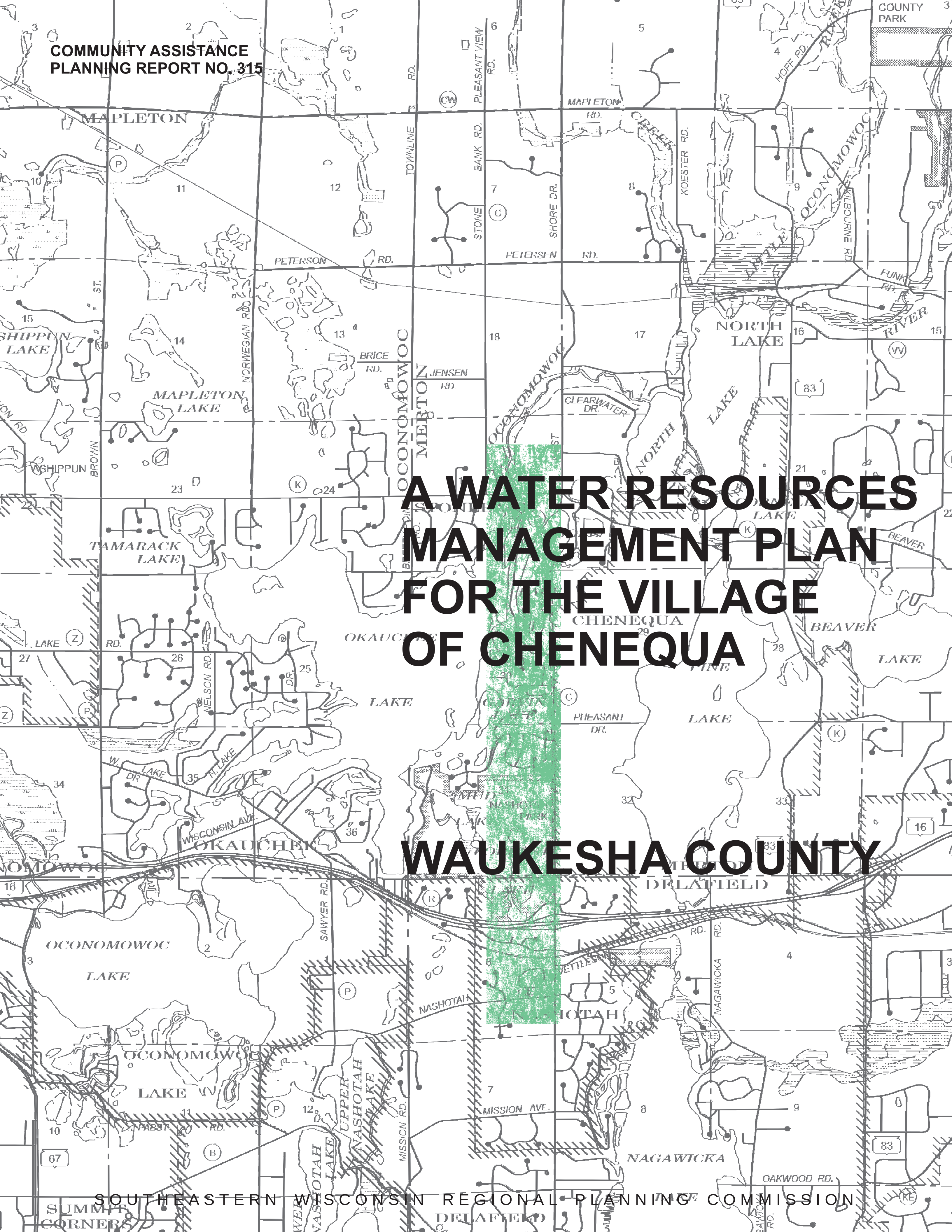
COMMUNITY ASSISTANCE
PLANNING REPORT NO. 315



A WATER RESOURCES MANAGEMENT PLAN FOR THE VILLAGE OF CHENEQUA

WAUKESHA COUNTY

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Special acknowledgement is due to Dr. Jeffrey A. Thornton, CLM, PH, former SEWRPC Principal Planner; Dr. Thomas M. Slawski, SEWRPC Principal Specialist Biologist; Ms. Beverly A. Saunders, SEWRPC Senior Specialist Biologist; Ms. Megan A. Beauchaine, SEWRPC Research Analyst; and Mr. Aaron W. Owens, SEWRPC Planner, for their contributions to the conduct of this study and the preparation of this report.

COMMUNITY ASSISTANCE PLANNING REPORT
NUMBER 315

A WATER RESOURCES MANAGEMENT PLAN FOR THE VILLAGE OF CHENEQUA WAUKESHA COUNTY, WISCONSIN

Prepared by the

Southeastern Wisconsin Regional Planning Commission
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June 2014

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Chapter I

INTRODUCTION

Residents of the Village of Chenequa and environs have become increasingly concerned about present and future impacts to Beaver, Cornell, North, and Pine Lakes and their ecosystems. In response to these concerns, the lake communities have created a Chapter 33, *Wisconsin Statutes*, public inland lake protection and rehabilitation district at North Lake, while the Beaver Lake community has created a Chapter 181, *Wisconsin Statutes*, nonstock, not-for-profit corporation to focus community actions on concerns related to Beaver Lake. The concerns raised are shared by all four Lakes, and relate to impacts such as decreased water clarity; increased growths of aquatic plants, including nonnative species such as Eurasian water milfoil; contamination of the lakes by nonpoint source pollutants; user-related aesthetic degradation and surface water use conflicts; and, potential development-related impacts likely to affect the water budgets of this chain-of-lakes. This comprehensive water resources management plan for the chain-of-lakes quantifies the magnitudes of these impacts and sets forth recommendations to 1) better control their consequences both to the Lakes and the lake-oriented communities and 2) provide for the continued recreational and residential use of the Lakes.

To this end, a phased program of lake and water resources management planning was undertaken as documented herein. This program is comprised of four components, involving all four lakes. The four components are: 1) groundwater model development, calibration, and scenario simulation by the U.S. Geological Survey (USGS); 2) hydrologic budget computation, also by USGS; 3) inventory compilation and analysis by the Southeastern Wisconsin Regional Planning Commission (SEWRPC); and 4) comprehensive management plan formulation, also by SEWRPC.

The Village of Chenequa is located in northwestern Waukesha County, in U.S. Public Land Survey Sections 4 and 5 in Township 7 North, Range 17 East, and Sections 20, 21, 28, 29, 32, and 33 in Township 8 North, Range 17 East. The Village is located between the Oconomowoc River to the north and the Bark River to the south, both of which form tributary streams to the Rock River. As shown on Maps 1 and 2, the Village lies almost entirely within the Oconomowoc River watershed.

The Village of Chenequa has abundant surface water and groundwater resources, with Pine Lake and Cornell Lake being located wholly within the Village limits, and North Lake and Beaver Lake being shared with the Town of Merton, in Waukesha County.[1] In recent years, the increase in urban area associated with the expansion of the City of Delafield, which has a shared border with, and is located immediately south of, the Village of

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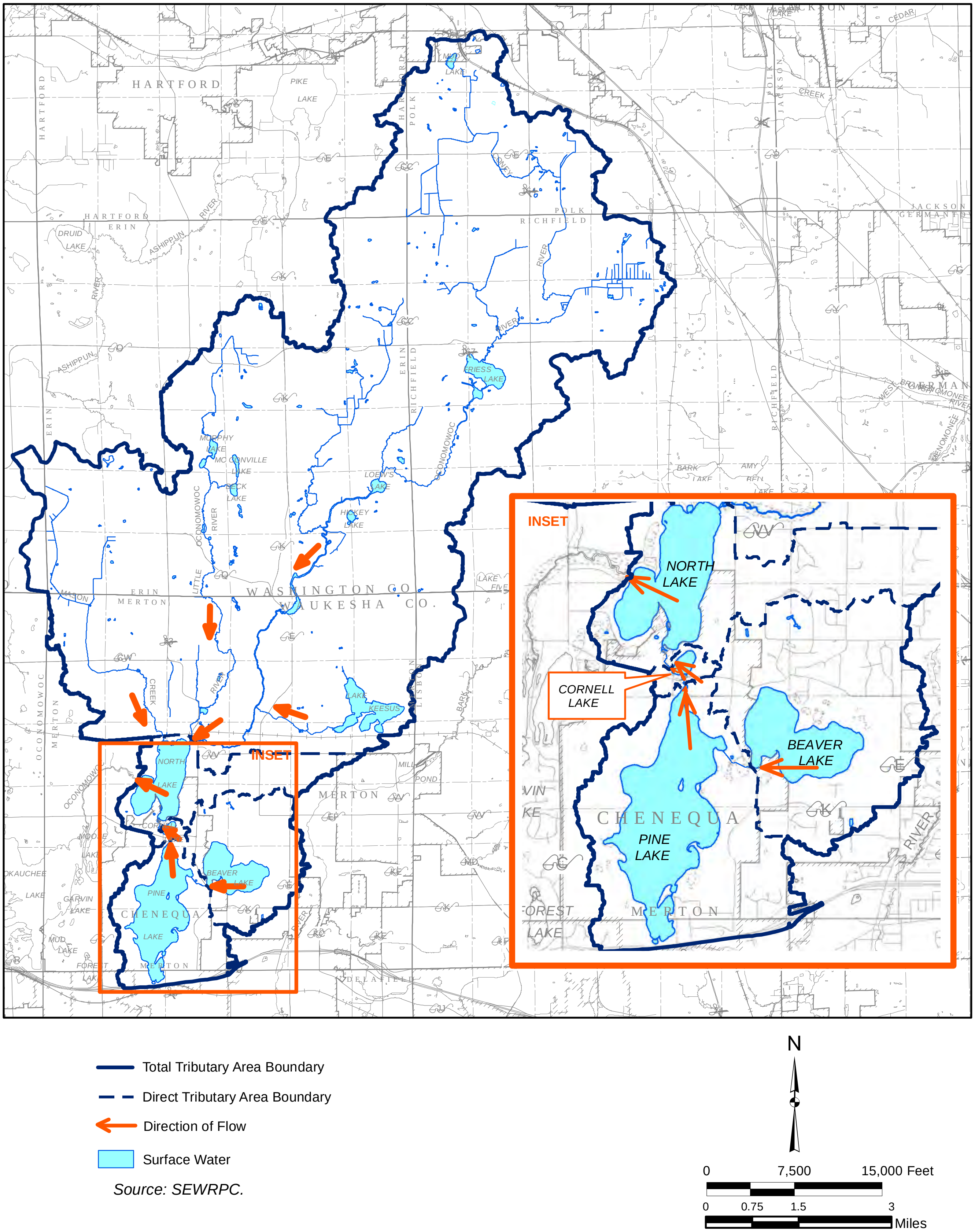
[1]*SEWRPC Memorandum Report No. 93,* A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report*, March 1995.*

Map 1

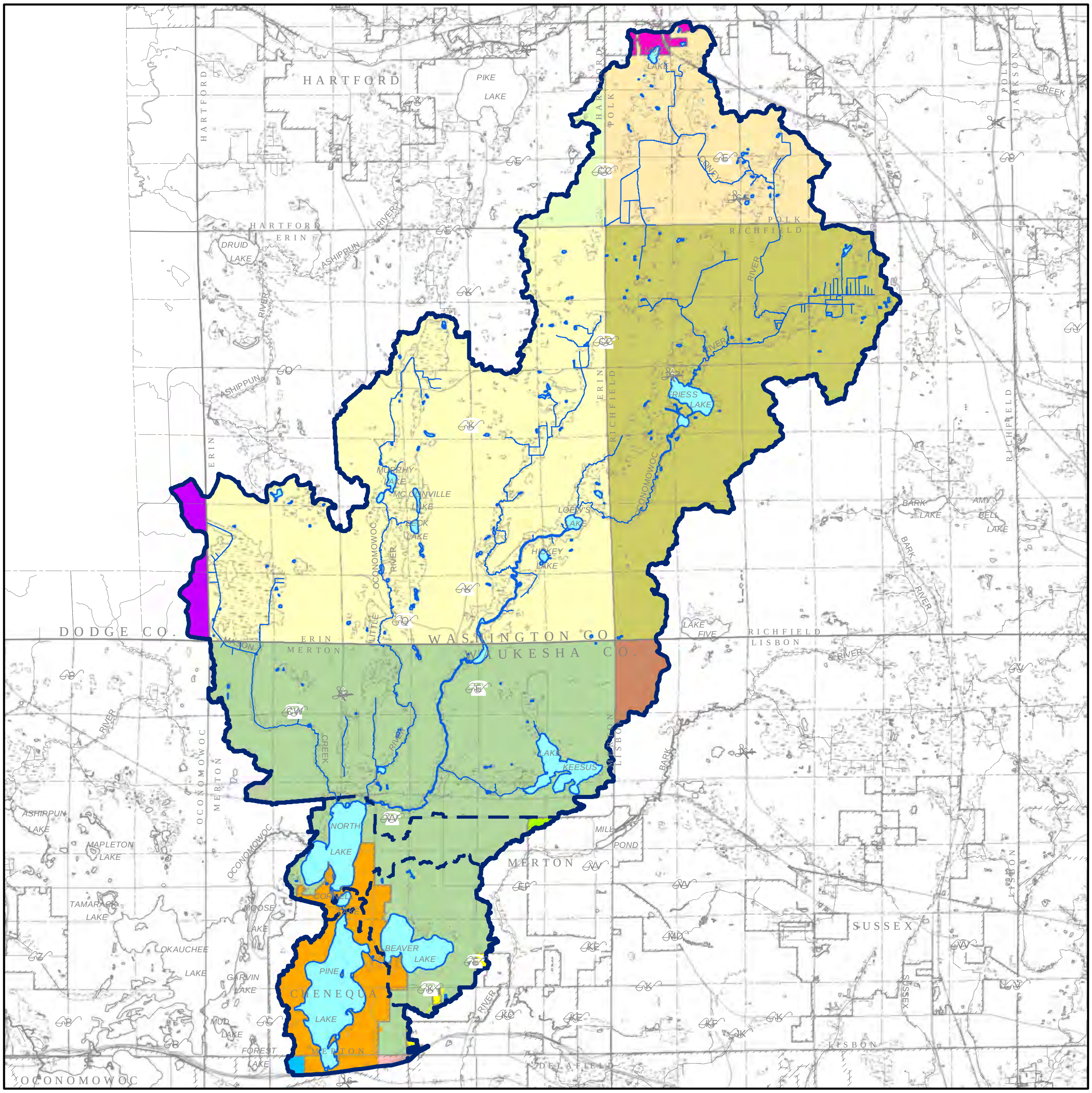
SURFACE WATER RESOURCES OF THE STUDY AREA



Source: SEWRPC.

Map 2

CIVIL DIVISIONS WITHIN THE STUDY AREA



CITY OF DELAFIELD
CITY OF HARTFORD
TOWN OF ASHIPPUN
TOWN OF ERIN
TOWN OF HARTFORD
TOWN OF LISBON
TOWN OF MERTON
TOWN OF OCONOMOWOC
TOWN OF POLK
VILLAGE OF CHENEQUA
VILLAGE OF HARTLAND
VILLAGE OF MERTON
VILLAGE OF NASHOTAH
VILLAGE OF RICHFIELD
VILLAGE OF SLINGER
TOTAL TRIBUTARY AREA BOUNDARY
DIRECT TRIBUTARY AREA BOUNDARY
SURFACE WATER

N

0 8,500 17,000 Feet

0 0.5 1 2 Miles

Source: SEWRPC.

Chenequa, has raised concerns among Village residents regarding groundwater/surface water interactions within the Village and environs. Of particular concern has been the potential impact of the use of shallow aquifer groundwater sources as a source of water supply by the northern portions of the City of Delafield.[2] This concern included the likely risks to the integrity of the Lakes within the Village that are fed primarily from groundwater sources.

In response to these concerns, the Village of Chenequa sought the assistance of the USGS,[3] and SEWRPC, in evaluating and addressing these risks. This water resources management plan responds to that request for assistance by documenting the relationships between the Lakes, the Rivers and the groundwater resources encompassed within the Village boundary; quantifying the water budgets of the Lakes; and providing recommended management measures that can be readily implemented by the Village, surrounding municipalities, Waukesha County, and State of Wisconsin to protect and preserve these water resources for future generations. This plan addresses both water quality and water quantity, which collectively define the availability and utility of the water resources of the Village for both human purposes and environmental purposes.

NATURE OF THE CONCERNS

During the planning process associated with the publication of an aquatic plant management plan for Pine and Beaver Lakes,[4] the Village Trustees and residents of the Village of Chenequa expressed concerns about the potential impact of water withdrawals from the shallow aquifer on the water balances of the Lakes, and on the water supply for Village residents, which is provided by individual, private wells. These concerns were predicated upon the continued reliance on shallow aquifer groundwater supplies to provide these essential services, and upon the perception of the Village residents and their visitors that the Lakes located within, and adjacent to, the Village form an important and defining element of the natural resource base.[5] During the aquatic plant planning period, prior to 2007, the Region was experiencing a period of below normal rainfall which was resulting in declining lake levels.[6] Consequently, the potential for additional demands being placed on the shallow aquifer by the City of Delafield was identified at that time as a cause for concern in the Village.

The residents of the Village of Chenequa have observed declining water quality in the Lakes, primarily associated with the occurrence of algal blooms dominated by blue-green algae or cyanobacteria.[7] These algae tend to form

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[2]*SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin, *Volume One of Two Volumes*, Chapters 1-12, *December 2010.*

[3]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwest Waukesha County*, Wisconsin, 2011. Access at:* http://pubs.usgs.gov/sir/2010/5214/pdf/sir2010-5214.pdf .

[4]*SEWRPC Memorandum Report No. 173,* An Aquatic Plant Management Plan for Pine and Beaver Lakes Waukesha County Wisconsin*, October 2008.*

[5]*SEWRPC Planning Report No. 42,* A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin, *September 1997, as amended; see also SEWRPC Planning Report No. 48,* A Regional Land Use Plan for Southeastern Wisconsin: 2035*, June 2006.*

[6]*See U.S. Geological Survey Scientific Investigations Report No. 2008–5235,* Flood of June 2008 in Southern Wisconsin*, 2008; U.S. Geological Survey Water-Data Report No. WI-07-1,* Water Resources Data, Wisconsin: Water Year 2007*, 2008; and similar.*

[7]*SEWRPC Memorandum Report No. 173,* op. cit., *see Appendix A.*

surface scums on the Lakes, which are both unsightly and potentially toxic. Toxin levels measured during August 2007, however, were within the World Health Organization (WHO) guidelines for evaluating potential toxicity, measuring less than 0.10 micrograms per liter (µg/l) in Pine Lake and 0.38 µg/l in Beaver Lake. The WHO guideline value for potential toxicity is 1.0 µg/l of microcystin. Microcystins are cyclic nonribosomal peptides, or cyanotoxins, produced by cyanobacteria, that can be extremely toxic to plants and animals, including humans. These toxins can cause serious liver damage. Microcystin-LR, reported in the aforereferenced aquatic plant management plan, is one of over 80 variants of the toxin known to occur in nature.

The coincidence of these events—reduced lake levels and the occurrence of cyanobacterial toxicity in 2007—provided the impetus for the Village Trustees to seek specific information on factors affecting both the quantity and quality of the Village water resources.

WATER RESOURCES PLANNING PROGRAM

In response to the foregoing concerns, the Village requested the assistance of the SEWRPC staff in formulating a planning program to address both surface water- and groundwater-related water quality and water quantity concerns. To this end, SEWRPC staff, in close cooperation with the USGS staff, undertook the formulation of a comprehensive planning program for the Village that would involve quantification of surface and subsurface water flows within the Village, determination of the relationship of those flows to observed phenomena, such as the declining lake levels and occurrence of algal toxicity, and formulation of a response to the observed events. A phased water resources planning program was formulated and funded, in part, through the State of Wisconsin Lake Management Planning Grant program administered by the Wisconsin Department of Natural Resources (WDNR).

This planning program builds upon and refines the regional-scale planning program developed through the SEWRPC regional water supply planning program. The USGS modeling studies were developed as an element of the regional groundwater model as documented in SEWRPC Technical Report No. 41.[8] This regional model incorporated consideration of the long-term pumping of deep groundwater and its associated "cone of depression" or cumulative impact of this ongoing pumpage. Both steady-state and transient scenarios were generated.[9]

The water resources planning program was comprised of the following four elements: 1) measurement of surface water elevations and flows and groundwater levels within the Village; 2) calculation of the water budget for the surface water resources of the Village with an emphasis on Beaver, Pine, and Cornell Lakes; 3) identification and consideration of issues of concern relating to elements of the water budget; and 4) formulation of appropriate land and water management responses. The first two elements were undertaken by the USGS, and the last two elements were undertaken by SEWRPC. This report summarizes the findings of the USGS studies,[10] and sets forth alternative and a recommended water resources management program for the Village. The USGS scientific investigations report is included as Appendix A of this report.

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[8]*See SEWRPC Technical Report No. 41,* A Regional Groundwater Model for Southeastern Wisconsin, *June 2005.*

[9]Ibid.

[10]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214*, op. cit.

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Chapter II

WATER RESOURCES OF THE VILLAGE OF CHENEQUA

Surface water and groundwater systems collectively form the water resources of the Village of Chenequa. In fact, these resources are highly interconnected not only to each other, but also to the local precipitation and land use patterns which supply these resources with water from runoff and precipitation. This interconnected process, driven by the hydrologic cycle, as shown schematically in Figure 1, requires that all of these components, i.e., surface water, groundwater, local land use and climate, be well understood and considered when developing a water management plan. Accordingly, this chapter seeks to provide the best available information for better understanding the water resources, within, and affecting, the Village of Chenequa.

This chapter is split into three major sections, namely: 1) Surface Water Resources; 2) Groundwater Resources; and 3) Climate and Hydrology. The first section covers the physical characteristics, water quality, and surrounding land use of Beaver, Pine, Cornell and North Lakes, as well as the upstream Oconomowoc River. Additionally, this section includes discussions of surface runoff pollution sources for each Lake, as well as provides some information about fish and wildlife populations in each lake, and the recreational uses of each Lake. The second section describes the groundwater resources in the Region, by summarizing the results of the U.S. Geological Survey (USGS) study completed as a part of this planning effort. Finally, the third section describes the general climate and hydrology of this Region.

The information provided in this chapter provides a basis for understanding the water resources of the Village of Chenequa, as well as serves to inform the water management recommendations provided as a part of this plan.

SURFACE WATER RESOURCES

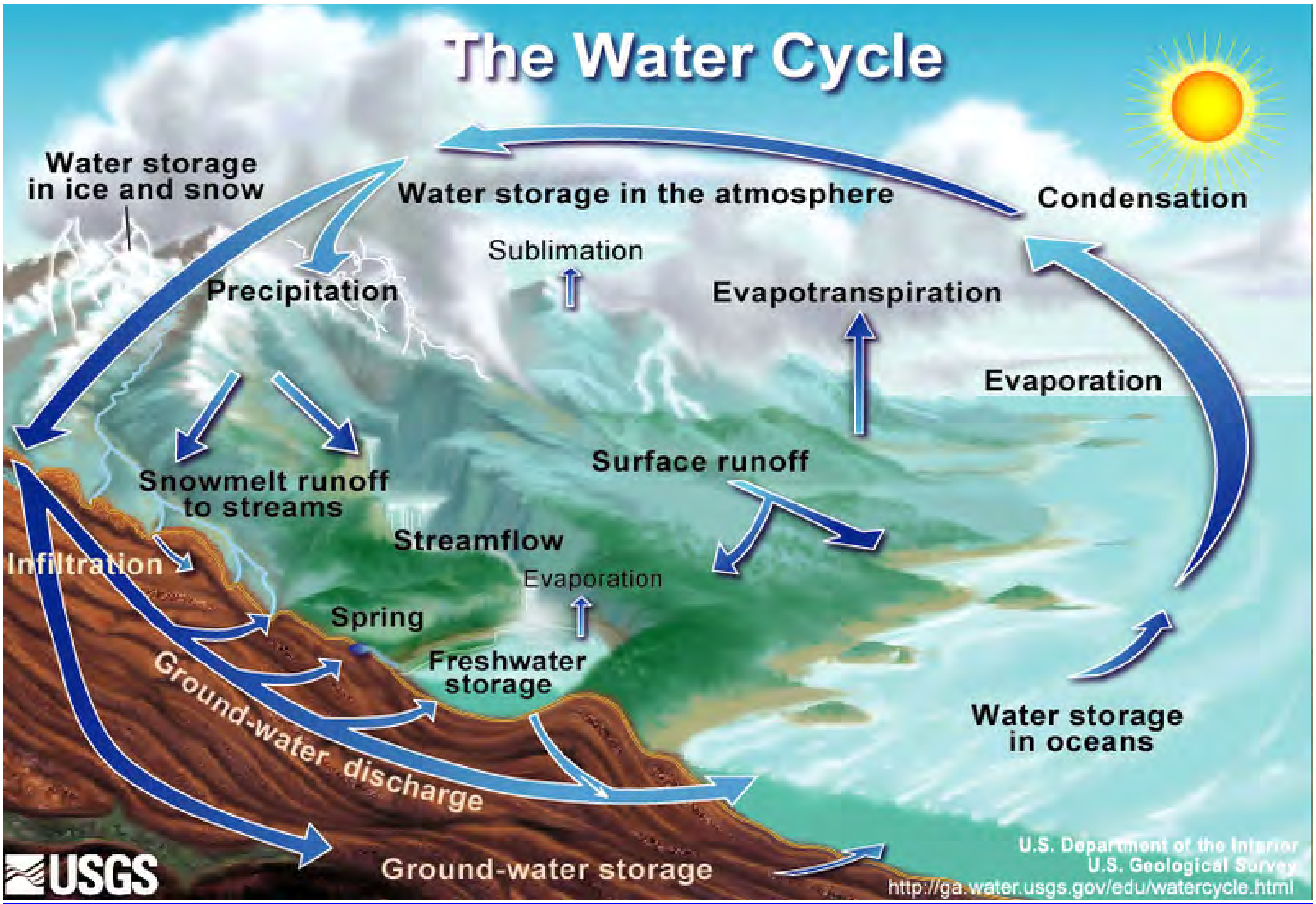
Waukesha County Hydrology

The topography of Waukesha County may be described as an undulating plain sloping to the southeast. Two major river systems, and several minor drainage systems, influence the direction of surface water flow in the County. The Illinois Fox River and its tributaries drain the central portion of the County to the south, while the Rock River drainage system drains the western portions of the County to the west. Both of these stream systems ultimately discharge into the Mississippi River. In addition, small portions of the County drain to Lake Michigan through the Menomonee River and Root River systems.

The majority of the natural lakes are located within the northwestern quarter of the County, along the line of the junction of the terminal moraines of the Green Bay and Lake Michigan lobes of the Late Wisconsin Ice Sheet. The moraine ridges are oriented generally in a south-to-north direction across the County. During the late Wisconsin stage of glaciation, which occurred approximately 10,000 years ago, the Green Bay glacier moved in a southeasterly direction, and the Michigan glacier moved in a southwesterly direction, across what is now

Figure 1

THE HYDROLOGICAL CYCLE



Source: U.S. Geological Survey.

Waukesha County. As a consequence, most of the natural lakes within the County lie along, and within, the parallel ridges in the area known as the Kettle Moraine.

Refined Surface Watershed Boundaries

The original water quality management plan for the Southeastern Wisconsin Region suggested that the surface waters of the Village, namely Beaver Lake, Pine Lake, Cornell Lake and North Lake, were internally drained or wholly contained within the boundary of the Village. This finding meant that the major lakes, specifically Pine Lake and Beaver Lake, lacked an outlet to either neighboring river system, either the Bark River to the south or the Oconomowoc River to the north.[1] This conclusion was based upon review of the landscape features, recorded on the USGS 7.5-minute topographic quadrangle maps, which were compiled at a contour interval of 10 feet. These maps were the best available topographic maps at that time.

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[1]*SEWRPC Planning Report No. 30,* A Regional Water Quality Management Plan for Southeastern Wisconsin—2000, *Volume Two*, Alternative Plans, *February 1979.*

In 2005, however, Waukesha County obtained a digital terrain model (DTM) that was used to develop two-foot contour interval maps suitable for display at a scale of one inch equals 100 feet. This information was used by the Southeastern Wisconsin Regional Planning Commission (SEWRPC) staff to refine the boundaries of the areas tributary to the lakes located wholly or partially within the Village of Chenequa. Based on this information, the surface drainage pattern was refined to show that Beaver Lake drained periodically to Pine Lake, which was connected by a defined flow channel through Cornell Lake to North Lake and the Oconomowoc River. Thus, for the purposes of this planning project, the Beaver Lake/Pine Lake/Cornell Lake/North Lake system is known to be a tributary system to the Oconomowoc River.

In short, given the new information, it can be concluded that the lakes located within and adjacent to the Village of Chenequa, are tributary to the Rock River and drain northwards to the Oconomowoc River, which trends in a southwesterly direction, roughly parallel with the Bark River to the south. North Lake is located on the Oconomowoc River, which flows into, and then out of, the Lake. The direction of water flow for the River as well as for Beaver, Pine, Cornell and North Lake are shown on Map 1, in Chapter I of this plan. The rest of this discussion will address each of these waterbodies individually in order to help understand the conditions affecting each of them.

Beaver Lake

Lake Morphometry

Beaver Lake is located in U.S. Public Land Survey Sections 21, 27, and 28, Township 8 North, Range 18 East, Town of Merton and Village of Chenequa, as shown on Map 2 in Chapter I of this report. Beaver Lake has a surface area of 316 acres, a maximum depth of 49 feet, and a shoreline development factor of 1.45, as shown in Table 1.[2] A seepage-fed lake[3] in the Kettle Moraine, Beaver Lake drains intermittently into Pine Lake through a culvert under STH 83, and, ultimately, into the Oconomowoc River system at North Lake through Pine and Cornell Lakes (see Map 1). The lake bottom consists primarily of sand and marl. The bathymetry of Beaver Lake is shown on Map 3.

Existing Land Use

The quality of a Lake is generally a product of the land use around the Lake. This is because different kinds of land uses result in different amounts, and different quality, of runoff. A commercial area with a lot of impervious surfaces such as parking lots, for example, can lead to a large amount of water runoff during heavy rain periods. This runoff would also likely contain the oils and pollutants which had previously accumulated on the impervious surfaces. In contrast, forested lands and wetlands, which have pervious cover, i.e., soils in which water can soak into, generally will soak up more water and will have natural pollution filtration capabilities through the removal of nutrients and pollutants by plant uptake and physical measures. Consequently, this kind of land use more likely produced low amounts of runoff of relatively good quality.

Due to this relationship between land and water quality, it is important to understand the land use around Beaver Lake, and all of the water resources discussed in this plan, in order to understand the "potential for pollution" for the Lake. Existing year 2010 land use information for Beaver Lake is shown graphically on Map 4. As of 2010, the land uses within Beaver Lake's 2,016 acre area direct tributary consisted of about 45 percent urban land uses and about 55 percent rural land uses, as shown in Table 2. Of the urban land uses, residential uses comprised

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[2]*Shoreline Development Factor is the ratio of shoreline length to the circumference of a circle with the same area. In general, when a high shoreline development factor is present this means that there is a large amount of shoreline. Since shorelines often good habitat for native plants and fish this can help indicate a biologically productive lake.*

[3]*Seepage fed means that all of its water supply is received by groundwater inputs and to a lesser extent precipitation directly on the Lake and its shorelines.*

Table 1

HYDROLOGY AND MORPHOMETRY OF THE CHENEQUA LAKES

Parameter	Beaver Lake	Cornell Lake	North Lake	Pine Lake
Size				
Surface Area of Lake	316 acres	41 acres	439 acres	703 acres
Total Tributary Area[a]	2,016 acres	96 acres	24,100 acres	2,081 acres
Lake Volume	4,740 acre-feet	164 acre-feet	17,480 acre-feet	27,417 acre-feet
Residence Time[b]	2.6 years	0.13 year	0.8 year	5.2 years
Shape				
Shoreline Development Factor[c]	1.45	1.78	1.31	1.96
Depth				
Maximum Depth	49 feet	12 feet	73 feet	85 feet
Mean Depth	15 feet	4 feet	40 feet	38 feet

[a]*The current measurement is based on elevation refinements made possible through SEWRPC digital terrain modeling analysis; excludes internally drained areas that do not contribute to surface runoff delivered to the Lakes on a frequently recurring basis.*

[b]*Residence time is estimated as the time period required for a volume of water equivalent to the volume of the lake to enter the lake during years of normal precipitation.*

[c]*Shoreline development factor is the ratio of the shoreline length to the circumference of a circular lake of the same area.*

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

about 763 acres, or approximately 38 percent of the total tributary area. Agricultural land uses comprised about 541 acres, or about 27 percent, of the total land in the area directly tributary to the Lake. The other major land uses were water (about 16 percent of the total area) and woodlands (about 11 percent).

Land Use Changes

Land use changes over time. In Wisconsin, generally these changes gravitate to the conversion of nonurban land, e.g., agricultural lands, forested areas, etc., to urban land uses, e.g., residential use, commercial use, etc. In order to control these changes, and prevent environmental degradation, land areas are “zoned” for particular types of development. Various components are considered prior to zoning being determined, including anticipated need for economic growth, anticipated population increases, environmental needs, etc. Planning for these changes in land use is crucial to water management because it can help prevent potential pollution prior to its deposition into the adjacent waterbodies. In general, the adopted County development plan[4] and the regional land use plan[5] indicate little potential for future urban development in the portion of the tributary area within the Village of Chenequa, but there is the potential for urban development in the Town of Merton.

In the Beaver Lake watershed, by the year 2035, the planned land uses, as shown on Map 5, will consist of about 69 percent urban land uses and about 31 percent rural land uses (see Table 2). Of the urban land uses, residential uses are expected to cover about 1,201 acres, or about 60 percent of the total tributary area. Agricultural land uses are anticipated to be comprised about 63 acres, or about 3 percent of the total tributary area. Other major land uses would be water (16 percent) and woodlands (10 percent).

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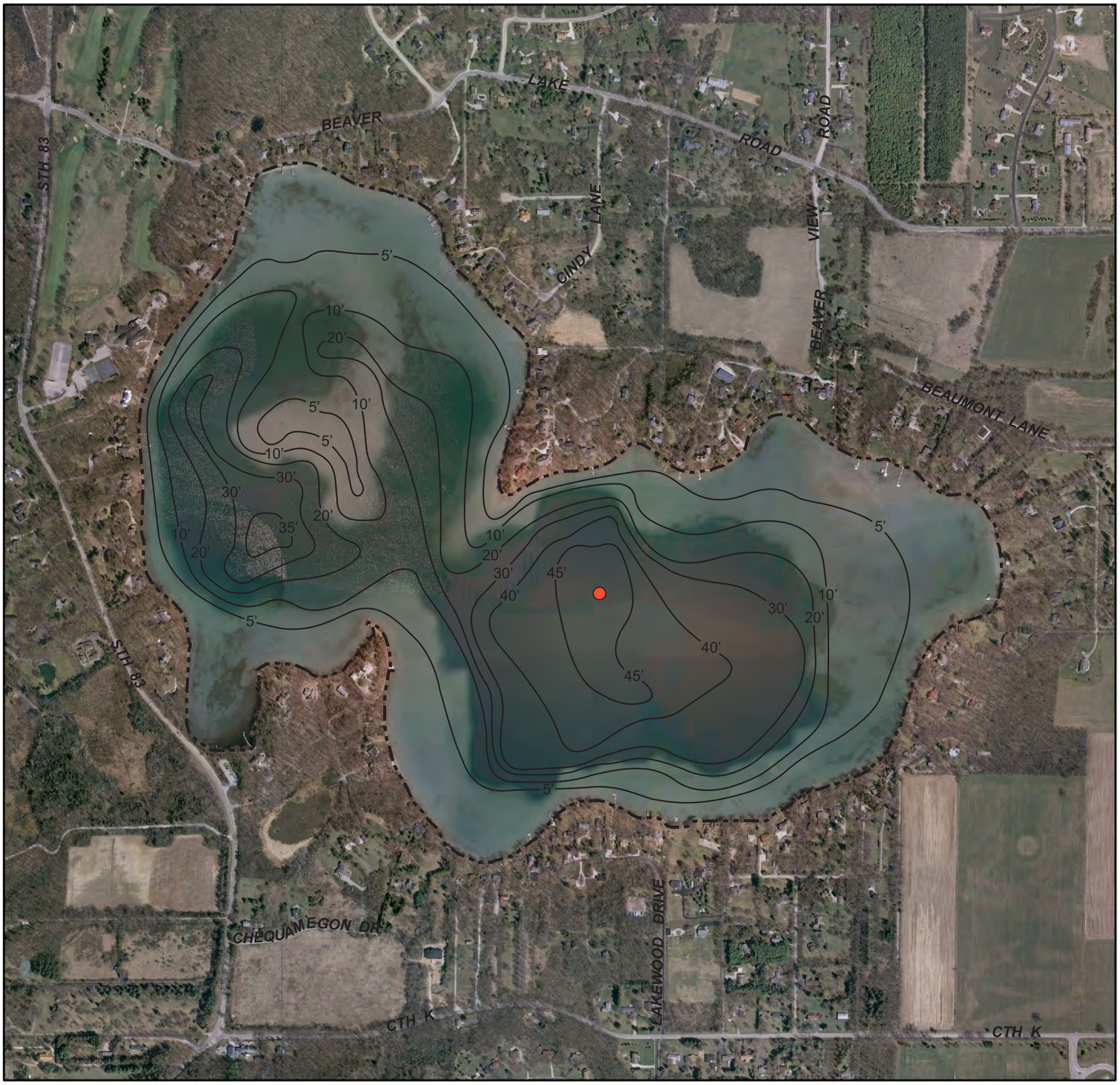
[4]*SEWRPC Community Assistance Planning Report No. 209,* A Development Plan for Waukesha County, Wisconsin, *August 1996, as amended.*

[5]*SEWRPC Planning Report No. 48,* A Regional Land Use Plan for Southeastern Wisconsin: 2035, *June 2006.*

Map 3

BATHYMETRIC MAP OF BEAVER LAKE



DATE OF PHOTOGRAPHY: APRIL 2005

20' WATER DEPTH CONTOUR IN FEET

MONITORING SITE

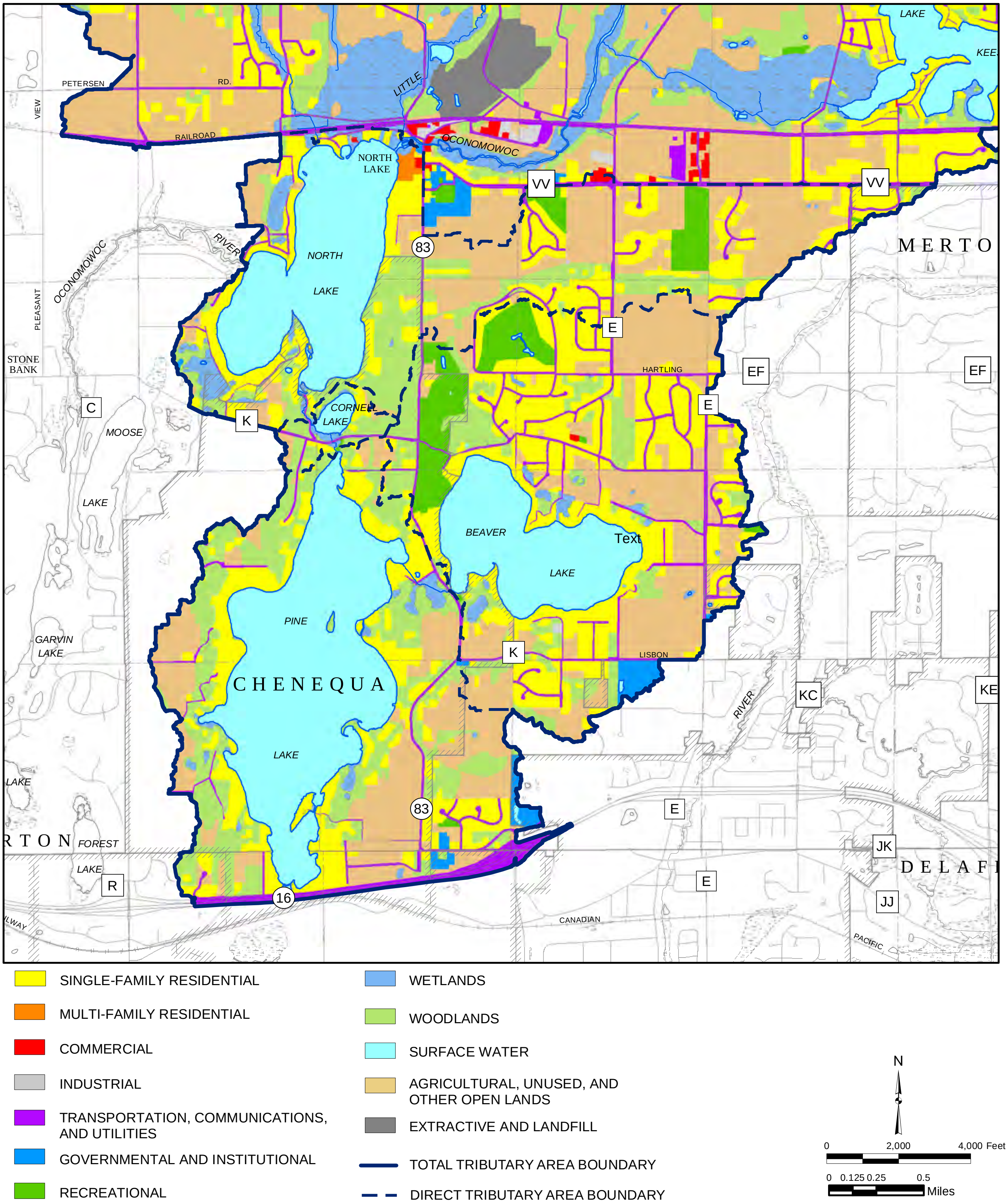
Source: U.S. Geological Survey and SEWRPC.

N

0 500 1000 FEET

Map 4

EXISTING LAND USE IN DIRECT TRIBUTARIES TO THE STUDY AREA: 2010



Source: SEWRPC.

Table 2

EXISTING AND PLANNED LAND USE WITHIN THE BEAVER LAKE TRIBUTARY AREA (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035

Land Use Categories[a]	2010 Acres	2010 Percent of Total	2035 Acres	2035 Percent of Total
Urban[b]				
Residential	763	37.8	1,201	59.6
Commercial	1	<0.1	1	<0.1
Industrial	1	<0.1	2	0.1
Governmental and Institutional	27	1.3	71	3.5
Recreational	118	5.9	120	6.0
Subtotal	910	45.1	1,395	69.2
Rural				
Agricultural and Other Open Lands	541	26.8	63	3.1
Wetlands	25	1.3	25	1.3
Woodlands	213	10.6	208	10.3
Water	327	16.2	325	16.1
Extractive	- -	- -	- -	- -
Landfill	- -	- -	- -	- -
Subtotal	1,106	54.9	621	30.8
Total	2,016	100.0	2,016	100.0

[a]*Parking included in associated use.*

[b]*Streets included in associated use.*

Source: SEWRPC.

Other Land Use Considerations

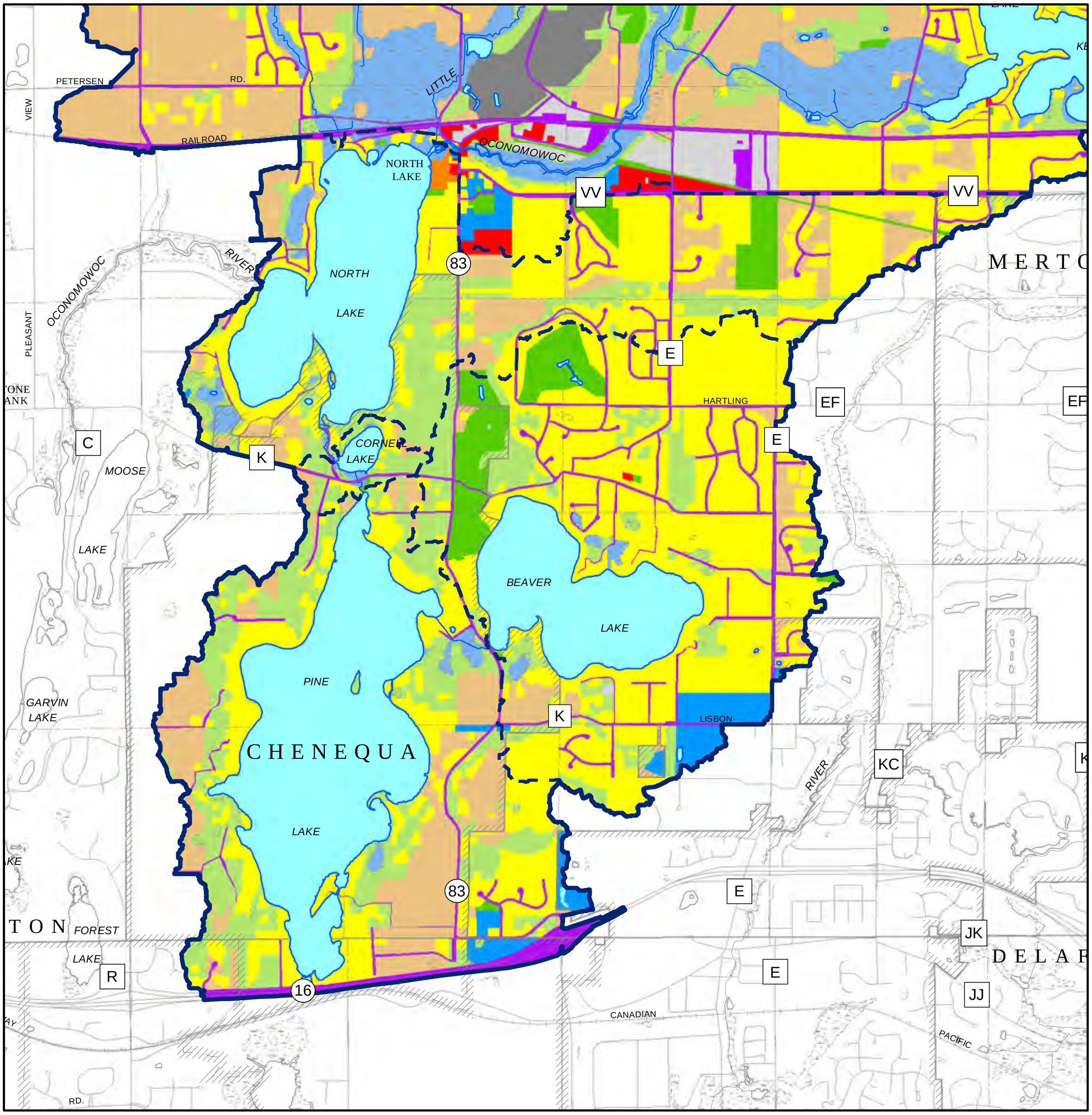
It is important to note that the land use codes used in the production of the 2010 and 2035 land use map are not always exactly reflective of on-the-ground conditions. This is due to the fact that some variation occurs with respect to how people use the lands which are given a particular classification. A farmer may choose to keep a proportion of their land forested, for example, thereby leading to the land looking different than the way the land use maps may imply. Consequently, the land use maps need be looked at to gain knowledge of the watershed and an understanding of local policies as it relates to land use.

This consideration is particularly true for Beaver Lake, and the other Lakes within the Village of Chenequa, due to the existence, and stringent enforcement, of an ordinance which restricts the cutting of trees and vegetation in residential areas within 75 feet of a waterbody[6] (as further discussed in Chapter III of this report). The results of these management efforts can be seen by comparing aerial photographs of the watershed with land use classifications and looking for mismatches as they relate to canopy cover. A schematic comparison of these two components in the Beaver Lake watershed is provided on Map 6, where it is evident that, even though much of the watershed is actually considered residential, canopy cover is quite high throughout the watershed. In fact, according to this analysis, the canopy covered area that is not considered forest encompasses about 252 acres, something that is not accounted for in land use classifications.

[6]*Village of Chenequa Ordinances*, Chapter 6: Zoning, *2009.*

Map 5

PLANNED USE IN DIRECT TRIBUTARIES TO THE STUDY AREA: 2035



SINGLE-FAMILY RESIDENTIAL

MULTI-FAMILY RESIDENTIAL

COMMERCIAL

INDUSTRIAL

TRANSPORTATION, COMMUNICATIONS, AND UTILITIES

RECREATIONAL

GOVERNMENTAL AND INSTITUTIONAL

WETLANDS

WOODLANDS

SURFACE WATER

AGRICULTURAL, UNUSED, AND OTHER OPEN LANDS

EXTRACTIVE AND LANDFILL

TOTAL TRIBUTARY AREA BOUNDARY

DIRECT TRIBUTARY AREA BOUNDARY

N

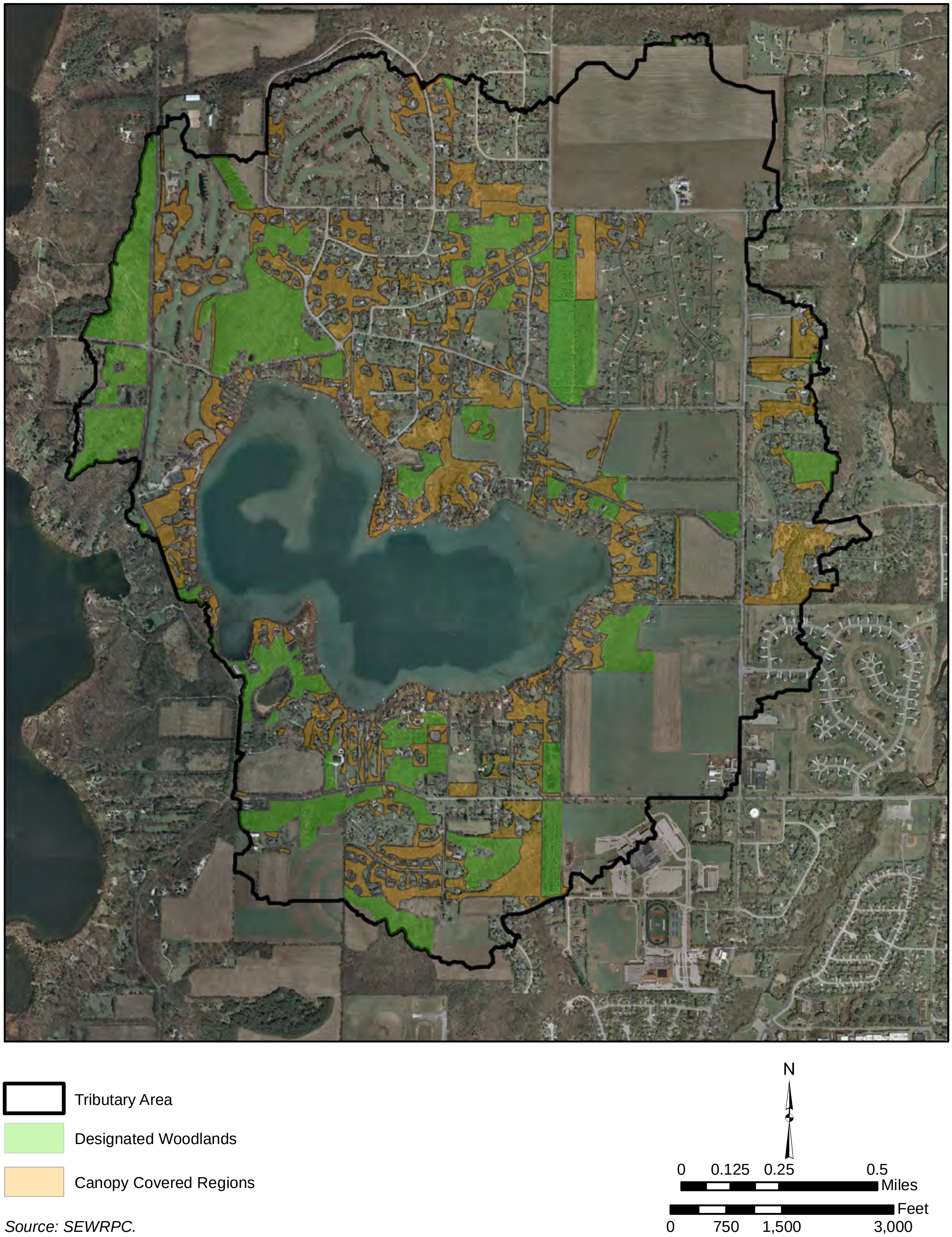
0 2,000 4,000 Feet

0 0.125 0.25 0.5 Miles

Source: SEWRPC.

Map 6

CANOPY COVER ANALYSIS FOR BEAVER LAKE WATERSHED



Source: SEWRPC.

Table 3

EXISTING AND FUTURE POLLUTION LOADS TO BEAVER LAKE (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035

Land Use Categories[a]	2010				2035 (no controls on new development loads)				2035 (NR 151 controls)[b]			
	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)
Urban												
Residential	7.4	153	- -	7.6	11.7	240	- -	12.0	8.3	196.5	0.0	8.9
Commercial	0.4	1	0.2	1.5	0.4	1	0.2	1.5	0.4	1.0	0.2	1.5
Industrial	0.6	2	0.3	2.2	0.6	2	0.3	2.2	0.6	2.0	0.3	2.2
Governmental and Institutional	6.8	36	1.9	21.4	18.1	96	5.0	56.8	9.1	66.0	2.8	32.0
Recreational	1.4	32	- -	- -	1.4	32	- -	- -	1.4	32.0	0.0	0.0
Subtotal	16.6	222	2.4	32.7	32.2	371	5.5	72.5	19.8	297.5	3.3	44.6
Rural												
Agricultural and Other Open Lands	98.1	387	- -	- -	14.3	55	- -	- -	14.3	55.0	0.0	0.0
Wetlands	- -	1	- -	- -	<0.1	1	- -	- -	<0.1	1.0	0.0	0.0
Woodlands	0.4	9	- -	- -	0.4	8	- -	- -	0.4	8.0	0.0	0.0
Water	30.7	42	- -	- -	30.6	42	- -	- -	30.6	42.0	0.0	0.0
Subtotal	129.2	439	- -	- -	45.3	106	- -	- -	45.3	106.0	0.0	0.0
Total	145.8	661	2.4	32.7	77.5	477	5.5	72.5	65.1	403.5	3.3	44.6

[a] *Parking included in associated use.*

[b] *Assumes a level of control consistent with the requirements of Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code*, which calls for an 80 percent reduction in total suspended sediment (TSS) from areas of new development. Consistent with that level of TSS reduction, a 50 percent reduction in total phosphorus and 70 percent reduction in metals was assumed.*

Source: SEWRPC.

Nonpoint Sources of Water Pollution

As mentioned above, different land uses produce different kinds of pollution, which then can drain into Lakes. Knowing this, studies have been completed in order to determine the average "pollutant load" per acre of each land use type with respect to phosphorous, sediment and heavy metals loads.[7] Using these averages in combination with land use data, it is, therefore, possible to develop predictions about how much pollution is entering a Lake from the surface watershed.

Under existing year 2010 conditions, Table 3 indicates that most of the nonpoint source sediment and phosphorus loads to Beaver Lake are generated from agricultural lands. The second largest sediment and phosphorus generator being residential lands. Under planned year 2035 conditions, agricultural lands would be expected to remain the largest source of sediment, but urban lands would be the greatest sources of phosphorus. The Oconomowoc River Priority Watershed Plan recommends minimal interventions within the Beaver Lake watershed to maintain the Lake in a mesotrophic condition.[8]

Under year 2010 land use conditions, it is estimated that approximately 661 pounds of phosphorus entered Beaver Lake, with about 404 pounds of phosphorus being expected to enter the Lake under year 2035 land use conditions, as shown in Table 3.[9] Under year 2010 land use conditions, it is also estimated that 146 tons of sediment would enter the Lake annually, with this load expected to decrease to 65 tons by 2035 as agricultural lands are converted to urban land uses and sediment controls are installed for new development as required under Chapter NR 151. Estimated copper and zinc loads, in contrast, are expected to increase from about 2.4 pounds of copper and about 32.7 pounds of zinc under 2010 land use conditions, to about 3.3 pounds of copper and 44.6 pounds of zinc under planned year 2035 conditions with NR 151 controls on runoff from new development. Those increases are primarily due to the increased urban development anticipated in the watershed, but as can be seen from Table 3, the implementation of the required controls on runoff from new development would have a significant effect in reducing the loads to the Lake, relative to the planned condition without controls.

Factors Affecting Loading Calculations

As mentioned above, land use codes do not always reflect how land is used within a certain classification. Though an area may be classified as commercial (having a large parking lot, for example), this land use code, and the associated unit area load associated with it, does not reflect the decisions that were made to reduce runoff on parking lots (e.g., impervious pavement, retention basins, rain gardens, green roofs, etc.). Consequently, the actions of those living within the watershed, and the enforcement of ordinances which reduce phosphorous and sediment loads, such as those implemented by the Village of Chenequa (see Chapter III), will result in less that which is predicted by the calculations made above.

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[7]*Cohn, T.A., Delong, L.L., Gilroy, E.J., Hirsch. R.M., and Wells, D.K.*, Estimating constituent loads*: Water Resources Research, v. 25, no. 5, p. 937-942, 198;* and *Corsi, S.R., Graczyk, D.J., Owens, D.W., and Bannerman, R.T.*, Unit-area loads of suspended sediment, suspended solids, and total phosphorus from small watersheds in Wisconsin: *U.S. Geological Survey Fact Sheet FS-195-97, 4 p., 1997.*

[8]*Wisconsin Department of Natural Resources Publication No. PUBL-WR-194 86,* Nonpoint Source Control Plan for the Oconomowoc River Priority Watershed Project, *March 1986.*

[9]*Under planned 2035 land use conditions, about 477 pounds of phosphorus could be washed off the land surface and delivered to the Lake in the absence of controls on runoff from planned development. Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code *requires implementation of stormwater management measures to reduce the total suspended solids (TSS) load from new development by 80 percent. A total phosphorus load reduction of about 50 percent and metals load reductions of about 70 percent are consistent with that level of TSS reduction. Thus, those load reduction factors were applied to the incremental loads from planned urban development between 2010 and 2035. The results are set forth in Tables 3, 7, 11, and 13.*

In Beaver Lake Watershed, for example, about a third of its residential land area is canopy cover (252 acres). This is classified as an area with medium impervious cover, which could lead to a runoff reduction of about 60 to 80 percent, in comparison to a fully impervious area depending on the conditions (according to studies conducted within the Wisconsin Region).[10] Consequently, the numbers given throughout this chapter as it relates to loading should really be used as a guidance for which areas need to be targeted for management, rather than an exact measure of pollution loading. Agricultural areas in Beaver Lake watershed, which are the primary source of sediments and phosphorous, for example, should be a focal area if phosphorous and sediments become an issue in the Lake.

Water Quality

Water clarity (i.e., Secchi-disk measurements), phosphorous concentrations, and algae measurements (i.e., chlorophyll-*a*) can all be used as indicators of "water quality." Water clarity, for example, tends to decrease as algae growth and sediments enter a lake, and thereby can be used as an indicator of pollution. Similarly, high phosphorous concentrations can stimulate high aquatic plant growth, as well as algae growth, and therefore can act as an indicator of "impairment." Relatedly, these measurements also help determine what is called a "trophic status." This classification, of either oligotrophic, mesotrophic, or eutrophic, essentially just refers to how biologically productive a lake is, and is highly related to the nutrient content of a Lake. Figure 2 provides an illustration of these different classifications. It is important to note that each of these classifications can happen naturally (i.e., without human interference) depending on the geology and location of the Lake and so these classifications should be looked at within the context of their geographic locations. There is, however, a special status, called hyper-eutrophic, which is generally only reached when humans over saturate the Lake with nutrient pollution, such as phosphorous from fertilizers. Figure 3, shows a picture of a lake considered "hyper eutrophic."

In general, monitoring phosphorous, algae, and water clarity, and in turn calculating a lake's trophic status over time, is a good way to keep track of a lake's "health" over time, and a good way to guide management efforts. If construction is causing erosion within the watershed, for example, it may be possible to see phosphorous increase, water clarity decrease, and algae increase during that period. These measurements can then help substantiate any future recommendations as it relates to upstream construction. This is why engaging in lake monitoring activities, like the Citizen Lake Monitoring Network (CLMN), is often crucial. Unfortunately, unlike some of the other Lakes within the Village of Chenequa, Beaver Lake has not had consistent water quality monitoring. In fact, the only field data that exists for the Lake was taken between 1973 and 1975, by the Wisconsin Department of Natural Resources (WDNR), and in 1995, through a statewide lake basin assessment. There are also some satellite based measurements of water clarity that were recorded in Beaver Lake from 2003 to 2012, as shown in Table 4. This data is collected by WDNR on many of the Lakes in Wisconsin; however, the accuracy of this data can vary widely and should be used only if it can be periodically checked against field samples. Consequently, due to the variation that was found on many of the recorded dates, as well as due the lack of field data to compare against, the satellite data should not be included in any analysis of the water quality of Beaver Lake.

None-the-less, we can make some conclusions related to the state of Beaver Lake, based on the limited data available. Available water quality data, for example, indicates that Beaver Lake had "good" to "very good" water quality both in the 1970s and in 1995, as can be inferred from Figure 4. Additionally, the Lake can be classified as an oligo-mesotrophic waterbody, or marginally enriched waterbody, with a Wisconsin Trophic State Index[11]

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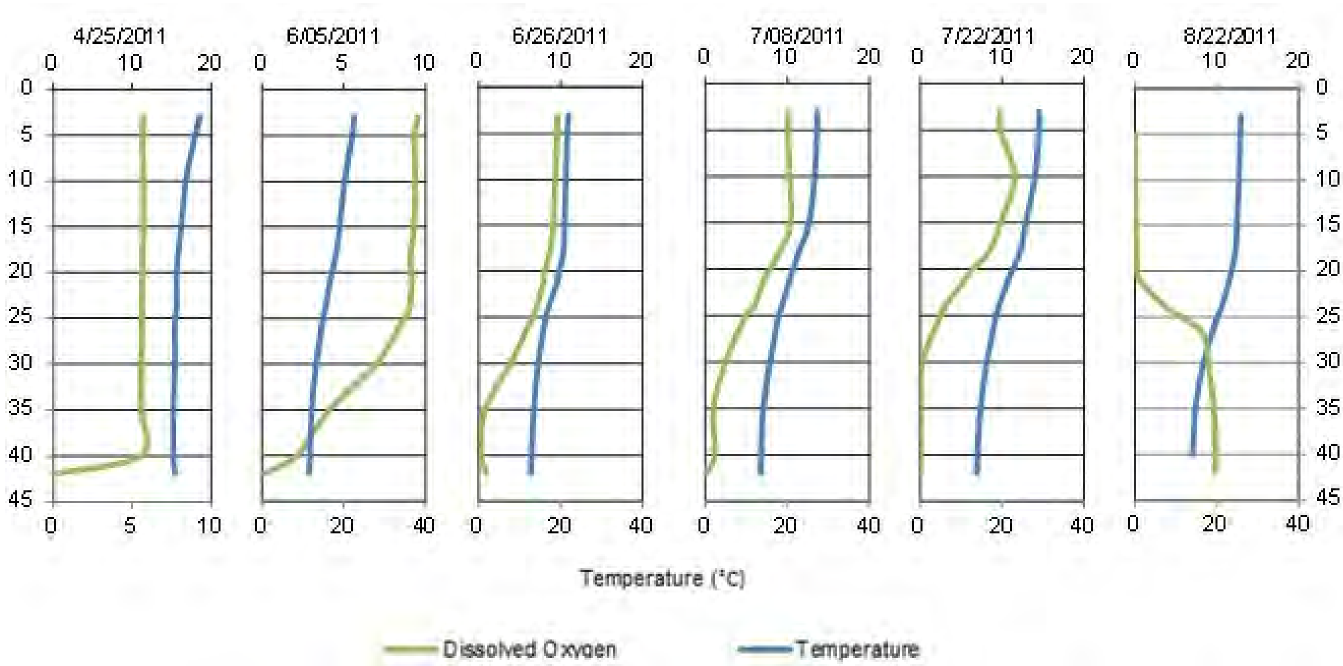
[10]*M.C. Dwyer and R.W. Miller,* Using GIS to Assess Canopy Benefits, *Journal of Arboriculture Vol. 25, March 1999.*

[11]*Trophic State Indices, or TSI's are based on near-surface concentrations of total phosphorous, chlorophyll*a *and Secchi depths, were developed by Carlson (1977) and modified for Wisconsin lakes by Lillie and others (1993). TSI's less than 40 indicate oligotrophic lakes, TSI's between 40 and 50 indicate mesotrophic lakes, TSI's greater than 50 indicate eutrophic lakes, and TSI's greater than 60 are considered hypereutrophic.*

Figure 2

STRATIFICATION IN SILVER LAKE



Source: SEWRPC.

(Wisconsin TSI) rating of approximately 36. The mean Secchi-disk transparency measurement, i.e., the measure of water clarity, was 9.4 feet or about 3.0 meters, and chlorophyll-*a*, i.e., the measure of the green pigments associated with algae, was measured once in 1995 at about 6.4 µg/l. Each of these measures is considered within the "good" water quality range, as determined by WDNR. A chlorophyll-*a* concentration greater than 10 micrograms per liter (µg/l) can result in a green coloration of the water visible to the human eye.

The mean total phosphorus concentration in the Lake for the mid 1970s is reported to be approximately 24 µg/l. In general, the standard for a healthy Lake is below 20 mg/l, thereby indicating that Beaver Lake had an issue with phosphorous loads during that time; however, as can be inferred by Figure 4, the phosphorous level found in 1995 was significantly lower that historical measurements, with a value of about 7.0 µg/l. This could indicate that the issue has been resolved since the 70s; however, more data would need to be collected to confirm this conclusion.

It is also important to note that zebra mussels[12] are present in Beaver Lake and were first officially recorded in the Lake in January of 2005. Though this species does tend to increase water clarity, due to its rapid consumption of particulates in the water column, there is no significant increase of water clarity recorded after this period (see Figure 4).

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[12]*Zebra mussels are high invasive, nonnative shellfish which cause significant damage or negative impacts to lake ecosystems through disrupting the food chain by feeding on and removing significant amounts of bacteria and smaller plankton. This reduces food available for a variety of other organisms such as larval and juvenile fishes, zooplankton, and native benthic organisms such as indigenous shellfish. Zebra mussels spread by attaching to boats which then get transported to other, noninfested lakes, if the boat is not cleaned.*

Figure 3

PHOTOGRAPH OF A HYPER-EUTROPHIC LAKE

Source: University of Minnesota, College of Natural Resources, 2003.

Other Monitored Parameters

In addition to phosphorous, chlorophyll-*a*, and water clarity, other parameters are also measured in lakes. These include nutrients such as nitrogen, ions such as sodium, and general characteristics such as alkalinity (i.e., buffering capacity). Several of these different parameters were measured in Beaver Lake in the 1970s and in 1995. The values that were found on these dates, as well as an explanation of each parameter, are shown in Table 5. Though none of the most recent values found in Beaver Lake were above regional averages or WDNR standards, there has been an apparent improvement in all of the parameters since the 1970s, with the exception of chlorides. This improvement could be due to mitigation measures within the watershed or the reduction of groundwater pollution, as previously discussed.

Chlorides in Beaver Lake, however, nearly tripled by 1995. Though this is fairly common within the all of the Lakes within Southeastern Wisconsin, as shown in Figure 5, where road salts, water softeners, and potash containing fertilizers all contribute to both surface and groundwater chloride pollution, it should still be considered an issue of concern. As stated in Table 5, the general standard for chlorides is around 250 mg/l, which is the point where stress can be seen on the native plants and animals; in 1995 the concentrations were at about 44 mg/l. It is likely that these concentrations have increased since that time and should, therefore, be considered a

Table 4

SATELLITE-BASED SECCHI-DISK MEASUREMENTS FOR BEAVER LAKE

Date	Satellite-Based Secchi Depth (feet)
07/27/99	17.0
09/02/01	23.0
09/17/03	11.2
07/25/04	25.8
07/19/05	12.4
08/03/07	3.9
06/28/09	8.8
07/07/09	17.8
08/15/09	6.7
08/24/09	28.5
08/31/09	25.9
07/01/10	6.7
07/10/10	27.8
07/17/10	37.4
08/18/10	6.3
08/27/10	19.9
09/12/10	17.1
09/28/10	33.9
07/04/11	14.8
07/05/11	15.3
08/22/11	13.8
08/29/11	18.6
09/07/11	13.9
07/31/12	13.9
09/01/12	15.8
10/03/12	14.5

Source: SEWRPC.

priority for monitoring. In general, further monitoring of the all parameters shown in Table 5, and subsequent comparison with historic values, would be particularly helpful when attempting to understand which pollutants to target (i.e., nutrients, chlorides, sediments, heavy metals, or all four) with future management efforts.

Confirming Loading Calculations

In order to validate the nutrient loading information developed from the SEWRPC unit area load (UAL) models, as discussed in the "Nonpoint Sources of Water Pollution" section of this chapter, it is possible to complete a series of calculations to determine what the phosphorus, Secchi disk, and chlorophyll-*a* measurements would be in a Lake. These numbers can then also be compared to measured, in-lake concentrations to determine if the calculated loadings are accurately reflect the on the ground conditions. These formulas were developed by the Organization for Economic Cooperation and Development (OECD)[13] and have been calculated for Beaver Lake.

Using the estimated total phosphorus load to Beaver Lake for year 2010 land use conditions, the forecast in-lake concentrations were 39 µg/l of total phosphorus and 9.4 µg/l of chlorophyll-*a*, and the forecast mean annual Secchi-disc transparency was 4.7 m, or about 15 feet. With the total phosphorous, chlorophyll-*a* and Secchi-disk averages for Beaver Lake being 12, 6.0 and 10 respectively, these predicted values, which are much higher than actual values (particularly in the case of phosphorous), indicate that the UAL calculations may not be accurately accounting for conditions within the watershed. This is consistent with the above "Factors Affecting Loading Calculations" discussion, where it was determined that the canopy cover in residential regions, as well as the low utilization of phosphorous based fertilizers in residential regions, were not accounted for in the UAL calculations. In short, the residential land around Beaver Lake, is producing less pollution than the average in Wisconsin. Consequently, the use of UALs to predict future water quality in Beaver Lake,[14] is likely not viable.

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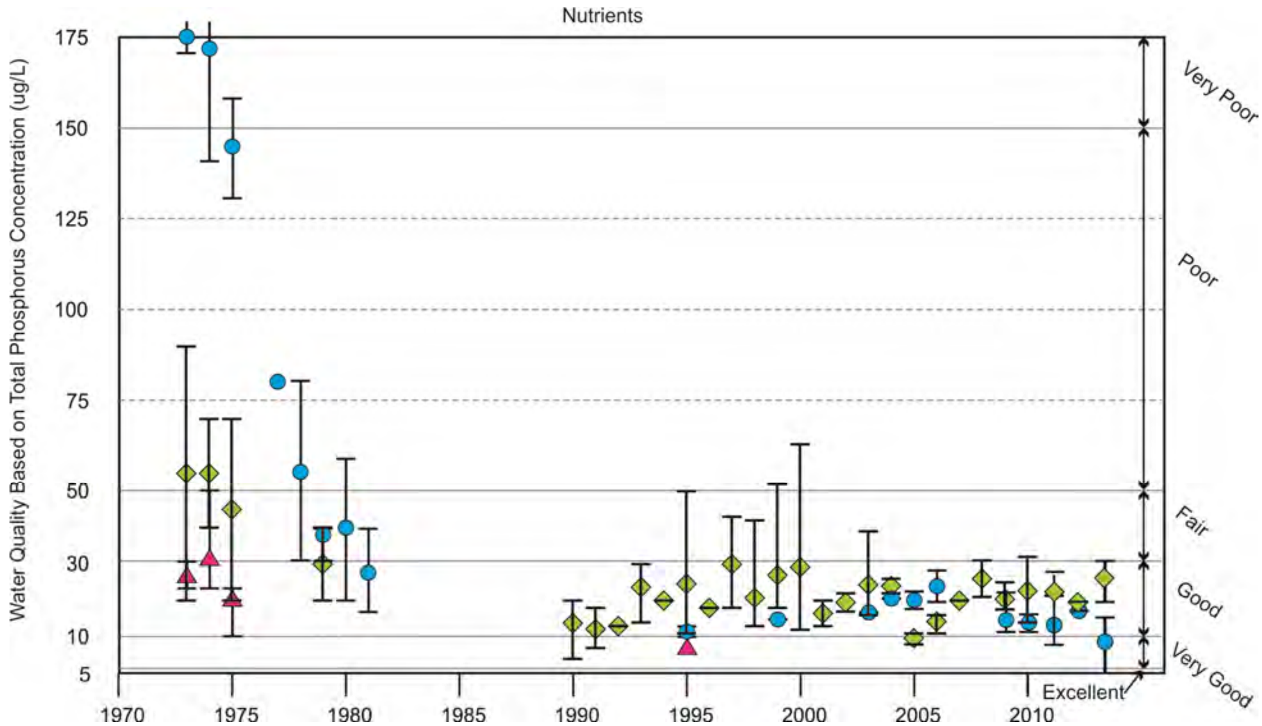
[13]*S.-O. Ryding and W. Rast, "The Control of Eutrophication of Lakes and Reservoirs,"* UNESCO Man and the Biosphere Series, *Volume 1, 1989, ISBN 92-3-102550-3.*

[14]*When the year 2035 land use data is used to forecast the future water quality of Beaver Lake, expected average concentrations of total phosphorus and chlorophyll-*a *in the Lake are about 30 µg/l and 7.3 µg/l, respectively, and the expected annual average transparency is about 5.4 m, or 18 feet.*

Figure 4

ANNUAL MEAN, MINIMUM, AND MAXIMUM WATER QUALITY INDICATOR OBSERVATIONS FOR PINE, BEAVER, AND NORTH LAKES: 1973-2013



NOTE: The mean and maximum total phosphorus concentrations exceeded the range of the graph for Pine Lake in 1973 and maximum concentration in 1974.

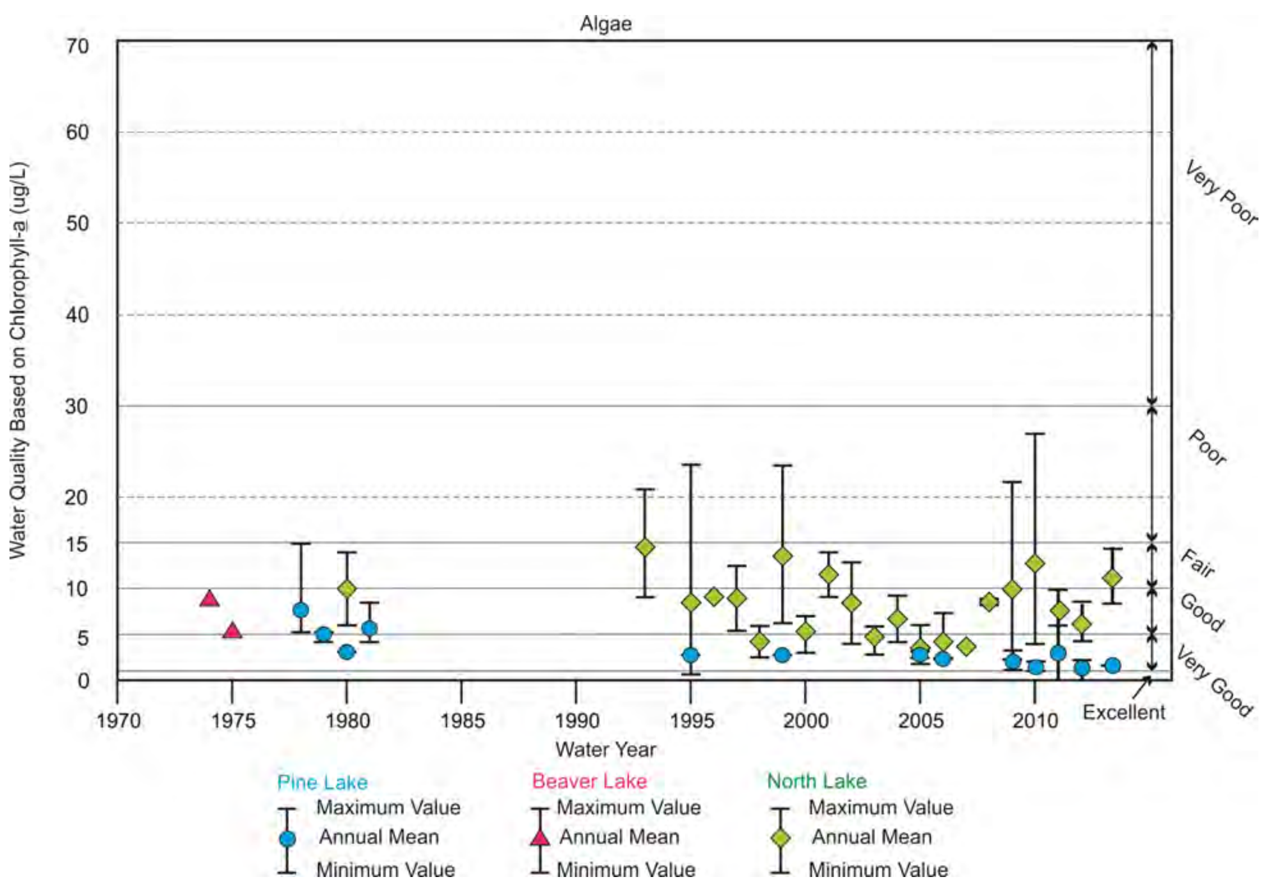
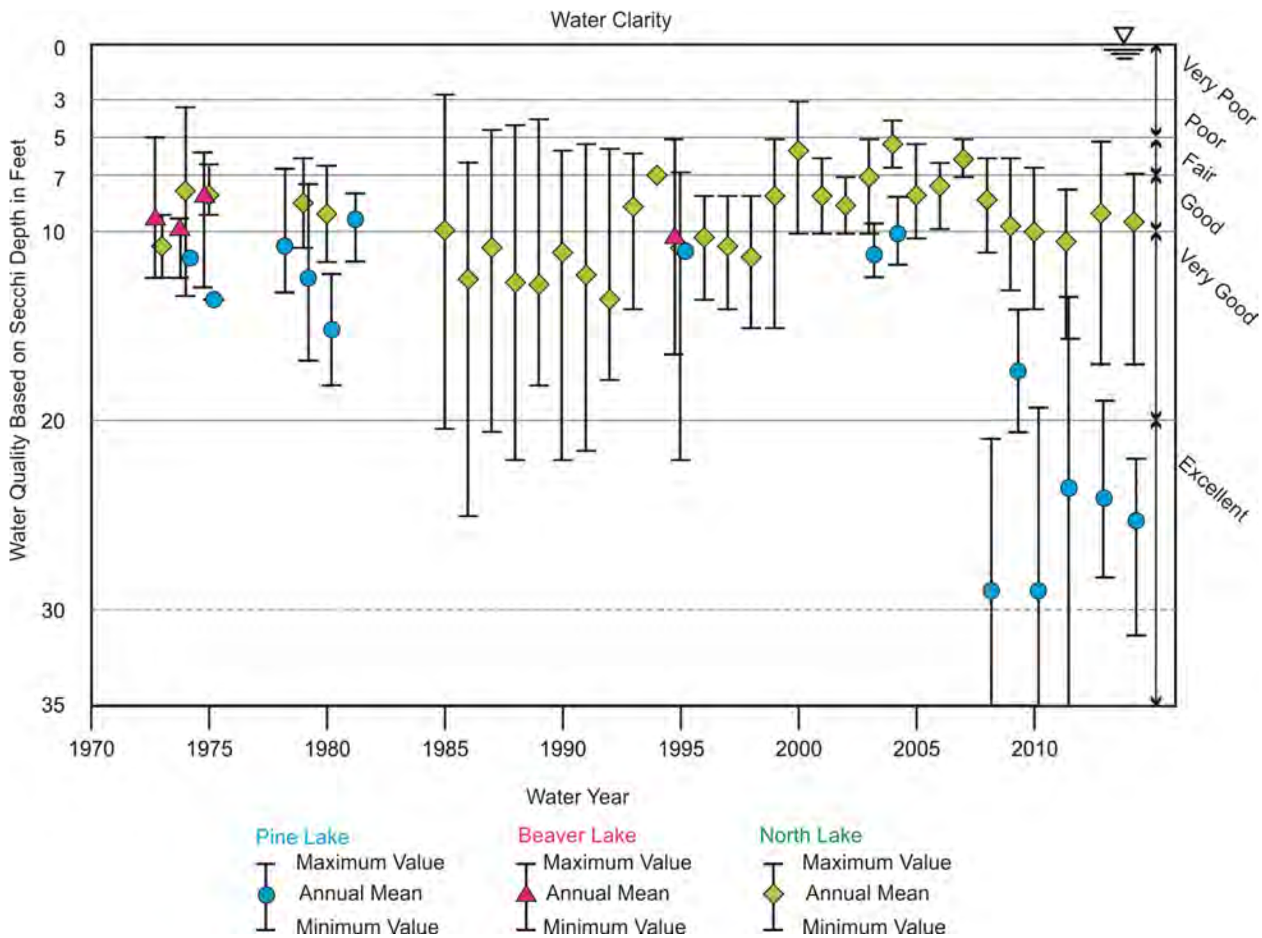


Figure 4 (continued)



NOTE: The observations for Secchi depth exceeded the range of the graph for Pine Lake on the dates of 06/02/2008 and 05/24/2010, which had maximum Secchi depth readings of 40 feet and 46 feet, respectively.

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

Aquatic Plants

An aquatic plant management plan, represented on Map 7, was completed for Beaver Lake, by SEWRPC, in 2008.[15] The Lake had sparse aquatic plant flora dominated by muskgrass. An incipient stand of Eurasian water milfoil,[16] which was first recorded in the Lake in June 1995, was noted in the southeastern corner of the Lake.[17] Utilizing mathematical relationships developed for the State of Wisconsin, based upon Secchi-disk transparency, the maximum depth of aquatic plant colonization in this Lake would be expected to be about 4.2 m, or about 14 feet. Observations conducted as part of the aquatic plant survey in the Lake confirmed this as the approximate depth to which aquatic plants grew in the Lake.

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[15]*SEWRPC Memorandum Report No. 173*, op. cit.

[16]*Eurasian water milfoil is an invasive, nonnative, aquatic plant, which survives well in disturbed areas and outgrows native plants through employing an early growth period. This plant grows in heavy mats which often impede navigation and can cause loss of certain kinds of fish due to natural habitat and food reductions. This plant is spread by uncleansed boats carrying plants from one infested lake to another, noninfested, lake.*

[17]Ibid.

Table 5

WATER QUALITY PARAMETERS FOR BEAVER LAKE ON ALL AVAILABLE DATES: 1973-1995

Parameter	Date														Standards
	1973		1974				1975				1995				
	09/19	11/21	02/06	04/02	07/10	11/20	02/20	04/23	07/01	11/05	02/21	04/26	07/11	07/27	
Conductance (UMHOS/cm) A measure of the amount of ions dissolved in the water	353	391	402	380	378	411	433	393	352	378	553	534	511	488	**500-600**[a]
pH Used to determine if water is acidic, neutral or basic	8.2	7.9	8.2	8.2	8.5	8.3	8.3	8.2	8.2	8.3	7.8	8.37	7.2	8.4	**AA8.1**[a]
Dissolved Oxygen (mg/l) Oxygen in the water column which supports aerobic life	8.0	12.4	11.2	12.2	8.0	10.4	14.8	11.1	8.2	9.6	12.7	11.8	8.6	8.2	**Above 5**[b]
Orthophosphate (mg/l) The phosphorous component which is readily used by plants	0.073	0.005	0.007	0.012	0.025	0.007	0.034	0.019	0.005	0.007	- -	- -	- -	- -	**Below 0.01**[b]
Nitrite and Nitrate (mg/l) Nitrogen components which are readily consumed by plants	0.403	0.279	0.316	0.558	0.336	0.156	0.237	0.414	0.268	0.152	- -	0.24	- -	- -	**Below 10.0**[b]
Ammonium (mg/l) The nitrogen based byproduct of decomposition	0.07	0.4	0.34	0.38	0.12	0.34	0.19	0.23	0.03	0.18	- -	- -	- -	- -	**Below 0.2**[b]
Total organic nitrogen The amount of nitrogen contained in organic materials	0.52	0.47	0.2	0.5	0.68	1.01	0.43	0.48	0.41	0.72	- -	- -	- -	- -	- -
Turbidity (NTUs) A measure of suspended particles in the water	2.3	1.5	1.9	1.25	0.8	2.0	1.5	2.2	2.4	2.2	- -	- -	- -	- -	- -
Calcium (mg/l) A measure of calcium deposits. Indicates buffering capacity	49.1	34.9	36	29	18	60	33	32	32	32	- -	- -	- -	- -	**36**[a]
Magnesium (mg/l) Measure of magnesium deposits. Indicates buffer capacity	41.1	25	29	19	18	44	37	31	44	35	- -	- -	- -	- -	**32**[a]

Table 5 (continued)

Parameter	Date														Standards
	1973		1974				1975				1995				
	09/19	11/21	02/06	04/02	07/10	11/20	02/20	04/23	07/01	11/05	02/21	04/26	07/11	07/27	
Sodium (mg/l) Indicator of road salt pollution. Linked to cyanobacteria growth	12.5	8.1	9	6	6	10	6	7	11	19	- -	20	- -	- -	- -
Potassium (mg/l) An indicator of pollution and linked to cyanobacteria growth	2.9	2.5	1.5	1.2	0.5	2.8	5.5	2.5	4.8	12.8	- -	1.7	- -	- -	- -
Sulfate (mg/l) An indicator of acid rain	22	22	28	30	28	26	30	29	29	30	- -	30	- -	- -	**Between 20-40**[b]
Chlorides (mg/l) An indicator of road salt pollution	13	12	14	14	17	13	15	14	14	15	- -	43.9	- -	- -	**Below 250**[b]

NOTE: Red font indicates values above established standards.

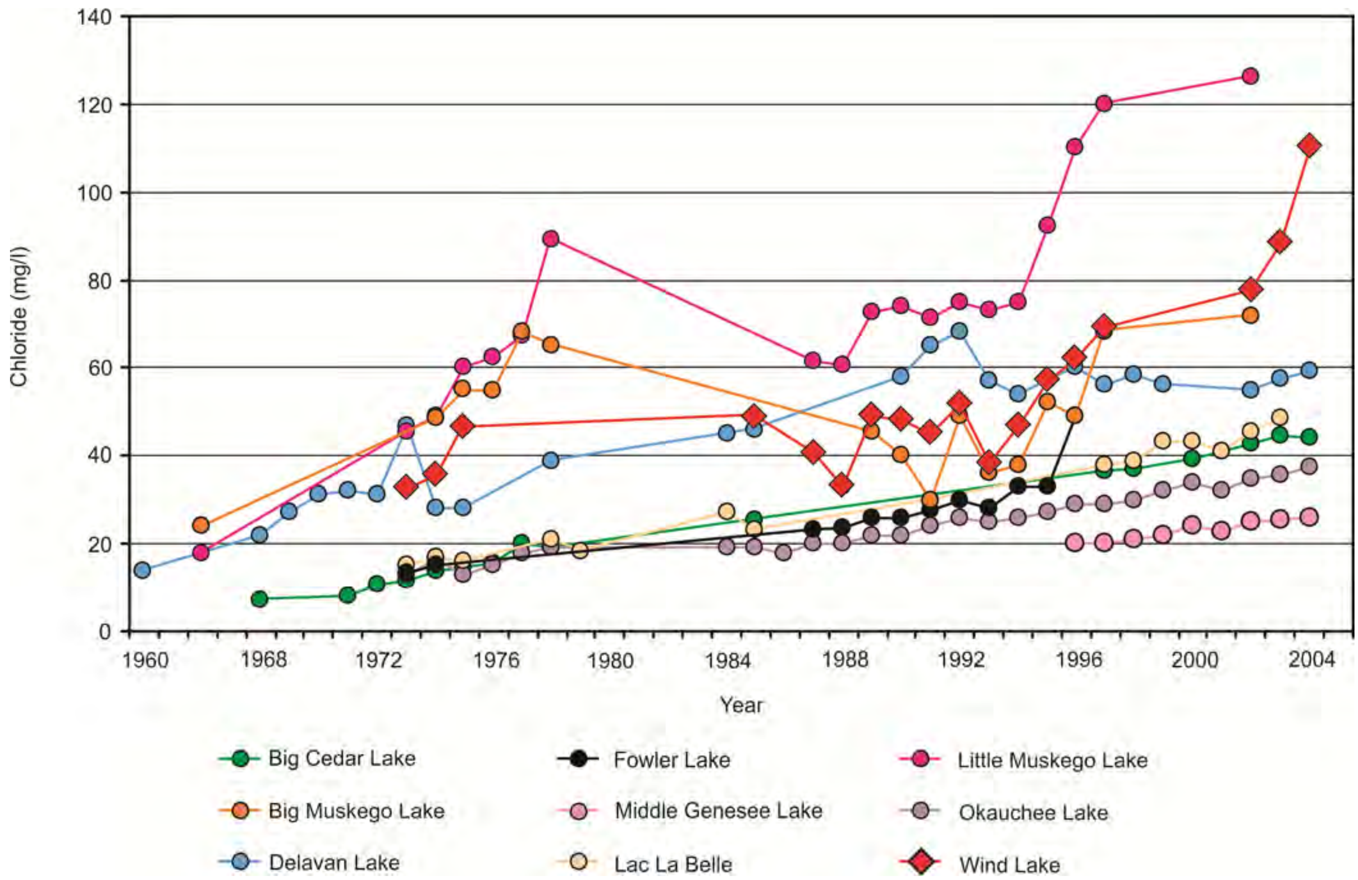
[a] *Southeastern Wisconsin regional averages.*

[b] *Established standards for the State of Wisconsin.*

Source: U.S. Geological Survey, Citizen Lake Monitoring Data, Wisconsin Department of Natural Resources, and SEWRPC.

Figure 5

TIME SERIES OF CHLORIDE CONCENTRATIONS IN SOUTHEASTERN WISCONSIN LAKES



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

Fish and Wildlife Populations

In 1963, the fishery consisted largely of largemouth bass, northern pike, and panfish, notably yellow perch and bluegill.[18] A fish survey conducted in 1975 reported the fishery to consist of largemouth bass, blacknose shiner, emerald shiner, mimic shiner, rainbow shiner, johnny darter, pumpkinseed, green sunfish, bluntnose minnow, bluegill, log perch, and yellow perch. [19] According the WDNR, panfish were reported to be common in Beaver Lake, with largemouth bass and northern pike being present in the Lake.[20]

As mentioned in the Beaver Lake water quality discussion, Zebra mussels have been present in the Lake since 2005. This is important for wildlife because Zebra Mussels tend to reproduce and grow to excess in Wisconsin Lakes due to lack of natural predators, thereby causing the loss of native mussels, as well as other important lake wildlife.

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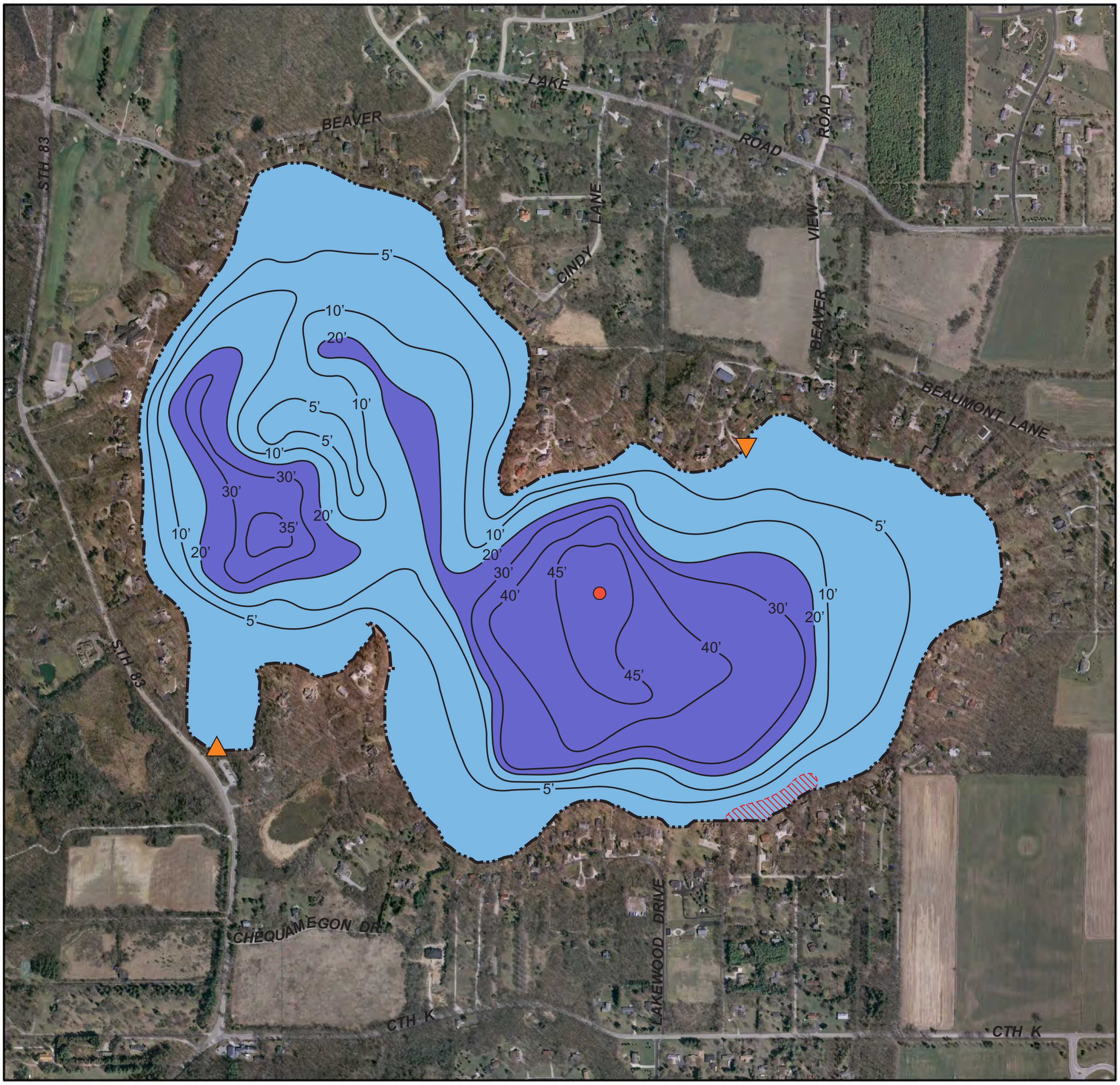
[18]*Wisconsin Conservation Department*, Surface Water Resources of Waukesha County, *1963.*

[19]*Wisconsin Department of Natural Resources Research Report No. 148,* Retrieval and Analysis System Used in Wisconsin's Statewide Fish Distribution Survey, Second Edition, *December 1988.*

[20]*Wisconsin Department of Natural Resources Publication No. PUBL-FH-800 2001*, Wisconsin Lakes, *2001.*

Map 7

RECOMMENDED AQUATIC PLANT MANAGEMENT PLAN FOR BEAVER LAKE



DATE OF PHOTOGRAPHY: APRIL 2005

20' WATER DEPTH CONTOUR IN FEET

MONITORING SITE

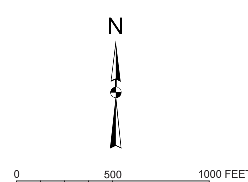
PUBLIC RECREATIONAL BOATING ACCESS SITE

CONSIDER PRIVATE RECREATIONAL BOATING ACCESS AGREEMENT PURSUANT TO CHAPTER NR 1

EURASIAN WATER MILFOIL CONTROL AREA

DEPTH GREATER THAN 20 FEET: NO CONTROL REQUIRED

OPEN WATER



Source: U.S. Geological Survey and SEWRPC.

Recreational Use

Public access is provided to Beaver Lake through a carry-in access site, and is considered adequate pursuant to an agreement between the community and the WDNR that predates the publication of Chapter NR 1 of the *Wisconsin Administrative Code*. Additional, private boating access is available to members of the Beaver Lake Yacht Club. At the time of a 2007 SEWRPC survey, approximately 400 watercraft of all descriptions were observed in and around Beaver Lake. Of these, between one and 20 watercraft were in operation at any given time, with larger numbers of watercraft utilizing the Lake on weekends. Fishing, swimming, boating, and canoeing formed the largest percentage of the recreational use of Beaver Lake.[21]

Pine Lake

Lake Morphometry

Pine Lake is located in U.S. Public Land Survey Sections 21, 28, 29, 32, and 33, Township 8 North, Range 18 East, and in U.S. Public Land Survey Section 5, Township 7 North, Range 18 East, Village of Chenequa, as shown on Map 2 in Chapter I of this report. The Lake has a surface area of about 703 acres, a maximum depth of 85 feet, and a shoreline development factor of 1.96, as shown in Table 1. Pine Lake occupies a dendritic basin, i.e., a basin with a stream and river drainage pattern which resembles branches in a tree, in the interlobate moraine. The bays, which make up the irregular shore, are smaller adjoining basins. The Lake is primarily spring-fed, although there is intermittent inflow from Beaver Lake and outflow to Cornell Lake and North Lake. The lake bottom is primarily gravel. The bathymetry of Pine Lake is shown on Map 8.

Existing Land Use

Existing year 2010 land use for the Pine Lake watershed is shown graphically on the aforementioned Map 4. As of 2010, the land uses within the approximately 2,081 acre tributary consisted of about 25 percent urban land uses and about 75 percent rural land uses, as shown in Table 6. Of the rural land uses, woodlands, wetlands, and surface water comprised about 1,194 acres, or about 57 percent of the land in the area tributary to Pine Lake. Rural agricultural lands comprised about 369 acres, or about 18 percent of the tributary area. Urban residential lands comprised about 436 acres, or about 21 percent of the tributary area.

Land Use Changes

Planned year 2035 land use information is shown graphically on the aforementioned Map 5. By the year 2035, the planned land uses within the area tributary to Pine Lake would consist of about 29 percent urban land uses and about 71 percent rural land uses, as also shown in Table 6. Of the urban land uses, residential uses would comprise about 506 acres or approximately 24 percent of the tributary area. Agricultural land uses are anticipated to comprise about 294 acres or about 14 percent of the total tributary area. Woodlands, wetlands, and surface water would comprise about 1,194 acres, or approximately 57 percent of the total area tributary to Pine Lake.

Other Land Use Considerations

As with Beaver lake, the existence and enforcement of the Village of Chenequa ordinance which restricts the cutting of trees and vegetation in residential areas[22] has also had an effect on the composition of the land uses in Pine Lake. As can be seen graphically on Map 9, a large amount of canopy cover is present in areas that are not considered forested. In fact this canopy cover was calculated to be about 293 acres of the water, being located in areas classified as both agricultural and residential.

Nonpoint Sources of Water Pollution

Under both existing year 2010 and planned 2035 land use conditions, it is estimated that sediment and phosphorus loads from the area tributary to Pine Lake are, or would be, primarily generated from agricultural lands along with atmospheric deposition directly on the Lake surface. The Oconomowoc River Priority Watershed Plan recom-

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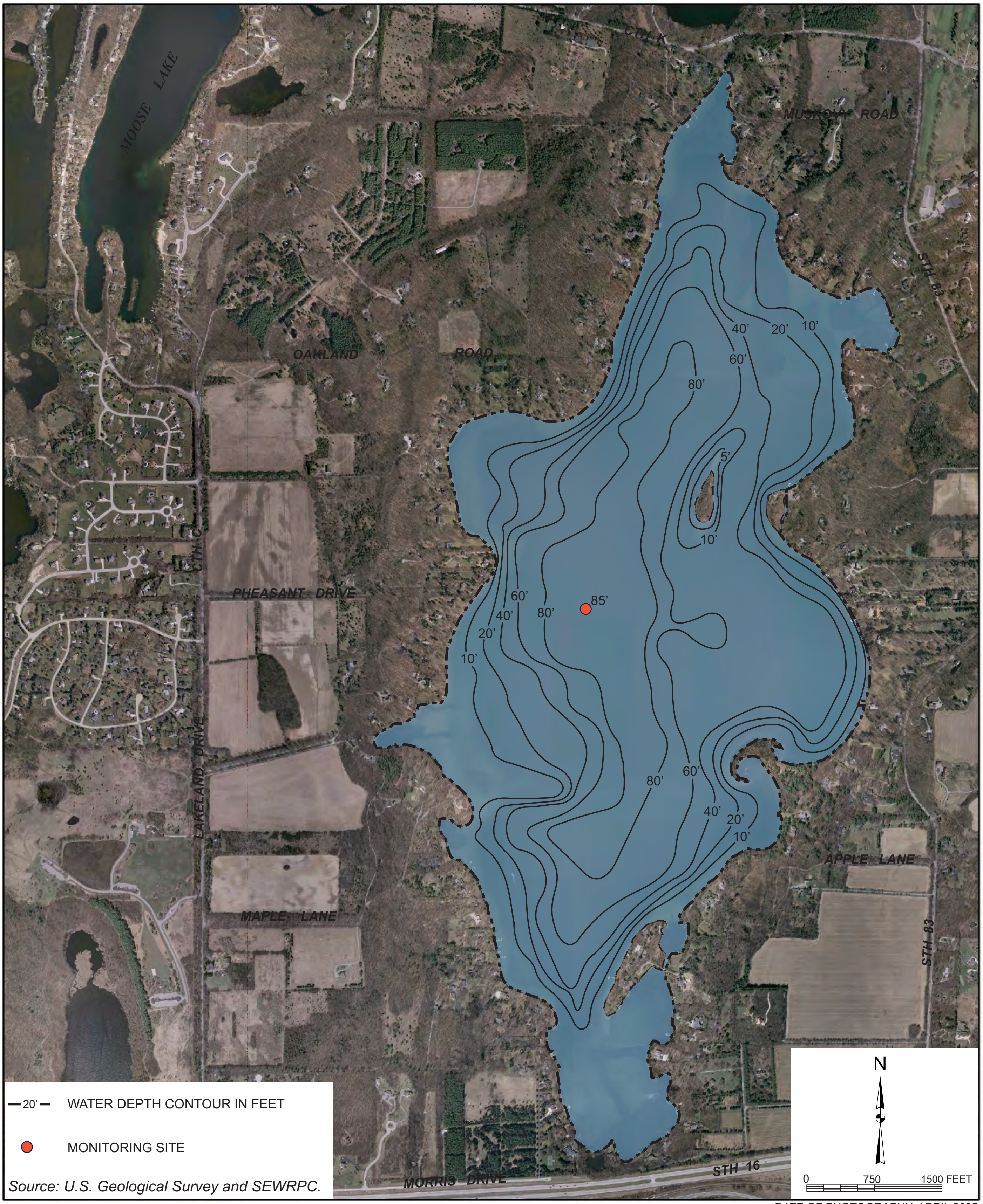
[21]Ibid.

[22]*Village of Chenequa Ordinances,* op. cit.

Map 8

BATHYMETRIC MAP OF PINE LAKE



20' WATER DEPTH CONTOUR IN FEET

MONITORING SITE

Source: U.S. Geological Survey and SEWRPC.

DATE OF PHOTOGRAPHY: APRIL 2005

Table 6

EXISTING AND PLANNED LAND USE WITHIN THE PINE LAKE TRIBUTARY AREA (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035

Land Use Categories[a]	2010 Acres	2010 Percent of Total	2035 Acres	2035 Percent of Total
Urban				
Residential	436	20.9	506	24.3
Commercial	- -	- -	- -	- -
Industrial	- -	- -	- -	- -
Governmental and Institutional	24	1.2	42	2.0
Transportation, Communication, and Utilities	56	2.7	56	2.7
Recreational	2	0.1	2	0.1
Subtotal	518	24.9	606	29.1
Rural				
Agricultural and Other Open Lands	369	17.7	294	14.1
Wetlands	31	1.5	31	1.5
Woodlands	439	21.1	428	20.6
Water	724	34.8	722	34.7
Extractive	- -	- -	- -	- -
Landfill	- -	- -	- -	- -
Subtotal	1,563	75.1	1,475	70.9
Total	2,081	100.0	2,081	100.0

[a]*Parking included in associated use.*

Source: SEWRPC.

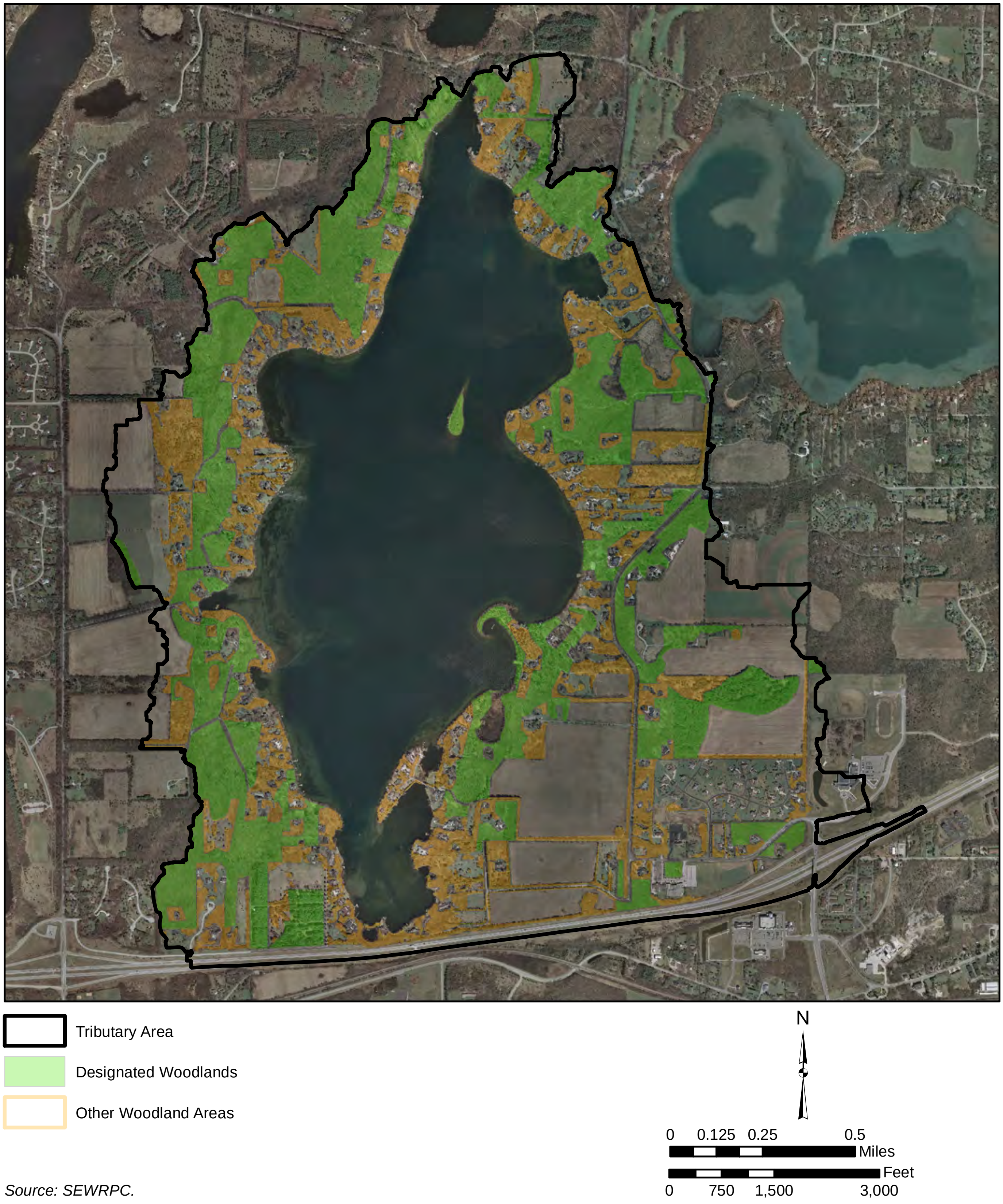
mends implementation of soil erosion and heavy metal control practices, especially along roadways, through application of appropriate stormwater management practices, to maintain the Lake in a mesotrophic condition, with a total phosphorus concentration of 0.02 to 0.03 milligrams per liter (mg/l).[23]

Under year 2010 land use conditions, it is estimated that the annual phosphorus load to Pine Lake would be approximately 489 pounds. A slight increase in load to about 510 pounds of phosphorus is expected under year 2035 land use conditions with Chapter NR 151 controls on runoff from new development accounted for as shown in Table 7. Under year 2010 land use conditions, it is estimated that 145 tons of sediment would enter the Lake annually, with this load expected to increase slightly to 149 tons by 2035, assuming sediment controls are installed for new development as required under Chapter NR 151. Estimated copper and zinc loads are expected to increase slightly from about 15 pounds of copper and about 72 pounds of zinc under 2010 land use conditions, to about 16 pounds of copper and 77 pounds of zinc under planned year 2035 conditions with NR 151 controls on runoff from new development. As can be seen from Table 7, the implementation of the required controls on runoff from new development would slightly reduce the heavy metals loads to the Lake, relative to the planned condition without controls.

[23]*Wisconsin Department of Natural Resources Publication No. PUBL- WR-194 86,* op. cit.

Map 9

CANOPY COVER ANALYSIS FOR PINE LAKE WATERSHED



Source: SEWRPC.

Table 7

EXISTING AND FUTURE POLLUTION LOADS TO PINE LAKE (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035

Land Use Categories[a]	2010				2035 (no controls on new development loads)				2035 (NR 151 controls)[b]			
	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)
Urban												
Residential	4.2	87	- -	4.4	4.9	101	- -	5.1	4.3	94	0.0	4.6
Commercial	- -	- -	- -	- -	- -	- -	- -	- -	0.0	0	0.0	0.0
Industrial	- -	- -	- -	- -	- -	- -	- -	- -	0.0	0	0.0	0.0
Governmental and Institutional	6.2	33	1.7	19.4	10.7	57	2.9	33.6	7.1	45	2.1	23.7
Transportation, Communication, and Utilities	3.1	6	13.5	48.5	3.1	6	13.5	48.5	3.1	6	13.5	48.5
Recreational	<0.1	1	- -	- -	<0.1	1	<0.1	<0.1	<0.1	1	<0.1	<0.1
Subtotal	13.5	127	15.2	72.3	18.7	165	16.4	87.2	14.5	146	15.6	76.8
Rural												
Agricultural and Other Open Lands	62.9	249	- -	- -	66.0	252	- -	- -	66.0	252	0.0	0.0
Wetlands	0.1	1	- -	- -	0.1	1	- -	- -	0.1	1	0.0	0.0
Woodlands	0.8	18	- -	- -	0.8	17	- -	- -	0.8	17	0.0	0.0
Water	68.0	94	- -	- -	67.9	94	- -	- -	67.9	94	0.0	0.0
Subtotal	131.8	362	- -	- -	134.8	364	- -	- -	134.8	364	0.0	0.0
Total	145.3	489	15.2	72.3	153.5	529	16.4	87.2	149.3	510	15.6	76.8

[a] *Parking included in associated use.*

[b] *Assumes a level of control consistent with the requirements of Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code*, which calls for an 80 percent reduction in total suspended sediment (TSS) from areas of new development. Consistent with that level of TSS reduction, a 50 percent reduction in total phosphorus and 70 percent reduction in metals was assumed.*

Source: SEWRPC.

Factors Affecting Loading Calculations

As with Beaver Lake, a large amount of the residential lands have canopy cover (approximately 40 percent). This is classified as an area with light impervious cover, which can lead to a runoff reduction of about 80 to 94 percent, in comparison to a fully impervious area, [24] depending on the conditions. Consequently, the residential loading calculations, given in Table 7, are potentially inaccurate for this watershed given that the area in Pine Lake likely produces less nonpoint pollution runoff than the state average for similar land types. None the less, if phosphorous and heavy metals are found to be a concern in the watershed, the loading calculations described above should be used as guidance for where to target mitigation efforts.

Water Quality

Pine Lake has a significant amount of available water quality data due to efforts by the Citizen Lake Monitoring Network, WDNR and USGS. Consequently, the Lake not only has the data obtained by WDNR between 1973 and 1981 and during the statewide lake basin assessment in 1995 and 1999, but also has an extensive amount of data from the year 2003 to 2013 collected by both citizen lake monitoring efforts and USGS. Available data indicates that Pine Lake has "good" to "very good" water quality, as can be inferred from Figure 4. Additionally, the Lake is a mesotrophic, or moderately enriched, waterbody, with a Wisconsin TSI rating of approximately 48.

The mean total phosphorus concentration for the Lake between 1973 and 1981 was about 35 µg/l; since that time the mean phosphorous concentration has reduced to about 15 µg/l. Generally, a natural lake should stay below 20 µg/l thereby indicating that the phosphorous concentrations used to be well above standards in the late 70s and have since reduced to acceptable levels. This trend can also be seen graphically in Figure 4. Similarly, average chlorophyll-*a* (an indicator of algal growth) decreased from 5.6 µg/l, in the 70s, to 2.4 µg/l, in the 2000s, while average Secchi-disk measurements, increased from 3.0 meters to 7.0 meters over those same dates. This is also consistent with reports that blue green algae, the toxic form of algae which can both contribute to high chlorophyll-*a* measurements and lowered water clarity, has reduced significantly over time.

As with Beaver Lake, zebra mussels were first recorded in Pine Lake in January of 2005; since that infestation there has been a significant increase in water clarity, as can be seen in Figure 4. However, this fact does not explain the decreases in phosphorous levels and chlorophyll-*a*. Given that the land use around the Lake has not significantly changed since that time, as can be seen in Figure 6, and due to the fact that the phosphorous reduction ordinances in the Village of Chenequa came into law in 2007, well after the reductions took place, it is likely that the improvement of water quality in Pine Lake primarily occurred due to reduced groundwater pollution. This reduced groundwater pollution could have taken place due to pollution reduction measures taken within the surface watershed, i.e., septic maintenance, phosphorous fertilizer reduction, etc., however, it is also likely that the widespread installation of sewerage systems throughout the Southeastern Wisconsin Region has reduced the pollution that was previously contaminating the aquifer supplying the Lake.

Other Monitored Parameters

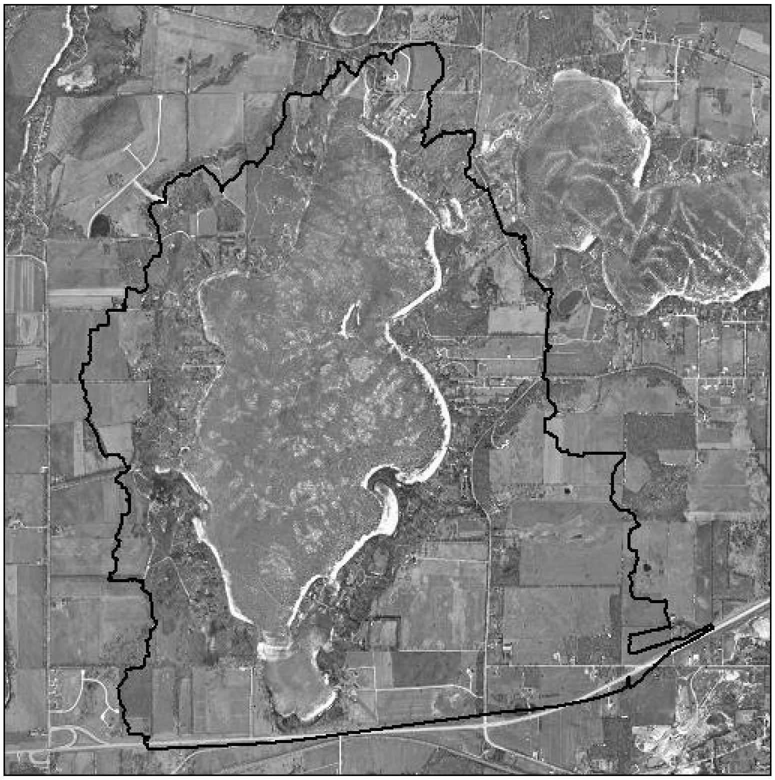
As with Beaver Lake, many parameters, in addition to phosphorous, chlorophyll-*a*, and water clarity, have been collected within Pine Lake. Specifically, physical characteristics, heavy metals, nutrients, and biological measurements were measured in 1973 to 1981 and 1995, by WDNR, and in 2005-2006, by USGS. These values, in combination with comparative standards, are presented in Table 8. The only standard which was above average was the ortho-phosphate readings. Ortho-phosphates are essentially phosphorous in a chemical form which can easily be used up by plants; therefore, it is rare for this component to go above 0.01 mg/l in lakes due to plants generally using it quickly. In Pine Lake, however, orthophosphates averaged 0.12 mg/l prior to 1985, and then lowered to an average 0.011 in 2005. When orthophosphates are elevated, it generally means one of two things: 1) that phosphorous pollution, specifically the most easily used form of phosphorous, is entering the Lake at a rate

[24] *M.C. Dwyer and R.W. Miller*, op. cit.

Figure 6

AERIAL PHOTOGRAPHS OF THE PINE LAKE WATERSHED: 1963 AND 2010

1963



2010

Source: SEWRPC.

Table 8

ANNUAL MEAN WATER QUALITY PARAMETERS IN PINE LAKE: 1973-2006

Parameter	1970s						1980s		1990s		2000s				Total Average	Standards
	1973	1974	1975	1977	1978	1979	1980	1981	1995	1999	2003	2004	2005	2006		
Conductance (UMHOS/cm)	300	323	320	- -	353	366	340	350	355.5		354.5	497.5	400	399	354	**500-600**[a]
pH	8.3	8.25	8.35	- -	8.6	8.3	8.7	8.0	8.2	8.7	8.3	8.6	8.4	8.5	8.3	**8.1**[a]
Dissolved Oxygen	6.2	10.2	11.95	- -	9.4	9.2	10.3	9.9	10.4	8.8	8.65	11.4	12.6	12.3	10.0	**Above 5**[b]
Orthophosphates	0.16	0.16	0.13	- -	0.029	0.033	0.026	- -	0.012	- -	- -	- -	0.008	0.011	0.15	**Below 0.01**[b]
Nitrate and Nitrite	0.10	0.09	0.10	0.02	0.08	0.048	0.02	0.02	- -	- -	- -	- -	0.028	- -	0.07	**Below 10.0**[b]
Ammonium	0.035	0.085	0.08	0.02	0.03	0.05	0.02	0.02	0.054	- -	- -	0.017	<0.01	0.04	0.05	**Below 0.2**[b]
Organic Nitrogen	0.63	0.93	0.60	0.7	0.6	0.95	0.7	- -	- -	- -	- -	- -	- -	- -	0.8	- -
Turbidity (NTUs)	2.25	2.7	2.35	- -	1.8	2.35	1.27	1.2	1	- -	- -	- -	2.9	1.3	2.01	- -
Calcium	37.9	32.5	30.5	- -	29	25.5	32	28	31	24	- -	27.3	31.1	29	30.51	**36**[a]
Magnesium	34	22.8	35.75	- -	24	26.5	25	25	28	- -	- -	26.1	25.7	24.3	28.1	**32**[a]
Sodium	3.5	5.5	5.5	- -	6	5	6	5	9.7	- -	- -	- -	12.5	13	6.3	- -
Potassium	1.9	1.5	2.5	- -	1.6	1.5	1.6	1.6	- -	- -	- -	- -	2	2	1.9	- -
Sulfate	13.5	17.5	18.25	- -	21	20	- -	21	21	- -	- -	- -	20.6	21.1	18.4	**Between 20-40**[b]
Chlorides	7.5	8.25	8.5	- -	8	12	- -	- -	20.7	- -	- -	- -	27.9	27.8	11.9	**Below 250**[b]

NOTE: All measurements are in milligrams per liter (mg/l) unless otherwise noted.

[a]*Southeastern Wisconsin regional averages.*

[b]*Established standards for the State of Wisconsin.*

Source: U.S. Geological Survey, Citizen Lake Monitoring Data, Wisconsin Department of Natural Resources, and SEWRPC.

much faster than the plants can uptake it (essentially, samples are taken during a high runoff period before plants can use it); or 2) the Lake is nitrogen limited rather than phosphorous limited.[25]

In order to investigate the second option of these two explanations, nitrogen to phosphorous ratios were conducted on all the dates where both total nitrogen and total phosphorous were available. In Pine Lake this occurred on only 3 dates, namely: May 1, 1979, May 17, 1980, and May 13, 2005. The nitrogen ratios on these dates were 11:1, 12:1 and 16:1. Generally lakes which have a ratio below 14:1 are nitrogen limited, thereby indicating that in 1979 and 1980 the Lake was nitrogen limited and that the Lake had become phosphorous limited by 2005. This confirms that the reason the ortho-phosphate levels were high in the Lake.

This result has management implications for Pine Lake. Most lakes in Wisconsin are consistently phosphorous limited due to the geology of the region with ratios around 40:1, which generally means that phosphorous pollution will spur excessive plant growth while nitrogen may not. This is generally why phosphorous is regulated on a statewide level. In Pine Lake, however, due to the fact that the limiting factor has been shown to sometimes be nitrogen rather than phosphorous, it is most likely that nitrogen pollution can also spur plant and algae growth depending on the chemistry at the time. Consequently, the control of nitrogen pollution is also an issue of concern.

Confirming Loading Calculations

The phosphorus load, developed from the SEWRPC UAL models, as presented in the Nonpoint Sources of Water Pollution section, was utilized in the previously discussed OECD eutrophication models to forecast in-lake average concentrations of total phosphorus and chlorophyll-*a*, and Secchi disk transparency.[26] Using the estimated total phosphorus load to Pine Lake for year 2010 land use conditions, the forecast in-lake concentrations were 11 µg/l of total phosphorus and 2.7 µg/l of chlorophyll-*a*. Additionally, the forecast mean annual Secchi-disk transparency was 9.5 m, or about 31 feet.[27] With 1998 to 2013 total phosphorous, chlorophyll-*a* and Secchi disk measurements being 15, 2.3 and 6.9 respectively, the actual total phosphorus and Secchi-disk measurements indicated lower quality than those that were predicted. This difference is likely due to the likely influence of groundwater pollution on the quality of the Lake, which is not accounted for in UAL calculations. Consequently, as with Beaver Lake, the use of UALs to predict water quality in the Lake,[28] is likely not viable for Pine Lake.

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[25]*Aquatic plants and algae require both phosphorus and nitrogen for growth. In lakes where the supply of one or more of these nutrients is limited, plant growth is limited by the amount of the nutrient that is available in the least quantity relative to all of the others. In the Southeastern Wisconsin Region, most lakes phosphorous limited, i.e., the total nitrogen to total phosphorous ratio is above 14 to 1. This designation means that when phosphorous enters a lake, it generally quickly stimulates aquatic plant and algae growth, and is the primary reason that phosphorous is regulated in the State.*

[26]*S.-O. Ryding and W. Rast,* UNESCO Man and the Biosphere Series, op. cit.

[27]*The OECD eutrophication model applies the in-lake total phosphorus concentration to forecast Secchi disc transparency. Because the observed and model-predicted total phosphorus concentrations are relatively close, but the observed and predicted Secchi disk transparency depths differ considerably, it appears that in this instance, the OECD model does not adequately represent the processes in the Lake that affect Secchi disc transparency. However, based on the relatively small differences in observed, calculated 2010, and calculated 2035 total phosphorus concentrations, the conclusion that, under 2035 land use conditions, the Secchi disk transparency depth would not be expected to change greatly relative to existing conditions is considered to be valid.*

[28]*When the year 2035 land use data is used to forecast the future water quality of Pine Lake, expected average concentrations of total phosphorus and chlorophyll-*a *in the Lake are about 12 µg/l and 2.9 µg/l, respectively, and the expected annual average transparency is about 9.2 m, or 30 feet.*

Table 9

FREQUENCY OF OCCURRENCE OF MAJOR PLANT SPECIES IN PINE LAKE: 1996, 2005, AND 2013

Aquatic Plant Species Present	Frequency of Occurrence[a]		
	1996	2005	2013
Bushy Pondweed (*Najas flexilis*)………………………	9.2	33.8	- -
Coontail (*Ceratophyllum demersum*)	12.2	23.6	7.6
Curly-Leaf Pondweed (*Potamogeton crispus*)……….....................	6.1	7.7	0.6
Eurasian Water Milfoil (*Myriophyllum spicatum*)	55.8	29.2	26.0
Flatstem Pondweed (*Potamogeton zosteriformes*)	7.6	8.2	1.6
Illinois Pondweed (*Potamogeton illinoensis*)..............................	6.9	16.4	1.4
Muskgrass (*Chara vulgaris*)	23.7	66.1	40.9
Native Water Milfoil (*Myriophyllum sibiricum*..............................	0.8	42.6	3.1
Sago Pondweed (*Potamogeton pectinatus*)…………	10.0	34.9	5.0

NOTE: Sampling occurred at 116 sites along 51 transects in 2005.

[a]*The percent frequency of occurrence is the number of occurrences of a species divided by the number of samplings with vegetation, expressed as a percentage. It is the percentage of times a particular species occurred when there was aquatic vegetation present, and is analogous to the Jesson and Lound point system.*

Source: SEWRPC.

Aquatic Plants

An aquatic plant inventory was completed for the Lake by SEWRPC in 1996 (report published in 1998). Another aquatic plant inventory was completed in 2005 and was included in a 2008 aquatic plant management plan.[29] Finally, an aquatic plant survey was completed by WDNR in 2013 (see Appendix B). As shown in Table 9, at the time of the 1996 aquatic plant survey, Eurasian water milfoil, which was first recorded in the Lake in July of 1978, dominated the aquatic plant flora of Pine Lake. By 2005, while Eurasian water milfoil remained widespread, it was replaced in dominance by muskgrass and pondweed species. In 2013, muskgrass remained the dominant species, Eurasian water milfoil was the second most frequently occurring species, and curly-leaf pondweed[30] had one of the lowest frequencies of occurrence. The changes in the Eurasian water milfoil population may reflect both the results of the aquatic plant management practices employed by the Village, as well as the natural periodicity associated with growths of Eurasian water milfoil in lakes within the Southeastern Wisconsin Region.

Another possible effect of the past aquatic plant management practices in Pine Lake, particularly active chemical treatments, may be the unintentional loss of Bushy pondweed, a native species that was observed in the 1996 and 2005 surveys but not in 2013 as can be seen in Table 9. This loss of native species occurrence in the Pine Lake provides support for the implementation of measures which prevent native aquatic plant loss during chemical treatments (e.g., chemical harvesting only between mid-April and end of May).

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[29]*SEWRPC Memorandum Report No. 124,* An Aquatic Plant Inventory for Pine Lake, Waukesha County, Wisconsin, *December 1998; see also SEWRPC Memorandum Report No. 173,* op. cit.

[30]*Curly leaf pondweed is an invasive, nonnative aquatic plant which generally thrives in conditions less habitable to native plant species. This plant can displace native plants, clog waterways, inhibiting aquatic recreation, and is considered a nuisance in some areas.*

The recommended aquatic plant management plan for Pine Lake, as originally set forth in the 2008 SEWRPC report,[31] is shown on Map 10. Future aquatic plant control operations can generally target the Eurasian water milfoil control areas shown on that map with adjustments made based on the 2013 survey's indication of a greater prevalence in the northwest lobe of the Lake and the northeast littoral area (see Figure 1 in Appendix B of this report). Based in Figure 2 in Appendix B, future control of curly-leaf pondweed could be focused on the northeast portion of the Lake. These control operations should be completed in the early growing season (mid-April through end of May) in order to prevent inadvertent damage to native plants.

Map 10 also includes recommended buoy placement, along the bay areas of the western side of the Lake, which was not included in the original 2008 SEWRPC report. This recommendation was added due to observed disturbances in these shallow areas resulting from motor boat activities.[32] These disturbances, which are a result of propellers causing sediment suspension in shallow areas, can cause turbidity and water quality issues as well as cause excessive growth of invasive species (which thrive in "disturbed areas").[33] This recommendation is therefore included as an aquatic plant management recommendation as well as a recommendation seeking to prevent future water quality issues.

Fish and Wildlife Populations

In 1963, the fishery of Pine Lake consisted largely of panfish, largemouth bass, northern pike, walleyed pike, and cisco.[34] Fish surveys conducted in 1975 and 1984 reported the fishery to consist of cisco or lake herring, golden shiner, yellow perch, bluntnose, minnow, bluegill, logperch, pumpkinseed, brook silverside, largemouth bass, northern pike, banded killifish, mimic shiner, black crappie, lake chubsucker, green sunfish, blackchin shiner, common carp, and blacknose shiner.[35] The banded killifish is listed as a State species of special concern. As of 2001, largemouth bass and smallmouth bass were reported to be common in the Lake, and northern pike, walleye, and panfish were reported to be present.[36]

As with Beaver Lake, Zebra mussels have been present in the Lake since 2005 and should be considered a priority for control if a successful control measure is found in the future.

Recreational Use

Public access is provided, and is considered adequate pursuant to Chapter NR 1 of the *Wisconsin Administrative Code*. At the time of the 2007 SEWRPC survey, approximately 450 watercraft of all descriptions were observed in and around Pine Lake. Of these, between 17 and 28 watercraft were in operation at any given time, with larger numbers of watercraft utilizing the Lake at the weekend. Fishing, boating, and sailing are important recreational uses of Pine Lake.[37]

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[31]*SEWRPC Memorandum Report No. 173,* op. cit.

[32]*WDNR Staff observation.*

[33]*Wisconsin Department of Natural Resources Publication No. PUBL-SS-948-00,* The Effects of Motorized Watercraft on Aquatic Ecosystems, *March 2000.*

[34]*Wisconsin Conservation Department*, op. cit.

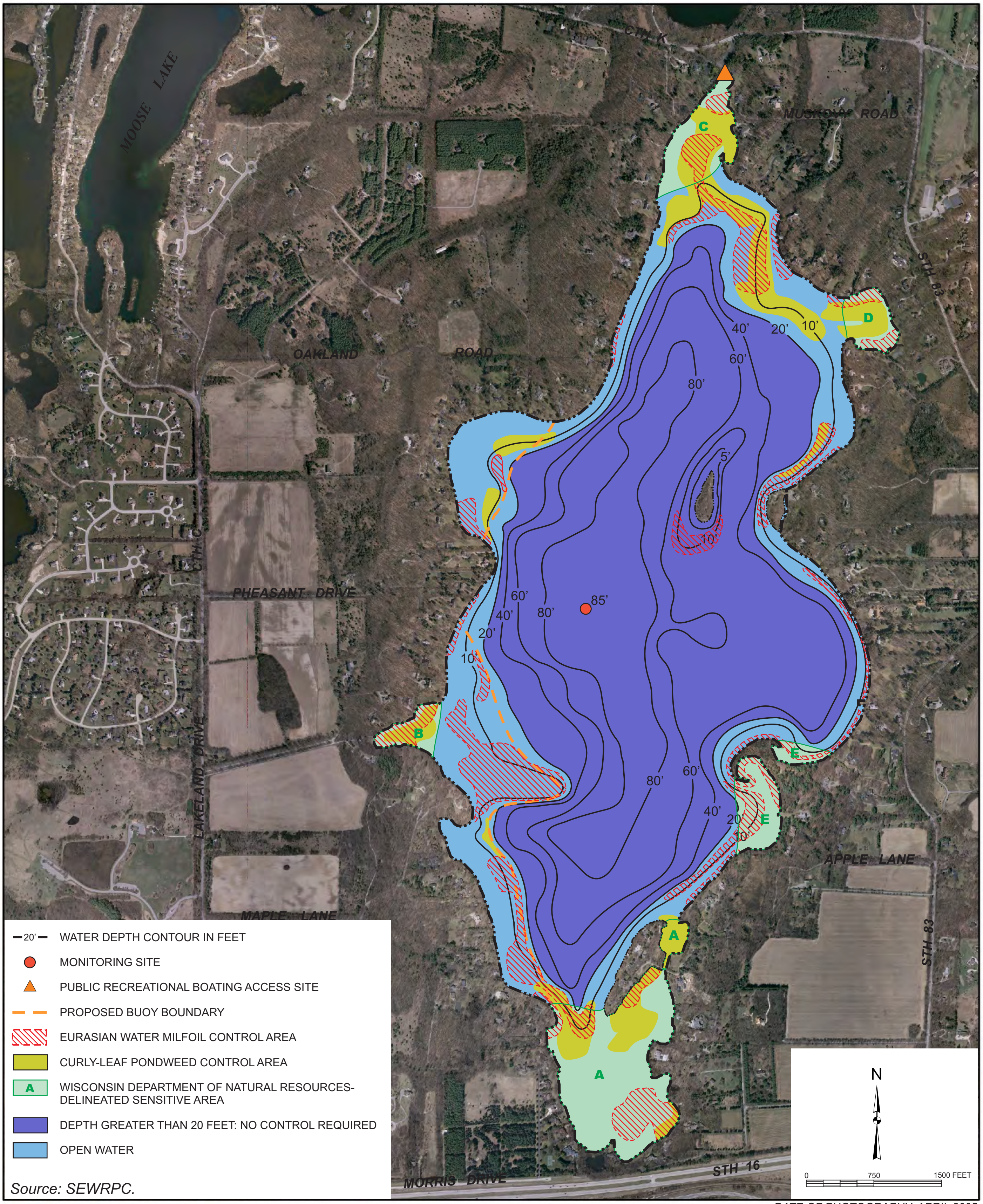
[35]*Wisconsin Department of Natural Resources Research Report No. 148,* op. cit.

[36]*Wisconsin Department of Natural Resources Publication No. PUBL-FH-800 2001,* op. cit.

[37]*SEWRPC Memorandum Report No. 173,*op. cit.

Map 10

RECOMMENDED AQUATIC PLANT MANAGEMENT PLAN FOR PINE LAKE



Source: SEWRPC.

DATE OF PHOTOGRAPHY: APRIL 2005

Table 10

EXISTING AND PLANNED LAND USE WITHIN THE CORNELL LAKE DIRECT TRIBUTARY AREA: 2010 AND 2035

Land Use Categories[a]	2010 Acres	2010 Percent of Total	2035 Acres	2035 Percent of Total
Urban[b]				
Residential	21	21.9	21	21.9
Commercial	- -	- -	- -	- -
Industrial	- -	- -	- -	- -
Governmental and Institutional	- -	- -	- -	- -
Recreational	1	1.0	1	1.0
Subtotal	22	22.9	22	22.9
Rural				
Open Lands	8	8.3	8	8.3
Wetlands	6	6.3	6	6.3
Woodlands	40	41.7	40	41.7
Water	20	20.8	20	20.8
Subtotal	74	77.1	74	77.1
Total	96	100.0	96	100.0

[a]*Parking included in associated use.*

[b]*Streets included in associated use.*

Source: SEWRPC.

Cornell Lake (Mud Lake)

Lake Morphometry

Cornell Lake is located in U.S. Public Land Survey Sections 20 and 21, Township 8 North, Range 18 East, Village of Chenequa, as shown on Map 2 in Chapter I of this report. The Lake has a surface area of about 41 acres, a maximum depth of 12 feet, and a shoreline development factor of 1.78, as shown in Table 1. Cornell Lake is a small, marsh-bordered, kettle lake in the interlobate moraine. The Lake is a drainage lake with inflow from Pine Lake and an outflow through marshlands to North Lake and the Oconomowoc River in Waukesha County. The Lake forms a hydraulic and hydrologic link between the upstream Pine and Beaver Lakes and the downstream North Lake on the mainstem of the Oconomowoc River.

Existing Land Use

Existing year 2010 land use information is shown graphically on Map 4. As of 2010, the land uses within the approximately 96 acre area directly tributary to Cornell Lake consisted of about 23 percent urban land uses and about 77 percent rural uses. Of the rural land uses, woodlands comprised about 42 percent of the total area, water comprised about 21 percent, and wetlands about 6 percent, as shown in Table 10. Open lands comprised the balance of the rural land uses, or about 8 percent, of the total tributary area. Urban residential land uses comprised about 21 acres, or 22 percent of the total area.

Land Use Changes

By the year 2035, the land uses within the area directly tributary to Cornell Lake are forecast to remain essentially unchanged.

Other Land Use Considerations
As was found in the Beaver Lake and Pine Lake watersheds, canopy cover was very common within the residential areas located on the Northeast corner of Cornell Lake, as can be seen graphically on Map 11. In fact the canopy cover which was not considered "forested" was calculated to be about 11 acres (11.4 percent) of the watershed and was located in areas classified as both agricultural and residential.

Nonpoint Sources of Water Pollution
Under existing year 2010, as shown in Table 11, most of the nonpoint source sediment and phosphorus loads from the area directly tributary to Cornell Lake are generated from rural lands, which cover about three-quarters of the direct tributary area to the Lake. Additional pollutant loads are contributed from Pine Lake, which is upstream of Cornell Lake.

Under year 2010 land use conditions, it is estimated that approximately 14 pounds of phosphorus entered Cornell Lake annually as runoff from the immediately tributary area, with a further 64 pounds being conveyed into Cornell Lake from Pine Lake, for a total of 78 pounds of phosphorus. That phosphorus loading is expected to change little under planned year 2035 conditions, since 1) the annual phosphorus load from the direct tributary area to the Lake would not be expected to increase and 2) relatively small increases in phosphorus loads from Pine Lake would be expected with NR 151 controls on runoff in place as indicated in Table 11. Similarly, under both existing 2010 land use conditions and planned 2035 conditions, it is estimated that sediment, copper, and zinc loads from the direct tributary area to the Lake would not increase and that the total increase in loads of those pollutants, accounting for loads from Pine Lake, would be small given the relatively small increases in the estimated sediment, copper, and zinc loads to Pine Lake under 2035 land use conditions with NR 151 controls on runoff.

Factors Affecting Loading Calculations
As with Beaver and Pine Lake, a large amount of the residential lands have canopy cover (approximately 30 percent). This is classified as an area with medium impervious cover, which can lead to a runoff reduction of about 60 to 80 percent, in comparison to a fully impervious area, depending on the conditions.[38] Consequently, the residential loading calculations, given in Table 11, are potentially inaccurate for this watershed given that the area in Cornell Lake likely produces less nonpoint pollution runoff than the state average for similar land types. None the less, as with Pine and Beaver Lakes, if phosphorous and heavy metals are found to be a concern in the watershed, the loading calculations described above should be used as guidance for where to target mitigation efforts.

Water Quality
Water quality data for Cornell Lake was only measured on one occasion in 1981; however, the water quality would not be expected to differ significantly from that of Pine Lake, located immediately upstream. The shallow character of Cornell Lake may cause the lake to be more turbid that Pine Lake, which is confirmed out by the one Secchi-disk measurement that was taken on the Lake at 2.5 feet (0.8 m); this measurement, however, is considered excellent for marshy lakes such as Cornell.

Confirming Loading Calculation
The phosphorus load, developed from the SEWRPC UAL models, was utilized in the OECD eutrophication models to forecast in-lake average concentrations of total phosphorus and chlorophyll-*a*, and Secchi-disk transparency.[39] Using the estimated total phosphorus load to Cornell Lake for year 2010 land use conditions, the forecast in-lake concentrations were 16 µg/l of total phosphorus and 3.9 µg/l of chlorophyll-*a*, while the forecast

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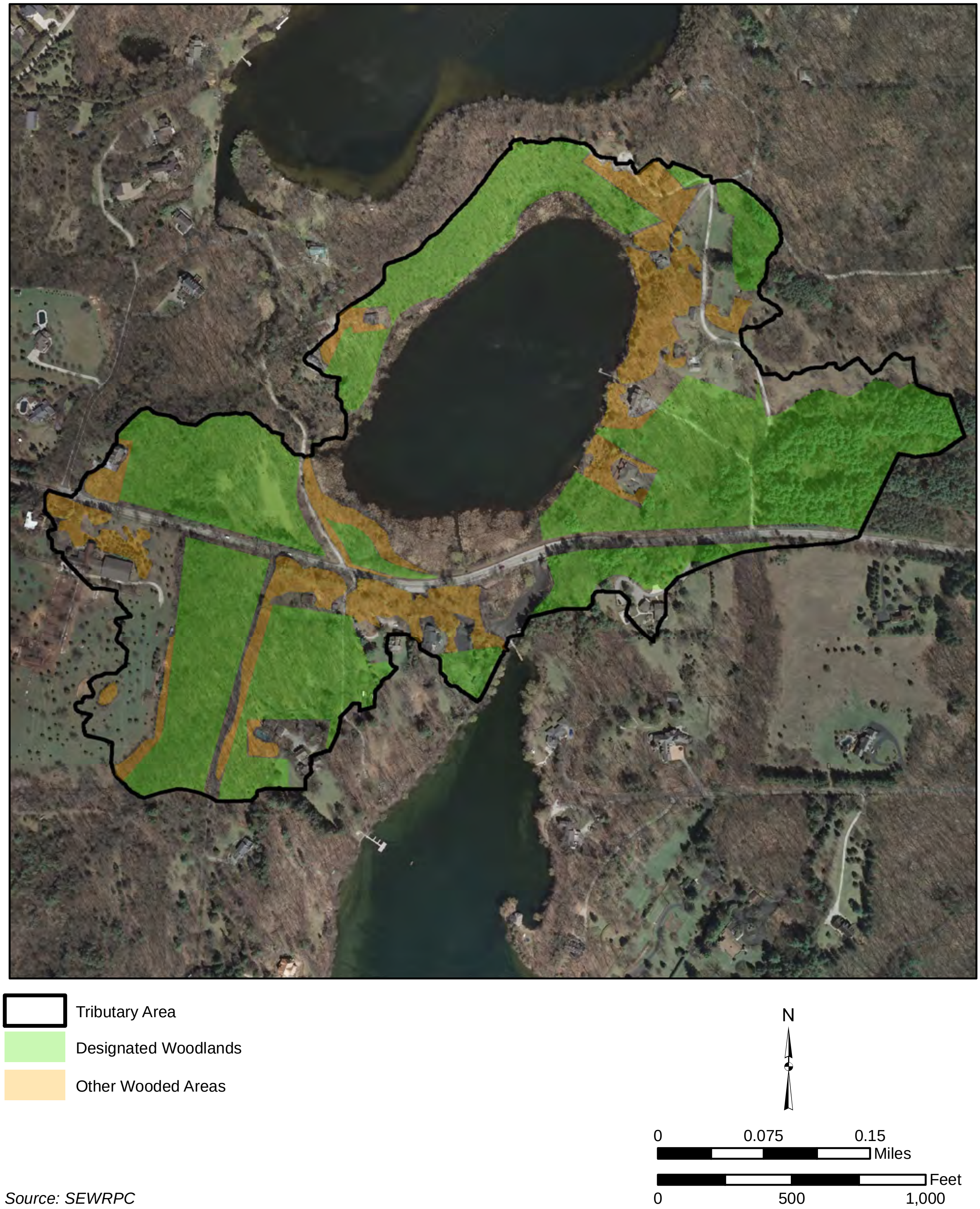
[38]*M.C. Dwyer and R.W. Miller*, op. cit.

[39]*S.-O. Ryding and W. Rast*, UNESCO Man and the Biosphere Series, op. cit.

Map 11

CANOPY COVER ANALYSIS FOR CORNELL LAKE WATERSHED



Source: SEWRPC

Table 11

EXISTING AND FUTURE POLLUTION LOADS TO CORNELL LAKE FROM THE DIRECT TRIBUTARY AREA[a] (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035

Land Use Categories[b]	2010				2035[c]			
	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)
Urban								
Residential	0.2	4.1	- -	0.2	0.2	4.1	- -	0.2
Commercial	- -	- -	- -	- -	- -	- -	- -	- -
Industrial	- -	- -	- -	- -	- -	- -	- -	- -
Governmental and Institutional	- -	- -	- -	- -	- -	- -	- -	- -
Recreational	<0.1	0.2	- -	- -	<0.1	0.2	- -	- -
Subtotal	0.2	4.3	0.0	0.2	0.2	4.3	0.0	0.2
Rural								
Open Lands[d]	1.3	5.4	- -	- -	1.3	5.4	- -	- -
Wetlands	<0.1	0.2	- -	- -	<0.1	0.2	- -	- -
Woodlands	0.1	1.6	- -	- -	0.1	1.6	- -	- -
Water	1.8	2.5	- -	- -	1.8	2.5	- -	- -
Subtotal	3.3	9.7	- -	- -	3.3	9.7	- -	- -
Total	3.5	14.0	0.0	0.2	3.5	14.0	0.0	0.2

[a]*See the Cornell Lake subsection of this report for information on approximate additional contributions from Pike Lake.*

[b]*Parking included in associated use.*

[c]*No change in land use planned between 2010 and 2035; therefore, unlike for the other lakes studied, there are no 2035 loads shown for an "NR 151 controls" condition.*

[d]*In the case of Cornell Lake, the "Agricultural and Other Opens Lands" category is only "Open Lands."*

Source: SEWRPC.

mean annual Secchi-disk transparency was 7.8 m or about 25 feet (i.e., water clarity should go down to the bottom of the Lake). Evaluated against the only existing data, i.e., the one Secchi-disk measurement, the OECD models overestimated the water clarity by a significant margin; however, this result is not unexpected given the extremely short water residence time in the Lake[40] and given the fact that the Lake water does not stay stagnant long enough to allow sediments to settle out (thereby reducing water clarity). Given the fact that land use was not expected to significantly change, and the fact that the UAL loads cannot accurately predict water quality in Cornell Lake, 2035 land use data was not used to forecast the future total phosphorus load to the Lake.

Aquatic Plants

No aquatic plant surveys have been conducted on Cornell Lake, although the presence of Eurasian water milfoil and curly-leaf pondweed were both officially recorded in the Lake in June of 2008. Utilizing mathematical relationships developed for the State of Wisconsin, based upon Secchi-disk transparency, the maximum depth of aquatic plant colonization in this Lake would be expected to be about 1.5 m or about 5.0 feet. Observations of the aquatic plant community in Cornell Lake confirmed this as the approximate depth to which aquatic plants grew.

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[40]*P.J. Dillon, "The Phosphorus Budget of Cameron Lake, Ontario: The Importance of Flushing Rate to the Degree of Eutrophy of Lakes."* Limnology and Oceanography, *Volume 20, 1975, pages 28-39.*

Fish and Wildlife Populations

In 1963, the fishery of Cornell Lake consisted largely of panfish.[41] Winterkill, which is a product of oxygen depletion in the Lake, was reported by the WDNR to be common in the Lake at that time. As of 2001, panfish were reported to be common in the Lake and largemouth bass were reported to be present.[42] The WDNR reports that waterfowl make very limited use of the adjoining wetlands and marsh.

Zebra mussels have not officially been recorded in Cornell Lake, which is unexpected given its hydrologic connection to Pine Lake. If infestation has not yet occurred, it should be avoided to the greatest extent possible.

Recreational Use

Public access is not available on Cornell Lake; however, the Lake is accessible by a navigable waterway both from the inlet and outlet of the Lake.

North Lake

Lake Morphometry

North Lake is located in U.S. Public Land Survey Section 17, Township 8 North, Range 18 East, Town of Merton and Village of Chenequa, as shown on Map 2. The Lake has a surface area of about 439 acres, a maximum depth of 73 feet, and a shoreline development factor of 1.31, as shown in Table 1. North Lake occupies a basin in outwash deposits within the interlobate moraine at the confluence of the Oconomowoc and Little Oconomowoc Rivers. The bottom is primarily sand and gravel with scattered marl beds. The Lake is part of the Oconomowoc River chain-of-lakes, being located downstream of Friess Lake in Washington County and upstream of Okauchee Lake, Oconomowoc Lake, Fowler Lake, and Lac La Belle in Waukesha County. North Lake is unimpounded. The bathymetry of North Lake is shown on Map 12.

Existing Land Use

As of 2010, the land uses within the approximately 36,545 acre (57.1 square mile) area tributary to North Lake[43] consisted of about 20 percent urban land uses and about 80 percent rural land uses. This tributary area includes direct tributary area, as shown on Map 4, as well as the upstream Oconomowoc basin, as shown on Map 13, due to the significant effect that the land use of this area would have on the water quality of the Lake. This area calculation does not include the Cornell, Pine, and Beaver Lake watersheds due to the fact that they only periodically drain to the Lake and would have a minimal impact on the Lake's water quality.

Of the rural land uses in the North Lake watershed, woodlands, wetlands, and surface water comprised about 12,573 acres, or about 34 percent of the area tributary to North Lake, as shown in Table 12. Agricultural lands comprised about 16,809 acres, or about 46 percent, of the tributary area. Urban residential lands comprised about 6,440 acres, or about 18 percent, of the tributary area. In the area directly tributary to the Lake in 2010, as shown on Map 4, about 30 percent of the area was developed in urban land uses and 70 percent in rural uses.

Land Use Changes

By the year 2035, the planned land uses within the total area tributary to North Lake would be comprised of about 27 percent urban land uses and about 73 percent rural land uses. Of the urban land uses, residential uses are expected to comprise about 8,632 acres or approximately 24 percent of the total tributary area, as also shown in Table 12. Agricultural land uses are anticipated to comprise about 14,145 acres, or about 39 percent, of the total area tributary to the Lake. Wetlands cover about 17 percent of the area, woodlands about 15 percent, and water

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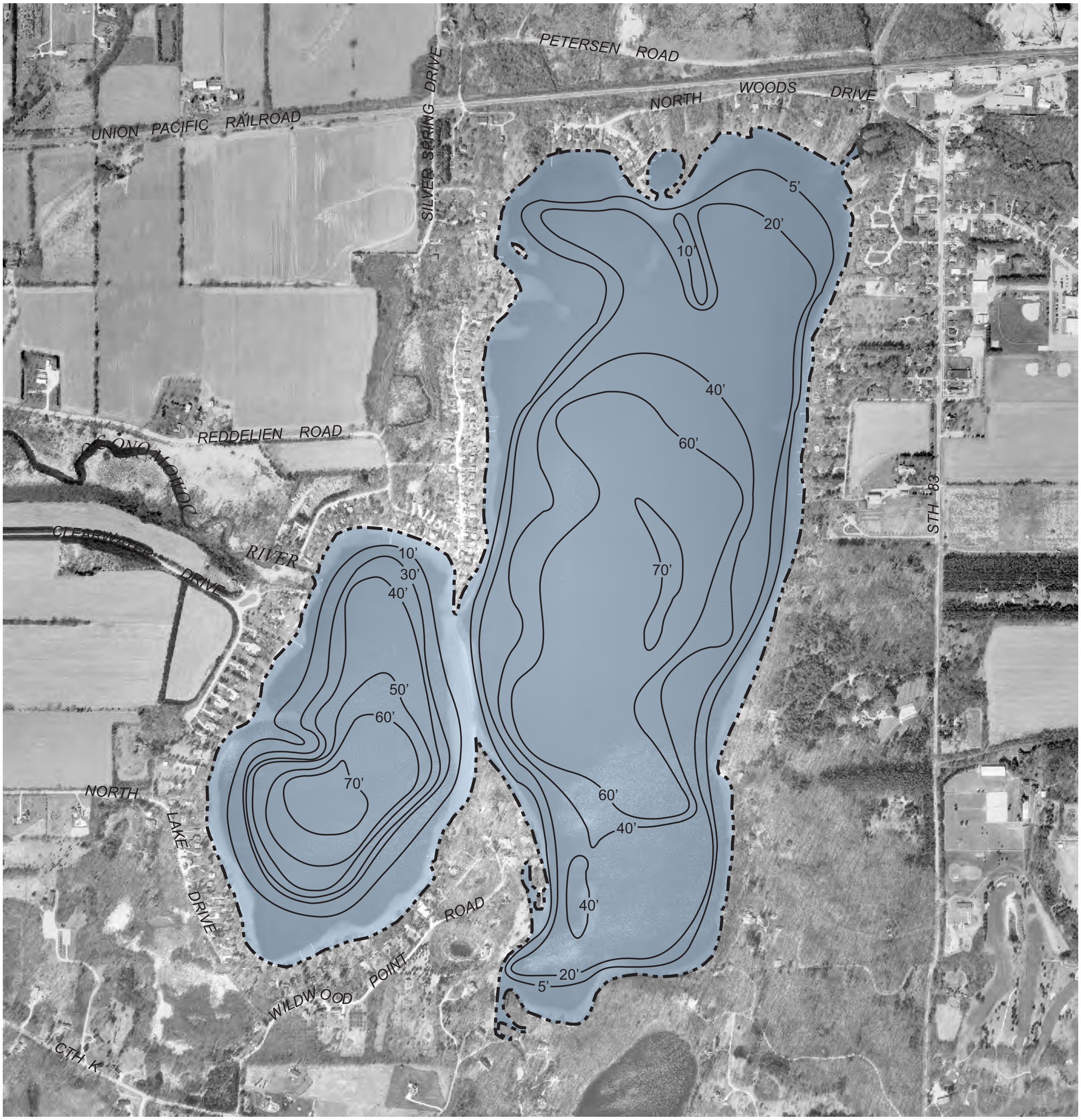
[41]*Wisconsin Conservation Department*, op. cit.

[42]*Wisconsin Department of Natural Resources Publication No. PUBL-FH-800 2001*, op. cit.

[43]*Excluding internally drained areas, which comprise an additional 6.6 square miles.*

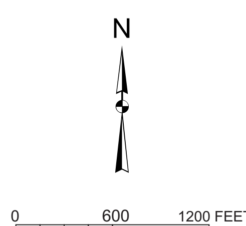
Map 12

BATHYMETRIC MAP OF NORTH LAKE



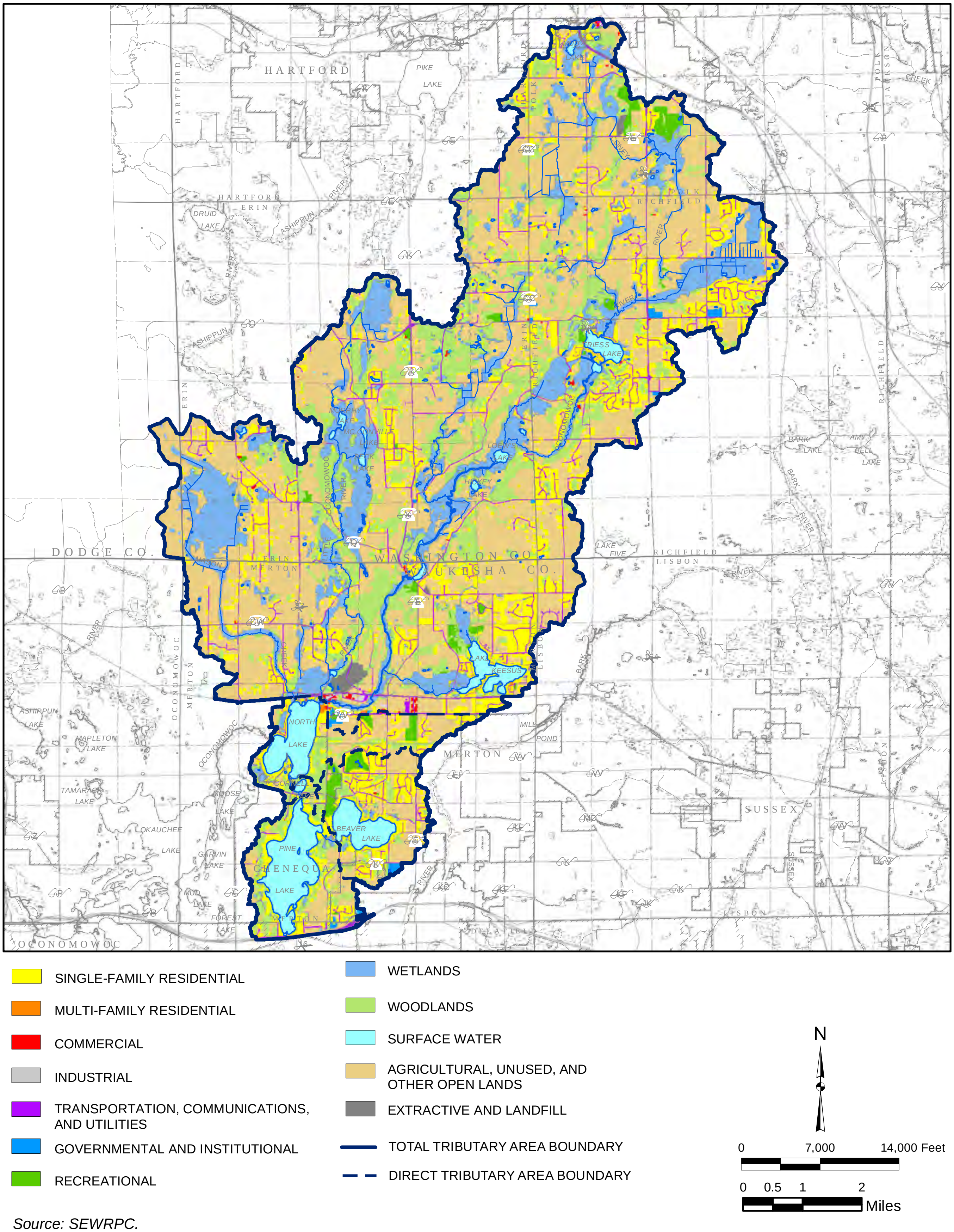
— 20' — WATER DEPTH CONTOUR IN FEET

Source: SEWRPC.



Map 13

EXISTING 2010 LAND USE FOR NORTH LAKE TRIBUTARY INCLUDING THE LARGER UPSTREAM OCONOMOWOC WATERSHED



Source: SEWRPC.

Table 12

EXISTING AND PLANNED LAND USE WITHIN THE NORTH LAKE DIRECT WATERSHED AND THE LARGER OCONOMOWOC TRIBUTARY AREA (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035[a]

Land Use Categories[b]	2010		2035	
	Acres	Percent of Total	Acres	Percent of Total
Urban[c]				
Residential	6,440	17.6	8,632	23.6
Commercial	68	0.2	185	0.5
Industrial	35	0.1	190	0.5
Governmental and Institutional	108	0.3	216	0.6
Transportation, Communication, and Utilities	91	0.3	91	0.3
Recreational	378	1.0	601	1.6
Subtotal	7,120	19.5	9,915	27.1
Rural				
Agricultural and Other Open Lands	16,809	46.0	14,145	38.7
Wetlands	6,074	16.6	6,074	16.6
Woodlands	5,365	14.7	5,062	13.9
Water	1,134	3.1	1,106	3.0
Extractive	43	0.1	243	0.7
Landfill	- -	- -	- -	- -
Subtotal	29,425	80.5	26,630	72.9
Total	36,545	100.0	36,545	100.0

[a]*The areas tributary to Beaver, Cornell, and Pine Lakes, which may periodically flow into North Lake, are excluded.*

[b]*Parking included in associated use.*

[c]*Streets included in associated use.*

Source: SEWRPC.

about 3 percent. The 2035 land use distribution between urban and rural lands, as shown on Map 14, is expected to become more equally divided between urban lands with about 45 percent of the area being urban and 55 percent of the area being rural.

Other Land Use Considerations

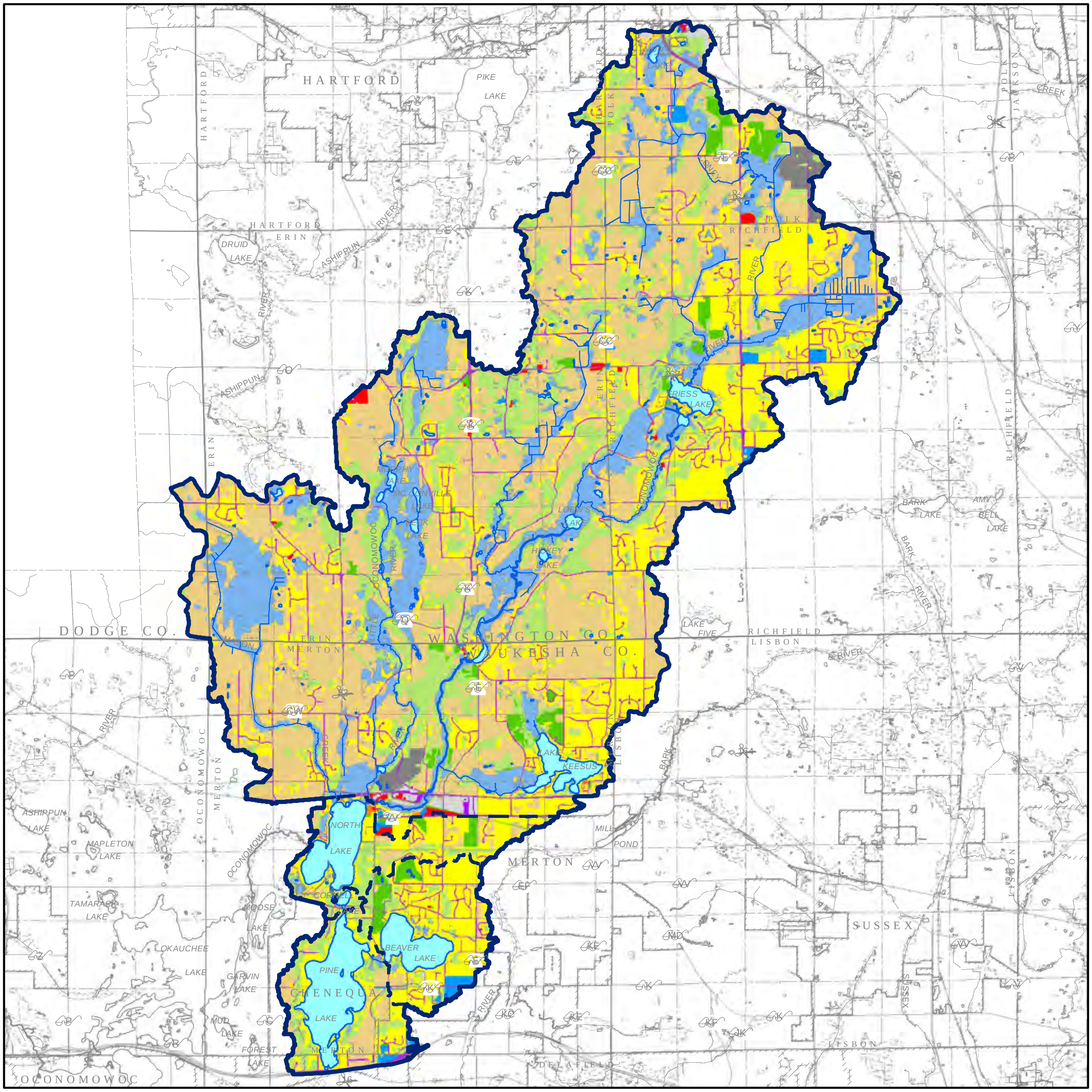
As with the other Lakes discussed in this plan, a "canopy cover" analysis was completed on the direct tributary area to North Lake as this area still partially falls within the Village of Chenequa's jurisdiction. This analysis, as shown graphically on Map 15, revealed that 182 acres of "nonforested" land uses, within the 1809 acre direct tributary had canopy cover, with approximately 75 percent of that land area being located in residential and commercial areas. This canopy cover may play a role in reducing pollution from the direct watershed, however, will likely be unsuccessful in preventing pollution from the greater upstream Oconomowoc watershed.

Nonpoint Sources of Water Pollution

Under existing year 2010 land use conditions, sediment and phosphorus loads from the area tributary to North Lake are generated primarily from agricultural lands which comprise about half of the total area tributary to the Lake. Under planned 2035 land use conditions, agricultural uses are expected to decrease to about four-fifths of the watershed area, but they would still be the largest sources of sediment and phosphorus. The Oconomowoc

Map 14

PLANNED 2035 LAND USE FOR NORTH LAKE TRIBUTARY INCLUDING THE LARGER UPSTREAM OCONOMOWOC WATERSHED



SINGLE-FAMILY RESIDENTIAL

MULTI-FAMILY RESIDENTIAL

COMMERCIAL

INDUSTRIAL

TRANSPORTATION, COMMUNICATIONS, AND UTILITIES

GOVERNMENTAL AND INSTITUTIONAL

RECREATIONAL

WETLANDS

WOODLANDS

SURFACE WATER

AGRICULTURAL, UNUSED, AND OTHER OPEN LANDS

EXTRACTIVE AND LANDFILL

TOTAL TRIBUTARY AREA BOUNDARY

DIRECT TRIBUTARY AREA BOUNDARY

N

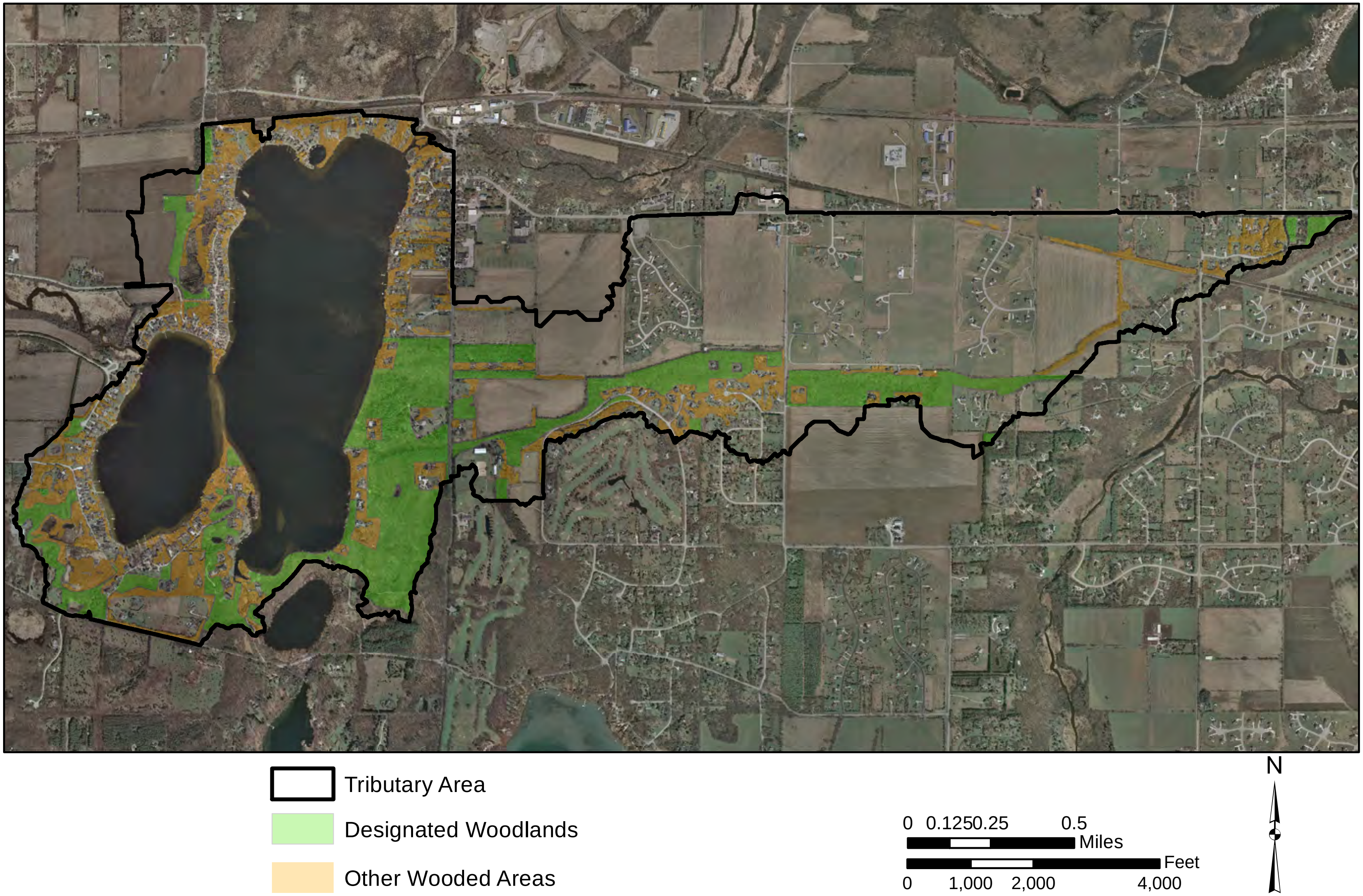
0 7,000 14,000 Feet

0 0.5 1 2 Miles

Source: SEWRPC.

Map 15

CANOPY COVER ANALYSIS FOR NORTH LAKE WATERSHED



Source: SEWRPC

River Priority Watershed Plan recommended reductions in phosphorus loading of 65 percent to the Lake, to restore the Lake to a mesotrophic condition, with a total phosphorus concentration of 0.02 to 0.03 mg/1.[44]

Under year 2010 land use conditions, it is estimated that the annual phosphorus load to North Lake would be approximately 15,429 pounds. A slight decrease in load to about 14,959 pounds of phosphorus is expected under year 2035 land use conditions with Chapter NR 151 controls on runoff from new development accounted for as shown in Table 13. Under year 2010 land use conditions, it is estimated that 3,663 tons of sediment would enter the Lake annually, with this load expected to decrease to 3,483 tons by 2035 as agricultural lands are converted to urban land uses and sediment controls are installed for new development as required under Chapter NR 151. Estimated copper and zinc loads, in contrast, are expected to increase from about 35 pounds of copper and about 337 pounds of zinc under 2010 land use conditions, to about 56 pounds of copper and 496 pounds of zinc under planned year 2035 conditions with NR 151 controls on runoff from new development. As can be seen from Table 13, the implementation of the required controls on runoff from new development would significantly reduce the heavy metals loads to the Lake, relative to the planned condition without controls.

Factors Affecting Loading Calculations

Though the canopy cover maintenance measures that are implemented by the Village of Chenequa will likely affect the direct area to North Lake in the same way it affected the other Lakes within this study, these policies will likely not affect the loadings coming from the larger watershed. There are however, other considerations that should be taken into account in this region; namely the presence of buffered vegetative regions[45] surrounding the upstream river.

In 2010, SEWRPC completed a review of the scientific literature to determine what buffer widths are necessary for providing pollution reduction and these widths vary from 25 feet to 300 feet for 75 percent nutrient reduction and 20 feet to 700 feet for 75 percent sediment reduction, with widths as small as 5.0 feet having some ability to filter pollution.[46] In order to determine if the presence of buffered regions could affect the pollution loadings entering the Oconomowoc River, and eventually North Lake, SEWRPC conducted a buffer analysis on the entire watershed. This analysis, represented graphically on Map 16, revealed that approximately 11,600 acres of the North Lake watershed is considered a part of a buffer area. Additionally, as is evident on Map 16, much of the upstream Oconomowoc River is well buffered, with widths sometimes expanding above 500 feet.

This analysis also reveals, however, that gaps in the buffered regions do exist. These gaps provide a pathway for runoff to bypass the buffered regions and thereby avoid the natural filtration the buffered area would have provided. Consequently, the loadings found for the North Lake tributary may be influenced by these buffer regions; however, if water quality issues become an issue in the Lake, the expansion of these buffers and other mitigation measures should likely be considered.

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[44]*Wisconsin Department of Natural Resources Publication No. PUBL- WR-194 86,* op. cit.

[45]*Buffered regions are essentially unobstructed plant life of which runoff would be forced to flow through prior to entering the river. The plants within these regions will then have a chance to filter sediments, nutrients, and other pollutants out of the runoff prior to the runoff entering the river or Lake.*

[46]*SEWRPC,* Managing the Water's Edge: Making Natural Connections, *May 2010.*

Table 13

EXISTING AND FUTURE POLLUTION LOADS TO NORTH LAKE DIRECT WATERSHED AND THE LARGER OCONOMOWOC (EXCLUDING INTERNALLY DRAINED AREAS): 2010 AND 2035

Land Use Categories[a]	2010				2035 (no controls on new development loads)				2035 (NR 151 controls)[b]			
	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)	Sediment (tons)	Phosphorus (pounds)	Copper (pounds)	Zinc (pounds)
Urban												
Residential	70.5	1,310	5.1	97.7	94.7	1,757	6.9	131.8	75.3	1,533.5	5.6	107.9
Commercial	26.6	81	14.9	101.1	72.6	222	40.8	276.0	35.8	151.6	22.7	153.6
Industrial	13.1	41	7.7	52.1	71.6	223	41.9	283.7	24.8	132.0	18.0	121.6
Governmental and Institutional	27.6	146	7.6	86.4	55.2	292	15.1	172.9	33.1	219.0	9.9	112.4
Transportation, Communication, and Utilities	0.4	10	- -	- -	0.4	10	- -	- -	0.4	10.0	0.0	0.0
Recreational	4.5	102	- -	- -	7.2	162	- -	- -	5.0	132.0	0.0	0.0
Subtotal	142.7	1,690	35.3	337.3	301.7	2,666	104.7	864.4	174.4	2,178.0	56.2	495.5
Rural												
Agricultural and Other Open Lands	3,392.5	13,129	- -	- -	3,182.6	12,165	- -	- -	3,182.6	12,165.0	0.0	0.0
Wetlands	11.2	243	- -	- -	11.2	243	- -	- -	11.2	243.0	0.0	0.0
Woodlands	9.9	215	- -	- -	9.4	202	- -	- -	9.4	202.0	0.0	0.0
Water	106.6	147	- -	- -	104.0	144	- -	- -	104.0	144.0	0.0	0.0
Extractive	0.2	5	- -	- -	1.2	27	- -	- -	1.2	27.0	0.0	0.0
Subtotal	3,520.4	13,739	- -	- -	3,308.4	12,781	- -	- -	3,308.4	12,781.0	0.0	0.0
Total	3,663.1	15,429	35.3	337.3	3,610.1	15,447	104.7	864.4	3,482.8	14,959.0	56.2	495.5

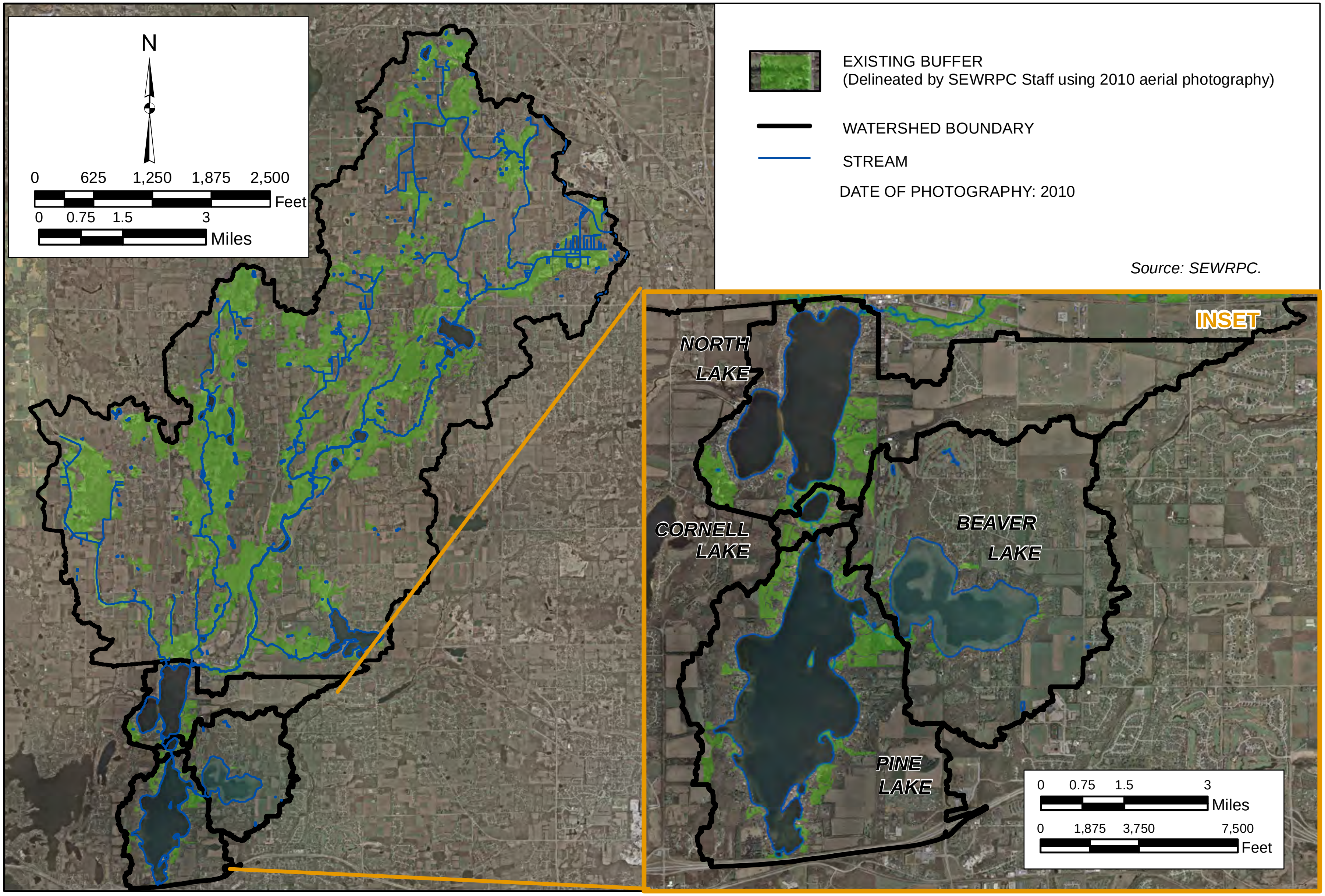
[a] *Parking included in associated use.*

[b] *Assumes a level of control consistent with the requirements of Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code, *which calls for an 80 percent reduction in total suspended sediment (TSS) from areas of new development. Consistent with that level of TSS reduction, a 50 percent reduction in total phosphorus and 70 percent reduction in metals was assumed.*

Source: SEWRPC.

Map 16

AREAS OF EXISTING BUFFER WITHIN THE NORTH LAKE AND OCONOMOWOC TRIBUTARY AREA



Water Quality

North Lake has the highest amount of available data out of the four lakes discussed in this plan. In fact, some sparse data is even available from 1906 to 1909.[47] In addition to this, data is available from 1960, between 1973 and 1977, from 1979 to 1980, and from 1995 which was collected by WDNR, as well as for every year since 1985, as collected though Citizen Lake Monitoring efforts.

This water quality data indicates that North Lake is a mesotrophic, or moderately enriched, waterbody with a Wisconsin TSI rating of approximately 51. In 1982, SEWRPC completed a water quality management plan was for the Lake,[48] the principle feature of which was an emphasis on sound land use management through enactment of development controls and associated land management requirements.

The mean total phosphorus concentration in the Lake for all total phosphorous measurements taken since 1990 is reported to be approximately 20 µg/l; the same level that should not be exceeded in natural lakes. This average decreased drastically from the average phosphorous level during the 1970s: 48.5 µg/l. This decrease in phosphorous levels, which can be seen graphically in Figure 4, is likely the result of a combination of factors; however, it is suspected that the push for sanitary sewerage service throughout the Southeastern Wisconsin Region, as well as urbanization of the upstream Oconomowoc watershed, contributed significantly to this change.

Data since 1990 indicates that the Lake has an average Secchi-disk transparency of about 10 feet or 3.0 m and average chlorophyll-*a* concentration of about 8.0 µg/l. Both of these values indicate slightly better water quality than historical averages of measurements taken prior to 1981 (see Figure 4); these averages were calculated to be approximately nine feet and 10 µg/l. These improvements, like with the phosphorous levels, are likely a result of upstream land use changes as well as sewerage system installation within the ground watershed.

Zebra mussels were first recorded in North Lake in January of 2002; however, there was no clear increase of water clarity recorded after this period.

Other Monitored Parameters

Physical characteristics, heavy metals, nutrients, and biological parameters were measured in North Lake between 1973 to 1981, by WDNR. Additionally, some chemical parameters were taken between 1906 and 1909 and in 1960, also by WDNR. This data is shown in Table 14, along standards and regional averages, for comparative purposes. Most of the parameters remained within an acceptable range from regional averages and standards, although sulfates do periodically rise slightly above 40, indicating this parameter should be monitored. The only parameter that was consistently above the standard was ortho-phosphates. As was done with Pine Lake, the nitrogen to phosphorous ratios were calculated for all dates where total phosphorous and total nitrogen were available, to determine if this was due to nitrogen being a limiting factor. The results of these calculations, as shown in Table 15, indicate that phosphorous is consistently the limiting nutrient, thereby confirming that the high orthophosphate levels are a result of periodic phosphorous pollution.

Confirming Loading Calculations

The phosphorus load, developed from the SEWRPC UAL models, was utilized in the OECD eutrophication models to forecast in-lake average concentrations of total phosphorus and chlorophyll-*a*, and Secchi-disk transparency.[49] Using the estimated total phosphorus load to North Lake for year 2010 land use conditions, the

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[47]*SEWRPC Community Assistance Planning Report No. 54*, A Water Quality Management Plan for North Lake, Waukesha County, Wisconsin, *July 1982.*

[48]Ibid.

[49]*S.-O. Ryding and W. Rast,* UNESCO Man and the Biosphere Series, op. cit.

Table 14

HISTORICAL MEASUREMENTS AND ANNUAL AVERAGES OF WATER QUALITY PARAMETERS IN NORTH LAKE: 1973-1995

Parameter	Prior to 1910				1960s and 1970s							Total Average	Standards
	07/30 1906	05/10 1907	06/07 1907	07/20 1909	10/01 1960	1973	1974	1975	1976	1977	1979		
Conductance (UMHOS/cm)	- -	- -	- -	- -	645	490.5	547.5	527	535	550	642.5	546	**500-600**[a]
pH	- -	- -	- -	- -	8.3	8.15	8.175	8.3	- -	- -	8.05	8.2	**8.1**[a]
Dissolved Oxygen	7.5	14	14	9	- -	8.45	10.45	9.7	11	14.5	11.2	10.5	**Above 5**[b]
Alkalinity	- -	- -	- -	- -	228	243	245	251	248	271	261	249	**Below 0.01**[b]
Orthophosphates	- -	- -	- -	- -	- -	0.04	0.05	0.04	0.05	0.02	0.011	0.041	**Below 10.0**[b]
Nitrate and Nitrite	- -	- -	- -	- -	- -	0.7	0.9	0.8	0.55	0.55	0.9125	0.8	**Below 0.2**[b]
Ammonium	- -	- -	- -	- -	- -	0.3	0.2	0.18	0.12	0.04	0.24	0.18	- -
Organic Nitrogen	- -	- -	- -	- -	- -	0.6	0.8	0.5	0.65	0.38	0.45	0.61	- -
Turbidity (NTUs)	- -	- -	- -	- -	- -	1.6	3.1	2.1	4.3	1.8	1.4	2.6	**36**[a]
Calcium	45	47.3	38.3	42.3	- -	60	88	60.5	63.7	53	67.5	63	**32**[a]
Magnesium	28.7	28	25.5	30.5	- -	35.8	41	41.25	42.7	39	39	38	- -
Sodium	- -	- -	2.2	4.8	- -	6.3	14	6.5	6.8	4	6	7.9	- -
Potassium	- -	- -	1.2	2.4	- -	2.4	2.6	2.7	1.8	6	1.8	2.4	**Between 20-40**[b]
Sulfate	- -	- -	- -	- -	- -	33.5	43	37	38	43	- -	38	**Below 250**[b]
Chlorides	3	4	6.8	4.2	- -	14	14	13	14	16	16	12.6	**500-600**[a]

NOTES: Red font indicates values above established standards.

All measurements are in milligrams per liter (mg/l) unless otherwise noted.

[a]*Southeastern Wisconsin regional averages.*

[b]*Established standards for the State of Wisconsin.*

Source: U.S. Geological Survey, Citizen Lake Monitoring Data, Wisconsin Department of Natural Resources, and SEWRPC.

Table 15

TOTAL NITROGEN TO TOTAL PHOSPHOROUS RATIOS FOR NORTH LAKE: 1973-1979

Date	Nutrients (mg/l)		Calculated Ratio
	Total Phosphorous	Total Nitrogen	
09/20/73	0.020	1.53	76.5
11/23/73	0.090	1.06	11.8
02/07/74	0.050	2.00	40.0
04/05/74	0.070	1.54	22.0
07/11/74	0.040	1.86	46.6
11/20/74	0.060	1.25	20.8
02/20/75	0.030	1.40	46.7
04/24/75	0.070	2.03	29.0
07/02/75	0.020	1.10	55.0
11/24/75	0.060	0.97	16.1
03/16/79	0.040	1.40	35.0
04/26/79	0.020	1.33	66.3
Average	**0.048**	**1.45**	**38.8***

NOTE: All ratios indicate that North Lake is phosphorous limited.

Source: Wisconsin Department of Natural Resources and SEWRPC.

forecast in-lake concentrations were 87 µg/l of total phosphorus, 20 µg/l of chlorophyll-*a* and a mean annual Secchi-disk transparency was 3.0 m or about 10.0 feet. With recorded averages for total phosphorous and chlorophyll-*a* being 20 µg/l and 8.0 µg/l respectively, the actual concentrations found in North Lake were significantly higher quality than those that were predicted. Additionally, the average Secchi disk measurement of 9.0 feet also indicated higher water quality than those predicted. These inconsistencies are likely due to a number of factors which are not accounted for in UAL calculations, including: 1) the presence of buffers along the entire upstream (as discussed above); 2) the entrapment of pollution loads and sediments in the naturally meandering upstream river and the impoundment associated with Monches dam; and 3) the biological uptake of pollutants within the upstream river. Consequently, as with Beaver and Pine Lakes, the use of Unit Area Loadings to predict future water quality in the Lake[50] is likely not viable for North Lake.

Aquatic Plants

An aquatic plant survey was conducted on North Lake in 1976.[51] Though plant growth was considered low to moderate, a significant population of curly-leaf pondweed was present. It is very likely that the plant communities have drastically changed since that time; therefore, the results of the survey are not particularly useful when developing plant management recommendations. Eurasian water milfoil chemical treatment activities were, however, undertaken in 2009, indicating that the invasive species, which was first recorded in the Lake in 1994, had been perceived as an issue of concern at that time.

Utilizing mathematical relationships developed for the State of Wisconsin, based upon Secchi-disk transparency, the maximum depth of aquatic plant colonization in this Lake would be expected to be about 4.2 m or about 14 feet. Observations of the aquatic plant community in the Lake confirmed this as the approximate depth to which aquatic plants grew.

Fish and Wildlife Populations

In 1963, the fishery of North Lake consisted largely of panfish, northern pike, walleyed pike, and largemouth bass.[52] Cisco were also reported. A fish survey conducted in 1975 reported the fishery to consist of brown bullhead, green sunfish, smallmouth bass, northern pike, common carp, yellow bullhead, bowfin, grass pickerel, bluntnose minnow, mimic shiner, brook silverside, johnny darter, common shiner, black crappie, rock bass, largemouth bass, walleyed pike, white bass, yellow perch, pumpkinseed, white sucker, and bluegill. As of 2001,

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[50]*When the year 2035 land use data is used to forecast the future water quality of North Lake, expected concentrations of total phosphorus and chlorophyll-*a *were about 87 µg/l and 20 µg/l, respectively, with a an annual average transparency of about 3.0 m or10.0 feet.*

[51]*SEWRPC Community Assistance Planning Report No. 54*, op. cit.

[52]*Wisconsin Conservation Department*, op. cit.

northern pike, largemouth bass, smallmouth bass, and panfish were reported to be common in the Lake, and walleye were reported to be present.[53] Waterfowl and upland game birds make limited migratory and resident use of the wetlands adjoining the Lake outlet.

As mentioned in the water quality section, zebra mussels have been present in the Lake since 2002 and should be considered a priority for control if a successful control measure is found in the future.

Recreational Use
Public access is provided only through the navigable outlet (and inlet) of the Lake. North Lake currently does not have adequate public access pursuant to Chapter NR 1 of the *Wisconsin Administrative Code*, although there are ongoing discussions between the community and the WDNR regarding provision of public recreational boating access to North Lake.

Oconomowoc River
Stream Morphometry
The Oconomowoc River is located in the northwest portion of Waukesha County. The River has a surface area of about 121 acres, a length of 14.3 miles, and a gradient of 5.9 feet per mile. Originating in Washington County, the Oconomowoc River is the major waterway of northwest Waukesha County. There are seven impounding structures and, in all, seven waterbodies on this stream.[54] Treated effluent from the City of Oconomowoc is discharged to the River downstream of Lac La Belle. The Oconomowoc River is in the Upper Rock River basin areawide water quality management planning area.[55] In addition, the Waukesha County portion of the Oconomowoc River is included within the Oconomowoc River Priority Watershed project area.[56] The River, between North Lake and Okauchee Lake, has been designated as an Exceptional Resource Water of the State pursuant to Chapter NR 102 of the *Wisconsin Administrative Code*.

Existing Land Use
Table 12 also sets forth existing year 2010 land use data for the portion of the Oconomowoc river watershed that drains to North Lake.[57] As of 2010, the land uses within the approximately 57-square-mile portion of the Oconomowoc River located upstream of north Lake in Dodge, Washington, and Waukesha Counties consisted of about 20 percent urban land uses and about 80 percent rural land uses. Agricultural land uses comprised about 46 percent of the land area and about 57 percent of the rural land in the subwatershed. Residential lands comprised about 18 percent of the total land area and about 90 percent of the urban land.

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[53]*Wisconsin Department of Natural Resources Publication No. PUBL-FH-800 2001,* op. cit.

[54]*These are, from upstream to downstream, Friess Lake, Little Friess Lake, North Lake, Okauchee Lake, Oconomowoc Lake, Fowler Lake, and Lac La Belle. Lake Keesus drains to the Oconomowoc River, joining the River in the Town of Merton. The Oconomowoc River, within Washington County, is designated as a Class 2 stream for purposes of water quality protection, pursuant to Chapter 23 of the* Washington County Code*. Class 2 waterbodies are subject to more stringent zoning requirements than those provided under and pursuant to Chapter 30 of the* Wisconsin Statutes*.*

[55]*Wisconsin Department of Natural Resources Publication No. PUBL-WR-190-95REV,* Upper Rock River Basin Water Quality Management Plan*, December 1995*.

[56]*Wisconsin Department of Natural Resources Publication No. PUBL-WR-194 86,* op. cit.

[57]*The data in Table 12 exclude internally drained areas and areas tributary to Beaver, Cornell, and Pine Lakes, which may periodically flow into North Lake.*

Land Use Changes
The Oconomowoc subwatershed is partially located within an area planned for urban development in the adopted County development and comprehensive land use plans.[58] As a consequence, urban land uses are anticipated to comprise about 27 percent of the watershed area under year 2035 land use conditions, with urban residential lands representing about 87 percent of the urban land area in the subwatershed (see Table 12). Rural lands would comprise about 73 percent of the watershed area under planned year 2035 conditions, with agricultural lands declining to about 39 percent of the subwatershed area.

Nonpoint Sources of Water Pollution
Estimated nonpoint source pollution loads within the portion of the Oconomowoc River subwatershed that drains to North Lake are set forth in Table 13. The planned conversion of rural to urban land in the period from 2010 through 2035 would not be expected to significantly change the estimated loads of sediment and phosphorus, but heavy metals, such as copper and zinc, which are characteristic of urban runoff, would increase substantially.

As previously discussed in the "Factors Affecting Loading Calculations" discussion of North Lake, buffered regions (see Map 16) may play a role in reducing some of the anticipated loadings.

Fish and Wildlife Populations
In 1963, the fishery of the Oconomowoc River was reported to consist largely of largemouth bass, panfish, channel catfish, and northern pike.[59] Rough fish are also common and may be considered a use problem in selected areas. Fish surveys conducted in 1971, 1973, 1975, 1976, 1985, 1994, and 1995 reported the fishery to consist of bluegill, largemouth bass, shorthead redhorse, yellow bullhead, brook silverside, common shiner, black bullhead, bluntnose minnow, brown bullhead, northern pike, blackside darter, common carp, golden redhorse, yellow perch, fathead minnow, banded darter, stonecat, slenderhead darter, rainbow darter, slender madtom, blackchin shiner, banded killifish, logperch, Iowa darter, largescale stoneroller, emerald shiner, longnose gar, lake chubsucker, golden shiner, sand shiner, green sunfish, spotfin shiner, johnny darter, smallmouth bass, and blackstripe topminnow.[60] The banded killifish is listed as a State species of special concern. The slender madtom is listed as a State endangered species.

Recreational Use
The Oconomowoc River has limited navigability in areas, but is generally navigable by canoe or similar watercraft. Public access is provided through the rights-of-way of county and town roads. Recreational boating access is provided on most of the Lakes located along this river system.

Summary
The following are the significant conclusions from the above discussion of the Village of Chenequa's Surface Water Resources:

Hydrology
- Refined watershed boundaries reveal that Beaver, Pine, and Cornell Lake periodically drain into North Lake, located along the Oconomowoc River which flows in a southwesterly direction.

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[58]*SEWRPC Community Assistance Planning Report No. 209,* op. cit.*; SEWRPC Community Assistance Planning Report No. 287,*op. cit.

[59]*Wisconsin Conservation Department,* op. cit.

[60]*Wisconsin Department of Natural Resources Research Report No. 148,* op. cit.

Water Quality

- Water quality parameters have improved since, or remained constant with, historic levels for all measured parameters, with the exception of chlorides, in Pine, Beaver, and North Lake. Data was not available for Cornell Lake.

- Beaver Lake shows signs of chloride pollution with values that almost tripled by 1995 since the 1970s. Though still within acceptable levels, this pollution should be further monitored and mitigated to prevent the Lake reaching a level which can cause biological stress to the Lake's ecosystem.

- Water clarity in Pine Lake is likely being affected by zebra mussel populations.

- Phosphorous pollution is evident in North Lake, although total phosphorous levels are still considered at an acceptable range. This should be maintained to the greatest extent possible with phosphorous reduction measures within the larger upstream Oconomowoc watershed.

- Pine Lake, though most recently shown to be phosphorous limited, has historically been shown to be a nitrogen-limited lake. Therefore, efforts to monitor nutrient components (both nitrogen and phosphorous), and to reduce both of these pollutants, are necessary.

Land Use and Pollution

- Agriculture from the direct tributary is the largest contributor of phosphorous loadings in Beaver and Pine Lakes.

- Residential runoff is considered a major contributor of phosphorous in Beaver Lake and a minor contributor in Pine Lake; however, the water quality of both Beaver and Pine Lake has likely been highly affected (positively) by the residential canopy cover located throughout their basins.

- Agricultural runoff is considered the highest contributor of sediments and phosphorous to North Lake and is coming from the upstream Oconomowoc watershed; however, North Lake's water quality is likely highly affected (positively) by the buffered regions located throughout the upstream Oconomowoc basin which filter upstream pollution prior to it getting to the Lake.

- Cornell Lake's major pollution source is flow from Pine Lake. The Lake also contains extensive canopy cover in addition to the forested areas in the direct watershed.

Data Availability

- While North and Pine Lake have an adequate amount of water quality data, Beaver and Cornell Lake require more extensive monitoring efforts.

- Extensive water quality data is available on North Lake, however, nutrient components, ions, and general characteristics have not been measured since 1979, thereby indicating that this needs to be done in the future.

GROUNDWATER RESOURCES

Groundwater is an important component of the water resources in the Village of Chenequa and environs. Groundwater in the vicinity of Beaver, Cornell, and Pine Lakes moves within two distinct systems: a shallow aquifer system and a deep aquifer system. The shallow aquifer consists of glacial deposits and the dolomite bedrock nearest the surface. This shallow aquifer interacts with the surface water system, contributing to the base flow of streams, the maintenance of lake levels, and the sustenance of wetlands.

The shallow sand and gravel aquifer, consisting of water-bearing sand and gravel, has a maximum thickness ranging from 100 to 200 feet in the vicinity of the Village.[61] Although the groundwater gradient in the surface aquifer is relatively flat in the vicinity of the Lakes, indicating limited horizontal movement, groundwater generally flows in a westerly to southwesterly direction, as shown on Map 17.

The deep aquifer includes bedrock, mostly sandstone, directly above the crystalline Precambrian basement rocks. This system has limited interchange with the shallow aquifer, and has significantly less influence on the surface water hydrology of the Beaver and Pine Lake flow system than does the shallow aquifer, despite the Village being located near the western boundary of Maquoketa Shale confining layer that separates the deep aquifer from the shallow aquifer across much of the Southeastern Wisconsin Region. Both the shallow and deep aquifers are used for municipal water supplies in the Region.[62] Individual wells developed in the shallow sand and gravel aquifer are most frequently used as a source of supply in areas with no municipal supply.

In a similar vein, the SEWRPC water supply planning program, which was conducted over the past decade, has resulted in the detailed documentation of the groundwater resources of the Region. SEWRPC technical reports on the Region's groundwater resources incorporated a large volume of data acquired by the Wisconsin Department of Natural Resources (WDNR) as part of their high-capacity well permitting program, in addition to data developed from numerous studies by the University of Wisconsin-Milwaukee and others.[63] The aquifers in southeastern Wisconsin can be divided into shallow and deep aquifers. The shallow aquifer system comprises two or three aquifers, depending on their location relative to the Maquoketa shale bedrock subcrop. Where the Maquoketa Formation is present, the shallow aquifer system consists of the Silurian dolomite aquifer and the overlying sand and gravel aquifer. The Maquoketa Formation is the lower limit of the shallow aquifer system. In the westernmost parts of Waukesha and Walworth Counties where the Maquoketa Formation is not present, the shallow aquifer system consists of the sand and gravel aquifer, the Galena-Platteville aquifer, and the upper sandstone aquifer, with its lower boundary in the St. Lawrence semi-confining unit, as described by the USGS.[64]

USGS Study

As part of this water resources management planning program, the USGS developed a MODFLOW model for the Village of Chenequa,[65] as an inset model within the regional groundwater flow model for the Southeastern Wisconsin Region.[66] The purpose of this inset model was to inform the conjunctive use of surface water and groundwater resources in the Village, by providing a tool that the Village could use to evaluate the interaction between surface waters and groundwater, thereby avoiding unintended impacts on either water system. Because

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[61]*See SEWRPC Technical Report No. 37,* op. cit.

[62]*See SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin, *Volume One of Two Volumes,* Chapters 1-12, *December 2010.*

[63]*See SEWRPC Technical Report No. 37,* Groundwater Resources of Southeastern Wisconsin, *June 2002.*

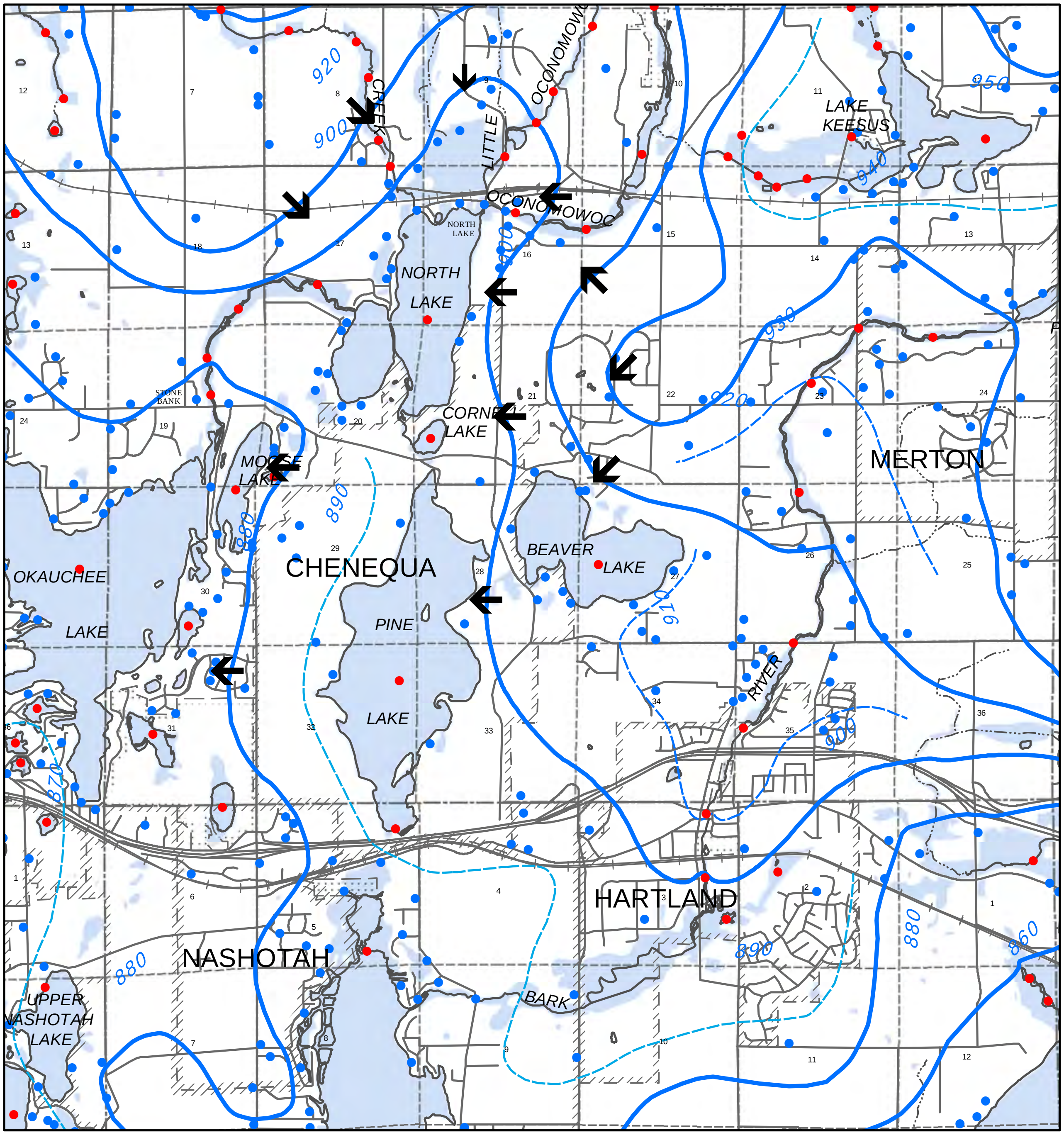
[64]*U.S. Geological Survey Water-Resources Investigations Report No. 83-4239,* An Overview of Ground-Water Quality Data in Wisconsin, *1984.*

[65]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwest Waukesha County, Wisconsin, *2011.*

[66]*SEWRPC Technical Report No. 41,* A Regional Aquifer Simulation Model for Southeastern Wisconsin, *June 2005.*

Map 17

DIRECTION OF GROUNDWATER FLOW IN THE PINE AND BEAVER LAKES AREA

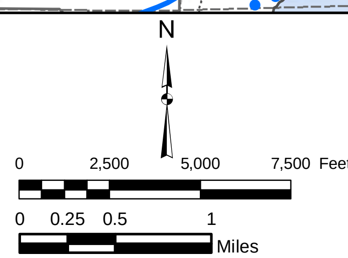


AVERAGE WATER-TABLE ELEVATION
(FEET ABOVE MEAN SEA LEVEL)

SUPPLEMENTAL CONTOUR

SURFACE WATER POINT

WELL DATA POINT



Source: U.S. Geological Survey and SEWRPC.

several of the major lakes within the Village are groundwater-dependent, and because these resources are heavily used by Village residents and visitors, over-pumping of the shallow aquifer could potentially result in negative impacts on the surface waters.

For the purposes of the analysis, the original regional model, developed using MODFLOW 96, was modified to run using MODFLOW–2005. The lower eight layers of the initially 18-layer background regional model—those representing the deep aquifer system—were combined into a single confined layer for use in the Chenequa-area model. The attributes of the deep aquifer were compiled into representative bulk hydraulic properties that preserved the spatial variation of transmissivity and storage capacity in the deep aquifer system. This simplification was appropriate because the primary objective of the inset model was to simulate the interaction between the shallow groundwater system and lakes. The remaining 11 layers were comprised of, from the land surface down to the deep aquifer, two layers representing the unlithified glacial material, one layer of negligible thickness representing the Pennsylvanian and Mississippian bedrock, which is absent in southeastern Wisconsin, three layers representing the Silurian dolomite, two layers representing the Maquoketa Formation, and two layers representing the Sinnipee Group. In general, the glacial deposits can act as an unconfined aquifer or a confining unit, the Silurian dolomite serves as an unconfined or semi-confined aquifer, the Maquoketa Formation is a confining unit, and the Sinnipee Group can act as a confining unit or contribute transmissivity to the underlying confined, deep aquifer system.

A 20-year "run-up" period was simulated to allow the regional model and the inset model for the Village of Chenequa to synchronize, beginning from 1990 parent regional model results and using the same discharge rates originally assigned the background regional model for the 1991 to 2000 interval. This hypothetical transient run-up does not correspond to an actual period of time, but was required to create the linkages necessary between the models to develop the conditions necessary to investigate the interactions of groundwater with the Chenequa-area lakes under several pumping, recharge, precipitation, and evaporation scenarios. The 1991 to 2000 pumping rates were sustained for this transient five-year observation period.

In order to demonstrate the utility of the Village of Chenequa model, the USGS utilized data for a City of Delafield well proposed to be located in the vicinity of the intersection of STH 83 and STH 16, approximately midway between Pine and Beaver Lakes and the Bark River upstream of Nagawicka Lake. The proposed point of groundwater abstraction was approximately 200 feet below the land surface, in model layer 4. Because this simulation corresponded generally to the actual location of a physical test well, the model forecasts could be compared with the actual observation made by Earth Tech, Inc., contractors to the City of Delafield.[67]

The USGS reported a close fit between the observed drawdown of the shallow aquifer water surface reported by Earth Tech, Inc., and the drawdown simulated by the model when the horizontal hydraulic conductivity in the east-west direction was assigned a value of 55 feet per day (ft/d), the horizontal hydraulic conductivity in the north-south direction was assigned a value of 110 ft/d, and the vertical hydraulic conductivity was assigned a value of 1.0 ft/d. The 2:1 relationship between the east-west and north-south directions was noted as possibly representing the orientation of the outwash material deposited in the bedrock valley, which crosses the study area from the northeast corner to the southwest.

While the simulation of the response of the groundwater was considered to be good, the USGS noted that the simulated water table response duplicated the slope of the observed water table, but not the absolute trend. This was likely to be related to the fact that the groundwater flow model released pore water immediately while the

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[67]*Earth Tech, Inc., "Report [to the City of Delafield Department of Public Works] on Test Well Construction and Aquifer Performance Testing, Test Well for Well 2, Delafield, Wisconsin," 2006, cited in U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* op. cit.

actual storage release was slower due to the elastic response of the aquifer to the pumping. The close fit to the slope of the drawdown, however, suggested that the model successfully simulated the combined effects of pore drainage, vertical resistance to flow, and horizontal transmissivity with respect to the shallow observation well.

Evidence from well-drillers' logs was used to properly simulate the divide between the Bark River watershed and the neighboring Pewaukee Lake watershed, and to ensure that the Bark River is, on balance, a "gaining" stream in the Village model. The logs indicated that the glacial deposits become finer between the area of glacial outwash deposits in the vicinity of the Lakes in the Village of Chenequa and Pewaukee Lake and the Fox River. Pewaukee Lake and the Fox River area is characterized by mixed clayey till, loamy till, and coarse channel deposits.[68]

The USGS used the calibrated model to simulate the hydrologic system in the Village of Chenequa under various weather and pumping conditions. The base-case condition uses the long-term average weather for southeastern Wisconsin: 32 inches per year (in/yr) of precipitation falling onto lakes, 29 in/yr of evaporation from lakes, and 8.5 in/yr average recharge to water table. The base-case also used the existing pumping rate of 854 gallons per minute (gpm) (1.23 million gallons per day) from the shallow aquifer system within the Village. Dry weather conditions were simulated by reducing the groundwater recharge and direct precipitation onto the lake surfaces by one-third for a period of five years, with evaporation being kept constant. This scenario was not intended to simulate an historical event, but, rather, to show the possible effects of a severe, prolonged drought on the Chenequa-area lakes. The same base-case pumping conditions (854 gpm) and surface water and groundwater fluxes were used under the dry weather conditions as were used for the long-term simulation. Comparison of the various scenarios was undertaken to illustrate the magnitude of the human impacts on the Lakes in comparison with the climatic or natural impacts that could potentially be expected.

The simulated results for base-case conditions show the relative importance of groundwater flows in the lake water budgets. Groundwater was the largest inflow component for Beaver Lake, equal to 59 percent of total inflow, while groundwater diminished in importance in the water budgets for Pine Lake and for Cornell and North Lakes, equal to 16 percent of the total inflow to Pine Lake and 5 percent of total inflows to Cornell and North Lakes, respectively. In these latter Lakes, groundwater inflow is less than the contribution from precipitation and surface water inflow.

The effects of changes to the base-case conditions on the lake budgets ranged from negligible to substantial. The addition of a simulated well south of the Village of Chenequa, with a pumping rate of 47 gpm, had little added effect on lake stages or streamflows after five years of simulated pumping. The stage and the surface water outflow from Pine Lake were simulated to decrease by only 0.03 foot and 3 percent, respectively, relative to base conditions. The chief explanations for these modest effects are the low pumping rate, the depth of the simulated well, and the high transmissivity of the unconsolidated aquifer, which allows the well to draw water from upstream along the bedrock valley and to capture inflow from the Bark River. However, if the pumping rate of the test well is assumed to increase to 200 gpm, the decrease in Pine Lake outflow is appreciably larger: the simulated drop in outflow is 14 percent relative to base flow conditions and the drop in stage is 0.12 foot. This indicates that, at an assumed pumping rate 200 gpm, there could be significant impacts to downstream flows, despite minimal impacts to the lake itself.

In contrast, severe drought could be expected to cause correspondingly severe reductions in lake stage and flows: the level of Pine Lake could decline by 3.7 feet and the surface water outflow to Cornell and North Lakes would cease. If during drought conditions a new public water supply well were to be activated at pumping rates of either 47 gpm or 200 gpm, the relative effects of pumping at those rates would be expected to be small because the effect of the drought is dominant.

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

Finally, the model results confirmed that the Village of Chenequa lakes are a source of water for the test well. The model results indicated that, although lake levels and fluxes were only modestly affected by simulated pumping, the lakes were important sources of water from the vantage point of the test well: increased induced flow and reduced base flow from the Chenequa-area lakes together accounted for 23 percent of the water flowing toward the well at a pumping rate of 47 gpm. At a simulated test rate of 200 gpm, the lakes accounted for 27 percent of the well supply. By way of comparison, however, the contribution of other waterbodies—the Bark River and outlying lakes—was about 65 percent of the test-well discharge for both the 47- and 200-gpm rates.

A far more significant threat to the lake water budgets is drought, which is forecast to significantly reduce lake levels as a result of increased evaporation. Severe drought conditions, represented by five years of precipitation and recharge rates reduced by one-third of the base value, showed severe reductions in lake stages and flows. Under simulated dry weather conditions, for example, the level of Pine Lake would be likely to decline by 3.7 feet and surface-water outflows would cease as lake levels dropped below its outlet sill elevation.

Summary

The following are the significant conclusions of the USGS study:

- The simulated results for base-case conditions (an existing aggregate pumping rate of 854 gpm from the shallow aquifer system within the Village of Chenequa) show that groundwater was the largest inflow component for Beaver Lake, equal to 59 percent of total inflow, while groundwater diminished in importance in the water budgets for Pine Lake and for Cornell and North Lakes, equal to 16 percent of the total inflow to Pine Lake and 5 percent of total inflows to Cornell and North Lakes, respectively.

- The addition of a simulated well south of the Village of Chenequa, with a pumping rate of 47 gpm, had little added effect on lake stages or streamflows after five years of simulated pumping. The stage and the surface water outflow from Pine Lake were simulated to decrease by only 0.03 foot and 3 percent, respectively, relative to base conditions. If the pumping rate of the test well is assumed to increase to 200 gpm, the decrease in Pine Lake outflow is appreciably larger: the simulated drop in outflow is 14 percent relative to base flow conditions and the drop in stage is 0.12 foot.

- Severe drought conditions would pose a much more significant threat to the levels of Pine Lake than would the addition of a well south of the Village of Chenequa, with a pumping rate of 47 to 200 gpm.

- The model results confirmed that the Village of Chenequa lakes are a source of water for the test well with lake water being transferred to the groundwater system and groundwater that would otherwise discharge to the lakes being diverted to the well.

CLIMATE AND HYDROLOGY

National Oceanic and Atmospheric Administration (NOAA) long-term average monthly air temperature and precipitation values for General Mitchell International Airport in the City of Milwaukee are set forth in Table 16. The records from this station may be considered typical of the Village of Chenequa area. The long-term mean annual temperature of 48.1 degrees Fahrenheit (°F) is similar to that reported from other recording locations in southeastern Wisconsin. As indicated in Table 16, during 2007[69] air temperatures were about normal, averaging 48.9°F. The greatest deviation above normal was about 6.5°F during October. The greatest deviation below normal was 8.6°F during February. Average monthly temperatures for January and March 2007 were about 4°F above normal.

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[69]*Calendar year 2007 was selected as the reference year for purposes of this study in order to correspond to field measurements made by the U.S. Geological Survey of the lakes and streams within the Village of Chenequa. These observations were used in validating the USGS surface and groundwater flow model.*

Table 16

LONG-TERM AND 2007 STUDY YEAR TEMPERATURE, PRECIPITATION, AND RUNOFF DATA FOR THE VILLAGE OF CHENEQUA AND ENVIRONS

Temperature													
Air Temperature Data (°F)	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Long-Term Mean Monthly	22.6	26.3	35.4	46.0	56.0	66.6	72.1	71.0	63.3	51.6	39.3	26.8	48.1
2007 Mean Monthly	26.8	17.7	39.7	44.5	58.8	68.0	71.6	72.2	65.2	58.1	38.0	26.3	48.9
Departure from Long-Term Mean	4.2	-8.6	4.3	-1.5	2.8	1.4	-0.5	1.2	1.9	6.5	-1.3	-0.5	0.8

Precipitation														
Precipitation Data (inches)	January	February	March	April	May	June	July	August	September	October	November	December	Mean	Total
Long-Term Mean Monthly	1.85	1.65	2.59	3.78	3.06	3.56	3.58	4.03	3.30	2.49	2.70	2.22	2.90	34.81
2007 Mean Monthly	0.86	1.36	3.21	3.04	2.26	4.17	1.40	8.50	1.93	3.47	0.36	3.69	2.85	34.25
Departure from Long-Term Mean	-0.99	-0.29	0.62	-0.74	-0.80	0.61	-2.18	4.47	-1.37	0.98	-2.34	1.47	-0.05	-0.56

Runoff[a]													
Runoff Data (inches)	January	February	March	April	May	June	July	August	September	October	November	December	Mean
Long-Term Mean Monthly	0.63	1.45	1.18	1.33	1.08	0.77	0.59	0.62	0.62	0.65	0.78	0.75	0.87
2007 Mean Monthly	0.91	0.53	1.76	2.15	1.08	0.63	0.32	1.46	1.09	0.92	0.58	0.80	1.01
Departure from Mean Monthly	0.28	-0.92	0.58	0.82	0.00	-0.14	-0.27	0.84	0.47	0.26	-0.20	0.05	0.14

[a]*Runoff data were computed for 2007.*

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

The year 2007 was a slightly drier year for the Village of Chenequa and for the Southeastern Wisconsin Region in general, with seven of the 12 months experiencing below normal amounts of precipitation. Precipitation at General Mitchell International Airport during calendar year 2007 was about 34.25 inches, or 1.6 percent, below the normal long-term mean annual precipitation at General Mitchell International Airport of about 34.81 inches. The greatest decrease from the long-term monthly average was 2.34 inches during November, and the greatest increase above the monthly average was 4.47 inches in August.

Table 16 also sets forth surface water runoff values derived from the USGS flow records for the Bark River at Rome in Jefferson County. Typically, about one-half of the normal yearly precipitation falls during the growing season, from May to September. Runoff rates are generally low during this period, since evapotranspiration rates are high, vegetative cover is good, and soils are not frozen. Normally, about 20 percent of the summer precipitation is expressed as surface runoff, but intense summer storms occasionally produce higher runoff fractions. In contrast, approximately 30 percent of the annual precipitation occurs during the winter or early spring when the ground is frozen, and higher surface runoff may result during those seasons. As shown in Table 16, runoff during 2007 was about normal, being less than 20 percent greater than normal, a result consistent with the amount of precipitation which was approximately normal during this period.

Lake Stage

The water levels of the four study Lakes were determined to be 909.62, 900.27, 898.33, and 896.18 feet above National Geodetic Vertical Datum of 1929 (NGVD 29) for Beaver, Pine, Cornell, and North Lake, respectively, based upon water surface elevation measurements obtained during 2007.[70] Using the long-term annual precipitation, evaporation, and groundwater recharge rate data developed by the USGS, the USGS model forecast elevations for the Lakes as 909.60, 900.24, 898.28, and 896.18 feet above NGVD 29, respectively. Thus, the model simulated the stages of Beaver, Pine, Cornell, and North Lakes to within 0.02, 0.03, 0.05, and 0.00 foot of the observed levels, indicating good agreement between observed and modeled lake stages. Similar good agreement was obtained for the shallow aquifer groundwater table, which was measured to be at an elevation of 898.8 feet NGVD 29. The USGS model forecast a water table elevation of 900.1 feet NGVD 29.

Water Budget

The long-term water budgets for the four study Lakes were computed by the USGS.[71] These water budgets were computed for each of the four study lakes using the USGS model. Inflows included water entering the Lakes as a result of direct precipitation onto the lake surface, surface runoff from the lands directly tributary to the Lakes, and water entering the Lakes from the upstream tributary areas in the cases of Pine Lake, Cornell Lake, and North Lake. The water budget for Beaver Lake, being upstream-most and primarily groundwater-fed, did not include a surface inflow term in the calculation. Both surface outflows and groundwater outflows were estimated for all four waterbodies.

For Beaver Lake, the USGS estimated inflow from direct precipitation onto the lake surface of about 890 acre-feet per year, and groundwater inflow of about 1,300 acre-feet, or a total inflow of 2,190 acre-feet per year. Outflows were estimated as evaporation from the lake surface of about 810 acre-feet per year, groundwater outflow of about 460 acre-feet, and surface water outflow to Pine Lake of about 920 acre-feet per year, or a total outflow of 2,190 acre-feet per year, resulting in no significant change in lake storage.

For Pine Lake, the USGS estimated inflow from direct precipitation onto the lake surface of about 1,830 acre-feet per year, groundwater inflow of about 530 acre-feet, and surface water inflow from Beaver Lake of about 920 acre-feet, or a total inflow of about 3,280 acre-feet per year. Outflows were estimated as evaporation from the lake surface about 1,650 acre-feet per year, groundwater outflow of about 1,150 acre-feet, and surface water outflow to Cornell Lake of about 480 acre-feet per year, resulting in no significant change in lake storage.

For Cornell Lake, the USGS estimated inflow from direct precipitation onto the lake surface of about 50 acre-feet per year, groundwater inflow of about 30 acre-feet, and surface water inflow from Pine Lake of about 495 acre-feet, or a total inflow of about 575 acre-feet per year. Outflows were estimated as evaporation from the lake surface of about 40 acre-feet per year, groundwater outflow of less than 1.0 acre-foot, and surface water outflow to North Lake of about 535 acre-feet per year, resulting in no significant change in lake storage.

For North Lake, the USGS estimated inflow from direct precipitation onto the lake surface of about 1,190 acre-feet per year, groundwater inflow of about 1,030 acre-feet, and surface water inflow of about 16,850 acre-feet, or a total inflow of about 19,070 acre-feet per year. Outflows were estimated as evaporation from the lake surface of about 1,080 acre-feet per year, groundwater outflow of about 130 acre-feet, and surface water outflow to the Oconomowoc River of about 17,860 acre-feet per year, resulting in no significant change in lake storage.

Water Residence Time

As a general rule, drainage or through-flow lakes generally have shorter water residence times than seepage lakes or drained lakes. Further, lakes with large tributary areas typically have shorter residence times than lakes with

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[70]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214*, op. cit.

[71]Ibid.

smaller tributary areas. The hydraulic or water residence time, also referred to as the retention time or inverse of the flushing rate, is the time needed for a volume of water equivalent to the full volume of a lake to enter that lake.

Residence time is important in determining the expected response time of a lake to increased or reduced nutrient and other pollutant loadings. Lakes having a short residence time of less than a year, such as small drainage lakes, through-flow lakes, and lakes with large amounts of groundwater inflow and outflow, will allow nutrients and pollutants to be flushed from the lake fairly rapidly. These rapidly flushed lakes generally respond well when nutrient inputs are decreased. Lakes with longer residence times, such as drained lakes with only outflowing streams, typically respond more slowly to changes in nutrient inputs from their tributary area, since it takes a long time for a volume equivalent to the full volume of the lake to enter the lake from its tributary area. Such lakes can accumulate nutrients for many years, recycling them each year during the periods spring and fall overturn, with the result that the effects of tributary area protection may not be immediately apparent.

For Beaver Lake, based upon the USGS-estimated inflow of 2,190 acre-feet per year, and an estimated lake volume of 4,740 acre-feet, the estimated water residence time would be 2.2 years, assuming no significant change in lake storage. This is slightly shorter than the estimated 2.6 year water residence time estimated by the Regional Planning Commission based upon surface flows only.[72]

For Pine Lake, based upon the USGS estimated inflow of 3,280 acre-feet per year, and an estimated lake volume of 27,420 acre-feet, the estimated water residence time would be 8.4 years, assuming no significant change in lake storage. In contrast to Beaver Lake, the estimated water residence time for Pine Lake is significantly longer than that estimated based solely on surface water inflows. SEWRPC staff estimated the water residence time of Pine Lake as 5.2 years based upon surface flows only.[73]

For Cornell Lake, based upon the USGS estimated inflow of 575 acre-feet per year, and an estimated lake volume of 80 acre-feet, the estimated water residence time would be 0.14 year, assuming no significant change in lake storage.

For North Lake, based upon the USGS estimated inflow of 19,070 acre-feet per year, and an estimated lake volume of 16,300 acre-feet, the estimated water residence time would be 0.85 year, assuming no significant change in lake storage. This is slightly longer than, but consistent with, the estimated water residence time of 0.79 year, or 9.5 months, reported by SEWRPC in the comprehensive management plan for North Lake.[74]

Based upon these long-term water residence times, Cornell and North Lakes can be considered to be well-flushed, Beaver Lake could be considered to have a moderately long water residence time, and Pine Lake a relatively long residence time. Most lakes in southeastern Wisconsin have estimated water residence times of about one year. In terms of contaminant loadings, lakes with longer water residence times are less likely to exhibit changes in water quality, whether such changes are a response to increased contaminant loadings or a response to decreased contaminant loadings. Lakes with short water residence times, conversely, are likely to be more responsive to changes in contaminant loadings.

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[72]*SEWRPC Memorandum Report No. 173,*op. cit.

[73]Ibid.*; Although a longer water residence time may at first seem counter-intuitive, this result reflects the combined influence of ground and surface water inflows and outflows which resulted in the longer water residence time.*

[74]*See SEWRPC Community Assistance Planning Report No. 54,* op. cit.

Chapter III

DESCRIPTION OF THE STUDY AREA: NATURAL RESOURCES AND MAN-MADE FEATURES

Water pollution and supply problems, and the ultimate solution to those problems, are primarily a function of the human activities on the land surface within the area tributary to a waterbody, and of the ability of the underlying natural resource base to sustain those activities. This is especially true in a direct tributary area to a lake because lakes are highly susceptible to water quality degradation attendant on human activities in this area. Similarly, groundwater resources are equally susceptible to contamination through human activities on the land surface within the recharge area of the aquifer, including placement of onsite sewage disposal systems, wells, and other underground structures. Degradation arising from such human activities is likely to interfere with desired water uses, and is often difficult and costly to correct. Accordingly, the land uses and population levels in the watershed of a lake, or in the recharge area of a groundwater aquifer, are important considerations in water resources management. In addition, in the case of drainage or through-flow lakes, human activities in the larger tributary watershed also can influence the nature of potential water resources concerns and the nature of community responses to observed conditions. Hence, consideration should also be given to the human activities in the wider watershed.

Given the interdependencies associated with lakes and the land around them, this chapter seeks to describe the tributary areas associated with the water resources of the Village of Chenequa, as described in Chapter II of this plan. This chapter covers 1) the natural resource base elements of the watersheds, which presents the high quality environmental areas within the tributary area that serve to protect the wildlife and water quality throughout the Village of Chenequa; 2) the man-made features, including civil divisions and land use, as previously discussed in Chapter I and II; 3) the population of the tributary areas; and finally 4) the land use and water resource regulations enforced by the Village of Chenequa area which seek to protect all of these resources.

The information provided in this chapter provides a basis for understanding the components which influence the overall "health" the lands and water resources contained within the Village of Chenequa. In addition, the information provided in this chapter, in combination with the information presented Chapter II, serves to inform the water management recommendations provided within this plan.

STUDY AREA DESCRIPTION

The Village of Chenequa, in northwestern Waukesha County, is bounded by the City of Delafield to the south and the Village of Nashotah to the southwest, and otherwise is surrounded by the Town of Merton, as shown on Map 2 in Chapter I of this report. The Village of Chenequa was founded in 1928 in order to provide fire and police protection, and plan for the orderly growth of the Village, while protecting the land and lakes. Since its inception, the Village has been conceived as a residential community: "The Village of Chenequa...is intended to be devoted solely to residence purposes so as to afford to its citizens the peace and quiet and restfulness unobtainable in the City."[1] The name "Chenequa" comes from the Potawatomi word for "pine," referring to a rare Southern Wisconsin grove of white pine. This same stand of white pine can be seen along the eastern shoreline of Pine Lake. The population of the Village is about 600 persons.

As discussed in Chapter II of this report, the advent of digital terrain models (DTMs) has enabled the process of watershed boundary delineation to be automated, and those procedures were applied to refine the boundaries of the areas tributary to the Lakes located wholly or partially within the Village of Chenequa. As shown on Map 1 in Chapter I of this report, the watershed areas tributary to Beaver, Cornell, and Pine Lakes are located in close proximity to the Village of Chenequa; however, the Oconomowoc River watershed area tributary to North Lake extends upstream into Washington County and a small part of Dodge County, and it includes the Coney River, Flynn Creek, the Little Oconomowoc River, and Mason Creek.

NATURAL RESOURCE BASE RELATED ELEMENTS

Many important interlocking and interacting relationships occur between living organisms and their environment. The destruction or deterioration of any one element may lead to a chain reaction of degradation or destruction among the others. The drainage of wetlands, for example, may have far-reaching effects. Such drainage may destroy fish spawning grounds, wildlife habitat, groundwater recharge areas, and natural filtration and floodwater storage areas. The resulting deterioration of surface water quality may, in turn, lead to a deterioration of the quality of the groundwater. Groundwater serves as a source of domestic, municipal, and industrial water supply and provides low flows in rivers and streams. The destruction of woodland and other upland cover types, 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 destruction of wildlife habitat. Although the effects of any one of these environmental changes in isolation may not 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. The need to protect and preserve the natural resource base within the watersheds contributing to the Village of Chenequa watershed area thus becomes apparent.

Environmental Corridors and Isolated Natural Resources

The environmental corridor and isolated natural resources concept was developed by SEWRPC for the purpose of identifying high quality natural areas which should be protected on a long-term basis for the purpose of maintaining environmental health and assuring quality of life for the people living in Wisconsin. These corridors and natural areas are delineated using maps that SEWRPC has developed including: lakes, streams, and associated shorelands and floodlands; wetlands; woodlands; wildlife habitat areas; areas of rugged terrain and high-relief topography; wet, poorly drained, and organic soils; and remnant prairies. In addition, the delineations also take into account natural resource-related features such as existing and potential park sites, sites of historic and archaeological value, areas possessing scenic vistas or viewpoints, and areas of scientific value. These delineations are then generally considered areas of significant natural resource, and resource-related features, which can be used to evaluate the "health" of a watershed, and are used to make land use planning decisions.

The environmental corridor concept includes designations of primary and secondary corridors as well as isolated natural resource areas, as described below. The areas in the study area within primary and secondary environmental corridors, and isolated natural resource areas, are set forth in Table 17.

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[1]*Village of Chenequa,* Village of Chenequa Code: Chapter 6. Zoning, *2011*.

Table 17

ENVIRONMENTAL CORRIDORS AND ISOLATED NATURAL AREAS IN THE STUDY AREA

Area in Study Area	Primary Environmental Corridor		Secondary Environmental Corridor		Isolated Natural Area	
	Area (acres)	Area (percent)	Area (acres)	Area (percent)	Area (acres)	Area (percent)
Beaver Lake Tributary Area	168	8	4	<1	44	2
Cornell Lake Tributary Area	68	71	- -	- -	- -	- -
North Lake Direct Tributary Area	280	15	76	4	- -	- -
North Lake Total Tributary Area	11,516[a]	29	1,119[a]	3	861[a]	2
Pine Lake Tributary Area	537	25	- -	- -	18	1
Total	12,289	28	1,123	3	923	2

[a]*Includes North Lake direct tributary area.*

Source: SEWRPC.

Primary Environmental Corridors

Primary environmental corridors (PEC) include a wide variety of important resource and resource-related elements; by definition, they are at least 400 acres in size, two miles in length, and 200 feet in width.[2] PEC encompassed about 12,289 acres, or about 28 percent of the total study area. These PECs represent a composite of the best remaining elements of the natural resource base, and contain almost all of the best remaining woodlands, wetlands, and wildlife habitat areas in the watershed. PECs in the study area are shown on Map 18.

Secondary Environmental Corridors

Secondary environmental corridors (SEC) generally connect with the primary environmental corridors and are at least 100 acres in size and one-mile long. In 2010, secondary environmental corridors encompassed about 1,123 acres, or about 3 percent of the total study area. Secondary environmental corridors also contain a variety of resource elements, often remnant resources from primary environmental corridors which have been developed for intensive urban or agriculture purposes. Secondary environmental corridors facilitate surface water drainage, maintain pockets of natural resource features, and provide corridors for the movement of wildlife, as well as for the movement and dispersal of seeds for a variety of plant species. Secondary environmental corridors in the study area are also shown on Map 18.

Isolated Natural Resource Areas

Smaller concentrations of natural resource features that have been separated physically from the environmental corridors by intensive urban or agricultural land uses have also been identified. These natural resource areas, which are at least five acres in size, are referred to as isolated natural resource areas. Widely scattered throughout the study area, isolated natural resource areas included about 923 acres, or about 2 percent, of the total study area. Isolated natural resource areas in the watershed are once again shown on Map 18.

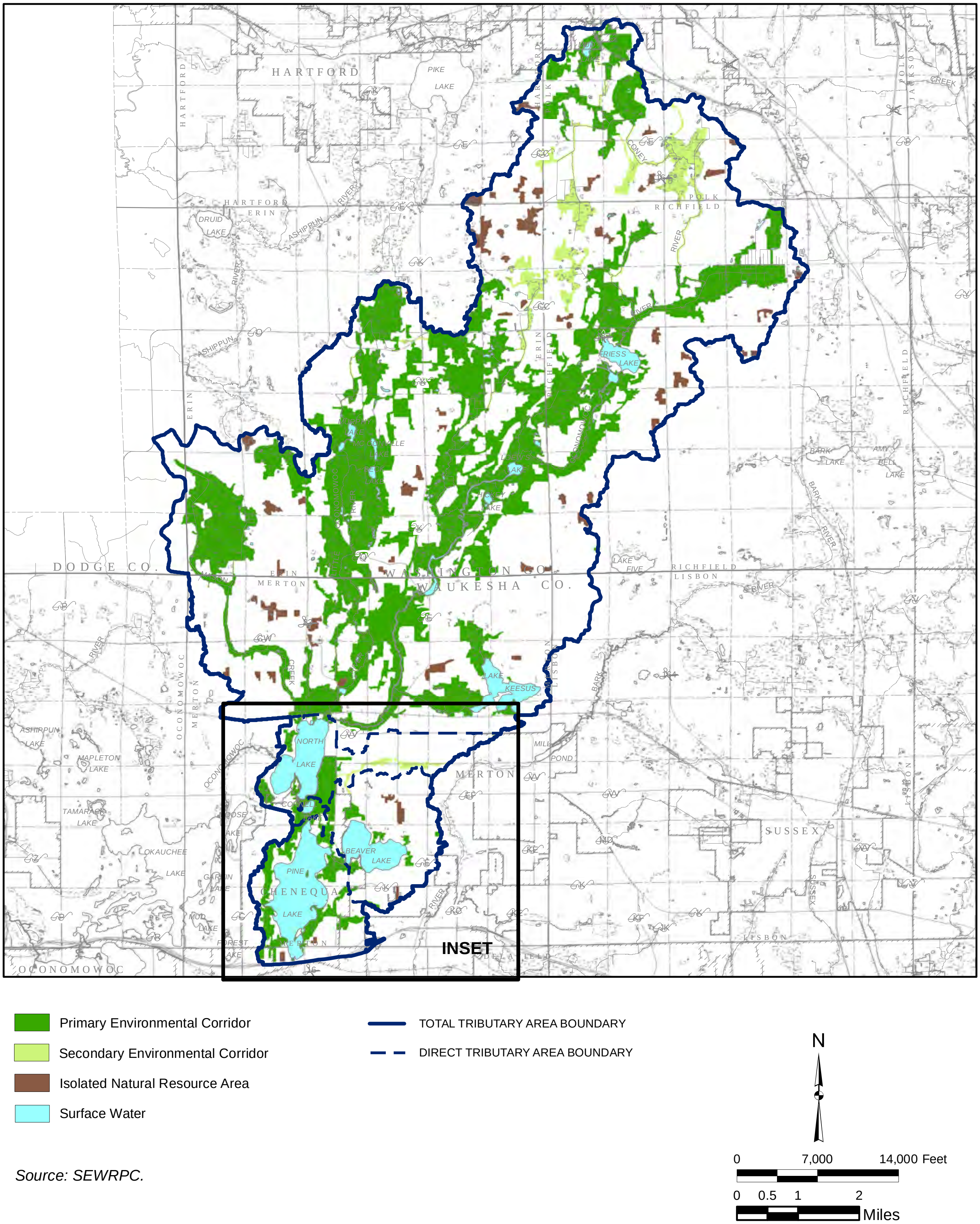
Natural Areas and Critical Species Habitat Sites

Natural areas, as defined by the Wisconsin Natural Areas Preservation Council, are tracts of land or water so little modified by human activity, or sufficiently recovered from the effects of such activity, that they contain intact

[2]*SEWRPC Planning Report No. 42,* A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin, *September 1997.*

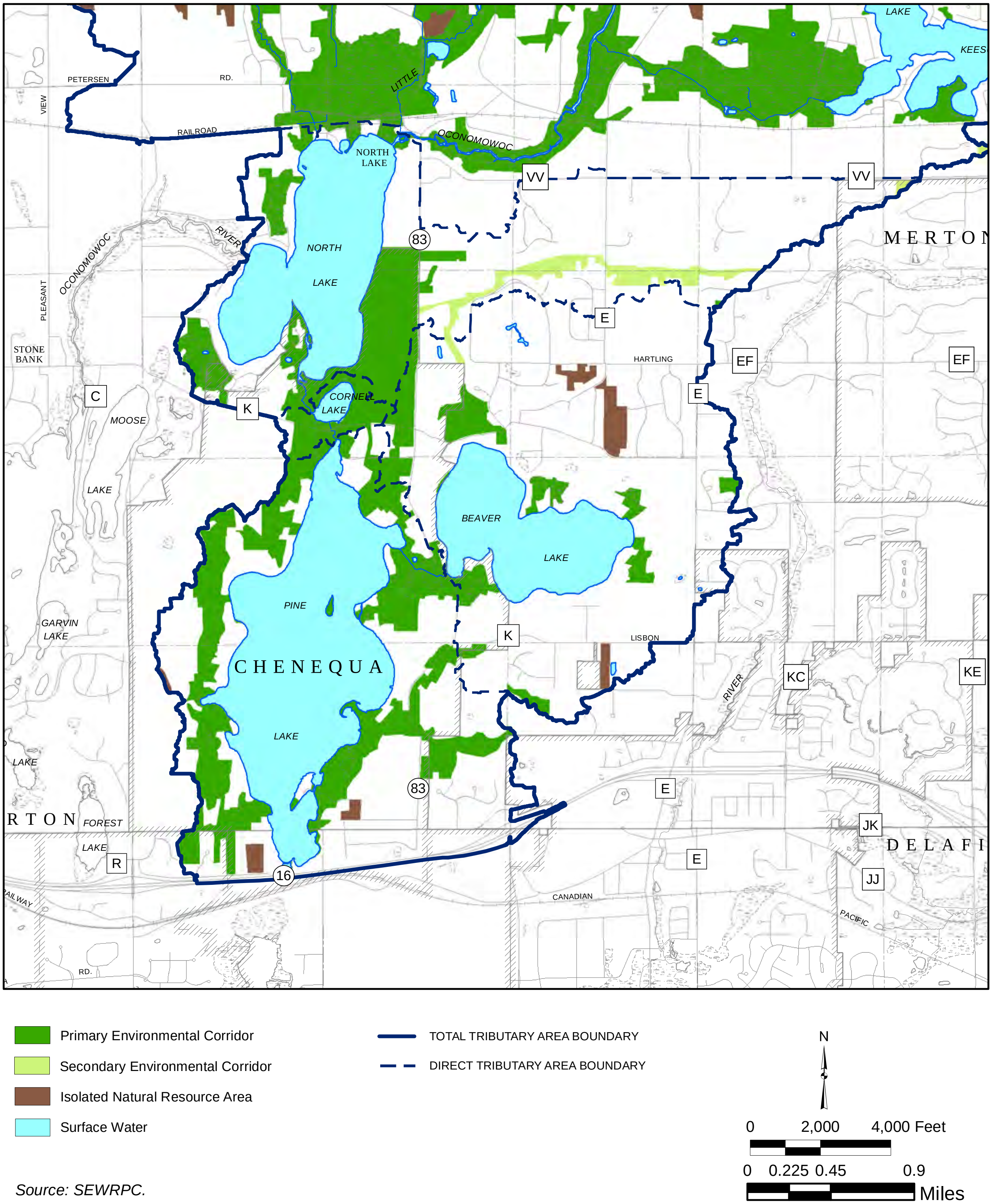
Map 18

ENVIRONMENTAL CORRIDORS AND ISOLATED NATURAL AREAS IN THE STUDY AREA



Source: SEWRPC.

Inset to Map 18



Source: SEWRPC.

native plant and animal communities believed to be representative of the pre-European settlement landscape. Natural areas are generally comprised of wetland or upland vegetation communities and/or complex combinations of both these fundamental ecosystem units. In fact, some of the highest quality natural areas within the Southeastern Wisconsin Region are wetland complexes that have maintained adequate or undisturbed linkages (i.e., landscape connectivity) between the upland-wetland habitats, which is consistent with research findings in other areas of the Midwest.[3] Natural areas have been identified for the seven-county Southeastern Wisconsin Region in SEWRPC Planning Report No. 42, "*A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin*," published in September 1997, and amended in 2008 and 2010. This plan was developed to assist Federal, State, and local units and agencies of government, and nongovernmental organizations, in making environmentally sound land use decisions including acquisition of priority properties, management of public lands, and location of development in appropriate localities that will protect and preserve the natural resource base of the Region.

The identified natural areas were classified into the following three categories:

1. Natural area of statewide or greater significance (NA-1);

2. Natural area of countywide or regional significance (NA-2); or

3. Natural area of local significance (NA-3).

Critical species are defined as those species of plants and animals that are designated by the State of Wisconsin to be endangered, threatened, or of special concern. There is one 38-acre critical species habitat site in the study area near the northeast part of North Lake.

The natural areas and critical species habitats identified in the study area are shown on Map 19. There are 3,965 acres of designated natural areas in the study area, and all of that land is located in the Oconomowoc River area tributary to North Lake.

WDNR-Designated Sensitive Areas

The WDNR identifies sites within lakes that have special importance biologically, historically, geologically, ecologically, or even archaeologically. Areas are identified as Sensitive Areas pursuant to Chapter NR 107 authorities after a comprehensive examination and study is completed by WDNR staff from many different disciplines and fields of study. As shown on Map 20, Pine Lake contains several WDNR-designated Sensitive Areas. To protect aquatic life, as well as the water quality of the Lake itself, the WDNR may place restrictions on specific activities within such Sensitive Areas. These restrictions run the gamut from restrictions on aquatic plant management measures to restrictions on dredging, and include recommendations pursuant to parallel WDNR authorities such as those set forth in Chapter 30 of the *Wisconsin Statutes*. Such restrictions for the WDNR-delineated sensitive areas in Pine Lake include: limiting the use of aquatic herbicides to treatment of Eurasian water milfoil; prohibition of in-lake activities such as filling, pea gravel/sand blankets, aquascreen, concrete, timber, or steel seawalls; limiting the use of riprap to areas with erosion problems; individual and marina piers allowable only on a case by case basis; prohibition of mechanical harvesting other than that associated with a research program to increase the diversity of aquatic plants, although small hand-cleared areas for swimming or navigation are allowable; and the adoption and strict enforcement of construction site erosion control, shoreland, and wetland ordinances.

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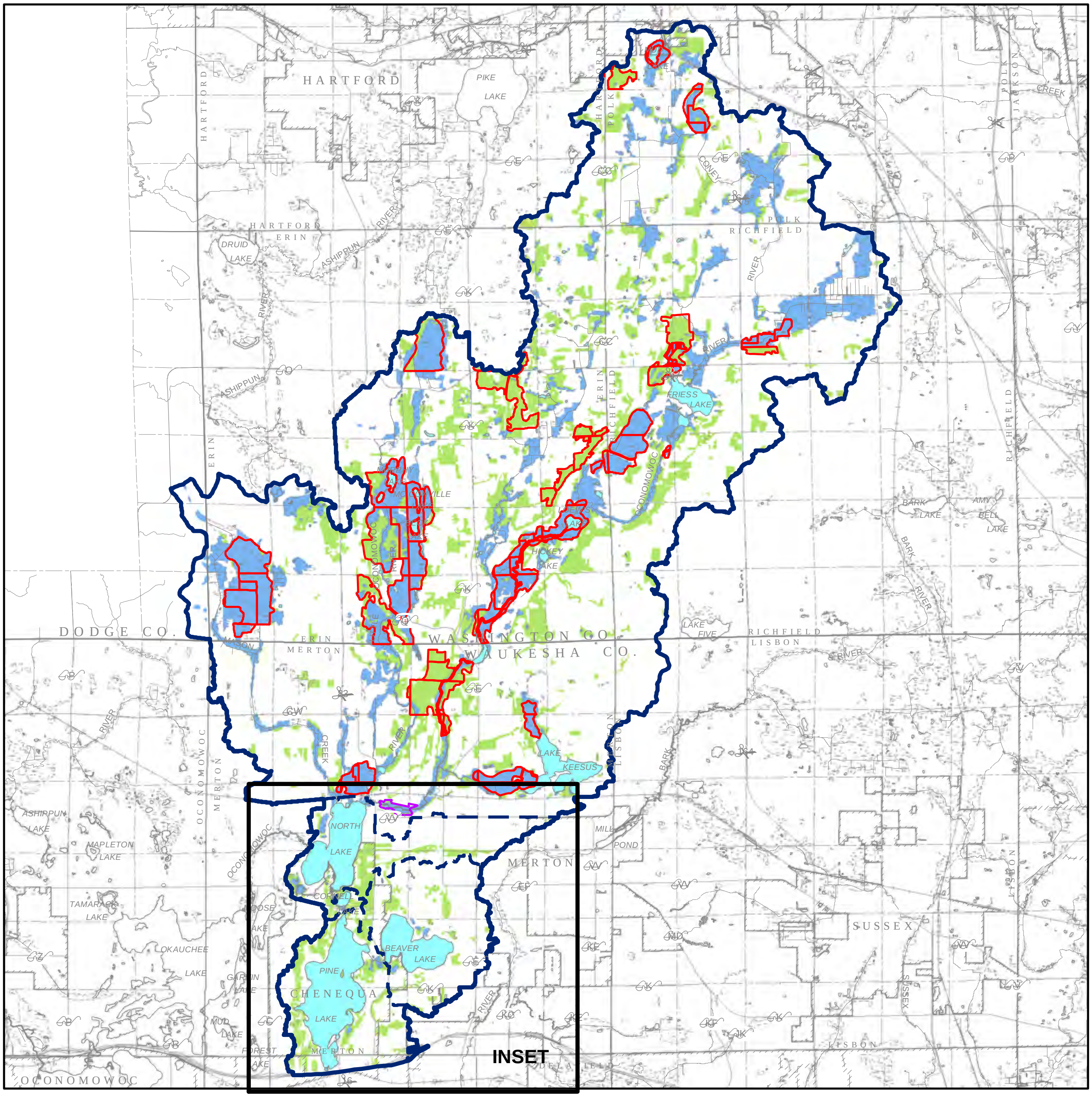
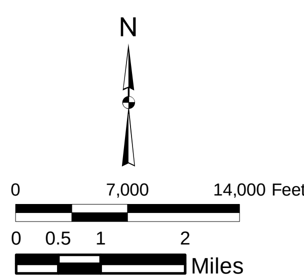
[3]*O. Attum, Y.M. Lee, J.H. Roe, and B.A. Kingsbury, "Wetland complexes and upland-wetland linkages: landscape effects on the distribution of rare and common wetland reptiles,"* Journal of Zoology*, Vol. 275, 2008, pages 245-251.*

Map 19

NATURAL AREAS AND CRITICAL SPECIES HABITAT SITES IN THE STUDY AREA



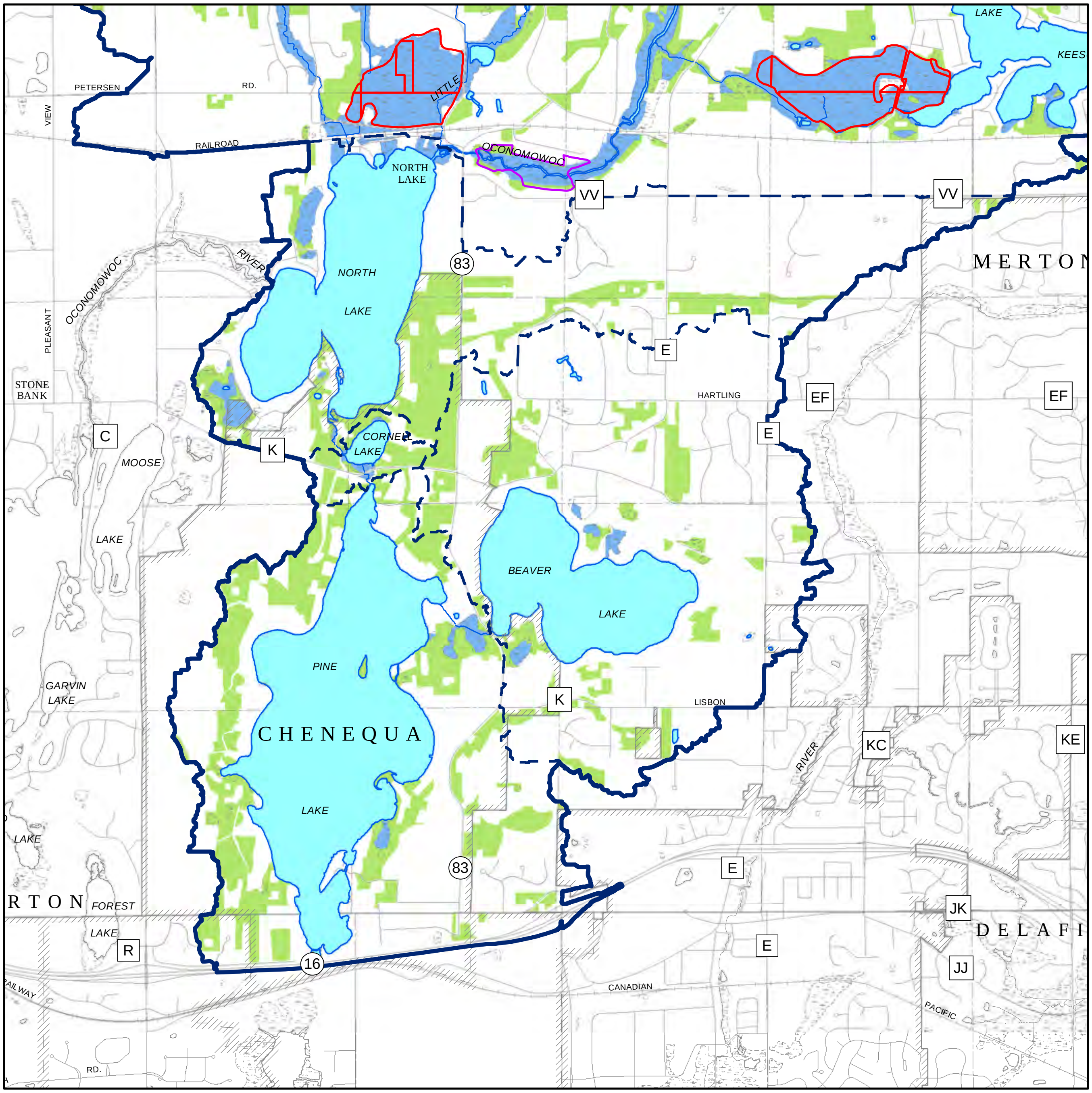
- Natural Area
- Critical Species Habitat Site
- Woodlands
- Wetlands
- Surface Water
- TOTAL TRIBUTARY AREA BOUNDARY
- DIRECT TRIBUTARY AREA BOUNDARY

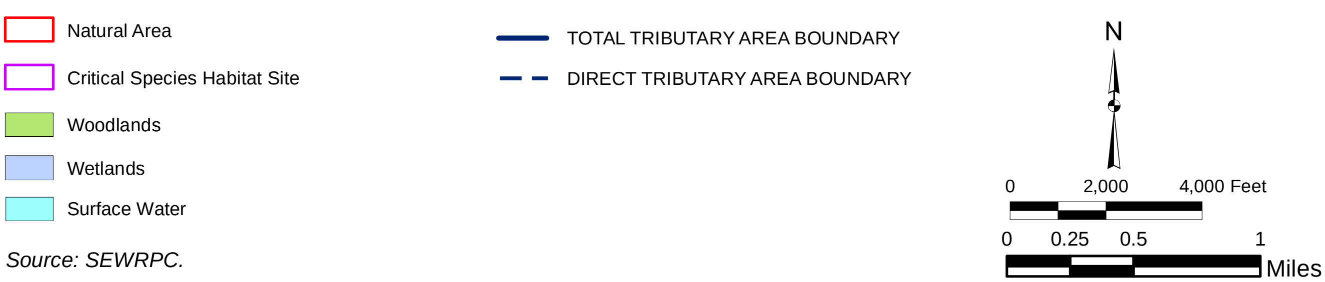


NOTE: Data for the portion of Dodge County is unavailable.

Source: SEWRPC.

Inset to Map 19

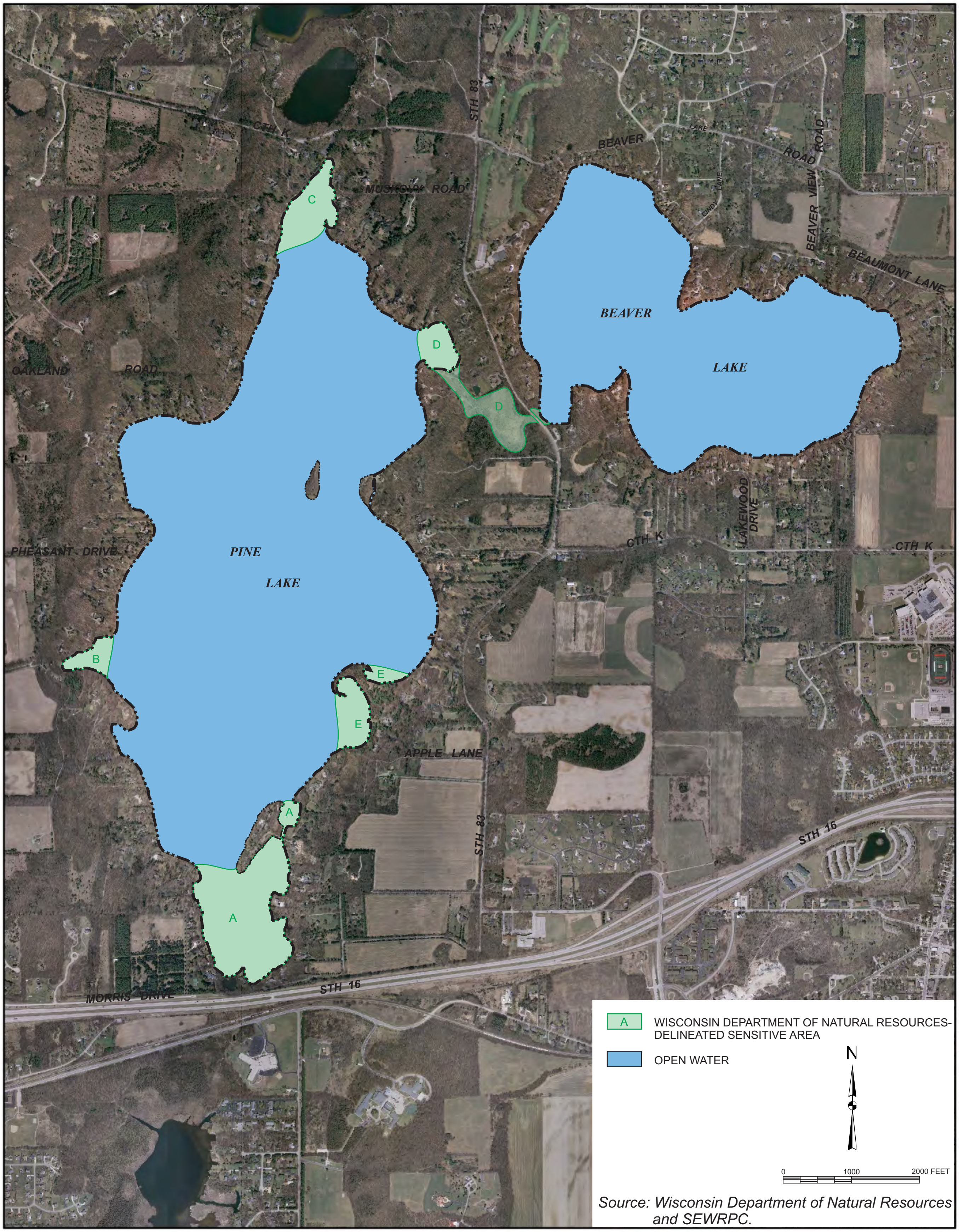




Source: SEWRPC.

Map 20

SENSITIVE AREAS WITHIN THE VICINITY OF PINE AND BEAVER LAKES



Source: Wisconsin Department of Natural Resources and SEWRPC.

DATE OF PHOTOGRAPHY: APRIL 2005

Land Forms
There is evidence of four major stages of glaciation in the Region. The last and most influential in terms of present physiography and topography was the Wisconsin stage of glaciation, which is believed to have ended in the State about 12,000 years ago. Glaciation has largely determined the physiography and topography as well as the soils of the Region.

The dominant physiographic and topographic feature is the Kettle Moraine, an interlobate glacial deposit formed between the Green Bay and Lake Michigan lobes of the continental glacier. The Kettle Moraine is oriented in a generally northeasterly-to-southwesterly direction across western Washington, Waukesha, and northwestern Walworth Counties. It is a complex system of hummocky sand and gravel deposits including kames, or crudely stratified conical hills; kettle holes, marking the site of buried glacial ice blocks that became separated from the ice mass and melted to form depressions; eskers, which consist of long, narrow ridges of drift deposited in tunnels in the ice; and, abandoned drainageways. In the vicinity of what is now the Village of Chenequa, the glacial deposits formed a series of hummocks between the surrounding outwash plains, giving the Village its distinctive topography and creating the opportunity for the formation of the major lakes and wetlands that characterize the Village landscape.

The Kettle Moraine of Wisconsin is considered one of the finest examples of glacial interlobate moraine in the world, principally because of its still predominantly rural character and exceptional natural beauty.[4] Nevertheless, it is precisely because of these features that the Kettle Moraine and the Village and its environs may be expected to be subjected to continued pressure for urban development.

Glacial landforms are of economic significance because some are prime sources of sand and gravel for highway and other construction purposes. Many of the larger topographic depressions of the Region have developed into the lakes that dot the Village, and which are popular both as recreational areas and as residential centers. In addition, significant areas of the Village are covered by wetlands and streams.

MAN-MADE FEATURES

Civil Divisions
Superimposed on the watersheds and recharge areas of Beaver Lake, Pine Lake, Cornell Lake, and North Lake are the local civil division boundaries, shown on Map 2 in Chapter I of this report. The geographic distribution and functional jurisdictions of the general- and special-purpose units of government also are important factors which must be considered in lake water quality management, since these local units of government provide the basic structure of the decision-making framework within which intergovernmental environmental problems must be addressed.

In addition to the Village of Chenequa, the surrounding governmental units include: portions of the City of Delafield, Village of Nashotah, and the Town of Merton, all in Waukesha County. These civil division boundaries do not necessarily follow the boundaries of either the surface waters or the groundwaters, but rather are artificially superimposed upon the landscape within which these features exist. Consequently, a water resources management plan for the Village of Chenequa must take into account the actions and regulations of the surrounding jurisdictions in the formulation of recommended management actions. As noted in Chapter II, the proposed withdrawal of groundwater from the shallow aquifer by the City of Delafield was one action that prompted the conduct of this study.

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

Land Use

The types, intensity, and spatial distributions of the various land uses within the Village of Chenequa and its surrounding jurisdictions are important determinants of lake water quality and recreational use demands, as well as of groundwater quantity and quality. By placing the existing land uses in the context of the historical development of the area, it is possible to evaluate the impacts arising from past land use practices and extrapolate the consequences of future actions for water resources management. These considerations form an important consideration in any water resources management planning effort.

The movement of European settlers into the Southeastern Wisconsin Region began in about 1830. Completion of the U.S. Public Land Survey of southeastern Wisconsin in 1836, and the subsequent sale of the public lands, brought a rapid influx of settlers into the area. Historical urban growth patterns in the total area tributary to the Lake since 1900 are shown on Map 21 and are tabulated in Table 18.

Significant urban development began to occur within the area that was to become the Village of Chenequa shortly after the completion of the U.S. Public Land Survey. The most rapid increase in urban land use development in the study area occurred between 1975 and 1990, when 2,863 acres were converted from rural to urban land uses. The existing land uses in the areas tributary to Beaver, Cornell, North, and Pine Lakes are shown on Maps 4 and 13 in Chapter II of this report, and quantified in Tables 2, 6, 10, and 12 also in Chapter II of this report.

As indicated in Table 19, the Village of Chenequa includes has a total area of 2,971 acres, with the lakes and other surface water resources encompassing 743 acres. About 698 acres, or about 23 percent of the Village, were devoted to urban land uses in 2010. The dominant urban land use was residential, encompassing 480 acres, or about 69 percent of the total area in urban use. About 2,272 acres, or about 77 percent of the Village were still devoted to rural land uses. About 682 acres, or about 30 percent of the rural area, were in agricultural land uses. Woodlands, wetlands, and surface water accounted for approximately 1,590 acres, or about 70 percent of the area in rural uses.

As seen from a comparison of Maps 4 and 5 in Chapter II of this report, under year 2035 conditions no significant changes in land use conditions within the Village of Chenequa are envisioned under the regional land use plan, although some infilling of existing platted lots and some backlot development may be expected to occur. In addition, the redevelopment of properties and the reconstruction of existing single-family homes also may be expected on lakeshore properties. Under the full buildout condition envisioned under the Waukesha County development plan,[5] most of the undeveloped lands outside the environmental corridors and other environmentally sensitive areas could potentially be developed for low-density urban uses. This development should occur in the form of residential clusters on smaller lots, thereby preserving portions of the remaining open space and, thus, reducing the impacts on the lakes. In addition, such future development would be subject to the numerous construction site and runoff management ordinances, identified below, that would be applicable to such development. It is envisioned that the application of such measures will further moderate any impacts arising from future development.

POPULATION

The resident population of the areas tributary to Beaver, Cornell, Pine, and North Lakes, has increased steadily since 1960, as shown in Table 20. However, between 2000 and 2010, the population of the areas tributary to Beaver, Cornell, and Pine Lakes and the area directly tributary to North Lake increased only slightly from 2,981 persons to 3,065 persons.

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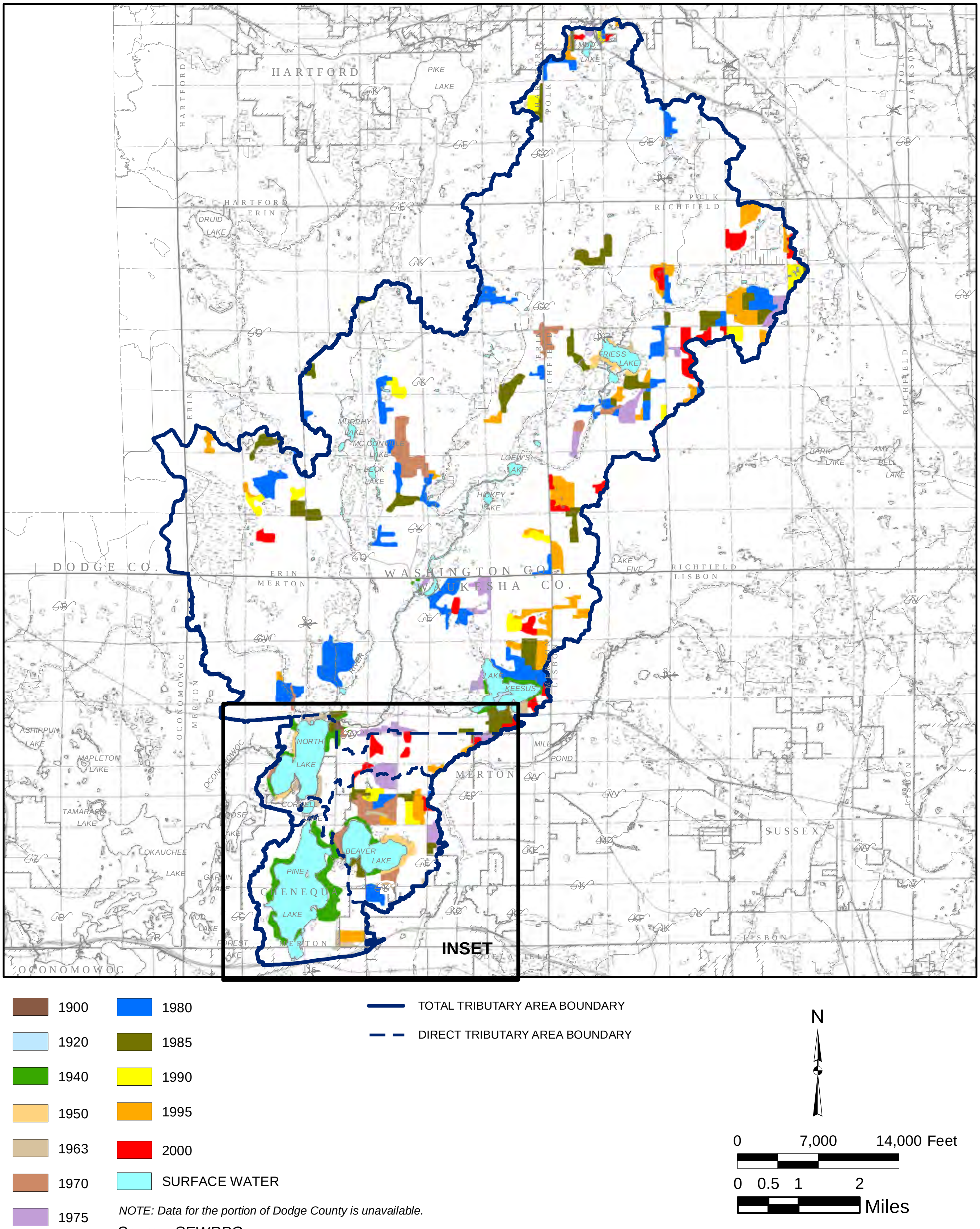
[5]*SEWRPC Community Assistance Planning Report No. 209,* A Development Plan for Waukesha County, Wisconsin, *August 1996, as amended.*

Map 21

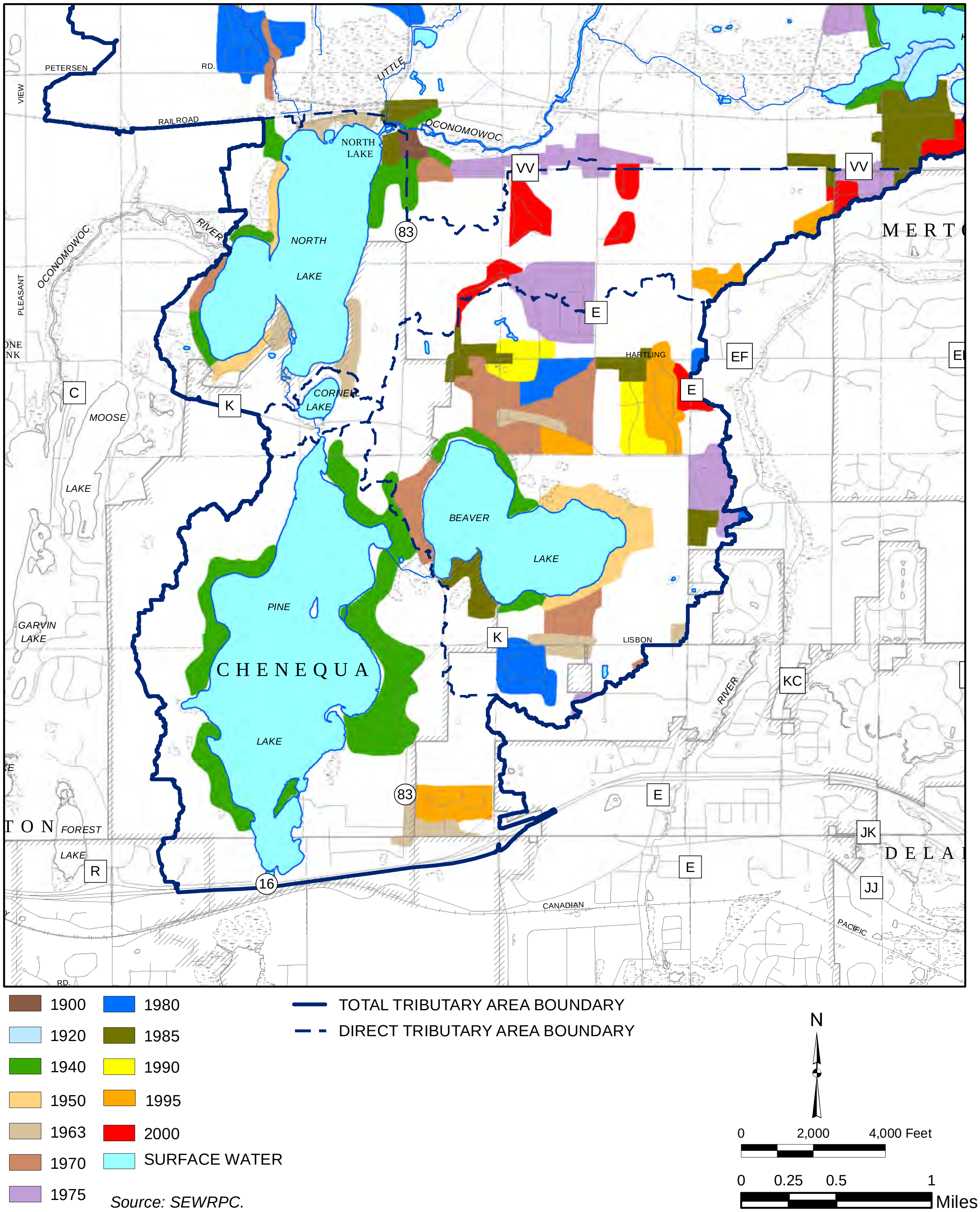
HISTORICAL URBAN GROWTH IN THE STUDY AREA



NOTE: Data for the portion of Dodge County is unavailable.

Source: SEWRPC.

Inset to Map 21



Source: SEWRPC.

Table 18

EXTENT OF HISTORICAL URBAN GROWTH IN THE AREAS TRIBUTARY TO THE VILLAGE OF CHENEQUA LAKES: 1900-2010

	Beaver Lake		Cornell Lake		North Lake[a]		Pine Lake	
Year	Extent of New Urban Development Occurring Since Previous Period (acres)[b]	Cumulative Extent of Urban Development (acres)[b]	Extent of New Urban Development Occurring Since Previous Period (acres)[b]	Cumulative Extent of Urban Development (acres)[b]	Extent of New Urban Development Occurring Since Previous Period (acres)[b]	Cumulative Extent of Urban Development (acres)[b]	Extent of New Urban Development Occurring Since Previous Period (acres)[b]	Cumulative Extent of Urban Development (acres)[b]
1900	0	0	0	0	12	12	0	0
1920	0	0	0	0	23	35	0	0
1940	47	47	0	0	144	179	298	298
1950	80	127	0	0	92	271	0	298
1963	42	169	6	6	99	370	28	326
1970	186	355	0	6	344	714	3	329
1975	104	459	0	6	444	1,158	0	329
1980	91	550	0	6	1,381	2,539	0	329
1985	94	644	0	6	902	3,441	0	329
1990	70	714	0	6	325	3,766	0	329
1995	75	789	0	6	849	4,615	47	376
2000	18	807	0	6	552	5,167	0	376
2010	27	834	0	6	560	5,727	6	382

NOTE: Historical urban growth in the area directly tributary to North Lake is as follows:

	Tributary Area	
Year	Extent of New Urban Development Occurring Since Previous Period (acres)	Cumulative Extent of Urban Development (acres)
1900	4	4
1920	0	4
1940	58	62
1950	33	95
1963	48	143
1970	13	156
1975	83	239
1980	0	239
1985	18	256
1990	0	256
1995	31	287
2000	89	376
2010	34	410

[a] *Includes urban growth for the area directly tributary to North Lake.*

[b] *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 urban in this analysis.*

Source: SEWRPC.

The number of resident households in the areas tributary to Beaver, Cornell, Pine, and North Lakes, also increased since 1960, as shown in Table 20. Consistent with the relatively small increase in population from the year 2000 through 2010, the number of households in the areas tributary to Beaver, Cornell, and Pine Lakes and the area directly tributary to North Lake increased only slightly from 1,039 to 1,118. As development in the area surrounding the Village continues as planned through year 2035 (see Tables , 2, 6, 10, and 12 in Chapter II of this report), however, the population of the area as a whole is expected to increase, placing continuing stress on the natural resource base of the area, and increasing both water resource demands and the potential for water use conflicts.

Table 19

2010 LAND USE VILLAGE OF CHENEQUA

Land Use Category	Acres
Urban	
Single-Family Residential	480.5
Governmental and Institutional	1.5
Transportation, Communication, Utilities	133.8
Recreational	82.5
Subtotal	698.3
Rural	
Agriculture and Other Open Lands	682.2
Wetlands	52.0
Woodlands	795.5
Surface Water	742.6
Subtotal	2,272.3
Total	2,970.6

Source: SEWRPC.

LAND USE AND WATER RESOURCE REGULATIONS

The comprehensive zoning ordinance represents one of the most important and significant administrative and regulatory tools available to local units of government for directing the use of lands within their areas of jurisdiction. Table 21 shows the land use regulations in effect in the civil divisions within the Village of Chenequa, which are further summarized below.

General Zoning

Villages in Wisconsin are granted comprehensive, or general, zoning powers under Section 61.35 of the *Wisconsin Statutes*. Counties also are granted general zoning powers within their unincorporated areas under Section 59.69 of the *Wisconsin Statutes*. However, a county zoning ordinance becomes effective only in those towns that ratify the county ordinance. Towns that have not adopted a county zoning ordinance may adopt village powers, and subsequently utilize the village zoning authority conferred in Section 62.23, subject, however, to county board approval where a general-purpose county zoning ordinance exists. Alternatively, a town may adopt a zoning ordinance under Section 60.61 of the *Wisconsin Statutes* where a general-purpose county zoning ordinance has not been adopted, but only after the county board fails to adopt a county ordinance at the petition of the governing body of the town concerned.

Zoning is a tool used to regulate the use of land in a manner that serves to promote the general welfare of the citizens, the quality of the environment, and the conservation of its resources. It also serves to implement a land use plan. Zoning is the delineation of areas or zones into specific districts which provides uniform regulations and requirements that govern the use, placement, spacing, and size of land and buildings. General zoning is in effect in the Village of Chenequa and its environs.

Within the Village of Chenequa, pursuant to Sections 61.35 through 61.354 of the *Wisconsin Statutes*, Chapters 3, Land; 4, Lakes (see Appendix C); 5, Building Code; and, 6, Zoning of the *Village Ordinances* govern land use and development within the Village. The land regulations address issues relating to the shorelands of Pine Lake, care of trees, and use of fertilizers within the Village. The lake regulations set forth regulations governing recreational boating use of Beaver, Pine, and North Lakes, as well as winter use of Pine and Cornell Lakes. This Chapter also regulates use of Beaver, Pine, and North Lakes during periods of high water such as were experienced during the summers of 2008,[6] 2009, and 2010. The building and zoning codes address the manner in which lands are developed and establish a process for land development and regulation, including an appeal process, for the Village.

Elsewhere in the vicinity of the Village of Chenequa, the Planning and Zoning Division of the Waukesha County Department of Parks and Land Use, pursuant to Subchapter VII of Chapter 59 of the *Wisconsin Statutes*, administers the zoning maps and the zoning ordinance for portions of the unincorporated areas of Waukesha

[6]*See U.S. Geological Survey Scientific Investigations Report No. 2008–5235,* Flood of June 2008 in Southern Wisconsin, *2008.*

Table 20

POPULATION AND HOUSEHOLDS FOR THE VILLAGE OF CHENEQUA WATER RESOURCES MANAGEMENT PLAN: 1960-2010

	Population and Households in the Area Tributary to:							
	Beaver Lake		Cornell Lake		Pine Lake		North Lake[a]	
Year	Population	Households	Population	Households	Population	Households	Population	Households
1960	422	125	31	8	214	58	2,884	776
1970	875	210	25	8	466	149	4,428	1,188
1980	1,409	421	22	8	382	130	6,325	1,921
1990	1,632	518	18	8	382	142	7,105	2,318
2000	1,772	582	38	16	398	150	9,503	3,283
2010	1,653	592	36	14	417	158	10,317	3,759

NOTE: Population and households in the area directly tributary to North Lake are as follows:

Year	Population	Households
1960	536	151
1970	463	156
1980	547	195
1990	579	221
2000	773	291
2010	959	354
Total	3,857	1,368

[a]*Includes population and households for the area directly tributary to North Lake.*

Source: SEWRPC.

County. The provisions of the *Waukesha County Code of Ordinances* apply to floodlands, shorelands, wetlands, and lands disturbed by construction activities within the Town of Merton. The Code is designed to provide standards for land development to provide for adequate sanitation, drainage, safety, convenience of access, the preservation and promotion of the environment, property values, and general attractiveness. The Town has its own general zoning code, Chapter 17 of the *General Code of the Town of Merton, Wisconsin*, pursuant to Section 60.61 of the *Wisconsin Statutes*.

The City of Delafield, pursuant to Sections 62.23 through 62.234 of the *Wisconsin Statutes*, administers regulations governing buildings, floodlands, shorelands, wetlands, and lands disturbed by construction activities within the City pursuant to the *Municipal Code of the City of Delafield, Wisconsin*, codified through Ordinance No. 641 and adopted November 1, 2010. Chapter 17 of the *Code* provides general zoning authority, while Chapters 14 through 16 regulate buildings, plumbing, and electrical installations; Chapters 18 and 20 regulate subdivisions and floodlands; and, Chapter 23 regulates constructions sites.

The Village of Nashotah, pursuant to Sections 61.35 through 61.354 of the *Wisconsin Statutes*, administers regulations governing buildings, floodlands, shorelands, wetlands, and lands disturbed by construction activities within the Village pursuant to the Municipal Code of the Village of Nashotah, Wisconsin, codified through Ordinance No. 179 and adopted May 5, 2010. Chapter 17 of the *Code* provides general zoning authority, while Chapters 14 and 16 regulate buildings, and shoreland wetlands, respectively, while Chapters 18, 19, and 23 regulate subdivisions, floodlands, and constructions sites.

Floodland Zoning

Section 87.30 of the *Wisconsin Statutes* requires that counties, with respect to their unincorporated areas, and villages adopt floodland zoning to preserve the floodwater conveyance and storage capacity of floodplain areas

Table 21

LAND USE REGULATIONS WITHIN THE AREA TRIBUTARY TO THE CHENEQUA LAKES BY CIVIL DIVISION

Community	Type of Ordinance				
	General Zoning	Floodland Zoning	Shoreland or Shoreland-Wetland Zoning	Subdivision Control	Construction Site Erosion Control and Stormwater Management
Waukesha County	Adopted	Adopted	Adopted and approved by WDNR	Floodland and shoreland only	Adopted
City of Delafield	Adopted	Adopted	Adopted	Adopted	Adopted
Village of Chenequa	Adopted	None	Adopted	None	Adopted
Village of Hartland	Adopted	Adopted	Adopted	Adopted	Adopted
Village of Merton	Adopted	Adopted	Adopted	Adopted	None
Village of Nashotah	Adopted	None	Adopted and approved by WDNR	Adopted	None
Town of Lisbon	Adopted	County ordinance	County ordinance	Adopted	Adopted
Town of Merton	Adopted	County ordinance	County ordinance	Adopted	None
Washington County	Adopted	Adopted	Adopted and approved by WDNR	Floodland and shoreland only	Adopted
Village of Richfield	Adopted	Adopted	Adopted	Adopted	Adopted
Village of Slinger	Adopted	Adopted	Adopted	Adopted	None
Town of Erin	Adopted	County ordinance	County ordinance	Adopted	County ordinance
Town of Hartford	Adopted	County ordinance	County ordinance	County ordinance	County ordinance
Town of Polk	Adopted	County ordinance	County ordinance	Adopted	County ordinance

Source: SEWRPC.

and to prevent the location of new flood-damage-prone development in flood hazard areas. The minimum standards which such ordinances must meet are set forth in Chapter NR 116, “Wisconsin’s Floodplain Management Program,” of the *Wisconsin Administrative Code*. The required regulations govern filling and development within a regulatory floodplain, which is defined as the area which has a one-percent-annual probability of being inundated. Under Chapter NR 116, local floodland zoning regulations must prohibit nearly all forms of development within the floodway, which is that portion of the floodplain required to convey the one-percent-annual-probability peak flood flow. Local regulations must also restrict filling and development within the flood fringe, which is that portion of the floodplain located outside the floodway that would be covered by floodwater during the one-percent annual-probability flood. Permitting the filling and development of the flood fringe area, however, reduces the floodwater storage capacity of the natural floodplain, and may, thereby, increase downstream flood flows and stages.

The Waukesha County ordinances related to shoreland and floodland protection recognize existing uses and structures and regulate them in accordance with sound floodplain management practices while protecting the overall water quality of stream systems. These ordinances are intended to: 1) regulate and diminish the proliferation of nonconforming structures and uses in floodplain areas; 2) regulate reconstruction, remodeling, conversion and repair of such nonconforming structures with the overall intent of lessening the public responsibilities attendant to the continued and expanded development of land and structures which are inherently incompatible with natural floodplains; and, 3) lessen the potential danger to life, safety, health, and welfare of persons whose lands are subject to the hazards of floods. Floodland zoning is in place for the City of Delafield, and Town of Merton. No flood hazard areas have officially been identified and mapped in either of the Villages of Chenequa or Nashotah.

Shoreland Zoning

Shoreland zoning regulations play an important role in protecting water resources. Under Section 59.692 of the *Wisconsin Statutes*, within their unincorporated areas, counties in Wisconsin are required to adopt zoning regulations within statutorily defined shoreland areas, which are defined as those lands within 1,000 feet of a navigable lake, pond, or flowage; 300 feet of a navigable stream; or to the landward side of the floodplain, whichever distance is greater.

Minimum standards for county shoreland zoning ordinances are set forth in Chapter NR 115, "Wisconsin's Shoreland Management Program" of the *Wisconsin Administrative Code*, which establishes minimum requirements regarding lot sizes and building setbacks; restrictions on cutting of trees and shrubbery; and restrictions on filling, grading, lagooning, dredging, ditching, and excavating. Those minimum requirements must be incorporated into county shoreland zoning regulations. Counties may enact more restrictive ordinance provisions as are appropriate. In addition, Chapter NR 115 requires that counties place all wetlands five acres or larger and within the statutory shoreland zoning jurisdiction area into a wetland conservancy zoning district to ensure their preservation after completion of appropriate wetland inventories by the WDNR. However, the rules regarding minimum lots sizes, building setbacks, and cutting of trees and shrubbery established in Chapter NR 115 for counties do not apply to villages, except for newly annexed areas. It should be noted that county shoreland zoning regulations remain in effect in areas which are annexed by a city or village after May 7, 1982, or for a town which incorporates as a city or village after April 30, 1994, according to Section 59.692(7)(a) of the *Wisconsin Statutes*, unless the ordinance requirements of the annexing or incorporating city or village are at least as stringent as those of the county. The only exception to this condition is if, after annexation, the annexing municipality requests the county to amend the county ordinance to delete or modify provisions that establish specified land uses or requirements associated with those uses. In such a situation, stipulations regarding land uses or requirements may be amended by the county.

Minimum standards for city and village shoreland-wetland zoning ordinances are set forth in Chapter NR 117 of the *Wisconsin Administrative Code*, "Wisconsin's City and Village Shoreland-Wetland Protection Program." The basis for identification of wetlands to be protected under Chapters NR 115 and NR 117 is the Wisconsin Wetlands Inventory. Mandated by the State Legislature in 1978, that inventory resulted in the preparation of wetland maps covering each U.S. Public Land Survey township in the State. The inventory was completed for counties in southeastern Wisconsin in 1982, with the wetlands being delineated by SEWRPC on its 1980, one inch-equals-2,000-feet-scale aerial photography. SEWRPC staff, working in conjunction with the WDNR, recently completed updating that wetland inventory based on interpretation of 2005 color digital orthophotography and field verification of selected wetland boundaries.

Wetland Regulations

The determination of permissible, or potentially permissible, activities in wetlands within and adjacent to the Village of Chenequa involves shoreland-wetland regulations as administered by the County and villages, all under the oversight of the WDNR, pursuant to authorities set forth in Chapter 30 of the *Wisconsin Statutes*, and elaborated in Chapter NR 103, "Wetland Water Quality Standards," of the *Wisconsin Administrative Code*. The procedures and criteria for the application, processing, and review of State water quality certifications are set forth in Chapter NR 299, "Water Quality Certification." Chapter NR 103 applies to the discharge of dredged or fill materials to wetlands, among other provisions. These regulations are administered by the WDNR and in some cases through delegated authority from the U.S. Army Corps of Engineers (USCOE) pursuant to Section 404 of the Federal Clean Water Act.

Chapters 23 and 330 of the *Wisconsin Statutes* require that counties regulate the use of all wetlands five acres or larger in shoreland zones of unincorporated areas. Wetland maps for Waukesha County that were originally prepared for the WDNR by SEWRPC in 1981 were recently updated. In accordance with Chapter NR 115 of the *Wisconsin Administrative Code*, Waukesha County has updated the shoreland zoning regulations and attendant maps to preclude further loss of wetlands in the shoreland areas. For development adjacent to statutory wetlands, the Waukesha County ordinances specifies a minimum setback, while the minimum developable lot sizes for parcels that include wetlands are regulated by the various jurisdictions having general zoning authority. The Waukesha County Wetland and Shoreland Zoning Ordinance provisions apply to the Town of Merton. The Villages of Chenequa and Nashotah administer their own zoning ordinances.

The existing zoning ordinances have proven to be effective in protecting the wetlands and water resources of the Village of Chenequa.

Subdivision Regulations

Chapter 236 of the *Wisconsin Statutes* requires the preparation of a subdivision plat whenever five or more lots of 1.5 acres or less in area are created, either at one time, or by successive divisions within a period of five years. The *Wisconsin Statutes* set forth requirements for surveying lots and streets, for plat review and approval by State and local agencies, and for recording approved plats. Section 236.45 of the *Wisconsin Statutes* allows any city, village, town, or county that has established a planning agency to adopt a land division ordinance, provided the local ordinance is at least as restrictive as the State platting requirements. Local land division ordinances may include the review of other land divisions not defined as "subdivisions" under Chapter 236, *Wisconsin Statutes*, such as when fewer than five lots are created or when lots larger than 1.5 acres are created.

The subdivision regulatory powers of towns and counties are confined to unincorporated areas, while city and village subdivision control ordinances may be applied to extraterritorial areas, as well as to the incorporated areas. It is possible for both a county and a town to have concurrent jurisdiction over land divisions in unincorporated areas, or for a city or village to have concurrent jurisdiction with a town or county in the city or village extraterritorial plat approval area. In the case of overlapping jurisdictions, the most restrictive requirements apply.

While the City of Delafield, Village of Nashotah, and Town of Merton all have adopted subdivision ordinances, the Village of Chenequa regulates subdivision development under its building code. The subdivision control ordinances adopted and administered by Waukesha County apply only to the unincorporated statutory shoreland areas of the County. However, the Waukesha County Storm Water Management and Erosion Control Ordinance also contains certain cross-compliance provisions that directly affect the subdivision plat review and approval process in all unincorporated areas.

Stormwater Management and Construction Site Erosion Control Regulations

Stormwater management and erosion control ordinances help minimize water pollution, flooding, and other negative impacts of urbanization on water resources (lakes, streams, wetlands, and groundwater) and property owners, both during and after construction activities. These ordinances are an important tool for accomplishing watershed protection goals because they apply to the whole watershed, not just a certain distance from the water resource.

The *Wisconsin Statutes* grant authority to counties, pursuant to Section 59.693; cities, pursuant to Section 62.234; villages, pursuant to Section 61.354; and, towns, pursuant to Section 60.627, to adopt ordinances for the prevention of erosion from construction sites and the management of stormwater runoff, which generally apply to new development from lands within their jurisdictions. A county ordinance would apply to all unincorporated areas and newly annexed lands, unless the annexing city or village enforces an ordinance at least as restrictive as the county ordinance. Towns may adopt village powers pursuant to Section 60.10 of the *Wisconsin Statutes* and subsequently utilize the authority conferred on villages to adopt their own erosion control and stormwater management ordinances. Town construction site erosion control and stormwater management zoning requirements adopted pursuant to Section 60.627 of the *Wisconsin Statutes* supersede county ordinances.

Construction Site Erosion Control

Specific construction site and erosion control requirements for the Village of Chenequa are set forth in Chapter 6, Zoning, of the *Village Ordinances* and govern land use and development within the Village. It should be noted that local erosion control ordinances do not apply to one- and two-family home construction as these are regulated under Chapter SPS 321 of the *Wisconsin Administrative Code*. Since the early 1990s, the Wisconsin Uniform

Dwelling Code has included erosion control requirements for one- and two-family homes that apply statewide and supersede all local ordinances.

Stormwater Management Regulations

In 1998, Waukesha County adopted an erosion control and post-construction stormwater management ordinance consistent with the state model ordinance and many local communities followed. Subsequently, beginning in 2004, the Waukesha County Storm Water Advisory Committee rewrote the County ordinance to reflect new performance standards set forth in Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code*. In addition, the Advisory Committee addressed a number of other implementation issues identified by the Waukesha County Department of Parks and Land Use. The Waukesha County Board adopted Chapter 14, Article VIII, "Storm Water Management and Erosion Control Ordinance of the Waukesha County Code," in 2005. This ordinance requires a Storm Water Permit from the Waukesha County Department of Parks and Land Use for all "land disturbing activities" of a certain size, and requires the preparation of an erosion control plan to reduce soil erosion and sedimentation during the construction and landscaping phases of a development. "Land development activities" generally result in the addition of impervious surfaces to the land (i.e., rooftops and pavement of at least one-half acre in size), which requires the preparation of a stormwater management plan to control post-construction stormwater runoff. The ordinance establishes a series of technical design standards intended to maintain predevelopment runoff patterns, peak flows, infiltration, water quality and the general hydrology of the site. For buildings designed for human occupation, to protect against flooding from surface water, the lowest exposed building surface must be a minimum of two feet above the peak water surface elevation produced by a 100-year recurrence interval (one-percent-annual-probability) storm and separated by a 50-foot horizontal distance from the maximum area flooded during such a storm. To protect against groundwater flooding, construction of basements in hydric soils should be avoided to the degree possible and the basement floor surfaces of habitable buildings must be a minimum of one foot above the seasonal high groundwater table. The County has developed specific procedures to be followed to meet the surface water design standards in internally drained areas and to meet the basement-groundwater separation standards. The County stormwater management ordinance applies to all unincorporated areas of the County except for the Town of Eagle.

While stormwater management standards may vary slightly between communities, the general intent and resulting best management practices on the landscape are usually similar, protecting the investments of local homebuyers, avoiding potential nuisance drainage issues, and minimizing costly publicly-funded solutions in the future. Within the Village of Chenequa, stormwater management planning is required pursuant to Chapter 6, Zoning, of the *Village Ordinances*.

Stormwater Discharge Permit System

The 1987 amendments to the Federal Clean Water Act established a Federal program for permitting stormwater discharges. The State of Wisconsin obtained certification from the U.S. Environmental Protection Agency which enabled the State to administer a stormwater discharge permitting program as an extension of the existing Wisconsin Pollutant Discharge Elimination System (WPDES) program. Section 283.33 of the *Wisconsin Statutes* provided the authority for the issuance of stormwater discharge permits by the State, which was elaborated in Chapter NR 216, "Storm Water Discharge Permits," of the *Wisconsin Administrative Code.* In addition, the State Legislature required the WDNR and the Wisconsin Department of Agriculture, Trade and Consumer Protection (WDATCP) to develop performance standards for controlling nonpoint source pollution from agricultural and nonagricultural land and from transportation facilities. These performance standards are set forth in Chapter NR 151 of the *Wisconsin Administrative Code*. New development, redevelopment, and in-fill development in the areas tributary to the lakes considered under this plan are subject to these requirements.

Chapter NR 151, "Runoff Management," of the Wisconsin Administrative Code

Through 1997 Wisconsin Act 27, the State Legislature required the WDNR and DATCP to develop performance standards for controlling nonpoint source pollution from agricultural and nonagricultural land and from transportation facilities.[7] The performance standards are set forth in Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code,* which became effective on October 1, 2002, and was revised in July 2004 and December 2010.

AGRICULTURAL LAND PERFORMANCE STANDARDS

Performance standards relate to four areas of agriculture: cropland soil erosion control, soil loss from riparian lands, manure management, and nutrient management. The agricultural performance standards are:

- Soil erosion rates on all cropland (and pastures as of July 1, 2012) must be maintained at or below "T" (Tolerable Soil Loss).

- As of 2005, for high-priority areas, such as impaired or exceptional waters, and 2008 for all other areas, application of manure or other nutrients to croplands must be done in accordance with a nutrient management plan, designed to meet State standards for limiting the entry of nutrients into groundwater or surface water resources (this standard does not apply to applications of industrial waste, municipal sludge, or septage regulated under other WDNR programs, provided that the material is not comingled with manure prior to application).

- Clean water runoff must be diverted away from contacting feedlots, manure storage facilities, and barnyards in water quality management areas (areas within 300 feet of a stream, 1,000 feet from a lake, or areas susceptible to groundwater contamination).

- All new or substantially altered manure storage facilities must meet current engineering design standards to prevent surface or groundwater pollution. In addition, inactive or unused manure storage facilities that are failing or leaking shall be properly upgraded, replaced, or closed.

The manure management prohibitions are:

- No direct runoff from animal feedlots to "waters of the State."

- No overflowing manure storage facilities.

- No unconfined manure piles in shoreland areas (areas within 300 feet of a stream, 1,000 feet from lakes).

- No unlimited livestock access to "waters of the State" where the livestock prevent sustaining an adequate vegetative cover.

In general, for land that does not meet the NR 151 standards and that was cropped or enrolled in the U.S. Department of Agriculture Conservation Reserve or Conservation Reserve Enhancement Programs as of October 1, 2002, agricultural performance standards are only required to be met if cost-sharing funds are avail-

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[7] *The State performance standards are set forth in the Chapter NR 151, "Runoff Management," of the* Wisconsin Administrative Code. *Additional code chapters that are related to the State nonpoint source pollution control program include: Chapter NR 152, "Model Ordinances for Construction Site Erosion Control and Storm Water Management;" Chapter NR 153, "Runoff Management Grant Program;" Chapter NR 154, "Best Management Practices, Technical Standards and Cost-Share Conditions;" Chapter NR 155, "Urban Nonpoint Source Water Pollution Abatement and Storm Water Management Grant Program;" and Chapter ATCP 50, "Soil and Water Resource Management." Those chapters of the* Wisconsin Administrative Code *became effective in October 2002. Chapter NR 120, "Priority Watershed and Priority Lake Program," and Chapter NR 243, "Animal Feeding Operations," were repealed and recreated in October 2002.*

able. Existing cropland that met the standards as of October 1, 2002, must continue to meet the standards. New cropland must meet the standards, regardless of whether cost-share funds are available.

The 2010 revision to NR 151 added new agricultural performance standards. The new performance standards include:

- A five- to 20-foot setback from the top of a surface water channel in agricultural fields within which no tillage is allowed for the purpose of maintaining streambank integrity and avoiding soil deposits into State waters;

- A limit on the amount of phosphorus that may run off croplands as measured by a phosphorus index; A prohibition against significant discharge of process water from milk houses, feedlots, and other similar sources; and

- A standard that requires crop and livestock producers to reduce discharges if necessary to meet a load allocation specified in an approved Total Maximum Daily Load (TMDL) by implementing targeted performance standards specified for the TMDL area using best management practices, conservation practices, and performance standards specified in Chapter ATCP 50 of the *Wisconsin Administrative Code*.

Under Chapter NR 216, "Stormwater Discharge Permits," of the *Wisconsin Administrative Code*, agriculture is not exempt from the requirement to submit a notice of intent (NOI) for one or more acres of land disturbance for the construction of structures such as barns, manure storage facilities or barnyard runoff control systems. Construction of an agricultural building or facility must follow an erosion and sediment control plan consistent with Section NR 216.46 of the *Wisconsin Administrative Code*, including meeting the performance standards of Section NR 151.11 of the *Wisconsin Administrative Code*. Agriculture is exempt from this requirement for activities such as planting, growing, cultivating and harvesting crops for human or livestock consumption and pasturing of livestock as well as for sod farms and tree nurseries. NR 216 establishes the criteria and procedure for issuance of stormwater discharge permits to limit the discharge of pollutants carried by stormwater runoff into waters of the State.

Nonagricultural (urban) Land Performance Standards

The nonagricultural performance standards set forth in Chapter NR 151 encompass two major types of land development. The first includes standards for areas of new development and redevelopment, and the second includes standards for existing developed urban areas. The performance standards address the following areas:

- Construction sites for new development and redevelopment,

- Post-construction stormwater runoff for new development and redevelopment,

- Developed urban areas, and

- Nonmunicipal property fertilizing.

Chapter NR 151 requires that municipalities with Wisconsin Pollutant Discharge Elimination System permits for their municipal separate storm sewer system (MS4), as required under Chapter NR 216, reduce the amount of total suspended solids (TSS) in stormwater runoff from areas of existing development that is in place as of October 2004 by 20 percent, or to the maximum extent practicable, by March 10, 2008.

Chapter NR 151 also establishes schedules for reducing TSS from areas of existing development by 40 percent, but 2011Wisconsin Act 32, as reflected in Section 281.16(2)(am) of the *Wisconsin Statutes*, states that WDNR "may not enforce a provision in a rule that establishes a date by which a covered municipality must implement methods to achieve a specified reduction in the level of total suspended solids carried by runoff, if the provision requires the covered municipality to achieve a reduction of more than 20 percent."[8] The Section notes that the requirement does not apply to new development or redevelopment, and it states that a covered municipality that has achieved a total suspended solids reduction of more than 20 percent as of July 1, 2011, "shall to the maximum extent practicable maintain all of the best management practices that the municipality has implemented on or before July 1, 2011, to achieve that reduction." The effect of this law is to eliminate the requirement of NR 151 that a municipality with an MS4 permit under Chapters NR 151 and 216, "Storm Water Discharge Permits," must achieve a 40 percent reduction in TSS in runoff from areas of existing development by a specific date.[9]

Also, permitted municipalities must implement the following: 1) public information and education programs relative to specific aspects of nonpoint source pollution control; 2) municipal programs for collection and management of leaf and grass clippings; and, 3) site-specific programs for application of lawn and garden fertilizers on municipally controlled properties with over five acres of pervious surface. Under the requirements of Chapter NR 151, by March 10, 2008, incorporated municipalities with average population densities of 1,000 people or more per square mile that are not required to obtain municipal stormwater discharge permits must have implemented those same three programs.

In addition, regardless of whether or not a municipality is required to have a stormwater discharge permit under Chapter NR 216, "Storm Water Discharge Permits," Chapter NR 151 requires that, as of January 1, 2013, all construction sites that have one acre or more of land disturbance must discharge no more than five tons of sediment per acre per year. With certain limited exceptions, those sites required to have construction erosion control permits must also have post-development stormwater management practices to reduce the TSS load from the site by 80 percent for new development, 40 percent from parking lots and roads associated with redevelopment, and 80 percent for infill development . If it can be demonstrated that the solids reduction standard cannot be met for a specific site, TSS must be controlled to the maximum extent practicable.

Section NR 151.123 establishes peak discharge performance standards for new development. Under that section, best management practices shall "maintain or reduce the 1-year, 24-hour and the 2-year, 24-hour post-construction peak runoff discharge rates to the 1-year, 24-hour and the 2-year, 24-hour pre-development peak runoff discharge rates respectively, or to the maximum extent practicable."

Section NR 151.124 requires infiltration of post-development runoff from areas developed on or after October 1, 2004, subject to specific exclusions and exemptions. For development with less than 40 percent connected imperviousness ("low imperviousness"), 90 percent of the annual predevelopment infiltration volume is required to be infiltrated. However, no more than 1 percent of the area of the project site is required to be used as effective infiltration area. For development with connected imperviousness ranging from more than 40 percent up to 80 percent ("moderate imperviousness"), 75 percent of the annual predevelopment infiltration volume is required to be infiltrated. For development with connected imperviousness greater than 80 percent ("high imperviousness"), 60 percent of the annual predevelopment infiltration volume is required to be infiltrated. In the case of moderate and high imperviousness areas, no more than 2 percent of the project site is required to be used as effective infiltration area.

Recent State Actions Affecting Construction Erosion Control and Stormwater Management Standards

2013 Wisconsin Act 20, which was passed by the State Legislature, and signed into law by the Governor, established additional requirements related to construction erosion control and stormwater management that are not yet embodied in the *Wisconsin Administrative Code*. Those requirements are described below.

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[8]*The statute defines a "covered municipality" as one that has been issued an individual municipal separate storm sewer system (MS4) permit, or that is covered by a general MS4 permit.*

[9]*The requirements of Section 281.16(2)(am) of the* Wisconsin Statutes *are not included in the* Wisconsin Administrative Code.

2013 Wisconsin Act 20 calls for:

- The Wisconsin Department of Safety and Professional Services to "establish statewide standards for erosion control at building sites that have a land disturbance that is less than one acre in area and that are for the construction of public buildings and buildings that are places of employment," and to "promulgate rules for the administration of construction site erosion control" consistent with the requirements of the Act,

- The WDNR to establish by rule uniform statewide standards for activities related to construction site erosion control at sites where one acre of land or more is disturbed,

- The WDNR to establish by rule uniform statewide standards for stormwater management,

- The WDNR to "prepare a model zoning ordinance for construction site erosion control … and for stormwater management in the form of an administrative rule," and

- Cities, villages, towns, or counties to comply with the uniform statewide construction site erosion control and stormwater management under any pertinent local zoning ordinance.

2013 Wisconsin Act 20 allows a municipality to establish ordinance provisions for stormwater management that are more restrictive than the uniform statewide standards if stricter standards are needed to control stormwater quantity or flooding or to comply with "[F]ederally-approved total maximum daily load requirements." Also, the uniform statewide standards are not required to be applied to municipal ordinance provisions relating to existing development or redevelopment.

Transportation Facility Performance Standards

Transportation facility performance standards that are set forth in Chapter NR 151 and in Chapter TRANS 401, "Construction Site Erosion Control and Storm Water Management Procedures for Department Actions," of the *Wisconsin Administrative Code* cover the following areas:

- Construction sites,

- Post-construction phase, and

- Developed urban areas.

The standards of TRANS 401 are applicable to Wisconsin Department of Transportation projects. 2013 Wisconsin Act 20 calls for WDNR to work with the Wisconsin Department of Transportation to "establish by rule uniform statewide standards for activities related to construction site erosion control and storm water management if those activities concern street, highway, road or bridge construction, enlargement, relocation or reconstruction."

Stormwater Facility Operation and Maintenance

As stormwater facilities become more complex, they will require more attention by the end users. Establishing an ongoing operation and maintenance program is critical to successful stormwater management. Waukesha County has developed a stormwater facility database that serves as such a repository for design, construction, and maintenance information on stormwater best management practices applied to lands under County jurisdiction. This database is being populated with new projects as they are permitted under the County ordinance. In addition, a process has been developed to populate the database with historical information about previously permitted projects. This database is accessible to municipal engineers around the County and will serve as a source of information for the continued maintenance of stormwater facilities into the future.

Chapter IV

RESOURCE ISSUES OF CONCERN IN THE VILLAGE OF CHENEQUA

The Village of Chenequa, in northwestern Waukesha County, was founded in 1928 in order, among other goals, to protect the land and the lakes. Since its inception, the Village has been conceived as a residential community intended to be devoted solely to residence purposes so as to afford to its citizens the peace and quiet and restfulness unobtainable in the City.[1] As noted in Chapter III, the name of the Village comes from the Potawatomi word for "pine," a stand of which still can be seen along the eastern shoreline of Pine Lake.

Despite this idyllic desire and an 80-year history of sound land management, a number of issues of concern to Village residents and visitors have arisen in recent years. To a large extent, these issues of concern are centered on the water resources that form the focal point of the Village of Chenequa. Previous planning projects undertaken within the Village highlight concerns about water quality in the major Lakes, groundwater quantity, and development-related issues leading to demands for utilization of water-resources, access to water-related recreation, and resolution of water-use conflicts.[2]

Resolution of these concerns is primarily a function of managing human activities on the land surface, managing human demands on Village water resources, and protecting the ability of the underlying natural resource base to sustain these activities and demands. As noted in Chapter III, these concerns are equally relevant to resolving the demands being placed on both surface and groundwater resources, which are highly susceptible to water quality degradation attendant on human activities.

In this Chapter, a number of water resources concerns, identified both through scientific investigations of the Village water resources as well as through testimony of Village Trustees, staff, and residents in various public fora, are identified and quantified, to the extent possible. These issues of concern will be further addressed in Chapter V, in terms of alternative approaches that could be considered for the resolution of these issues of concern, and in Chapter VI, in terms of a recommended water resources management strategy and plan for the Village. As in any planning process, the location of the Village of Chenequa within a jurisdictional hierarchy as well as a geographic landscape means that actions to be considered by parties other than those under the direct

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[1]*Village of Chenequa,* Village of Chenequa Code: Chapter 6. Zoning*, 2011.*

[2]*See, for example, SEWRPC Memorandum Report No. 173,* An Aquatic Plant Management Plan for Pine and Beaver Lake, Waukesha County, Wisconsin, *October 2008.*

authority of the Village need to be highlighted. To this end, Chapter VI also will highlight potential participants in plan implementation in addition to the Village of Chenequa and its residents.

CONCERNS RELATED TO WATER RESOURCE USE

Water resources uses can be distinguished by the source water being utilized; namely, whether the source water is surface water or groundwater in origin. Within the Village of Chenequa, surface waters are used primarily for recreation and aesthetic appreciation. Some local lawn or garden watering also may take place. Surface water is rarely used for consumption, although there is some anecdotal evidence of limited use of surface waters for consumption in the Village. In the case of the Village of Chenequa, surface waters receive stormwater runoff from the surrounding landscape but do not directly receive treated wastewater or other discharges.

Groundwater, in contrast, is used both for drinking water supply and for disposal of wastewater through onsite sewage disposal systems. Individual or private wells also supply water for gardening and landscaping. In the surrounding communities, groundwater is abstracted for the public drinking water supply,[3] while public sanitary sewerage systems convey wastewater to centralized treatment facilities for disposal.[4] Treated sewage effluent—in the case of the City of Delafield, the Village of Hartland, and the Village of Nashotah—is discharged to the Bark River by the Delafield-Hartland Water Pollution Control Commission wastewater treatment facility downstream of Crooked Lake, in Waukesha County.

Use of Surface Water Resources

The principal uses of the surface water resources of the Village are for recreation and aesthetic enjoyment. The Beaver Lake Sailing Club (1946), Pine Lake Yacht Club (1890), and North Lake Yacht Club (1953) all utilize these resources. The Clubs hold regattas during the open water boating season and sponsor various social programs, including programming on lake water quality issues of concern, throughout the year. The Clubs historically have formed the nucleus for lake management actions within the Village and surrounding area.

In the case of Beaver Lake, the Friends of Beaver Lake, Inc., a Federal section 501(c)(3) not-for-profit corporation, was formed in 2004 for the purpose of creating the “structures and systems needed to inspire all lake residents to serve as lake stewards.” This voluntary association has adopted a mission which states that “through education, collaboration and action, but with regard for individual rights, lake residents will act together to maintain and improve the overall ecological health of Beaver Lake.”

In contrast, North Lake is served by a public inland lake protection and rehabilitation district, the North Lake Management District, a special purpose unit of government formed under Chapter 33 of the *Wisconsin Statutes*. This lake district was formed in 1990 for the purpose of managing the Lake with particular regard to the "quality and environmental protection, rehabilitation and safe enjoyment for the riparian owners and the public, both present and future generations." This district has sponsored boating safety classes and fish stocking of North Lake, among other activities, as part of their lake management program.

Given the limited surface area and small size of the resident community around Cornell Lake, use of this waterbody is limited to aesthetic enjoyment and operation of small craft.

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[3] *See SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin, *Volume One of Two Volumes, December 2010: the Hartland Municipal Water Utility dates from 1933, while the City of Delafield Municipal Water Utility was created in 1994.*

[4] *SEWRPC Community Assistance Planning Report No. 127,* Sanitary Sewer Service Area for the City of Delafield and the Village of Nashotah and Environs, Waukesha County, Wisconsin*, November 1992, as amended.*

Control of Water Quality

Because the lakes are extensively utilized for recreation, water quality is an issue of concern. As noted in Chapter II, the Wisconsin Trophic State Index (TSI) values derived for the Lakes range from 36 to 51, with the TSI values increasing from upstream (Beaver Lake) to downstream (North Lake). Cornell Lake was an outlier in this sequence, having a WTSI value of 63, primarily due to the turbid nature of its waters. North Lake was greatly influenced by the flows of the Oconomowoc River, which constitutes the principal inflow to that Lake.[5] Under the 1982 water quality management plan for North Lake, the Regional Planning Commission staff calculated that about 70 percent of the estimated 5,000 pounds of phosphorus delivered to the Lake under 1975 land use conditions originated from the Oconomowoc and Little Oconomowoc Rivers while only about 650 pounds of phosphorus were calculated as entering the Lake annually downstream of Cornell Lake. The percentage of the load currently contributed through the Oconomowoc and Little Oconomowoc Rivers may be even greater than that estimated in the 1970s. A slight reduction in this loading rate is anticipated between 2010 and achievement of planned 2035 land use conditions, and any substantial change in phosphorus loading is likely to arise from the Oconomowoc River watershed since it is the primary source of phosphorus.[6]

The forecast phosphorus loads to North Lake can be expected to continue to decline over the planning period as stormwater management systems are developed and implemented by the watershed communities. As a likely result of land use changes and management practices installed under the priority watershed program, the Wisconsin TSI values observed in North Lake have decreased from about 60 at the time of the comprehensive lake management plan for North Lake to about 50 in recent years.[7] Such a change is consistent with the general improvement in water quality noted throughout the Southeastern Wisconsin Region between 1979 and 1995.[8]

Canopy Cover Maintenance

As discussed in Chapter II and III, the Village of Chenequa has ordinances which act to prevent the loss of canopy cover, namely:

- "a permit is required by anyone wanting to remove/trim trees or shrubbery within a 75 foot section parallel to the shoreline buffer zone;" and

- "if removed the vegetation should be replaced with another species that is equally effective in preventing runoff, erosion and preserving nature."[9]

These ordinances, along with other Village policies, have likely influence the currently high amount of residential canopy cover in each of the Lake watersheds, as is shown on Maps 6, 9, 11, and 15 in Chapter II of this report. This canopy cover is a likely reason why water quality has continued to improve in all of the Lakes despite high predicted nonpoint pollution loads.

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[5]*See SEWRPC Community Assistance Planning Report No. 54,* A Water Quality Management Plan for North Lake, Waukesha County, Wisconsin, *July 1982.*

[6]*See Wisconsin Department of Natural Resources Publication WR-194-86,* A Nonpoint Source Control Plan for the Oconomowoc River Priority Watershed Project, *March 1986.*

[7]*SEWRPC Memorandum Report No. 145,* Lake and Stream Resources Classification Project for Waukesha County, Wisconsin: 2000, *December 2005.*

[8]*SEWRPC Planning Report No. 30, A Regional Water Quality Management Plan for Southeastern Wisconsin–2000, Volume Two,* Alternative Plans, *February 1979; SEWRPC Memorandum Report No. 93,* A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report, *March 1995.*

[9]*Village of Chenequa Ordinances,* Chapter 6: Zoning, *2009.*

Protection and Expansion of Buffered Regions

As found in the buffer analysis discussed in Chapter II, a large proportion of the upstream Oconomowoc River is buffered. This buffered region likely contributes to water quality in North Lake being better than the water quality that would be predicted for a Lake with such a large watershed. However, as can be seen in Map 16 of Chapter II, gaps in these buffers do exist. Consequently, the protection and enhancement of these buffers on the upstream Oconomowoc River may be considered an issue of concern.

Though not discussed in Chapter II, the buffer analysis was also completed for each of the smaller Lake watersheds. As can be seen on Map 16, in Chapter II, Beaver Lake contained a very small amount of actual buffered region. This was surprising considering the canopy cover analysis revealed highly covered residential region; however, this issue seems valid when the role of a buffer is further explained. A buffer can fulfill the role of pollution reduction only when runoff is forced to run through it; for this to take place the buffer needs to be continuous. In general, any road, culvert or lawn will help the runoff to bypass any pollution reduction benefits a "buffered region" could provide.

Protection of Ecologically Valuable Areas

The regional natural areas and critical species habitat protection and management plan does not identify any known natural areas within the Village limits, although the plan does identify a natural area of local significance (NA-3) along the northern shores of North Lake.[10] The Chenequa Wetland Complex is a lowland complex of shrub-carr, sedge meadow, shallow marsh, tamarack relict, and lowland hardwoods located in Sections 8 and 9, and 16 and 17 of Township 8 North, Range 18 East, in the Town of Merton. This area includes 267 acres of wetland and is partially in County ownership. The natural areas plan recommends that the County consider acquisition of an additional 100 acres of this wetland, as proposed in the County development plan.[11]

Shoreland Management

The shorelands of the four lakes are in a moderately undisturbed condition, although shoreland surveys conducted by SEWRPC staff suggest that the shores may be in a largely naturally-protected state. As shown on Maps 7 and 10 in the aforereferenced aquatic plant management plan for Beaver and Pine Lakes, much of the shoreline can be described as being protected by riprap.[12] That said, it is likely that such armoring could be of geological origin with the shoreland protection being the result of exposure of cobbles and boulders that are naturally occurring within the moraines that form the shorelands of the Lakes, especially in the case of Pine Lake where much of the shoreland is occupied by large-lot suburban density residential development. In contrast, the more densely settled shorelands of Beaver Lake are more likely to have been purposely protected by placement of riprap in order to minimize shoreland damages due to ice flows or wind waves. The shorelands of Cornell Lake were observed to be in a well-vegetated state, while the shorelands of North Lake also were reported to be largely undisturbed.[13] Shoreland management within the Village is subject to Section 6.09, "Bulkhead Line," of the *Village Ordinance*, that restricts cutting of lakeshore vegetation within 75 feet of the shoreline, in order to enhance shoreland aesthetics, promote wildlife habitat, and filter runoff from the shoreland landscape to protect water quality. The Village Forester notes that, in keeping with the name of the Village as noted in Chapter III of this plan, "The Chenequa shores of Pine, Beaver and North Lakes have traditionally resembled northern Wisconsin rather than the more common 'house and lawn' look of the surrounding lakes."

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[10]*SEWRPC Planning Report No. 42,* A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin, *September 1997, as refined.*

[11]*SEWRPC Community Assistance Planning Report No. 209*, A Development Plan for Waukesha County, Wisconsin, *August 1996, as refined.*

[12]*SEWRPC Memorandum Report No. 173,* op. cit.

[13]*SEWRPC Community Assistance Planning Report No. 54,* op. cit.

The Village has adopted stringent setback requirements, pursuant to Section 6.05, "Residence District Regulations," of the *Village Ordinance* relating to lakefront properties, summarized as follows:

- "the minimum distance measured over the contour of the ground between the lake frontage and nearest point of the structure or any projection thereof shall be not less than 75 feet;
- within the area located between the lake frontage and a line 30 feet distant therefrom and parallel thereto, ground level marine railways, below-ground water pumping facilities, one uncovered stairway and one uncovered walkway level with the ground and not exceeding four feet in width may be constructed and maintained;
- within the area located between the 30 foot line referred to above and a line 75 feet from the lake frontage and parallel thereto, uncovered terraces, patios, stairs, ground level marine railways, below-ground water pumping facilities, and walkways located at or beneath the ground level may be constructed and maintained;
- within the entire area between the lake frontage and a line 75 feet from the lake frontage and parallel thereto, one flagpole, one satellite dish, and a temporary fence to be used as a goose barrier as provided in Section 5.19(3)(a) of the ordinances may be constructed and maintained;
- no structure shall hereafter be erected, rebuilt, altered or moved on any lot in the Village of Chenequa abutting upon any lake if such structure shall exceed 4000 square feet, unless the minimum distance measured over the contour of the ground between the lake frontage and the nearest point of the structure or any projection thereof shall be more than 100 feet; and,
- no structure shall hereafter be erected, rebuilt, altered, or moved on any lot in the Village of Chenequa abutting on any lake if the Living Area of that structure exceeds 13,000 square feet, unless the following setback requirements are met:
    - for structures of 13,000 square feet but less than 15,000 square feet, the minimum setback is to be 125 feet,
    - for structures of 15,000 square feet but less than 17,000 square feet, the minimum setback is to be 150 feet,
    - for structures of 17,000 square feet or greater, the minimum setback is to be 175 feet."

These requirements provide for floodwater storage in the Lakes as well as for the protection of shoreland properties within the Village. In addition, Sections 4.09, "Emergency Slow No Wake Speed at Times of High Water on Pine Lake," and 4.10, "Emergency Slow No Wake Speed at Times of High Water on Beaver Lake and North Lake," of the *Village Ordinance*, provide additional protection of shorelands during periods of high water on the major Lakes.

Stormwater Management

Portions of the area tributary to the Oconomowoc River and North Lake are subject to stormwater runoff management requirements pursuant to Chapter NR 216, "Storm Water Discharge Permits," of the *Wisconsin Administrative Code*. The goal of this Chapter of the *Wisconsin Administrative Code* is to minimize the discharge of contaminants carried by stormwater runoff from certain industrial facilities, construction sites and municipal separate stormwater sewer systems to the waters of the State. Chapter NR 216 also establishes criteria for defining those stormwater discharges requiring Wisconsin Pollution Discharge Elimination System (WPDES) stormwater discharge permits, as a basis for implementing the appropriate performance standards set forth in Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code*. Pursuant to these requirements, Communities Waukesha County, the City of Delafield, the Village of Nashotah, and the Town of Merton have coverage under

WPDES Municipal Separate Storm Sewer System (MS4) general permit number WI-S050075-1. At the time of writing, the Village of Chenequa and the Village of Richfield portions of the tributary area were not subject to this permitting requirement.

Use of Groundwater Resources

Whereas the surface water resources of the Village are widely used for recreational and aesthetic purposes, the groundwaters of the Village are primarily utilized for water supply purposes. Groundwaters in the Village also are the receiving waters for the treated effluents generated from onsite wastewater disposal facilities within the Village. Groundwater outflows form a major water source sustaining the major Lakes within the Village, providing the major inflow to Beaver Lake and forming important components of the inflows to Pine Lake and North Lake.[14]

Regulating Withdrawal

There currently are no Village regulations affecting the volume of groundwater that can be withdrawn. That said, the then proposed placement of high capacity wells, abstracting more than 100,000 gallon per day, in proximity to the Village by the City of Delafield to supply water to the City invoked considerable concern within the Village. The concern was focused on the likely impact of high volume water withdrawals from the surface aquifer adjacent to waterways within the Village. It was surmised that such withdrawals could potentially have a negative influence on the water balance of the Village water resources in contravention of the aforementioned efforts by the Village to protect both water quantity and quality by regulating use of water resources within the Village boundary. In response to this concern, the Village undertook the monitoring of groundwater levels within several monitoring wells placed at points around the Village, and commissioned the U.S. Geological Survey (USGS) to conduct a model-based assessment of the potential impacts on groundwater resources associated with the possible placement of such high capacity wells.[15] The results of this simulation indicated that placement of a high capacity well along the boundary between the City of Delafield and Village of Chenequa would have a minimal influence on the surface water resources of the Village; rather, the primary impact of such withdrawals would affect the Bark River and its associated surface waters.

Control of Water Quality

Section 5.12, "Plumbing Work," of the *Village Ordinance*, provides that the construction, reconstruction, installation, and alteration of all plumbing, drainage, and plumbing ventilation shall conform to Chapters SPS 320 through SPS 325 of the *Wisconsin Administrative Code* as amended. In addition, the Village of Chenequa ordinance restricts the placement of seepage pits and drainage fields to locations more than five feet from any lot line, more than 25 feet from any dwellings or cisterns, or within 100 feet of any water well, lake, stream or other watercourse. No sewage tanks are to be located within two feet of any lot line, 10 feet of any cistern, or 75 feet from any well or other source of water supply used for domestic purposes. These requirements are intended to protect the public health and to minimize the risk of cross contamination between water supply and wastewater treatment systems in the Village.

Nevertheless, some groundwater quality problems can be caused by natural factors which cannot be controlled by regulating human interventions such as those noted above. For example, the abundant dolomite underlying the Region is comprised of calcium and magnesium carbonate. Calcium and magnesium form about one-half of all of the ions in groundwater and are the principal components of hardness. Hardness can be objectionably high in the groundwater underlying most of the Region, and "softening" is required for almost all water uses.

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[14]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwestern Waukesha County, Wisconsin, *2010.*

[15]*See U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* op. cit.

Similarly, naturally occurring radioactivity from radium in groundwater has become a concern in Wisconsin in recent years. Naturally occurring radium, present within certain rock formations in the deep sandstone aquifer, has resulted in one or more exceedences of the current five picocuries per liter (pCi/l) State maximum contaminant level (MCL) and U.S. Environmental Protection Agency (USEPA) standard for radium (combined Radium-226 and Radium-228). Most of these exceedances have occurred in wells open to Cambrian sandstone formations.

Arsenic (As) is another naturally occurring element of concern in the Region. Data from the WDNR Groundwater Reporting Network (GRN) databases indicate that during the period from January 1, 1998 through December 31, 2006, 1,243 wells in the Region were tested for arsenic.[16] Water from about 5 percent of the municipal and private wells tested exceeded the Federal standard and State MCL of 10 micrograms per liter (µg/l). The State preventive action limit of 1.0 µg/l was exceeded in about one-half of the wells tested. Arsenic is found in several different geologic units, including igneous rocks of the Precambrian shield, Paleozoic sedimentary rocks and Quaternary glacial deposits. Oxidation of sulfide-containing minerals can release naturally-occurring arsenic. This oxidation may have occurred at some time in the geologic past or may be due to the introduction of oxygen as a result of the water levels in wells dropping to levels at or just below the sulfide rich zones. Arsenic bound to iron-hydroxide minerals in Quaternary glacial deposits also can be reductively released to groundwater under conditions of low dissolved oxygen concentrations. A recent study that examined a core through the Quaternary aquifer obtained in the vicinity of Geneva Lake and sediment samples from previous drilling efforts in this area showed that these minerals are widely dispersed throughout the aquifer.[17]

There are numerous other potential groundwater contaminants resulting from human activities, including bacteria, viruses, prions, nitrate, pesticides, and volatile organic compounds (VOCs). While these contaminants can affect the quality of water in private wells, they generally do not constitute a major problem. Coliform bacteria have been detected in, on average, 15 percent of the private wells in the Southeastern Wisconsin Region. A recent study, which surveyed 50 private wells on a quarterly basis throughout the State of Wisconsin, found that 8 percent of wells tested positive for the presence of at least one enteric virus[18] (i.e. viruses which infect the gastrointestinal tract and, therefore, are indicators of potential fecal contamination). No data are available on the presence of prions in the groundwater. The risks to groundwater are thought to be highest in situations where large numbers of infected animals are destroyed and buried to control the spread of animal diseases and where overland flow transports material from carcasses in fields or prion-contaminated animal-based fertilizers directly into poorly-constructed wells. Data from the WDNR suggest that nitrate contamination is a relatively minor problem in the Region. WDNR data for the Region during the period from January 1, 1998 through December 31, 2006, shows that 1) most pesticide compounds sampled were detected in fewer than 15 percent of the wells sampled and 2) most VOC compounds were detected in less than 10 percent of the wells sampled. For most VOC compounds, State preventive action limits and enforcement standards were exceeded in less than 1 percent of the wells sampled.

Protection of Groundwater Quantity

The protection of groundwater quantity remains an emerging issue of concern in the State of Wisconsin.[19] Most regulations concerning groundwater have focused historically on groundwater quality, with attention only recently

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[16]*SEWRPC Planning Report No. 52*, op. cit.

[17]*T. Root, J.M. Bahr, and M.B. Gotkowitz, "Controls on Arsenic Concentrations in Groundwater near Lake Geneva, Wisconsin," IN: P.A. O'Day, D. Vlassopoulos, X. Meng, and L.G. Benning (Eds.),* Advances in Arsenic Research, *American Chemical Society Symposium Series, volume 915, pages 161-174, 2005.*

[18]*Mark A. Borchardt and others, "Incidence of Enteric Viruses in Groundwater from Household Wells in Wisconsin,* Applied and Environmental Microbiology, *Volume 69, 2003.*

[19]*P.G. Kent and T.A. Dudiak,* Wisconsin Water Law: A Guide to Water Rights and Regulations, 2nd Edition, *University of Wisconsin-Extension Publication No. G3622, 2001.*

being shifted toward groundwater quantity. Until recently, the only restrictions on the placement of high capacity wells relate to limitation of impacts on adjacent public water supply wells; within 1,200 feet of outstanding (ORW) or exceptional resources waters (ERW) of the State, as defined pursuant to Chapter NR 102, "Water Quality Standards for Wisconsin Surface Waters," of the *Wisconsin Administrative Code*, and trout streams in Groundwater Protection Areas; and, springs with a discharge rate of 1 cubic foot per second for at least 80 percent of the time.[20] [21]At the time of writing, the water resources of the Village of Chenequa do not meet these criteria.

Localized concerns regarding the connection and inter-relationships between surface and groundwater resources have led to the promulgation of local ordinances for groundwater protection. One of the first ordinances of this type was adopted by Portage County. This ordinance was primarily focused on groundwater quality, and established wellhead protection zones within which certain land uses, such as those involving underground storage facilities, were stringently regulated and/or prohibited. More recently, the Lake Beulah Management District adopted a local ordinance restricting the diversion of surface and groundwaters from the Lake Beulah basin.[22] Although the provisions of this Ordinance requiring return flows to Lake Beulah basin were overturned by the June 16, 2010 ruling of the Waukesha District Court of Appeals, and this action to overturn was upheld by the July 6, 2011 ruling of the Wisconsin Supreme Court, both decisions recognized the WDNR's statutory duty to enforce the public trust doctrine—the constitutionally based body of law that protects navigable waters for the public benefit—as it applies to groundwater which becomes surface water. The State Supreme Court ruling affirmed the portion of the Court of Appeals ruling that stated that the WDNR "has the authority and duty to consider the environmental impact of a proposed high capacity well if presented with sufficient scientific evidence suggesting potential harm to waters of the state". This legal linkage between groundwater and surface water, which has taken over 160 years to be affirmed, establishes the responsibility of the WDNR to enforce the public trust doctrine to protect all navigable waters of the State, not just the ORW/ERW waters, trout streams, and springs explicitly noted in Chapter 281 of the *Wisconsin Statutes*.[23] In addition, the Supreme Court decision noted that, in the event of actual harm being created as a consequence of the operation of the high capacity well, the Lake Beulah Management District would not be precluded from pursuing a remedy in the future through an enforcement or nuisance action.

CONCERNS RELATED TO RECREATIONAL USE

As noted above, the principal uses of the surface water resources of the Village of Chenequa are for recreation and aesthetic enjoyment. The Beaver Lake Sailing Club, Pine Lake Yacht Club, and North Lake Yacht Club all utilize these water resources and hold regattas during the open water boating season. The Clubs, together with the Friends of Beaver Lake, Inc., and the Village of Chenequa, also sponsor various informational programs throughout the year, including programming on lake water quality issues of concern.

Water Quality

Because many of the recreational water uses made of the Lakes within and adjacent to the Village of Chenequa involve full or partial body contact with the water, water quality is an issue of concern to Village residents and their visitors. In this regard, fisheries management and aquatic plant management reflect ongoing concerns of the

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[20]*See Section 281.34 of the* Wisconsin Statutes*.*

[21]*Recent legal and legislative developments related to WDNR authority with respect to groundwater quantity considerations are described below in this report subsection.*

[22]*Lake Beulah Management District Ordinance No. 2006-03, "An Ordinance Prohibiting the Net Transfer of Groundwater and Surface Water from the Lake District Hydrologic Basin," December 2006.*

[23]*2013 Wisconsin Senate Bill 302 is being considered by the State legislature. The bill establishes conditions for WDNR review of high capacity well permit applications.*

community, while algal blooms and toxicity reflects an emerging issue of concern. Water quality data, while collected intermittently since 1972,[24] suggest Pine and Beaver Lakes have remained in a relatively stable, mesotrophic, or moderately enriched, condition that can be considered as being relatively undisturbed under prevailing conditions in Southeastern Wisconsin. Closer examination of Figure 4 in Chapter II of this report suggested that, between 1972 and 1982, Pine Lake periodically had phosphorus concentrations indicative of a degraded or eutrophic condition, with concentrations exceeding 40 micrograms of phosphorus per liter (µg/l) on several occasions during 1975, 1977, and 1981, although these peaks in total phosphorus concentrations did not seem to have resulted in excessive algal blooms (defined as a chlorophyll-*a* concentration of greater than 10 µg/l).[25] In recent years, since 2007 (not shown on the aforereferenced Figure 4), citizens have reported more frequent algal blooms, which analysis has indicated to be comprised of blue-green algae/cyanobacteria.

Algal Blooms and Algal Toxicity

During 2007, Village staff noted the presence of an algal bloom on Pine and Beaver Lakes, and collected water quality samples which were analyzed for blue-green algal toxicity by the Wisconsin State Laboratory of Hygiene. Additional samples were obtained for phytoplankton analysis, which was carried out by PhycoTech, Inc. Samples from both Pine Lake and Beaver Lake contained the blue-green algae, *Microcystis aeruginosa*, a known toxin forming species. In addition, *Anabaena lemmermannii* and *Lyngbya birgei* were reported to be present in the sample from Pine Lake. The measured level of algal toxicity in Pine Lake was less than the level of detection for microcystin, but was reported to be about 0.4 µg/l in Beaver Lake. A level of 1.0 µg/l is considered to be the chronic consumption maximum contaminant guideline level by the World Health Organization (WHO). Additional information on blue green algae/cyanobacteria is provided in Appendix D.

Since the aforementioned 2007 algal blooms, it has been reported, by the Village, that blue green has significantly reduced; however, although not reported in the aforereferenced aquatic plant management plan for Pine and Beaver Lakes, nontoxic algal blooms were reported by citizens and Village staff during subsequent years, suggesting that they are likely to be recurring in nature. This recurrence may be indicative of a number of causes, including increased insolation leading to warmer surface water temperatures, increased runoff as a consequence of several large rainfall events experienced since 2007,[26] altered influences of surface runoff and groundwater infiltration,[27] and higher water surface elevations in the Lakes, reducing the available habitat for rooted aquatic plants which otherwise would compete with the phytoplankton for available nutrients. The extent to which these conditions will continue to recur in the Lakes is unknown, but forecasts of the effects of climate change in Wisconsin suggest that future occurrences are likely.[28]

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[24]*See SEWRPC Memorandum Report No. 124,* An Aquatic Plant Inventory for Pine Lake, Waukesha County, Wisconsin, *December 1998.*

[25]*SEWRPC Memorandum Report No. 173,* op. cit.

[26]*J.F. Walker, and W.R. Krug,* Flood-frequency Characteristics of Wisconsin Streams, *U.S. Geological Survey Water-Resources Investigations Report 03–4250, 2003; F.A. Fitzpatrick, M. C. Peppler, J.F. Walker, W.J. Rose, R. J. Waschbusch, and J.L. Kennedy,* Flood of June 2008 in Southern Wisconsin, *Scientific Investigations Report No. 2008-5235, 2008.*

[27]*See U.S. Geological Survey Water-Data Report, 2008, accessed on November 21, 2011:* http://wdr.water.usgs.gov/wy2008/pdfs/425535088131701.2008.pdf; http://wdr.water.usgs.gov/wy2008/pdfs/425607088173001.2008.pdf.

[28]*Wisconsin Initiative on Climate Change Impacts,* Wisconsin's Changing Climate: Impacts and Adaptation, *University of Wisconsin-Madison and Wisconsin Department of Natural Resources, 2011.*

Nitrogen Pollution

As discussed in Chapter II, phosphorous is generally the nutrient which spurs plant growth within a Lake due to its being the "limiting nutrient"; however, in Pine Lake it was found that nitrogen was historically the limiting factor (although today it seems that this has changed). This indicates that nitrogen pollution, in addition to phosphorous pollution, which largely comes from both urban and agricultural land use (through fertilizer runoff), is an issue of concern in this region. This may also be why algae has been shown to be an issue of concern in this Lake; as most of the Lakes in Wisconsin are phosphorous limited, most of the implemented control measures and laws focus on reducing phosphorous pollution rather than nitrogen.[29] This, therefore, does not address the source of the issue, i.e. nitrogen pollution primarily from fertilizers, for those lakes which are nitrogen limited.

Chlorides

Though some chloride is natural in lakes if found in small quantities, concentrations found to be higher than the range of 20-30mg/l normally stem from pollution sources like road salt, run off of chloride containing fertilizers, and salt discharged from water softeners and sewage. There has been an extensive observed increase in chloride concentrations in southern Wisconsin lakes, particularly since the 1960s, as is evident by data that SEWRPC has compiled for the region (as shown Figure 6). This increase seems to be closely connected to increases in the use of road salts for winter de-icing.

In general, a major issue with chlorides is that they are not used up over time and so they can continue to concentrate in a lake over time, resulting in the lake becoming progressively more saline. This increased concentration can then eventually negatively affect plant growth and threaten aquatic organisms. Negative effects can be seen starting at concentrations around 250 mg/l, and are considered severe in excess of 1,000 mg/l. However, chloride does not affect all flora and fauna species. It has been found that Eurasian Water Milfoil, for example, is more tolerant of chlorides than native plants; magnifying the increase of invasive plants over natives. Keeping chloride concentrations in check can, therefore, prevent further issues associated with this invasive species. Wisconsin has two standards set in place as it relates to chlorides, including: 757 mg/l as the acute toxicity level for fish and 395 mg/l as the chronic toxicity for fish and other aquatic life.[30]

Though chloride pollution does not currently seem to be an issue in any of the Lakes located within the Village of Chenequa, according to measurements taken in Pine, Beaver and North lakes, chlorides should nonetheless be considered a pollutant of concern; particularly due to the amount of water supplied by groundwater (which can be subject to chloride pollution) and due to the amount of urban land use within the tributary area.

Fisheries

The Lakes in and around the Village of Chenequa have long been known to be good fishing lakes.[31] Beaver Lake was reported in 1963 by the Wisconsin Conservation Department to have a fishery comprised of northern pike, largemouth bass, yellow perch, and bluegill, with the WDNR reporting in 2005 that the game fishes were present while panfish were noted as being common. Cornell Lake was noted by the Wisconsin Conservation Department as having a limited fishery. Observing that the fishery was comprised primarily of panfish, the Wisconsin

[29]*An example of phosphorous reduction measures which neglect nitrogen pollution is the new Wisconsin law prohibiting phosphorous containing fertilizers for turf management. These fertilizers still have nitrogen and, therefore, still cause algae blooms and other issues in nitrogen limited lakes. This law, none the less, is very beneficial for most lakes in Wisconsin, due to the fact that most of them are phosphorous limited.*

[30]*SEWRPC Technical Report NO. 39,* Water Quality Conditions and Sources of Pollution in the Greater Milwaukee Watersheds*, November, 2011.*

[31]*Wisconsin Conservation Department,* Surface Water Resources of Waukesha County*, 1963; see also Wisconsin Department of Natural Resources Publication No. PUB-FH-800,* Wisconsin Lakes*, 2009.*

Conservation Department surmised that winter kill was most likely a common occurrence in this waterbody. The WDNR also reported panfish as common in this Lake but also reported that largemouth bass were present. North Lake and Pine Lake had the most diverse fisheries, with both Lakes being reported by the Wisconsin Conservation Department as having panfish, northern pike, walleye, largemouth bass, and cisco. Cisco were noted as providing a good ice-fishing opportunity in the two Lakes. By 2005, the WDNR reported that, in North Lake, northern pike, largemouth bass, smallmouth bass, and panfish were common, and walleye were present. In Pine Lake, the WDNR reported that largemouth and smallmouth bass were common, and northern pike, walleye, and panfish were present.

Aquatic Invasive Species

As discussed in Chapter 2 of this plan, all of the Lakes in the Village of Chenequa are reported to have established populations of Eurasian water milfoil,[32] a nonnative aquatic invasive plant species identified in Chapters NR 40, "Invasive Species Identification, Classification and Control," and NR 109, "Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations," of the *Wisconsin Administrative Code*. The first infestation was officially reported in Pine Lake in 1978. Curly leaf pondweed, another nonnative aquatic plant, is also recorded in all of the Lakes with the exception of Beaver Lake. This invasive plant was first recorded in 1976 through an aquatic plant survey conducted by SEWRPC.[33]

All of the Lakes, with the exception of Cornell, are also reported to have an established population of zebra mussels. These invasive animals were first reported in that North Lake in 2002 and were then officially confirmed in both Beaver and Pine Lake in 2005. These invasive shellfish, listed as nonnative invasive species pursuant to Chapter NR 40, have been reported to be present throughout the Oconomowoc River chain-of-lakes in Waukesha County, beginning in 1999.

The presence of these invasive, nonnative species invokes the need for recreational water users to take special and specific precautions when transporting watercraft and associated equipment from these Lakes to other Lakes in the State.[34] These precautions include emptying wet wells and bait buckets; removing visible plant growth from boats, motors, and trailers; and allowing decks and hulls to air dry for at least three-days prior to transporting a watercraft to another Lake. Alternatively, pressure washing decks and hulls with hot water can reduce the time required before transporting a watercraft to another Lake.[35] Appropriate signage describing these precautions has been posted at the various access points around the Lakes.

Recreational Uses

Beaver Lake, North Lake, and Pine Lake are extensively used for water-based recreation by both the resident community as well as their guests and visitors. Recreational access to these waterbodies is provided through public and private entry points. Of the four Lakes considered as being within and adjacent to the Village of Chenequa, Pine Lake alone currently has adequate public recreational boating access, as defined in Chapter NR 1, "Natural Resources Board Policies," of the *Wisconsin Administrative Code*. The public recreational boating access provided for Beaver Lake predates the adoption of Chapter NR 1 requirements, and provides carry-in access only. There is no boat ramp at the Beaver Lake access site. Lake access is also provided to Beaver Lake through the Beaver Lake Sailing Club, but is restricted to members of the Club. Public recreational boating access

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[32]*Wisconsin Department of Natural Resources Publication No. PUB-FH-800 2009,* op. cit.

[33]*SEWRPC Community Assistance Planning Report No. 54,* op. cit.

[34]*University of Wisconsin Sea Grant Institute,* Zebra Mussel Boater's Guide, *1992.* http://sgnis.org/publicat/wi-boat.htm.

[35]Ibid.

to North Lake have been negotiated and litigated by the WDNR, the North Lake Management District, and the Reddelien Road Neighborhood Association.[36] Access to Cornell Lake is restricted to access by the riparian property owners.

Recreational Boating Access

Beaver Lake and Pine Lake have significant populations of watercraft. Approximately 330 watercraft were documented as being docked, moored, or stored on and around Pine Lake at the time of the initial aquatic plant inventory in 1996.[37] By 2005, the numbers of watercraft has increased by 25 percent from 330 watercraft of all descriptions to about 440 watercraft.[38] Over 400 watercraft of all descriptions were observed on and around Beaver Lake during this latter period.[39] Motorized watercraft were the most numerous class of watercraft on both Lakes, although power boats were most numerous on Pine Lake and pontoon boats most numerous on Beaver Lake. About 2 percent of these watercraft were in operation during typical week days and weekend days.[40]

Chapter 4 of the *Village Ordinances* set forth specific regulations for Pine Lake, North Lake, and Beaver Lake, the latter two lakes being only partially encompassed within the jurisdiction of the Village of Chenequa. The regulations governing recreational boating on North Lake and Beaver Lake are jointly enacted with the Town of Merton and are enforceable by either municipality. While the lake ordinances primarily adopt the State of Wisconsin boating regulations, lake specific requirements governing the use of the lake surfaces for regattas, and related activities also are included in this Chapter. Slight differences do exist in these ordinance requirements. For example, water skiing on Pine Lake can be done between sunrise and sunset, while water skiing on Beaver and North Lakes can be done between 9:00 a.m. and sunset. Chapter 4 of the *Village Ordinances* is reproduced herein as Appendix C.

Additional regulations relating to Pine Lake, including the regulation of on-water, marine refueling services, are included in Chapter 4 of the *Village Ordinances*.

As noted above, the occurrence of persistent high lake level conditions as a result of the large floods experienced since 2007 have led to the adoption of Sections 4.09, “Emergency Slow No Wake Speed at Times of High Water on Pine Lake,” and 4.10, “Emergency Slow No Wake Speed at Times of High Water on Beaver Lake and North Lake,” of the *Village Ordinance*. These emergency regulations are intended to provide additional protection for shoreland areas during periods of high water on the three major Lakes.

Access to Ice-Bound Waters

Chapter 4 of the *Village Ordinances* set forth specific regulations relating to the operation of motorized vehicles on icebound waters, prohibiting the operation of such vehicles on North Lake, Pine Lake, and Cornell Lake. The prohibition on Cornell Lake and Pine Lake also includes the operation of snowmobiles on those waterbodies.

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[36] *See SEWRPC Memorandum Report No. 189,* Proposed North Lake Boat Launch Site Wetland Delineation, Waukesha County, Wisconsin, *July 2009.*

[37] *SEWRPC Memorandum Report No. 124,* op. cit.

[38] *SEWRPC Memorandum Report No. 173,* op. cit.

[39] Ibid.

[40] *See Tables 18 and 19, SEWRPC Memorandum Report No. 173,* op. cit.

CONCERNS RELATED TO CONFLICTING WATER USES

Ongoing urban density development in northwestern Waukesha County is contributing to increasing demands on the area's water resources, not only from the point of view of access to recreational and aesthetic opportunities but also from the point of view of water supply and sanitation.[41] The Village of Chenequa, like many of its neighboring communities, is served by onsite sewage disposal systems and private wells, although the City of Delafield has public sewerage and water supply available to its residents. The growth of the City in the vicinity of STH 16 has resulted in some concern within the Village of Chenequa regarding the possible impact of the City's public water supply well on the private wells in the Village. At the same time, this urban growth in the City of Delafield in proximity to the major Lakes located within and adjacent to the Village of Chenequa is likely to increase recreational use pressures on those waterbodies, especially through the public recreational boating access sites. In this regard, the likelihood of increasing numbers of recreational use conflicts within these waterbodies also is increasing.

Open Water Use Conflicts

The presence on the three major Lakes of yacht clubs—namely, the Beaver Lake Sailing Club, Pine Lake Yacht Club, and North Lake Yacht Club—which utilize the Lakes for regattas and other related events during the open water season has the potential to increase the numbers of surface water conflicts between motorized and nonmotorized watercraft. Currently, these conflicts appear to be minimal, with the holding of regattas being regulated by Village (and Town) permit requirements pursuant to Chapter 4 of the *Village Ordinances*.

In addition, the Lakes are periodically patrolled by the Village of Chenequa Police Department and WDNR wardens. The Village Police Department holds boating safety classes that are required for persons born after 1988 who wish to operate a motorized watercraft. During 2010,[42] there were two reportable boating incidents each involving two watercraft operating on Pine Lake, resulting in injuries to four persons. Both accidents occurred on July 8, 2010. No fatalities have been reported during the last three-year period, from 2008 through 2010.

Ice-Bound Water Use Conflicts

The operation of motorized vehicles on ice-bound waters in the Village of Chenequa is prohibited under Chapter 4 of the *Village Ordinances*. This prohibition extends to the operation of snowmobiles on Pine and Cornell Lakes which are wholly within the Village. No injuries or fatalities arising from the operation of motorized vehicles on ice-bound waters within the Village of Chenequa have been reported during the last three-year period, from 2008 through 2010.[43]

Water Supply and Sanitation

Properties within the Village of Chenequa rely on individual groundwater wells for their drinking water supply. Wastewater disposal is primarily through conventional onsite sewage disposal systems, although some mound systems and holding tanks are reported. As noted, residents of the Village have expressed some concerns regarding the continuing efficacy of these private water and sanitation facilities due to increasing water supply demands in the vicinity of STH 16 in the City of Delafield which has led to the installation of a high capacity well near the intersection of STH 16 and STH 83. Investigations by the USGS have suggested that there is minimal

[41]*See SEWRPC Planning Report No. 52*, op. cit.; see also *SEWRPC Community Assistance Planning Report No. 127*, op. cit., *and SEWRPC Community Assistance Planning Report No. 209*, op. cit.

[42]*Wisconsin Department of Natural Resources Publication No. PUB-LE-314-2010*, 2010 Wisconsin Boating Program Report, *2010.*

[43]*Wisconsin Department of Natural Resources Publication No. PUB-LE-203 2009,* Wisconsin Department of Natural Resources 2008-2009 Snowmobile Enforcement & Safety Report, *2009.*

cause for such concerns associated with the City of Delafield well.[44] However, should the well near the intersection of STH 16 and STH 83 be utilized at a greater capacity than is currently planned, there is some risk of groundwater that currently flows into Pine Lake being intercepted for withdrawal, with corresponding reductions in lake surface elevation being experienced.[45] The likely impact of continued pumping at the current rate will occur primarily in the Bark River. Based upon existing State and local government law governing groundwater withdrawal,[46] it is possible that the City could increase their rate of withdrawal, although this rate is governed by permit conditions and not technological constraints. The Village is continuing to monitor the situation using a series of monitoring wells located throughout the Village.

Public Health and Safety

Where related to water-based recreation, water supply, or sanitation, the primary concern of the Village of Chenequa is the maintenance and continued improvement of public health and safety within the Village boundary. To this end, the Village has enacted ordinances and undertaken specific studies to ensure the security of their water resources. These ordinances and their enforcement appear to adequately address public health and safety concerns related to recreational water uses, during both open water and ice bound water periods. Similarly, Village ordinances relating to waste management appear to adequately ensure the public health.

The Village of Chenequa also has enacted ordinances to protect the surface water in the Village through preservation of shoreland vegetation. Prior to the adoption Statewide of regulations limiting the application of fertilizers containing phosphorus, the Village of Chenequa had adopted and was enforcing regulations to this effect. Combined with effective wastewater management, these landscape practices have protected and maintained the very good water quality observed in the Village Lakes. Trends toward greater nutrient enrichment within the surface waters of Pine and Beaver Lakes, suggested in Figure 4 in Chapter II of this report, are unlikely to continue.[47] Indeed, available Lake water quality data suggest that water quality has improved since the 1970s, and forecasts set forth in Chapter II of this report indicate further water quality improvements can be anticipated. Similarly, the absence of frequent excessive algal blooms (defined as a chlorophyll-*a* concentration of greater than 10 µg/l) is consistent with the relatively low concentrations of total phosphorus observed. That said, however, the presence of measureable concentrations of blue-green algal phycotoxins, as noted above, remains an ongoing issue of concern. Continued monitoring and the issuance of periodic notices regarding preventative measures are warranted, at least for the immediate future.

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[44]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214*, op. cit.

[45]Ibid.

[46]*P.G. Kent and T.A. Dudiak*, op. cit.

[47]*SEWRPC Memorandum Report No. 173*, op. cit.

Chapter V

RESOURCE MANAGEMENT ALTERNATIVES FOR THE VILLAGE OF CHENEQUA

Chapter IV summarized concerns expressed by decision-makers, citizens, and staff of the Village of Chenequa regarding water quality in the major Lakes, groundwater quantity, and development-related issues leading to demands for utilization of water-resources, access to water-related recreation, and resolution of water-use conflicts. Resolution of these concerns is primarily a function of managing human activities on the land surface, managing human demands on the Village water resources, and protecting the ability of the underlying natural resource base to sustain those activities and demands. This chapter presents alternative approaches that could be considered for the resolution of the issues of concern, from which a recommended water resources management strategy and plan for the Village can be derived. This recommended plan will be set forth in the next chapter.

CONCERNS RELATED TO WATER RESOURCE USE

Water resources, consisting of surface waters in lakes and streams and in the associated wetlands and floodlands, and the groundwater aquifers underlying the Region, form important elements of the natural resource base of the Southeastern Wisconsin Region. The regional water supply plan notes that the contribution of these resources to the social and economic development of the Region, to recreational activities within the Region, to the ecology of the Region, and to the aesthetic quality of the Region is immeasurable.[1] The underlying groundwater aquifers constitute a major source of supply for domestic, municipal, and industrial water users in areas of the Region lying west of the subcontinental divide, as well as for some areas of the Region lying east of the subcontinental divide, primarily in Ozaukee and Washington Counties.

Understanding the interaction of the surface water and groundwater resources of the Region is essential to sound water supply system planning. The surface and groundwater of the Region are interrelated components of, in effect, a single hydrologic system. The groundwater resources of the Region are hydraulically connected to the surface water resources inasmuch as the former provide the base flow of streams, and affect the water levels of wetlands and inland lakes. Surface waters interact with groundwater in three basic ways: surface waters gain water from inflow of groundwater; surface waters lose water from outflow to groundwater; or surface waters both gain and lose water from and to groundwater, depending upon the relative locations of the surface water features and the groundwater table and other factors, such as precipitation patterns.

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[1]*SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin, Volume One of Two Volumes, *December 2010.*

Use of Surface Water Resources

A basic element of any water resources management effort is the promotion of sound land use development and management within the area tributary to surface waters and the recharge area of groundwaters. The types and locations of future urban and rural land uses in these areas tributary to Beaver Lake, Pine Lake, Cornell Lake, and North Lake will determine, to a large degree, the character, magnitude, and distribution of nonpoint sources of pollution; the practicality of, as well as the need for, stormwater management; and, to some degree, the water quality of the Lakes. Additionally, the use of water within this tributary area, and especially of groundwater resources underlying the drainage basin, will affect the hydrology and physical limnology of the Lakes, which form parts of the Oconomowoc River watershed.

Practically, potentially applicable tributary area management measures start at the lake shore and extend into the tributary areas surrounding each Lake. These same lands form part of the groundwater recharge area, within which Lakes appear as groundwater discharge points.

Development in the Shoreland Zone

Existing year 2010 and planned year 2035 land use patterns and existing zoning regulations in and around the Village of Chenequa have been described in Chapter II and III. The Waukesha County development plan indicates continuing urban development within the Village, generally on large suburban-density lots. If these recommendations, set forth in the adopted Waukesha County development plan and the regional land use plan,[2] are followed, it may be expected that, under year 2035 conditions, some additional urban residential development would occur within the Village. Much of this development is likely to occur on agricultural lands, and consist of the infilling of existing platted lots as well as some backlot development, redevelopment, and reconstruction of existing single-family homes. Land development or redevelopment proposals should be evaluated for potential impacts on the Lakes as such proposals are advanced.

Careful review of applicable zoning ordinances, to incorporate levels and patterns of development consistent with the adopted plans, as required pursuant to Chapters 4 and 6 of the *Village Ordinances*, should be considered. Consideration should be given to minimizing the areal extent of future residential development by developing specific provisions and incentives to encourage cluster residential development, or conservation development, on smaller lots while preserving, to the greatest extent practicable, the open space on each property or group of properties considered for development.[3]

Control of Water Quality

At the time of the current study, urban residential development located in the Village is served by onsite sewage disposal systems. As reported in Chapter II, because total phosphorus loadings from onsite sewage disposal systems are estimated to contribute only a minor proportion of the total phosphorus load to the Lakes, onsite sewage disposal is likely to remain the primary wastewater treatment method. It is, however, recommended that an onsite sewage disposal system management program continue to be carried out by the Village, including the ongoing conduct of an informational and educational effort to enhance awareness of the need for regular maintenance of these systems. Homeowners should be advised periodically of the rules, regulations, and system limitations governing onsite sewage disposal systems, and should be encouraged to undertake preventive maintenance programs.

Rural Nonpoint Source Controls

Upland erosion from rural lands is a major contributor of sediment to streams and lakes. Estimated phosphorus and sediment loadings from rural lands in the area tributary to the major Lakes were presented in Chapter II.

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[2]*SEWRPC Community Assistance Planning Report No. 209,* A Development Plan for Waukesha County, Wisconsin, *August 1996, as refined; see also, SEWRPC Planning Report No. 48*, op. cit..

[3]*See SEWRPC Planning Guide No. 7*, Rural Cluster Development Guide, *December 1996.*

These data were utilized in determining the pollutant load reduction that could be achieved, the types of practices needed, and the extent of the areas to which the practices need to be applied within the Village. While agricultural land uses are declining within the Village, agriculture is likely to continue to contribute a significant proportion of the sediment loads to the waterbodies, especially in the case of North Lake. To the extent necessary, detailed farm conservation plans should be developed to adapt and refine erosion control and nutrient and pest management practices for individual farm units. Generally these plans are prepared with the assistance of staff from the U.S. Natural Resources Conservation Service (NRCS) and/or county land and water conservation departments, and identify desirable tillage practices, cropping patterns, and rotation cycles. The plans also consider the specific topography, hydrology, and soil characteristics of the farm; identify the specific resources of the farm operator; and, articulate the operator objectives of the owners and managers of the land.

Urban Nonpoint Source Controls

As of 2010, established urban land uses, excluding internally drained areas, comprised about 698 acres, or about 23 percent, of the total area of the Village. The urban nonpoint source pollutant loads that are most controllable include runoff from the residential lands adjacent to the Lakes, and urban runoff from areas with a high proportion of impervious surface. Potentially applicable urban nonpoint source control measures include stormwater infiltration measures, such as rain gardens, biofiltration, and bioswales; wet detention basins; grassed swales; 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 educational 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 pesticides, improved pet waste and litter control, the substitution of plastic for galvanized steel and copper roofing materials and gutters, proper disposal of motor vehicle fluids, increased leaf collection, and continued use of reduced quantities of street deicing salt. As noted, the recent adoption by the State of Wisconsin of limitations on the use of phosphorus-based fertilizers on urban lands, which post-date Village Ordinance requirements, should continue to contribute significantly to minimizing the introduction of phosphorus to the aquatic environment. It is, however, also important to note that Pine lake requires some special management due to evidence of it being a nitrogen limited Lake, as discussed in Chapter II. Consequently, measures to reduce nitrogen pollution, primarily through reduction of fertilizer use and buffer enhancement, would be highly beneficial in this region.

Particular attention also should be given to reducing loadings from high pollutant loading areas, such as parking lots. To the extent practicable, parking lot stormwater runoff should be diverted to areas covered by pervious soils and appropriate vegetation, or to specially constructed facilities to infiltrate stormwater, rather than being directly discharged to surface waters.[4] Street and parking lot sweeping, increased catch basin cleaning, leaf litter and vegetation debris collection, and stormwater storage and infiltration measures can enhance the control of nonpoint-source pollutants from urban and urbanizing areas, and reduce urban nonpoint source pollution loads by up to about 50 percent. The proper design and application of such urban nonpoint source control measures is consistent with the Waukesha County stormwater ordinance provisions.

Shoreland Management

Recent studies of the potential impact of riparian landscaping activities on the nutrient loadings to lakes in southeastern Wisconsin have suggested that urban residential lands can contribute up to twice the mass of

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[4]*Infiltration of runoff from impervious surfaces where chlorides are applied to melt ice and snow may pose a threat to groundwater, since chlorides are generally in dissolved form and are not removed by stormwater infiltration devices. In such areas, snow and ice removal procedures should be followed that minimize application of chlorides, consistent with maintaining public safety.*

phosphorus to a lake when subjected to an active program of urban lawn care than similar lands managed in a more natural fashion.[5] While the State of Wisconsin has adopted new turf management regulations pursuant to 2009 *Wisconsin Act* 9, the application of other agrochemicals to such lands in excess of the plant requirements is likely to continue to result in enhanced contaminant loadings directly to the adjacent waterbodies. For this reason, maintenance and expansion of riparian buffers around watercourses within the Village, as well as the maintenance of canopy cover complements other land management measures,[6] such as implementation of community-level land use plans and zoning regulations, installation of stormwater management infrastructure, and introduction of measures for protecting, maintaining and expanding the integrity of riparian corridors.

Protection and Expansion of Buffered Regions

As discussed in Chapter II and III, buffers can play a significant role in reducing pollution loading. Consequently, forming partnerships with the Villages and Towns in which the upstream Oconomowoc River is located, for the purpose of protecting and further developing the existing buffers along the river is recommended. This will be particularly important as urban development continues upstream, potentially increasing phosphorous and heavy metal loads. Additionally, in the Beaver Lake watershed, it is highly recommended that connectivity of forested areas and canopy covered regions be made a priority. This will help expand the buffers in a way that will promote pollution reduction.

Protection of Ecologically Valuable Areas

Environmentally sensitive lands within the Village of Chenequa include wetlands, woodlands, and wildlife habitat areas. Nearly all of these areas are included within the environmental corridors and isolated natural resource features delineated by the Southeastern Wisconsin Regional Planning Commission (SEWRPC). Upland areas, woodlands, and wildlife habitat areas are currently protected primarily through local land use regulation, while wetlands enjoy a wider range of protections set forth in State and Federal laws.

Golf Course Management

Given the presence of the Chenequa Country Club, with 1,000 feet of waterfront on Beaver Lake, encouraging the Club to join the Audubon Cooperative Sanctuary Program for Golf Courses,[7] and obtaining the associated certification, would greatly enhance shoreland management in the Village. To participate in this program, a golf course must develop and implement an environmental management plan and document its results. The plan must include environmental management practices in five key areas; namely:

- Wildlife and habitat management: the golf course would seek to enhance existing natural habitats and utilize landscaping to promote wildlife and biodiversity conservation in a manner consistent with its location, size, and layout, as well as special wildlife species and habitat considerations.

- Chemical use reduction and safety: the golf course would implement best management practices (BMPs) at the maintenance facility and on the course to ensure that chemicals are stored, handled, applied, and disposed of safely. In addition, the maintenance staff would employ integrated pest management strategies to track and target specific pests and minimize chemical use.

- Water conservation: the golf course could employ conservation management strategies to maximize the efficient use of water, including maximizing irrigation efficiency; determining proper irrigation

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[5] *U.S. Geological Survey Water-Resources Investigations Report 02–4130,* Effects of Lawn Fertilizer on Nutrient Concentration in Runoff from Lakeshore Lawns, Lauderdale Lakes, Wisconsin*, July 2002.*

[6] *SEWRPC,* Managing the Water's Edge: Making Natural Connections*, May 2010.*

[7] *See* http://www.auduboninternational.org/acsp .

timing schedules; reducing irrigated acreage where possible; recapturing and re-using water; and incorporating native, drought-tolerant plant species.

- Water quality management: the golf course would implement best management practices to eliminate potential nutrient or pesticide contamination of water sources, as well as employing environmentally-sensitive management practices in ponds, streams, and wetlands; utilizing proper equipment and chemical storage and handling techniques; and, monitoring water quality to verify results. and

- Outreach and education: golf course personnel would build support for the environmental management program through a variety of communication, educational, and outreach activities.

A Resource Advisory Group, comprised of people who provide technical advice and volunteer assistance to help implement the environmental plan, would help to ensure the long-term success of environmental management practices, especially if staff assignments change. In the case of the Audubon Program, recertification is required every two years.

Stormwater Management

Waukesha County adopted a stormwater management ordinance in 2000. The Waukesha County ordinance reflects best practices for the determination of stormwater flows, mitigation of flooding potential, and the control of contaminants from the land surface. While the Village of Chenequa is not subject to the Waukesha County ordinance, it can serve as a resource to the Village for evaluating possible applicable stormwater management measures to help improve and maintain water quality in the Lakes in the Village. Periodic review of this ordinance and its provisions by the Village staff should be undertaken to facilitate control of urban nonpoint source contaminants that could potentially be delivered to the Lakes. Efficient use of stormwater management practices such as swales and infiltration features, protection of riparian buffers, and maintenance of wetlands and floodlands to store flood waters are effective management techniques that should be considered by the Village.

Because developing areas can generate significantly higher pollutant loadings, albeit for relatively short periods, consistent applications of construction site erosion control practices are important water quality control measures. Such controls include temporary measures that can be taken to reduce pollution loads from construction sites during stormwater runoff events. Effectively installed and adequately maintained construction erosion controls may be expected to reduce pollutant loadings from such sites by about 75 percent. While such controls may have only a minimal impact on the total pollutant loading to a Lake due to the relatively small land area being developed at any given time, such controls are important pollution control measures that can abate localized short-term loadings of phosphorus and sediment from the 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.

Use of Groundwater Resources

Some of the earliest inland groundwater supply systems within the Region included those for the Cities of Oconomowoc and Waukesha in Waukesha County (1900 and 1886, respectively). Innovations in well pumping technology and equipment also encouraged municipal system development throughout the Region. From the standpoint of groundwater occurrence, all rock formations that underlie the Region can be classified either as aquifers or as confining beds. An aquifer is a rock formation or sand and gravel unit that will yield water in a useable quantity to a well or spring. A confining bed, such as shale or siltstone, is a rock formation unit having relatively low permeability that restricts the movement of groundwater either into or out of adjacent aquifers and does not yield water in useable amounts to wells and springs.

The aquifers of southeastern Wisconsin extend to depths reaching in excess of 2,000 feet in the eastern parts of the Region. The aquifer systems in southeastern Wisconsin can be divided into two types: unconfined water table aquifers and semi-confined or confined deep aquifers. Water-table conditions generally prevail in the Quaternary deposits and Silurian dolomite, both of which comprise the shallow aquifer in areas where they lie above the

Maquoketa Formation that forms a relatively impermeable barrier between the overlying shallow and underlying deep aquifers in much of the Region. The western edge of the Maquoketa shale is located near, but generally east of the Village of Chenequa. West of the Maquoketa Formation, water-table conditions also generally prevail in the Galena-Platteville aquifer, which is located beneath the Quaternary deposits and Silurian dolomite. Thus, these three aquifers are interconnected west of the Maquoketa Formation, and are commonly referred to collectively as the "shallow aquifer" in that area." These shallow aquifers provide water for most private domestic wells and some municipal wells.

In the deep sandstone aquifer beneath the Maquoketa Formation, the water can be under artesian pressure. Deep high-capacity wells in the eastern and central part of the Region extract millions of gallons per day from the sandstone aquifer, creating a decline in water pressure within this aquifer that extends throughout most of the Region. Heavy pumping on the high-capacity wells has caused the gradual, steady decline in the artesian pressure and a reversal of the predevelopment, upward flow of groundwater. Flowing wells, still common within the Region in the late 1880s, ceased flowing at the beginning of the 1900s. The piezometric surface of the sandstone aquifer has been gradually declining and is now lower than the water table throughout most of the Region. On the average, water levels in deep observation wells have been declining at the rate of about five feet per year around the City of Waukesha since the beginning of record in the late 1940s.

Regulating Withdrawal

The effects of pumping are different for the shallow and deep aquifers underlying the Region. Pumping from the shallow aquifer generally causes little regional drawdown because local surface water features—streams, lakes, and wetlands—help to offset the withdrawal. Often the major effect of pumping from shallow wells is to reduce the amount of groundwater discharge to local surface water features. The current status of State authority to regulate high capacity wells is summarized in the "Protection of Groundwater Quantity" subsection in Chapter IV of this report. Both the City of Delafield and Village of Hartland have municipal high capacity wells. Delafield's well is developed in the deep sandstone aquifer and Hartland's wells are developed in the sand and gravel and the Galena-Platteville dolomite strata of the shallow aquifer.

While model-based studies of the groundwater system adjacent to and underlying the Village of Chenequa, conducted by the U.S. Geological Survey (USGS) as part of this planning program, indicated that withdrawals along the boundaries of the City of Delafield and Village of Hartland would most likely influence water flows in the Bark River rather than lake levels in the Village,[8] there is a need for coordinating pumping rates and high capacity well placement in the future to ensure that the private wells serving the Village of Chenequa and its environs remain productive. Large rainfall events in 2008[9] and 2010, and the occurrence of a wetter-than-normal period from the fall of 2007 through 2010, contributed to recharge of the groundwater aquifers that is likely to have minimized any impact of the recently-constructed municipal wells in the City of Delafield and Village of Hartland on the groundwater resources of the Village of Chenequa. However, groundwater quantity remains an issue of concern to Village of Chenequa residents and visitors.

Control of Groundwater Quality

The chemical composition of groundwater largely depends on the composition and physical properties of the soil and rock formations it has been in contact with, the residence time of the water, and the antecedent water quality.

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[8]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwestern Waukesha County, Wisconsin*, 2010.*

[9]*See J.F. Walker, and W.R. Krug,* Flood-frequency Characteristics of Wisconsin Streams*, U.S. Geological Survey Water-Resources Investigations Report 03–4250, 2003; F.A. Fitzpatrick, M. C. Peppler, J.F. Walker, W.J. Rose, R. J. Waschbusch, and J.L. Kennedy,* Flood of June 2008 in Southern Wisconsin*, Scientific Investigations Report No. 2008-5235, 2008.*

The chemical composition of groundwater in the Region is primarily a result of its movement through, and the interaction with, Pleistocene unconsolidated materials and Paleozoic rock formations. The latter contain large amounts of dolomite—$CaMg(CO_3)_2$—that is dissolved by water passing through the rock formations. In general, groundwater quality tends to be relatively uniform within a given aquifer, both spatially and temporally, but major differences in groundwater quality exist within the Region. The current quality of groundwater in both the shallow and deep aquifers underlying the Region is generally good and suitable for most uses.

The exceptions to this generality include the concentration of radium which exceeds drinking water standards in portions of the deep sandstone aquifer underlying the Region, and the concentration of arsenic exceeding drinking water standards in isolated areas generally in the sand and gravel aquifer. Some water quality problems are caused by natural factors, which cannot be controlled. For example, the abundant dolomite material underlying the Region releases calcium and magnesium, which form about one-half of all ions in groundwater and are the principal components of hardness, which is objectionably high in the groundwater underlying most of the Region, and softening is required for almost all uses of such groundwater.

In Wisconsin, nitrate-nitrogen is the most commonly found groundwater contaminant that exceeds the State drinking water standard of 10 milligrams per liter (mg/l). Nitrate can enter groundwater from many sources, including nitrogen-based fertilizers, animal waste storage facilities, feedlots, septic tanks, and municipal and industrial wastewater and sludge disposal sites. In samples collected from 4,857 wells in the Region during the period January 1, 1998 through December 31, 2006, nitrate-nitrogen was found to exceed the enforcement standard of 10 mg/l in only about 3 percent of wells and in excess of the preventive action limit of 2.0 mg/l in about 17 percent of wells.

Other contaminants include bacteria which can be introduced into wells from septic tanks, leaking sanitary sewer lines, feedlots, and manure pits and piles. The presence of coliform bacteria usually indicates an improperly constructed well or a well too shallow for local conditions, such as a well placed in thin soils or fractured bedrock. Coliform bacteria, on average, have been detected in 15 percent of the private wells in the Region, although there is a wide geographic and seasonal variability.

Protection of Groundwater Quantity

The regional water supply plan notes that, as of 2005, locally proposed water supply system modification and expansion plans existed for, among others, the City of Delafield and the Village of Hartland. Plans for the Delafield Municipal Water Utility system indicated that the Utility is proposing the construction of a new well to be located along Vettleson Road in the southwest quadrant of STH 83 and STH 16. The well is proposed to serve new development in the vicinity and would be connected with a transmission main to the Utility's water system at IH 94 and STH 83. The water from the new well would be blended with water from an existing Golf Road well which currently serves the IH 94 and STH 83 service area in order to meet the radium level maximum contaminant level requirements. The potential influence of the new well was modeled by the USGS as part of this planning program. The results of that modeling study indicated that the well would most likely influence water flows in the Bark River.[10]

Plans for the Hartland Municipal Water Utility system indicated that the Utility conducted a joint sewer and water study in 1993 in order to determine and evaluate the impacts of projected growth on both infrastructure systems. This study provided the basis for further planning and system evaluation, and a determination was made that an additional well was required to meet increasing demand, and that system improvements were required, including the addition of booster pumping facilities to enhance pressure in higher elevation areas. As recommended in the 1993 study, a third elevated storage tank was constructed in 1995. The 1993 study also recommended that future well planning should consider well placement in the shallow aquifer. However, because the shallow aquifer is more susceptible to contamination than the deep aquifer, the study recommended careful well siting and

[10]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214*, op. cit.

development of well head protection areas. One of the older Utility wells, constructed in 1973, was finished in the shallow sand and gravel aquifer and was found to be contaminated with trichloroethylene (TCE). This well was still active in 2006, and a stripping tower treatment facility was added to bring the TCE levels to below the level of detection. The Village of Hartland completed construction of Well No. 6 during 2006 with a capacity of about 1,000 gallons per minute. The Village of Hartland Water Utility provides water service to Arrowhead High School, and the Swallow Grade School in the Town of Merton north of the Village, and the Wee Know School and one residence in the Town of Delafield just west of the Village.

As previously noted, the surface and ground waters of the Region, in effect, are interrelated components of a single hydrologic system. The groundwater resources of the Region are hydraulically connected to the surface water resources inasmuch as the former provide the base flow of streams, and the water levels of wetlands and inland lakes. Surface waters interact with groundwater in three basic ways: surface waters gain water from inflow of groundwater; surface waters lose water from outflow to groundwater; or surface waters both gain and lose water from and to groundwater, depending upon the reaches and locations involved and other factors, such as precipitation patterns. Consequently, conjunctive management of these systems should be considered. However, such an integrated management approach would most likely involve a change in legislation at the State level. While the issue of regulating conjunctive use of surface and ground waters remains under debate, continued monitoring of groundwater levels within the boundary of the Village of Chenequa will provide important warning of any potential concerns.

CONCERNS RELATED TO RECREATIONAL USE

The intensive recreational use of the surface water resources of the Village of Chenequa has been documented. Recreational uses, both passive and active, will remain a significant use of the Village water resources for the foreseeable future. To this end, concerns remain regarding surface water quality and recreational access to the Lakes in and adjacent to the Village.

Water Quality

Water quality, as related to recreational water uses, commonly can be understood as being related to aquatic organisms, including plant life such as aquatic macrophytes and algae as well as fishes. Previous planning programs conducted on the water resources of the Village of Chenequa have focused on these aspects of water quality. In particular, the presence of aquatic invasive species in Beaver and Pine Lakes and North Lake have been identified in the aquatic plant management plan for Beaver and Pine Lake and in the comprehensive lake management plan for North Lake.[11]

Algal Blooms and Algal Toxicity

The recent occurrence of algal blooms in Southeastern Wisconsin has introduced the management of algal blooms as an issue of concern in the Region's lake-oriented communities. The Village of Chenequa is no exception. Data acquired by the Village has generally indicated that the levels of blue-green algal/cyanobacterial toxins in the water are below the action limits recommended by the World Health Organization. Nevertheless, it is possible that some degree of intervention in the composition, if not the cycle, of algal blooms may be possible. In those parts of the world where cyanobacterial toxicity has been a major concern,[12] the occurrence of such blooms has been coincident with high surface water temperatures and high concentrations of the plant nutrients, nitrogen and phosphorus. While it is not practicable to attempt to control weather, it is possible to manage the input of nutrients

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[11]*See SEWRPC Memorandum Report No. 173,* An Aquatic Plant Management Plan for Pine and Beaver Lake, Waukesha County, Wisconsin, *October 2008; and, SEWRPC Community Assistance Planning Report No. 54,* A Water Quality Management Plan for North Lake, Waukesha County, Wisconsin, *July 1982.*

[12]*See, for example, W. R. Harding and B. R. Paxton,* Cyanobacteria in South Africa: A Review, *Water Research Commission Report No. TT 153/01, July 2001.*

to the Lakes. The Village of Chenequa initiated this process during 2007, with the adoption of Section 3.12 of the *Village Ordinances*, which regulated the application of fertilizers to residential lands in the Village. In addition, Chapters 3, 4, and 6 of the *Village Ordinances* address the protecting shorelands, limiting the removal of trees and other vegetation, regulating the placement of onsite waste disposal facilities, and requiring erosion control practices when landowners are engaged in land distributing activities. All of these practices are positive steps toward minimizing the introduction of nutrients and other pollutants into the Lakes.

Chlorides

Given the increases in chloride pollution throughout the Southeastern Wisconsin Region, as discussed in Chapter IV, chlorides should likely be considered a priority in order to prevent following similar trends. These efforts could involve trying to reduce chloride pollution at its source; however, given the fact that chlorides have not risen above historical levels, periodic monitoring of chlorides in all of the Lakes would likely be the most efficient use of current efforts. If any increases in chloride levels are found, efforts such as brine mixture promotion, educational campaigns, and potentially ordinance referring to salt reductions, should then be made. These programs should seek to reduce chloride pollution in the groundwater recharge areas as well as the surface watershed areas for each lake.

Fisheries

Angling has been a major lake use since the early days of settlement in the vicinity of the current Village of Chenequa. Fishing remains a popular recreational pursuit both for Village residents and visitors. The three major Lakes—Beaver Lake, Pine Lake, and North Lake—are all known to be excellent sport fishing lakes, especially for bass and panfish. Consequently, the Wisconsin Department of Natural Resources (WDNR) should consider conducting periodic fishery surveys on these waterbodies with a view toward developing a stocking plan and/or lake specific creel limits to ensure continued quality angling experiences.

Aquatic Invasive Species

The Village of Chenequa has ensured that all of the public recreational boating access sites in the Village are appropriately posted with signage to remind lake users of the need to minimize the risks of transporting nonnative invasive species between lakes. That said, the presence of such species in the Lakes has been noted; consequently, the WDNR and the Village Police Department and Water Patrol should consider partnering to maintain the signage and enforce the requirements set forth in Chapters NR 40, “Invasive Species Identification, Classification and Control,” and NR 109, “Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations,” of the *Wisconsin Administrative Code*. This enforcement includes ensuring that boats, motors, and trailers are free of aquatic plant fragments, as well as reminding lake users of the requirement to empty wet wells, bait buckets, and other containers of unused bait and other organisms.

In addition, the Village has effectively enforced its shoreland regulations prohibiting the planting of invasive shoreland plants and requiring control of plants such as purple loosestrife on the Lake shores. Such programming is recommended to continue.

Annually including informational items in the Village newsletters and other communications with landowners in the Village forms a convenient and cost effective mechanism by which such information can be distributed. In addition, it is suggested that the Village lake committee consider an annual state-of-the-lake meeting at which such informational materials can be distributed, and new information provided to residents and other attendees. To this end, the Village staff may wish to utilize the services of the WDNR, SEWRPC, the University of Wisconsin-Extension (UWEX), and the Wisconsin Association of Lakes in developing a workshop and assembling relevant materials for distribution.

As noted in Chapter II and IV, there are no measures available which have proven successful at reducing zebra mussel populations. There are, however, many studies occurring on the topic; consequently, it is recommended that the Village remain informed on these different studies so that control of this species may be implemented once a successful technique is found.

Recreational Uses
A major element of lake-oriented recreation is related to the ability of users to access the waterbodies, both during open water periods and ice bound water periods.

Recreational Boating Access
In the case of Pine Lake, maintenance of the public recreational boating access site, in conformance with the requirements of Chapter NR 1, “Natural Resources Board Policies,” of the *Wisconsin Administrative Code*, is recommended. Similarly, maintenance of the Beaver Lake access also is recommended. In the case of the Beaver Lake access, consideration should be given to working with the community to bring this access site into conformation with Chapter NR 1 as it is currently written. The carry-in access provided by the Beaver Lake site predates the promulgation of the requirement for provision of boat-trailer unit access in lakes with a surface area equal to that of Beaver Lake. Provision of access to North Lake is currently being pursued by the WDNR, and is intended to be in conformance with the Chapter NR 1 standards. Given the small surface area of Cornell Lake and since the entire shoreline is in private ownership, provision of public recreational boating access to that Lake other than through the stream connections of this waterbody with North Lake and Pine Lake appears to be impractical at present. In any event, use of the surface waters of Cornell Lake should be limited to nonpowered watercraft operating at slow-no-wake speeds.

Access to Ice-Bound Waters
While the public recreational boating access sites often provide a mechanism for ice-bound water access, Chapter 4 of the *Village Ordinances* prohibit the operation of motorized vehicles on North Lake, and Pine Lake and Cornell Lake. The prohibition on Cornell Lake and Pine Lake also includes the operation of snowmobiles on those waterbodies.

CONCERNS RELATED TO CONFLICTING WATER USES

Water use conflicts within the Village of Chenequa are relatively few. The Village of Chenequa Police Department regularly monitors the public recreational boating access sites on those lakes within the Village having such access (Pine and Beaver Lakes), while the boat patrol operates periodically throughout the open water season. The major concerns identified by the Village staff related to water supply and sanitation, and to public health and safety, the latter principally in connection with the occurrence of blue-green algal/cyanobacterial blooms in the Lakes.

Open Water Use Conflicts
The Village of Chenequa Police Department operates a seasonal water patrol on Beaver Lake—in concert with the Town of Merton—and Pine Lake. This patrol regularly issues warning and citations, albeit in small numbers, indicating that the lake users tend to be law abiding. The Village of Chenequa Police Department also facilitates the conduct of boater safety programs by the WDNR in the Village. This programming is likely to be a major factor in ensuring safe boating experiences on the Village Lakes.

It is suggested that the Village consider holding a complimentary boat inspection during the spring in order to provide lake users with updates on regulations, ensure boaters are appropriately equipped, and answer any questions which lake users may have. This inspection could coincide with UWEX programming under the Clean Boats, Clean Waters awareness program, as well as other awareness activities.

Ice-Bound Water Use Conflicts
The Village of Chenequa Police Department operates a seasonal patrol on the Lakes in order to ensure that the Village ordinance requirements are being met, including enforcement of the prohibition of motorized vehicles of the ice. Continuation of this patrol and of the posting of notices regarding ice thickness on the Village website represents sound practice.

Water Supply and Sanitation
Continuity of water supply and provision of safe water supplies in view of increasing water demands is a concern facing the Village. At this time, there are no recommendations for creating either a public water utility or a public wastewater treatment facility to serve the Village. However, actions by neighboring municipalities have the potential to affect private wells within the Village. This is especially the case with regard to the location of high capacity wells serving the City of Delafield and Village of Hartland in proximity to the Village of Chenequa boundary. While the studies conducted by the USGS in concert with this planning program have suggested minimal concerns under current conditions, the monitoring of groundwater elevations should be continued, especially following the high rates of groundwater recharge experienced in Southeastern Wisconsin since 2007.[13]

Additionally, periodic inspection of onsite wastewater treatment facilities as required by Chapter SPS383, "Private Onsite Wastewater Treatment Systems," of the *Wisconsin Administrative Code* should be considered. Periodic analysis of well water for evidence of fecal contamination should also be considered. Placement of high capacity wells may alter the flow patterns within the aquifers being utilized for both water supply and wastewater treatment. Hence, periodic testing for bacterial contamination would be warranted.

Public Health and Safety
Ongoing enforcement of the *Village Ordinances* is intended to address the most commonly occurring threats to public health and safety, whether related to traffic—in the sense of both open water boating and ice-bound water operations, building codes—including water supply and sanitation, or other water-related activities.

SUMMARY

This chapter has described options that could be employed in managing the types of concerns faced by the surface water and groundwater resources of the Village of Chenequa, and which could, singly or in combination, assist in achieving and maintaining the water quality and water quantity use objectives established for these waters. An evaluation of the potential management measures for managing the surface water and groundwater resources was carried out on the basis of the effectiveness, relative cost, and technical feasibility of the measures. Those alternative measures considered further at this time, include:

Surface Water: Land-Based Alternative Actions

1. Ongoing management of land development in the areas tributary to the four study area lakes, and particularly in the shoreland zone, including consideration of clustered residential development;

2. Ongoing protection of environmental corridors and isolated natural resource features;

3. Continued enforcement of lake front setbacks and wetland protective areas;

4. Maintenance and expansion of existing shoreland buffers, including control of invasive plants and a continued prohibition on planting of invasive plants in shoreland areas;

5. Consideration by the Chenequa Country Club of enrolling in the Audubon Cooperative Sanctuary Program for Golf Course or equivalent program;

Surface Water: Water Quality-Based Alternative Actions

6. Enforcement of construction site erosion control requirements;

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[13]*See F.A. Fitzpatrick, M. C. Peppler, J.F. Walker, W.J. Rose, R. J. Waschbusch, and J.L. Kennedy,* op. cit.

7. Continued enforcement of the Village ordinance regulating the application of fertilizers to residential lands, as well as consider nitrogen reduction measures in the Pine Lake watershed;

8. Preparation and implementation of farm nutrient and pest management plans as appropriate;

9. Continued water quality monitoring with periodic monitoring for chloride level increases and for algal toxicity during periods in which algal blooms occur;

10. Continue Village policy of only applying road salt on hills and at intersections.

Surface Water: In-Lake Fishery and Nonnative Species Alternative Actions

11. Conduct of periodic fisheries surveys by the WDNR and development by WDNR of stocking plans and/or lake-specific creel limits;

12. Conduct of ongoing awareness programming related to the movement and occurrence of nonnative species;

Surface Water: Lake Use Alternative Actions

13. Maintenance of public recreational boating access sites and consideration of provision of additional sites in conformance with the current public access standards set forth in Chapter NR 1 of the *Wisconsin Administrative Code*, and

14. Continued enforcement of Village ordinances and State laws governing water use during both open water and ice-bound water periods to minimize use conflicts and protect public health, safety, welfare, and convenience.

Groundwater-Related Alternative Actions

15. Continuing management and inspection of onsite sewage disposal systems;

16. Conjunctive management of groundwater and surface water resources;

17. Introduction of periodic monitoring of domestic water supply well [bacterial] quality;

18. Continued monitoring of groundwater levels.

The preceding measures are considered viable options for incorporation into the recommended water resources management plan for the Village of Chenequa described in Chapter VI.

Chapter VI

A RECOMMENDED WATER RESOURCES MANAGEMENT PLAN FOR THE VILLAGE OF CHENEQUA

Chapter IV summarized the water resources issues of concerns expressed by decision-makers, citizens, and staff of the Village of Chenequa. These issues included concerns over water quality in the major Lakes, groundwater quantity, and development-related issues related to the utilization of water-resources, access to water-related recreational opportunities, and resolution of water-use conflicts. Chapter V presented alternative approaches that could be considered for the resolution of the issues of concern. These alternatives form the foundation of the recommended water resources management strategy and plan set forth in this Chapter.[1]

Many of the actions set forth herein represent a continuation of actions already being taken by the Village of Chenequa and its residents and visitors. Other elements recommended for consideration represent an extension or expansion of current levels of effort being invested by the Village and its staff in water resources management. All of the actions recommended generally provide benefit in terms of the management of both surface and ground water resources within and adjacent to the Village. Some actions are recommended for consideration by State agencies and local organizations. These latter actions generally represent new or innovative responses required for the conjunctive use management of the combined surface and ground water resources of the Village. Collectively, the recommended measures are designed to protect and preserve the water resources in and around the Village of Chenequa for the foreseeable future, while continuing to ensure adequate and appropriate access to surface and ground water resources by Village residents and landowners.

MANAGEMENT OF SURFACE WATER RESOURCES

As noted elsewhere in this report, the Village of Chenequa Ordinances currently include many measures designed to protect and preserve the surface waters of the Village and its neighbors. These measures are included herein as ongoing or continuing actions recommended for the management of the surface water resources of the Village into the future. Such measures include the provisions of the Village of Chenequa zoning code and land development ordinances.[2]

Specifically recommended actions for the protection of surface water are:

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[1]*Recommendations are indicated by bold text.*

[2]*See Village of Chenequa*, Village of Chenequa Code, *2011*.

Surface Water: Land-Based Recommendations

1. **Ongoing management of land development in the areas tributary to the four study area lakes, and particularly in the shoreland zone, including consideration of clustered residential development;** this includes the continued enforcement of efforts to maintain canopy cover throughout the Village of Chenequa.

2. **Ongoing protection of environmental corridors and isolated natural resource features throughout the watershed;** these efforts should specifically focus on those areas which coincide with buffered regions, and woodlands areas located in upland regions.

3. **Continued enforcement of lake front setbacks and wetland protective areas;** these efforts should be focused specifically on the wetland complexes which connect the four Lakes as well as the upstream Oconomowoc River. This can be done partnerships formed with the Towns and Villages in which the upstream Oconomowoc watershed is located, including the Towns of Erin, Merton, and Polk, and the Village of Richfield.

4. **Maintenance and expansion of existing shoreland buffers, including control of invasive plants and a continued prohibition on planting of invasive plants in shoreland areas;** these efforts should focus on Beaver Lake watershed to begin with in order to ensure that the Lake's surrounding residential regions are not contributing pollution. Additionally, wetland areas should be considered highest priority for the control of wetland invasive plants as these areas require naturally occurring wetland plants to perform their pollution reduction role.

5. **Consideration by the Chenequa Country Club of enrolling in the Audubon Cooperative Sanctuary Program for Golf Course or equivalent program.** The location of the Country Club on the shores of Beaver Lake make it ideally placed not only to review and refine their operational procedures in a manner that benefits the entire community but also to serve as a demonstration project to encourage other landowners to adopt similar environmentally-friendly and sustainable land management practices.

Surface Water: Water Quality-Based Recommendations

6. **Enforcement of construction site erosion control requirements.** While construction site erosion controls are in place for limited durations, they have the potential to introduce contaminants to the waterways that can have long lasting consequences. For example, sediment laden runoff has historically led to the deposition of excessive volumes of sediment and associated nutrients and other pollutants in the Region's waterways.

7. **Continued enforcement of the Village ordinance regulating the application of fertilizers to residential lands;** A particular focus should be placed on Beaver Lake's residential areas due to the absence of buffered regions, however, this should be well enforced throughout the watershed.

8. **Consideration of nitrogen fertilizer control measures, as well as buffer maintenance in the Pine Lake watershed**; this may help reduce the amount of algal blooms which occur in this historically nitrogen limited Lake.

9. **Preparation and implementation of farm nutrient and pest management plans as appropriate,** Assistance in the preparation of such plans is available from the U.S. Department of Agriculture (USDA) through the Natural Resources Conservation Service (NRCS) and from county land conservation departments. These efforts will largely need to target the upstream Oconomowoc watershed; however, some efforts in the southeastern portion of Pine Lake may also be beneficial.

10. **Continued monitoring of in-lake water quality, pursuant to the protocols set forth under the University of Wisconsin-Extension (UWEX) Citizen Lake Monitoring Network (CLMN) to provide an ongoing assessment of water quality in Pine, and North Lakes. An expanded monitoring program should begin in Beaver Lake and Cornell Lake.** These efforts should include the Secchi Disk, phosphorous, and chlorophyll-a monitoring, as well as periodic chloride monitoring. Additionally, periodic monitoring of nitrogen components in Pine Lake is also recommended.

    Periodic monitoring for algal toxicity (during periods in which algal blooms occur). Algal toxicity should be monitored in all of the Lakes with a particular emphasis on Beaver Lake due to previous detection of toxicity.

11. **Continue Village policy of only applying road salt on hills and at intersections, while providing an appropriate level of public safety.** These efforts should focus on the Beaver Lake watershed as well as the upstream Oconomowoc watershed, as these contain major highway crossings.

Surface Water: In-Lake Fishery and Nonnative Species Recommendations

12. **Conduct of periodic fisheries surveys by the WDNR and development, by WDNR, of stocking plans and/or lake-specific creel limits;** these efforts should focus on Beaver, Pine, and North Lake.

13. **Conduct of ongoing awareness programming related to the movement and occurrence of nonnative species through placement of signage at the access sites and distribution of awareness materials through the Village newsletter.** These efforts will be focused on Beaver and Pine Lake given that they are the only two Lakes with public access sites available.

Surface Water: Lake Use Recommendations

14. **Maintenance of public recreational boating access sites and consideration of provision of additional sites in conformance with the current public access standards set forth in Chapter NR 1, "Natural Resources Board Policies," of the *Wisconsin Administrative Code.* With regard to the provision of adequate public recreational boating access, the use of private provider agreements, pursuant to Section NR 1.91(6) of the *Wisconsin Administrative Code* should be explored by the Village, WDNR, and community organizations such as the Beaver Lake Sailing Club, Pine Lake Yacht Club, North Lake Yacht Club, and Chenequa Country Club, in an effort to bring all of the surface water into conformance with the requirements of Chapter NR 1.**

15. **Continued enforcement of Village ordinances and State laws governing water use during both open water and ice-bound water periods to minimize use conflicts and protect public health, safety, welfare, and convenience.**

MANAGEMENT OF GROUNDWATER RESOURCES

Many of the actions recommended for the protection of surface water resource quality also can serve for the protection and preservation of groundwater resources. To this end, the previously-stated recommendations directed toward surface waters which call for ongoing management of land development in the shoreland zone, preparation and implementation of farm nutrient and pest management plans, continuing management of onsite sewage disposal systems, enforcement of the Village ordinance limiting the applications of fertilizers on residential properties, and continuation of the Village policy to limit application of salt to roadways, also address issues associated with the quality of water infiltrating to the groundwater aquifers. One positive example of the surface water/groundwater nexus is promoting infiltration of runoff to recharge groundwater through appropriate land management and impervious surface density and through ongoing protection of environmental corridors and isolated natural resource features, shoreland wetlands, and floodlands.

Groundwater-Related Recommendations

Specifically recommended actions for the protection of groundwater are:

1. **Continuing management and inspection (at two- to three-year intervals) of onsite sewage disposal systems;**

2. **Conjunctive management of groundwater and surface water resources (the following report subsection elaborates on this recommendation);**

3. **Introduction of periodic monitoring of domestic water supply wells for [bacterial] water quality and other potential Lake pollutants such as phosphorous and chlorides;**

4. **Continued monitoring of groundwater levels.**

5. **General protection of groundwater recharge areas**

Given the ongoing urban density development occurring in the vicinity of the Village of Chenequa, the introduction of periodic monitoring of domestic water supply wells for bacteria, the continuation of monitoring of groundwater levels, and regular maintenance and inspection of onsite sewage disposal systems are recommended to guard against groundwater contamination. Unlike surface water resources, actions on the land surface that adversely affect the availability and quality of groundwater resources are not visible. While the modeling study conducted by the U.S. Geological Survey (USGS) has suggested that there are no immediate threats to groundwater within the Village of Chenequa,[3] the lack of visibility means that threats to the public health, safety, and welfare may not readily manifest in a meaningful way. Also, any such changes could be relatively subtle, as in a case where there is sufficient abstraction at a point on the landscape that groundwater is drawn from a wider area than was historically the case. By altering the subsurface flow pattern, septage could potentially seep into a well. Hence, periodic monitoring of drinking well water quality could provide timely evidence of changes in groundwater flows and/or functioning of onsite sewage disposal systems.

Conjunctive Use and Management of Surface Water and Groundwater Resources In and Around the Village of Chenequa

Chapter V of this report reinforced the fact that surface and ground waters are interrelated components of a single hydrologic system. With few exceptions, current State laws do not reflect this intimate connection between surface and ground water resources. Indeed, in most cases, these conjoined water resources are treated as separate bodies of water having extremely limited interaction. While the USGS groundwater modeling conducted under this planning study suggest limited impacts of surrounding high capacity wells on the water resources of the Village of Chenequa,[4] this assessment is based on current conditions, well capacities, and pumping demands. While current forecasts suggest that these demands may not change substantially in the near future,[5] it is not impossible that a scenario could develop in the future wherein levels of abstraction do exceed volumes such that there are impacts to the surface water resources of the Village. Under current land use planning recommendations,[6] this increased demand would most likely arise in the incorporated municipalities surrounding

[3]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214,* Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwestern Waukesha County, Wisconsin*, 2010; see also SEWRPC Planning Report No. 52,* A Regional Water Supply Plan for Southeastern Wisconsin, Volume One of Two Volumes*, December 2010.*

[4]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214*, op. cit.

[5]*SEWRPC Planning Report No. 52*, op. cit.

[6]*SEWRPC Community Assistance Planning Report No. 209,* A Development Plan for Waukesha County, Wisconsin*, August 1996, as refined.*

the Village of Chenequa that utilize public water supply and sanitation systems.[7] Such conflicts have occurred elsewhere within the Region, as documented in the case involving the Lake Beulah Management District, Town of East Troy, and Village of East Troy (summarized in Chapter IV of this report).

The SEWRPC 2010 regional water supply plan[8] recommends that studies related to the siting of all new high-capacity wells (such as municipal water supply wells) include analyses of potential impacts of such wells on the shallow aquifer, existing wells, and surface waters. Subsequent monitoring of the actual impacts after wells are constructed is also recommended. The siting studies should be designed to develop the necessary understanding of the hydrogeological system associated with each candidate site and to assess the likelihood of impacts of proposed wells upon nearby existing wells and surface waterbodies. The studies should include identification of significant potential negative impacts, needed mitigative actions, or site location revisions. Water levels in the vicinity of new high-capacity wells in the shallow aquifer should be monitored before and after wells are constructed and placed into operation to establish a baseline including levels expected to be maintained in private wells and to develop performance and impact data during the test well phase of well development and during the subsequent operation of the well over time.

The regional water supply plan also recommends that, while it is recognized that siting wells in the shallow aquifer is dependent upon locating productive areas, some additional factors should be considered when siting wells constructed in this aquifer. Preference should be given to site locations that are less likely to produce adverse impacts upon surface waterbodies and existing wells. In addition, preference should be given to sites adjacent to major rivers receiving treated effluent from municipal wastewater treatment plants downstream from their treatment plants. Such application of riverbank filtration has the potential to increase available water supplies without degrading the environment.

The regional water supply plan recommends that measures be taken to enhance rainfall infiltration, particularly in areas where evaluations conducted in conjunction with the siting of high-capacity wells in the shallow aquifer indicate probable reductions in baseflow on nearby streams and in water levels in lakes and wetlands due to installation and operation of these wells. Two means of achieving the desired enhancement are envisioned. One involves the construction of rainfall infiltration systems in areas where adverse impacts of new wells on surface water features may be anticipated. Locating these systems will require site-specific analyses to ensure that the systems are located in the recharge areas of the waterbodies expected to be impacted and in areas well suited for shallow groundwater recharge. The specific measures comprising the systems must be selected and designed on a case-by- case, site-specific basis. The systems include measures such as rain gardens, larger bioretention basins, infiltration ponds, infiltration ditches, and subsurface storage and infiltration galleries. The second means of providing for additional groundwater recharge is through applications of farming practices that reduce or eliminate tillage of fields. This means has potential to be applied on an areawide basis, as well as in areas potentially affected by high capacity wells.

Information on the available artificial recharge methodologies is presented in SEWRPC Technical Report No. 43[9] It is envisioned that there would be a total of 32 of these rainfall infiltration systems installed within the Region under the recommended regional water supply plan. That plan calls for considering development a groundwater monitoring program in conjunction with each of the rainfall infiltration systems. The monitoring program would be based upon site-specific considerations, such as size of the system, relationship to wells, and tributary land uses. The general locations of the rainfall infiltrations systems that are envisioned under recommended plan

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[7]*SEWRPC Planning Report No. 52,* op. cit.*; SEWRPC Memorandum Report No. 93,* A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report*, March 1995.*

[8]*SEWRPC Planning Report No. 52,* op. cit.

[9]*SEWRPC Technical Report No. 43,* State-of-the-Art of Water Supply Practices*, July 2007.*

conditions are shown in the regional water supply plan report. Based on plan recommendations for providing sustainable public and private water supplies under planned year 2035 conditions, the regional water supply recommends that several municipal high-capacity wells be installed in the vicinity of the Village of Chenequa, and the regional groundwater model indicates that baseflow depletion of 10 percent to more than 25 percent could occur in the vicinity of the southern part of Pine Lake, but the plan does not indicate that shallow aquifer groundwater recharge facilities would be needed to offset the effects of high-capacity municipal water supply wells in the vicinity of the Village. However, **if new high-capacity wells are proposed, the Village would have the option of commissioning a groundwater modeling study of the area to assist in ascertaining the potential impacts of such wells**. The groundwater model prepared by the USGS for the regional water supply plan and the groundwater model developed by USGS for their northwestern Waukesha County study[10] would provide suitable frameworks in which to develop a more-detailed “inset” model to evaluate impacts of wells in the immediate vicinity of the Village and its surface and ground water resources.

Beaver Lake, Pine Lake, and Cornell Lake, all of which are tributary to the Oconomowoc River, and North Lake, which is located on the Oconomowoc River, are valuable elements of the natural resource base both in the Village of Chenequa and Southeastern Wisconsin. These surface water resources provide an abundance of natural vistas, good quality wildlife habitat, and opportunities for recreational activities that provide for an enriched quality of life.[11] Increases in population, urbanization, income, leisure time, and individual mobility forecast for the Region in general, and northwestern Waukesha County more specifically, may be expected to result in additional pressure for development in the area, for water-based recreation on the Lakes, and for water supply and sanitation based upon the area’s abundant groundwater resources. Adoption and administration of an effective water resources management program for the Village of Chenequa and its environs, based upon the recommendations set forth herein, will provide the protection of both the water quality and water quantity needed to maintain conditions suitable for human use, a range of recreational uses, and the survival of fishes and other aquatic life.

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[10]*U.S. Geological Survey Scientific Investigations Report No. 2010-5214*, op. cit.

[11]*SEWRPC Planning Report No. 42,* A Regional Natural Areas and Critical Species Habitat Protection and Management Plan for Southeastern Wisconsin, *September 1997, as amended.*

APPENDICES

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Appendix A

U.S. GEOLOGICAL SURVEY
SCIENTIFIC INVESTIGATIONS REPORT 2010-5214

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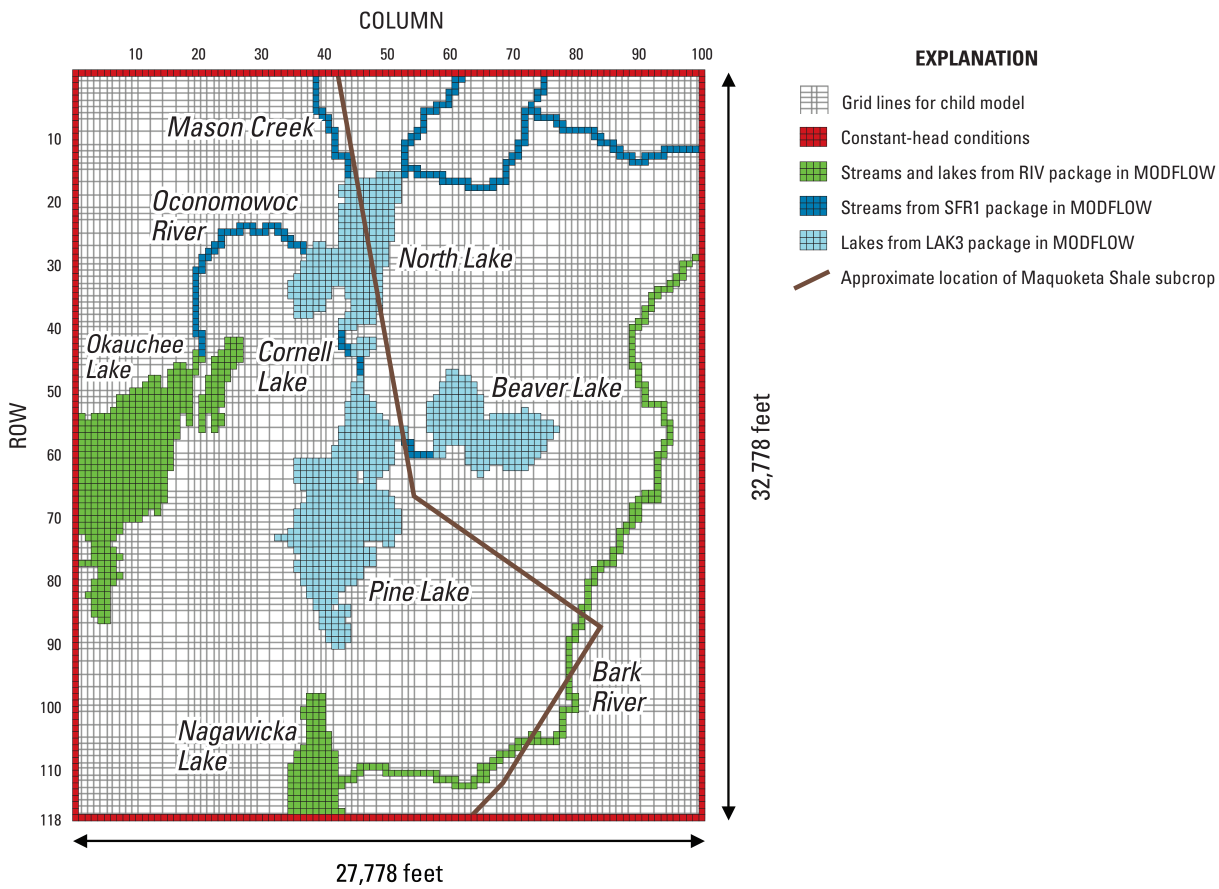
Prepared in cooperation with the Village of Chenequa, the Southeastern Wisconsin Regional Planning Commission and the Wisconsin Department of Natural Resources

Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwestern Waukesha County, Wisconsin



Scientific Investigations Report 2010–5214

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The preparation of the report depended on timely contributions from USGS colleagues Michelle Greenwood, Reports Specialist; Leah Leonard, Science Support; Michael Eberle, Technical Publications Editor, and Rosemary Stenback, Illustrator.

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Conversion Factors and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Flow, precipitation, evaporation, and recharge rates	
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Transmissivity	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Vertical coordinate information is referenced to the insert National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) and the Albers projection.

Application of the Local Grid Refinement Package to an Inset Model Simulating the Interaction of Lakes, Wells, and Shallow Groundwater, Northwestern Waukesha County, Wisconsin

By D.T. Feinstein, C.P. Dunning, P.F. Juckem, and R.J. Hunt

Abstract

Groundwater use from shallow, high-capacity wells is expected to increase across southeastern Wisconsin in the next decade (2010–2020), owing to residential and business growth and the need for shallow water to be blended with deeper water of lesser quality, containing, for example, excessive levels of radium. However, this increased pumping has the potential to affect surface-water features. A previously developed regional groundwater-flow model for southeastern Wisconsin was used as the starting point for a new model to characterize the hydrology of part of northwestern Waukesha County, with a particular focus on the relation between the shallow aquifer and several area lakes. An inset MODFLOW model was embedded in an updated version of the original regional model. Modifications made within the inset model domain include finer grid resolution; representation of Beaver, Pine, and North Lakes by use of the LAK3 package in MODFLOW; and representation of selected stream reaches with the SFR package. Additionally, the inset model is actively linked to the regional model by use of the recently released Local Grid Refinement package for MODFLOW–2005, which allows changes at the regional scale to propagate to the local scale and vice versa.

The calibrated inset model was used to simulate the hydrologic system in the Chenequa area under various weather and pumping conditions. The simulated model results for base conditions show that groundwater is the largest inflow component for Beaver Lake (equal to 59 percent of total inflow). For Pine and North Lakes, it is still an important component (equal, respectively, to 16 and 5 percent of total inflow), but for both lakes it is less than the contribution from precipitation and surface water. Severe drought conditions (simulated in a rough way by reducing both precipitation and recharge rates for 5 years to two-thirds of base values) cause correspondingly severe reductions in lake stage and flows. The addition of a test well south of Chenequa at a pumping rate of 47 gal/min from a horizon approximately 200 feet below land surface has little effect on lake stages or flows even after 5 years of pumping. In these scenarios, the stage and the surface-water outflow from Pine Lake are simulated to decrease by only 0.03 feet and 3 percent, respectively, relative to base conditions. Likely explanations for these limited effects are the modest pumping rate simulated, the depth of the test well, and the large transmissivity of the unconsolidated aquifer, which allows the well to draw water from upstream along the bedrock valley and to capture inflow from the Bark River. However, if the pumping rate of the test well is assumed to increase to 200 gal/min, the decrease in simulated Pine Lake outflow is appreciably larger, dropping by 14 percent relative to base-flow conditions.

Introduction

Shallow high-capacity wells will likely continue to be drilled across southeastern Wisconsin in the next decade (2010–20) for numerous purposes, including new water supplies for residential and business growth and blending of shallow water with deeper water of lesser quality—for example, water with excessive concentrations of radium—in order to improve overall quality of the drinking-water supply. Pumping wells, particularly where they intercept substantial groundwater flow to surface water, have the potential to affect lake levels; the groundwater inflow to wetlands, creeks, and rivers; and water temperature. The effect of pumping can be pronounced because in many hydrogeologic settings, and particularly in much of southeastern Wisconsin, groundwater is in direct hydraulic connection with lakes, wetlands, and streams. Quantifying hydrologic changes resulting from groundwater pumping and assessing the effect on hydrologic and biologic resources is a challenge faced by many communities and lake organizations across southeastern Wisconsin.

The U.S. Geological Survey and cooperating organizations, such as the Wisconsin Geological and Natural History Survey (WGNHS) and the Southeastern Wisconsin Regional Planning Commission (SEWRPC), have previously worked together to develop a regional understanding of the hydrology of southeastern Wisconsin. This work has taken the form of geologic mapping, groundwater-flow modeling, quantifying and predicting demand on surface and groundwater resources, and field investigations. A southeastern Wisconsin regional groundwater-flow model was developed as part of this work to serve as a framework for hydrologic studies addressing a wide range of water-supply concerns. In a recent extension of this longstanding research, the USGS joined with the Southeastern Wisconsin Regional Planning Commission and the Village of Chenequa in work funded by the Wisconsin Department of Natural Resources under the Chapter NR 190 Lake Management Planning Grant Program, to characterize the hydrology of part of northwestern Waukesha County (fig. 1), with a particular focus on the relation between the shallow aquifer and area lakes. The specific objectives of this study were to

1. improve the overall understanding of the dynamics of the shallow aquifer in northwestern Waukesha County near Chenequa;
2. evaluate the role of groundwater on maintaining lake levels in northwestern Waukesha County by using Beaver, Cornell, North, and Pine Lakes as examples;
3. develop hydrologic budgets for the area; and
4. develop databases and a refined groundwater-flow model that may have future benefit to researchers and water-resource professionals in the northwestern Waukesha County area.

The steps undertaken to achieve the objectives were

- compilation of existing hydrologic data;
- limited collection of surface-water-flow data to support model development and calibration;
- development of an inset MODFLOW model originating from the regional groundwater-flow model and implementing the recently released Local Grid Refinement package for MODFLOW-2005 (Mehl and Hill, 2005);
- calibration of the inset model to available head and flow targets;
- analysis of the results of the base-case simulation, focusing on the water budgets of the Chenequa-area lakes; and
- simulation of selected scenarios involving changes in climatic conditions and local pumping rates.

The complexity of the inset model increased compared to that of the existing regional model but was commensurate with the extent of the dataset in the local area. Changes to model layering and zonation of hydrologic parameter values were based on interpretation of available data.

This report presents the findings from the above-mentioned study and describes the interrelations within the hydrologic system simulated in this study, which encompasses the lakes, streams, and shallow groundwater system.

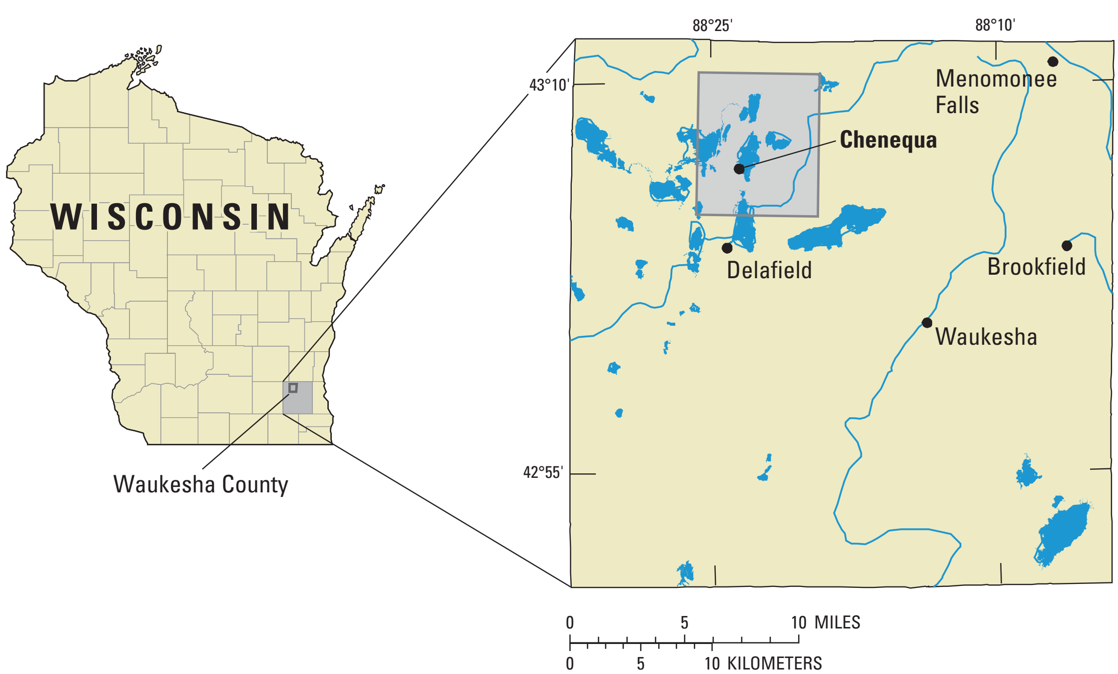


Figure 1. Location of study area, near Chenequa, Waukesha County, Wisconsin.

Southeastern Wisconsin Background Regional Model

The inset model is based on the previously developed three-dimensional finite-difference MODFLOW groundwater-flow model of the seven-county region of southeastern Wisconsin administered by the SEWRPC. The Southeastern Wisconsin background regional model (hereafter called the background regional model) was constructed cooperatively by the WGNHS and the USGS. Readers are directed to Feinstein, Eaton, and others (2005) and Feinstein, Hart, and others (2005) for detailed explanation of the development and application of the background regional model.

The hydrogeologic setting of the Chenequa area is typical of the part of southeastern Wisconsin represented in the background regional model. Crystalline bedrock of Precambrian age underlies the region; sandstone and carbonate units of Cambrian and Ordovician age overlie the crystalline bedrock (fig. 2). These units consist of the Mount Simon Formation, Eau Claire Formation, Wonewoc Formation, Tunnel City Group, Trempealeau Group, Prairie du Chien Group, and St. Peter Formation. Directly overlying the St. Peter Formation is the Sinnipee Group and Maquoketa Formation, a sequence with generally low vertical hydraulic conductivity, that isolates glacial and carbonate aquifers above (Silurian and younger) from the sandstone-dominated deep aquifer system below (Ordovician and older). The near-surface stratigraphy of southeastern Wisconsin consists of unlithified, glacially derived Pleistocene and Holocene deposits. Owing to the eastward dip of the consolidated bedrock stratigraphic units in southeastern Wisconsin, progressively younger bedrock units pinch out to the west. The Maquoketa Formation is present over most of Waukesha County but pinches out in areas of the southern and northwestern parts of the county; it is present only under part of the Chenequa study area. Where the Maquoketa Formation is absent, the shallow, unlithified deposits are in better hydraulic connection to the underlying sandstone aquifers, but resistive layers in the Sinnipee Group still limit somewhat the amount of vertical exchange.

Child Model Embedded in Parent Regional Model

In the field of groundwater modeling, one-way coupling from a coarse regional model to a local and refined model grid is commonly called telescopic mesh refinement (TMR) and is most often accomplished by using some form of interpolation of either heads or fluxes, or both, from the coarse grid onto the boundaries of the refined grid (for example, Buxton and Reilly, 1986; Ward and others, 1987; Leake and Claar, 1999; Davison and Lerner, 2000; Hunt and others, 2001). This approach is fairly straightforward and works well for many problems. The one-way coupling, however, does not allow for feedback from the refined grid (hereafter called the child grid) to the coarse grid (hereafter called the parent grid). Therefore, after running both models, the modeler must determine whether heads along and fluxes across the interfacing boundaries are consistent for both models (Leake and Claar, 1999, p. 5–7). If they do not match, then the modeler must make adjustments by trial and error: there is no formal mechanism for adjusting the models to achieve better agreement. For this reason, TMR methods generally lack numerical rigor and sometimes lead to significant, often undetected errors (Mehl and Hill, 2002a,b).

A numerically more rigorous method that ensures consistency of heads and fluxes between the two grids—local grid refinement (LGR)—is an iteratively coupled method that links the parent and child grids in a way that provides feedback from the child grid to the parent grid, thus allowing two-way communication between the grids. Two-way iterative coupling is used to ensure that the models have consistent boundary conditions along their adjoining interface. Solutions with feedback can be achieved either through iteration or through simultaneous solution schemes. LGR couples the models by means of shared nodes; that is, the grids are constructed such that nodes of the parent grid are coincident with selected boundary nodes of the child grid. LGR uses the iteratively coupled shared-node method of local grid refinement developed and tested by Mehl and Hill (2002 a,b; 2003; 2004) and Mehl (2003).

Inset Model Grid Refinement

The first modification in creating the inset model for the Chenequa study was made to the entire domain of the southeastern Wisconsin background regional model. The original regional model was developed with MODFLOW 96 and was modified to run under MODFLOW–2005. The lower 8 layers of the initially 18-layer background regional model—those constituting the sandstone-dominated deep aquifer system (fig. 3)—were combined into a single confined layer with representative bulk hydraulic properties. These bulk properties preserve the spatial variation of the transmissivity and storage capacity of the deep aquifer system. This simplification was appropriate because the primary objective of the inset model is to simulate the interaction between the shallow groundwater system and area lakes. Given that confining units within the Maquoketa Formation and Sinnipee Group hydraulically separate the deep aquifer system from the shallow aquifers in this area, the shallow modeling results are largely insensitive to a detailed representation of the internal flow dynamics of the deep aquifer system. The new refined version of the regional model is hereafter referred to as the “parent regional model.” Layers 1 through 10 are the same in both versions of the regional models, but layer 11 of the parent regional model combines layers 11 through 18 of the background model. The inset model embedded inside the parent regional model also represents the deep aquifer system with the single layer 11 (fig. 3*B*).

Geologic time interval	Years before present	Stratigraphic unit	Lithology
Quaternary Period	0	(Holocene) sediments	Soil, estuarine and alluvial deposits
	10,000	(Pleistocene) Kewaunee, Oak Creek and New Berlin Formations	Three distinct till units Fine-, medium- and coarse-grained, proglacial-lake sediment Complex and variable ice margin unit
	20,000		
Silurian and Devonian Periods	360 million	Undifferentiated	Dolomite
Ordovician Period	440 million	Maquoketa Formation	Shale and dolomite
		Sinnipee Group	Dolomite with limestone and shale
		St. Peter Formation	Orthoquartzite sandstone with minor limestone
		Prairie du Chien Group	Dolomite with some sandstone and shale
Cambrian Period	490 million	Trempealeau Group Tunnel City Group Wonewoc Formation Eau Claire Formation Mount Simon Formation	Sandstone with some dolomite and shale
Precambrian	540 million	Undifferentiated	Crystalline

Figure 2. Stratigraphic section for southeastern Wisconsin (modified from Brown and Eaton, 2002).

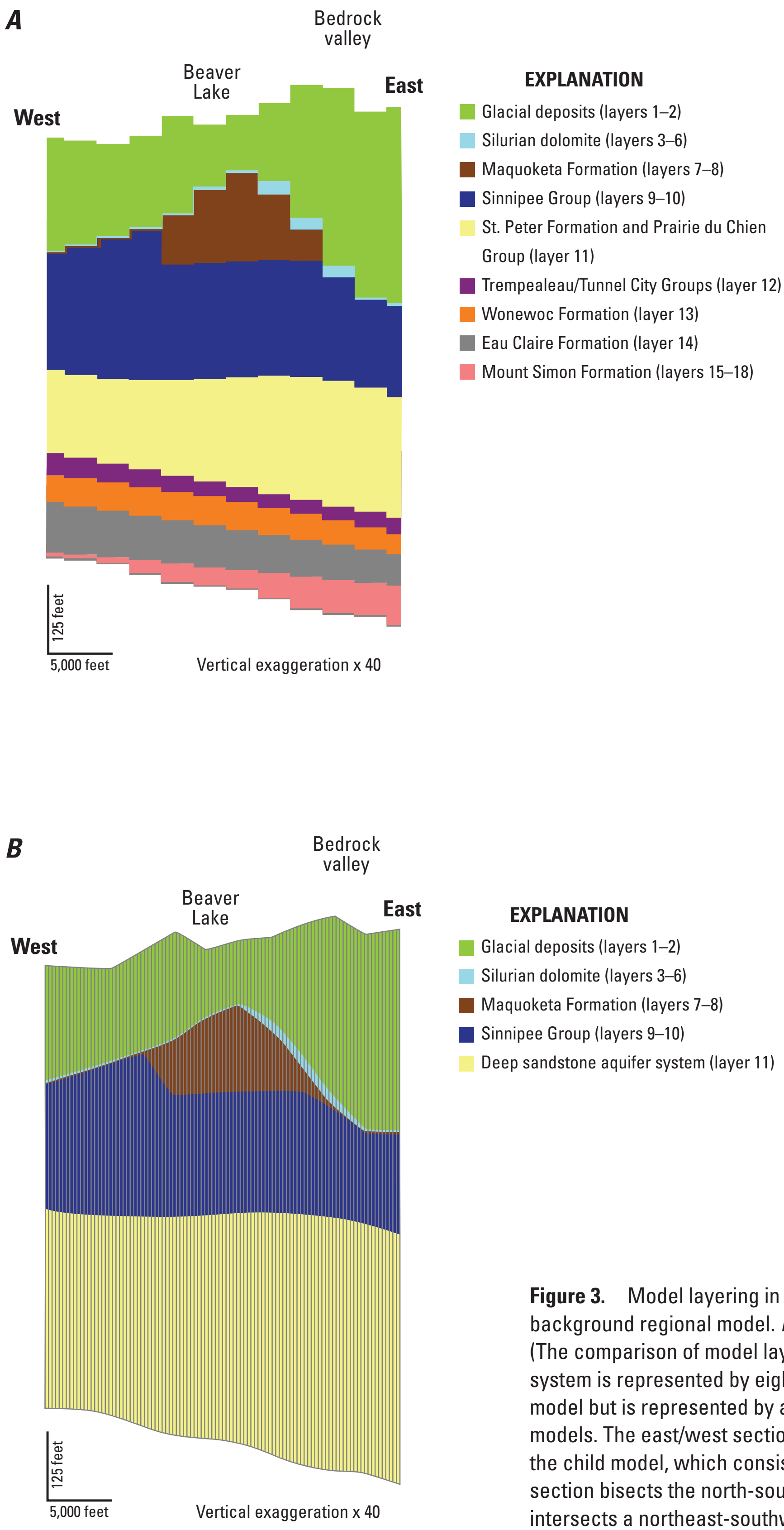


Figure 3. Model layering in example east-west section. *A*, Layering in background regional model. *B*, Layering in parent regional and child model. (The comparison of model layering shows that the deep sandstone aquifer system is represented by eight model layers in the background regional model but is represented by a single layer in the parent regional and child models. The east/west section contains the entire east-west extent of the child model, which consists of 100 columns, each 277.78 ft wide. The section bisects the north-south extent of Beaver Lake and further to the east intersects a northeast-southwest-trending bedrock valley. See fig. 4 for the trace (*A*–*A´*) of the example section.)

In both the parent regional and child models, Layers 1 through 10 maintain the hydrostratigraphic sequence used in the background regional model (fig. 3*B*). The top two layers represent the unlithified glacial material, layer 3 represents Pennsylvanian and Mississippian bedrock (absent in southeastern Wisconsin and therefore this layer is given a negligible thickness), layers 4 through 6 represent the Silurian dolomite, layers 7 and 8 represent the Maquoketa Formation, and layers 9 and 10 represent the Sinnipee Group. In general, the glacial deposits can act as an unconfined aquifer or a confining unit, the Silurian dolomite serves as an unconfined or semi-confined aquifer, the Maquoketa Formation is a confining unit, and the Sinnipee Group can act as a confining unit or contribute transmissivity to the underlying confined, deep aquifer system. Descriptions of the properties of these units, including thickness and permeability, can be found in Feinstein, Eaton and others, 2005.

The inset (child) model constructed for the Chenequa study is derived from the parent regional model. The child model was sized to include Beaver, Pine, and North Lakes (lakes of primary interest to the study), as well as some distant surface-water boundaries, while keeping the model size relatively compact (fig. 4). The child model grid was refined by use of a TMR approach similar to one described by Ward and others (1987). The TMR routine was run with Groundwater Vistas (Rumbaugh and Rumbaugh, 2007). In the parent regional model, grid spacing is 2,500 ft (fig. 5); in the child model, the grid is one-ninth the spacing, or 277.8 ft on a side. Thus, every parent regional model node is represented by 81 nodes in the child model. The layering of the child model is identical to the layering in the parent model. The child model has 118 rows and 100 columns (fig. 6). With 118 rows, 100 columns, and 11 layers, the child model has 129,800 cells, all of which are active. As a result of smaller grid spacing, the

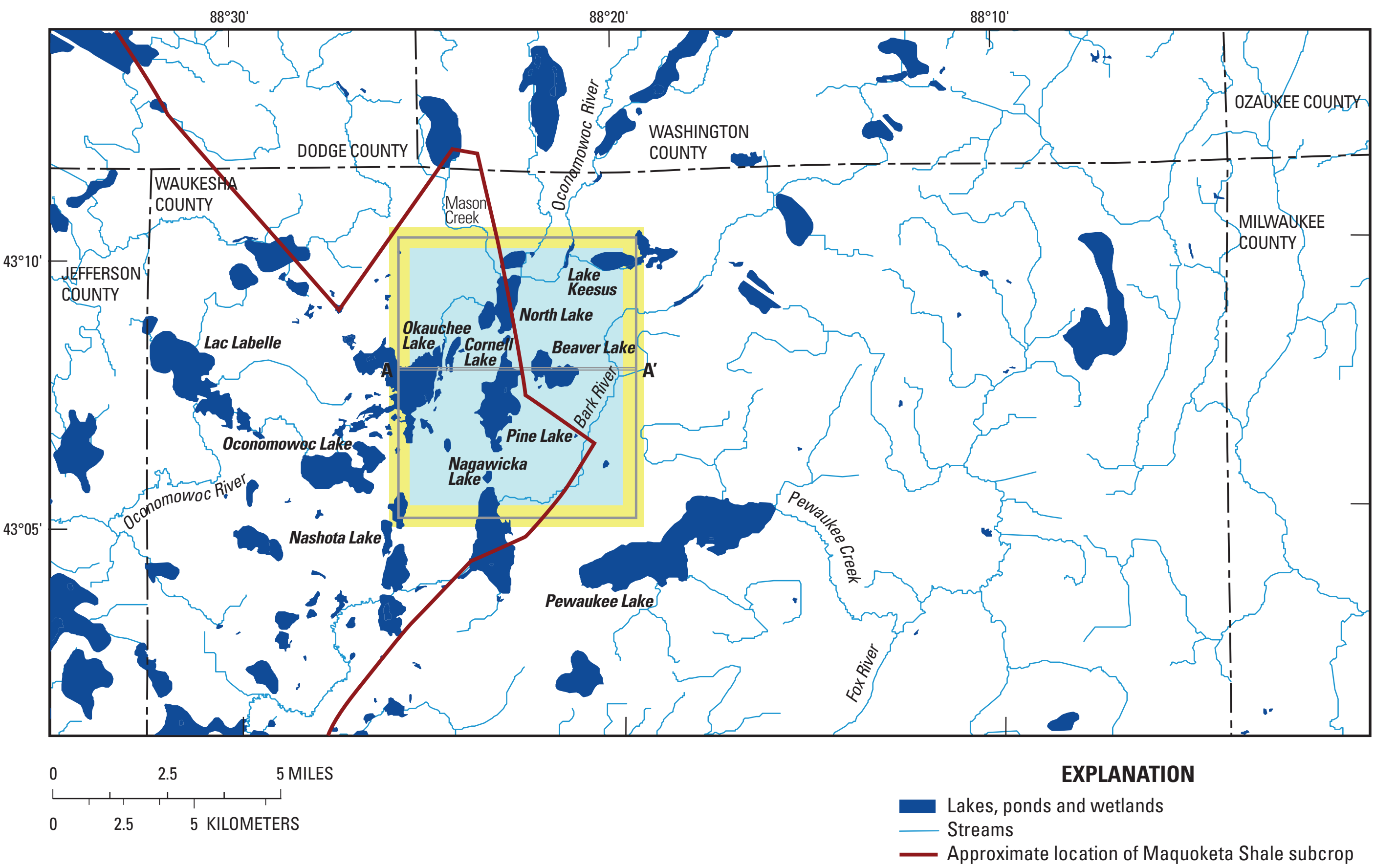


Figure 4. Location of the child model centered on Beaver, Pine, Cornell, and North Lakes. (The brown line is the westernmost extent of the Maquoketa Formation confining unit that separates the shallow and deep systems where it is present. The yellow perimeter corresponds to the parent regional model cells that are shared with the child model. The child model extends half the distance into the yellow perimeter. The A–A′ trace shows the location of the sections in fig. 3.)

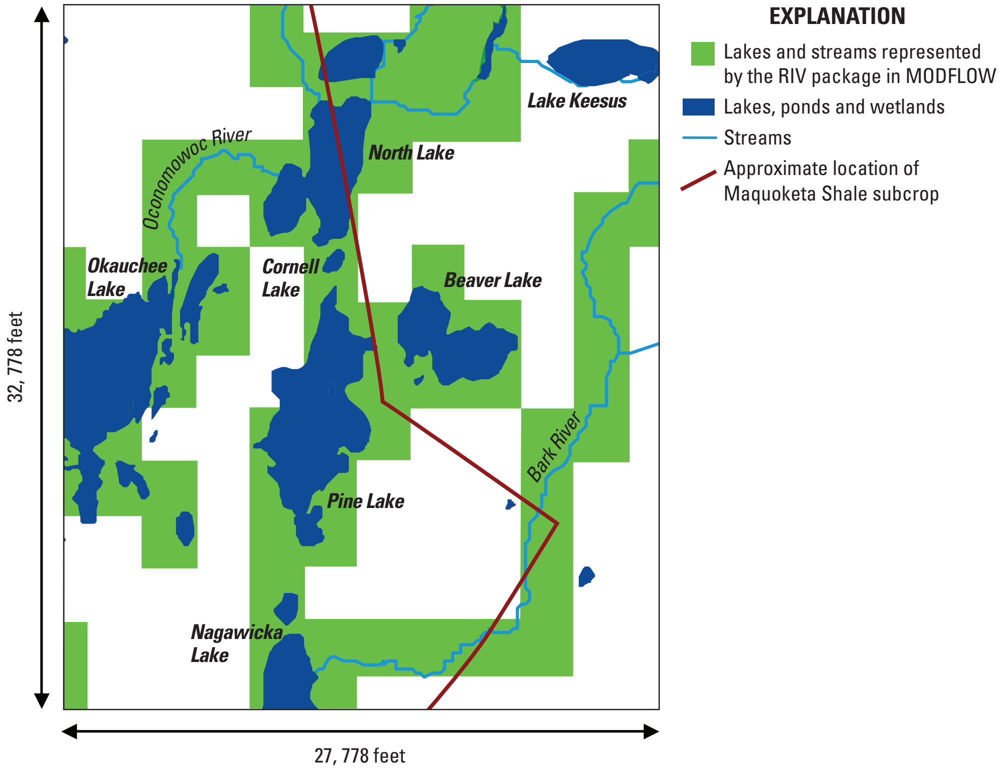


Figure 5. Original discretization and boundary conditions in parent regional model for area replaced by child model. (Cells in parent regional model are 2,500 feet on a side.)

surface-water features, pumping stresses, and the hydraulic-head distribution are represented more accurately in the child model than in the regional model. Therefore, interactions between streams and lakes, as well as three-dimensional flows near those features, are also simulated more accurately.

In addition to the greater resolution built into its grid, the child model is designed to more actively portray surface-water features. Selected streams were converted from the MODFLOW River Package (McDonald and Harbaugh, 1988), shown in figure 5, to the more sophisticated Stream Routing (SFR1) Package (Prudic and others, 2004), shown in figure 6. The latter allows accounting of streamflow and limits the amount of water a stream can lose to the aquifer to the amount of water captured upstream. In the child model, SFR cells are used to represent stream segments connecting the Chenequa lakes and streams entering and exiting North Lake, whereas the River Package is used to simulate the Bark River and parts of Lakes Okauchee and Nagawicka (fig. 6) because neither stream routing nor the ability to control infiltration quantities was required for these features.

A final refinement in the child model was the conversion of Beaver, Pine, and North Lake from the MODFLOW River Package (fig. 5) to the more sophisticated Lake (LAK3) Package (Merritt and Konikow, 2000) (fig. 6). This package provides for active model grid cells representing the aquifer adjacent to and beneath lakes; these active cells can simulate exchange of water between an aquifer and a lake at a rate determined by relative heads and by conductances that are based on grid-cell dimensions, hydraulic conductivities of the aquifer material, and user-specified precipitation, evaporation, and leakance distributions that represent the resistance to flow through the material of the lakebed (fig. 6). The use of the LAK3 package allows the lake stages to be calculated (instead of specified) and the complete lake water budget to be evaluated.

Input to the Parent Regional Model

The parameterization of the surface-water network, hydraulic conductivity of unconsolidated and bedrock units, and the distribution of recharge in the parent regional model is identical to the input to the background regional model described in Feinstein, Eaton, and others (2005). No changes were made to the regional input except to assign an average hydraulic conductivity to the cells in the single layer that represents the units composing the deep sandstone aquifer (in order to preserve the combined transmissivity assigned the multiple layers in the background regional model).

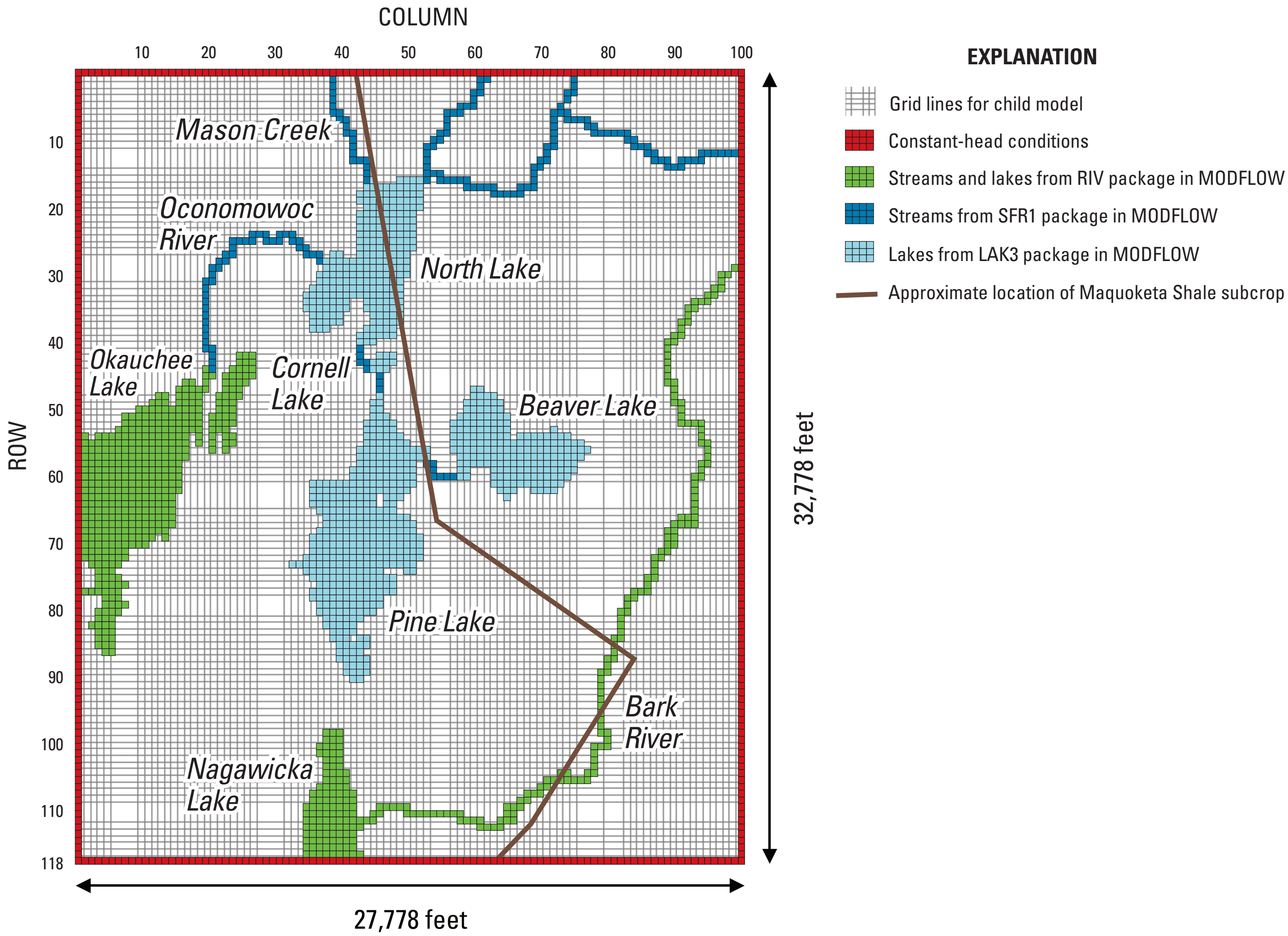


Figure 6. Grid discretization and boundary conditions for child model. (Cells in child model are 277.8 feet on a side.)

Temporal Discretization of the Models

The parent regional and child models incorporate the deep pumping which, since the late 19th century, created and has gradually enlarged a regional cone of depression under southeastern Wisconsin in the deep sandstone aquifer system (Feinstein, Hart, and others, 2005). The effects of shallow pumping in the Silurian dolomite and glacial deposits, although less dramatic and more local in terms of drawdown, also are simulated by the models. For the purposes of this analysis, the historical rates of shallow and deep pumping used originally in the 18-layer background regional model to simulate conditions for multiple intervals between 1864 and 1990 were input to the 11-layer parent regional model. As in the case of the background regional model, the parent regional model was used first to simulate steady-state predevelopment conditions, and then transient results were obtained for the 1864 to 1990 period starting from the simulated steady-state condition. Both the steady-state and transient results are similar to the original results reported by Feinstein, Hart, and others (2005) for the background regional model. The parent regional model was then linked to the embedded child model by using the LGR procedure enabled by MODFLOW–2005 (Mehl and Hill, 2005). A 20-year runup period was simulated, beginning from 1990 parent regional model results and using the same discharge rates originally assigned the background regional model for the 1991–2000 interval. This hypothetical transient runup period is needed to allow the model to react to the linking of the two models and reach a new set of stable conditions (it does not correspond to an actual period of time). Finally, an additional 5-year period was added to the end of the linked transient simulation in order to investigate the interactions of groundwater and the Chenequa-area lakes under several pumping, recharge, precipitation, and evaporation scenarios. The 1991–2000 pumping rates were sustained for this transient 5-year observation period.

River Package Input to the Child Model

Within the child model, the Bark River and outlying lakes (Nagawicka Lake and Okauchee Lake) were represented by means of the MODFLOW RIV package. Stage was specified on the basis of elevations recorded on topographic maps. In the case of the Bark River, the topographic elevations were used to determine the slope of the stream surface within the child grid. The hydraulic conductivity of the bed of the Bark River was assumed to be 1 ft/d, and the bed thickness was assumed to be 1 ft. The hydraulic conductivity and thickness of the lake beds was assumed to be 0.1 ft/d and 1 ft, respectively.

Streamflow Routing Package (SFR1) Input to the Child Model

The MODFLOW SFR1 package allows stream stage to be calculated as part of the model solution. The code also routes flow from upgradient to downgradient stream nodes along the network, allowing the model to keep track of the streamflow and the surface water available to be captured, for example, by pumping. The channel connections between the Chenequa-area lakes were represented by SFR nodes. In addition, the flow in tributaries to North Lake within the child model domain (including Mason Creek and stretches of the Oconomowoc River) was handled by the SFR1 package. In each case the hydraulic conductivity of the lakebed was assumed to be 1 ft/d and the bed thickness to be 1 ft.

The slopes of the streambeds input to the SFR1 package are based on topographic contours reported on U.S. Geological Survey maps (Stonebank and Merton topographic quadrangles, 1959, scale 1:24,000). The streambed elevations at the outlets of Beaver, Pine, Cornell, and North Lakes are estimated to be between 0.1 and 2 ft below the target lake stage and are implemented in the child model so that stream depth increases downstream.

Lake Package Input to the Child Model

The geometries of the child-model layers and model cells representing Beaver, Pine, and North Lakes are based on information in historical bathymetric maps (fig. 7). The hydrologic characteristics of the lake model cells were assigned by using existing data and were refined through the calibration process. Of particular importance are the conductance values assigned to the lakebeds because they control the flow between the groundwater system and the water bodies. Beaver, Pine, and North Lakes were assigned higher conductance values under the shoreline (littoral zone) than under the interior of the lake (profundal zone). The littoral zone was defined to be one cell wide, equivalent to 278 ft.

Also important are the stage-discharge relations assumed for each lake. Observed outflows from the lakes vary widely in response to season and stage. Measured streamflow out of Beaver Lake (table 1) varied from 107,136 ft^3/d on June 7, 2007, to zero on July 17, 2007, to 86,400 ft^3/d on September 27, 2007. Measured streamflow out of Pine Lake (table 1) varied from 254,018 ft^3/d, zero, and 5,357 ft^3/d on the same successive dates. Given the scarcity of flow data, it was necessary to base an average outflow condition for these lakes on the average of the three available measurements. This discharge was assumed to correspond to the long-term average elevation of the lakes as shown on the USGS topographic maps for the Chenequa area (Stonebank and Merton quadrangles, 1959, scale 1:24,000): 909 ft elevation for Beaver Lake, 900 ft elevation for Pine Lake, and 896 ft elevation for North Lake; Cornell Lake elevation was estimated as the average of the stages of Pine and North Lakes. These levels were selected because they are consistent with stream input also drawn from topographic maps. However, data collected for Beaver and Pine Lakes in 2006–8 indicated higher levels, averaging 1 ft higher in the case of Beaver Lake and between 2 and 3 ft in the case of Pine Lakes (Jeffrey Kante, Village of Chenequa, written commun., February 9, 2009). These recent data indicate a degree of uncertainty in lake levels, possibly connected to climate variability.

Input to the LAK3 package also includes precipitation and evaporation to the lake surfaces. These values were assumed to be 32 and 29 in/yr, respectively, on the basis of average long-term observations in northwestern Waukesha County (Linsley and others, 1982, p. 78 for precipitation rate and p. 154 for evaporation rate). The long-term average rate of overland flow to the lakes was assumed to be negligible because of the generally coarse soils in the area, so it was set to zero in the model input.

Recharge Input to the Child Model

Recent research by the Wisconsin Geological and Natural History Survey (Hart and others, 2008) involving a GIS-based soil-water-balance model (Westenbroek and others, 2010) produced a detailed recharge distribution over time for all of southeastern Wisconsin including the Chenequa area. This approach, however, is partially unconstrained in that it encompasses only the soil zone and therefore does not track or integrate infiltration out of the soil zone to surface-water features where flow measurements are made (Westenbroek and others, 2010). The groundwater-flow model constructed for the Chenequa-area study does integrate upgradient recharge at surface-water features, so it was used to constrain a multiplier applied to the spatial recharge distribution of Hart and others (2008). The Hart and others pattern for the child-model domain was scaled so as to agree with the average recharge rate input for the Chenequa area in the background regional model (8.5 in/yr). Around this average recharge rate of 8.5 in/yr, recharge in the child model varies between a low of 3.9 in/yr and a high of 19.5 in/yr. (fig. 8). The higher values reflect the presence of sandy soils over much of the area. No recharge was applied to the lakes in the child model.

A. **Beaver Lake**

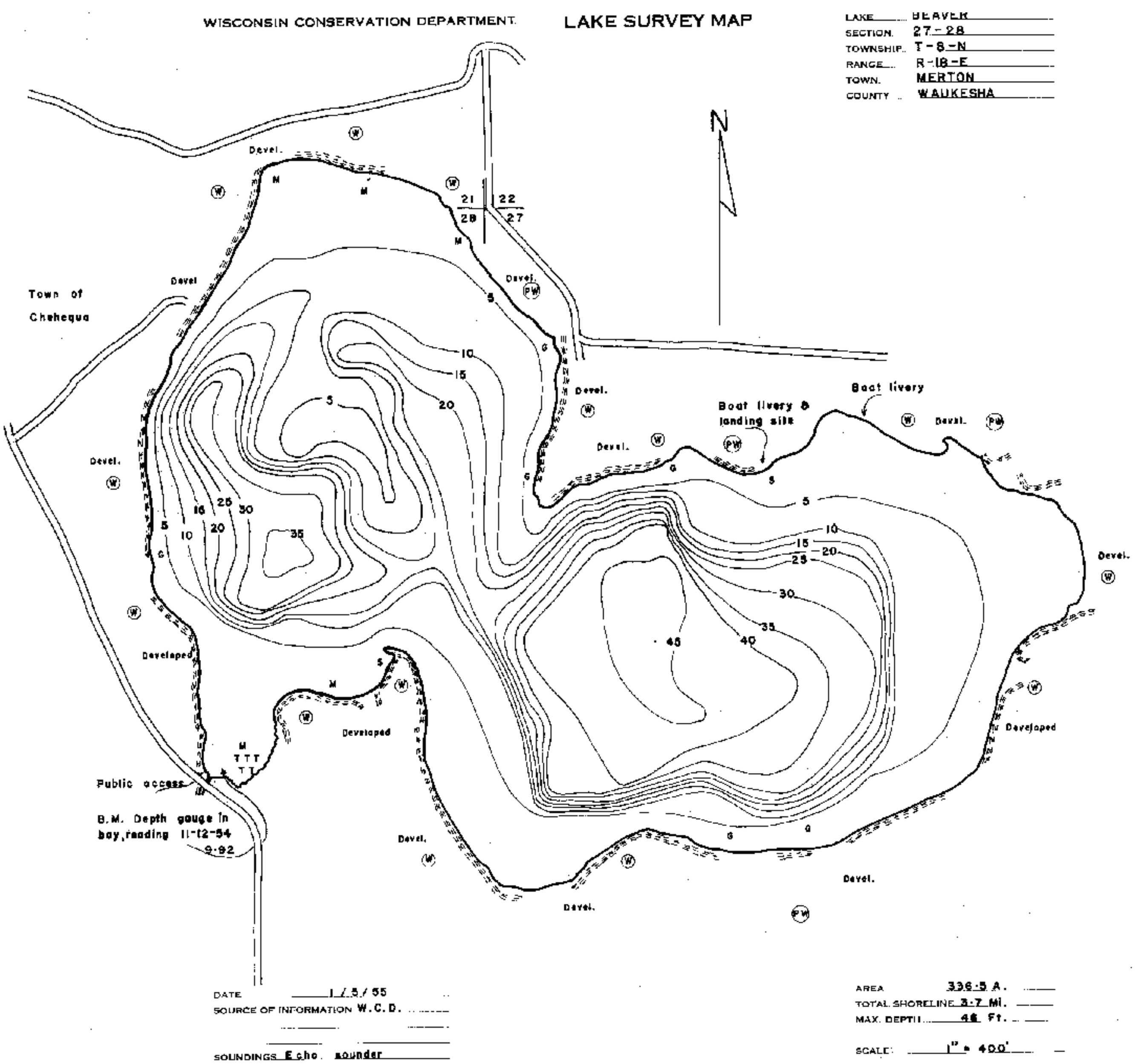


Figure 7*A*. Bathymetry of Beaver Lake (from Wisconsin Conservation Department, 1941 and 1955).

B. **Pine Lake**

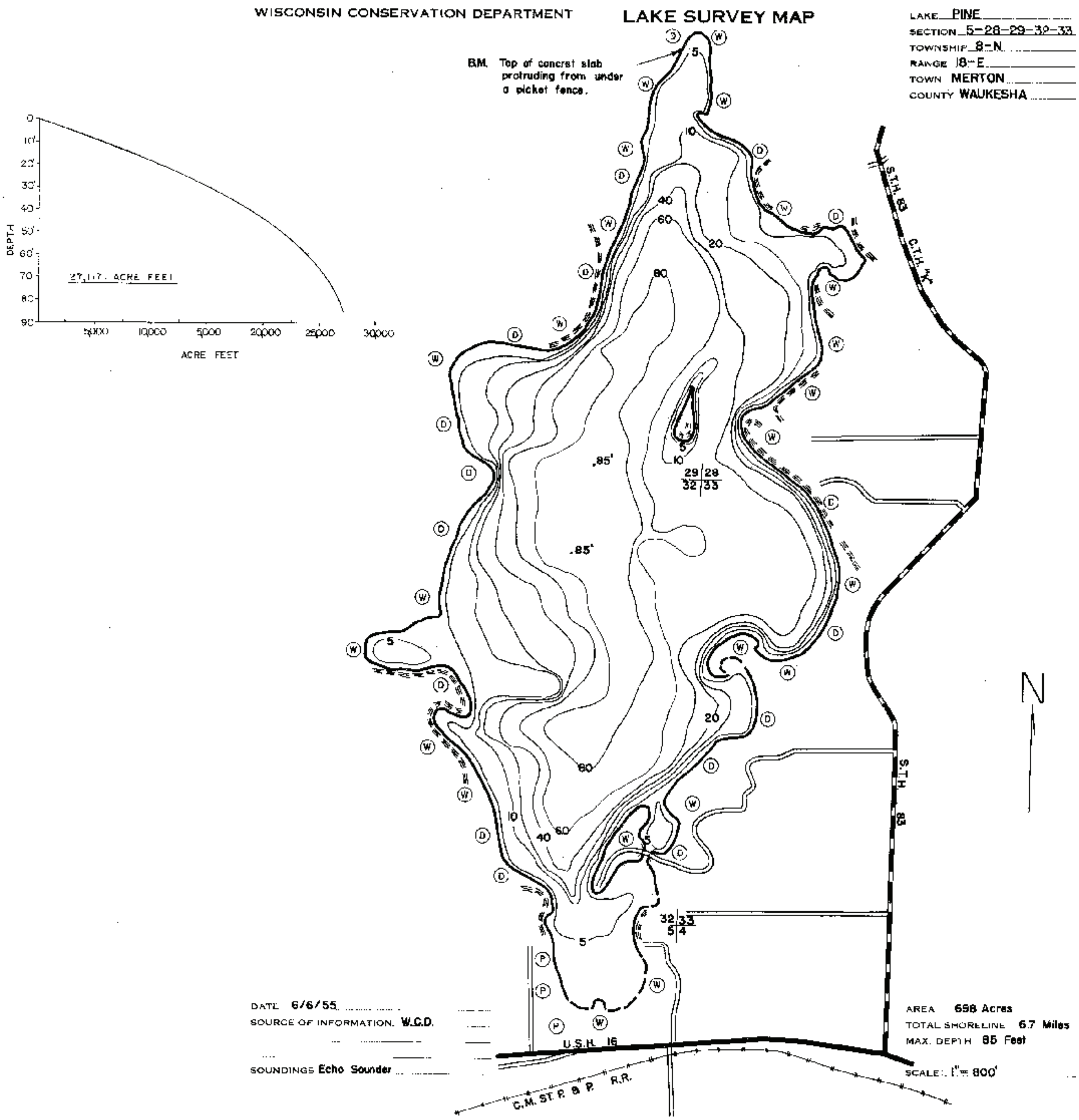


Figure 7*B*. Bathymetry of Pine Lake (from Wisconsin Conservation Department, 1941 and 1955).

C. **North Lake**

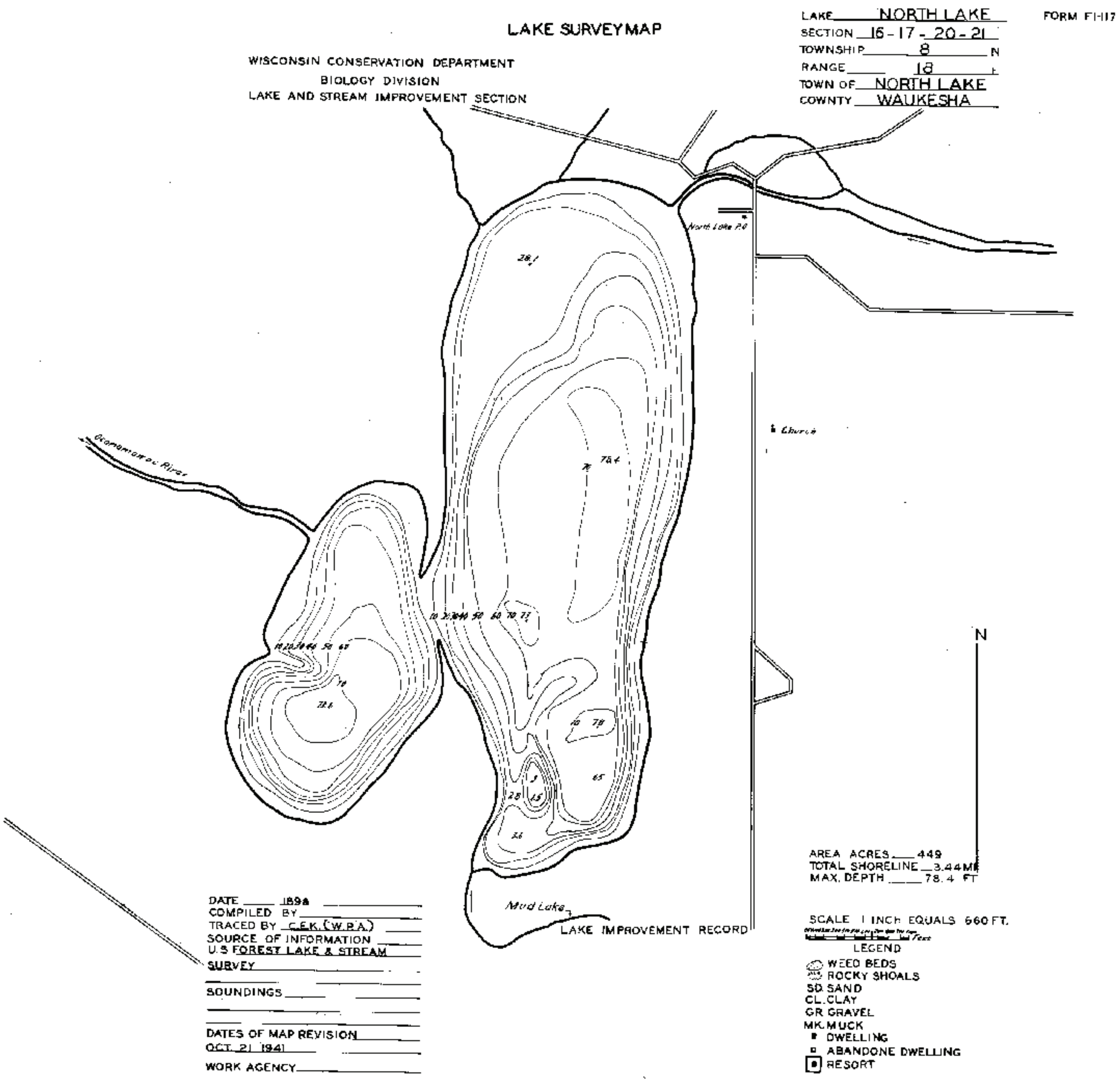


Figure 7*C*. Bathymetry of North Lake (from Wisconsin Conservation Department, 1941 and 1955).

Table 1. Summary of flow measurements in Chenequa area, Wisconsin.

[Site locations are shown in fig. 12; —, not measured]

Site number	Site name	Measured streamflow, in cubic feet per day, by date		
		6/7/2007	7/17/2007	9/27/2007
1	Beaver Lake outlet at Hwy 83	107,136	0	86,400
2	Pine Lake outlet at Cty Hwy K	254,018	0	5,357
3	Bark River at Dorn Road near Merton	1,676,160	1,054,080	1,667,520
4	Bark River at Nagawicka Road at Delafield	2,246,400	1,296,000	2,073,600
5	Lake Keesus outlet at Whitcomb Road	155,520	19,872	117,504
6	Oconomowoc at Funk Road	2,220,480	1,071,360	1,728,000
7	Oconomowoc at North Lake	—	—	2,039,040
8	Oconomowoc at Westshore Drive	—	—	3,049,920
9	Oconomowoc at Cty Hwy K at Stonebank	—	2,021,760	3,257,280

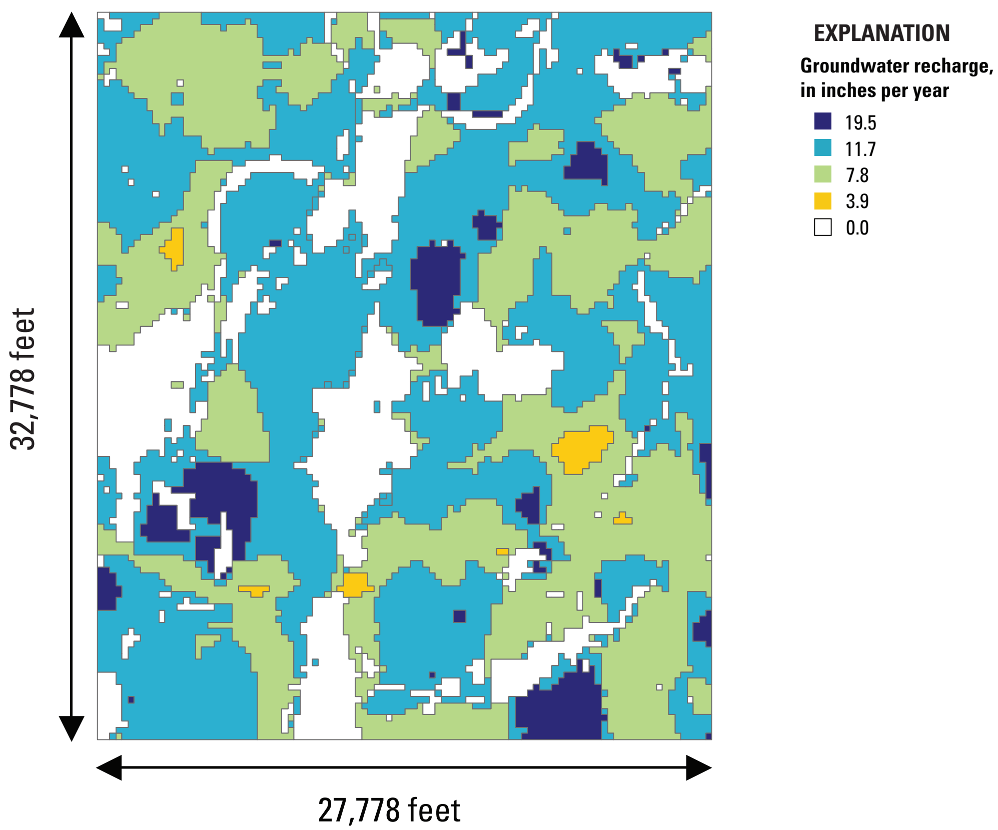


Figure 8. Recharge distribution in child model.

Hydraulic Conductivity and Storage Input to the Child Model

In 2005, investigations were performed by the City of Delafield to plan for a new public-supply well to supplement the existing set of high-capacity wells in the area (fig. 9). An aquifer test conducted in late 2005 near Pine Lake in the City of Delafield (Earth Tech, Inc., 2006), at the location marked “Test well” in fig. 9, provided new information on the hydraulic conductivity of the unconsolidated sediments in the vicinity of the Chenequa-area lakes, thereby allowing the original values from the background regional model to be updated. The USGS did not perform the aquifer test; details of the test, including 1) a detailed description of the test methods and procedures, 2) a map of the test site, 3) well construction, 4) site hydrogeologic characteristics, 5) time-discharge records of the pumped well, 6) water-level records, and 7) methods and computations of adjustments to measured drawdowns are included in Earth Tech, Inc. (2006). A hard copy of Earth Tech, Inc. (2006) is included as part of the physical aquifer-test archive, on file in the Wisconsin Water Science Center.

The purpose of the USGS analysis of the aquifer-test data was to evaluate aquifer properties to better characterize the child-model domain. As part of the USGS analysis, Earth Tech, Inc. (2006) aquifer-test data were incorporated in a special groundwater-flow model designed to reproduce the drawdown and recovery patterns observed during the aquifer test. The aquifer-test model treated the entire thickness of the glacial material near the test well as a single unconfined flow system. The model consisted of four layers (used exclusively to represent the glacial thickness) and a nonuniform lateral grid spacing centered on the pumping well. The row and column spacing increased by a factor of 1.2 outward from the pumping well, a resolution which allowed the three observation wells surrounding the pumping well to be precisely located horizontally as well as vertically. Boundary conditions were provisionally inserted to take account of surface-water features (Pine Lake and the Bark River); but, likely because of the distance to these features relative to the strength and duration of the aquifer-test stress, the model results were largely insensitive to presence or absence of boundary conditions. Earth Tech, Inc. reported that the pumping well was open approximately 200 ft below land surface, corresponding

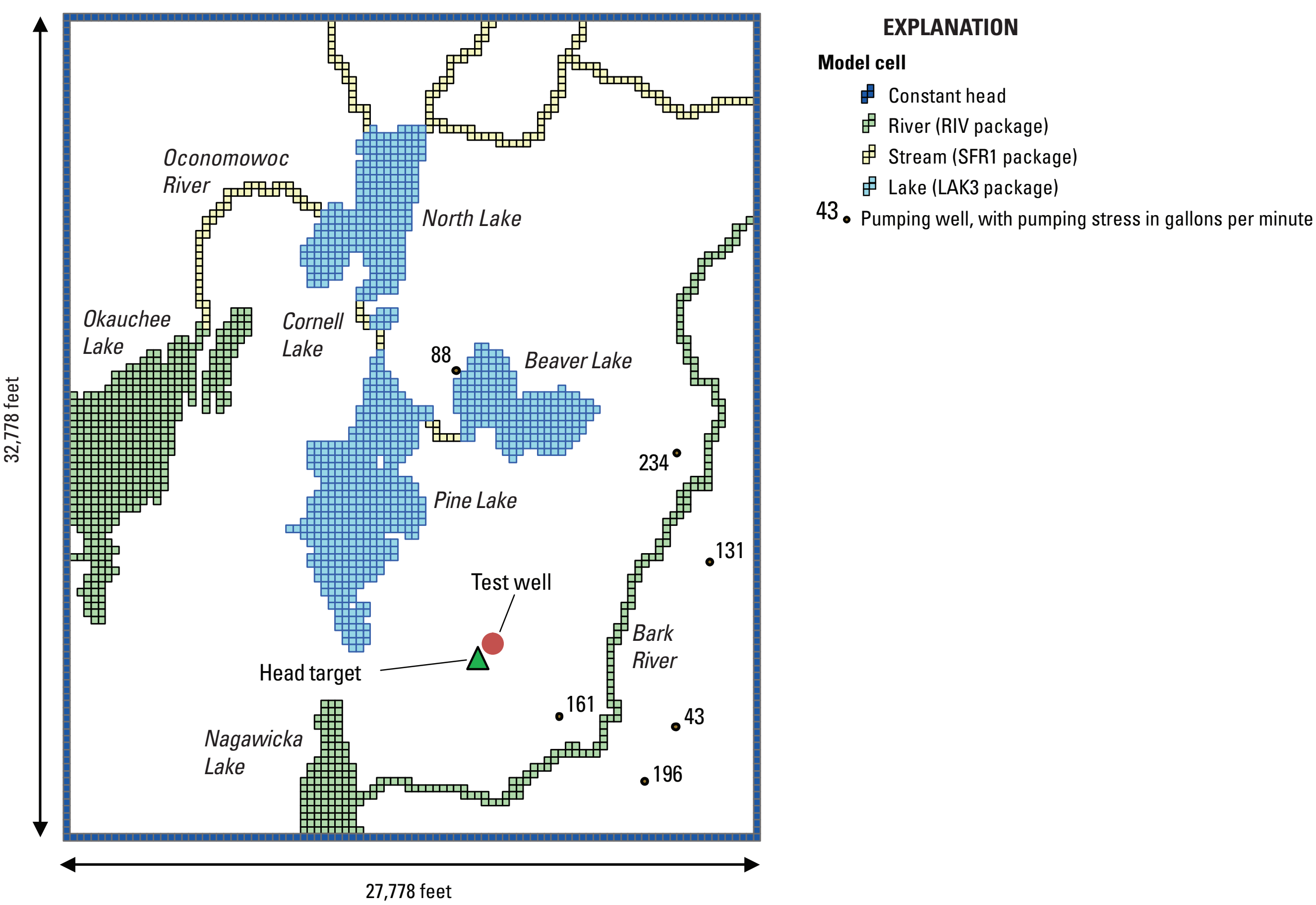


Figure 9. Location of pumping wells in child model.

to model layer 4, and was pumped at a rate of 539 gal/min for 3 days. These pumping conditions were duplicated by the model, and a 3-day recovery phase of the test also was simulated. During the test, water levels were recorded at one observation well (OW–1) 150 ft east of the pumping-test well and a second (OW–3) 300 ft north of the pumping-test well. Both observation wells were open to the unconsolidated aquifer at the same elevation as the pumping-test well. A third observation well 150 ft east of the pumping-test well was open at a shallower interval at the water table. This arrangement allowed the transient aquifer-test data to be used to calculate not only the horizontal but also the vertical hydraulic conductivity of the unconsolidated aquifer by fitting the shallow and deep water-level responses simulated by the model to the observed responses.

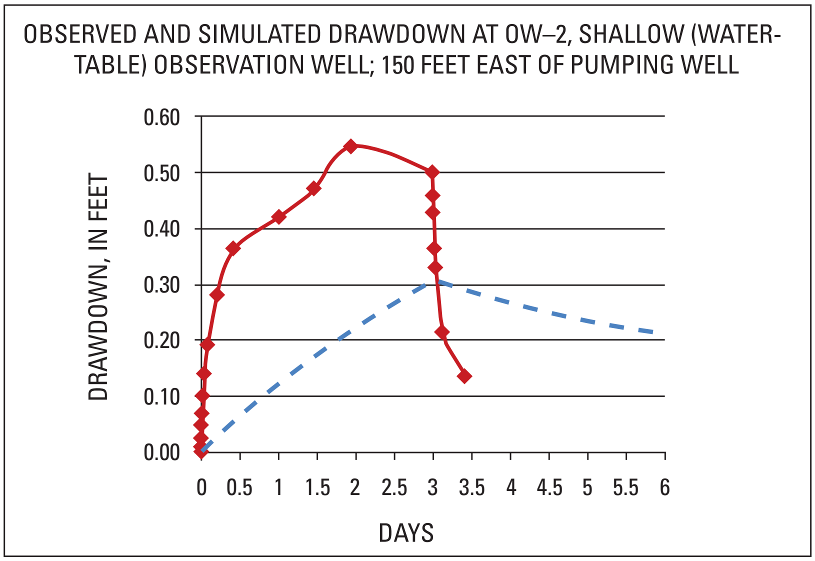
A close fit was achieved between the observed drawdown reported by Earth Tech, Inc.[1] and the drawdown simulated by the aquifer-test model (fig. 10) when the horizontal hydraulic conductivity in the east/west direction was assigned a value of 55 ft/d, the horizontal hydraulic conductivity in the north/south direction was assigned a value of 110 ft/d, and the vertical hydraulic conductivity was assigned a value of 1 ft/d. The horizontal anisotropy of 2:1 between the east-west and north-south directions possibly represents a directional fabric of the outwash deposited in the bedrock valley, which crosses the child-model domain from its northeast corner in a south to southwest direction. Although the simulation of the deeper wells was good (figs. 10*B* and 10*C*), the simulated response in the water-table observation well OW–2 (fig. 10*A*) duplicates the slope of the observed response but not the absolute trends. The likely reason for this discrepancy is that the groundwater-flow model releases storage immediately by the mechanism of pore drainage; however, in the actual test, this source of storage is slightly delayed at the beginning of the test, and the only actual storage release is due to the elastic response of the aquifer, producing a very steep initial drawdown curve. Nevertheless, the close fit to the slope of the drawdown suggests that the model is successfully simulating the combined effects of pore drainage, vertical resistance to flow, and horizontal transmissivity with respect to the shallow observation well. The specific yield implied by the slope of the drawdown curve for the shallow observation well shown in figure 10*A* is 0.06, a value needed for the transient simulations with the child model.

The horizontal anisotropy and associated hydraulic conductivity of the unconsolidated layers in the child model were specified by using the aquifer-test results for most of the child-model domain (fig. 11). However, in the southeastern corner of the domain east of the Bark River (an area that is not informed by the aquifer test on the west side of the river), lower hydraulic conductivities were assigned. The lower values are needed to properly simulate the divide between the Bark River watershed and the neighboring Pewaukee Lake watershed (located in the parent regional model) and to ensure that the Bark River is, on balance, a gaining stream where it crosses the child model. Evidence from well-drillers' logs in the vicinity indicates that the glacial deposits, in fact, do become finer starting from the area of the Chenequa lakes, which is dominated by outwash deposits, and moving southeast toward Pewaukee Lake and the Fox River, an area characterized by mixed clayey till, loamy till, and coarse channel deposits (Douglas Cherkauer, University of Wisconsin-Milwaukee, oral commun., December 2009). The lower horizontal hydraulic conductivity in the southeast corner of the child-model grid is paired with a lower value for vertical hydraulic conductivity—0.03 ft/d—as opposed to a vertical conductivity equal to 1 ft/d over the remainder of the domain.

The abrupt transition between the hydraulic conductivity assigned the two unconsolidated layers in the child model and the parent regional model produced instability in the coupled LGR solution. The instability disappeared when the regional values were extended three rows and columns (about 800 ft) into the child grid, as shown in figure 11.

The zonation of hydraulic conductivity values assigned the bedrock layers of the child model is identical to the values input to the background regional model except in the case of layer 11, representing the deep sandstone aquifer units, where the child-model values are averaged across the multiple deep sandstone layers in the background regional model. Accordingly, the Silurian dolomite is assigned a horizontal hydraulic conductivity of 4 ft/d and a vertical hydraulic conductivity of 1×10^{-2} ft/d; the Maquoketa Formation is assigned a horizontal hydraulic conductivity that ranges from 0.3 to 0.0003 ft/d and a vertical hydraulic conductivity value that ranges from 1×10^{-3} to 5×10^{-6} ft/d; the Sinnipee Group is assigned a horizontal hydraulic conductivity that ranges from 0.3 to 0.04 ft/d and a vertical hydraulic conductivity that ranges from 1×10^{-2} to 5×10^{-4} ft/d; and the deep sandstone aquifer system layer is assigned a horizontal hydraulic conductivity between 2.0 and 4.0 ft/d and a vertical hydraulic conductivity everywhere in the neighborhood of 6×10^{-4} ft/d. As in the background regional model, the specific storage assigned to the bedrock layers in the child model is 2.6×10^{-7} 1/ft.

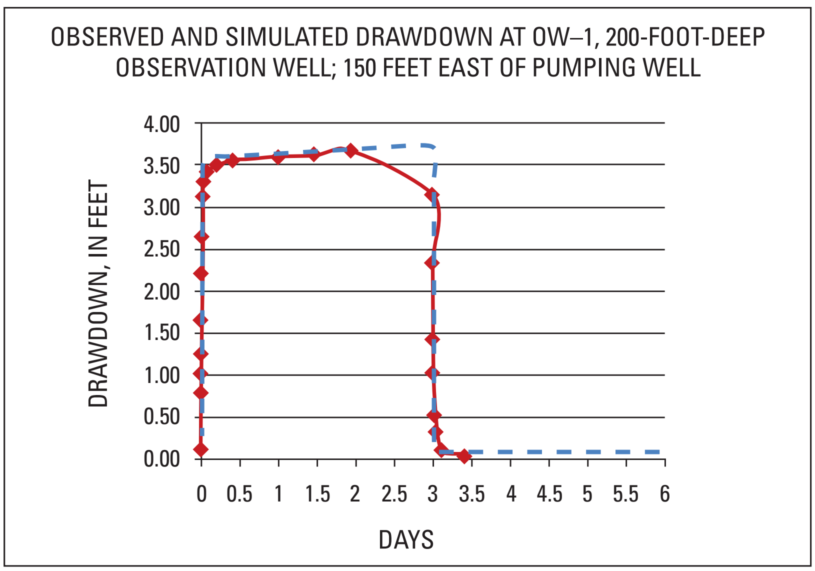
[1] The Earth Tech, Inc. report (2006) contains an analysis of the pumping test based on analytical solutions for leaky aquifers applied to the two deep observation wells, OW–1 and OW–3. Assumed in the analysis is that the aquifer is overlain by a leaky confining unit. These analyses yield an average transmissivity equal to 13,847 ft^2/d and a storativity equal to 1×10^{-4}. For comparison to the values derived from the numerical modeling described above, if the aquifer thickness is assumed to be between 150 ft and 200 ft (depending on the thickness of the supposed confining unit), the isotropic hydraulic conductivity implied by the analytical solution is between 69 and 92 ft/d. The reported storativity, corresponding to the response of a semiconfined aquifer, and implying a specific storage of approximately 5×10^{-7} per ft for a 200-ft-thick aquifer, is much lower than the specific yield derived from the numerical model analysis, which reflects the dewatering of pores at the water table and the assumption that the entire glacial system is unconfined rather than semiconfined.



EXPLANATION

Observed drawdown

Simulated drawdown



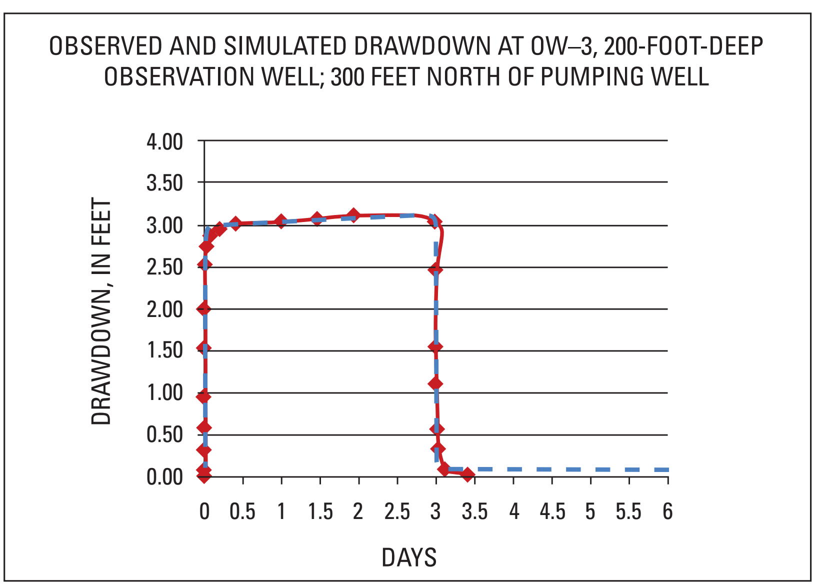
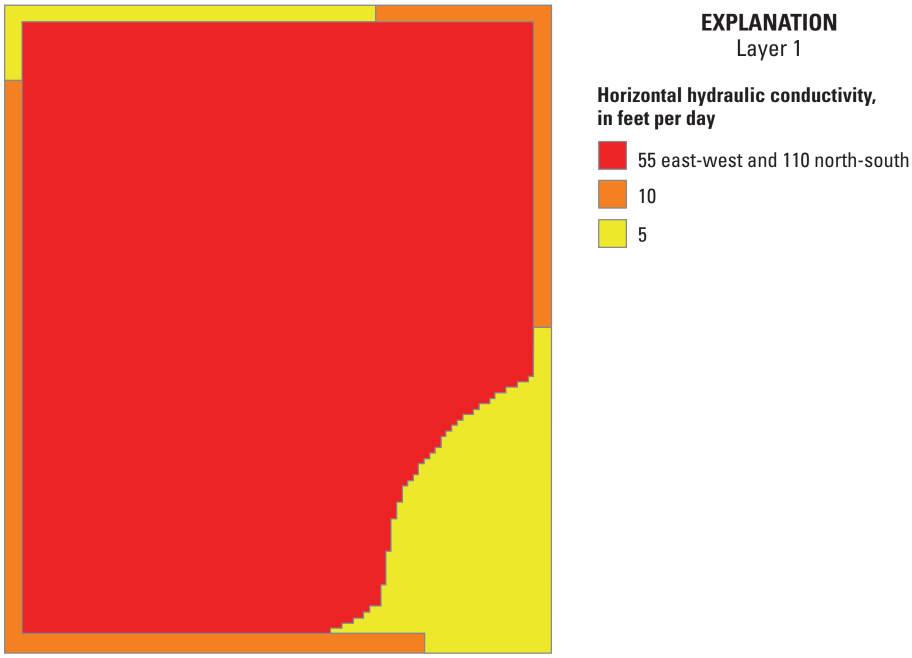


Figure 10. Aquifer-test analysis of drawdowns at three observation wells. (Note: The vertical drawdown scale for the shallow observation well is different from the scale for the two deep observation wells because much less drawdown was registered in the shallow observation well.)



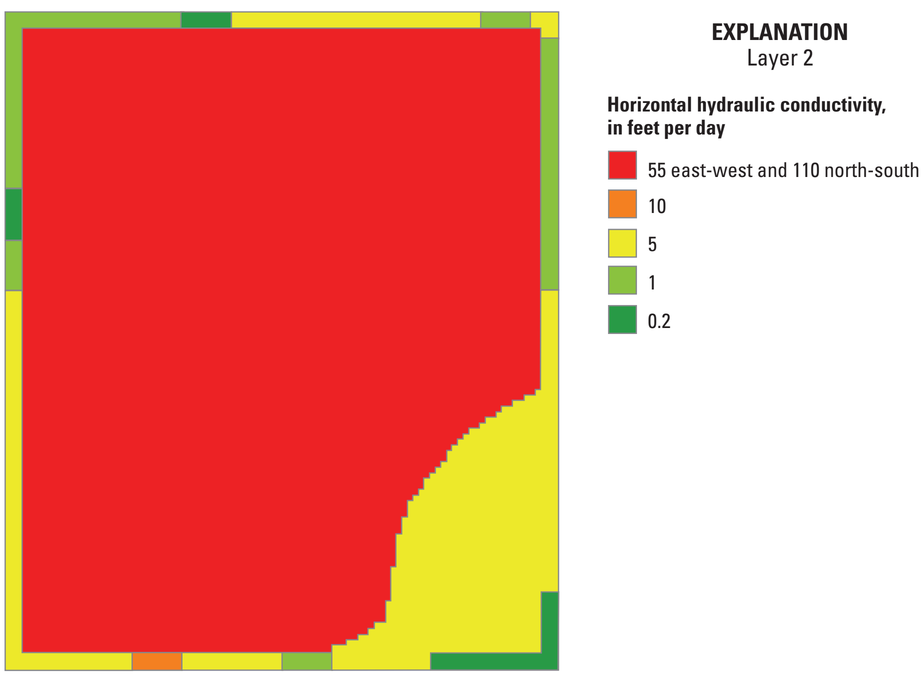


Figure 11. Distribution of horizontal hydraulic conductivity in child model, layers 1 and 2.

Water Withdrawals from Wells in the Child Model

Available records from the Wisconsin Department of Natural Resources and the Waukesha Public Service Commission provide estimates of average 2008 pumping from six high-capacity wells in the Chenequa area (fig. 9). The wells include one at the Chenequa Country Club on the shores of Beaver Lake, several Hartland public-supply wells located east and southeast of Beaver Lake, and a water-supply well for the city of Delafield. Each well withdraws water from the unconsolidated glacial aquifer; there are no records of active bedrock wells. The combined pumping from the six wells in the unconsolidated aquifer is 853 gal/min. A seventh well, called Delafield2, began to pump in 2007. It is not included in the base version of the child model.

Calibration of the Child Model

Calibration of the child model consisted of trial-and-error adjustment of parameters to improve the agreement between observed and simulated values representative of average conditions for a limited number of targets. Five types of targets were used to calibrate the model:

- *Stages for Beaver, Pine, and North Lakes*, corresponding to elevations recorded on 1:24,000-scale U.S. Geological Survey quadrangle maps (Stonebank, 1959; and Merton 1959, revised 1971); the stage of Cornell Lake, a very small surface-water feature, was estimated as the average of Pine and North.

- A single *water-level measurement* near Pine Lake, collected at the outset of the Delafield pumping test from a water-table observation well (Earth Tech, Inc., 2006). (See fig. 9 for location of head target.)

- An estimate of *groundwater inflow to Beaver Lake*, computed as the average of the calculated values for 1983–84 (1.36×10^6 ft^3/d) and for 1987 (3.5×10^6 ft^3/d) reported by Carman (1988).

- *Stream outflows from Beaver and Pine Lakes* (see fig. 12 for outlet locations), equated with the average of the three field measurements reported in table 1.

- *Gain in streamflow for stretches of the Oconomowoc River and Bark Rivers* (see fig. 12 for measurement locations), based on streamflow measurements collected at times when base flow (that is, groundwater inflow) was likely responsible for most, if not all, of the streamflow. The calibration target for the Bark River was the average gain in streamflow between sites 3 and 4 in table 1 for the three measurement dates. The two calibration targets for the Oconomoc River were equal to the gain between sites 6 and 7 and between sites 8 and 9 for the September set of measurements only (owing to the availability of fewer than three measurements for some of the sites).

The calibration process was restricted to adjusting the location and configuration of hydraulic-conductivity zonation and values of the unconsolidated deposits (as described in the previous section) and the hydraulic conductivity of the beds of Beaver, Pine, Cornell, and North Lakes in an effort to improve fit. When a 1-ft lakebed thickness was assumed, the following lakebed hydraulic conductivities provided reasonably close agreement between the observed and simulated targets:

- Littoral value for Bark Lake, 2.5×10^{-2} ft/d.

- Littoral value for Pine and North Lake, 1.0×10^{-2} ft/d.

- Profundal value for Bark Lake, 2.5×10^{-3} ft/d.

- Profundal value for Pine and North Lake, 1.0×10^{-3} ft/d.

- Cornell Lake (very small), a single value of 1.0×10^{-3} ft/d.

The agreement across targets is shown in table 2. The simulated lake stages are fairly close to the observed values, as are the base-flow gains in the Oconomowoc River. The simulated outflows from Beaver and Pine Lake and the base flow for Beaver Lake show larger discrepancies, but the overall rates of flow are comparable to the observed values given the temporal variability in the natural flows. The Bark River was not a primary calibration target, owing to its distance from the lakes of interest, and it is not well simulated. This poor representation of base flow in the Bark River is likely due to artifacts related to the model boundary conditions that poorly approximate the actual contributing areas to the flow system that are outside the child-model domain.

The calibrated child model corresponds to the base version of the child model. It incorporates the surface-water, recharge, aquifer hydraulic conductivity, lakebed hydraulic conductivity, and pumping inputs described in the previous report sections. Because the calibration of the child model was performed by trial and error, the calibration is likely not optimal in terms of reducing the target residuals (observed minus simulated values). In order to evaluate the quality of the calibration and its dependence on model inputs in greater detail, a sensitivity analysis was done in which the following sets of parameters of the child model were perturbed while all other inputs to the child and parent regional models were left unchanged:

1. *The recharge rate applied to the water table.*—The spatial distribution was left unchanged, but the rates were increased and decreased by 10 percent.

2. *The horizontal and vertical hydraulic conductivities assigned model layers 1 and 2 corresponding to the unconsolidated material above bedrock.*—The spatial zonation was left unchanged, but the values were increased and decreased by 30 percent.

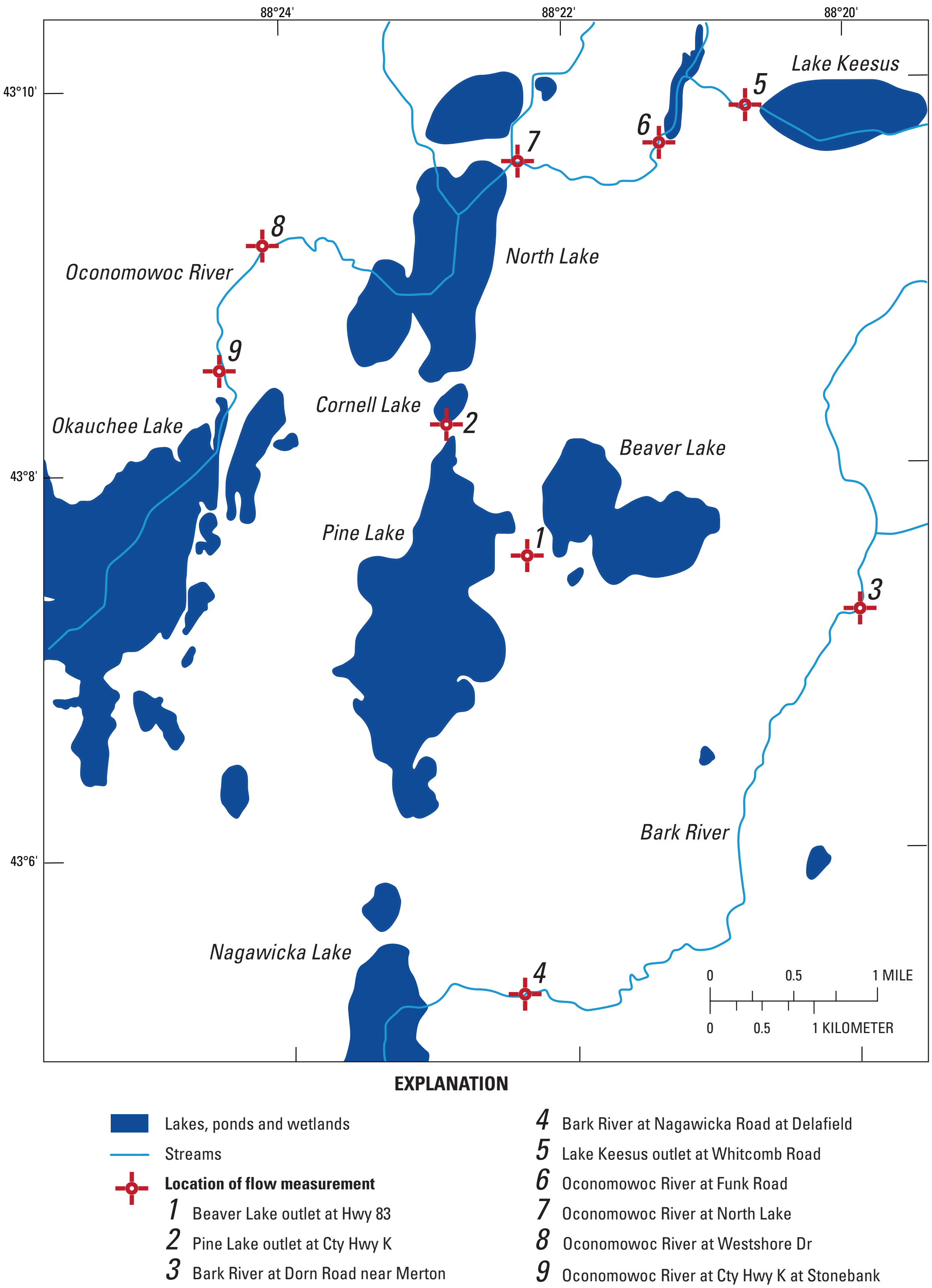


Figure 12. Locations of flow measurements.

Table 2. Comparison of measured to simulated values for calibration targets for base-case simulation.

[Base case omits test well and incorporates average weather conditions (32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area); ft^3/d, cubic feet per day]

Stream or lake characteristic	Measured	Simulated	Difference
Lake stage, feet above NGVD 29:			
Beaver Lake	909.00	909.62	−0.62
Pine Lake	900.00	900.27	−0.27
Cornell Lake	898.00	898.33	−0.33
North Lake	896.00	896.18	−0.18
Lake outflow, ft^3/d:			
Beaver Lake	64,512	107,082	−42,570
Pine Lake	86,458	59,122	27,336
Streamflow gain, ft^3/d:			
Bark River	406,080	188,374	217,706
Oconomowoc River, Funk Road to North Lake	311,040	284,754	26,286
Oconomowoc River, Westshore to Stonebank	207,360	231,131	−23,771
Groundwater:			
Groundwater level in test well, feet above NGVD 29	898.80	900.11	.31
Base flow to Beaver Lake, ft^3/d	232,039	154,999	77,040

3. *The hydraulic conductivity assigned the lakebed sediments underneath Beaver, Pine, Cornell, and North Lakes.*—The littoral and profundal zonation was left unchanged, but the values were multiplied by 5 and divided by 5.

4. *The net precipitation assigned Beaver, Pine, Cornell, and North Lakes.*—The evaporation rate was changed so that the difference between precipitation and evaporation on the lakes was raised from the base value of 3 in/yr to 55 in/yr and reduced to 55 in/yr.

The results for the eight sensitivity runs are presented in table 3 in terms of the change in residuals for each calibration target relative to the residuals in the base child simulation. Two overall conclusions can be drawn. First, the base simulation yields lake levels that are somewhat too high, so reducing the recharge to the water table or reducing the net precipitation to the lakes has a favorable effect insofar as it results in lower lake levels. Second, none of the sensitivity changes produces consistent improvements across the remaining targets—the test-well water level, groundwater flows into Beaver Lake, surface-water outflows from Beaver and Pine Lakes, or base-flow rates to stretches of the Bark and Oconomowoc Rivers—suggesting that the parameters in the base child simulation produce a reasonable overall fit with respect to these targets. The recharge and net precipitation rates in the base child model were maintained despite the overestimated lake levels because, as mentioned earlier, Village of Chenequa measurements from 2006 to 2008 indicated levels in Beaver and Pine Lakes 1 or 2 ft higher than the values reported on topographic maps. Indeed, such variation is often expected in Wisconsin lakes (House, 1985). Given this evidence, it was judged counterproductive to lower recharge and net precipitation values linked to previous studies in order to reproduce target lake levels that are lower than recently recorded levels.

Table 3. Sensitivity analysis.

[Residuals for model targets are defined as the observed target value minus the simulated target value. Target residuals have been computed for the BASE (calibrated) simulation and a series of sensitivity simulations for which the values of one set of parameters is increased or decreased by a fixed amount or proportion. The RATIO of sensitivity residual to BASE residual by target is a measure of changes to model fit in terms of improvement (values less than 1) or deterioration (values greater than 1).
Ratios between 0.95 and 1.05 are considered to indicate no change in model fit and are colored gray. Ratios less than 0.95 are considered to indicate improvement and are colored blue; ratios less than 0.67 indicate large improvement and are underlined. Ratios greater than 1.05 are considered to indicate deterioration and are colored red; ratios greater than 1.50 indicate large deterioration and are underlined. K is hydraulic conductivity, horizontal and vertical; K_v is vertical hydraulic conductivity; Net Precip. is the precipitation minus evaporation; in/yr, inches per year; ft^3/d, cubic feet per day]

Target	Target value	Base residual	Ratio of sensitivity residual to base residual							
			Increased recharge by 10 percent	Decreased recharge by 10 percent	Increased glacial K by 30 percent	Decreased glacial K by 30 percent	Increased lakebed K_v multiplied by 5	Decreased lakebed K_v divided by 5	Increased net precip. to lakes from 3 in/yr to 4.55 in/yr	Decreased net precip. to lakes from 3 in/yr to 1.55 in/yr
Beaver Lake stage (ft)	909.00	−0.62	1.24	0.79	0.87	1.16	1.11	0.49	1.08	0.92
Pine Lake stage (ft)	900.00	−0.27	2.33	0.22	0.22	3.81	0.37	1.64	1.56	0.52
Cornell Lake stage (ft)	898.00	−0.33	2.61	0.79	1.61	3.27	0.36	1.68	1.73	0.27
North Lake stage (ft)	896.00	−0.18	1.22	0.72	1.06	0.89	1.00	0.92	1.06	0.89
Test-well water level (ft)	898.80	−1.31	1.26	0.76	0.77	1.44	1.01	0.98	1.02	0.97
Beaver Lake base flow (ft^3/d)	232,039	77,040	0.91	1.09	0.89	1.14	0.06	2.01	1.01	0.99
Beaver Lake outflow (ft^3/d)	64,512	−42,570	1.27	0.74	0.86	1.20	1.13	0.23	1.09	0.91
Pine Lake outflow (ft^3/d)	86,458	27,336	0.32	1.86	2.34	0.23	1.49	0.62	0.69	1.34
Bark River gain (ft^3/d)	406,080	217,706	0.87	1.12	0.92	1.09	1.05	0.95	0.99	1.01
Oconomowoc gain (ft^3/d):										
Funk Road to North Lake	311,040	26,286	0.68	1.32	0.91	3.16	1.54	0.35	0.99	1.01
Westshore to Stonebank	207,360	−23,771	1.47	0.54	2.54	0.72	1.15	0.96	1.02	0.99

Model Results

The calibrated child model was used to simulate the hydrologic system in the Chenequa area under various weather and pumping conditions. The base-case condition is average weather (32 in/yr precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within child model area) and existing pumping from the shallow system within the child model—a total of 854 gal/min or 1.6×10^5 ft^3/d (fig. 9). The calibrated child model was used to simulate the water-table configuration for the study area (fig. 13). The model simulates the surface-water and groundwater fluxes under these conditions for each of the lakes (table 4); the terms of the water balance are precipitation, evaporation, groundwater inflow and outflow, and surface-water inflow and outflow. This water balance is also depicted graphically for Beaver, Pine, and North Lakes (fig. 14). The comparison of the summed inflow and outflow terms of this balance for any lake is an indication of how well the model has succeeded in balancing inflows and outflows; this comparison is expressed as an error (as a percent of inflow). The balance in water fluxes also determines the stage of each lake under average weather conditions (table 5).

Dry weather conditions were simulated in child model by reducing the groundwater recharge and lake precipitation by one-third for a period of 5 years (lake evaporation was kept constant). This scenario was not intended to be a realistic simulation of a historical event (in which recharge and lake precipitation would not likely change in the exact same proportion and evaporation rates would probably not remain constant); rather, it was meant to be a heuristic treatment in the sense of showing possible effects of a severe, prolonged drought on the Chenequa-area lakes. For the same base-case pumping conditions (854 gal/min), the surface-water and groundwater fluxes under dry weather conditions were

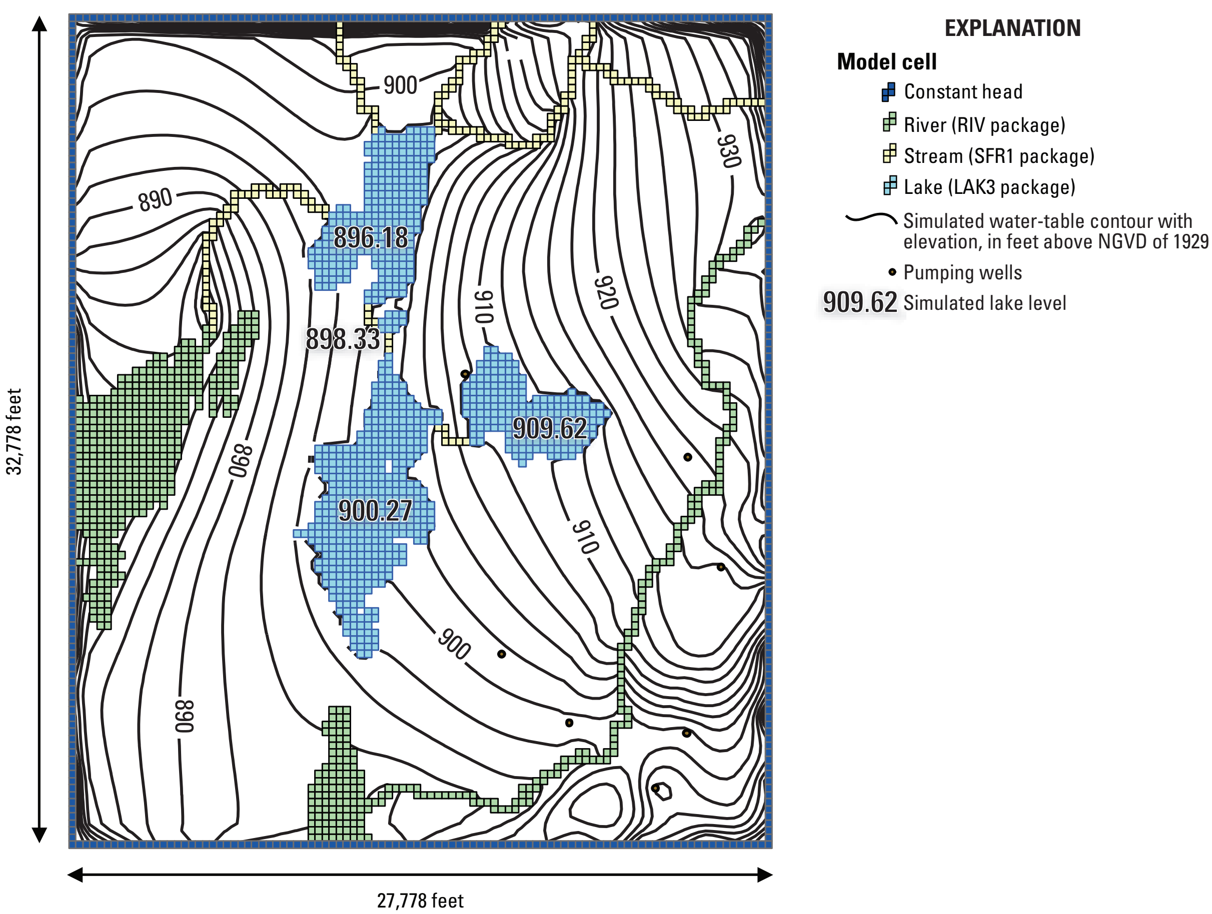


Figure 13. Child-model domain showing the simulated water-table elevation for the calibration run. (Steep contours along part of the child-model perimeter reflect the effect of the hydraulic-conductivity transition zone between the parent regional and child models used for numerical stability, as discussed in text.)

Table 4. Lake budgets for base-case simulations.

[Base model omits test well and incorporates average weather conditions (32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area); ft^3/d, cubic feet per day]

Lake	Precipitation (ft^3/d)	Evaporation (ft^3/d)	Groundwater		Surface Water	
			Inflow (ft^3/d)	Outflow (ft^3/d)	Inflow (ft^3/d)	Outflow (ft^3/d)
Beaver	$1.06 x 10^5$	$-9.60 x 10^4$	$1.55 x 10^5$	$-5.52 x 10^4$	0	$-1.10 x 10^5$
Pine	$2.18 x 10^5$	$-1.97 x 10^5$	$6.34 x 10^4$	$-1.37 x 10^5$	$1.10 x 10^5$	$-5.78 x 10^4$
Cornell	$5.64 x 10^3$	$-5.11 x 10^3$	$3.65 x 10^3$	$-3.48 x 10^1$	$5.91 x 10^4$	$-6.33 x 10^4$
North	$1.42 x 10^5$	$-1.29 x 10^5$	$1.23 x 10^5$	$-1.53 x 10^4$	$2.01 x 10^6$	$-2.13 x 10^6$

Lake	Inflow terms (ft^3/d)	Outflow terms (ft^3/d)	Difference (ft^3/d	Error (percentage of inflow)
Beaver	$1.06 x 10^5$	$-1.06 x 10^5$	$1.06 x 10^0$	-0.003%
Pine	$1.06 x 10^5$	$-1.06 x 10^5$	$1.06 x 10^1$	-0.018%
Cornell	$5.64 x 10^4$	$-5.11 x 10^4$	$3.65 x 10^0$	-0.006%
North	$1.42 x 10^6$	$-1.29 x 10^6$	$1.23 x 10^2$	-0.006%

simulated and compared to the average weather conditions (table 5). The comparison is expressed in terms of lake stage (Beaver, Pine, Cornell, and North Lakes) and lake outflow (Beaver and Pine Lakes).

Different pumping conditions were simulated in the child model by adding a test well in row 91, column 62, layer 2. Two different rates were applied to this test well—47 gal/min and 200 gal/min. The magnitude of these rates can be scaled relative to the combined groundwater inflow to nearby Beaver and Pine Lakes: they represent 4 and 18 percent, respectively, of the lake groundwater inflow. For the two pumping scenarios, amounting to 901 gal/min (854 + 47 gal/min) and 1,054 gal/min (854 + 200 gal/min) total discharge, the surface-water and groundwater fluxes were simulated and compared to the base-case pumping conditions amounting to 854 gal/min total discharge (table 6). The comparison is expressed in lake stage (Beaver, Pine, Cornell, and North Lakes) and lake outflow (Beaver and Pine Lakes). In addition, a simulation was done that compared surface-water and groundwater fluxes at base pumping conditions (854 gal/min) under average weather conditions to a model pumping condition of 901 gal/min under dry weather conditions (table 7). This comparison is likewise expressed in terms of lake stage (Beaver, Pine, Cornell, and North Lakes) and lake outflow (Beaver and Pine Lakes).

Simulation of the source of water to wells lends insight into changes in the surface-water and groundwater fluxes resulting from different stresses due to pumping and weather. In table 8, a comparison is made between base-case conditions (average weather and 854 gal/min pumping) and total pumping of 901 and 1,054 gal/min under average weather conditions, as well as between base-case conditions and 901 gal/min total pumping under dry weather conditions (table 8). The comparison in each case considers increased induced flow to groundwater from surface water, reduced base flow to surface water, increased net storage release, and decreased lateral net outflow. The comparison of these different simulations is expressed as the percentage of the total additional water that is coming from those four categories. The categories “increased induced flow to groundwater” and “reduced base flow to surface water” are both subdivided into the percentage of the total for that category coming from the Bark River and far-field lakes on the one hand and internal lakes (Beaver, Pine, Cornell, and North Lakes) on the other.

The groundwater inflow to the four lakes simulated under the range of weather and pumping conditions (average and dry weather and total pumping of 854, 901, or 1,054 gal/min) is compiled in table 9, which provides a comparison of groundwater inflow for each lake under various conditions and between lakes for the same conditions.

One aspect of the model results that merits discussion is the role of storage release. Given that the simulation is transient, storage is a source and sink of groundwater. The smaller the contribution of storage relative to other sources and sinks of water, the closer the model is to a long-term steady-state condition and to stable water levels. By design, the base model simulation is very close to steady-state conditions throughout the 5-year observation period inserted subsequent to the 20-year runup period. Storage release represents only 0.05

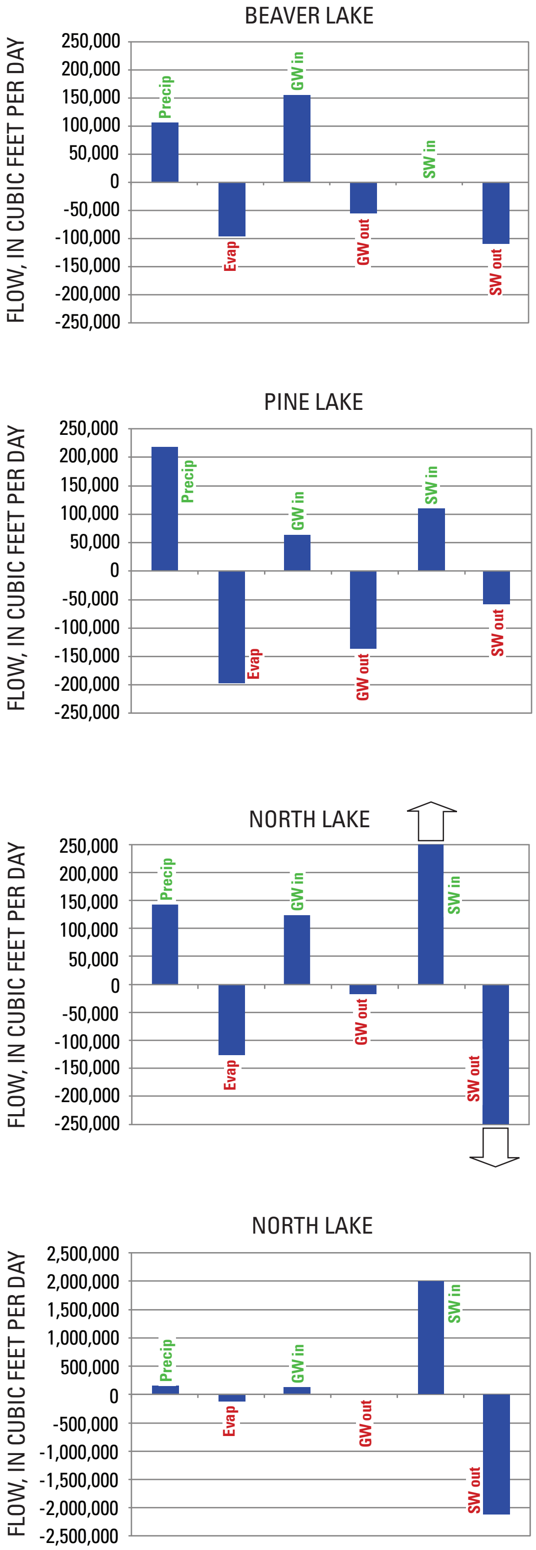


Figure 14. Simulated water budgets of Beaver, Pine, and North Lakes under base-case conditions. (North Lake is shown twice, at two scales.)

percent of the total inflow to the child domain (dominated by recharge) after 6 months into the observation period and only 0.006 percent after 5 years, whereas storage uptake represents only 0.008 percent of the total outflow of groundwater (dominated by base flow to surface water) after 6 months into the observation period and only 0.0008 percent of total outflow after 5 years.

More careful analysis would be needed to quantify the approach to steady state in response to a simulated stress such as pumping or drought conditions. Both these types of stresses tend to lower the water table and release water from storage by draining pores at the water table. Starting from the same starting conditions after the 20-year runup period as does the base model simulation, the two pumping scenarios show a decreasing contribution from storage over the 5-year observation period within the child domain. For the case where the simulated test well pumps 47 gal/min (9,126 ft^3/d), the storage inflow is 47 percent of the pumping stress 6 months into the observation period but only 2.5 percent of the stress after 5 years. For the higher simulated pumping rate equal to 200 gal/min (38,506 ft^3/d), storage release is also appreciable after 6 months (34 percent of the pumping stress) but again quite small after 5 years (1 percent of the pumping stress). The drought case shows a similar approach to steady-state conditions over the observation period. The difference in the recharge rate over the child domain between the base and drought simulations is 560,545 ft^3/d. Storage release contributes 38 percent of this amount after 6 months of simulation but only 2.4 percent after 5 years. In general, the simulated groundwater-flow system shifts almost all the response to the simulated pumping and drought stresses away from storage release (proportional to declines in the water table) and replaces it, under stable water-table conditions, with water drawn from diverted base flow to surface water and from flow induced into the subsurface from surface water.

Discussion

The Chenequa-area lakes (Beaver, Pine, Cornell, and North) are explicitly represented within the child-model domain. Within this area, properties inherited from the background regional model have been changed to incorporate additional information and enhanced model capabilities. First, the child grid spacing, set at 278 ft on a side, is much finer than that for the surrounding parent regional model, which inherited a spacing of 2,500 ft from the background regional model. The finer discretization permits a more accurate solution of water levels and flows in the vicinity of the lakes. Second, the LGR coupling allows stresses in the child model to propagate to the parent regional model (and vice versa), ensuring that the flows into and out of the child model are properly simulated. Third, the lakes and connecting waterways in the child model are represented by advanced modeling packages that allow for lake stages to be simulated instead of specified and for the

Table 5. Simulated change to stage of Beaver, Pine, Cornell, and North Lakes and change to outflow from Beaver and Pine Lakes due to 5 years of dry weather conditions.

[gal/min, gallons per minute]

Location	Total pumping in child model		Difference in lake stage
	Average weather conditions [1], base run (854 gal/min)	Dry weather conditions [2], base run (854 gal/min)	
Lake stage, feet above NGVD 29:			
Beaver Lake	909.62	908.97	- 0.65 ft
Pine Lake	900.27	896.62	- 3.65 ft
Cornell Lake	898.33	897.66	- 0.67 ft
North Lake	896.18	895.97	- 0.21 ft
Lake outflow, cubic feet per day:			
Beaver Lake	107,081	21,367	- 80 %
Pine Lake	59,122	≈ 0	- 100 %

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

[2] Dry weather conditions last 5 years; recharge and lake precipitation reduced by one-third, lake evaporation kept constant.

Table 6. Simulated change to stage of Beaver, Pine, Cornell, and North Lakes and change to outflow from Beaver and Pine Lakes with test well pumped for 5 years at 47 gallons per minute and at 200 gallons per minute under average weather conditions.

[gal/min, gallons per minute; ft, feet; %, percent]

Location	Total pumping in child model in average weather conditions [1]		Difference in lake stage	Total pumping in child model in average weather conditions [1]		Difference in lake stage
	Base run, 854 gal/min	Base run + 47 gal/min = 901 gal/min		Base run, 854 gal/min	Base run + 200 gal/min = 1,054 gal/min	
Lake stage, feet above NGVD 29:						
Beaver Lake	909.62	909.60	- 0.02 ft	909.62	909.56	- 0.06 ft
Pine Lake	900.27	900.24	- 0.03 ft	900.27	900.15	- 0.12 ft
Cornell Lake	898.33	898.28	- 0.05 ft	898.33	898.12	- 0.21 ft
North Lake	896.18	896.18	- 0.00 ft	896.18	896.17	- 0.01 ft
Lake outflow, cubic feet per day:						
Beaver Lake	107,081	105,935	- 1 %	107,081	102,251	- 5 %
Pine Lake	59,122	57,198	- 3 %	59,122	50,744	- 14 %

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

Table 7. Simulated change to stage of Beaver, Pine, Cornell, and North Lakes and change to outflow from Beaver and Pine Lakes with test well pumped for 5 years at 47 gallons per minute under dry weather conditions.

[gal/min, gallons per minute; ft, feet]

Location	Total pumping in child model: Average weather conditions[1] Base run, 854 gal/min	Total pumping in child model: Dry weather conditions[2] Base run + 47 gal/min = 901 gal/min	Difference in lake stage
Lake stage, feet above NGVD 29:			
Beaver Lake	909.62	908.96	−0.66 ft
Pine Lake	900.27	896.54	−3.73 ft
Cornell Lake	898.33	897.64	−0.69 ft
North Lake	896.18	895.97	−0.21 ft
Lake outflow, cubic feet per day:			
Beaver Lake	107,081	19,657	82 %
Pine Lake	59,122	≈ 0	100 %

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

[2] Dry weather conditions last 5 years; recharge and lake precipitation reduced by one-third, lake evaporation kept constant.

Table 8. Simulated sources to test well pumped for 5 years at 47 gallons per minute (for average and dry weather conditions) and at 200 gallons per minute (for average weather conditions).

[gal/min, gallons per minute; —, no percentages shown because the base run is the basis of comparison; values in **bold type** indicate totals]

	Total pumping in child model in average weather conditions[1]			Total pumping in child model in dry weather conditions[2]	
	Base run, 854 gal/min	Base run + 47 gal/min = 901 gal/min	Base run + 200 gal/min = 1,054 gal/min	Base run, 854 gal/min	Base run + 47 gal/min = 901 gal/min
Source of additional water		Percentage of total	Percentage of total		Percentage of total
Increased induced flow to groundwater	**—**	**11.9**	**15.6**	**—**	**15.8**
Bark River and far-field lakes	—	7.1	5.6	—	12.2
Internal lakes	—	4.8	10.0	—	3.6
Reduced base flow to surface water	**—**	**74.3**	**78.6**	**—**	**75.6**
Bark River and far-field lakes	—	56.4	61.5	—	62.6
Internal lakes	—	17.9	17.1	—	13.0
Increased net storage release	**—**	**0.6**	**0.6**	**—**	**1.5**
Decreased lateral net outflow	**—**	**13.2**	**5.2**	**—**	**7.1**
TOTAL		**100.0**	**100.0**	**—**	**100.0**

[1] Average weather conditions correspond to 32 inches per year (in/yr) precipitation to lakes, 29 in/yr evaporation from lakes, and 8.5 in/yr average recharge to water table within local model area.

[2] Dry weather conditions last 5 years; recharge and lake precipitation reduced by one-third, lake evaporation kept constant.

Table 9. Simulated groundwater inflow to lakes under various pumping and weather conditions.

[gal/min, gallons per minute]

Condition	Beaver Lake	Pine Lake	Cornell Lake	North Lake
Base-case simulation	1.55×10^{5}	6.34×10^{5}	3.65×10^{3}	1.23×10^{5}
Test well pumped 47 gal/min[1]	1.54×10^{5}	6.30×10^{5}	3.71×10^{3}	1.23×10^{5}
Test well pumped 200 gal/min[1]	1.53×10^{5}	6.13×10^{5}	3.92×10^{3}	1.23×10^{5}
Dry weather conditions[2]	1.28×10^{5}	8.82×10^{4}	1.59×10^{3}	9.16×10^{4}
Dry weather conditions with test well pumped 47 gal/min[1,2]	1.27×10^{5}	8.85×10^{4}	1.58×10^{3}	9.13×10^{4}

[1]Test well pumps for 5 years.

[2] Dry weather conditions last 5 years; recharge and lake precipitation reduced by one-third, lake evaporation kept constant.

entire budget of each lake to be explicitly evaluated. Finally, the zonation of properties—notably, hydraulic conductivity and recharge—was updated in the child model by use of results from a recent aquifer test and new estimates of how recharge varies over space.

The simulated model results for base conditions show the relative importance of groundwater flow in the lake budgets (table 4 and fig. 14). Groundwater is the largest inflow component for Beaver Lake (equal to 59 percent of total inflow). For Pine and North Lakes, it is an important component (equal, respectively, to 16 and 5 percent of total inflow) but less than the contribution from precipitation and surface-water inflow.

Effects of changes to base conditions on the lake budgets range from negligible to substantial. The addition of a test well south of Chenequa at the reported 2008 pumping rate of 47 gal/min of the new Delafield well has little effect on lake stages or flows after 5 years of simulated pumping (table 6), by which time the low rate of storage release indicates that the groundwater-flow system in the child domain is very close to steady-state conditions. The stage and the surface-water outflow from Pine Lake are simulated to decrease by only 0.03 ft and 3 percent, respectively, relative to base conditions. The chief explanations for these modest effects are the low pumping rate, the depth of the test well (which, like the new Delafield well, is assumed to pump from a horizon approximately 200 ft below land surface), and the high transmissivity of the unconsolidated aquifer, which allows the well to draw water from upstream along the bedrock valley and to capture inflow from the Bark River. However, if the pumping rate of the test well is assumed to increase to 200 gal/min, the decrease in Pine Lake outflow is appreciably larger: the simulated drop in outflow is 14 percent relative to base-flow conditions, although the drop in stage is only 0.12 ft.

Severe drought (represented by 5 years of precipitation and recharge rates reduced by one-third relative to base values) would cause correspondingly severe reductions in lake stage and flows (table 5). For example, the model indicates that, under the simulated dry condition, the level of Pine Lake would decline by 3.7 ft and that surface-water outflow would cease because the lake level would be well below its outlet sill elevation. The simulated conditions are so severe that the small feature corresponding Cornell Lake, which is assumed to be underlain by relatively tight lakebed material, maintains a higher level than the upgradient Pine Lake (table 5). The addition of pumping at the 47-gal/min rate to dry weather conditions has little effect on the simulated outcome because the effect of the drought is so dominant (comparison of tables 5 and 7).

Pumping wells can affect lakes by reducing stage and flows; lakes can affect pumping wells (and the drawdown around them) by acting as a source of the water withdrawn. The lakes act as a source in two ways: lake water is transferred to the groundwater system (that is, increased induced flow) and groundwater that would otherwise discharge to lakes is diverted to the well (that is, reduced base flow). The model results (table 8) indicate that the lakes are a source of water for the test well: increased induced flow and reduced base flow from the Chenequa-area lakes together account for 23 percent of the water flowing toward the well at a pumping rate of 47 gal/min. At a test rate of 200 gal/min, the Chenequa lakes account for 27 percent of the well supply. By way of comparison, the contribution of other water bodies—the Bark River and outlying lakes—is about 65 percent of the test-well discharge for both the 47- and 200-gal/min rates.

Model Limitations

The child and parent models are simplifications of reality. Both discretize properties of the subsurface into a limited number of zones that only approximate heterogeneous natural conditions. The degree of connection between the shallow aquifer and surface-water features, both rivers and lakes, is not well known. Although stresses such as recharge and pumping change not only across space but also through time, they are represented in the child and parent models by time-constant values.

The application of advanced modeling techniques to the Chenequa study adds assumptions and limitations to the modeling process. The use of the LAK3 package to simulate stages and water budgets for Beaver, Pine, and North Lakes requires the specification of additional inputs, some of which are based on available data (for example, the bathymetry of the lake bottom) and some of which are only partly constrained by field observations (for example, the elevation of the outlets controlling surface-water flow draining the lakes and the assumption that overland flow to the lakes is a negligible part of their water budgets). More precise measurements of these elevations and flows could serve to update and improve the existing child model. Although changes were made to the unconsolidated hydraulic-conductivity fields within the child-model domain on the basis of aquifer-test analysis, the parent regional model inherited all its parameter values from the background regional model, resulting in an abrupt shift in permeability at the child/parent boundary. The effect of this shift was mitigated by extending the regional hydraulic-conductivity values a short distance into the child-model grid (fig. 7).

The calibration process for the coupled child and parent regional model was done by trial and error. Although the quality of the calibration is acceptable, a more sophisticated automated approach to calibration applying a parameter-estimation code might improve the agreement between measured and simulated targets by further minor adjustment of parameter values. The calibration targets used to characterize flow through the lakes are associated with considerable uncertainty because available measurements show much variability, making it difficult to estimate the long-term average. Future measurements of these flows could be used to test the performance of the model, and, if necessary, provide justification for reevaluating inputs such as lakebed conductance and recharge and outputs such as target lake levels.

Summary and Conclusions

In cooperation with the Village of Chenequa, Wis., the Southeastern Wisconsin Regional Planning Commission and the Wisconsin Department of Natural Resources, the USGS characterized the hydrology of part of northwestern Waukesha County, with a particular focus on the interaction between the shallow aquifer and area lakes. A previous regional groundwater-flow model developed in conjunction with the Southeastern Wisconsin Regional Planning Commission was the framework for this effort and the starting point for development of an inset model for the project area embedded in a "parent" regional model. The complexity of the input to the inset model, or "child" model, is greater than that of the regional model and is commensurate with the extent of the existing data in the local area. The groundwater/surface-water system was simulated by using the combined three-dimensional, transient child and parent regional models. Given the focus of the study on shallow groundwater conditions, the computational burden could be reduced by modifying the layering inherited from the background regional model, reducing the original eight layers used to represent the deep sandstone aquifer system to a single layer in both the regional parent model and the embedded child model. The child model has greater grid resolution than the regional parent model: cell area is refined from 2,500 ft by 2,500 ft to 278 ft by 278 ft, a factor of 81. The increased discretization permits a more accurate solution of water levels and flows in the vicinity of the Chenequa-area lakes. Beaver, Pine, and North Lakes were simulated within the MODFLOW groundwater-flow model by use of the LAK3 package, which allows for explicit calculation of lake budgets; selected stream reaches connecting the lakes were simulated with the SFR1 package which allows explicit calculation of stream stages. The Local Grid Refinement (LGR) package allowed hydrologic stresses in the child model to propagate to the parent regional model and vice versa. The zonation of properties—notably, hydraulic conductivity and recharge—were updated in the child model based on the basis of results from a recent aquifer test and the availability of new estimates of how recharge varies over space.

The simulated model results for base conditions show the relative importance of groundwater flow in the lake budgets: 59 percent of total inflow for Beaver Lake and 16 and 5 percent of total inflow, respectively, for Pine and North Lakes. Severe drought conditions are represented by 5 years of precipitation and recharge rates reduced by one-third relative to base value. Simulation of drought conditions shows severe reductions in lake stage and flows. For example, the model indicates that under the simulated dry weather condition, the level of Pine Lake will decline by 3.7 ft and surface-water outflow will cease because the lake level is below its outlet sill elevation. The addition of a test well south of Chenequa at the reported 2008 pumping rate of 47.4 gal/min (9,126 ft^3/d, equivalent to 4 percent of the combined groundwater inflow to nearby Beaver and Pine Lakes in the absence of test-well discharge) has little effect on lake stages and fluxes, probably because of the modest pumping rate simulated in conjunction with the pumping depth of the test well (approximately 200 ft below land surface) and the large transmissivity assigned the unconsolidated aquifer, which allows the well to draw water from upstream along the bedrock valley and to capture inflow from the Bark River. The model results indicate that although lake levels and fluxes are only modestly affected by simulated pumping, the lakes are important sources of water from the vantage point of the test well: increased induced flow and reduced base flow from the Chenequa-area lakes together account for 23 percent of the water flowing toward the well at a pumping rate of 47 gal/min. At a simulated test rate of 200 gal/min, they account for 27 percent of the well supply. By way of comparison, the contribution of other water bodies—the Bark River and outlying lakes—is about 65 percent of the test-well discharge for both the 47- and 200-gal/min rates.

The use of Local Grid Refinement in this study, allowing the boundary conditions of the child model to adjust to changing regional conditions, ensures that the flows into and out of the child model are properly simulated. This modeling approach is an important tool that allows simulated forecasting scenarios to account not only for changes to hydrologic stresses in the Chenequa area but also for changes in conditions in surrounding areas outside the child domain. In addition, the effect within the child model of regional trends, such as drawdown in the deep sandstone aquifer, can be simulated. This approach results in computational efficiency while representing both local and regional hydrogeologic characteristics and stresses.

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Feinstein and others—**Application of the Local Grid Refinement Package to an Inset Model, Northwestern Waukesha County, Wisconsin**—Scientific Investigations Report 2010–5214

Appendix B

WISCONSIN DEPARTMENT OF NATURAL RESOURCES PINE LAKE AQUATIC PLANT SURVEY REPORT

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State of Wisconsin
DEPARTMENT OF NATURAL RESOURCES
2801 Progress Rd.
Madison WI 53716

Scott Walker, Governor
Cathy Stepp, Secretary

WISCONSIN DEPT. OF NATURAL RESOURCES

December 3, 2013

To whom it may concern:

This summer you requested information regarding an aquatic plant survey that staff from the Research Bureau of the Department of Natural Resources conducted on June 11, 2013 on Pine Lake in Waukesha County, WI. The plant survey was conducted as part of a statewide monitoring project. This data will be used by the Department to understand the variation in aquatic plant growth among lakes across the state, how aquatic plant populations respond to management regimes, and how plant communities change over time. Pine Lake is one of the lakes chosen for this project because it meets certain criteria (size, region, nutrient levels, presence of milfoil, timing of milfoil establishment, etc.) for this study.

Importance of Aquatic Plants

Aquatic plants form the foundation of healthy lake ecosystems. They not only protect water quality, but also produce life-giving oxygen. Aquatic plants are a lake's own filtering system, helping to clarify the water by absorbing nutrients like phosphorus and nitrogen that could stimulate algal blooms. Plant beds stabilize soft lake bottoms and prevent shoreline erosion by reducing the effect of waves and currents. Healthy native aquatic plant communities help prevent the establishment of invasive non-native plants such as Eurasian water milfoil and curly-leaf pondweed. Native aquatic plants also provide important reproductive, food, and cover habitat for fish, invertebrates, and wildlife. By leaving or restoring a natural buffer area of emergent vegetation along the shoreline, property owners can reduce erosion, help maintain water quality, and provide habitat and travel corridors for wildlife.

Invasive Aquatic Plant Species

Invasive aquatic species are a huge threat to Wisconsin lakes both ecologically and economically. Ecological impacts of introduced invasive species can range in severity depending on differing ecosystem variables. Specific impacts are difficult to predict. Invasive plants are problematic because they can grow to nuisance levels. These dense populations of non-native plants often have a negative impact on native plant communities because they are able to out-compete them for available resources needed for survival. Changes in the native plant community have far-reaching effects on fish, birds and invertebrates that need native plants to survive. Nuisance levels of non-native aquatic plants may also inhibit recreational activities (such as fishing, swimming, boating, etc.), decrease aesthetic value, and negatively effect water quality. Some industries such as sport and commercial fishing and raw water users (power companies and utilities), are also negatively affected by invasive species. It is important that everyone utilizing Wisconsin's lake resources do their part to help prevent and stop the spread of aquatic invasive species.

Point-Intercept Sampling Method

Based on area and depth specific to Pine Lake, we mapped a 1231-point sampling grid over the entire lake surface. Using a GPS, we navigated by boat to each of the pre-determined grid points. At each point we used a two-sided rake to sample approximately 1 foot along the bottom. After pulling the plants to the surface, the overall rake as well as individual species on the rake were assigned a fullness rating of 1, 2 or 3 to estimate density of plant growth (see Figure 1 for descriptions of rake fullness ratings). We also recorded visual sightings of species within six feet of the sample point, as well as any additional species seen in the lake during a general boat survey. For more detailed information on the point-intercept sampling method and how data were collected please visit: *http://www4.uwsp.edu/cnr/uwexlakes/ecology/APM/PI-Protocol-2010.pdf*

Species frequencies of occurrence reflect the percentage of times a species was found out of the total number of points sampled. Littoral frequency of occurrence (given in Table 1) indicates how often a species was found considering only areas of the lake that are capable of supporting plant growth (known as the "littoral area"). The maximum depth of plant growth is the deepest depth at which plants were found in the lake. Species richness is a count of the total number of different plant species found in a lake. The Floristic Quality Index (FQI) is a metric that evaluates the closeness of the flora in a lake to that of an undisturbed condition. The higher a FQI value, the closer that plant community is to an undisturbed ecosystem. Statewide and ecoregion averages are calculated from a subset of approximately 250 lakes across Wisconsin.

Table 1: Species Present

% Frequency of Occurrence (Littoral): This estimation of frequency of occurrence is calculated by taking the total number of times a species is detected in a lake divided by the total number of points in a lake at which the growth of plants is possible. Voucher specimens have been sent to the UW-Stevens Point Herbarium, therefore all species identifications are subject to change pending verification.

Common Name	Scientific Name	Growth Form (Floating, free floating, submerged, emergent)	% Frequency of Occurrence
Muskgrasses	*Chara* spp.	Submerged	40.39
Eurasian water milfoil*****	*Myriophyllum spicatum**	Submerged	26.02
Fries' pondweed	*Potamogeton friesii*	Submerged	16.12
Spiny naiad	*Najas marina*	Submerged	7.96
Coontail	*Ceratophyllum demersum*	Submerged	7.57
Water star grass	*Heteranthera dubia*	Submerged	6.21
Sago pondweed	*Stuckenia pectinata*	Submerged	5.05
Northern water milfoil	*Myriophyllum sibiricum*	Submerged	3.11
Flat-stem pondweed	*Potamogeton zosteriformis*	Submerged	1.55
Hybrid pondweed	*Potamogeton X undulatas*	Submerged	1.55
Illinois pondweed	*Potamogeton illinoensis*	Submerged	1.36
White water crowfoot	*Rananculus aquatilis*	Submerged	1.36
Stiff pondweed	*Potamogeton strictifolius*	Submerged	1.36
Variable pondweed	*Potamogeton gramineus*	Submerged	1.17
Curly leaf pondweed*****	*Potamogeton crispus**	Submerged	0.58
Floating-leaf pondweed	*Potamogeton natans*	Floating	0.58
Common waterweed	*Elodea canadensis*	Submerged	0.39
Southern naiad	*Najas guadalupensis*	Submerged	0.39
White water lily	*Nymphaea odorata*	Floating	0.39
Bald spikerush	*Eleocharis erythropoda*	Emergent	0.19
Spatterdock	*Nuphar variegata*	Floating	Visual

Arrowhead	*Sagittaria* sp.	Emergent	Visual
Yellow iris*	*Iris pseudacorus**	Emergent	Visual
Common forget-me-not*	*Myosotis scorpioides**	Emergent	Boat survey
Hemlock waterparsnip	*Sium suave*	Emergent	Boat survey
Cattail	*Typha* sp.	Emergent	Boat survey
Bittersweet nightshade*	*Solanum dulcamara**	Emergent	Boat survey
Sweet flag	*Acorus* sp.	Emergent	Boat survey
Horned pondweed	*Zannichellia palustris*	Submerged	Boat survey
Common bur-reed	*Sparganium eurycarpum*	Emergent	Boat survey
Filamentous algae			27.38
Freshwater sponge			0.19

***** = species non-native and potentially invasive in WI

Survey Summary

	LAKE	STATEWIDE AVERAGE	SWTP ECOREGION AVERAGE
Littoral Frequency of Occurrence (%)	**63.1**	**74.3**	**79.0**
Maximum Depth of Plant Growth (feet)	**28.0**	**15.3**	**15.4**
Species Richness	**23**	**16.8**	**15.0**
Floristic Quality Index (FQI)	**21.9**	**24.1**	**20.0**

Figure 1: A map of the approximate location of Eurasian water milfoil.

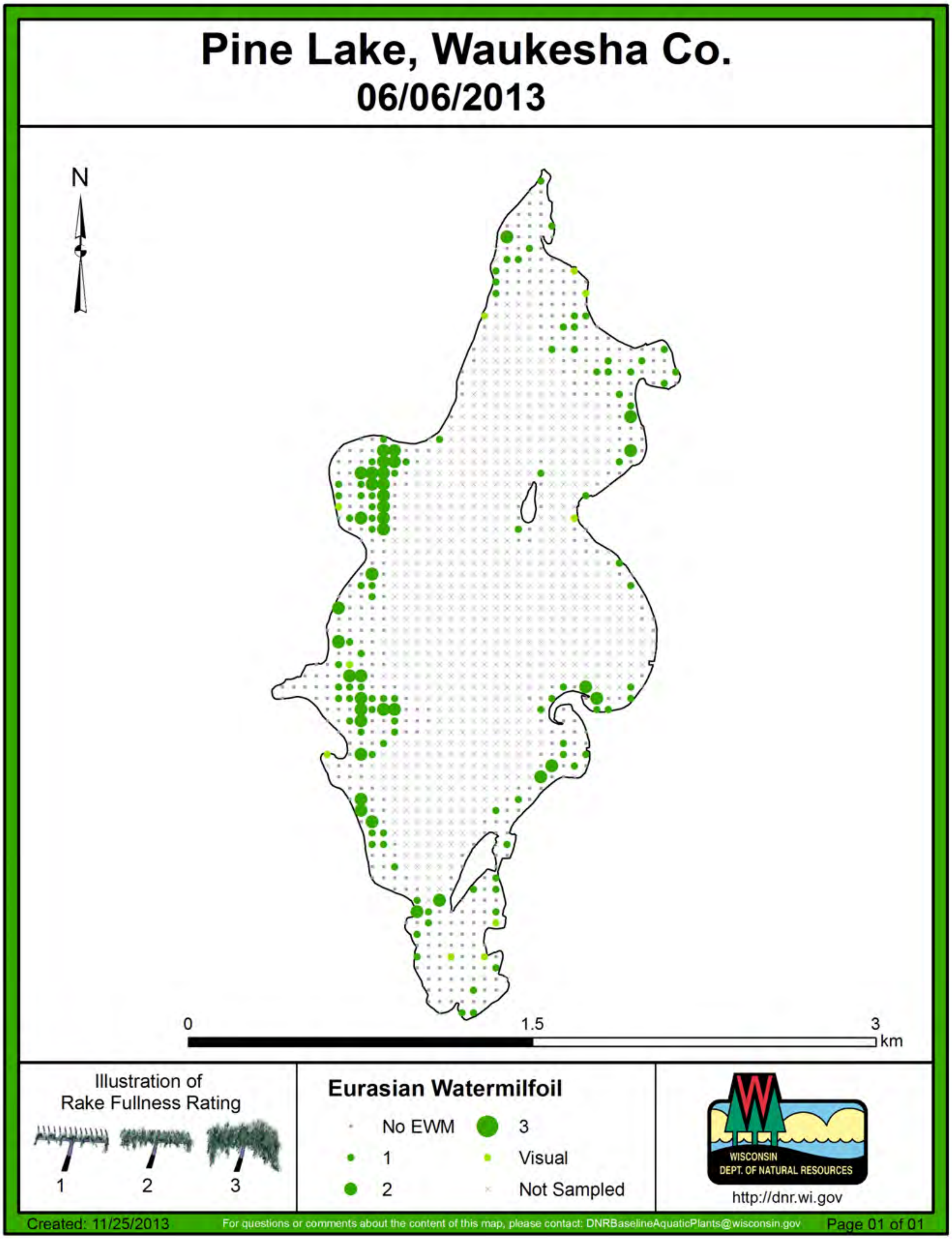
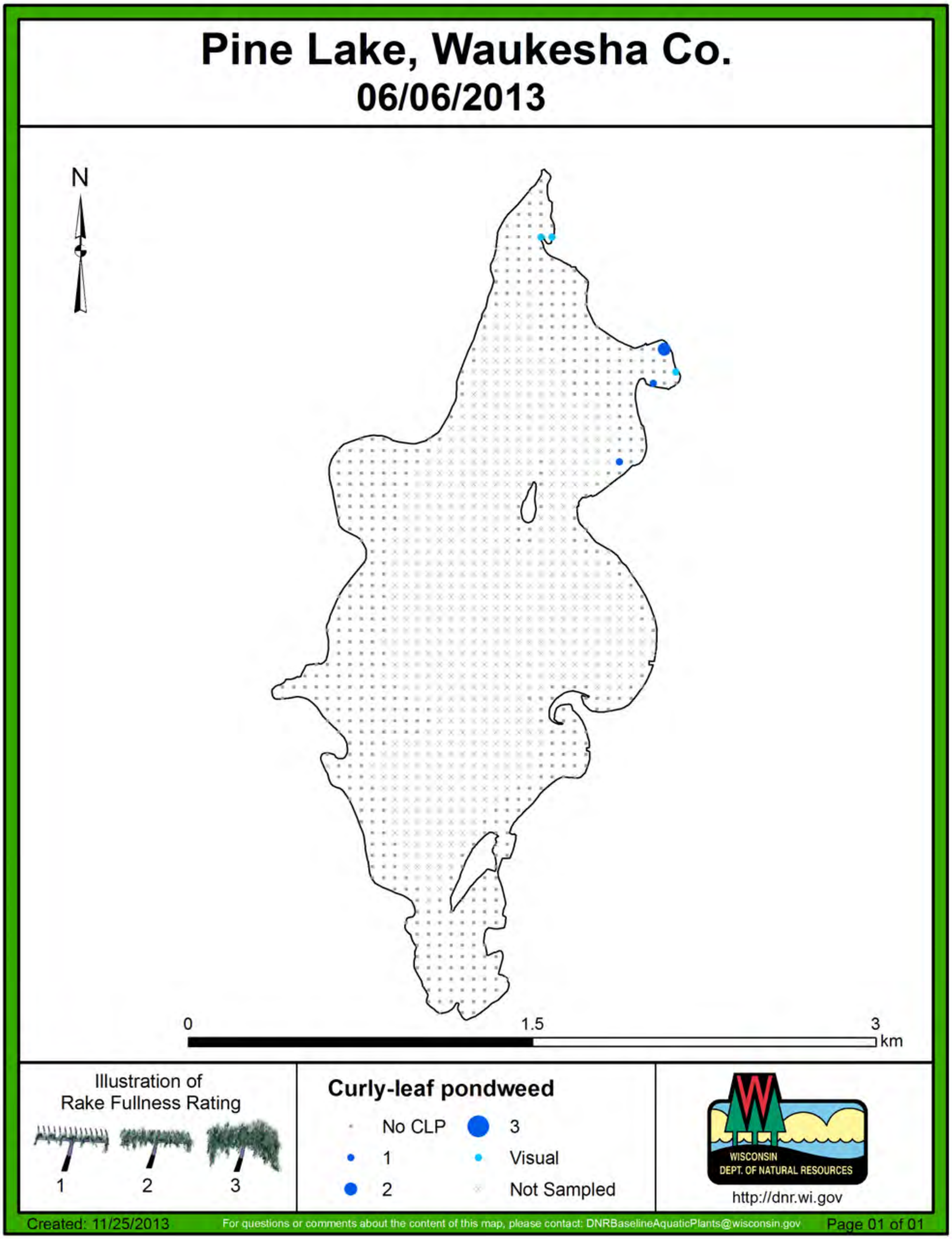


Figure 2: A map of the approximate location of Curly-leaf pondweed.



Additional Resources:

Wisconsin State Herbarium and Plant Identification
http://www.botany.wisc.edu/wisflora/

Invasive Species in Wisconsin
http://dnr.wi.gov/invasives/

Wisconsin's Lakes
http://dnr.wi.gov/lakes/

Aquatic Plant Management in Wisconsin
http://www4.uwsp.edu/cnr/uwexlakes/ecology/APMguide.asp

Please note that while this study conforms to statewide protocol and standards for baseline data collection, it may not be suitable for management purposes. For information as to whether this survey meets requirements for management plans or permitting requirements, please contact your local DNR lake coordinator (copied below).

If you have any additional questions regarding the DNR Research Bureau's survey or study, please feel free to contact us.

Sincerely,

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Appendix C

VILLAGE OF CHENEQUA ORDINANCE CHAPTER 4

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CHAPTER 4: LAKES

4.01 PROHIBITING PARKING OF BOATS.

(l) The parking or fastening of boats upon public property in the Village of Chenequa for longer than two hours consecutively is hereby prohibited, and declared unlawful.

(2) Any person violating the provisions of this section 4.01 shall be punished by a fine of Fifteen Dollars ($15.00) and the costs of prosecution.

(3) Police officers of the Village are authorized to remove any boat found parked for more than twenty-four hours in violation of this section 4.01 and to destroy or otherwise dispose of the same unless redeemed by the payment of the fine and costs for violation of this section 4.01 including hauling and storage, within thirty days from the date of seizure.

4.02 BOATING - PINE LAKE. (Rev. 6/12)

(l) PURPOSE. The Village Board of the Village of Chenequa determine and declare it to be in the interest of the public health, safety and welfare to adopt regulations relative to water traffic, boating and water sports on Pine Lake in the Village of Chenequa.

(2) APPLICABILITY. The provisions of this section 4.02 shall apply to the waters of Pine Lake in the Village of Chenequa.

(3) STATE BOATING AND WATER SAFETY LAWS ADOPTED. The statutory provisions describing and defining regulations with respect to water traffic, boats, boating and related water activities in the following enumerated sections of the Wisconsin statutes are hereby adopted and by reference made a part of this ordinance as if fully set forth herein. Any act required to be performed or prohibited by the provisions of any statute incorporated by reference herein is required or prohibited by this section 4.02.

30.50	Definitions
30.501	Capacity plates on boats
30.51	Certification of number and registration; requirements; exemptions
30.52	Certificate of number and registration; application; certification and registration period; fees; issuance
30.523	Certification or registration card to be on board; display of stickers or decals and identification number
30.541	Transfer of boat titles
30.55	Notice of abandonment or destruction of boat or change of address

30.60 Classification of motorboats

30.61 Lighting equipment

30.62 Other equipment

30.625 Rental of personal watercraft

30.64 Patrol boats

30.65 Traffic rules

30.66 Speed restrictions

30.67 Accidents and accident reports

30.675 Distress signal flag

30.68 Prohibited operation

30.681 Intoxicated boating

30.682 Preliminary breath screen test

30.683 Implied consent

30.684 Chemical tests

30.686 Report arrest to department

30.687 Officer’s action after arrest for violating intoxicated boating law

30.69 Water skiing

30.70 Skin diving

30.71 Boats equipped with toilets

(4) SPEED RESTRICTIONS

(a) WITHIN TWO HUNDRED (200) FEET OF SHORELINE. A person operating a motorboat shall operate at slow-no-wake speed when within two hundred (200) feet of a shoreline.

(b) BOATS PASSING SWIMMERS, BOATS OR OTHER OBJECTS. A person operating a motorboat shall operate at slow-no-wake speed when within one hundred (100) feet of a swimmer, diving flag, canoe, rowboat, sail boat, non-operating motorboat or raft.

(c) [RESERVED] (REV. 5/12)

(d) OPERATION IN CIRCUITOUS COURSE. No person shall operate or use a motorboat or personal watercraft repeatedly in a circuitous course with a diameter of less than 200 feet at a speed in excess of slow-no-wake speed.

(e) DAYTIME SPEEAD RESTRICTIONS, NIGHTTIME SPEED RESTRICTIONS. A person shall operate or use a motorboat or personal watercraft at speeds no greater than 45 miles per hour from one hour before sunrise to one hour after sunset each day. A person shall operate or use a motorboat or personal watercraft at slow-no-wake speed from one hour after sunset each day until one hour before sunrise of the next day. (REV. 5/12)

(5) SAFE OPERATION REQUIRED. No person shall operate, direct or handle a boat in such manner as to unreasonably annoy, unnecessarily frighten or endanger the occupants of his or other boats.

(6) RACING PROHIBITED. No person shall operate a motorboat in a race or speed contest with any other motorboat, except as provided in section 4.02(9).

(7) WATER SKIING.

(a) DISTANCE FROM SWIMMERS, BOATS OR OTHER OBJECTS. No person on water skis, aquaplane, surfboard or similar device shall pass, and no person operating a boat which is pulling or towing such skier or rider shall cause such skier or rider to pass within one hundred (100) feet of a swimmer, diving flag, canoe, row boat, sailboat, non-operating motorboat, raft or pier, except in the course of the skier or rider taking off from, or landing at, such pier.

(b) HOURS. No person shall operate a boat, while towing a person on water skis, aquaplane, surfboard or any similar device, at any time from sunset to sunrise.

(c) OCCUPANTS OF BOAT. No person shall operate a boat while pulling or towing any person on water skis, aquaplane, surfboard or any similar device, or permit himself to be towed for such purpose, unless there are two persons over 12 years of age in such boat, and the operator of the boat shall maintain a forward lookout.

(d) EXEMPTIONS FROM SPEED RESTRICTIONS. The following are exempt from the speed restrictions in section 4.02(4)(a): (i) a boat commencing to tow a person on water skis, aquaplane, surfboard or similar device, or landing such person, and (ii) a boat towing a water skier to make a jump over a ski jump platform anchored in the water within 200 feet from a shoreline, provided the location of such platform is approved in a permit issued therefore by the Chief of Police.

(8) ANCHORAGES AND STATIONARY OBJECTS.

(a) MOORING LIGHTS REQUIRED. No person shall moor or anchor any boat more than 100 feet from the shoreline between one hour after sunset and one hour before sunrise unless there is prominently displayed thereon a white light of sufficient size and brightness to be visible from any direction for a distance of 1500 feet on a dark night with clear atmosphere.

(b) RAFTS AND BUOYS. No person shall erect or maintain any raft, platform or buoy more than 100 feet from the shore unless it is so anchored that it has at least 10 inches of free board above the water line, and either (i) is painted white and has attached thereto not less than 12 inches from each corner or projection a red reflector in good condition not less than 3 inches in diameter, or (ii) is painted with a band at least three inches in width of luminous paint so as to be visible from any direction.

(9) RACES, REGATTAS, SPORTING EVENTS, EXHIBITIONS, COURSES AND JUMP PLATFORMS.

(a) PERMIT REQUIRED. No person shall direct or participate in any boat race, regatta, water ski meet, or other water sporting event or exhibition, nor shall any person set up or use a boat or waterski course or jump platform, unless such event, course or jump platform has been authorized and a permit issued therefor by the Chief of Police.

(b) PERMIT. A permit issued under this section shall specify the course or area of water to be used by the permittee for such event, course or jump platform and the permittee shall be required to place markers, flags or buoys approved by the Chief of Police designating the specified area. Any waterway markers authorized by the Chief of Police must meet the size and shape requirements as set forth in NR 5.09(7)(b), Wis. Adm. Code, or any successor thereto. Permits shall be issued only if in the opinion of the Chief the proposed use of the water can be carried out safely and without danger to or substantial obstruction of other watercraft or persons using the lake. Permits shall be valid only for the hours and areas specified thereon.

(c) RIGHT OF WAY PARTICIPANTS. Boats, waterskiers and participants in any such permitted event or who have received a permit to set up and use a boat or waterski course or jump platform shall have the right of way on the marked area and no other person shall obstruct such area during the race, event or other permitted use or interfere therewith.

(10) LITTERING WATERS PROHIBITED. No person shall deposit, place or throw any cans, paper, bottles, debris, refuse, garbage, solid or liquid waste into the water of, or upon the ice of, the lake.

(11) SPEAR GUNS. No person shall have in his possession any loaded spear gun.

(12) MARKERS AND NAVIGATION AIDS; POSTING ORDINANCE.

(a) DUTY OF CHIEF. The Chief of Police is authorized and directed to place and maintain suitable markers, navigation aids and signs in such water areas as shall be appropriate to advise the public of the provisions of this ordinance and to post and maintain a copy of this ordinance at all public access points within the jurisdiction of the village.

(b) STANDARD MARKERS. All markers placed by the Chief or any other person upon the waters of the lake shall comply with the regulations of the Wisconsin Department of Natural Resources.

(c) INTERFERENCE WITH MARKERS PROHIBITED. No person shall without authority remove, damage or destroy or moor or attach any watercraft to any buoy, beacon or marker placed in the waters of the lake by the authority of the United States, state or village or by any private person pursuant to the provisions of this ordinance.

(13) PENALTIES. Any person violating any provision of this Section 4.02 shall upon conviction thereof be subject to the penalties provided in Section 30.80 of the Wisconsin Statutes, which is hereby adopted and by reference made a part of this ordinance as if fully set forth herein, except that all references to fines are amended to forfeitures and all references to imprisonment deleted. Any violation of this Section 4.02 for which no specific penalty is provided in Section 30.80 of the Wisconsin Statutes shall be subject to the penalties provided in Section 30.80(1) of the Wisconsin Statutes.

4.03 BOATING - NORTH LAKE AND BEAVER LAKE.

(1) PURPOSE: The Town Board of the Town of Merton, and the Village Board of the Village of Chenequa, each being a municipality as defined in Chapter 30 of Wisconsin Statutes, and each having jurisdiction of a portion of North Lake and Beaver Lake, both being inland lakes, located in Waukesha County, do ordain jointly and identically in conformity with sections 30.77 and 30.81 of the Wisconsin Statutes, as follows:

(2) INTENT. The intent of this ordinance is to provide safe and healthful conditions for the enjoyment of aquatic recreation consistent with public rights and interest and the capability of the water resource.

(3) APPLICABILITY AND ENFORCEMENT. The provisions of this Ordinance shall apply to the waters of North Lake and Beaver Lake, within the jurisdiction of the Town of Merton and Village of Chenequa. The provisions of this ordinance shall be enforced by the officers of the Water Safety Patrol of the Town of Merton and/or the Village of Chenequa.

(4) STATE BOATING AND WATER SAFETY LAWS ADOPTED. The statutory provisions describing and defining regulations with respect to water traffic, boats, boating and related water activities and safety in the following enumerated sections of the Wisconsin Statutes, exclusive of any provisions therein relating to the penalties to be imposed or the punishment for violation of said statutes, are hereby adopted and by reference made a part of this ordinance.

30.50	Definitions
30.51	Operation of unnumbered motorboats prohibited
30.52	Certificate of number
30.523	Identification number to be displayed on boat; certificate to be carried
30.541	Transfer of ownership of numbered boat
30.55	Notice of abandonment or destruction of boat or change of address
30.60	Classification of motorboats
30.61	Lighting equipment
30.62	Other equipment
30.635	Motorboat prohibition
30.64	Patrol boats exempt from certain traffic regulations
30.65	Traffic rules
30.66	Speed restrictions
30.67	Accidents and accident reports
30.675	Distress signal flag
30.68	Prohibited operation
30.681	Intoxicated boating
30.682	Preliminary Breath Screening Test
30.683	Implied Consent
30.684	Chemical Tests
30.686	Report Arrest to Department
30.687	Officers Action After Arrest for Violating 30.681
30.69	Water skiing

30.70 Skin diving

30.71(1) Boats equipped with toilets

All deletions, additions and amendments which may be made to the sections of the state laws enumerated under subsection 4.03(4) above are hereby adopted and incorporated herein by reference as of the time of their respective effective dates, as if they were to be set out herein verbatim.

(5) DEFINITIONS.

(a) "Swimming zone" means an authorized area marked by regulatory markers to designate a swimming area.

(b) "Designated anchorage" means an area of water established and marked as an anchorage by lawful authority.

(c) "Public access' means any access to the water by means of public property.

(d) "Navigation lane" means an area designated by authorized aids to navigation.

(e) "Slow-no-wake" is defined as the slowest possible speed so as to maintain steerage.

(6) SPEED RESTRICTIONS.

(a) NIGHT LIMIT. No person shall operate a boat at a speed in excess of slow-no-wake speed from one hour after sunset each day until one hour before sunrise of the next day.

(b) SPEED LIMIT -MAXIMUM. No person shall operate a boat at a speed in excess of 35 miles per hour on North Lake at any time.

(c) SPEED LIMIT - TURTLE BAY OF BEAVER LAKE. No person shall operate a boat at a speed in excess of slow-no-wake or at any time to exceed a maximum speed of three (3) miles per hour in Turtle Bay.

(d) OPERATION IN CIRCUITOUS COURSE. No person may operate or use a motor boat or personal watercraft repeatedly in a circuitous course with a diameter of less than 200 feet at a speed in excess of slow-no-wake speed.

(7) PROHIBITED OPERATION. INTOXICATED PERSON NOT TO RIDE IN BOATS. No person shall permit any person who is so intoxicated or under the influence of a

controlled substance who would be unable to provide for his own safety, to be a passenger in a boat operated by him, except in a case of emergency.

(8) CAPACITY RESTRICTIONS. No person shall operate or loan, rent or permit a boat to leave the place where it is customarily kept for operation on the waters covered by this ordinance with more passengers or cargo than a safe load.

(9) STATIONARY OBJECTS.

(a) REFLECTORS REQUIRED. All piers, rafts, ski jumps or other stationary objects, extending into and/or located upon the waters covered by this ordinance, shall have red reflector signals on each side thereof and in the case of piers, such reflectors shall not be less than three (3) feet from the outer limits thereof and shall be at least three (3) inches in diameter.

(b) RAFTS. No person shall erect or maintain any raft or platform more than 100 feet from the shore unless it is so anchored that it has at least 10 inches of free board above the waterline, and either (i) is painted white and has attached thereto on each side above the waterline one or more reflectors in good condition not less than 3 inches in diameter, or (ii) is painted with a band at least three (3) inches in width of luminous paint so as to be visible from any direction.

(c) PERMITS REQUIRED. No water ski jump shall be placed upon the waters covered by this ordinance at any time unless a permit is obtained from the Water Safety Patrol. No raft or other stationary object shall be placed more than 100 feet from the shore unless a permit is obtained from the Water Safety Patrol.

(d) A permit issued under this section shall specify the location of the ski jump, raft or other structure. and in the case of ski jumps, the area of water to be used by users of such jump. Permits shall be issued only if in the opinion of the Water Safety Patrol, the proposed use of the water and location of the structure is such so as not to interfere with or obstruct navigation and other uses of the water.

(10) SAFE OPERATION REQUIRED. No person shall operate, direct or handle a boat in such manner as to unreasonably annoy, unnecessarily frighten or endanger the occupants of his or other boats.

(11) SWIMMING REGULATIONS. Any persons swimming more than 150 feet from the shoreline of the lakes covered by this ordinance and more than 50 feet from a diving raft anchored more than 100 feet from the shoreline of said lakes shall be accompanied by a boat for the protection of the swimmer and as an aid to other boats in determining the location of the swimmer and such swimmer shall be not more than 50 feet from the boat accompanying him.

(12) LITTERING AND POLLUTING PROHIBITED. No persons shall deposit, place or throw from any boat, raft, pier, platform or similar structure or from the shore, any cans, paper, bottles, debris, refuse, garbage, solid or liquid waste, into the water.

(13) RACES, REGATTAS, SPORTING EVENTS AND EXHIBITIONS.

(a) PERMIT REQUIRED. No person shall direct or participate in any boat race, regatta, water ski meet or other water sporting events or exhibition unless such event has been authorized and a permit issued therefor by the Water Safety Patrol.

(b) PERMIT. A permit issued under this section shall specify the course of area or water to be used by participants in such event and the permittee shall be required to place markers, flags or buoys approved by the Water Safety Patrol, designating the specified area. Permits shall be issued only if in the opinion of the Water Safety Patrol, the proposed use of the water can be carried on safely and without danger to or substantial obstruction of other watercraft or persons using the lakes. Permits shall be valid only for the hours and area specified thereon.

(c) RIGHT-OF-WAY OF PARTICIPANTS. Boats and participants in any such permitted events shall have the right-of-way on the marked area and no other person shall obstruct such area during the race or event or interfere therewith.

(14) WATER SKIING.

(a) HOURS. No person shall water ski and no person shall operate a boat while towing a person on water skis aquaplane, surfboard or any similar device at any time between sunset of any day and 9:00 A.M. of the following day.

(b) All persons water skiing, aquaplaning, surfboarding or using any similar device must wear a personal flotation device.

(c) No persons shall water ski and no person shall operate a boat while towing a person on water skis, aquaplane, surfboard or any similar device on North Lake unless in a counter-clockwise direction. This restriction shall not apply to the operator of a boat attempting to pick up a skier who has fallen.

(d) No person shall tow another who is either barefoot or on water skis, aquaplane, kneeboard or other similar device, nor shall any person tow another on tubes, torpedoes or other similar inflated appliances, unless such person is wearing a Coast Guard approved personal flotation device or a wetsuit having flotation capabilities.

(15) MARKERS AND NAVIGATION AIDS: POSTING ORDINANCE.

(a) The Water Safety Patrol is authorized and directed to place and maintain suitable markers, navigation aids and signs in such water areas as shall be appropriate to advise the public of the provisions of this ordinance and to post and maintain a copy of this ordinance at all public access points on waters covered by this ordinance.

(b) STANDARD MARKERS. All markers placed by the Water Safety Patrol or any other person upon the waters covered by this ordinance shall comply with the regulations of the Department of Natural Resources.

(c) INTERFERENCE WITH MARKERS PROHIBITED. No person shall without authority remove, damage or destroy or moor or attach any watercraft to any buoy, beacon, or marker placed on the waters of any lake covered by this ordinance, by the authority of the United States, State, County or Town or by any private person, pursuant to the provisions of this ordinance.

(16) PENALTIES AND DEPOSITS.

(a) Any person violating any provision of this section 4.03 for which a penalty is not provided by subsection (b) below shall, upon conviction thereof, forfeit not more than Fifty ($50) Dollars together with the cost of prosecution and in default of payment of such forfeiture and costs, shall be imprisoned in the county jail until full payment thereof is made, but not to exceed thirty (30) days.

(b) Any persons violating subsection 30.67(1) or 30.68(1), adopted by reference in subsection 4.03(4) of this ordinance, shall, upon conviction thereof, forfeit not more than Two Hundred ($200) Dollars, together with the cost of prosecution and in default of such forfeiture and costs, shall be imprisoned in the county jail until full payment thereof is made, but not to exceed sixty (60) days.

(c) Any person violating sections 30.681 or 30.684(5) of the Wisconsin Statutes, as adopted by this ordinance, shall, upon conviction thereof, forfeit not less than $150 nor more than $300 together with the costs of prosecution and in default of such forfeiture and costs, shall be imprisoned in the county jail until full payment thereof is made, but not to exceed 60 days. In addition to any penalty, the court shall enter the orders required by subsections 30.80(6)(d) and (e) of the Wisconsin Statutes.

(d) MONEY DEPOSITS. Any officer arresting a person for violation of a provision of this ordinance who is unable to bring the person arrested before the proper court without unnecessary delay shall permit such person to make a money deposit as provided in section 30.76 of the Wisconsin Statutes. Such deposit shall be made to whom and at the office designated by the Water Safety Patrol Officer.

(17) WISCONSIN STATUTES DEFINED. Whenever used in this Ordinance the term "Wisconsin Statutes" shall mean the Wisconsin Statutes of 1973 and all amendments thereof.

(18) REPEAL OF CONFLICTING ORDINANCES. All ordinances regulating water traffic, boats, boating or water sports upon the waters covered by this ordinance and all ordinances or parts of ordinances in conflict with this ordinance, heretofore enacted by the Town Board of the Town of Merton and the Village Board of the Village of Chenequa, are hereby repealed.

(19) SEVERABILITY. The provisions of this ordinance shall be deemed severable and it is expressly declared that the Town Board of the Town of Merton and the Village Board of the Village of Chenequa would have passed the other provisions of this ordinance irrespective of whether or not one or more provisions may be declared invalid and if any provisions of this ordinance or the application thereof to any person or circumstances is held invalid, the remainder of the ordinance and the application of such provisions to other persons or circumstances shall not be affected thereby.

4.04 AUTOMOBILES AND TRUCKS ON NORTH LAKE.

(1) The Town Board of the Town of Merton and the Village Board of the Village of Chenequa, each being a municipality as defined in Chapter 30 of the Wisconsin Statutes, and each having jurisdiction of a portion of North Lake, an inland lake located in Waukesha County, do ordain jointly and identically in conformity with 30.77 and 30.81, Stats., as follows:

(2) No person shall operate or park or permit to be operated or parked any automobile or truck upon the ice of North Lake.

(3) The definitions contained in Chapter 340 and any amendments thereto are hereby incorporated by reference as if fully set forth herein.

(4) Any person violating any provision of this ordinance shall, upon conviction thereof, forfeit an amount set forth in the general penalties section of the General Code of Ordinances of the Town of Merton and the Municipal Code of the Village of Chenequa.

(5) All ordinances or parts of ordinances contravening or inconsistent with the provisions of this ordinance be and they are hereby repealed.

(6) Should any section, clause or provision of this ordinance be declared to be invalid, the same shall not affect the validity of the ordinance as a whole or any part thereof, other than the part so declared to be invalid.

4.05 OPERATION AND PARKING OF MOTOR VEHICLES ON ICE - CORNELL LAKE.

(1) PURPOSE. The Village Board of the Village of Chenequa determine and declare it to be in the interest of the public health, safety and welfare to prohibit the use, operation and parking of motor and other motorized vehicles, including without limitation snowmobiles, on the ice surface of Cornell Lake in the Village of Chenequa.

(2) PROHIBITING USE AND PARKING OF MOTORIZED VEHICLES. No person shall use, operate or park a motor or other motorized vehicle, including without limitation snowmobiles, on the ice surface of Cornell Lake in the Village of Chenequa. (5/10/93)

4.06 REGULATION OF USE OF PINE LAKE PUBLIC BOAT ACCESS FACILITY.

(1) FACILITY HOURS. The public boat access facility located on Pine Lake in the Village of Chenequa (the "Facility") shall be open from 6:00 A.M. to 10:00 P.M., except on the general fishing opening weekend when the Facility shall be open on that first Saturday and Sunday from 4:00 A.M. to midnight. No boat or equipment incident to navigation (hereinafter referred to collectively as "boat") may be launched during a time the Facility is not open, but a boat on the lake at the applicable closing time may be retrieved from the lake after such closing time and a vehicle in the designated parking area at such closing time may remain there until the boat transported by such vehicle is retrieved. Except as set forth above, no person shall enter or remain on the Facility premises and no parking shall be allowed on the Facility premises at a time when the Facility is not open.

(2) USE OF PUBLIC LAUNCH SITE RESTRICTED. No person shall launch a boat from the Facility launch site unless (a) at the time of such launching, there is an available parking place in the designated parking area for the vehicle which transported the boat and (b) such vehicle is then parked in a parking place in the designated parking area; provided, however, to assure that parking in the designated parking area is limited to the general public, no owner or tenant of property on Pine Lake shall be required or permitted to park in the designated parking area after launching a boat owned by such person at the Facility's launch site.

(3) USE OF PARKING AREA RESTRICTED. A person shall only park a vehicle in the Facility's designated parking area provided that:

(a) the vehicle is being used to transport a boat for use on Pine Lake or to transport persons for the purposes incident to navigation on Pine Lake,

(b) the person remains in the Facility or upon Pine Lake the entire time the vehicle remains in the designated parking area,

(c) the vehicle is parked in a marked parking place in the Facility's designated parking area, and

(d) each parking stall contains no more than one (1) vehicle and one (1) trailer.

(4) USE OF FACILITY RESTRICTED. The Facility shall be used only for the launching of boats on Pine Lake and for providing access for purposes incident to navigation on Pine Lake and for parking associated therewith. The Facility shall not be used for fishing, hunting, camping, picnicking, swimming, sunbathing, fish cleaning, maintenance of boats and/or motors or for other recreational purposes not expressly permitted above, or sales of products and services except for collection of fees for launching of boats and parking.

(a) POWER LOADING. No person shall engage in the act of powering a motor boat of 17' in length or greater on or off the trailer at the Pine Lake Boat Launch within the Village of Chenequa with the engine being operated at a speed greater than idle speed. No person shall continue to operate the engine while engaged in the act of launching or retrieving a motorboat after the motorboat is at rest on the trailer. A sign shall be posted at the Pine Lake launch site advising of the requirement of this sub-section, indicating no power loading, minimum forfeiture of $150 to a maximum of $500 for first offense and may be increased to $1,000 for subsequent offenses.

(5) PARKING FEES. Fees for parking of vehicles and vehicles with trailers at the Facility's designated parking area may be charged by the Village in amounts determined from time to time by the Village Board of the Village, but in no event shall such fees exceed the fees permitted under Sections NR 1.91 through 1.93 of the Wisconsin Administrative Code.

(6) PENALTY. Any person found guilty of a violation of any of the terms or provisions of this ordinance shall be subject to a fine of not less than $20.00 and not more than $200.00 for each violation.

(7) These Code provisions shall be in full force and effect upon the opening of Facility, as determined by the President of the Village of Chenequa, and publication as provided by law.

4.07 OPERATION AND PARKING OF MOTOR VEHICLES ON ICE -PINE LAKE.

(1) PURPOSE. The Village Board of the Village of Chenequa determine and declare it to be in the interest of the public health, safety and welfare to prohibit the use, operation and parking of motor and other motorized vehicles, including without limitation snowmobiles, on the ice surface of Pine Lake in the Village of Chenequa.

(2) PROHIBITING USE AND PARKING OF MOTORIZED VEHICLES. No person shall use; operate or park a motor or other motorized vehicle, including without limitation snowmobiles, on the ice surface of Pine Lake in the village of Chenequa.

4.08 MARINE REFUELING SERVICES.

(1) PURPOSE. The Village Board of the Village of Chenequa shall determine and declare that certain regulations and restrictions will be placed upon entities engaged in marine refueling services on the waterways of Pine Lake.

(2) PERMITTING. The permitting process to conduct marine refueling services will be administered by the Village of Chenequa Administrator and/or Village of Chenequa Police Department. Permits will be considered and issued on an annual basis. All permits will expire no later than the last day of each year.

(3) APPLICABILITY. The provisions of this section shall apply to the waterways of Pine Lake within the jurisdiction of the Village of Chenequa.

(4) LIMITATIONS/RULES OF APPROVAL. Any and all portions of this section shall function as the conditions of approval for permit(s) that could be granted by the Village

Administrator and/or the Board of the Village of Chenequa in regard to marine refueling services along with such other conditions as the Village Administrator deems appropriate to carry out the purpose of this section including a reasonable permit fee. A violation of any portion of this section is considered material and could result in the revocation of a permit already granted under this section or the denial of a permit under this section.

(5) RULES OF OPERATION. Persons operating marine refueling services must comply with the following minimum requirements:

(a) Refueling services are restricted from being offered on weekends and holidays.

(b) Refueling services can only be offered from May 1 through September 30 of each year.

(c) A marine refueling service shall only make one round trip around Pine Lake per day.

(d) Refueling services shall operate from sunrise to no later than 3:00 p.m.

(e) Any marine craft used for refueling services shall be trailored at all times when not in use.

(6) WATER CRAFT LIMITATIONS. Water crafts under this section must comply with the following limitations:

(a) Water craft used for refueling services shall not exceed twenty-one (21) feet.

(b) Water craft used for refueling services shall be equipped with a seventy-five foot long hose on a reel.

(c) Water craft used for refueling services shall be equipped with an electric fuel transfer pump.

(d) Water craft used for refueling services shall be equipped with an automatic shutoff nozzle.

(e) Water craft used for refueling services shall comply with all relevant requirements by applicable state and federal rules and regulations.

(7) SAFETY REQUIREMENTS. Persons operating marine refueling services shall observe the following minimal safety requirements:

(a) Persons operating marine refueling services shall adhere to all federal, state, county and local laws and ordinances when conducting marine refueling services within the jurisdiction of the Village of Chenequa.

(b) Any water craft used for refueling services shall operate within fifty (50) feet of the shoreline, at slow-no-wake speeds.

(c) Any water craft used for refueling services shall operate in no-wake zones.

(d) Refueling services shall not operate during weekends or holidays.

(e) Any water craft used for refueling services shall not be left unattended.

(f) All refueling equipment used by marine refueling services shall comply with all requirements and codes set forth by all relevant state and federal agencies.

(g) Any and all efforts shall be made by persons operating marine refueling services to prohibit or inhibit the spread of zebra mussels and Eurasian milfoil or other hazardous nuisance as determined by the Village Board.

(h) No fuel spills will be tolerated and could result in an immediate termination of a license which allows for marine refueling services.

(i) Any person operating a water craft used for marine refueling services must be at least twenty-one (21) years of age.

(j) Any water craft used by marine refueling services shall be primarily powered by two motors of equal power to aid in the maneuverability of the marine water craft.

(k) All operators of water craft used by marine refueling services shall be trained in regard to operating and emergency response procedures.

(l) Any water craft used by marine refueling services shall be equipped with proper on-board fire protection.

(m) The design and operation of any marine refueling service shall be in accordance with any and all information provided by the Wisconsin Department of Commerce.

(n) Refueling of any water craft used for marine refueling shall not take place through the use of a secondary fuel source within the Village of Chenequa.

(o) Marine refueling services shall be prohibited from operation if: (i) winds on Pine Lake exceed twenty (20) miles per hour; or (ii) a severe weather alert has been issued.

(p) Services shall not take place on those days when an organized outing is taking place and lake traffic is generally restricted.

(8) INSURANCE. Before commencing any services, any operator of a marine refueling service must present to the Village Administrator: a specific insurance policy which provides coverage for spills and environmental cleanup costs, property damage (through collision, fire, explosion, environmental) and personal injury; and proof that the coverage shall be in effect at all times, regardless of whether the marine refueling water craft is in the water, in transport or in storage.

4.09 EMERGENCY SLOW NO WAKE SPEED AT TIMES OF HIGH WATER ON PINE LAKE. (added 7/14/08).

(1) DEFINITIONS. Terms used in this Section shall have the following meanings:

High water: When the waters of Pine Lake exceed an elevation of 903.2 MLS as based upon the USGS benchmark.

Slow no wake: The meaning specified in §30.50(12), Wis. Stats.

Motorboat: The meaning specified in §30.50(6), Wis. Stats.

MSL: Near sea level or the average height for the surface of the water.

(2) SLOW NO WAKE SPEED REQUIRED. No person shall operate a motorboat at a speed in excess of slow no wake on Pine Lake after notice of high water condition has been declared until the declaration of the high water condition is repealed.

(3) NOTICE. Notice of a high water condition shall be posted (a) at the public launch site at CTH K in the Village of Chenequa; (b) by publication of a notice in the *Lake Country Reporter*; and (c) on the Village website. The posted notice shall state the time of the declaration of a high water condition. The Village shall endeavor to post a flag at appropriate places on the lake.

(4) POSTING REQUIREMENTS. This ordinance shall be posted at the Village of Chenequa boat launch on CTH K.

4.10 EMERGENCY SLOW NO WAKE SPEED AT TIMES OF HIGH WATER ON BEAVER LAKE AND NORTH LAKE. (added 5/15/09)

(1) PURPOSE: The Town Board of the Town of Merton, and the Village Board of the Village of Chenequa, each being a municipality as defined in Chapter 30 of Wisconsin Statutes, and each having jurisdiction of a portion of North Lake and Beaver Lake, both being inland lakes, located in Waukesha County, do ordain jointly and identically in conformity with sections 30.77 and 30.81 of the Wisconsin Statutes, as follows:

(2) INTENT. The intent of this ordinance is to provide safe and healthful conditions for the enjoyment of aquatic recreation consistent with public rights and interest and the capability of the water resource.

(3) APPLICABILITY AND ENFORCEMENT. The provisions of this Ordinance shall apply to the waters of North Lake and Beaver Lake, within the jurisdiction of the Town of Merton and Village of Chenequa. The provisions of this ordinance shall be enforced by the officers of the Water Safety Patrol of the Town of Merton and/or the Village of Chenequa.

(4) COOPERATION. The Village of Chenequa and the Town of Merton agree that neither shall change the provisions of this ordinance or the Town of Merton's corresponding ordinance without first providing written notice to the other outlining the proposed revisions and allowing the other an opportunity to comment on the proposed revisions to the applicable ordinance.

(5) DEFINITIONS. Terms used in this Section shall have the following meanings:

High water: When the waters of Beaver Lake exceed an elevation of 910.2 msl as based upon the USGS benchmark and North Lake waters exceed an elevation of 910.3 msl as based upon the USGS benchmark.

Slow no wake: The meaning specified in §30.50(12), Wis. Stats.

Watercraft: Motorboats, as defined in §30.50(6), Wis. Stats., jet skis, and all other personal watercraft.

MSI: Near sea level or the average height for the surface of the water.

(6) SLOW NO WAKE SPEED REQUIRED. No person shall operate a motorboat at a speed in excess of slow no wake on Beaver Lake and /or North Lake after notice of high water condition has been declared until the declaration of the high water condition is repealed.

(7) NOTICE. Notice of a high water condition on Beaver Lake shall be posted (a) at the Beaver Lake Yacht Club; (b) by publication of a notice in the *Lake Country Reporter*; and (c) on the Village website. Notice of a high water condition on North Lake shall be posted: (a) at the North Lake Yacht Club; (b) by publication of a notice in the *Lake Country Reporter*; and (c) on the Village website. The posted notice shall state the time of the declaration of a high water condition. The Village shall endeavor to post a flag at appropriate places on the lake.

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Appendix D

SEWRPC STAFF MEMORANDUM BLUE GREEN ALGAE/CYANOBACTERIA IN SOUTHEASTERN WISCONSIN LAKES SEPTEMBER 24, 2007

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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION
W239 N1812 ROCKWOOD DRIVE • PO BOX 1607 • WAUKESHA, WI 53187-1607• TELEPHONE (262) 547-6721
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SEWRPC STAFF MEMORANDUM

TO: Friends of Beaver Lake, Inc.

FROM: Dr. Jeffrey A. Thornton, Environmental Planning Division

DATE: September 24, 2007

SUBJECT: BLUE GREEN ALGAE/CYANOBACTERIA IN SOUTHEASTERN WISCONSIN LAKES

BACKGROUND

Blue green algae, also known as cyanobacteria, are one of several families of phytoplanktonic organisms that occur in lakes and waters worldwide. They are naturally present in most waterways, although they can achieve extraordinary levels of growth when conditions are favorable, forming surface scums or blooms. Frequently, excessive growths of blue green algae have tended to occur in the tropics, and have not been so prominent a feature of lakes in the temperate zone. Recent blooms of cyanobacteria, and reports of toxicity arising from such blooms, have reenforced their presence in local waters and brought these algae to prominence in the Region. Such blooms have been reported previously from Pewaukee Lake, and from both Pine and Beaver Lakes in the Village of Chenequa during 2007. This Memorandum responds to a request from the Friends of Beaver Lake and the Village of Chenequa for information on the causes, consequences, and correctives applicable to the management of blue green algae in lakes.

FACTORS CONTRIBUTING TO TOXIN FORMATION

Certain blue green algae have the potential to produce toxins as metabolites, along with other photosynthetic products which are released into the environment. Physically, the algae that produce such toxins are visually indistinguishable from nontoxic varietals of the same microscopic plant. Genera that commonly form toxic varietals include *Anabaena*, *Cylindrospermopsis*, *Microcystis*, and *Oscillatoria*, among others. The conditions that lead to toxicity are not well known, although there are a number of factors that tend to favor cyanobacterial dominance in lakes and reservoirs. These factors include:

- Temperature—blue green algae typically favor warm water conditions such as those that occur during the summer months

- Water Column Stability—blue green algae prefer stable conditions and many species have buoyancy mechanisms that allow them to exist at or near the water surface, providing them with ample sunlight and helping them to compete with other algae by allowing them to capture the available sunlight

- Nutrient Enrichment—certain blue green algae have the ability to accumulate surplus phosphorus within their cells and/or to fix or use atmospheric nitrogen to support and sustain their growth, while blue green algae as a family tend to dominate during conditions of high nutrient concentration

- Alkalinity—blue green algae tend to influence pH in lakes, causing the pH to rise or become more alkaline

- Oxygen Concentration—blue green algae, like most other plants, produce oxygen by photosynthesis during daylight hours and consume oxygen by respiration during hours of darkness and upon senescence and death as the cells decompose, which can lead to substantial fluctuations in dissolved oxygen concentrations in enriched lakes dominated by blue green algae.

One factor that benefits blue green algae relative to other phytoplankton species is the fact that they are less palatable than some or most other species of algae; hence, they are not as readily consumed by zooplankton, fish and other planktivorous organisms as are other types of algae. This could influence their persistence in the environment during time of heavy predation on other types of algae; such times commonly also coincide with the summer months when predators are most active.

BLUE GREEN ALGAL TOXINS AND IMPACTS

The toxins that are produced by blue green algae include alkaloid toxins, peptides, and lipo-poly-saccharides that have been associated with incidents of wildlife and domestic animal mortality, and cases of human gastro-enteritis (diarrhea) primarily in the tropics, although cases have been reported from Europe and recently blue green algal toxins have been implicated in human fatalities.

The earliest cases of cyanobacterial toxicity were reported from southern Africa and the Pacific islands during the late-1940s. The connection between algal blooms and toxicity, however, was only proposed in the 1960s when a medical practitioner in Zimbabwe noticed the coincidence between the onset of algal blooms in water supply reservoirs and the occurrence of gastro-enteritis in school children. In the intervening years, various reports of toxicosis affecting domestic livestock were published, but it has only been in recent years that advances in scientific methodologies and reported human mortalities (of dialysis patients in Brazil) have coincided to allow quantitative assessment of the occurrence and presence of algal toxins in aquatic systems. Today enzyme-based tests allow rapid determination of the presence of microcystins, while high pressure liquid chromatographic techniques allow quantitative determination of the full range of blue green algal toxins: the World Health Organization (WHO) notes that "progress in analytical chemistry has enabled the isolation and structural identification from toxic cyanobacteria of three neurotoxins (anatoxin-a, anatoxin-a(s) and saxitoxins), one general cytotoxin, which inhibits protein synthesis (cylindrospermopsin), and a group of toxins termed microcystins (or nodularins, found in brackish waters), which inhibit protein phosphatases."

Blue green algal toxins manifest in various ways. The WHO note that symptoms reported include "abdominal pain, nausea, vomiting, diarrhoea, sore throat, dry cough, headache, blistering of the mouth, atypical pneumonia and elevated liver enzymes in the serum, as well as hay fever symptoms, dizziness, fatigue, and skin and eye irritations." Commonly, symptoms of blue green algal toxicity are sublethal in humans. Additionally, skin irritations and photo-sensitivity are observed, and respiratory distress has also been noted as a possible symptom of blue green algal toxicity. Aerosols appear to contribute to the build up of toxins. In acute cases, microcystin toxicity can lead to liver and kidney failure in a manner similar to strychnine. When waters containing blue green algae are utilized for drinking water supply, taste and odor (geosmin) problems are common concerns.

WORLD HEALTH ORGANIZATION GUIDELINES

Global concerns regarding the human health effects of blue green algae have led the WHO to establish guidelines for drinking water supplies facing blue green algae concerns. Their primary recommendations are that 1) "every effort should be made to prevent blooms forming," and 2), "where there are heavy algal blooms, it is best to consider an alternative source of water unless appropriate treatment is available." Where avoidance of exposure is not an option, "the resulting guideline value for total microcystin-LR (free plus cell-bound) is one microgram per liter (μg/l) (rounded figure) in drinking-water."

With respect to recreational use of waters, the WHO note that "the risk for human health associated with the occurrence of toxic algae or cyanobacteria during recreational activities is limited to a few species and geographical areas." Consequently, they conclude that" it is inappropriate to recommend specific guideline values." "Precautionary measures include avoiding areas with visible algal concentrations and/or algal scums in the sea as well as on the shore, avoiding sitting downwind of any algal material drying on the shore and showering to remove any algal material." Because human health impacts include both "irritative symptoms caused by unknown cyanobacterial substances and the potentially more severe hazard of exposure to high concentrations of known cyanotoxins, particularly microcystins, a single guideline value is not considered appropriate." Consequently, the WHO have defined a series of guideline values:

- For protection from the irritative or allergenic effects of cyanobacterial compounds, the guideline level for action is 20,000 cyanobacterial cells/ml (corresponding to 10 μg chlorophyll-a/liter under conditions of cyanobacterial dominance);

- For the issuance of health alerts affecting recreational waters, the guideline level for action is 100,000 cyanobacterial cells/ml (equivalent to approximately 50 μg chlorophyll-a/liter if cyanobacteria dominate); and,

- For protection from cyanobacteria in swimming areas, which represents the highest risk of adverse health effects, dermal contact, ingestion, or aspiration of toxic cyanobacteria should be avoided by precluding, discouraging or cancelling water sports activities such as competitions.

COMMUNITY RESPONSE STRATEGIES

Response strategies to minimize the risk from blue green algae should focus on three principal areas of action, in addition to the conduct of informational programming. All three actions involve the control of water quality degradation, and are aimed at human activities within the shoreland areas and watersheds adjacent to lakes and stream. Informational programming to create and continue public awareness of these steps and the risks associated with blue green algal blooms is a common element of each action.

1. Maintain onsite sewage treatment systems: improperly functioning wastewater treatment systems represent one pathway by which plant nutrients such as phosphorus and nitrogen enter waterways and contribute to the growth of aquatic plants, including algae. Regular inspection and pumping of septic tanks and related onsite wastewater treatment systems should be carried out on all systems, as required under Subchapter V of Chapter Comm 83 of the *Wisconsin Administrative Code*, on at least a three-yearly basis.

2. Manage lawn care chemicals: use of artificial fertilizers, especially in shoreland areas, forms a major pathway by which nutrients enter waterways. Maintenance of at least a 20-feet shoreland buffer around waterways will limit the movement of excess quantities of

phosphorus and nitrogen from gardens and lawns to waterways. This guideline is set forth in the Wisconsin Department of Natural Resources (WDNR) Technical Standard No. 1100, *Turf Nutrient Management*, issued in January 2006, and is consistent with the 35-feet shoreland zone management requirements set forth in Chapter NR 115 of the *Wisconsin Administrative Code*. To this end, many communities are considering or have adopted no-phosphorus or low-phosphorus fertilizers requirements within their turf management ordinances.

3. Control stormwater runoff to lakes and streams: rainfall and meltwater are mechanisms by which contaminants including the plant nutrients, nitrogen and phosphorus, are transferred from the land surface to aquatic systems. Minimizing the rate and/or volume of runoff through stormwater management techniques including detention/retention/infiltration basins, rain gardens, buffer strips and swales addresses a further anthropogenic pathway by which nutrients enter aquatic systems. Implementation of such techniques is consistent with the requirements of Chapter NR 151 of the *Wisconsin Administrative Code* and is applicable to both agricultural and nonagricultural land use activities, including residential lands.

Use of algicides following bloom formation is not recommended as algal mortality can result in the release of toxins into the waterbody.

Should incidental contact with algae-rich water occur, it is strongly recommended that both people and domestic pets wash with clean water as soon as possible after contact to minimize exposure to potential toxins. As a "rule of thumb," if the waters do not look appealing for recreational use, foregoing such use is recommended.

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cc: Jeffrey Kante, Village of Chenequa