969	--	--	--	--	--	--	--	--	--	--	--
1970	5.0	7.00	--	--	--	--	--	--	--	--	50
1971[a]	--	--	--	--	--	--	--	--	--	--	--
1972[a]	--	--	--	--	--	--	--	--	--	--	--
1973[a]	--	--	--	--	--	--	--	--	--	--	--
1974[a]	--	--	--	--	--	--	--	--	--	--	--
1975	--	--	--	--	--	--	--	--	--	160.0	--
1976[b]	--	--	--	--	--	--	--	--	--	--	--
1977[a]	--	--	--	--	--	--	--	--	--	--	--
1978	--	--	--	--	20	--	--	--	--	--	--
1979	--	7.00	--	165.5	--	--	--	--	--	83.5	--
1980	--	36.00	--	129.0	--	8.5	--	--	--	49.0	35
1981	--	49.00	--	167.0	--	--	--	--	--	52.5	--
1982	--	119.00	--	63.0	--	--	--	--	--	72.0	--
1983[b]	--	--	--	--	--	--	--	--	--	--	--
1984	--	61.00	40	120.5	40	--	--	--	--	123.5	80
1985	--	27.00	--	86.0	--	--	--	--	--	88.5	--
1986	2.0	43.00	--	31.0	27	--	--	--	--	22.0	25
1987	50.5	10.00	--	--	--	--	--	--	--	101.0	--
1988	--	61.50	--	89.0	--	--	--	--	--	41.0	--
1989	11.0	90.40	--	17.5	--	--	--	--	--	68.5	--
1990	6.0	25.00	--	--	--	--	--	--	--	68.0	--
1991	--	--	18	--	--	--	--	--	--	--	--
1992	35.0	36.25	--	--	--	--	--	--	--	35.0	--
1993	29.0	27.00	--	--	--	--	--	--	--	52.5	--
1994	19.0	21.50	--	--	--	--	--	--	--	13.5	--

[a]*No chemicals named were applied during the year listed.*

[b]*No records were available for the year listed.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Drawdown can also encourage the growth of some plant species. For these reasons, drawdown is not a recommended technique for Little Muskego Lake at this time.

Other physical controls, such as the placement of bottom barriers and use of shoreline protection structures such as rip-rap, may be more practicable for Little Muskego Lake. Extensive use of shoreline protection structures have occurred in Little Muskego Lake as shown on Map A-3. These structures have been installed primarily to control erosion of the shoreline but have been successful in limiting the growth of rooted aquatic plants in the shoreland zone of the main lake basin. Little scope currently exists for installing additional areas of rip-rap. The use of such techniques in the inflow arm of the Lake is not to be recommended as the macrophyte growth in this embayment forms and ecologically valuable biological filter for the Lake.

Chemical Controls

Chemical controls are viewed by the community as having uncertain long-term environmental impacts as well as possible consequences for human health. While all of the herbicides recently used on Little Muskego Lake have met applicable U.S. Environmental Protection Agency standards and are applied by registered applicators, the use of chemical control techniques can contribute to an ongoing aquatic plant problem by augmenting the natural rates of accumulation of decayed organic matter in the lake sediments, releasing the nutrients contained in the plants back into the water column where they can be reused in new plant (or algal) biomass production, contributing to the oxygen demand that produces anoxic conditions in the Lake, and damaging or destroying nontarget plant species that provide needed habitat for fish and other aquatic life, all of which favor less-desirable, invasive plants over the more beneficial species. Hence, this option is not feasible on the scale required to control the infestations of aquatic plants in Little Muskego Lake.

However, chemical control is the recommended technique for the control of the relatively small-scale infestations of milfoil in the Lake. Chemical applications should be conducted in accordance with current DNR administrative rules, under the authority of the appropriate permit, by a licensed applicator working under the supervision of DNR staff. A recommended checklist is provided as Figure A-1.

Manual Controls

Manual methods, such as raking or hand-pulling, are difficult to employ on a large-scale. Although very effective for small-scale application—for example, in and around docks and piers—manual techniques are generally the least efficient of the aquatic plant control methods. While manual means will be needed to control nearshore plant growths and collect floating material from mechanical harvesting operations, this method is too inefficient and time-consuming to employ on the scale need to manage aquatic plant problems over the entire basin of Little Muskego Lake.

Mechanical Controls

Based on previous experience of the use of mechanical harvester technologies on Little Muskego Lake, mechanical harvesting of aquatic plants appears to be a practicable and efficient means of controlling plant growth in Little Muskego Lake in an environmentally sensitive manner. Harvesting removes the plant biomass and nutrients from the Lake. While mechanical harvesting can potentially impact fish and other aquatic life caught up by the machine, disturb loosely consolidated lake bottom sediments, and result in the fragmentation and spread of some aquatic plants, it has also been shown to have some benefit in ultimately reducing the regrowth of other plants. Harvesting also removes attached, epiphytic algal growths with the harvested plant material, and leaves sufficient plant material in the Lake to continue to provide forage and shelter for fish and other aquatic life while stabilizing the lake sediments to prevent increased turbidity due to wind/wave resuspension. Mechanical harvesting is the method of choice in Little Muskego Lake.

Biological Controls

Another alternative approach to controlling nuisance aquatic plant conditions (in this particular case, Eurasian water milfoil) is biological control. Classical biological control has been successfully used to control both weeds and herbivorous insects.[2] Recent documentation states that Euhrychiopsis lecontei, an aquatic

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[2]*C. B. Huffacker, D. L. Dahlsen, D. H. Janzen, and G. G. Kennedy, "Insect Influences in the Regulation of Plant Population and Communities," 1984, pp. 659-696, in C. B. Huffacker and R. L. Rabb, editors, Ecological Entomology, John Wiley, New York, New York, USA.*

Map A-3

SHORELINE CONDITIONS ON LITTLE MUSKEGO LAKE: 1993

LEGEND

- BEACH
- RIPRAP
- NATURAL
- BULKHEAD
- REVETMENT

Source: SEWRPC.

Figure A-1

DISTRICT CHECKLIST FOR HERBICIDE APPLICATION

- [ ] Nuisance report completed defining areas of potential treatment
- [ ] Permit filed with the Wisconsin Department of Natural Resources
- [ ] Certified applicator hired[a]
- [ ] Required public notice in the newspaper
- [ ] Public informational meeting (required if five or more parties request a meeting)
- [ ] Posting of areas to be treated in accordance with regulations (discussed previously in report)
- [ ] Weather conditions cooperating
  - Wind direction and velocity
  - Temperature

[a]A licensed applicator will determine the amount of herbicide to be used, based upon discussions with appropriate staff from the Wisconsin Department of Natural Resources, and will keep records of the amount applied.

Source: SEWRPC.

weevil species, has the potential as a biological control agent for Eurasian water milfoil. In 1989, the weevil was discovered during a study investigating a decline of Eurasian water milfoil growth in a Vermont pond. Euhrychiopsis proved to have significant effects on Eurasian water milfoil in the field and in the laboratory. The adult weevil feeds on the milfoil causing lesions which make the plant more susceptible to pathogens, such as bacteria or fungi, while the weevil burrows in the stem of the plant causing enough tissue damage for the plant to lose buoyancy and collapse.[3] Although studies thus far indicate that the weevil has the potential to be a biological control for Eurasian water milfoil, at present there is not enough supporting evidence and actual exposure to warrant recommending this type of control on Little Muskego Lake except on an experimental basis.

Information and Education

In addition to these in-lake rehabilitation methods, an ongoing campaign of community information will support the aquatic plant management program by encouraging the use of shoreland buffer strips, responsible use of household and garden chemicals, and environmentally-friendly household and garden practices to minimize the input of nutrients from these riparian areas. This information program will also remind riparian residents of the habitat and other benefits, such as shoreline stabilization, provided by the aquatic flora of the Lake, and promote the preservation of an healthy aquatic flora in Little Muskego Lake.

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[3]Sally P. Sheldon, "The Potential for Biological Control of Eurasian Water Milfoil (Myriophyllum spicatum) 1990-1995 Final Report," Department of Biology Middlebury College, February 1995.

RECOMMENDED AQUATIC PLANT MANAGEMENT PLAN

Harvesting Plan

The recommended aquatic plant management plan for Little Muskego Lake is set forth in Map A-4. As indicated, it is proposed that aquatic plant management activities be restricted in certain ecologically valuable areas of the Lake. For this reason, aquatic plant management activities will be confined to zones A, B, F, O and R of the Lake. Further, aquatic plant management operations will be concentrated in Zones B and F (especially near the boating access ramps and in the principal boating use and fishing areas).

The environmentally sensitive areas, identified by the Department of Natural Resources, will be restricted from harvesting and chemical applications. In addition, harvesting will not take place in shallow waters (generally three feet or less) to avoid disturbance of fish spawning areas and beds of native aquatic plants (as per NR 103). Special efforts will be made to avoid disturbing major spawning and habitat areas of bass in Little Muskego Lake during the spring spawning season—May 1 to June 30 annually.

As noted above, the goal of the management program is to accommodate recreational uses of the Lake insofar as possible and to enhance the public perception of the Lake without inflicting irreparable damage on the lake ecosystem, its structure and functioning. To accomplish this goal, specific control measures will be applied in the various lake zones identified on Map A-4. The recommended sequence of harvester operations on Little Muskego Lake is portrayed in Figure A-2. The following are the aquatic plant management treatments that will be applied in each of the six lake zones:

- Zone A (Access): Narrow channels, approximately 10 to 15 feet wide, will be harvested along a portion of the eastern bay and inlet area to provide boating access to the main body of Little Muskego Lake. The total area harvested is approximately 29.2 acres. No chemicals should be used in this area.

- Zone B (Boating): Zone B is an important largemouth bass fish spawning area on a hard substrate. Harvesting would be limited to 10- to 15-foot-wide channels extending perpendicular to the shore to allow boat access to the central portion of the Lake. The total area harvested would be approximately 67.0 acres. Chemical use, if required, would be restricted to pier and dock areas and would not extend more than 50 feet from the shore.

- Zone F (Fishing): Zone F would accommodate fishing from the shore. In this zone, approximately 10- to 15-foot-wide channels will be harvested perpendicular to the shore at about 100 foot intervals. The total area harvested would be approximately 39.5 acres. Chemical use, if required, would be restricted to nuisance milfoil control near the public access.

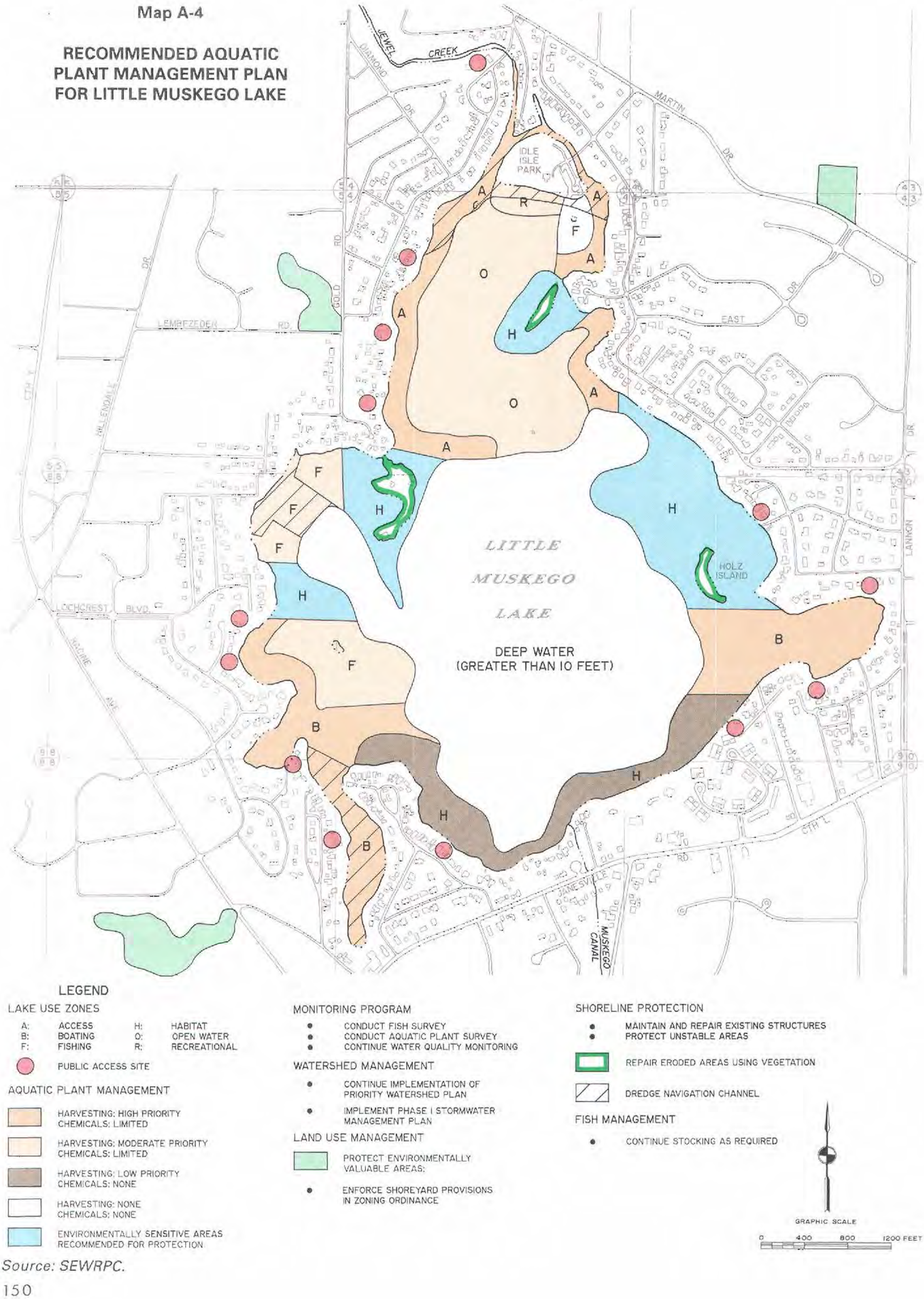
- Zone H (Habitat): Portions of Little Muskego Lake would be preserved as a high-quality habitat area. This zone and adjacent lands would be managed for fish habitat. No harvesting or in-lake chemical application would be conducted, although some herbicide application may be required for the control of Eurasian water milfoil. Debris and litter cleanup would be needed in some adjacent areas; the immediate shoreline would be preserved in natural, open use to the extent possible. This zone totals about 111.5 acres in areal extent.

- Zone O (Open Water): Harvesting would be conducted in selected areas of the deeper water to provide a larger shared space for boating and fishing. Navigation channels approximately 30 feet in width, would be harvested. This zone would supplement those areas with a water depth greater than 20 feet which do not have excessive macrophyte growth. The total area harvested would be approximately 65.2 acres. No chemicals should be used.

- Zone R (Recreation): Zone R contains the most heavily used areas of shoreline. Nuisance aquatic macrophyte growth within 150 feet of shoreline would be harvested to provide maximum opportunities for boating, fishing, and limited swimming. Additional 30-foot-wide shared-access channels would extend to the center of the Lake. The maximum total area harvested would be approximately 4.0 acres. The entire area may not require intensive management. Harvesting should be concentrated in areas

Map A-4

RECOMMENDED AQUATIC PLANT MANAGEMENT PLAN FOR LITTLE MUSKEGO LAKE



Source: SEWRPC.

Figure A-2

HARVESTING SEQUENCE FOR LITTLE MUSKEGO LAKE

A. HARVEST CHANNELS ABOUT 10 to 15 FEET WIDE IN **ZONE A** TO PROVIDE BOATING ACCESS TO THE MAIN BODY OF LITTLE MUSKEGO LAKE, AS SHOWN ON MAP A-4

B. HARVEST 10- TO 15-FOOT WIDE NAVIGATIONAL CHANNELS PERPENDICULAR TO THE SHORELINE EXTENDING TOWARDS THE CENTER OF THE LAKE IN **ZONE B** TO PROVIDE BOAT ACCESS TO THE CENTRAL PORTION OF THE LAKE, AS SHOWN ON MAP A-4

C. HARVEST NUISANCE AQUATIC MACROPHYTE GROWTH WITHIN 150 FEET OF THE SHORELINE IN ADDITION TO 30-FOOT WIDE SHARED ACCESS CHANNELS EXTENDING TO THE CENTER OF THE LAKE WITHIN **ZONE R**, AS SHOWN ON MAP A-4. THIS ENTIRE AREA MAY NOT REQUIRE INTENSIVE MANAGEMENT

D. HARVEST 10- TO 15-FOOT CHANNELS EXTENDING PERPENDICULAR FROM THE SHORELINE AT ABOUT 100-FOOT INTERVALS WITHIN **ZONE F**, AS SHOWN ON MAP A-4

E. HARVEST NAVIGATIONAL CHANNELS 30 FEET IN WIDTH IN SELECTED AREAS OF **ZONE O** TO PROVIDE A LARGER SHARED SPACE FOR BOATING AND FISHING, AS SHOWN IN MAP A-4

[a]*No harvesting would be conducted in Zone H or within 100 feet of the island areas.*

Source: SEWRPC.

of abundant macrophyte growth. Patterns of harvesting will vary yearly dependant on macrophyte abundance. Chemical use, if required, would be restricted to pier and dock areas and would not extend more than 50 feet from shore.

Depth of Harvesting and Treatment of Fragments

The Aquarius H-420 Aquatic Plant Harvester has a maximum cutting depth of five feet. While this may exceed the actual water depth in some areas, it is not the intention of the owners or operators of the equipment to denude the Lake of aquatic plants given the heavy angling use of the waterbody, its morphology (which is not conducive to extensive motorized boat traffic), and the program goals. All plant cuttings and fragments will be collected *in situ* by the harvester. Those fragments accumulating along the shoreland areas will be collected by the District or the riparian homeowners. Fragments can be used by the homeowners as garden mulch.

Buoyage

Temporary marker buoys may be used to direct harvesting operations in the lake basin by marking the areas to be cut. However, the size of the Lake generally precludes the need for such buoys except insofar as they are required for the control of boating traffic on the Lake. The harvester operators will be provided with a laminated copy of the harvesting plan, and made familiar with the plan and local landmarks to the degree necessary to carry out the plan without the use of buoyage. Harvesting operations are regularly supervised by District staff.

Harvested Plant Material Transfer Site(s)

Off-loading of harvested plant material will take place at the City of Muskego lake access parcel Number 8 located on Shore Lane on the southern end of Little Muskego Lake. Plant material will be removed from the harvester on a transporter and conveyed to off-loading area, where it will be transferred to a dump truck using a conveyor and transported to disposal sites identified by the Little Muskego Lake Management District in consultation with the City of Muskego. Plant material will be collected and disposed of daily to avoid leaching of nutrients back into the Lake and to minimize the visual degradation of the environment near the boat launching site. The operators will stringently police the off-loading site to ensure minimal disruption of boaters and of the people using the riparian areas of the Lake.

Disposal of Harvested Plant Material

Harvested plant material will be used as land-spread on area farms.

Precautions to Protect Wildlife and Ecologically Valuable Areas

Operators will be provided with a laminated copy of the approved harvesting plan map and flowchart, as set forth in Map A-4 and Figure A-2, showing the limits of harvesting operations. A copy of this map will be kept on the harvester at all times. Operations will be forbidden in those areas of three feet or less in depth to protect bass habitat and spawning areas. Harvesting operations in the areas identified as suitable for bass spawning will be restricted until July to permit undisturbed spawning.

Public Information

It is the policy of the Little Muskego Lake Management District to maintain an active dialogue with the community. This dialogue is carried out through the medium of the public press and in public fora through various public meetings and other scheduled hearings. Further, the Little Muskego Lake Association holds regular public meetings at which issues of concern to lakeshore residents are discussed. The Association regularly publishes summaries of these meetings and the Lake Management District meetings in their newsletter, where necessary, personal contacts with homeowners will be made.

Harvesting Schedule

The harvesting season will begin no earlier than May 15 and will end no later than September 15 of each year. Harvesting will average 30 to 35 hours per week over a five-day week, depending on weather conditions and plant growth, to minimize recreational conflicts. Further, harvesting will be confined to daylight hours to minimize public disturbances resulting from harvester and plant removal operations. As provided for above, the harvesting operations will also be modified to protect fish spawning areas and other ecologically valuable areas of the Lake as set forth on Map A-4.

EQUIPMENT NEEDS AND OPERATION

Equipment Needs and Total Costs

Harvester:	Aquarius Systems model H-420	
Manufacturer:	Aquarius Systems, D&D Products, Inc., North Prairie, Wisconsin	
Costs:	(1) H-420 Aquatic Plant Harvester	$65,000
	(1) Trailer and Shore Conveyor	25,000
	Total Cost	$90,000

Maintenance Schedule, Storage, and Related Costs

Routine maintenance will be performed by the Little Muskego Lake Management District in accordance with the manufacturer's recommended maintenance schedule. Maintenance costs will be borne by the Little Muskego Lake Management District.

Winter storage of the harvesting equipment will be the responsibility of the Little Muskego Lake Management District. The harvester will be stored at the Municipal Garage.

Insurance Coverage

Insurance coverage on the harvester will be incorporated into the policy held by the Little Muskego Lake Management District on all capital equipment. Liability insurance for the operation of the harvester will also be borne by the District. The relevant certificates of insurance will be held by the Little Muskego Lake Management District.

Operators, Training, and Supervision

The harvester will be owned and operated by the Little Muskego Lake Management District, who will be responsible for day-to-day operations of the equipment. The District will provide operator training as required. District staff have extensive experience in the operation of this type of machinery. Initial training will be provided by Aquarius Systems on delivery of the machinery.

Day-to-day supervision will be by the District staff, with oversight by Lake District Commissioners.

EVALUATION AND MONITORING

Daily Record-Keeping Relating to the Harvesting Operation

Daily harvesting activities will be recorded by the operator in a harvester operations log. An annual summary of the harvesting program will be submitted to the Little Muskego Lake Management District (or designated Committee thereof), and made available to the public at that time.

It is the intention of the Little Muskego Lake Management District to undertake a periodic, formal review of the harvesting program as set forth in the Management Plan for Little Muskego Lake, a copy of which has been lodged with the Department's Southeast District Office.

Daily Record-Keeping Relating to the Harvester

Daily maintenance and service records showing engine hours, fuel consumed and oil used will be recorded in a harvester operations log.

Appendix B

NONPOINT SOURCE POLLUTION CONTROL, STREAM CHANNEL REHABILITATION AND LAKE REHABILITATION MEASURES IN REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE AND STATUS REPORT

NONPOINT SOURCE POLLUTION CONTROL MEASURES

Nonpoint, or diffuse, sources of water pollution include urban sources such as runoff from residential, commercial, industrial, transportation, and recreational land uses; construction activities; and onsite sewage disposal systems and rural sources such as runoff from cropland, pasture, and woodland, atmospheric contributions, and livestock wastes. These sources of pollutants discharge to surface waters by direct overland drainage, by drainage through natural channels, by drainage through engineered stormwater drainage systems, and by deep percolation into the ground and subsequent return flow to the surface waters.

A summary of the methods and estimated effectiveness of nonpoint source water pollution control measures is set forth in Table B-1. These measures have been grouped for planning purposes into two categories: basic practices and additional. Application of the basic practices will have a variable effectiveness in terms of control level of pollution control depending upon the subwatershed area characteristics and the pollutant considered. The additional category of nonpoint source control measures has been subdivided into four subcategories based upon the relative effectiveness and costs of the measures. The first subcategory of practices can be expected to generally result in an about 25 percent reduction in pollutant runoff. The second and third subcategory of practices, when applied in combination with the minimum and additional practices, can be expected to generally result in up to a 50 and 75 percent reduction in pollutant runoff, respectively. The fourth subcategory would consist of all of the preceding practices, plus those additional practices that would be required to achieve a reduction in ultimate runoff of more than 75 percent.

Table B-1 sets forth the diffuse source control measures applicable to general land uses and diffuse source activities, along with the estimated maximum level of pollution reduction which may be expected upon implementation of the applicable measures. The Table also includes information pertaining to the costs of developing the alternatives set forth in this chapter.[1] These various individual nonpoint source control practices are summarized by group in Table B-2.

Of the sets of practices recommended for various levels of diffuse source pollution control presented in Table B-2, not all practices are needed, applicable, or cost-effective for all watersheds, due to variations in pollutant loadings and land use and natural conditions among the watersheds. Therefore, it is recommended that the practices indicated as needed for nonpoint source pollutant control be refined by local level nonpoint source control practices planning, which would be analogous to sewerage facilities planning for point source pollution abatement. A locally prepared plan for nonpoint abatement measures should be better able to blend knowledge of current problems and practices with a quickly evolving technology to achieve a suitable, site specific approach to pollution abatement.

STREAM CHANNEL REHABILITATION MEASURES

The ability of streams in southeastern Wisconsin to satisfy desired water use objectives is contingent on the tributary pollution loads to the stream and the instream characteristics. In recognizing the need to harmonize these two management aspects within a comprehensive water quality plan, the Commission proposes stream bank protection measures as a best management practice, in addition to land management measures. Stream

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[1] *Costs are presented in more detail in the following SEWRPC Technical Reports: No. 18, State of the Art of Water Pollution Control in Southeastern Wisconsin, Volume three: Urban Storm Water Runoff, July 1977; No. 18, State of the Art of Water Pollution Control in Southeastern Wisconsin, Volume four: Rural Storm Water Runoff, December 1976; and No. 31, Costs of Urban Nonpoint Source Water Pollution Control Measures, June 1991.*

Table B-1

GENERALIZED SUMMARY OF METHODS AND EFFECTIVENESS OF DIFFUSE SOURCE WATER POLLUTION CONTROL MEASURES

Applicable Land Use	Control Measures[a]	Summary Description	Approximate Percent Reduction of Released Pollutants[b]	Assumptions for Costing Purposes
Urban	Litter and pet waste control ordinance	Prevent the accumulation of litter and pet waste on streets and residential, commercial, industrial, and recreational areas	2-5	Ordinance administration and enforcement costs are expected to be funded by violation penalties and related revenues
	Improved timing and efficiency of street sweeping, leaf collection and disposal, and catch basin cleaning	Improve the scheduling of these public works activities, modify work habits of personnel, and select equipment to maximize the effectiveness of these existing pollution control measures	2-5	No significant increase in current expenditures is expected
	Management of onsite sewage treatment systems	Regulate septic system installation, monitoring, location, and performance; replace failing systems with new septic systems or alternative treatment facilities; develop alternatives to septic systems; eliminate direct connections to drain tiles or ditches; dispose of septage at sewage treatment facility	10-30	Replace one-half of estimated existing failing septic systems with properly located and installed systems and replace one-half with alternative systems, such as mound systems or holding tanks; all existing and proposed onsite sewage treatment systems are assumed to be properly maintained; assume system life of 25 years. The estimated cost of a septic tank system is $5,000-$6,000 and the cost of an alternative system is $10,000. The annual maintenance cost of a disposal system is $250. An in-ground pressure system is estimated to cost $6,000-$10,000 with an annual operation and maintenance cost of $250. A holding tank would cost $5,500-$6,500 with an annual operation and maintenance cost of $1,800
	Increased street sweeping	On the average, sweep all streets in urban areas an equivalent of once or twice a week with vacuum street sweepers; require parking restrictions to permit access to curb areas; sweep all streets at least eight months per year; sweep commercial and industrial areas with greater frequency than residential areas	30-50	Estimate curb miles based on land use, estimated street acreage, and Commission transportation planning standards; assume one street sweeper can sweep 2,000 curb miles per year; assume sweeper life of 10 years; assume residential areas swept once weekly, commercial and industrial areas swept twice weekly. The cost of a vacuum street sweeper is approximately $120,000. The cost of the operation and maintenance of a sweeper is about $25 per curb/mile swept
	Increased leaf and clippings collection and disposal	Increase the frequency and efficiency of leaf collection procedures in fall; use vacuum cleaners to collect leaves; implement ordinances for leaves, clippings, and other organic debris to be mulched, composted, or bagged for pickup	2-5	Assume one equivalent mature tree per residence plus five trees per acre in recreational areas; 75 pounds of leaves per tree; 20 percent of leaves in urban areas not currently disposed of properly. The cost of the collection of leaves in a vacuum sweeper and disposal is estimated at $180-$200 per ton of leaves

Table B-1 (continued)

Applicable Land Use	Control Measures[a]	Summary Description	Approximate Percent Reduction of Released Pollutants[b]	Assumptions for Costing Purposes
Urban (continued)	Increased catch basin cleaning	Increase frequency and efficiency of catch basin cleaning; clean at least twice per year using vacuum cleaners; catch basin installation in new urban development not recommended as a cost-effective practice for water quality improvement	2-5	Determine curb miles for street sweeping; vary percent of urban area served by catch basins by watershed from Commission inventory data; assume density of 10 catch basins per curb mile; clean each basin twice annually by vacuum cleaner. The cost of cleaning a catch basin is approximately $10
	Reduced use of deicing salt	Reduce use of deicing salt on streets; salt only intersections and problem areas; prevent excessive use of sand and other abrasives	Negligible for pollutants addressed in this plan but helpful for reducing chlorides and associated damage to vegetation	Increased costs, such as for slower transportation movement, are expected to be offset by benefits such as reduced automobile corrosion and damage to vegetation
	Improved street maintenance and refuse collection and disposal	Increase street maintenance and repairs; increase provision of trash receptacles in public areas; improve trash collection schedule; increase cleanup of parks and commercial centers	2-5	Increase current expenditures by approximately 15 percent
	Parking lot stormwater temporary storage and treatment measures	Construct gravel-filled trenches, sediment basins, or similar measures to store temporarily the runoff from parking lots, rooftops, and other large impervious areas; if treatment is necessary, use a physical-chemical treatment measure such as screens, dissolved air flotation, or a swirl concentrator	5-10	Design gravel-filled trenches for 24-hour, five year recurrence interval storm; apply to off-street parking acreages. For treatment—assume four-hour detention time. The capital cost of stormwater detention and treatment facilities is estimated at $40,000-$80,000 per acre of parking lot area, with an annual operation and maintenance cost of about $200 per acre
	Onsite storage—residential	Remove connections to sewer systems; construction onsite stormwater storage measures for subdivisions	5-10	Remove roof drains and other connections from sewer system wherever needed; use lawn aeration if applicable; apply dutch drain storage facilities to 15 percent of residences. The capital cost would approximate $500 per house, with an annual maintenance cost of about $25
	Stormwater infiltration—urban	Construct gravel-filled trenches for areas of less than 10 acres or basins to collect and store temporarily stormwater runoff to reduce volume, provide groundwater recharge and augment low stream flows	45-90	Design gravel-filled trenches or basins to store the first 0.5 inch of runoff; provide at least a 25-foot grass buffer strip to reduce sediment loadings. The capital cost of a stormwater infiltration is estimated at $12,000 for a six-foot deep, 10-foot wide trench, and at $70,000 for a one-acre basin, with an annual maintenance cost of about $10-$350 for the trench, and of about $2,500 for the basin

Table B-1 (continued)

Applicable Land Use	Control Measures[a]	Summary Description	Approximate Percent Reduction of Released Pollutants[b]	Assumptions for Costing Purposes
Urban (continued)	Stormwater storage—urban	Store stormwater runoff from urban land in surface storage basins or, where necessary, subsurface storage basins	10-35	Design all storage facilities for a 1.5 inch of runoff event, which corresponds approximately to a five-year recurrence interval event with a storm event being defined as a period of precipitation with a minimum antecedent and subsequent dry period of from 12 to 24 hours; apply subsurface storage tanks to intensively developed existing urban areas where suitable open land for surface storage is unavailable; design surface storage basins for proposed new urban land, existing urban land not storm sewered, and existing urban land where adequate open space is available at the storm sewer discharge site. The capital cost for stormwater storage would range from $35,000 to $110,000 per acre of basin, with an annual operation and maintenance cost of about $40-$60 per acre
	Stormwater treatment	Provide physical-chemical treatment which includes screens, microstrainers, dissolved air flotation, swirl concentrator, or high-rate filtration, and/or disinfection, which may include chlorination, high-rate disinfection, or ozonation to stormwater following storage	10-50	To be applied only in combination with stormwater storage facilities above; general cost estimates for microstrainer treatment and ozonation were used; same costs were applied to existing urban land and proposed new urban development. Stormwater treatment has an estimated capital cost of from $900-$7,000 per acre of tributary drainage area, with an average annual operation and maintenance cost of about $35-$100 per acre
Rural	Conservation practices	Includes such practices as strip cropping, contour plowing, crop rotation, pasture management, critical area protection, grading and terracing, grassed waterways, diversions, wood for management, fertilization and pesticide management, and chisel tillage	Up to 50	Costs for Natural Resources Conservation Service (NRCS)-recommended practices are applied to agricultural and related rural land; the distribution and extent of the various practices were determined from an examination of 56 existing farm plan designs within the Region. The capital cost of conservation practices ranges from $3,000-$5,000 per acre of rural land, with an average annual operation and maintenance cost of from $5-$10 per rural acre

Table B-1 (continued)

Applicable Land Use	Control Measures[a]	Summary Description	Approximate Percent Reduction of Released Pollutants[b]	Assumptions for Costing Purposes
Rural (continued)	Animal waste control system	Construct stream bank fencing and crossovers to prevent access of all livestock to waterways; construct a runoff control system or a manure storage facility, as needed, for major livestock operations; prevent improper applications of manure on frozen ground, near surface drainageways, and on steep slopes; incorporate manure into soil	50-75	Cost estimated per animal unit; animal waste storage (liquid and slurry tank for costing purposes) facilities are recommended for all major animal operations within 500 feet of surface water and located in areas identified as having relatively high potential for severe pollution problems. Runoff control systems are recommended for all other major animal operations. It is recognized that dry manure stacking facilities are significantly less expensive than liquid and slurry storage tanks and may be adequate waste storage systems in many instances. The estimated capital cost and average operation and maintenance cost of a runoff control system is $100 per animal unit and $25 per animal unit, respectively. The capital cost of a liquid and slurry storage facility is about $1,000 per animal unit, with an annual operation and maintenance cost of about $75 per unit. An animal unit is the weight equivalent of a 1,000-pound cow
	Base-of-slope detention storage	Store runoff from agricultural land to allow solids to settle out and reduce peak runoff rates. Berms could be constructed parallel to streams	50-75	Construct a low earthen berm at the base of agricultural fields, along the edge of a floodplain, wetland, or other sensitive area; design for 24-hour, 10-year recurrence interval storm; berm height about four feet. Apply where needed in addition to basic conservation practices; repair berm every 10 years and remove sediment and spread on land. The estimated capital cost of base-of-slope detention storage would be about $500 per tributary acre, with an annual operation and maintenance cost of $25 per acre
	Bench terraces	Construct bench terraces, thereby reducing the need for many other conservation practices on sloping agricultural land	75-90	Apply to all appropriate agricultural lands for a maximum level of pollution control. Utilization of this practice would exclude installation of many basic conservation practices and base-of-slope detention storage. The capital cost of bench terraces is estimated at $1,500 per acre, with an annual operation and maintenance cost of $100 per acre
Urban and Rural	Public education programs	Conduct regional- and county-level public education programs to inform the public and provide technical information on the need for proper land management practices on private land, the recommendations of management programs, and the effects of implemented measures; develop local awareness programs for citizens and public works officials; develop local contact and education efforts	Intermediate	For first 10 years includes cost of one person, materials, and support for each 25,000 population. Thereafter, the same cost can be applied for every 50,000 population. The cost of one person, materials, and support is estimated at $55,000 per year

Table B-1 (continued)

Applicable Land Use	Control Measures[a]	Summary Description	Approximate Percent Reduction of Released Pollutants[b]	Assumptions for Costing Purposes
Urban and Rural (continued)	Construction erosion control practices	Construct temporary sediment basins; install straw bale dikes; use fiber mats, mulching and seeding; install slope drains to stabilize steep slopes; construct temporary diversion swales or berms upslope from the project	20-40	Assume acreage under construction is the average annual incremental increase in urban acreage; apply costs for a typical erosion control program for a construction site. The estimated capital cost and operation and maintenance cost for construction erosion control is $250-$5,500 and $250-$1,500 per acre under construction, respectively
	Materials storage and runoff control facilities	Enclose industrial storage sites with diversions; divert runoff to acceptable outlet or storage facility; enclose salt piles and other large storage sites in crib and dome structures	5-10	Assume 40 percent of industrial areas are used for storage and to be enclosed by diversions; assume existing salt storage piles enclosed by cribs and dome structures. The estimated capital cost of industrial runoff control is $2,500 per acre of industrial land. Material storage control costs are estimated at $75 per ton of material
	Stream protection measures	Provide vegetative buffer zones along streams to filter direct pollutant runoff to the streams; construct stream bank protection measures, such as rock riprap, brush mats, tree revetment, jacks, and jetted willow poles where needed	5-10	Apply a 50-foot-wide vegetative buffer zone on each side of 15 percent of the stream length; apply stream bank protection measures to 5 percent of the stream length. Vegetative buffer zones are estimated to cost $21,200 per mile of stream, and streambank protection measures cost about $37,000 per stream mile
	Pesticide and fertilizer application restrictions	Match application rate to need; eliminate excessive applications and applications near or into surface water drainageways	0-3	Cost included in public education program
	Critical area protection	Emphasize control of areas bordering lakes and streams; correct obvious erosion and other pollution source problems	Intermediate	Intermediate

[a]Not all control measures are required for each subwatershed. The characteristics of the watershed, the estimated required level of pollution reduction needed to meet the applicable water quality standards, and other factors will influence the selection and estimation of costs of specific practices for any one subwatershed. Although the control measures costed represent the recommended practices developed at the regional level on the basis of the best available information, the local implementation process should provide more detailed data and identify more efficient and effective sets of practices to apply to local conditions.

[b]The approximate effectiveness refers to the estimated amount of pollution produced by the contributing category (urban or rural)that could be expected to be reduced by the implementation of the practice. The effectiveness rates would vary greatly depending on the characteristics of the watershed and individual diffuse sources. It should be further noted that practices can have only a "sequential" effect, since the percent pollution reduction of a second practice can only be applied against the residual pollutant load which is not controlled by the first practice. For example, two practices of 50 percent effectiveness would achieve a theoretical total effectiveness of only 75 percent control of the initial load. Further, the general levels of effectiveness reported in the table are not necessarily the same for all pollutants associated with each source. Some pollutants are transported by dissolving in water and others by attaching to solids in the water; the methods summarized here reflect typical pollutant removal levels.

[c]For highly urbanized areas which require retrofitting of facilities into developed areas, the costs can range from $400,000 to $1,000,000 per acre of storage.

Source: SEWRPC.

Table B-2

ALTERNATIVE GROUPS OF DIFFUSE SOURCE WATER POLLUTION CONTROL MEASURES PROPOSED FOR STREAMS AND LAKE WATER QUALITY MANAGEMENT

Pollution Control Category	Level of Pollution[b] Control	Practices to Control Diffuse Source Pollution from Urban Areas[c]	Practices to Control Diffuse Source Pollution from Rural Areas[b]
Basic Practices	Variable	Construction erosion control; onsite sewage disposal system management; streambank erosion control	Streambank erosion control
	25 percent	Public education programs; litter and pet waste control; restricted use of fertilizers and pesticides; construction erosion control; critical areas protection; improved timing and efficiency of street sweeping, leaf collection, and catch basin cleaning; material storage facilities and runoff control	Public education programs; fertilizer and pesticide management; critical area protection; crop residue management; chisel tillage; pasture management; contour plowing; livestock waste control
Additional Diffuse Source Control Practices[a]	50 percent	Above, plus: Increased street sweeping; improved street maintenance and refuse collection and disposal; increased catch basin cleaning; stream protection; increased leaf and vegetation debris collection and disposal; stormwater storage; stormwater infiltration	Above, plus: Crop rotation; contour strip-cropping; grass waterways; diversions; wind erosion controls; terraces; stream protection
	75 percent	Above, plus: An additional increase in street sweeping, stormwater storage and infiltration; additional parking lot storm-water runoff storage and treatment	Above, plus: Base-of-slope detention storage
	More than 75 percent	Above, plus: Urban stormwater treatment with physical-chemical and/or disinfec-tion treatment measures	Bench terraces[c]

[a]*In addition to diffuse source control measures, lake rehabilitation techniques may be required to satisfy lake water quality standards—see Table B-4.*

[b]*Groups of practices are presented here for general analysis purposes only. Not all practices are applicable to, or recommended for, all lake and stream tributary watersheds. For costing purposes, construction erosion control practices, public education programs, and material storage facilities and runoff controls are considered urban control measures and stream protection is considered a rural control measure.*

[c]*The provision of bench terraces would exclude most basic conversation practices and base-of-slope detention storage facilities.*

Source: SEWRPC.

bank protection measures, primarily designed to prevent erosion and preserve streamside vegetation, are most applicable to natural stream channels. However, portions of streams which flow through the highly urbanized areas of the Region, such as the Menomonee and Kinnickinnic River watersheds, have undergone major channel modifications. These channelized stream reaches require specialized management techniques to provide a suitable habitat for fish and other aquatic life which serve as important indicators of the chemical and biological condition of a stream.

Channel modifications—more commonly called channelization—may include one or more of the following major changes to the natural stream channel, all designed to increase the capacity of the channel: straightening, widening, and deepening; placement of a concrete invert and concrete sidewalls; and construction of culverts to carry the stream under roads and railroads as needed. In some instances, a completely new length of channel may be constructed so as to bypass a natural channel reach, as has been done for a portion of Underwood Creek in the City of Wauwatosa. The function of channel modifications or enclosures is to yield a lower, hydraulically more efficient waterway through which a given flood discharge can be conveyed at a much lower flood stage relative to that which would exist under natural or prechannelization conditions. However, modified channels are detrimental to the support of fish and aquatic life for the following reasons:

1. They eliminate habitat areas needed by fish, aquatic insects, and benthic organisms. These habitat areas provide food, shelter, and spawning substrate necessary for the support of fish and other aquatic animals.

2. They eliminate plant substrate. Besides providing food, shelter, and spawning substrate for aquatic animals, aquatic plants provide oxygen to the water, remove nutrients, and trap sediments and other pollutants. Plants also provide shade, thereby lowering the temperature of the stream.

3. Some structures and dams provide barriers to the migration of fish and other aquatic animals, often necessary for feeding, spawning, and colonization purposes.

In addition, the aesthetic qualities of modified channels are generally poor, thereby reducing recreational use potential. Temporary storage of pollutants within the stream channel is also minimized, thereby increasing the first flush pollutant load effects on downstream receiving waters. These factors indicate that habitat improvement techniques, in addition to water pollution control measures, may need to be implemented to satisfy fish and aquatic life objectives within these channelized stream reaches.

The basic approach to improving the biological potential of a modified stream channel is to: 1) provide protective areas where a suitable sediment substrate may at least temporarily accumulate; 2) increase vegetative growth; and 3) eliminate barriers to aquatic animal migration. Table B-3 presents a description of selected measures which could be used to increase the biological potential of existing and future modified channels. In addition to providing suitable habitat for aquatic life, stream channel rehabilitation enhances the aesthetic qualities of the stream and—through temporary sediment storage, aeration, increased shading, and biological nutrient uptake—improves the water quality of the stream. It is recognized that most of these rehabilitation measures by their nature decrease the hydraulic efficiency of the stream channel. However, in many cases the hydraulic efficiency could be maintained at a level which would not preclude achievement of flood control design. A site-specific study would be required to determine the potential of each stream reach to provide biological habitat and at the same time be acceptable for flood control purposes.

LAKE REHABILITATION MEASURES

The reduction of nutrient inputs to lakes in southeastern Wisconsin, while preventing further water quality deterioration, may not necessarily result in the elimination of existing water quality problems. The indicated water quality improvements expected from a reduced nutrient input will be inhibited or prevented by conditions which include, for example, in eutrophic lakes, the presence of continued mixing or an anaerobic hypolimnion (the lower layer of a stratified lake), which may release significant amounts of phosphorus from the sediments to the overlying water column. Similarly, rooted aquatic plants may continue to grow prolifically in nutrient-rich bottom sediments, regardless of the nutrient content of the overlying water. If this occurs, or if other characteristics of a lake result in a restricted water use potential, the application of lake rehabilitation techniques should be considered.

Lake rehabilitation techniques that are applicable to southeastern Wisconsin include dredging, sediment covering or consolidation, nutrient inactivation, hypolimnetic aeration, and total aeration. Other techniques, perhaps more properly classified as lake management practices, would include macrophyte harvesting or chemical control, algae chemical control, and fish management. The applicability of experimental techniques, such as biological control, selective discharge, algal harvesting, dilution/flushing, and inflow treatment, requires additional study. Many of these techniques require federal and/or state permits to be issued prior to implementation. A brief description of lake rehabilitation techniques is set forth in Table B-4.

The applicability of specific lake rehabilitation techniques is highly dependent on the characteristics of an individual lake. As most techniques available have a relatively high cost, and as the state-of-the-art of lake

Table B-3

SELECTED BIOLOGICAL LIFE HABITAT REHABILITATION MEASURES FOR EXISTING AND PLANNED CHANNEL MODIFICATIONS

Rehabilitation Measure		Description and Application
Existing Modified Channels	Riffle and pool development	Use various methods below to create riffle-pool sequences. Riffles are sections of streams containing rocks, gravel, or other coarse substrate in which the current is swift enough to remove silt and sand. Riffles should occur at intervals equal to five to seven channel widths. A water depth of six inches is desirable. Riffles help aerate the stream and provide ideal biological habitat. Pools are deeper, slower sections of streams and provide valuable food and resting and refuge areas for fish. Pools ideally should be designed so that the sediments are not completely flushed out during storm events
	Installation of low gabion, rock, or concrete check dams	Low dams provide a pooling effect and accumulate sediment for biological habitat. Dams should be low enough to provide for fish migration
	Installation of gabion or rock wing deflectors	Wing deflectors provide a riffle-pool effect and accumulate sediment. They provide cover for fish and other aquatic life
	Use of scattered rocks	Installation of rocks create a riffle effect and provide cover for fish and other aquatic life. They also temporarily trap some sediment
	Vegetation improvement	Plant erosion-resistant native grasses, shrubs, and trees as close as practical to the stream channel to provide cover, food supply, and shade. Provide buffer strip along channel
	Removal of barriers to migrating species	Remove dams, drop structures, chutes, and steep grades which cannot be crossed by migrating fish and other aquatic life. Construct alternative grade control structures
Planned Modified Channels	Channel section and grade design	The low flow channel cross-section should approach a natural stream condition. The bottom width of the channel and the channel grade can be varied to create a riffle-pool sequence
	Avoidance of straight channels	Constructed channels should be aligned as much as possible with the natural stream curvature
	Vegetation and wetland preservation	Preserve native vegetation and wetlands as much as possible to provide shade trees and shrubs and maintain the water quality, environmental, and aesthetic benefits of wetlands
	Installation of channel bank reservoirs	Various storage measures may be incorporated into the channel bank design to temporarily store runoff, reduce size requirements for downstream channels, and accumulate sediment, thereby providing suitable biological habitat
	Avoidance of barriers to migrating species	Do not construct steep drop structures which cannot be crossed by fish or other aquatic life
	Use of construction erosion controls	Construction erosion controls are essential for channel modi fication projects. Stabilize the exposed surface, control runoff, and prevent sediment delivery to the stream

Source: SEWRPC.

management, for the most part, is still in its early stages of development, a cautious approach to implementing lake rehabilitation techniques is desirable. Application of any lake rehabilitation technique, therefore, should be contingent upon the completion of detailed, local, lake-specific management plans, which would be analogous to sewerage facilities planning for point source pollution abatement, and upon the actual experiences with the proposed technique in similar waterbodies in the Region, if possible. For these reasons, it is recommended that lake rehabilitation techniques be applied first to lakes in which: 1) nutrient inputs

Table B-4

DESCRIPTION OF LAKE REHABILITATION TECHNIQUES APPLICABLE TO SOUTHEASTERN WISCONSIN

Technique	Description and Effectiveness	Disadvantages
Dredging	Dredging is effective in deepening lakes. A hydraulic dredge is often used. Benefits are an increased depth, possible induced lake stratification, and reduced mixing of the sediments and water layers; removal of a suitable bottom substrata for macrophytes; improved navigation; and, if nutrient-poor sediments can be exposed, reduced nutrient release from sediments	Possible adverse environmental effects, increased turbidity during operation, nutrient release from disturbed sediments, and high costs
Sediment Covering	Covering lake sediments may prevent release of nutrients and organic material from the sediments, prevent continued resuspension of the sediments, inhibit macrophyte growth by elimination of suitable bottom stabilization of sediments, and minimization of water loss via infiltration. Several cover materials have been proposed, including sand, clay, plastic, rubber, fly ash, and gels	Unknown ecological and environmental impacts, possible return of macrophytes if an organic layer is deposited above the covering, possible algal problems if macrophytes are eliminated, and questionable long-term effectiveness
Sediment Consolidation	This technique involves lake drawdown and sediment drying. The dewatering reduces the volume of sediments which are highly organic, and increases the lake depth. The effects are irreversible; the sediments will not expand upon lake refilling	Sediment chemical changes may occur, increasing nutrient release to the water
Nutrient Inactivation	This technique has worked effectively for stratified lakes. The treatment may convert nutrients into a form unavailable for plant uptake, remove nutrients from the water column, and prevent release of nutrients from the sediments. The most commonly used material is alum (an aluminum compound), although iron compounds, calcium compounds, ion exchange resins, fly ash, and clay have also been used. Application may be on ice surfaces or under ice cover, or through water surface broadcast or subsurface manifold injection. This technique is effective in reducing algal problems	Limited applicability
Hypolimnetic (bottom) Aeration	The intent of this technique is to increase the dissolved oxygen content in the hypolimnion of stratified lakes without destroying the stratification. Typically, bottom water is lifted to the surface via a vertical tube and oxygenated water is returned to the hypolimnion. The decomposition of organic matter is increased and nutrient release is decreased. Available habitat for desirable fish species may be increased	The ecological effects of aeration need to be more thoroughly addressed. The practice is too expensive to be feasible in lakes larger than one or two hundred acres in size
Total Aeration/Circulation	The prevention of fish winterkill and the destratification of lakes to provide oxygen to bottom layers are the primary intents of this technique. The general approach has been to circulate and thereby destratify lakes by pumping or injecting compressed air to the bottom water. The effect of destratification during winter is the maintenance of an open water area, which increases photosynthesis and oxygen diffusion from the air	Destratification could eliminate cold water areas during summer required for some fish species
Macrophyte (weed) Harvesting	Harvesting macrophytes with mechanical harvesters increases the recreational use potential of lakes subject to with excessive plant growth	The macrophytes must be harvested every year and disposal may be a problem. Some nutrients are removed from the lake but the amounts are usually minimal in terms of the total nutrient content of the lake
Chemical Control	Excessive macrophyte growths, algal blooms, and undesirable fish populations may be controlled by chemical treatment. It is most applicable in highly eutrophic lakes where nutrient loads cannot be sufficiently reduced and where severe water use restrictions occur	Because of the potential adverse effects of adding poisonous chemicals to lakes, this technique requires cautious use in only the most extreme circumstances

Table B-4 (continued)

Technique	Description and Effectiveness	Disadvantages
Inflow Treatment	It is possible to treat inflowing surface runoff by many of the same procedures recommended for treatment of urban runoff	Required high levels of sophisticated equipment and technical expertise and high costs have prevented the adequate demonstration of this technique
Dilution/Flushing	This technique involves the replacement of nutrient-rich lake water with nutrient-poor water from a stream or the groundwater. The method may be effective in reducing algal blooms	Long-term effects are questionable. Dilution/flushing is probably not applicable to most lakes in the Region, which are characteristically shallow and contain nutrient-rich sediments
Selective Discharge	Selective discharge involves the release of nutrient-rich, anaerobic water from the hypolimnion of a eutrophic lake. Nutrient levels are reduced and dissolved oxygen in the hypolimnion is increased	Further research on the overall effectiveness of this technique is needed, and it appears that the water quality of downstream reaches would be adversely affected
Biological Controls	This technique is a highly desirable approach and is inexpensive. Techniques are generally categorized into predatory-prey relationships; species manipulation; and pathological reactions. Control organisms being evaluated include the white amur (grass carp), walleye, northern pike, snails, crayfish, waterfowl, insects, aquatic mammals, plant viruses, and fish parasites	This technique is still in the experimental stage and possible adverse environmental impacts could be substantial; grass carp are prohibited from being imported into Wisconsin

Source: Wisconsin Department of Natural Resources and SEWRPC.

to the lake have been reduced to below the critical level on the basis of watershed point and nonpoint source pollution control measures; 2) there is the greatest probability of success based upon the results of in-lake studies to be conducted prior to implementing a lake rehabilitation program; and 3) the possibility of adverse environmental impacts is minimal. Proper technical support and monitoring programs, together with additional research and development, should maximize the chance of successful lake management and minimize adverse environmental impacts, and provide a range of management experiences that can be transferred to other situations as appropriate.