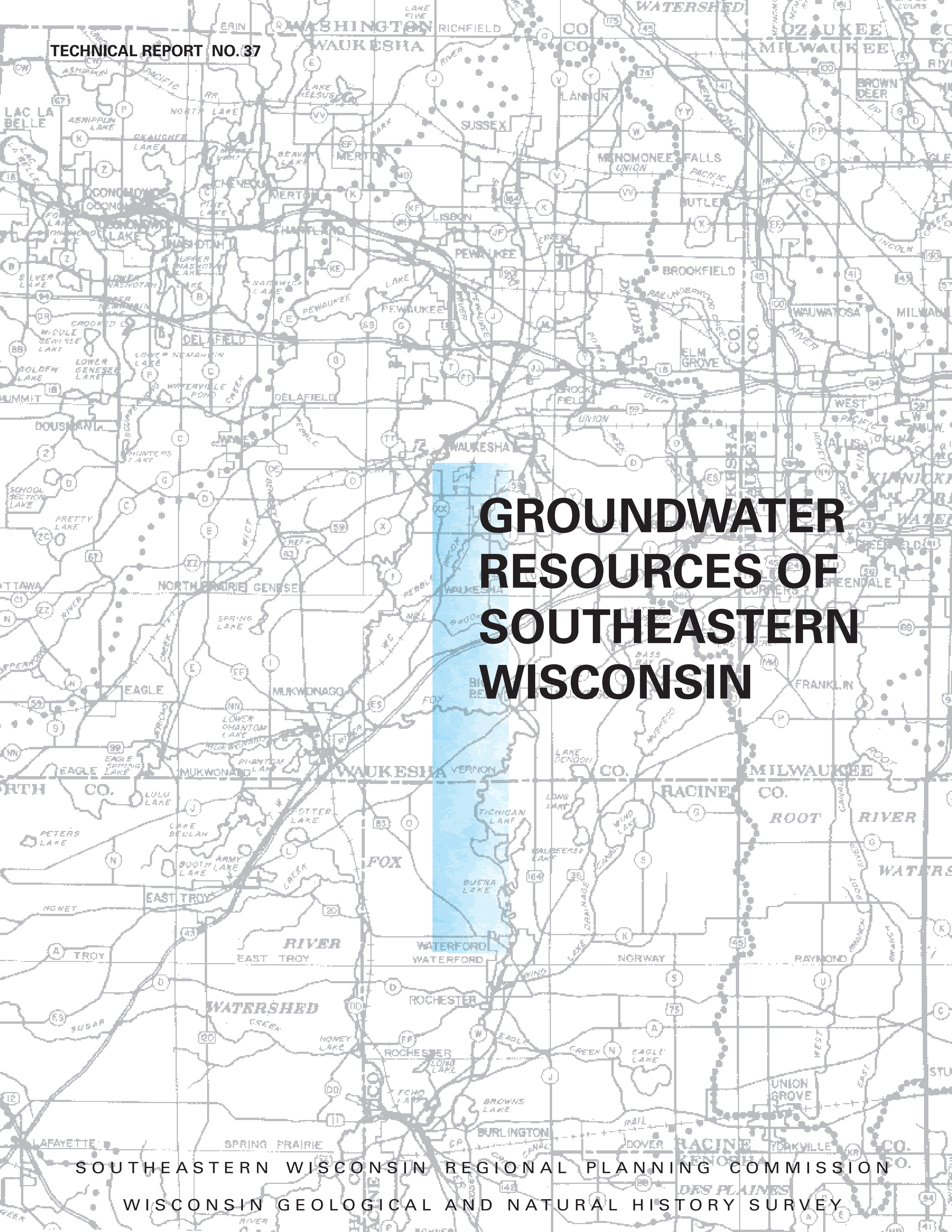
TECHNICAL REPORT NO. 37



GROUNDWATER RESOURCES OF SOUTHEASTERN WISCONSIN

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

KENOSHA COUNTY

Leon T. Dreger
Thomas J. Gorlinski
Sheila M. Siegler

RACINE COUNTY

Richard A. Hansen
Jean M. Jacobson, Secretary
James E. Moyer

MILWAUKEE COUNTY

Daniel J. Diliberti
William R. Drew, Vice-Chairman
David A. Novak

WALWORTH COUNTY

Anthony F. Balestrieri
Allen L. Morrison, Treasurer
Robert J. Voss

OZAUKEE COUNTY

Leroy A. Bley
Thomas H. Buestrin, Chairman
Gus W. Wirth, Jr.

WASHINGTON COUNTY

Kenneth F. Miller
Daniel S. Schmidt
Peter D. Ziegler

WAUKESHA COUNTY

Duane H. Bluemke
Kenneth C. Herro
Paul G. Vrakas

INTERAGENCY STAFF GROUNDWATER RESOURCES STUDY

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Philip C. Evenson .... Executive Director, Southeastern Wisconsin Regional Planning Commission
Kurt W. Bauer .... Executive Director Emeritus, Southeastern Wisconsin Regional Planning Commission
Robert P. Biebel .... Chief Environmental Engineer
John G. McDougall .... Geographic Information Systems Manager
Bradley T. Subotnik .... Senior GIS Applications Specialist
Michael G. Gosetti .... Geographic Information Systems Supervisor

WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

James M. Robertson .... Director, Wisconsin Geological and Natural History Survey; State Geologist
Ronald G. Hennings .... Assistant Director, Wisconsin Geological and Natural History Survey; Hydrogeologist
Bruce A. Brown .... Geologist
Kim J. Cates .... Soil Specialist
Michael L. Czechanski .... Geospatial Analyst
Timothy T. Eaton .... Hydrogeologist
Marcia J. Jesperson .... Word Processor
Irene D. Lippelt .... Water Resources Specialist
Fred W. Madison .... Soil Scientist
Kathleen Massie-Ferch .... Geologic Data Base Specialist
Alexander Zaporozec .... Hydrogeologist; Project Manager

TECHNICAL REPORT
NUMBER 37

GROUNDWATER RESOURCES OF SOUTHEASTERN WISCONSIN

Prepared by the

Southeastern Wisconsin Regional Planning Commission
W239 N1812 Rockwood Drive
P.O. Box 1607
Waukesha, Wisconsin 53187-1607
and the
Wisconsin Geological and Natural History Survey
3817 Mineral Point Road
Madison, Wisconsin 53705-5100

In Cooperation with the
Wisconsin Department of Natural Resources

June 2002

Inside Region $15.00
Outside Region $30.00

TABLE OF CONTENTS

Page

Page

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

Figure | Page

Chapter VI

Chapter VII

LIST OF MAPS

Map | Page

Chapter I

Chapter II

Chapter III

Chapter IV

Chapter V

Map Page

Chapter VI

Chapter VII

Chapter I

INTRODUCTION

BACKGROUND

Groundwater constitutes one of the most important elements of the natural resource base of Southeastern Wisconsin. The groundwater not only sustains lake levels and provides the base flows of the streams in the Region, but comprises a major source of water supply for domestic, municipal, and industrial users. Like surface water, groundwater is susceptible to depletion in quantity and to deterioration in quality. An important consideration in any land use and public facility planning and development, therefore, is the protection of the quantity and quality of this valuable resource.

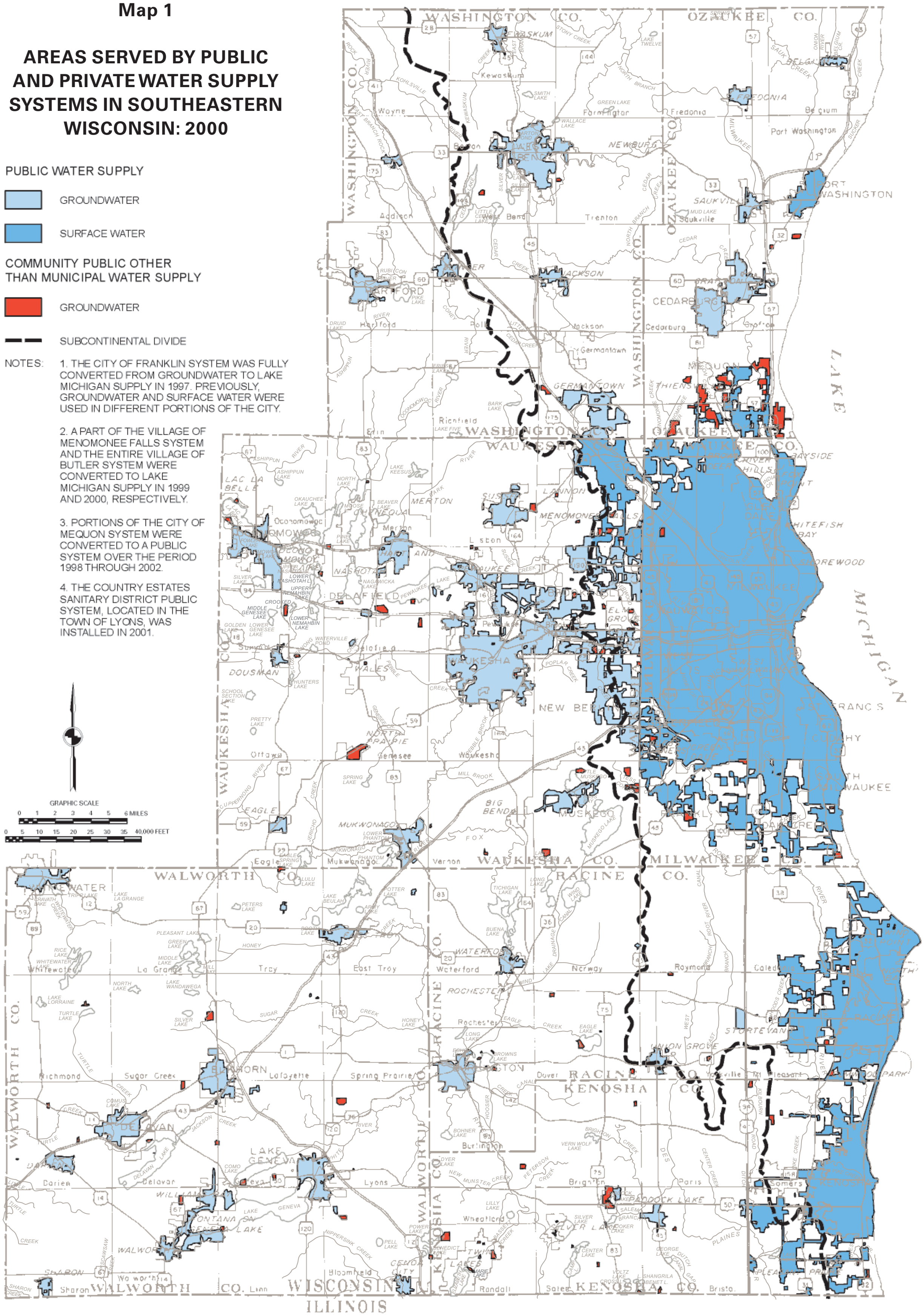
Three major aquifers underlie the seven-county Southeastern Wisconsin Region. From the land surface downward, the three aquifers are: the sand and gravel deposits of glacial origin; the shallow dolomite strata of the underlying bedrock; and the deeper sandstone, dolomite, and siltstone complex. Because of their relative proximity to the land surface and their hydraulic interconnection, the first two aquifers are commonly referred to collectively as the "shallow aquifer," while the latter is commonly referred to as the "deep aquifer." Wells tapping these aquifers are referred to as shallow or deep wells, respectively. With the exception of the most westerly area, the shallow and deep aquifers underlying the Region are separated by the Maquoketa shale, which forms a relatively impermeable barrier between the two aquifer systems.

Together these aquifers provide the source of potable water to about 700,000 persons, or about 37 percent of the resident population of Southeastern Wisconsin. The remaining 63 percent of the population is provided with public water supply drawn from Lake Michigan. Map 1 shows the areas served by public and private water supply systems in Southeastern Wisconsin and the location of the subcontinental divide. That divide traverses the Region and separates the Mississippi River and the Great Lakes drainage basins. Owing to legal constraints placed on the diversion of surface water across the divide, the use of Lake Michigan water as a source of supply for those areas of the Region lying west of the divide is, for all practical purposes, precluded. The extension of Lake Michigan water to areas lying west of the subcontinental divide is possible only if the spent water is returned to Lake Michigan via sewerage systems. Only very limited diversion is legally possible in the absence of such return. As shown on Map 1, the service areas of major water utilities within the Region include significant areas lying west of the divide.

Recognizing the importance of the groundwater resource, the Southeastern Wisconsin Regional Planning Commission and the University of Wisconsin-Extension Wisconsin Geological and Natural History Survey, in 1994, initiated a groundwater resources inventory and protection planning program. The scope and content of the groundwater inventory and protection planning program was developed in cooperation with the Wisconsin Department of Natural Resources.

Map 1

AREAS SERVED BY PUBLIC AND PRIVATE WATER SUPPLY SYSTEMS IN SOUTHEASTERN WISCONSIN: 2000



Source: Wisconsin Department of Natural Resources and SEWRPC.

The groundwater resources inventory and protection planning program includes a detailed inventory and analysis of the groundwater resources of the seven-county Southeastern Wisconsin planning region. The findings of this inventory and analysis are documented in this technical report. This report also presents a general description of possible groundwater protection strategies that appear to be viable for use in the study area, given the results of the groundwater inventories and analyses. In addition, specific areas that are considered as having the highest priority for implementation of groundwater protection measures are defined based upon analyses of the inventory data.

In the longer term, it is envisioned that a regional three-dimensional aquifer simulation model will be developed by the Regional Planning Commission in cooperation with the U.S. Geological Survey (USGS), the Wisconsin Geological and Natural History Survey (WGNHS), and the public water utilities within the planning region that utilize the groundwater reservoir as a source of supply. The simulation model can be used in the preparation of a water supply system plan for the Southeastern Wisconsin Region, as well as for subregional and local water supply system planning and optimization. The findings of the inventory and analysis of the groundwater resources of the planning areas as herein reported are intended to serve as an important basis for the ultimate development of the aquifer simulation model and of a regional water supply system plan.

This report focuses on the characteristics of the shallow aquifer in Southeastern Wisconsin and its potential for contamination since that aquifer is most vulnerable to contamination from the land surface. Pertinent information is also provided, however, regarding the deep sandstone aquifer. As already noted, this aquifer is largely isolated from the effects of land use development, except in the western areas of Walworth, Washington, and Waukesha Counties within the Region and the eastern areas of Dodge, Jefferson, and Rock Counties immediately adjacent to the Region, where the recharge of that deep aquifer takes place.

PREVIOUS STUDIES

The hydrogeology and water quality of aquifers in Southeastern Wisconsin have been the subject of many studies and reports, both published and unpublished (Appendix A), from the earliest reports by Alden (1906) and Weidman and Schulz (1915) until today. These earliest reports, together with an even older report on artesian wells in eastern Wisconsin by Chamberlin in Volume II of Geology of Wisconsin (1877), are important sources of information on original potentiometric levels and early well yields, dating back to the 1850s.

Various county reports published by the Wisconsin Geological and Natural History Survey and U.S. Geological Survey have described the general availability of groundwater in the seven counties comprising the Region. The USGS began studying the hydrogeology of Southeastern Wisconsin in the mid-1940s. The early county reports dealt primarily with the basic hydrogeologic framework of the sandstone aquifer and pumpage for Milwaukee County and the eastern half of Waukesha County (Drescher, 1948; Drescher and others, 1953; Foley and others, 1953; and Green and Hutchinson, 1965). Later reports appraised the geology, groundwater resources, and water quality in the counties of Racine/Kenosha (Hutchinson, 1970), Waukesha (Gonthier, 1975), Walworth (Borman, 1976), and Washington/Ozaukee (Young and Batten, 1980). During the late 1970s, the USGS prepared water table maps for the counties of Kenosha (Sherrill and Schiller, 1979a), Milwaukee (Sherrill and others, 1979), Racine (Sherrill and Schiller, 1979b), Walworth (Sherrill and Erickson, 1979), and Waukesha (Gonthier, 1979).

Planning reports of the Southeastern Wisconsin Regional Planning Commission (No. 9, 1966; No. 12, 1969; No. 13, 1970-71; No. 26, 1976; and No. 35, 1983) for the watersheds of the Root, Fox (Illinois), Milwaukee, Menomonee, and Pike Rivers, respectively, provided analysis and evaluation of groundwater flow movement, groundwater/surface water relationships, potential problems in groundwater quality, and water supply needs and demands in the watersheds.

During the last 15 years, Professor Douglas Cherkauer, Department of Geosciences of the University of Wisconsin at Milwaukee, and his students have studied hydrogeologic conditions in various parts of the Region, and especially, the relationship between Lake Michigan and the shallow aquifer system. For example, Bues (1983), Cherkauer and Carlson (1997), Cherkauer and Hensel (1986), Cherkauer and Zvibleman (1981), Lawton (1979), Rovey (1990), Rovey and Cherkauer (1994a; 1994b), and Thompson (1981).

Modeling studies performed in Southeastern Wisconsin are presented in reports by Bonestroo, Rosene, Anderlik & Associates (1996), Mandle and Kontis (1992), Mueller (1992), Nader (1990), Rovey (1983), Young (1976), and Young and others (1989).

Hydrogeologic conditions and water quality of Southeastern Wisconsin, in general, have also been mentioned within the framework of statewide or regional studies, such as an overview of groundwater resources in the USGS river basin reports (Cotter and others, 1969; Skinner and Borman, 1970). During the 1980s, the USGS undertook a regional assessment of the Cambrian-Ordovician aquifer system in the northern Midwest, which resulted into publications by Mandle and Kontis (1992), Siegel (1989), and Young (1992a, 1992b). The USGS also produced a series of reports summarizing water quality in Wisconsin, with some information and data on the Region (Kammerer, 1981; 1984; 1995; Sherrill, 1979).

Some aspects of contamination potential analysis were addressed in two reports. Ketelle (1971) analyzed the suitability of land in the Region for liquid waste disposal. Sherrill (1979) constructed a map of contamination potential in the Silurian dolomite aquifer in eastern Wisconsin. The Wisconsin Department of Natural Resources prepared a statewide map of groundwater contamination susceptibility (Schmidt and Kessler, 1987).

In spite of these and many other publications (see Appendix A), the groundwater resources of the Region—their availability, quality, and contamination—have not been studied comprehensively with respect to the needs of the long-range planning program.

PURPOSE AND OBJECTIVES

The primary objectives of the groundwater resource inventory conducted under this planning program were:

1. To determine and map the contaminant attenuation capacity of the soils covering the planning area;

2. To map the near surface geology of the planning area, concentrating on the Pleistocene geology and depth to bedrock;

3. To map existing depths to the water table within the planning area and to identify regional groundwater divides and groundwater flow directions of the shallow aquifer;

4. To evaluate and interpret the hydrogeologic characteristics of the unsaturated zone and to determine and map the contaminant attenuation potentials of the near-surface strata of the planning area;

5. To develop a system for the evaluation and mapping of the susceptibility of the groundwater resources of the planning area to contamination; and

6. To identify and map the potential groundwater contamination sources within the planning area.

As already noted, the information presented in this report is intended to form the basis for the development of recommendations for the protection and wise use of the groundwater resources of the planning area, for the development of a regional aquifer simulation model, and for the eventual development of a regional water supply system plan for Southeastern Wisconsin. This report thus provides, on a uniform areawide basis, valuable hydrogeologic information for use in groundwater management planning and development.

SCOPE OF WORK

The work reported on herein includes the collation of existing pertinent hydrogeologic data about the planning area; the conduct of field work to collect new hydrogeologic data; mapping; and report preparation. The hydrogeologic data collated and collected included data on soils, geology, groundwater, precipitation, lake levels and streamflows, and water table elevations. The inventory also include collation and analyses of existing well logs and data from observation stations measuring precipitation, lake levels, streamflows, and groundwater levels. Importantly, the inventory included the collection of data on the location of major potential groundwater contamination sources. The work included the preparation of interpretive maps indicating the contaminant attenuation potential of the soils and underlying glacial deposits; the preparation of depth to bedrock and depth to water table maps; and the preparation of new maps related to the potential for groundwater contamination. Data were collected and collated to more accurately map the western limits of the Maquoketa shale and, thereby, identify the primary recharge area of the deep sandstone aquifer underlying the Region. Finally, the work included the preparation of maps showing the location of public water supply wells, other high-capacity wells, observation wells, precipitation stations, surface water gauging stations, known waste disposal sites, and other relevant potential groundwater contamination sources.

The basic inventories conducted under this program were documented on Regional Planning Commission base mapping at scales of one inch equals 2,000 feet and one inch equals 4,000 feet showing planimetric features and hypsometry, the latter with a 10-foot contour interval. These maps utilize the State Plane Coordinate System referenced to North American Datum of 1927 as the map projection. Elevation data are based upon the National Geodetic Vertical Datum of 1929. This mapping was supplemented as necessary by Commission 1995 orthophotographs at scales of one inch equals 400 feet and one inch equals 2,000 feet and large scale topographic mapping having a contour interval of two feet and scales of one inch equals 100 or 200 feet, with matching cadastral overlays. All of the mapping used is in digital format suitable for computer manipulation and reproduction.

This report summarizes the findings of the inventories and analyses conducted, characterizes the groundwater resources of the Region and the susceptibility of those resources to contamination, and describes the existing and potential sources of contamination.

Chapter II

REGIONAL SETTING

INTRODUCTION

The Southeastern Wisconsin Planning Region, as shown on Map 2, is comprised of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha Counties. Exclusive of Lake Michigan, these seven counties have a total area of 2,689 square miles, or about 5 percent of the total area of Wisconsin. These counties, however, account for about 1.9 million persons, or about 36 percent of the total population of the State, about 38 percent of all jobs in the State, and about 40 percent of the total real property value of the State as measured by equalized assessed valuation. The Region contains 154 local units of government, exclusive of school and other special-purpose districts, all of which participate in the work of the Southeastern Wisconsin Regional Planning Commission.

Geographically the Region is located in a relatively good position with regard to continued growth and development. It is bounded on the east by Lake Michigan, on the south by the rapidly expanding northeastern Illinois metropolitan region, and on the west and north by the fertile agricultural lands and desirable recreation areas of the rest of the State of Wisconsin.

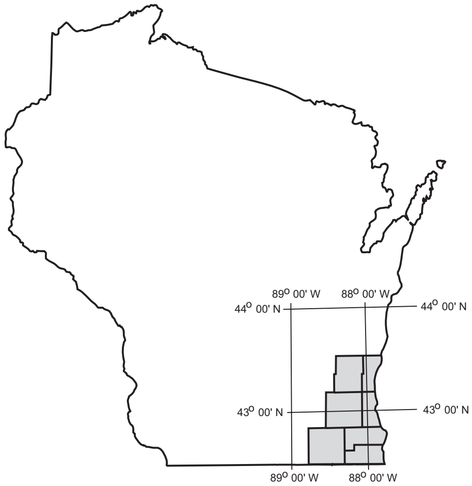
Groundwater is a valuable component of the underlying and sustaining natural resource base of the Region, and an important consideration in any planning for the development of the Region. Because of the important relationships between groundwater and the man-made and natural resource base of the Region, this chapter summarizes information on the population and economic activity levels and associated land use, as well as climate and selected natural resource features within the Region that most directly impact or are impacted by the groundwater resources.

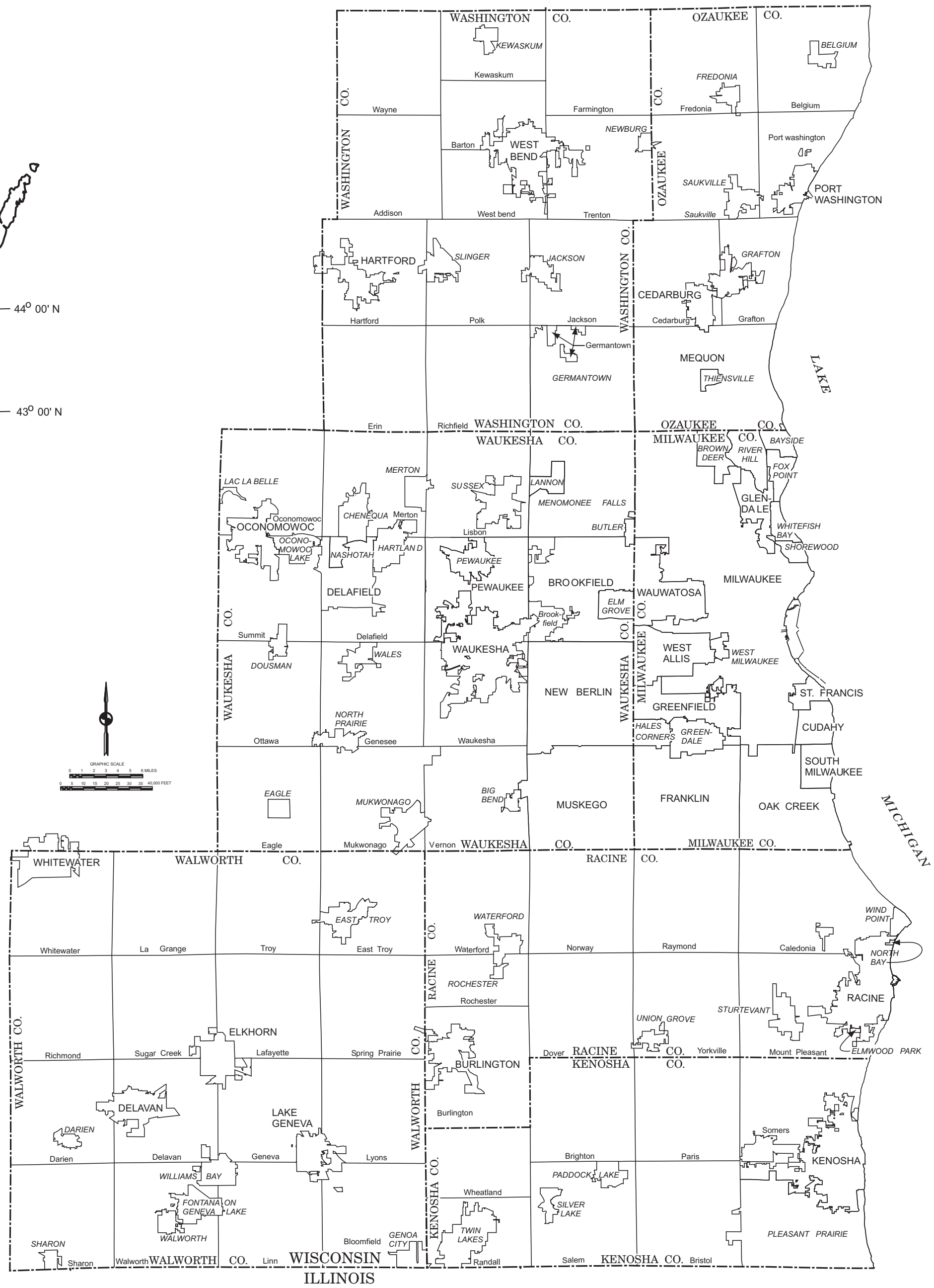
POPULATION, HOUSEHOLD, AND ECONOMIC ACTIVITY

Current and historic information concerning the size and characteristics of the resident population and the size and structure of the economy are important considerations in planning for the protection and wise use of the groundwater resources of the Region, as are soundly conceived projections of future regional population and economic activity levels. Such information relates directly to groundwater usage and in some cases to the potential for groundwater contamination. Under the continuing regional planning program, the Commission periodically undertakes intensive studies of the regional population and economy, initiating such studies upon release of data from the decennial Federal censuses. These studies culminate in the preparation of long-range projections of population, households, and employment for the Region, with the projection and forecast period extending about 20 years into the future.

Map 2

THE SOUTHEASTERN WISCONSIN REGION





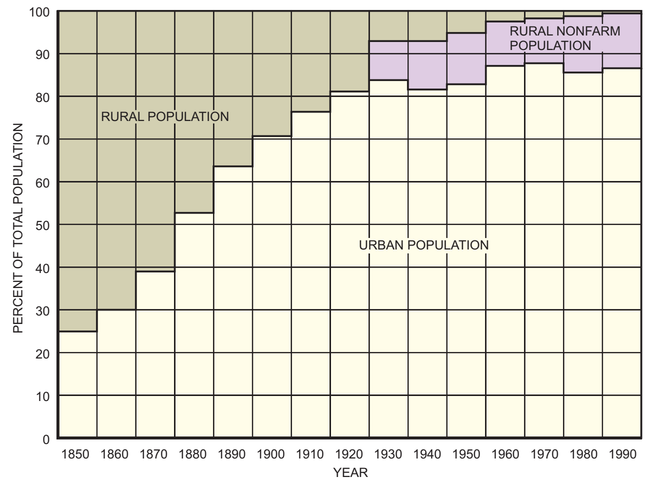
Source: SEWRPC.

The most recent regional demographic study completed by the Commission described and analyzed trends in population and household levels and characteristics through the year 1990, the year of the most recent U.S. Census of Population, and culminated in the preparation of new projections of population and households for the Region through the year 2020. A related economic study described and analyzed trends in the level and type of employment opportunities, or jobs, provided within the Region through the year 1990, and presented a corresponding set of year 2020 employment projections for the Region.

To deal with the uncertainties inherent in making long-range socioeconomic projections, the Commission prepared alternative high-growth, intermediate-growth, and low-growth projections of population, household, and employment levels. This range of projections is useful for the development of robust system plans at the regional level, as well as facility plans at the local level. Plans developed using the range of projections may be expected to remain viable under varying future conditions.

Figure 1

URBAN AND RURAL POPULATION IN THE REGION: CENSUS YEARS 1850-1990



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

Population Levels

The 1990 resident population level of the Region was about 1,810,400 persons, an increase of about 569,800 persons, or 46 percent, over the 1950 population level of about 1,240,600 persons. The 1998 estimated resident population level of the Region was 1,908,000 persons, an increase of about 97,600 persons, or about 5 percent over the 1990 level.

The composition of the population of the Region, like that of most metropolitan regions of the United States, has become increasingly urban—as measured in terms of urban and rural place of residence. As indicated in Figure 1, the population of the Region was approximately 76 percent rural and 24 percent urban in 1850. By 1910, this relationship had reversed to 24 percent rural and 76 percent urban. In response to increasing suburbanization occurring nationwide, the U.S. Bureau of the Census, in taking the 1930 decennial census of population, divided the rural category into rural-farm and rural-nonfarm categories. The rural-nonfarm classification is comprised of persons living in rural areas but generally employed in urban occupations, whose socioeconomic characteristics are urban rather than rural. As shown in Figure 1, the portion of total rural population in the Region has not changed substantially since 1930. However, the rural farm portion of the regional population decreased from about 7 percent in 1930 to about 1 percent by 1990; while the nonfarm portion increased from 9 percent in 1930 to about 13 percent in 1990.

The population levels and rates of change in those levels from 1950 to 1990 for each county of the Region are shown in Table 1. The greatest rates of population growth over the period 1950 to 1990 occurred in Ozaukee, Washington, and Waukesha Counties, with population increases of 212 percent, 181 percent, and 255 percent, respectively. Kenosha, Racine, and Walworth Counties experienced population increases between 60 and 80 percent, while the Milwaukee County population increased by 10 percent. The largest absolute increases in population occurred in Waukesha County. Milwaukee County experienced a population loss of about 95,000 persons from 1970 to 1990. Commission population projections for the Region and its constituent counties under three regional growth scenarios are set forth in Table 2.

Household Levels

The number of households within each county of the Southeastern Wisconsin Region for the period 1950 to 1990, and the rates of change in those numbers are presented in Table 3. The number of households in the Region in 1990 was about 676,100, an increase of about 321,600, or 91 percent, over the 1950 level of about 354,500. The number of households within the Region in 1998 was estimated at about 717,300 in 1995—about 41,200 households, or 6.1 percent above the 1990 level.

The greatest rates of growth in the number of households over the period 1950 to 1990 occurred in Ozaukee, Washington, and Waukesha Counties, with increases in households of 290 percent, 251 percent, and 349 percent, respectively. The remaining four counties in the Region experienced increases of 50 percent to 123 percent in the number of households between 1950 and 1990.

Table 1

POPULATION IN THE REGION BY COUNTY: 1950-1990

County	Population 1950	1960	1970	1980	1990
Kenosha	75,238	100,615	117,917	123,137	128,181
Milwaukee	871,047	1,036,041	1,054,249	964,988	959,275
Ozaukee	23,361	38,441	54,461	66,981	72,831
Racine	109,585	141,781	170,838	173,132	175,034
Walworth	41,584	52,368	63,444	71,507	75,000
Washington	33,902	46,119	63,839	84,848	95,328
Waukesha	85,901	158,249	231,335	280,203	304,715
Region	1,240,618	1,573,614	1,756,083	1,764,796	1,810,364

County	1950-1960 Change		1960-1970 Change		1970-1980 Change		1980-1990 Change		1950-1990 Change	
	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Kenosha	25,377	33.7	17,302	17.2	5,220	4.4	5,044	4.1	52,943	70.4
Milwaukee	164,994	18.9	18,208	1.8	-89,261	-8.5	-5,713	-0.6	88,228	10.1
Ozaukee	15,080	64.6	16,020	41.7	12,520	23.0	5,850	8.7	49,470	211.8
Racine	32,196	29.4	29,057	20.5	2,294	1.3	1,902	1.1	65,449	59.7
Walworth	10,784	25.9	11,076	21.2	8,063	12.7	3,493	4.9	33,416	80.4
Washington	12,217	36.0	17,720	38.4	21,009	32.9	10,480	12.4	61,426	181.2
Waukesha	72,348	84.2	73,086	46.2	48,868	21.1	24,512	8.7	218,814	254.7
Region	332,996	26.8	182,469	11.6	8,713	0.5	45,568	2.6	569,746	45.9

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

Between 1950 and 1990, the number of households in the Region increased at a rate nearly double that of the resident population. During this time, household sizes decreased significantly. Between 1950 and 1990, the average household size in the Region decreased from 3.36 to 2.62 persons, or by 22 percent, as shown in Table 4. Commission projections of household levels for the Region and its constituent counties under three regional growth scenarios are set forth in Table 5.

Employment Levels

Employment levels and rates of employment change for each county of the Region for the period 1950 to 1990 are presented in Table 6. The number of jobs in the Region in 1990 was about 1,067,200, an increase of about 493,700 jobs, or about 86 percent, over the 1950 level of about 573,500. Commission employment projections for the Region and its constituent counties under three regional growth scenarios are set forth in Table 7.

LAND USE

The regional land use plan for Southeastern Wisconsin has been developed using the extensive data base of the physical characteristics of the Region, which has been compiled by the Commission over the past 35 years. Under the regional planning program, the Commission has assembled data on the man-made and natural features of the Region, collating data from secondary sources where feasible and undertaking primary data collection activities as necessary. The assembled data include, among others, information on the physiography and topography, soils, climate and weather, land use patterns, transportation facilities, streamflow, stream and lake stages, water quality, floodlands, wetlands, woodlands, wildlife habitat, and environmental corridors. Of particular importance to this study is the information collected on the sanitary sewer, water supply, and stormwater management systems of the Region. The water supply systems have a direct relationship to the groundwater system. The sanitary sewerage and stormwater management systems have more indirect, but never-the-less important, relationships to the groundwater system.

Table 2

EXISTING AND PROJECTED POPULATION IN THE REGION BY COUNTY: 1990-2020

County	Actual 1990 Population Level	Projected Population Levels				Projected Change 1990 to 2020	
		Scenario	2000	2010	2020	Number	Percent
Kenosha	128,200	Low-growth	136,900	141,100	143,000	14,800	11.5
		Intermediate-growth	146,700	155,600	159,600	31,400	24.5
		High-growth	158,700	173,300	180,000	51,800	40.4
Milwaukee	959,300	Low-growth	957,300	955,200	953,000	-6,300	-0.7
		Intermediate-growth	975,600	992,300	1,010,000	50,700	5.3
		High-growth	1,011,000	1,063,900	1,120,000	160,700	16.8
Ozaukee	72,800	Low-growth	80,500	82,800	84,000	11,200	15.4
		Intermediate-growth	85,800	89,700	91,700	18,900	26.0
		High-growth	99,000	106,900	111,000	38,200	52.5
Racine	175,100	Low-growth	177,400	178,800	180,000	4,900	2.8
		Intermediate-growth	184,900	190,800	195,600	20,500	11.7
		High-growth	197,200	210,400	221,000	45,900	26.2
Walworth	75,000	Low-growth	80,000	82,800	85,000	10,000	13.3
		Intermediate-growth	86,500	93,000	98,000	23,000	30.7
		High-growth	94,900	106,300	115,000	40,000	53.3
Washington	95,300	Low-growth	111,100	117,300	120,000	24,700	25.9
		Intermediate-growth	118,500	127,500	131,500	36,200	38.0
		High-growth	136,700	152,800	160,000	64,700	67.9
Waukesha	304,700	Low-growth	341,600	353,800	360,000	55,300	18.1
		Intermediate-growth	362,600	381,700	391,500	86,800	28.5
		High-growth	408,300	442,500	460,000	155,300	51.0
Region	1,810,400	Low-growth	1,884,800	1,911,800	1,925,000	114,600	6.3
		Intermediate-growth	1,960,600	2,030,600	2,077,900	267,500	14.8
		High-growth	2,105,800	2,256,100	2,367,000	556,600	30.7

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

Table 3

HOUSEHOLDS IN THE REGION BY COUNTY: 1950-1990

County	Households				
	1950	1960	1970	1980	1990
Kenosha	21,958	29,545	35,468	43,064	47,029
Milwaukee	249,232	314,875	338,605	363,653	373,048
Ozaukee	6,591	10,417	14,753	21,763	25,707
Racine	31,399	40,736	49,796	59,418	63,736
Walworth	12,369	15,414	18,544	24,789	27,620
Washington	9,396	12,532	17,385	26,716	32,977
Waukesha	23,599	42,394	61,935	88,552	105,990
Region	354,544	465,913	536,486	627,955	676,107

County	1950-1960 Change		1960-1970 Change		1970-1980 Change		1980-1990 Change		1950-1990 Change	
	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Kenosha	7,587	34.6	5,923	20.0	7,596	21.4	3,965	9.2	25,071	114.2
Milwaukee	65,643	26.3	23,730	7.5	25,048	7.4	9,395	2.6	123,816	49.7
Ozaukee	3,826	58.0	4,336	41.6	7,010	47.5	3,944	18.1	19,116	290.0
Racine	9,337	29.7	9,060	22.2	9,622	19.3	4,318	7.3	32,337	103.0
Walworth	3,045	24.6	3,130	20.3	6,245	33.7	2,831	11.4	15,251	123.3
Washington	3,136	33.4	4,853	38.7	9,331	53.7	6,261	23.4	23,581	251.0
Waukesha	18,795	79.6	19,541	46.1	26,617	43.0	17,438	19.7	82,391	349.1
Region	111,369	31.4	70,573	15.1	91,469	17.0	48,152	7.7	321,563	90.7

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

Table 4

HOUSEHOLD SIZE IN THE REGION BY COUNTY: 1950-1990

County	Average Persons per Household				
	1950	1960	1970	1980	1990
Kenosha	3.36	3.36	3.26	2.80	2.67
Milwaukee	3.34	3.21	3.04	2.59	2.50
Ozaukee	3.51	3.65	3.66	3.04	2.79
Racine	3.37	3.39	3.35	2.86	2.70
Walworth	3.25	3.28	3.16	2.74	2.60
Washington	3.55	3.64	3.63	3.14	2.86
Waukesha	3.51	3.66	3.66	3.11	2.83
Region	3.36	3.30	3.20	2.75	2.62

County	1950-1960 Change		1960-1970 Change		1970-1980 Change		1980-1990 Change		1950-1990 Change	
	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Kenosha	0.00	0.0	-0.10	-3.0	-0.46	-14.1	-0.13	-4.6	-0.69	-20.5
Milwaukee	-0.13	-3.9	-0.17	-5.3	-0.45	-14.8	-0.09	-3.5	-0.84	-25.1
Ozaukee	0.14	4.0	0.01	0.3	-0.62	-16.9	-0.25	-8.2	-0.72	-20.5
Racine	0.02	0.6	-0.04	-1.2	-0.49	-14.6	-0.16	-5.6	-0.67	-19.9
Walworth	0.03	0.9	-0.12	-3.7	-0.42	-13.3	-0.14	-5.1	-0.65	-20.0
Washington	0.09	2.5	-0.01	-0.3	-0.49	-13.5	-0.28	-8.9	-0.69	-19.4
Waukesha	0.15	4.3	0.00	0.0	-0.55	-15.0	-0.28	-9.0	-0.68	-19.4
Region	-0.06	-1.8	-0.10	-3.0	-0.45	-14.1	-0.13	-4.7	-0.74	-22.0

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

Table 5

EXISTING AND PROJECTED HOUSEHOLDS IN THE REGION BY COUNTY: 1990-2020

County	Actual 1990 Household Level	Projected Household Levels				Projected Change 1990 to 2020	
		Scenario	2000	2010	2020	Number	Percent
Kenosha	47,000	Low-growth	51,800	55,100	57,700	10,700	22.8
		Intermediate-growth	54,800	59,200	61,800	14,800	31.5
		High-growth	58,500	64,200	67,000	20,000	42.6
Milwaukee	373,100	Low-growth	382,200	391,400	401,200	28,100	7.5
		Intermediate-growth	384,300	395,700	407,800	34,700	9.3
		High-growth	393,100	413,200	434,500	61,400	16.5
Ozaukee	25,700	Low-growth	29,900	32,500	34,900	9,200	35.8
		Intermediate-growth	31,500	34,300	36,600	10,900	42.4
		High-growth	35,900	39,800	42,500	16,800	65.4
Racine	63,700	Low-growth	67,500	71,200	75,100	11,400	17.9
		Intermediate-growth	69,400	73,900	78,200	14,500	22.8
		High-growth	73,100	79,400	84,900	21,200	33.3
Walworth	27,600	Low-growth	30,400	32,500	34,500	6,900	25.0
		Intermediate-growth	32,400	35,500	38,100	10,500	38.0
		High-growth	35,100	39,500	43,000	15,400	55.8
Washington	33,000	Low-growth	41,000	46,500	51,300	18,300	55.5
		Intermediate-growth	43,200	49,200	54,000	21,000	63.6
		High-growth	49,300	57,600	63,100	30,100	91.2
Waukesha	106,000	Low-growth	124,400	135,100	144,400	38,400	36.2
		Intermediate-growth	130,400	141,900	150,600	44,600	42.1
		High-growth	144,900	160,300	170,100	64,100	60.5
Region	676,100	Low-growth	727,200	764,300	799,100	123,000	18.2
		Intermediate-growth	746,000	789,700	827,100	151,000	22.3
		High-growth	789,900	854,000	905,100	229,000	33.9

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

Table 6

EMPLOYMENT IN THE REGION BY COUNTY: 1950-1990

County	Employment				
	1950	1960	1970	1980	1990
Kenosha	29,100	42,200	42,000	53,900	50,900
Milwaukee	453,500	503,300	524,900	581,700	613,300
Ozaukee	6,600	10,200	21,200	28,100	36,400
Racine	44,500	49,900	64,500	80,900	88,800
Walworth	13,200	19,600	26,300	33,400	40,200
Washington	10,200	15,200	24,300	35,000	46,100
Waukesha	16,400	32,600	80,900	132,200	191,500
Region	573,500	673,000	784,100	945,200	1,067,200

County	1950-1960 Change		1960-1970 Change		1970-1980 Change		1980-1990 Change		1950-1990 Change	
	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent	Absolute	Percent
Kenosha	13,100	45.0	-200	-0.5	11,900	28.3	-3,000	-5.6	21,800	74.9
Milwaukee	49,800	11.0	21,600	4.3	56,800	10.8	31,600	5.4	159,800	35.2
Ozaukee	3,600	54.5	11,000	107.8	6,900	32.5	8,300	29.5	29,800	451.5
Racine	5,400	12.1	14,600	29.3	16,400	25.4	7,900	9.8	44,300	99.6
Walworth	6,400	48.5	6,700	34.2	7,100	27.0	6,800	20.4	27,000	204.5
Washington	5,000	49.0	9,100	59.9	10,700	44.0	11,100	31.7	35,900	352.0
Waukesha	16,200	98.8	48,300	148.2	51,300	63.4	59,300	44.9	175,100	1,067.7
Region	99,500	17.3	111,100	16.5	161,100	20.5	122,000	12.9	493,700	86.1

Source: U.S. Bureau of Economic Analysis and SEWRPC.

Table 7

EXISTING AND PROJECTED EMPLOYMENT IN THE REGION BY COUNTY: 1990-2020

County	Actual 1990 Employment Level	Projected Employment Levels				Projected Change 1990 to 2020	
		Scenario	2000	2010	2020	Number	Percent
Kenosha	50,900	Low-growth	56,800	62,500	66,900	16,000	31.4
		Intermediate-growth	58,400	64,900	70,200	19,300	37.9
		High-growth	60,700	68,000	74,900	24,000	47.2
Milwaukee	613,300	Low-growth	620,800	629,800	623,100	9,800	1.6
		Intermediate-growth	639,000	654,000	653,900	40,600	6.6
		High-growth	663,600	685,600	697,700	84,400	13.8
Ozaukee	36,400	Low-growth	40,800	45,200	48,700	12,300	33.8
		Intermediate-growth	42,000	46,900	51,100	14,700	40.4
		High-growth	43,600	49,200	54,500	18,100	49.7
Racine	88,800	Low-growth	94,900	100,300	103,400	14,600	16.4
		Intermediate-growth	97,700	104,100	108,600	19,800	22.3
		High-growth	101,400	109,200	115,800	27,000	30.4
Walworth	40,200	Low-growth	52,700	56,200	58,400	18,200	45.3
		Intermediate-growth	54,200	58,400	61,300	21,100	52.5
		High-growth	56,300	61,200	65,400	25,200	62.7
Washington	46,100	Low-growth	51,500	56,700	60,800	14,700	31.9
		Intermediate-growth	53,000	58,900	63,800	17,700	38.4
		High-growth	55,000	61,700	68,100	22,000	47.7
Waukesha	191,500	Low-growth	214,700	237,400	255,600	64,100	33.5
		Intermediate-growth	221,000	246,500	268,200	76,700	40.1
		High-growth	229,400	258,400	286,200	94,700	49.5
Region	1,067,200	Low-growth	1,132,200	1,188,100	1,216,900	149,700	14.0
		Intermediate-growth	1,165,300	1,233,700	1,277,100	209,900	19.7
		High-growth	1,210,000	1,293,300	1,362,600	295,400	27.7

Source: U.S. Bureau of Economic Analysis and SEWRPC.

Land Use Patterns

The Commission has, at five-year intervals, conducted land use inventories of the Region since 1963. These inventories are intended to serve as a relatively precise, high quality record of the land use pattern within the Region at selected points in time. The inventories are conducted by aerial photographic interpretation, supplemented by field inspection. The photographs used from 1963 through 1990 were ratioed and rectified to a scale of one inch equals 400 feet. In 1995, digital orthophotographs at a scale of one inch equals 400 feet, meeting National Map Accuracy Standards, were used in the inventories. The land use delineations are available in computer-manipulable digital as well as hard copy form.

The classification system used in the land use inventories consists of nine major categories, which are divisible into 66 minor categories, making the inventory suitable for land use, transportation system, stormwater management, sanitary sewerage, water supply, and community facility planning. Areas considered as urban under the land use inventory include areas of any size and location that are used for residential, commercial, industrial, transportation, communication, utility, governmental, institutional, and intensive recreational purposes. Unused urban lands are also included in the urban land use category.[1] Areas considered as rural under the land use inventory include areas used for agricultural, extractive, landfill, and extensive recreational purposes; woodlands, wetlands, and other open lands; and surface water.

The existing pattern of land use development within the Region in 1990 is shown on Map 3. Data on the amount and proportion of land devoted to each of the major land use categories, and on changes in these amounts and proportion over time are provided in Table 8.

Although Southeastern Wisconsin is an urban region, less than one-quarter of its total area was in 1990 devoted to urban land uses. From 1963 to 1990, urban land use within the Region increased from about 443 square miles to about 637 square miles, or by about 194 square miles, or 44 percent (Table 8). Each of the major urban land use categories, with the exception of unused urban land, increased significantly over this time period. Residential land comprised the largest urban land use category, encompassing about 305 square miles, or about 48 percent of all urban land, and 11 percent of the total area of the Region. Transportation, communication, and utility lands encompassed about 195 square miles, or about 31 percent of all urban lands and seven percent of the total area of the Region. No other urban land uses comprised more than 6.4 percent of the urban land, or 1.5 percent of the total area of the Region.

Rural—or nonurban—lands within the Region—comprised about 2,053 square miles in 1990, or about 76 percent of the total area of the Region (Table 8). Agricultural land comprised the largest nonurban land use category, encompassing about 1,395 square miles, or about 68 percent of all nonurban land and 52 percent of the total area of the Region. Wetlands, woodlands, and surface water, in combination, encompassed about 532 square miles, representing about 26 percent of all nonurban lands and about 20 percent of the total area of the Region. Unused rural and other open lands, consisting of open lands other than wetlands and woodlands, agricultural lands, and landfills and extractive lands, encompassed about 126 square miles, representing about 6 percent of all nonurban lands and about 5 percent of the total area of the Region. Nonurban land uses within the Region decreased by about 194 square miles, or about 9 percent, between 1963 and 1990.

Public Utility Service Areas

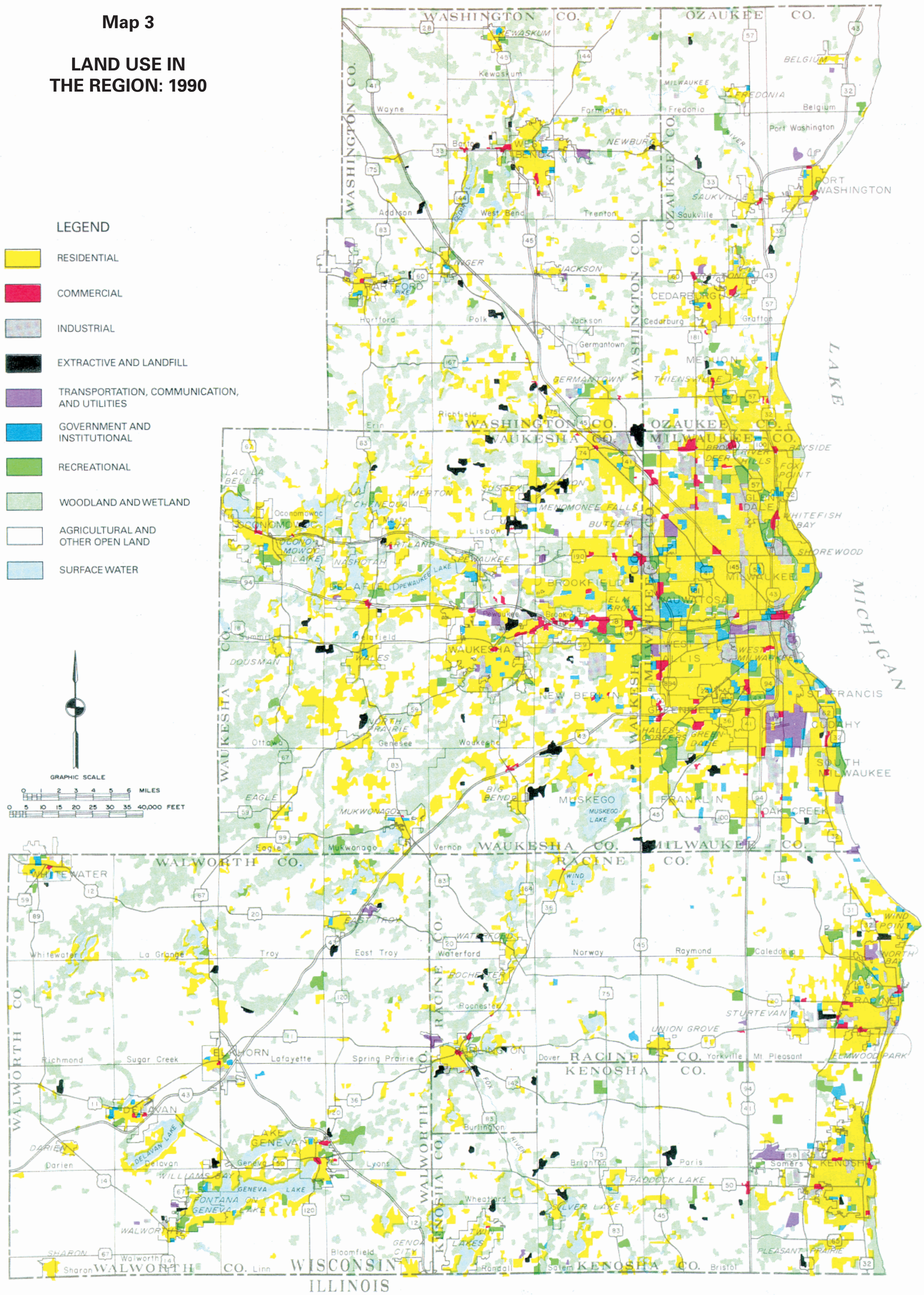
Urban development is highly dependent upon the existence of utility systems, including electric power, natural gas, communication, water supply, sanitary sewerage, and stormwater management systems. Water supply, sanitary sewerage, and stormwater management systems are particularly important considerations in groundwater planning because the location and density of urban development influences the need for such facilities, and the existence of such facilities shapes the urban land use pattern and directly influences the groundwater usage.

---

[1]*Unused urban lands consist of open lands other than wetlands and woodlands that are located in urban areas, which have not yet been developed for or committed to a particular use.*

Map 3

LAND USE IN THE REGION: 1990



This map summarizes the spatial distribution of the various land uses existing within the Region in 1990. Urban land uses—consisting of lands devoted to residential, commercial, industrial, recreational, governmental and institutional, and transportation, communication, and utility uses—occupied a total of about 637 square miles, or about 24 percent of the area of the Region, in 1990. Nonurban land uses—consisting of agricultural lands, wetlands, woodlands, surface water, extractive and landfill sites, and unused rural lands—totaled 2,053 square miles, or about 76 percent of the Region. While urban land uses encompassed less than one-quarter of the Region, those uses were diffused throughout the Region, creating an impression of widespread urbanization.

Source: SEWRPC.

Table 8

LAND USE IN THE SOUTHEASTERN WISCONSIN REGION: 1963, 1970, 1980, AND 1990

Land Use Category	Existing Land Use											
	1963			1970			1980			1990		
	Square Miles	Percent of Urban/ Nonurban	Percent of Total	Square Miles	Percent of Urban/ Nonurban	Percent of Total	Square Miles	Percent of Urban/ Nonurban	Percent of Total	Square Miles	Percent of Urban/ Nonurban	Percent of Total
Urban												
Residential	191.5	43.2	7.1	223.0	44.1	8.3	281.0	47.5	10.4	307.7	48.3	11.4
Commercial	8.8	2.0	0.3	10.5	2.1	0.4	12.8	2.2	0.5	15.2	2.4	0.6
Industrial	11.4	2.6	0.4	14.3	2.8	0.5	17.5	3.0	0.7	20.5	3.2	0.8
Transportation, Communication, and Utilities[a]	143.2	32.3	5.3	162.0	32.1	6.0	183.9	31.1	6.8	194.9	30.6	7.2
Governmental and Institutional	20.4	4.6	0.8	24.8	4.9	0.9	26.6	4.5	1.0	27.0	4.3	1.0
Recreational	26.2	5.9	1.0	33.2	6.6	1.2	38.0	6.4	1.4	40.9	6.4	1.5
Unused Urban Land	41.7	9.4	1.6	37.5	7.4	1.4	31.1	5.3	1.2	30.5	4.8	1.1
Urban Subtotal	443.2	100.0	16.5	505.3	100.0	18.7	590.9	100.0	22.0	636.7	100.0	23.6
Nonurban												
Natural Areas												
Surface Water	71.6	3.2	2.7	74.0	3.4	2.7	76.2	3.6	2.8	76.9	3.7	2.9
Wetlands	274.3	12.2	10.2	270.3	12.4	10.1	266.6	12.7	9.9	268.7	13.1	10.0
Woodlands	186.8	8.3	6.9	184.3	8.4	6.9	181.9	8.7	6.8	185.9	9.1	6.9
Subtotal	532.7	23.7	19.8	528.6	24.2	19.7	524.7	25.0	19.5	531.5	25.9	19.8
Agricultural	1,637.1	72.9	60.9	1,564.7	71.7	58.2	1,475.4	70.3	54.8	1,395.4	68.0	51.9
Unused Rural and Other Open Land	76.3	3.4	2.8	90.4	4.1	3.4	98.4	4.7	3.7	125.9	6.1	4.7
Nonurban Subtotal	2,246.1	100.0	83.5	2,183.7	100.0	81.3	2,098.5	100.0	78.0	2,052.8	100.0	76.4
Total	2,689.3	- -	100.0	2,689.0	- -	100.0	2,689.4	- -	100.0	2,689.5	- -	100.0

Land Use Category	Change in Land Use							
	1963-1970		1970-1980		1980-1990		1963-1990	
	Square Miles	Percent	Square Miles	Percent	Square Miles	Percent	Square Miles	Percent
Urban								
Residential	31.5	16.4	58.0	26.0	26.7	9.5	116.2	60.7
Commercial	1.7	19.3	2.3	21.9	2.4	18.7	6.4	72.7
Industrial	2.9	25.4	3.2	22.4	3.0	17.1	9.1	79.8
Transportation, Communication, and Utilities[a]	18.8	13.1	21.9	13.5	11.0	6.0	51.7	36.1
Governmental and Institutional	4.4	21.6	1.8	7.3	0.4	1.5	6.6	32.4
Recreational	7.0	26.7	4.8	14.5	2.9	7.6	14.7	56.1
Unused Urban Land	-4.2	-10.1	-6.4	-17.1	-0.6	-1.9	-11.2	-26.9
Urban Subtotal	62.1	14.0	85.6	16.9	45.8	7.8	193.5	43.7
Nonurban								
Natural Areas								
Surface Water	2.4	3.4	2.2	3.0	0.7	0.9	5.3	7.4
Wetlands	-4.0	-1.5	-3.7	-1.4	2.1	0.8	-5.6	-2.0
Woodlands	-2.5	-1.3	-2.4	-1.3	4.0	2.2	-0.9	-0.5
Subtotal	-4.1	-0.8	-3.9	-0.7	6.8	1.3	-1.2	-0.2
Agricultural	-72.4	-4.4	-89.3	-5.7	-80.0	-5.4	-241.7	-14.8
Unused Rural and Other Open Land	14.1	18.5	8.0	8.8	27.5	27.9	49.6	65.0
Nonurban Subtotal	-62.4	-2.8	-85.2	-3.9	-45.7	-2.2	-193.3	-8.6
Total	-0.3	0.0	0.4	0.0	0.1	0.0	0.2	0.0

NOTE: The change in the total area of the Region is the net effect of Lake Michigan shoreline erosion, accretion, and landfill activities.

[a]*Includes off-street parking areas with more than 10 spaces associated with various urban land uses.*

Source: SEWRPC.

Areas served by public water utilities in 1990 encompassed about 344 square miles, or about 13 percent of the total area of the Region (Map 1 shows these areas updated to 1995). As indicated in Table 9, these areas were inhabited by about 1,486,000 persons in 1990, or about 82 percent of the total resident population of the Region. Map 1 displays the water supply service areas broken down into areas served by groundwater and by surface water sources

Table 9

AREA AND POPULATION SERVED BY PUBLIC WATER UTILITIES IN THE REGION BY COUNTY: 1970 AND 1990

County	Area Served by Public Water Utilities				Population Served by Public Water Utilities			
	1970		1990		1970		1990	
	Square Miles	Percent of County Area	Square Miles	Percent of County Area	Persons	Percent of County Populatio n	Persons	Percent of County Populatio n
Kenosha	16.4	5.9	26.7	9.6	81,000	68.7	97,000	75.6
Milwaukee	165.2	68.1	176.5	72.8	1,013,900	96.2	942,500	98.2
Ozaukee	7.2	3.1	11.5	4.9	25,700	47.2	35,900	49.3
Racine	25.2	7.4	38.0	11.2	120,900	70.8	142,700	81.5
Walworth	12.7	2.2	16.1	2.8	36,300	57.2	40,900	54.5
Washington	8.1	1.9	15.6	3.6	28,300	44.4	50,900	53.4
Waukesha	24.6	4.2	59.1	10.2	84,400	36.5	174,700	57.4
Region	259.4	9.6	343.5	12.8	1,390,500	79.2	1,484,600	82.0

NOTE: In addition to publicly owned water utilities, there were numerous private or cooperatively owned water utilities in the Region in 1990 serving residential subdivisions, apartment and condominium developments, mobile home parks, and institutions. These private or cooperatively owned water supply systems served areas encompassing about 11 square miles, with a population of about 35,000 persons, in the Region in 1990.

Source: SEWRPC.

of supply. Surface water as a source of supply was used in about 230 square miles, or 67 percent, of the 344 square miles of total service area inhabited by 1,152,000 persons, or about 78 percent of total population served. Groundwater as a source of supply was used in about 114 square miles, or 33 percent, of total the total service area inhabited by 334,000 persons, or about 22 percent of the total population served.

Areas served by public sanitary sewers in 1990 encompassed about 433 square miles, or about 16 percent of the total area of the Region (Map 4). As indicated in Table 10, these areas were inhabited by about 1,594,300 persons in 1990, or about 88 percent of the total resident population of the Region.

ENVIRONMENTAL CORRIDORS AND VEGETATION

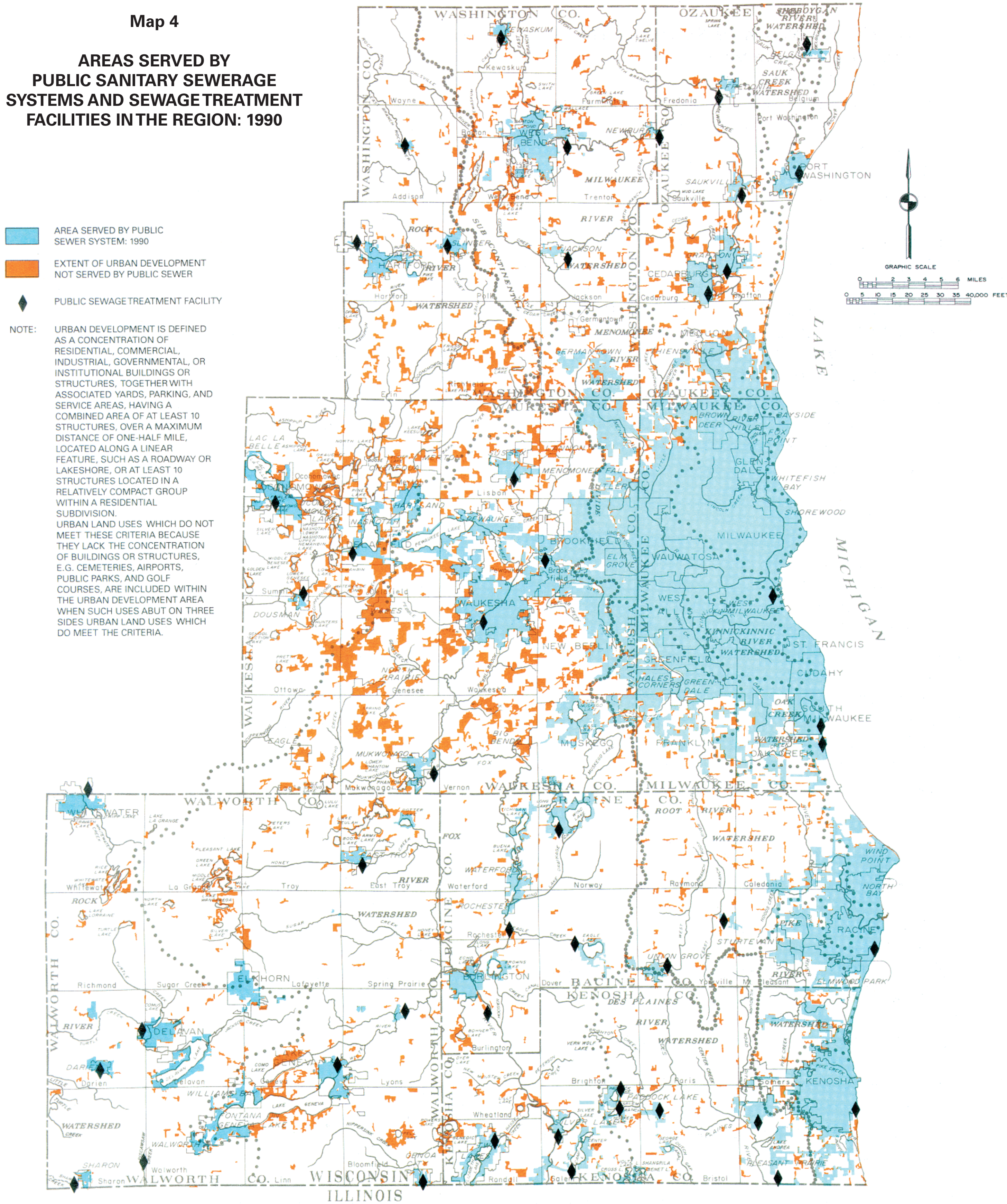
One of the most important tasks completed under the regional planning program for Southeastern Wisconsin has been the identification and delineation of those areas of the Region in which concentrations of the best remaining elements of the natural resource base occur, including the best remaining woodlands, wetlands, and wildlife habitat areas; surface waters and associated shorelands and floodlands; areas covered by organic soils; areas containing rough topography and significant geologic formations; sites having scenic, historic, and scientific value; and areas of groundwater recharge or discharge. These features occur in an essentially linear pattern of relatively narrow, elongated areas, which have been termed “environmental corridors” by the Commission (SEWRPC, 1981).

The preservation of the corridors in essentially natural, open uses will not only do much to ensure the maintenance of the overall environmental quality of the Region, but will also help prevent the creation of costly environmental problems. These problems include surface and groundwater contamination; poor drainage and flooding; failing onsite sewage treatment and disposal systems; excessive infiltration of clear water into sanitary sewage systems; wet basements and excessive operation of building foundation drain sump pumps; and settlement and structural failure of roadways, parking area, utilities, and buildings.

Primary environmental corridors include a variety of the important natural resource and resource-related elements and are at least 400 acres in size, two miles in length, and 200 feet in width. The secondary environ-

Map 4

AREAS SERVED BY PUBLIC SANITARY SEWERAGE SYSTEMS AND SEWAGE TREATMENT FACILITIES IN THE REGION: 1990



Centralized public sanitary sewer service in the Region was provided to an area of about 433 square miles, or about 16 percent of the total area of the Region, in 1990. About 1.59 million persons, or about 88 percent of the total resident population of the Region at that time, were then served by sanitary sewers. The remaining 12 percent of the resident population, or about 216,000 persons, relied on private onsite sewage disposal systems or holding tanks. A relatively small portion of these, about 10,000 persons, lived on farms. The remaining 206,000 persons were urban dwellers generally living in scattered fashion throughout the rural and rural-urban fringe areas of the Region.

Source: SEWRPC.

Table 10

AREA AND POPULATION SERVED BY PUBLIC SANITARY SEWERS IN THE REGION BY COUNTY: 1970 AND 1990

County	Area Served by Public Sanitary Sewers				Population Served by Public Sanitary Sewers			
	1970		1990		1970		1990	
	Square Miles	Percent of County Area	Square Miles	Percent of County Area	Persons	Percent of County Population	Persons	Percent of County Population
Kenosha	23.8	8.6	40.6	14.6	94,000	79.7	111,900	87.3
Milwaukee	179.0	73.9	190.7	78.6	1,034,700	98.2	954,600	99.5
Ozaukee	17.3	7.4	22.3	9.5	36,300	66.7	54,900	75.4
Racine	29.5	8.7	52.3	15.4	135,900	79.6	154,900	88.5
Walworth	11.9	2.1	20.5	3.6	35,500	56.0	45,200	60.2
Washington	9.4	2.2	18.0	4.1	30,200	47.3	53,300	55.9
Waukesha	38.5	6.6	88.5	15.2	122,100	52.8	219,500	72.0
Region	309.4	11.5	432.9	16.1	1,488,700	84.8	1,594,300	88.1

Source: SEWRPC.

mental corridors generally connect with the primary environmental corridors and are at least 100 acres in size and one mile in length. In addition, smaller concentrations of natural resource base elements that are separated physically from the environmental corridors by intensive urban or agricultural land uses have also been identified. These areas, which are at least five acres in size, have been termed isolated natural resource areas by the Commission.

In any consideration of environmental corridors and important natural features, it is important to note that the preservation of such features can assist in groundwater protection, as well as flood flow attenuation and water contamination abatement. In addition, because of the many interacting relationships existing between living organisms and their environment, the destruction or deterioration of one important element of the total environment may lead to a chain reaction of deterioration and destruction of other elements. The drainage of wetlands, for example, may destroy fish spawning areas, wildlife habitat, groundwater discharge and recharge areas, and natural filtration and floodwater storage areas of interconnecting stream systems. The resulting deterioration of surface water quality may, in turn, lead to a deterioration of the quality of the groundwater, which serves as a source of domestic, municipal, and industrial water supply, and upon which low flows of rivers and streams may depend.

Primary Environmental Corridors

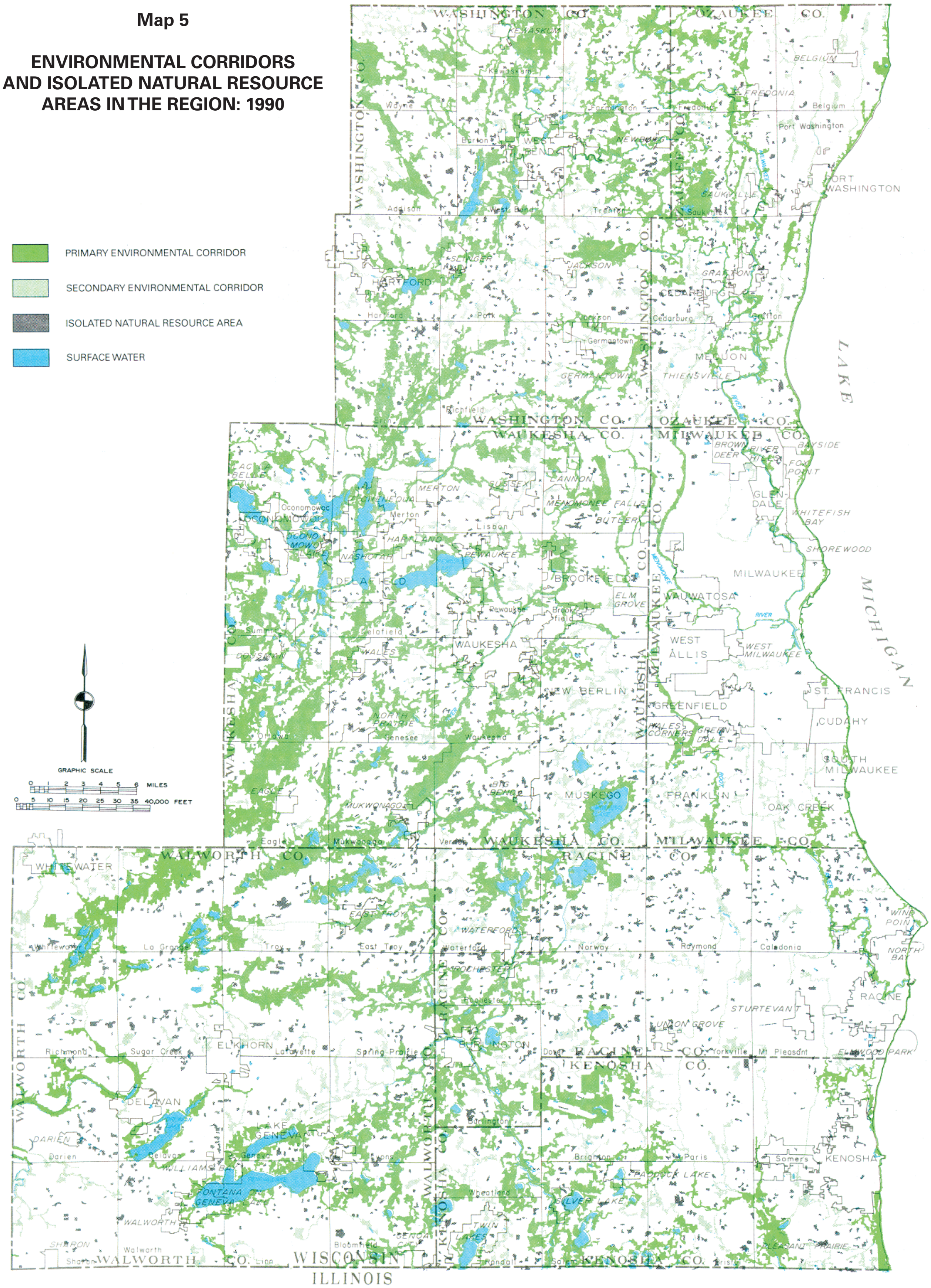
As shown on Map 5, the primary environmental corridors in the Region are generally located along major stream valleys, around major lakes, and along the Kettle Moraine. These primary environmental corridors contain almost all of the best remaining woodlands, wetlands, and wildlife habitat areas in the Region, and represent a composite of the best remaining elements of the natural resource base. The protection of the primary environmental corridors from additional intrusion by incompatible land uses, degradation, and destruction is one of the principal objectives of the regional land use plan. As already noted, the preservation of these corridors in essentially natural, open uses, including park and open space uses, will help to maintain a high level of environmental quality in the Region, and provide valuable recreation opportunities. As indicated in Table 11, in 1990 primary environmental corridors encompassed about 470 square miles, or about 18 percent of the total area of the Region.

Secondary Environmental Corridors

As also shown on Map 5, secondary environmental corridors are generally located along the small perennial and intermittent streams within the Region. These secondary environmental corridors are often comprised of remnants of primary environmental corridors that have been developed for intensive agricultural and urban purposes. In 1990, secondary environmental corridors encompassed 76 square miles, or about 3 percent of the total area of the Region.

Map 5

ENVIRONMENTAL CORRIDORS AND ISOLATED NATURAL RESOURCE AREAS IN THE REGION: 1990



The most important elements of the natural resource base of the Region—lakes, rivers and streams, wetlands, woodlands, prairies, wildlife habitat areas, and steeply sloped areas—are found in the environmental corridors and isolated natural resource areas identified on this map. The preservation of these areas in natural, open uses will help maintain the overall quality of the environment of the Region; preserve its natural beauty; and provide opportunities for recreational, educational, and scientific pursuits. Moreover, because these areas are generally poorly suited for urban development, their preservation will help to avoid the creation of new environmental and developmental problems.

Source: SEWRPC.

Table 11

ENVIRONMENTAL CORRIDORS AND ISOLATED NATURAL RESOURCE AREAS IN THE REGION BY COUNTY: 1990

County	Primary Environmental Corridors		Secondary Environmental Corridors		Isolated Natural Resource Areas		Total: Environmental Corridors and Isolated Natural Resource Areas		Area Outside of Environmental Corridors and Isolated Natural Resource Areas		Total Area of County	
	Square Miles	Percent of County	Square Miles	Percent of County	Square Miles	Percent of County	Square Miles	Percent of County	Square Miles	Percent of County	Square Miles	Percent of County
Kenosha	44.8	16.1	9.8	3.5	5.8	2.1	60.4	21.7	218.0	78.3	278.4	100.0
Milwaukee	15.6	6.4	5.2	2.2	3.5	1.4	24.3	10.0	218.3	90.0	242.6	100.0
Ozaukee	32.5	13.8	7.7	3.3	5.4	2.3	45.6	19.4	189.5	80.6	235.1	100.0
Racine	37.5	11.0	11.0	3.3	11.7	3.4	60.2	17.7	280.3	82.3	340.5	100.0
Walworth	100.7	17.5	14.6	2.5	12.9	2.2	128.2	22.2	448.3	77.8	576.5	100.0
Washington	94.0	21.6	15.5	3.6	10.2	2.3	119.7	27.5	316.0	72.5	435.7	100.0
Waukesha	145.0	25.0	12.2	2.1	13.4	2.3	170.6	29.4	410.0	70.6	580.6	100.0
Region	470.1	17.5	76.0	2.8	62.9	2.3	609.0	22.6	2,080.4	77.4	2,689.4	100.0

Source: SEWRPC.

Isolated Natural Resource Areas

As already noted, in addition to the primary and secondary environmental corridors, other smaller pockets or concentrations of natural resource base elements exist within the Region. These pockets are isolated from the environmental corridors by urban development or agricultural use. Although separated from the environmental corridor network, these isolated natural resource areas have significant value. The isolated natural resource areas in the Region are shown on Map 5 and include isolated wetlands, woodlands, and wildlife habitat areas. In 1990, isolated natural resource areas encompassed about 63 square miles, or about 2 percent of the total area of the Region.

Vegetation

Presettlement Vegetation

Historically, vegetational patterns in the Region were influenced by such factors as climate, soils, fire, topography, and natural drainage patterns. Historical records, particularly the records of the original U.S. Public Land Survey carried out within the Region in 1835 and 1836, indicate that large portions of Southeastern Wisconsin consisted of open, level plains containing orchard-like stands of oak or prairies dominated by big blue-stem grass and colorful prairie forbs. Other portions of the Region were covered by mixed hardwood forests. The upland timber for the most part consisted of such deciduous hardwood species such as sugar maple, oak, elm, ash, hickory, beech, linden, walnut, and ironwood; and one coniferous species, white pine. The lowland timber consisted of such species as black ash, elm, willow, cedar, tamarack, aspen, and soft maple.

Prairies

Prairies are treeless or generally treeless areas dominated by perennial native grasses. Prairies, which have important ecological and scientific value, consist of four basic types: low prairie, mesic or moderately moist prairie, dry prairie, and savannah. Prairies, which once covered extensive areas of Southeastern Wisconsin, have been reduced to scattered remnants, primarily in the southern and western portions of the Region. The chief causes of loss of prairie is their conversion to urban and agricultural use and the suppression of wildfires, which had served to constrain the advancing shrubs and trees that shade out the prairie plants.

Woodlands

Six woodland types are recognized within the Region: northern upland hardwoods, southern upland hardwoods, northern lowland hardwoods, southern lowland hardwoods, northern lowland conifers, and northern upland conifers. The northern and southern upland hardwood types are the most common in the Region and are most utilized for production of commercial forest products. Lowland wood areas, such as tamarack swamps, are classified as wetlands in the regional land use inventory.

The remaining natural stands of trees within the Region consist largely of even-aged mature, or nearly mature, specimens with insufficient reproduction and saplings to maintain the stands when the old trees are harvested or die of disease or age. The lack of young growth is an unnatural condition brought about by mismanagement, and is most often associated with many years of excessive grazing by livestock.

Upland woodlands encompassed a total of about 116,200 acres, or about 7 percent of the total area of the Region, in 1990. The distribution of upland woodlands in the Region is shown on Map 6. Concentrations of woodlands are evident in the Kettle Moraine area and in certain major stream valleys in outlying areas of the Region.

Wetlands

Wetlands are areas in which the water table is at, near, or above the land surface and which are characterized by both hydric soils and the growth of sedges, cattails, and other wetland vegetation. Wetlands generally occur in depressions and near the bottom of slopes, particularly along lakeshores and stream banks, and on large land areas that are poorly drained. Wetlands may, however, under certain conditions, occur on slopes and even on hilltops.

Wetlands perform an important set of natural functions which include support of a wide variety of desirable, and sometimes unique, forms of plants and animal life; stabilization of lake levels and streamflows; reduction in stormwater runoff by providing areas for floodwater impoundment and storage; protection of shorelines from erosion; and, importantly, provision of groundwater discharge areas.

Wetlands encompassed a total of about 169,000 acres, representing about 10 percent of the total area of the Region, in 1990 (Map 7). Concentrations of wetlands occur in the Cedarburg Bog in Ozaukee County, the Jackson and Theresa Marshes in Washington County, and the Tamarack Swamp and Vernon Marsh in Waukesha County (Map 7).

It should also be noted that wetlands are constantly changing in response to changes in drainage patterns and climatic conditions and that, while wetland inventory maps provide a sound basis for areawide planning, they should be viewed as a providing point of departure for regulatory purposes. In view of the dynamic nature of wetlands, detailed field investigations are often necessary to precisely identify wetland boundaries for individual tracts of land at a given point in time.

PHYSICAL SETTING

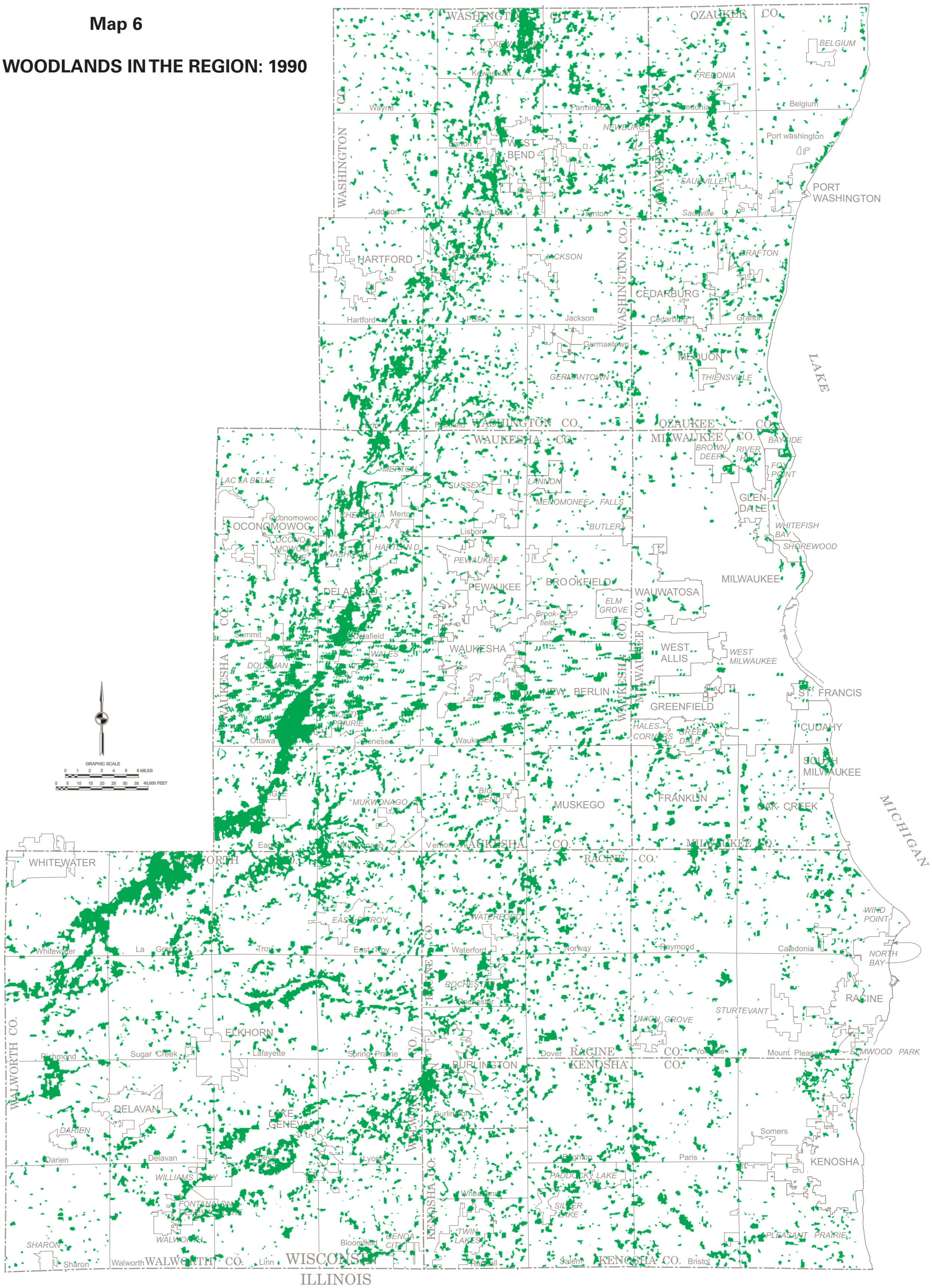
The Southeastern Wisconsin Region is located in the Upper Midwest between Lake Michigan on the east, the Green Bay-Lake Winnebago lowlands on the north, the Rock River basin on the west, and the low dunes and wetlands of the headwater areas of the Illinois River on the south. The seven-county Region (Map 2) extends for approximately 52 miles from east to west at its widest point, and approximately 72 miles from north to south. The Region encompasses approximately 2,613 square miles of land area and 76 square miles of inland water area, exclusive of Lake Michigan, or a total gross land and water area of approximately 2,689 square miles. Topographic elevations range from approximately 580 feet above mean sea level at the Lake Michigan shore, to about 1,320 feet at Holy Hill in southwestern Washington County. The Region lies astride a major subcontinental divide between the Upper Mississippi River and Great Lakes-St. Lawrence River drainage basins (Map 1).

Physiographic and Topographic Features

Glaciation has largely determined the physiography and topography as well as the soils of the Region. The physiographic features, that is, surficial land forms in Southeastern Wisconsin, are shown on Map 8. The variation in elevation within the Region is shown in a generalized manner on Map 9. There is evidence of several stages of glaciation in the Region. The last and most influential in terms of present physiography and topography was the Wisconsin stage, which is believed to have ended in the Region about 11,000 years ago.

Map 6

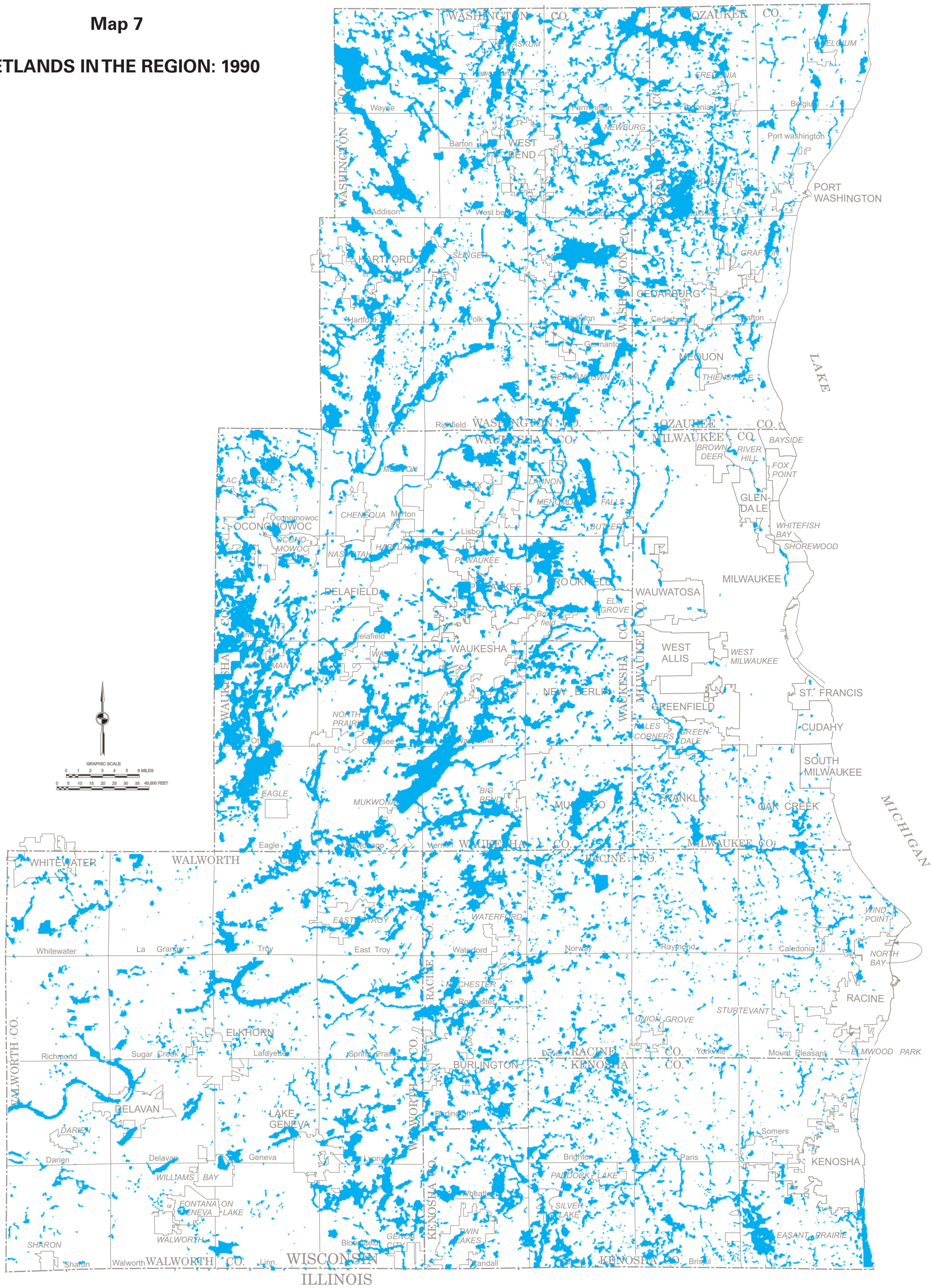
UPLAND WOODLANDS IN THE REGION: 1990



Source: SEWRPC.

Map 7

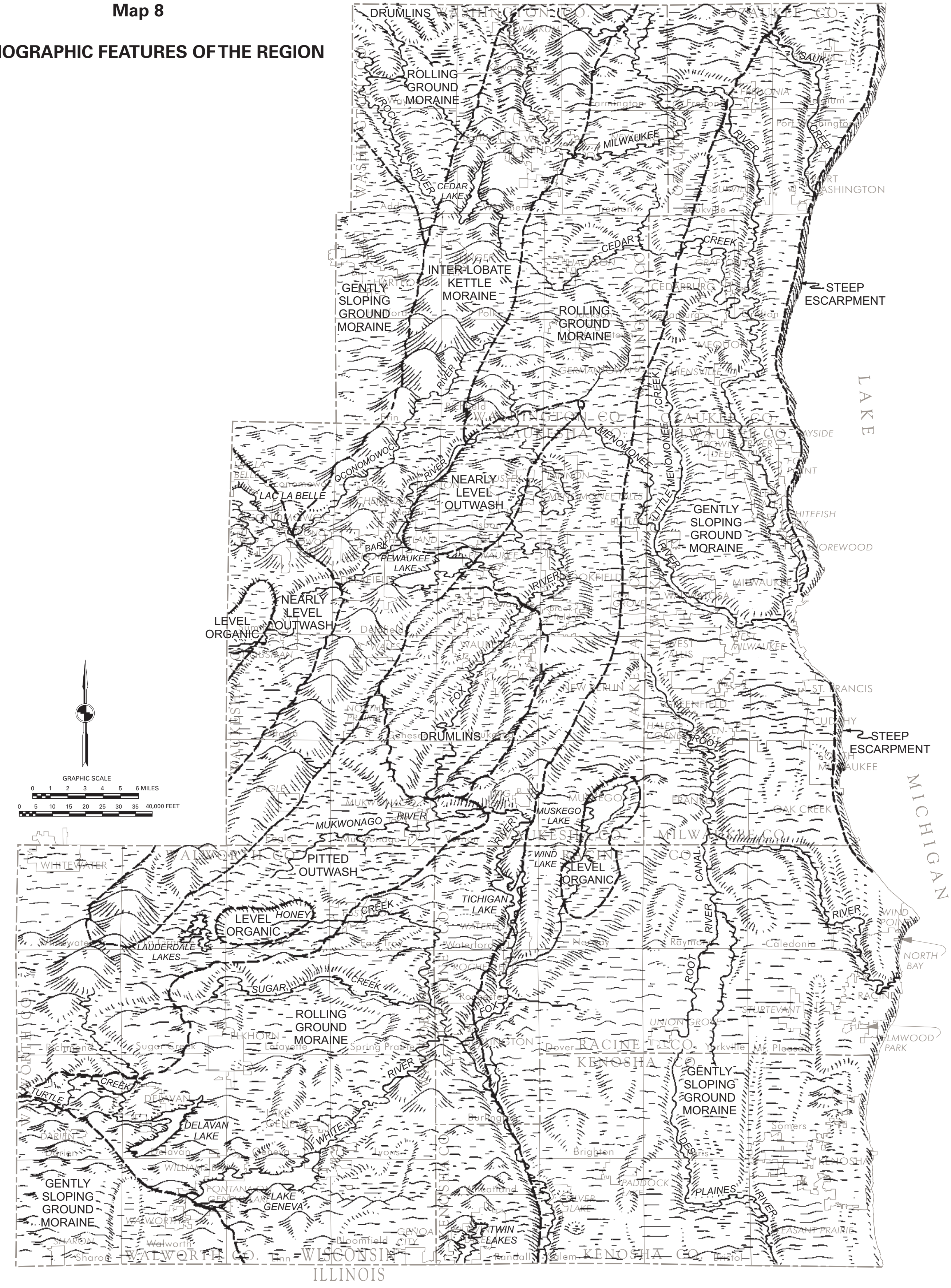
WETLANDS IN THE REGION: 1990



Source: SEWRPC.

Map 8

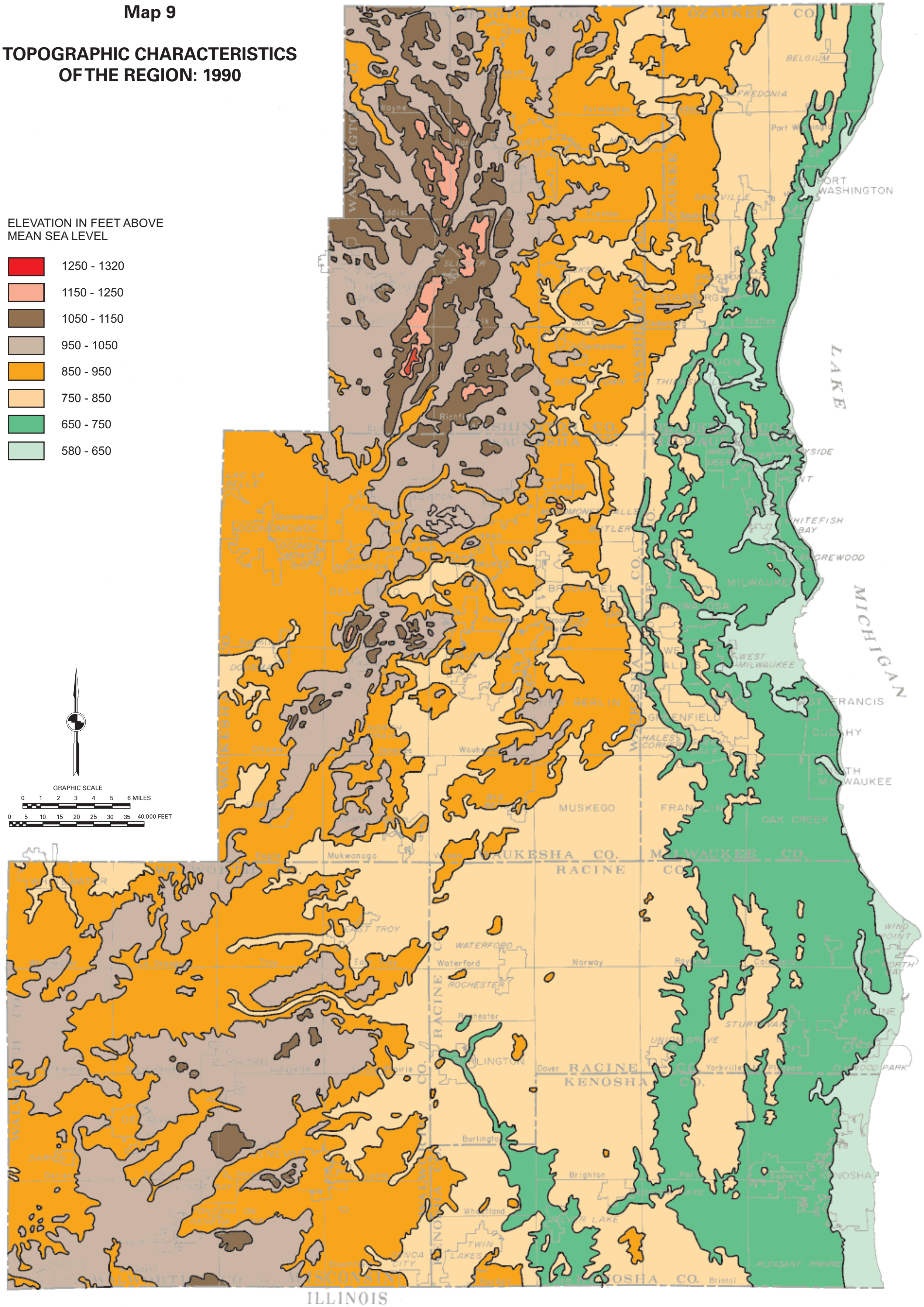
PHYSIOGRAPHIC FEATURES OF THE REGION



Source: SEWRPC.

Map 9

TOPOGRAPHIC CHARACTERISTICS OF THE REGION: 1990



Source: SEWRPC.

The dominant physiographic and topographic feature is the Kettle Moraine, an interlobate glacial deposit or moraine, formed between the Green Bay and Lake Michigan lobes of the continental glacier that moved in a generally southerly direction from its origin in what is now Canada. Topographic high points in the Kettle Moraine include areas in southwestern Waukesha County north of Eagle, areas in central Waukesha County around Lapham Peak, and areas around Holy Hill and Hartford in southwestern and western Washington County. The Kettle Moraine, which is oriented in a general northeast-southwest direction across western Washington, Waukesha, and northwest Walworth Counties (Map 8), is a complex system of hummocky sand and gravel. Some of its features include 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 of ice; and abandoned drainageways. It forms some of the most attractive and interesting landscapes within the Region, and is, as well, the area of the highest elevation and the area of greatest local elevation difference, or relief, within Southeastern Wisconsin (Map 9). The Kettle Moraine of Wisconsin, much of which lies within the Region, is considered one of the finest examples of glacial interlobate moraine in the world. Because of its still predominantly rural character and its exceptional natural beauty, the Kettle Moraine and the surrounding area is and may be expected to continue to be subjected to increasing pressure for urban development.

The remainder of the Region is covered by a variety of glacial landforms and features, including rolling landscapes of heterogeneous material deposited beneath the ice; end moraines, consisting of material deposited at the forward margins of the ice sheet; lacustrine basins, or former lake site; outwash plains, formed by the action of flowing glacial meltwater; drumlins, or elongated mounds of glacial deposits streamlined parallel to the flow of the glacier; and eskers.

Surface Drainage

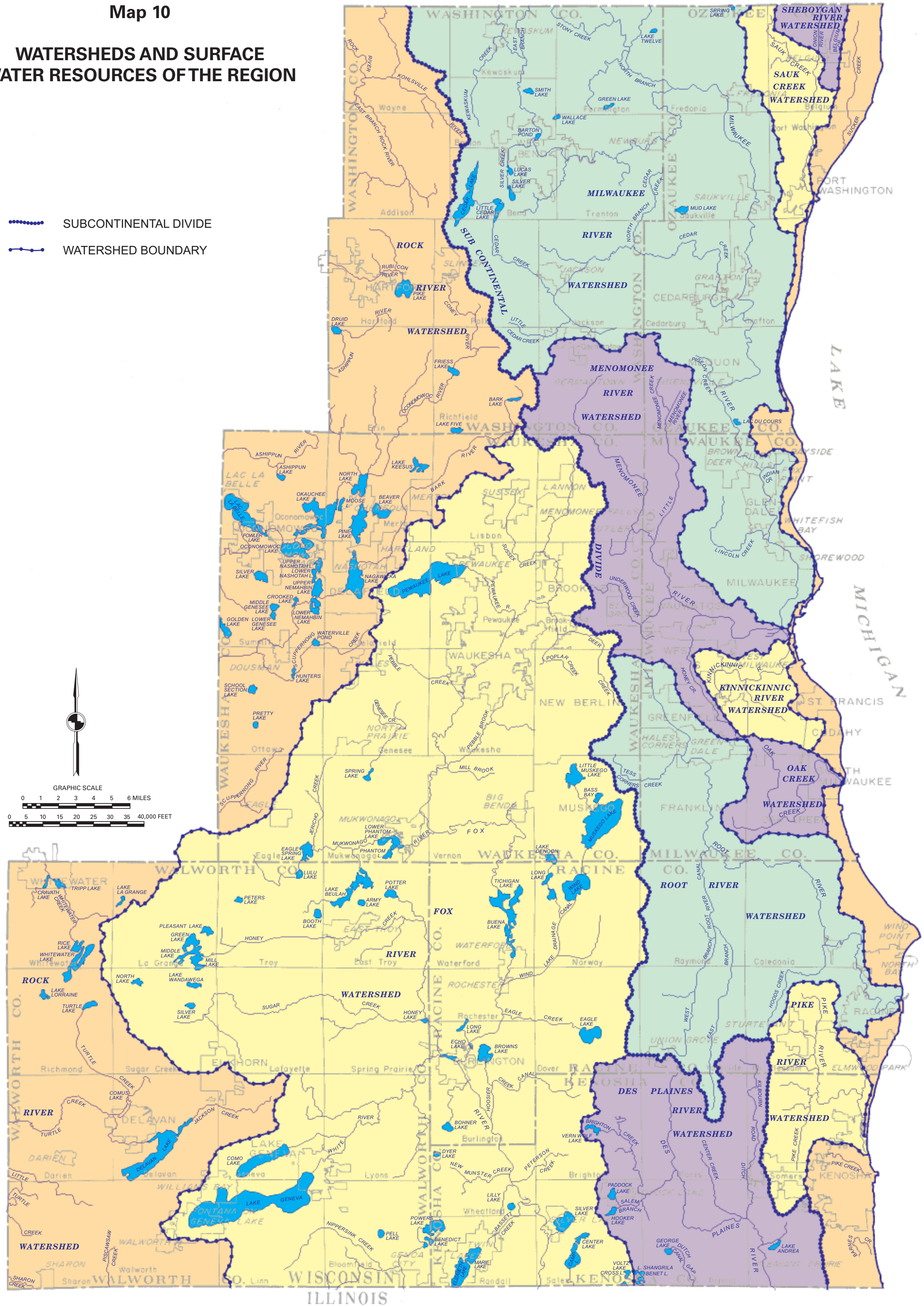
Surface drainage is poorly developed and very complex within the Region because of the effects of the relatively recent glaciation. The land surface is complex as a result of being covered by glacial deposits, containing thousands of closed depressions that range in size from potholes to large areas. Significant areas of the Region are covered by wetlands, and many streams are mere threads of water through these wetlands. The 11 major watersheds of Southeastern Wisconsin are depicted on Map 10, along with the surface drainage pattern of the major perennial stream systems.

A major subcontinental drainage divide, oriented in a generally northwesterly-southeasterly direction, approximately bisects the Region (Map 10); about 1,680 square miles west of the divide, or 62 percent of the Region, drain to the Upper Mississippi River system, and the remaining 1,009 square miles, or 38 percent, drain to the Great Lakes-St. Lawrence River system. The subcontinental divide not only exerts a major physical influence on the gross drainage pattern of the Region, but also carries with it certain legal constraints on the diversion of water across the divide, and thereby constitutes an important consideration in water supply and sanitary sewerage planning.

The surface water drainage pattern of Southeastern Wisconsin may be further subdivided to identify 11 major watersheds; five of which, the Root River, Menomonee River, Kinnickinnic River, Oak Creek, and Pike River watersheds, are wholly contained within the Region. In addition, to these 11 major watersheds, there are numerous small catchment areas contiguous to Lake Michigan that drain directly to the lake by local natural watercourses and artificial drainageways. Together, these areas may be considered to comprise together a twelfth watershed. The Fox River watershed and the headwaters of the Rock River and Des Plaines River watersheds drain to the south and southwest toward their confluences with the Illinois River, a tributary of the Mississippi River. The remainder of the Region drains in a generally easterly direction toward Lake Michigan by way of Milwaukee, Menomonee, and Root watersheds and other Lake Michigan direct drainage. The Commission has completed comprehensive watershed plans for seven of the 12 watersheds—the Fox, Kinnickinnic, Oak Creek, Menomonee, Milwaukee, Pike, and Root River watersheds—and in 2001 had such a plan nearing completion for the Des Plaines River watershed. The watershed plans contains recommendations for land use development, park and open space preservation, environmental corridor protection, water supply, sanitary sewerage, and drainage and flood control within each watershed.

Map 10

WATERSHEDS AND SURFACE WATER RESOURCES OF THE REGION



Source: SEWRPC.

Hydrologic Data Points
A sound comprehensive water resource management planning program requires, among other things, knowledge of the system of obtaining information about the condition of the water resources and knowledge of the degree of utilization of the water resources.

Southeastern Wisconsin has a good coverage of hydrologic data stations, which monitor all phases of the hydrologic cycle—atmospheric, surface, and subsurface. Map 11 shows the location of climatological data stations (monitoring the amount of precipitation), stream-gaging and lake-gaging stations (monitoring stream discharges, lake levels, and water quality of streams and lakes), and observation wells (monitoring groundwater levels). Besides active monitoring stations discontinued stations with record longer than 10 years are also shown. Not shown are the water quality stations from short-term studies of lakes carried out by the U.S. Geological Survey (USGS) between 1991 and 1994 in the Oconomowoc River watershed (Okauchee Lake), Bark River watershed (Upper Nemahbin Lake), and Mukwonago River/Muskego Canal watershed (Wind Lake).

Precipitation data are collected through a cooperative network of voluntary observers, maintained by the National Climatic Data Center (NCDC). The data are available from the NCDC in Asheville, NC, or the State Climatologist Office in Madison. The comprehensive stream-gaging network is a result of the cooperative, voluntary, intergovernmental program established by the Commission. The U.S. Geological Survey maintains and operates the network. Two-thirds of the gaging stations are financially supported by five local agencies under the Commission's cooperative program. The remaining stations are supported through cooperation of the USGS with another six local and state agencies. Records on stream discharges, lake levels, and water quality of streams and lakes are available from the USGS District Office in Madison. Water level measurements on observation wells are available from the USGS or the Wisconsin Geological and Natural History Survey (WGNHS) who jointly operate the groundwater observation well network.

A large number of high-capacity wells are being used in the Region for supplying water for municipal water supply systems, industrial operations, irrigation of fields, subdivision and mobile home water supplies, schools, apartment and condominium complexes, and recreational facilities. Owners of the high-capacity wells are required to obtain a permit from the Wisconsin Department of Natural Resources (DNR) before using the well. Listing of the permitted high-capacity wells was obtained from the DNR Public Water Supply Section. Locations of the high-capacity wells were verified for approximately 60 percent of the listed wells.

All monitoring stations and verified high-capacity wells are presented on corresponding tables in Appendix B.

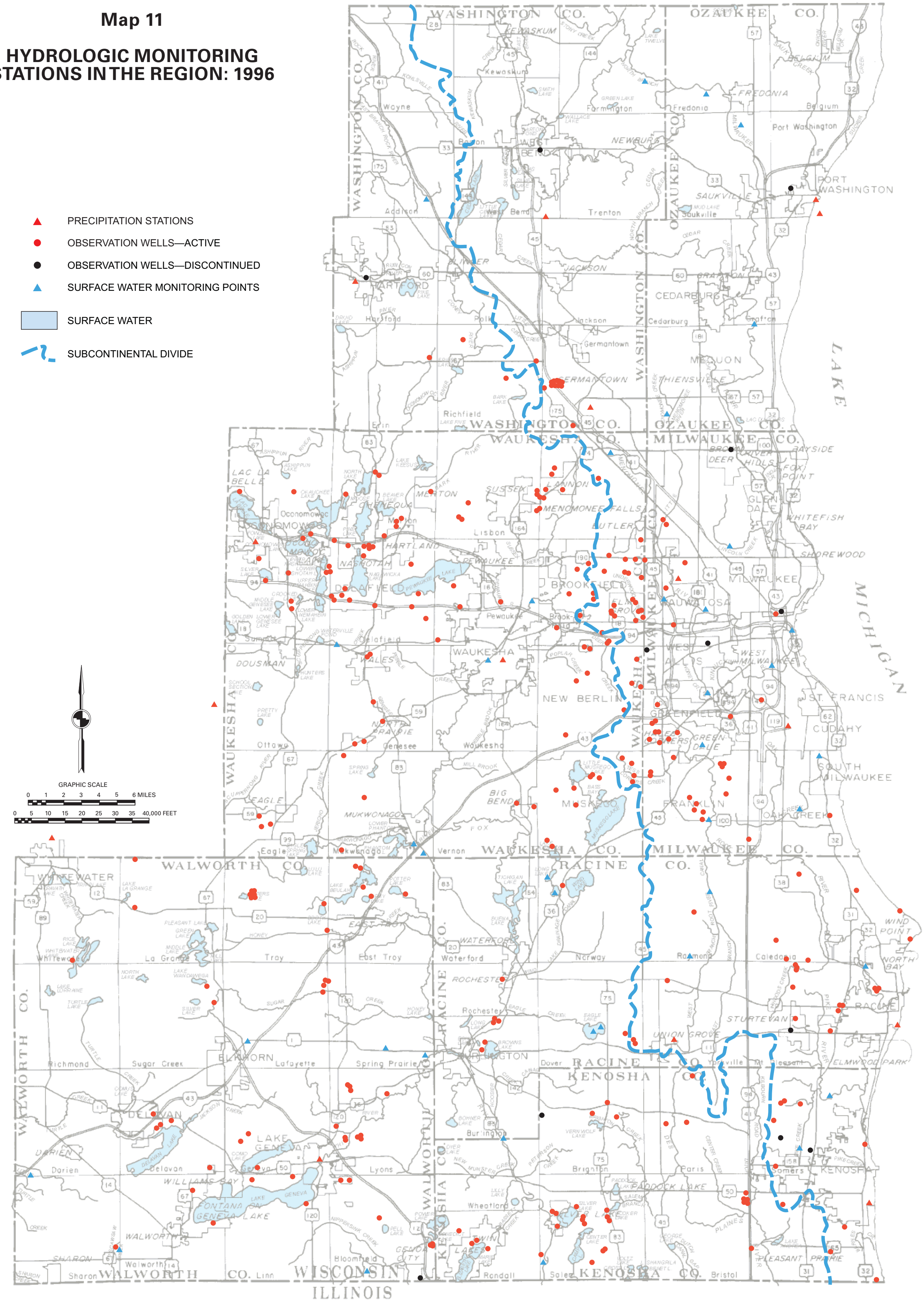
CLIMATE

Climate, especially extreme variations in three principal elements of climate—temperature, precipitation, and snow cover—directly affects the quantity and quality of the groundwater of the area. The Southeastern Wisconsin Region is positioned astride cyclonic storm tracks along which low pressure centers move from the west and southwest. The Region also lies in the path of high pressure centers moving in generally southeasterly direction. This location at the confluence of major migratory air masses results in the Region as a whole being influenced by a continuously changing pattern of different air masses. This results in frequent weather changes being superimposed on the aforementioned large annual range in weather characteristics, particularly in winter and spring, when distinct weather changes normally occur at least once every two to three days. These temporal weather changes consist of marked temperature variations as well as variations in the type and amount of precipitation, relative humidity, wind magnitude and direction, and cloud cover.

Because of its proximity to Lake Michigan, the Region also exhibits spatial variations on weather, particularly during spring, summer, and fall, when the temperature differential between the lake water and the land air masses tends to be greatest. During these periods the presence of the lake tends to moderate the climate of the eastern border of the Region. It is common , for example, for midday summer temperatures in shoreline areas to be 10°F lower than in inland areas due to the effects of cooling lake breezes generated by air rising from the warmer

Map 11

HYDROLOGIC MONITORING STATIONS IN THE REGION: 1996



Source: University of Wisconsin-Extension, Wisconsin Geological and Natural History Survey, and SEWRPC.

land surfaces. This Lake Michigan temperature influence is generally limited to a narrow band within several miles of the shoreline.

Temperature

Data for six selected temperature observation stations in Southeastern Wisconsin, three of which—Port Washington, Milwaukee, and Kenosha—are located near the Lake Michigan shoreline, and three of which—West Bend, Waukesha, and Lake Geneva—are located at least 15 miles inland, are presented in Table 12 and Figure 2. These data, which encompass periods of record ranging from 29 to 48 years for the various observations, indicate the temporal and spatial variations in temperature and the temperature ranges that may be expected to occur in the Region. The temperature data also illustrate how regional air temperatures lag approximately one month behind summer and winter solstices during the annual cycle, with the result that July is the warmest month in Southeastern Wisconsin and January the coldest. The effects of Lake Michigan are seen when comparisons are made between inland and lakeshore observation stations that have the same latitude.

The growing season, which is defined as the number of days between the last freeze in the spring and the first freeze in the fall, averages about 165 days for the Region, approximately from April 15 to October 15. The lakeshore area has a growing season of about 175 days, while inland locations have a shorter growing season of about 155 days. The last frost in the spring normally occurs during the last week of April for areas near Lake Michigan, and during the first half of May for inland locations. The average date of the last freeze in the spring is the break between April and May, and of the first freeze around the middle of October. The average frost depth reaches maximum in mid-February (Wisconsin Agricultural Statistics Service, 1989). Lake Michigan's moderating effect inhibits spring frost formation in the eastern extremities of Southeastern Wisconsin, thereby giving that portion of the Region a slightly longer growing season.

Precipitation

Precipitation within the Region takes the form of rain, sleet, hail, and snow. It ranges from gentle showers of trace quantities to destructive thunderstorms. Major rainfall and snowmelt events can cause property and crop damage, inundation of poorly drained areas, and stream flooding.

Precipitation is normally adequate for the vegetation or water supplies of the Region. Normal annual precipitation is about 32 inches, with the greatest amount concentrated in the six months of the growing season. The wettest months are June and July with about three to four inches and the driest month is February with amounts of about one inch (Figure 3). Between 70 to 80 percent of the average precipitation is lost by evapotranspiration, and 20 to 30 percent runs off in streams (Cotter and others, 1969). Nearly two-thirds of the streamflow is contributed by groundwater.

Precipitation data are available from stations at Hartford, West Bend, Port Washington, Germantown, Oconomowoc, Sullivan, Waukesha, Milwaukee-Mount Mary College, Milwaukee–General Mitchell International Airport, Whitewater, Lake Geneva, Burlington, Union Grove, Racine, and Kenosha.

Precipitation and snowfall data for six representative precipitation observation stations in Southeastern Wisconsin located on the Lake Michigan shoreline at Port Washington, Milwaukee, and Kenosha and inland at West Bend, Waukesha, and Lake Geneva are presented in Table 13 and Figure 3. One of the stations with the longest period of precipitation record is at Waukesha, starting in 1897 (Figure 4). These data, which encompass periods of record ranging from 43 to over 100 years for the various observation stations, illustrate the temporal and spatial variations in the type and amount of precipitation that normally occur within the Region.

Precipitation data indicate that Lake Michigan does not have as pronounced an effect on precipitation within the Region as it does on temperature. A minor Lake Michigan effect is evident in a rainfall reduction of up to about 0.5 inch per month in late spring and summer in the eastern areas of the Region relative to the western areas. This may be attributable to cool lake waters maintaining a cooler lower atmosphere, which inhibits convective precipitation.

Table 12

TEMPERATURE CHARACTERISTICS AT SELECTED LOCATIONS IN THE REGION

Month	Observation Station[a]																		Regional Summary		
	Lakeshore Locations									Inland Locations											
	Port Washington			Milwaukee			Kenosha			West Bend			Waukesha			Lake Geneva					
	1959-1988			1940-1988			1948-1988			1940-1988			1940-1987			1945-1988					
	Average Daily Maximum[b]	Average Daily Minimum[b]	Mean[c]	Average Daily Maximum[b]	Average Daily Minimum[b]	Mean[c]	Average Daily Maximum[b]	Average Daily Minimum[b]	Mean[c]	Average Daily Maximum[b]	Average Daily Minimum[b]	Mean[c]	Average Daily Maximum[b]	Average Daily Minimum[b]	Mean[c]	Average Daily Maximum[b]	Average Daily Minimum[b]	Mean[c]	Average Daily Maximum[d]	Average Daily Minimum[d]	Mean[e]
January	26.6	10.5	18.6	27.2	12.4	19.8	28.4	12.2	20.3	26.4	9.6	18.0	26.6	10.7	18.7	28.2	11.4	19.8	27.2	11.1	19.2
February	31.1	15.6	23.4	30.8	16.1	23.5	32.5	17.3	24.9	29.9	13.2	21.6	31.1	15.2	23.2	32.7	14.9	23.8	31.4	15.4	23.4
March	39.7	24.5	32.1	40.4	25.5	33.0	41.1	25.8	33.5	39.5	23.2	31.4	40.6	23.5	32.1	42.5	24.5	33.5	40.6	24.5	32.6
April	50.6	34.4	42.5	53.3	36.2	44.8	52.7	35.8	44.3	54.9	34.1	44.5	55.9	35.2	45.6	57.4	35.6	46.5	54.1	35.2	44.7
May	61.1	43.5	52.3	64.6	44.6	54.6	63.5	44.1	53.8	66.6	44.0	55.3	67.5	45.4	56.5	69.9	45.8	57.9	65.5	44.6	55.1
June	71.7	53.1	62.4	75.1	55.0	65.1	74.7	53.9	64.3	77.1	54.3	65.7	78.1	55.2	66.7	80.3	56.2	68.3	76.2	54.6	65.4
July	77.7	60.3	69.0	80.3	61.5	70.9	79.8	60.9	70.4	82.0	59.7	70.9	83.1	60.5	71.8	84.5	61.5	73.0	81.2	60.7	71.0
August	77.2	59.5	68.4	78.8	61.2	70.0	78.8	60.6	69.7	79.8	58.6	69.2	80.8	59.3	70.1	82.9	60.3	71.6	79.7	59.9	69.8
September	70.2	52.8	61.5	71.0	53.3	62.2	71.7	52.9	62.3	71.9	50.7	61.3	73.0	51.3	62.2	75.0	52.5	63.8	72.1	52.3	62.2
October	59.2	42.0	50.6	60.1	42.6	51.4	60.9	42.3	51.6	60.9	41.1	51.0	62.2	40.8	51.5	63.1	42.4	52.8	61.1	41.9	51.5
November	45.3	30.7	38.0	45.1	30.3	37.7	46.9	30.9	38.9	44.8	28.9	36.9	45.0	29.0	37.0	46.2	30.2	38.2	45.6	30.0	37.8
December	34.4	18.5	26.5	32.0	18.2	25.1	34.7	18.7	26.7	31.8	16.1	24.0	32.1	17.2	24.7	32.8	17.9	25.4	33.0	17.8	25.4
Yearly Average	53.7	37.1	45.4	54.9	38.1	46.5	55.5	38.0	46.8	55.5	36.1	45.8	56.3	36.9	46.6	58.0	37.8	47.9	55.7	37.3	46.5

[a] *Observation stations were selected both on the basis of the length of record available and geographic location within the Southeastern Wisconsin Region. Port Washington, Milwaukee, and Kenosha are representative of areas with temperatures influenced by Lake Michigan, whereas West Bend, Waukesha, and Lake Geneva are typical of inland areas having temperatures that are not generally influenced by Lake Michigan. Kenosha and Lake Geneva are representative of southerly areas in the Region, whereas Port Washington and West Bend typify northern locations.*

[b] *The monthly average daily maximum temperature and the monthly average daily minimum temperature are obtained by using daily measurements to compute an average for each month in the period of record. The results are then averaged for all the months in the period of record.*

[c] *The monthly mean temperature is the mean of the average daily maximum temperature and the average daily minimum temperature for each month.*

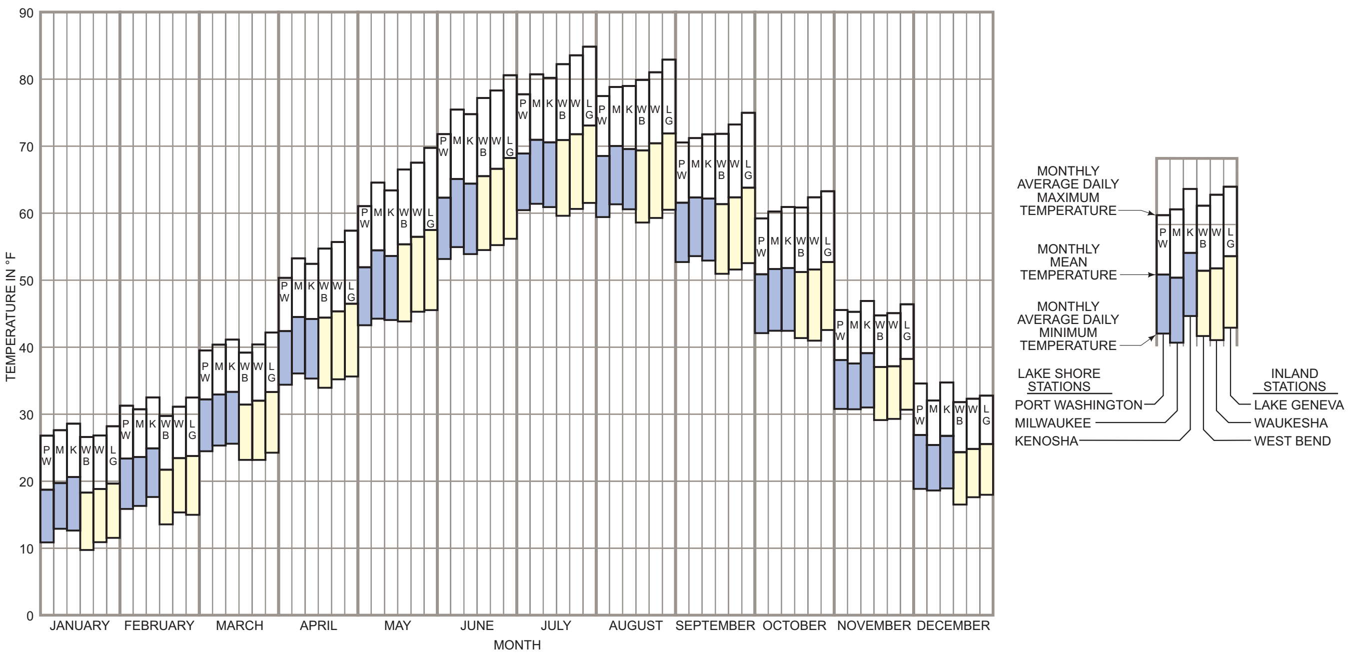
[d] *The monthly average daily maximum and minimum temperatures for the Region as a whole were computed as averages of the corresponding values for the six observation stations.*

[e] *The monthly mean for the Region as a whole is the mean of the regional monthly average daily maximum and average daily minimum, which is equivalent to the average of the monthly means for the six observation stations.*

Source: Wisconsin Statistical Reporting Service, National Climatic Data Center, and SEWRPC.

Figure 2

TEMPERATURE CHARACTERISTICS AT SELECTED LOCATIONS IN THE REGION



Source: Wisconsin Statistical Reporting Service, National Climatic Data Center, and SEWRPC.

The influence of Lake Michigan as a source of moisture is reflected by slightly higher seasonal snowfalls for the entire Region relative to inland areas lying west of the Region. Minor intraregional spatial snowfall differences occur in that seasonal snowfall tends to be greatest in the topographically higher northwest portion of the Region because moisture masses moving through that area are forced up onto the higher terrain, where low temperatures normally associated with increased height induce more snowfall than that which would occur in the absence of topographic barrier.

Extreme precipitation data for Southeastern Wisconsin, based on observations for stations located throughout the Region for the 115-year period from 1870 to 1985, are presented in Table 14. The minimum annual precipitation within Southeastern Wisconsin, as determined from the tabulated data for the indicated observation period, occurred at Waukesha in 1901, when only 17.30 inches of precipitation occurred, or 55 percent of the average annual precipitation of 31.30 inches for Southeastern Wisconsin (Table 15). The maximum annual precipitation within Southeastern Wisconsin occurred at Milwaukee in 1876, when 50.36 inches of precipitation was recorded, equivalent to 161 percent of the average annual precipitation.

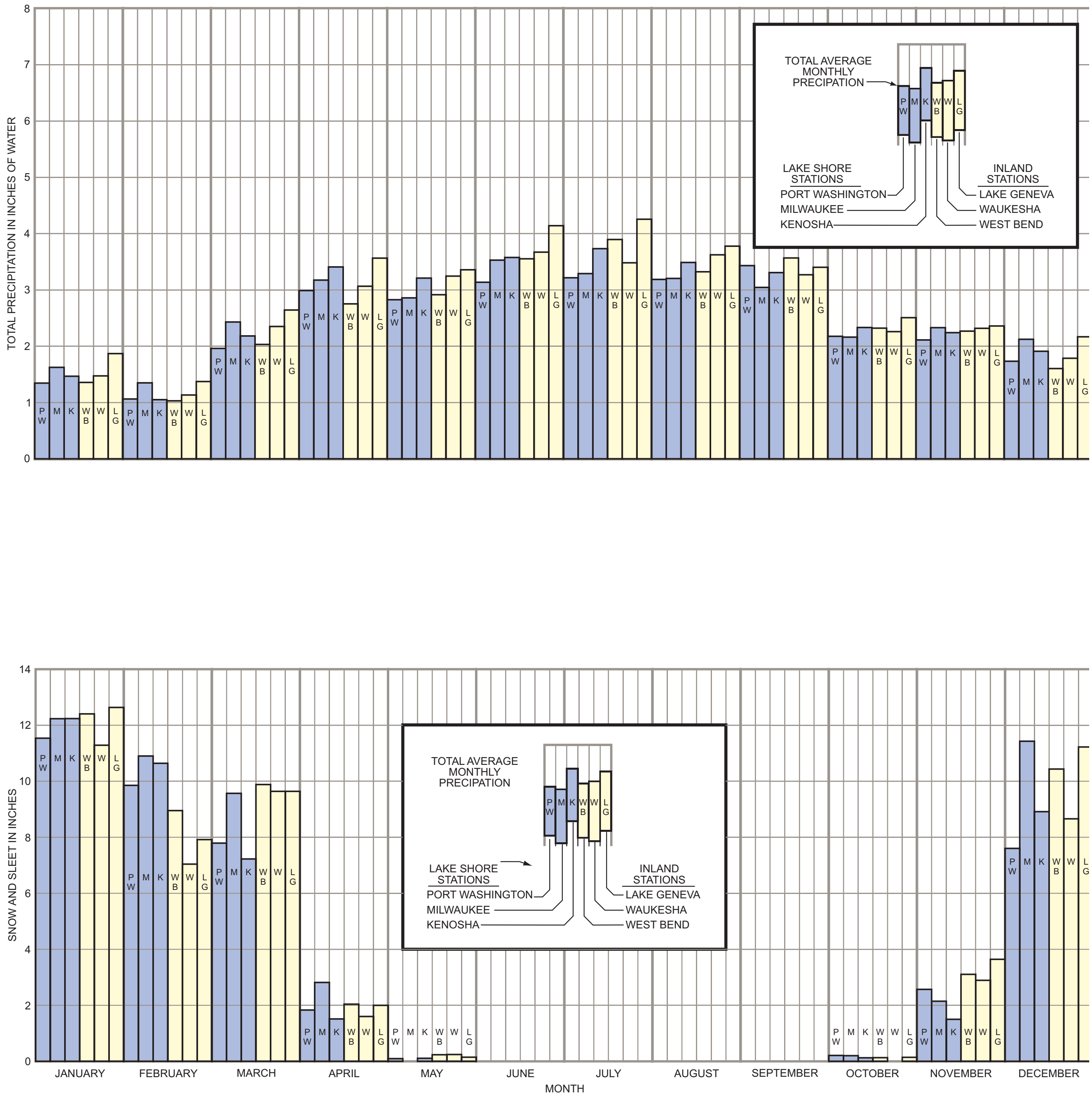
Even though Southeastern Wisconsin is located in a humid climatic zone with plentiful precipitation, drought periods (prolonged and abnormal moisture deficiencies) are quite common and may cause problems in agriculture and water supplies in the Region by depleting soil moisture, lowering groundwater and lake levels, and reducing streamflow. If we take as a somewhat arbitrary definition of drought 85 percent or less of normal precipitation, there were 22 drought years at Waukesha during the last 100 years (Table 15). The most serious droughts were in 1901, 1932, 1930, 1963, and 1962—below 70 percent of normal—with the record of 54.6 percent in 1901. The wettest years on record were 1938 and 1916, when the rainfall amounts exceeded 130 percent of normal precipitation.

Snow Cover

Snow depth as measured at Milwaukee for the 88-year period of 1900 through 1988 is summarized and presented in Table 16. It should be emphasized that the tabulated data pertain to snow depth on the ground as measured at the place and time of observation, and are not a direct measure of average snowfall. Recognizing that snowfall and

Figure 3

PRECIPITATION CHARACTERISTICS AT SELECTED LOCATIONS IN THE REGION

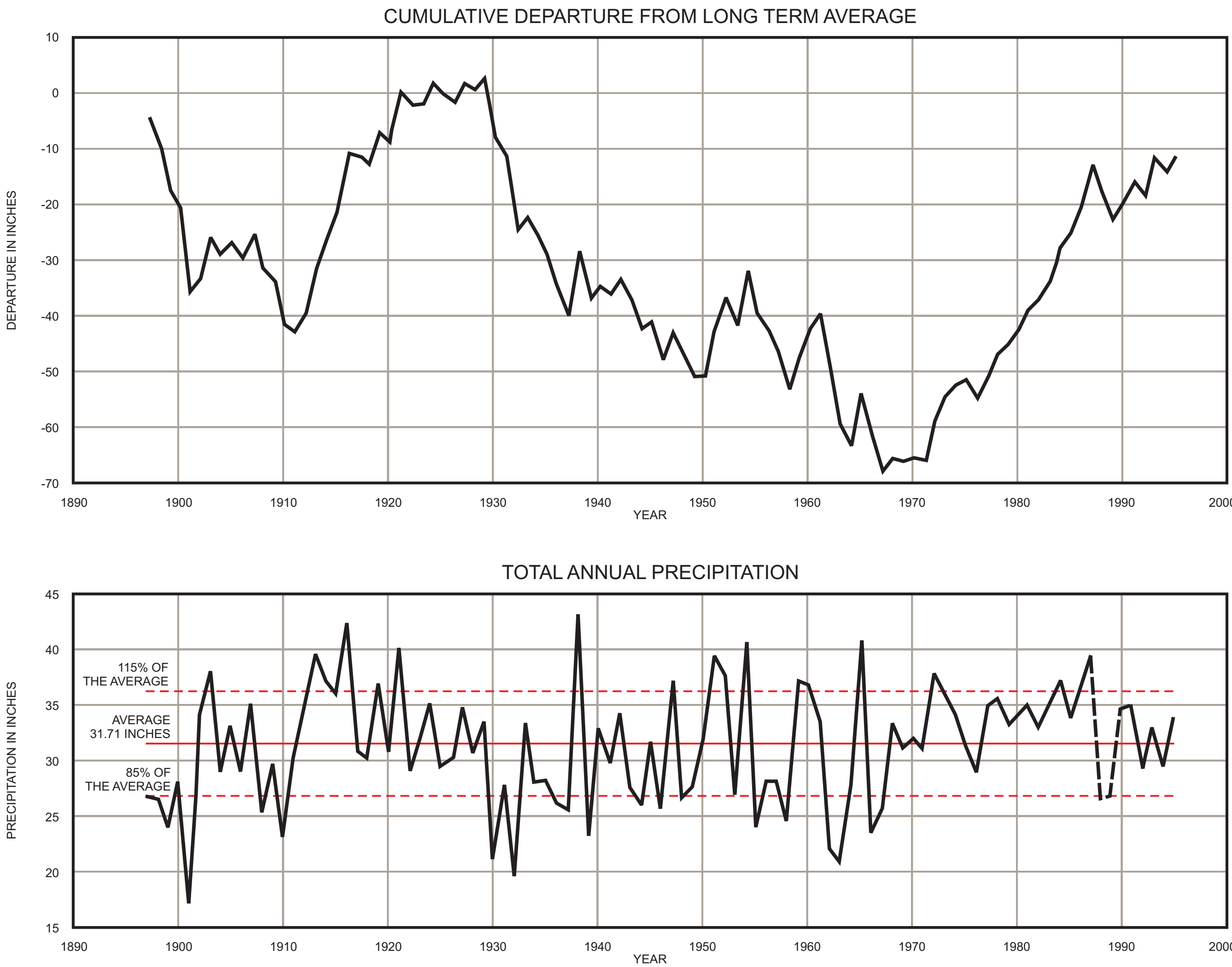


Source: Wisconsin Statistical Reporting Service, National Climatic Data Center, and SEWRPC.

temperatures, and therefore snow accumulation on the ground, vary spatially within the Region, the Milwaukee area data presented in Table 16 should be considered as an approximation of conditions that would be encountered in other parts of the Region. As indicated by the data, snow cover is most likely during months of December, January, and February, during which at least a 0.40 probability exists of having one inch or more of snow cover at Milwaukee.

Figure 4

WAUKESHA PRECIPITATION - 1897-1998



Source: University of Wisconsin-Extension, Wisconsin Geological and Natural History Survey, and SEWRPC.

Table 13

PRECIPITATION CHARACTERISTICS AT SELECTED LOCATIONS IN THE REGION

Month	Observation Station[a]												Regional Summary	
	Lakeshore Locations						Inland Locations							
	Port Washington		Milwaukee		Kenosha		West Bend		Waukesha		Lake Geneva			
	1940-1988	1894-1988[b]	1940-1988	1940-1988	1945-1988	1945-1988	1940-1988	1930-1988	1940-1987	1930-1987	1945-1988	1945-1988		
	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet	Average Total Precipitation	Average Snow and Sleet
January	1.35	11.5	1.62	12.2	1.50	12.2	1.36	12.4	1.49	11.3	1.89	12.6	1.54	12.0
February	1.07	9.8	1.38	10.9	1.07	10.6	1.03	8.9	1.16	7.1	1.39	7.9	1.18	9.2
March	1.99	7.7	2.48	9.6	2.19	7.2	2.01	9.9	2.38	9.6	2.67	9.6	2.29	8.9
April	3.02	1.8	3.20	2.8	3.44	1.5	2.79	2.0	3.10	1.6	3.63	2.0	3.20	2.0
May	2.88	0.1	2.89	0.0	3.22	0.1	2.95	0.2	3.28	0.2	3.35	0.1	3.10	0.1
June	3.18	0.0	3.53	0.0	3.57	0.0	3.56	0.0	3.70	0.0	4.16	0.0	3.62	0.0
July	3.24	0.0	3.31	0.0	3.78	0.0	3.91	0.0	3.51	0.0	4.26	0.0	3.67	0.0
August	3.21	0.0	3.24	0.0	3.53	0.0	3.33	0.0	3.64	0.0	3.81	0.0	3.46	0.0
September	3.44	0.0	3.09	0.0	3.33	0.0	3.59	0.0	3.31	0.0	3.42	0.0	3.36	0.0
October	2.21	0.2	2.19	0.2	2.37	0.1	2.36	0.1	2.30	0.0	2.56	0.1	2.33	0.1
November	2.14	2.5	2.34	2.1	2.30	1.7	2.31	3.2	2.33	2.9	2.40	3.6	2.30	2.7
December	1.76	7.6	2.13	11.4	1.96	8.9	1.62	10.4	1.83	8.6	2.20	11.2	1.92	9.7
Yearly Average	29.49	41.2	31.40	49.2	32.26	42.3	30.82	47.1	32.03	41.3	35.74	47.1	31.97	44.7

[a] *Observation stations were selected both on the basis of the length of record available and geographic location within the Southeastern Wisconsin Region. Port Washington, Milwaukee, and Kenosha are representative of areas where precipitation would be influenced by Lake Michigan, whereas West Bend, Waukesha, and Lake Geneva are typical of inland areas having precipitation that is not generally influenced by Lake Michigan. Kenosha and Lake Geneva are representative of southerly areas in the Region, whereas Port Washington and West Bend typify northern locations.*

[b] *Snow and sleet data for Port Washington are based upon the periods 1894 to 1950 and 1960 to 1988; data are not available for the period 1951 to 1959.*

Source: Wisconsin Statistical Reporting Service, National Climatic Data Center, and SEWRPC.

Table 14

EXTREME PRECIPITATION PERIODS IN SOUTHEASTERN WISCONSIN: SELECTED YEARS, 1870 THROUGH 1985

Observation Station		Period of Precipitation Records, Except Where Indicated Otherwise	Total Precipitation						
			Maximum Annual		Minimum Annual		Maximum Monthly		
Name	County		Amount	Year	Amount	Year	Amount	Month	Year
Mitchell Field	Milwaukee	1870-1986	50.36[a]	1876	18.69[a]	1901	10.03	June	1917
Racine	Racine	1895-1986	48.33	1954	17.75	1910	10.98	May	1933
Waukesha	Waukesha	1982-1986	43.57	1938	17.30	1901	11.41	July	1952
West Bend	Washington	1922-1986	41.43	1984	19.72	1901	13.14[b]	August	1924
West Allis	Milwaukee	1954-1986	42.85	1960	17.49	1963	9.63	June	1954
Mt. Mary College	Milwaukee	1954-1986	41.25	1965	18.50	1963	10.17	June	1968

[a] *Based on the period 1941 through 1986.*

[b] *Based on the period 1895 through 1959 in* A Survey Report for Flood Control on the Milwaukee River and Tributaries, *U.S. Army Engineer District, Chicago, Corps of Engineers, November 1964.*

Source: U.S. Army Corps of Engineers, National Weather Service, Wisconsin Statistical Reporting Service, and SEWRPC.

Table 15

DRIEST AND WETTEST YEARS AT WAUKESHA, WISCONSIN (LONG-TERM AVERAGE 31.71 INCHES)

Driest Years				Wettest Years			
Year	Total Precipitation (inches)	Percent of Total	Rank	Year	Total Precipitation (inches)	Percent of Total	Rank
1897	26.80	84.5	20	1903	38.30	120.8	10
1898	26.71	84.2	18	1913	39.67	125.1	7
1899	24.10	76.0	9	1914	37.17	117.2	16
1901	17.30	54.6	1	1915	36.12	113.9	21
1908	25.57	80.6	12	1916	42.34	133.5	2
1910	23.43	73.9	6	1919	36.98	116.6	19
1930	21.13	66.6	3	1921	40.42	127.5	5
1932	19.52	61.6	2	1938	43.57	137.4	1
1936	26.33	83.0	16	1947	37.42	117.4	15
1937	25.93	81.8	14	1951	39.80	125.1	6
1939	23.50	74.1	7	1952	38.00	119.8	12
1944	26.42	83.3	17	1954	40.73	128.5	4
1946	25.87	81.6	13	1959	37.47	118.2	14
1948	26.85	84.7	21	1960	37.09	117.0	18
1955	24.36	76.8	10	1965	40.98	129.2	3
1958	24.77	78.1	11	1972	38.41	121.1	9
1962	22.29	70.3	5	1984	37.50	118.3	13
1963	21.36	67.4	4	1986	36.44	114.9	20
1966	23.88	75.3	8	1987	39.62	124.9	8
1967	26.10	82.3	15	1991*	36.40	114.8	22
1988*	26.74	84.3	19	1993	38.02	119.9	11
1989*	27.00	85.2	22	1998	37.14	117.1	17

*Not measured 1988-1991. Total annual precipitation estimated from records of the surrounding stations at Burlington, Hartford, Lake Geneva, Oconomowoc, Watertown, West Bend, and Whitewater.

Source: SEWRPC.

Table 16

SNOW COVER PROBABILITIES AT MILWAUKEE BASED ON DATA FOR 1900-1988

Month	Day	Snow Cover[a] 1.0 Inch or More: Number of Occurrences[b]	1.0 Inch or More: Probability of Occurrence[c]	5.0 Inches or More: Number of Occurrences[b]	5.0 Inches or More: Probability of Occurrence[c]	10.0 Inches or More: Number of Occurrences[b]	10.0 Inches or More: Probability of Occurrence[c]	15.0 Inches or More: Number of Occurrences[b]	15.0 Inches or More: Probability of Occurrence[c]	Average (inches): Per Occurrence[d]	Average (inches): Overall[e]
November	15	5	0.06	0	0.00	0	0.00	0	0.00	1.3	0.1
	30	16	0.18	2	0.02	1	0.01	0	0.00	2.9	0.5
December	15	41	0.46	14	0.16	0	0.00	0	0.00	3.5	1.6
	31	45	0.51	13	0.15	2	0.02	0	0.00	3.6	1.8
January	15	57	0.64	28	0.31	6	0.07	4	0.04	5.5	3.5
	31	62	0.70	30	0.34	13	0.15	5	0.06	6.5	4.5
February	15	58	0.65	33	0.37	12	0.13	5	0.06	6.5	4.2
	28	36	0.40	11	0.12	4	0.04	1	0.01	4.3	1.8
March	15	28	0.31	8	0.09	4	0.04	0	0.00	3.7	1.2
	31	8	0.09	1	0.01	1	0.01	0	0.00	2.7	0.2

[a]Data pertain to snow depth on the ground as it was measured at the time and place of observation, and are not a direct measure of average snowfall.

[b]Number of occurrences is the number of times during the period of record when measurements revealed that the indicated snow depth was equaled or exceeded on the indicated date.

[c]Probability of occurrence for a given snow depth and date is computed by dividing the number of occurrences by 89, and is defined as the probability that the indicated snow cover will be reached or exceeded on the indicated date.

[d]Average snow cover per occurrence is defined as the sum of all snow cover measurements in inches for the indicated date divided by the number of occurrences for that date—that is, the number of times in which 1.0 inch or more of snow cover was recorded.

[e]Overall average snow cover is defined as the sum of all snow cover measurements in inches for the indicated date divided by 89—that is, the number of observation times.

Source: Wisconsin Statistical Reporting Service, National Climatic Data Center, and SEWRPC.

Chapter III

THE SOILS OF SOUTHEASTERN WISCONSIN AND THEIR ABILITY TO ATTENUATE CONTAMINANTS

GENERAL CHARACTERISTICS OF SOILS

Soils usually compose only the upper two to four feet of unconsolidated materials at the earth's surface. Soils are the basis of agricultural production; they provide the foundation for buildings and roads; and if properly used, they aid in the treatment and recycling of wastes from homes, from the production of livestock and poultry, and from municipal and industrial sewage treatment plants. Soil characteristics, particularly depth, texture, and permeability, are significant factors in determining the rate and extent of groundwater recharge and the degree of natural protection against contamination. Land characteristics such as slope, vegetation type, and type of rock or unconsolidated material will, in conjunction with the soil, determine the overall potential of the environment to protect groundwater. These land characteristics along with climate, particularly temperature and precipitation, and time determine what kinds of soil develop. For instance, in Southeastern Wisconsin soils have only developed in the past approximately 11,000 years. In a geologic sense, this is not a long period of time, and for soils it is a time span that only allows early soil maturity to be reached on stable uplands.

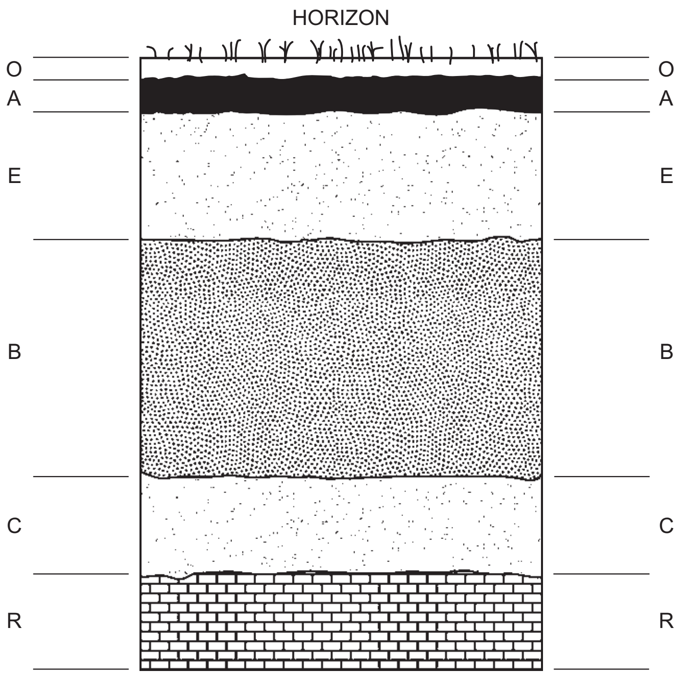
Each soil is characterized by a sequence of horizons (layers). This sequence is termed a soil profile (Figure 5). Individual horizons vary in depth or may be absent because of erosion, soil age, or the specific soil development factors. Figure 5 describes the major soil horizons of a soil developed under forest vegetation.

The glacial history of Southeastern Wisconsin is described in Chapter IV of this report. From a soils perspective, two factors of the glacial and early post-glacial history are important. First is the distribution of glacial materials, particularly tills. Those found in Washington, Waukesha, and Walworth Counties are predominantly sandy loam in texture and often contain large volumes of coarse fragments greater than 2 millimeters in size. In the counties along Lake Michigan, these sandy loam tills were covered by fine-textured materials deposited by two subsequent ice advances. Tills of the first of these two advances are silty clay loam to clay loam in texture, and those of the second advance are clay-textured.

The second factor was westerly winds following the final retreat of the ice, which picked up silt-sized materials that had been transported great distances from the ice and deposited in broad flood plains and lake basins and redeposited them to varying depths on the land surface, covering much of the outwash and till. These silt-sized materials, called loess, together with the various glacial materials make up the vast majority of the soil parent materials in Southeastern Wisconsin. In addition to the parent material from which a soil formed, other factors such as relief, climate, natural vegetation, and the time that the soil has had to form, influence the type of soil that develops in an area.

Figure 5

FORESTED SOIL PROFILE



O - ORGANIC MATERIALS IN VARYING STAGES OF DECOMPOSITION.

A - UPPERMOST MINERAL HORIZON CONTAINING ORGANIC MATTER THAT TENDS TO GIVE A DARKER COLOR THAN THAT OF THE LOWER HORIZONS.

E - HORIZON OF MAXIMUM LOSS OF CLAY, IRON, AND ALUMINUM IN THE SOIL. IT HAS A CORRESPONDING CONCENTRATION OF RESISTANT MINERALS, SUCH AS QUARTZ, IN THE SAND SIZE. GENERALLY LIGHTER IN COLOR THAN THE A.

B - SUBSOIL HORIZON. ZONE OF MAXIMUM ACCUMULATION OF CLAYS AND IRON. THESE MAY HAVE MOVED DOWN FROM UPPER HORIZONS OR MAY HAVE FORMED IN PLACE. ORGANIC MATTER CONTENT IS GENERALLY HIGHER THAN THAT OF E. MAXIMUM DEVELOPMENT OF THE SOIL IS LOCATED HERE.

C - THE C HORIZON IS THE UNCONSOLIDATED MATERIAL UNDERLYING THE A AND B HORIZONS. IT MAY OR MAY NOT BE THE SAME AS THE PARENT MATERIAL FROM WHICH THE SOIL FORMED. IT IS OUTSIDE THE ZONES OF MAJOR BIOLOGICAL ACTIVITIES AND IS LITTLE AFFECTED BY SOIL FORMING PROCESSES. ITS UPPER LAYERS MAY IN TIME BECOME A PART OF THE SOIL AS WEATHERING AND EROSION CONTINUE.

R - BEDROCK

Source: Modified from Entine, 1992.

For mapping, classification, and interpretation purposes, soils are grouped into soil series on the basis of similar physical and chemical characteristics, type of parent material, and arrangement of horizons or layers. A grouping of individual soils into soil associations based solely on physical and chemical characteristics is required to evaluate the potential of soils for attenuating contaminants. An evaluation system was developed to assess those soil properties that play a role in the attenuation of potential groundwater contaminants resulting from land use activities.

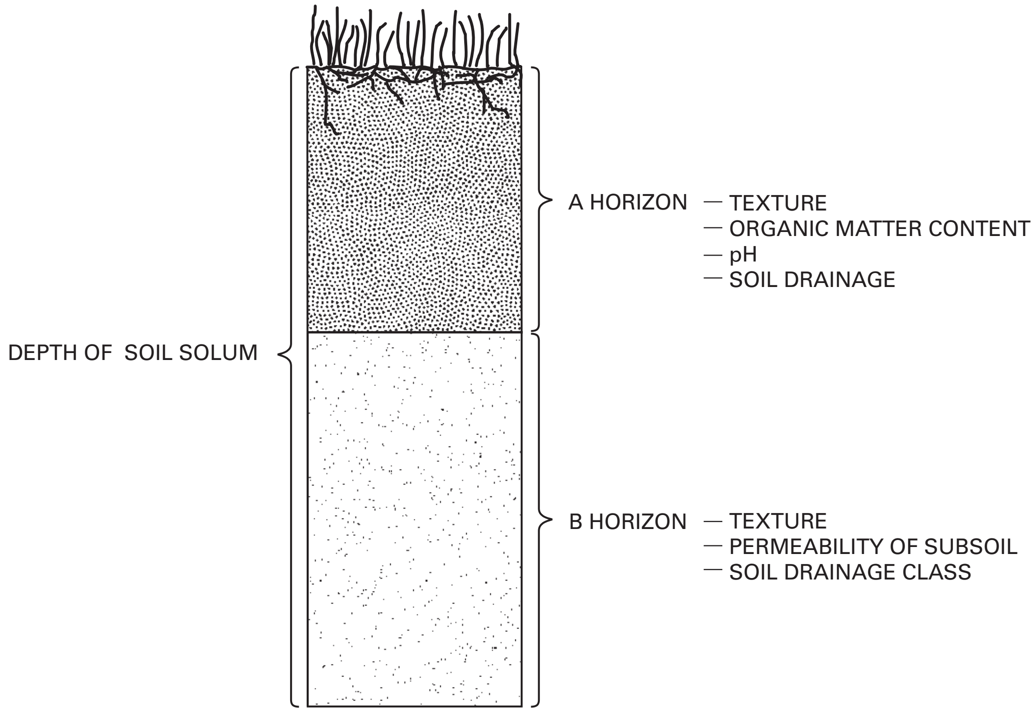
EVALUATION OF THE CAPACITY OF SOILS TO ATTENUATE CONTAMINANTS

The soil is an integral part of the natural protection of groundwater from surface-applied contaminants. Attenuation is a series of complex processes, all of which are not clearly understood. During attenuation, the soil holds essential plant nutrients for uptake by agronomic crops, immobilizes metals that might be contained in municipal sewage sludge, or removes bacteria contained in animal or human wastes. However, the natural contaminant attenuation capacity of the soil, like that of any other natural resource, is limited; sometimes soils that retain contaminants become contaminated. Cleaning contaminated soil can be as difficult as cleaning contaminated groundwater.

The evaluation system herein presented is intended to comprise a planning tool for the preliminary screening of areas on the basis of sensitivity to the impact of land use activities. The soil-attenuation-potential map does not replace the need for detailed on-site investigations. It does, however, reduce the number of areas to be studied in

Figure 6

COMPONENTS OF THE SOIL CONTAMINANT ATTENUATION MODEL



Source: University of Wisconsin-Extension, Wisconsin Geological and Natural History Survey.

detail by identifying the areas of best and least attenuation potential. Local details usually are generalized to fit the mapping scale, which cannot accommodate small, local variations in soil characteristics.

The system for the evaluation of soil capacity to attenuate contaminants was originally developed by F.W. Madison in 1985 for a groundwater protection study of Rock County, Wisconsin (Zaporozec, 1985) and was subsequently named Soil Contaminant Attenuation Model (SCAM). The third iteration of SCAM—SCAM 3, which was used in this report, was created as a result of a comparative groundwater susceptibility study of Dane County, Wisconsin (Bridson and others, 1994).

This system evaluates the ability of the soil solum (the A and B horizons) to attenuate potential contaminants resulting from activities above or within the soil zone (Figure 6). The soil-attenuation capacity is considered only in general terms and is not contaminant-specific. Different contaminants may behave differently—some may be completely eliminated by soil organisms, some may be used by plants, some may be adsorbed on soil particles, and some may eventually pass through the soil solum unchanged.

PHYSICAL AND CHEMICAL CHARACTERISTICS TO ESTABLISH SOIL ATTENUATION RATINGS

For assessing soil potential for attenuation of contaminants in Southeastern Wisconsin, seven physical and chemical characteristics were selected for each soil series and were given weighted values (Table 17). The following paragraphs, adopted from Zaporozec (1985), explain the selected characteristics:

"Soil texture is a measure of the percentage of sand-, silt-, and clay-sized particles present in a representative sample of a given soil horizon. It is a good indicator of the rate of water movement through the soil, of the ability

Table 17

RATING SYSTEM FOR EVALUATING THE ATTENUATION POTENTIAL OF SOILS IN SOUTHEASTERN WISCONSIN

1. Texture of surface A horizon

loam, silt loam, sandy clay loam, silt	9
clay, sandy clay, silty clay, clay loam, silty clay loam	8
loamy fine sand, loamy very fine sand, fine sandy loam, very fine sandy loam	4
sand, fine sand, loamy sand, sandy loam, organic materials (all "O" horizons), and all textural classes with coarse fragment class modifiers (such as "gravelly loam")	1

2. Texture of subsoil (B) horizon

When the B horizon is composed of two or more sub-horizons, the texture of the B horizon shall be the finest texture of the B sub-horizon whose thickness constitutes more than 30% of the thickness of the entire B horizon. If there is no B horizon, then consider the type of materials approximately 2 feet below the land surface and rank accordingly.

clay, sandy clay, silty clay, silt	10
sandy clay loam, loam, silt loam, clay loam, silty clay loam	7
loamy fine sand, loamy very fine sand fine sandy loam, very fine sandy loam	4
sand, fine sand, loamy sand, sandy loam, organic materials, all textural classes with coarse fragment modifiers (such as "gravelly loam"), and bedrock if there is no B horizon or if bedrock < 20 inches from land surface	1

3. pH of surface (A or O) horizon

6.6 or greater (the surface horizon description will include one of the following terms: neutral, mildly alkaline, moderately alkaline, or strongly alkaline)	6
less than 6.6 (the surface horizon description will include one of the following terms: slightly acid, moderately acid, or strongly acid)	4

4. Depth of soil solum (depth of the O, A, E, and B horizons)

The depth is considered to the top of the C or R horizons, whichever comes first. For eroded soils, if the erosion losses are not considered in the soil profile description, subtract 4 inches from the surface horizon for a moderately eroded soil (level 2) and 6 inches for a severely eroded soil (level 3). If there are buried horizons (2O, 2Ab, 2Bb or 2Eb), soil depth will be taken to the bottom of these horizons or to the top of 2Cb, whichever is deeper.

>60 inches	10
40-59 inches	8
30-39 inches	5
<30 inches	1

5. Soil drainage

well drained	10
well to moderately well drained	7
moderately well drained	4
somewhat poorly, poorly, and very poorly drained; somewhat excessively and excessively drained	1

6. Permeability of subsoil (B) horizon

a. If your soil series description indicates that bedrock is found within 20 inches of the surface, or if bedrock is present in the soil mapping unit within 40 inches of the surface, use the following ranking:

bedrock at 20-40 inches	3
bedrock < 20 inches	1

b. For soils other than those listed in 6a, look in the "family" column of the "Classification of Soil Series" table and rank accordingly (except Histosols, see below). If there is more than one particle-size class (such as "fine silty over sandy or sandy skeletal"), choose the underlying material (which in this case is "sandy or sandy skeletal"). If a soil family classification does not exist and/or if your soil is a Histosol, then use the suborder classification.

moderately low, low to very low (fine, very fine, clayey, clayey-skeletal; or saprist suborder)	10
moderate (fine loamy, fine silty, coarse silty, loamy-skeletal; or hemist suborder)	8
moderately high (loamy)	5
high (sandy or sandy skeletal, coarse loamy; or fibrist suborder)	3
very high (coarse sand, fragmental, sandy; or psammentic suborder)	1

For 6b, 7a, and 7c, consult the table "Classification of Soil Series" in county soil surveys (see References). Consult a NRCS specialist if the soil survey does not contain this information.

Table 17 (continued)

7. Organic matter content of surface (O and A) horizon

a. If the "Classification of Soil Series" table classifies your soil as a Histosol soil order, Aquic suborder, or Lithic, Aquollic and Aquic subgroups, use ranking: 1

b. If not the above and your soil has been tested for organic matter content, use the following ranking:

high (4-10%)	10
medium (2-4%)	7
moderately low (1-2%)	5
low (0.5-1%)	3
very low (< 0.5%)	1

c. If your soil has not been tested for organic matter, use the soil order from the "Classification of Soil Series" table. However, if the soil mapping unit indicates an eroded soil (level 2 or 3), then lower the score by one level.

Mollisol	8
Alfisol, Mollisol (eroded)	5
Inceptisol, Entisol, Spodosol, Alfisol (eroded)	3
Inceptisol, Entisol, Spodosol (all eroded)	1

Rating of soil series in the Region

Total Score	Soil's Potential to Attenuate Contaminants	Rank
51+	Best	4
41-50	Good	3
31-40	Marginal	2
0-30	Least	1

The subdivision of soil series in the Region into four soil associations with respect to their attenuation potential is given in Appendix C, together with acreage and proportional extent of each association.

Source: University of Wisconsin-Extension, Wisconsin Geological and Natural History Survey.

of the soil to supply water and nutrients for plant uptake, and of the erosion potential of the soil. The textures of both the surface (A) and subsoil (B) horizons are included in the rating system (Figure 6).

The pH level of a soil is included because breakdown processes function better at pH values between 6 and 7.

The depth of the soil solum (Figure 6), which is the combined thickness of the A and B horizons, is an important factor because the effectiveness of the soil as a treatment/recycling system depends on the amount of contact time that water-transported contaminants have with the mineral and organic constituents of the soil. A deep, medium-textured, well-aerated soil offers the best opportunity for soil water to percolate through with maximum contact between potential contaminants and the mineral and organic constituents.

Natural soil drainage class is a measure of the nature and extent of soil wetness. The terms used suggest not only the elevation at which the water stands in the soil solum but also how much of the time in any given year a particular soil will be wet.

The rate at which water moves through the soil is critical for assessing attenuation of contaminants. A standard measure of this rate is soil permeability, or the vertical hydraulic conductivity. Unfortunately, this measure is based on saturated flow, which rarely occurs, and is, therefore, not a particularly good assessment of what actually happens. Soils in their natural state have large and small pores through which water can move. Under saturated flow in a medium-textured soil, water moves through the larger pores at a relatively rapid rate. In most instances, however, soil water moves as unsaturated flow through the smaller soil pores at a slower rate, which increases the potential for contaminant attenuation. Thus, a standard permeability rate for a medium-textured soil will tend to underestimate the ability of a soil to treat and recycle waste. To estimate the rate of water movement through the subsoil (B) horizon, various characteristics—including the textural classification at the family level in the soil taxonomy, the type and grade of structure, and the soil consistence—were considered. Five classes were established representing the range of rates of water movement commonly encountered in soils (6b in Table 17).

The organic matter content of the soil is important because it increases the ability of the soil to hold nutrients, water, and complex heavy metals and to adsorb organic materials such as pesticides. In addition, it provides a valuable energy source for soil microorganisms, which play an important part in the breakdown of organic wastes and pesticides."

Values assigned to each characteristic were determined subjectively, with 1 representing the poorest and 10 the best attenuation potential (Table 17). These values were summed, and soils with total point scores within certain ranges were grouped into four soil associations, which, in turn, reflect different attenuation potentials (Appendix C). The distribution of these soil associations is shown on Map 12. The map was prepared at one inch equals 4,000 feet scale, in digital form. Soil associations consist of two or more dissimilar series that occur on the landscape in a regularly repeating pattern.

Information needed for this assessment was taken entirely from detailed soil survey reports prepared by the U.S. Soil Conservation Service under contract to the Southeastern Wisconsin Regional Planning Commission (USDA, 1970a; 1970b; 1971a; 1971b; and 1971c). All soil series mapped were ranked on the basis of their characteristics in a natural state. Man-induced changes, such as tiling and ditching, may affect the attenuation potential of a particular soil. In those instances where alteration has been extensive, a reassessment may be required. Although shallow depths to bedrock are not indicated on the maps, there are soil series where bedrock is within five feet of the land surface (Appendix C). Even though the rock may be covered with two to four feet of soil materials that have good capacity for contaminant attenuation, the proximity of the bedrock to the land surface still limits surface and subsurface land-use activities.

The soil contaminant attenuation model was designed to be a simple evaluative system that utilizes information contained in typical county soil survey reports generated by the U.S. Natural Resources Conservation Service, formerly the U.S. Soil Conservation Service. However, soil information for individual soil series may differ from county to county. For example, the depth of a particular soil series may be described at 28 inches in one county and at 33 inches in an adjacent one. This difference can affect the score and/or rank of a soil in such a way that the map units on the soil attenuation potential maps may not match over county lines.

In order to be sure that map units (Map 12) matched across county lines in the Region, soil series that ranked differently were studied to determine the reason for the differences. Soil depth, pH of the surface horizon, texture of the subsoil (B) horizon, and natural soil drainage all cause differences in soil attenuation ratings. The observed differences were resolved to insure the matching of map units across county lines.

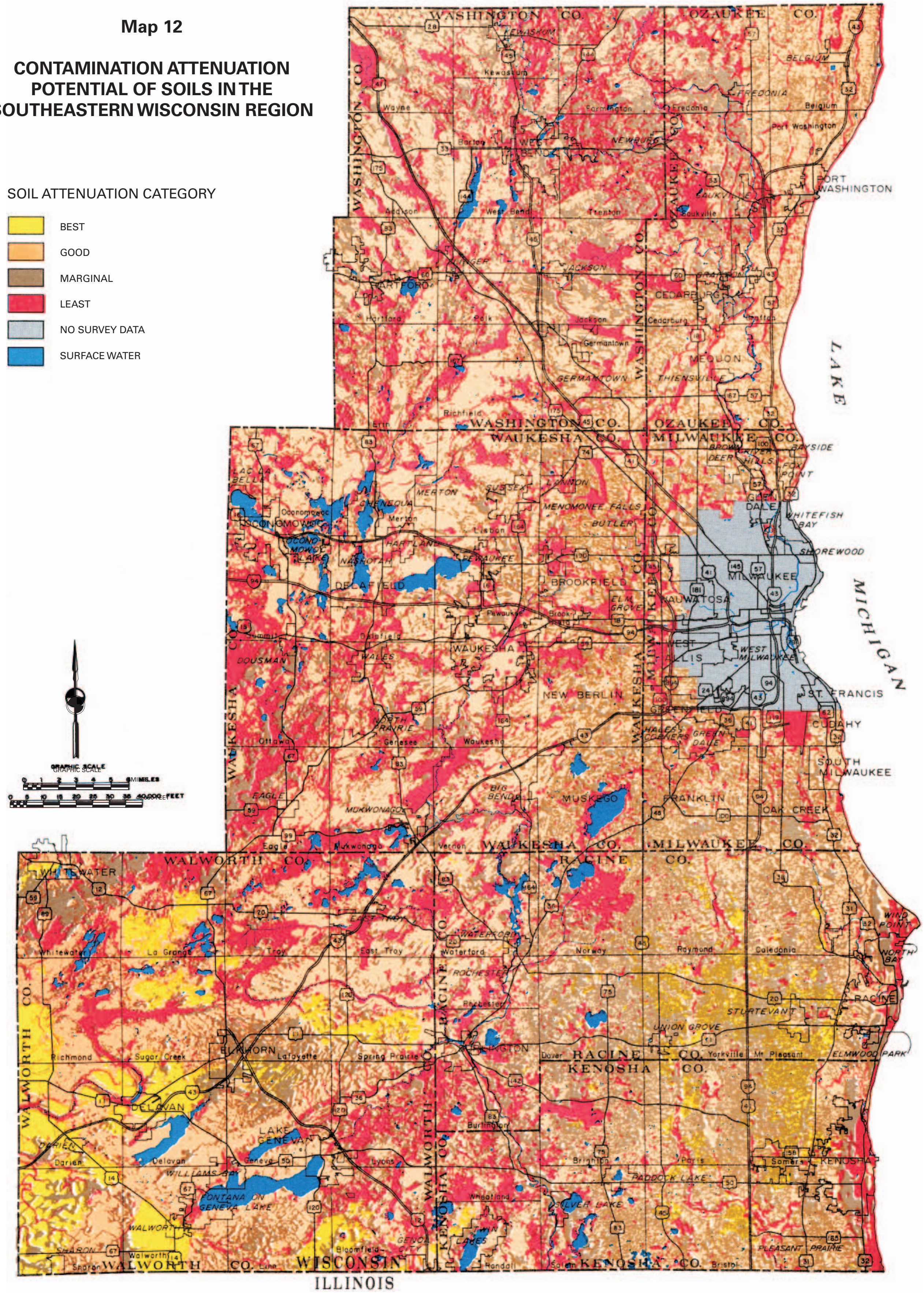
SOIL CONTAMINANT ATTENUATION POTENTIAL

In the inland counties of the Southeastern Wisconsin Region—Washington, Waukesha, and Walworth—soils with good attenuation potential cover much of the landscape (Map 12). Soils formed in less than 10 inches of silt (Hochheim) or in 10 to 22 inches of silt (Theresa) over highly calcareous sandy loam or loam till are widespread. Well aggregated, medium-textured surface horizons allow water to infiltrate easily into these soils; percolating water is slowed by an increase in clay content in the B horizons. Slowly moving water has increased contact with soil particles, which maximizes the potential for contaminant attenuation. Overall, soil attenuation is limited somewhat by the relatively shallow depth of these soils. Attenuation in Miami and Brookston soils formed in less than 20 inches of silt over calcareous loam till is limited by the shallow depth of these soils, and in the case of Brookston, by natural soil drainage. That soil is saturated for extended periods of time during any given year. If the saturation represents fluctuations of the water table, then clearly the potential for the introduction of contaminants to the saturated zone exists.

Soils with the best ability to attenuate contaminants are found mostly in Walworth County, where Plano soils are extensively present (Map 12). These soils formed under prairie vegetation in 40 to 60 inches of silts over calcareous sandy loam or loam tills. The physical and chemical characteristics of these soils give them the best attenuation potential.

Map 12

CONTAMINATION ATTENUATION POTENTIAL OF SOILS IN THE SOUTHEASTERN WISCONSIN REGION



Source: University of Wisconsin-Extension, Wisconsin Geological and Natural History Survey and SEWRPC.

In the lakeshore counties of the Southeastern Wisconsin Region—Ozaukee, Milwaukee, Racine, and Kenosha—where soils have formed in up to 20 inches of silty materials over silty clay loam to clay loam tills, the Markham, Varna, and Morley soils are widely present. These soils all have good potential for contaminant attenuation (Map 12). Ashburn, Elliot, and Blount soils, which are formed in the same materials, have marginal to least attenuation potentials due primarily to poor natural soil drainage. In these soils, which cover vast acreages, there simply is not enough well-drained, well-aerated soil for attenuation processes to be effective.

The clay tills of the last advance of the ice of the Lake Michigan Lobe are limited primarily to Milwaukee and Ozaukee Counties. Kewaunee soils, which formed in up to 20 inches of silt over the red clay till, have good attenuation potential, especially in those settings where the silty coverings are thick and have not been eroded away. Many of these soils have been formed over the years, and where they have not been carefully managed, erosion losses have been significant. Once these soils have lost their topsoil, water does not infiltrate easily into them and their ability to attenuate contaminants is reduced.

Outwash deposits throughout Southeastern Wisconsin are generally covered with up to 40 inches of loamy materials. Soils called Casco, Fox, Warsaw, and Rodman are mapped in these areas; their attenuation potential is very closely related to the thickness of the loamy coverings on them and ranges from marginal to good.

As the glaciers moved across the landscape, grinding off the tops of hills and filling in valleys, they very effectively blocked most of the natural drainage, and lakes formed as ice melted. Blocks of ice were covered with a protective layer of glacial debris that collapsed in to fill the void left when the ice finally melted. Collapse features and blocked drainage have produced many of the modern lakes in Southeastern Wisconsin. Depressions where water stands are also ideal for the accumulation of organic materials and the formation of organic soils. Houghton soils, which form in greater than 50 inches of decaying plant materials, are widely mapped in all counties in the Region. Because of the role the standing water plays in the formation of these soils, they basically have, in their natural state, no attenuation potential. Many of these organic soils in the Region have been drained primarily for vegetable production. Lowering the water table to drain these soils would appear to change their ability to attenuate contaminants somewhat.

SUMMARY

Approximately 55 percent of the seven-county Southeastern Wisconsin planning region is covered by soils with good and excellent containment attenuation potential (Appendix C), and thus, may be considered less susceptible to contamination from land use activities. These soils are evenly distributed across the Region on upland till surfaces. Soils that have the least contaminant attenuation potential cover about 16 percent of the Region and are concentrated in terminal moraine areas where surface drainage has been extensively disrupted by glacial debris. Approximately 27 percent of the Region is covered by soils that have marginal attenuation potential (Appendix C). The remaining 2 percent includes miscellaneous land type acreage, not classified.

Chapter IV

GLACIAL GEOLOGY OF SOUTHEASTERN WISCONSIN AND ITS IMPLICATIONS FOR HYDROGEOLOGY

REGIONAL DESCRIPTION

The surficial geology of Southeastern Wisconsin, like that of most of the State, with the exception of the Driftless Area, was greatly influenced by the events of the Wisconsin Glaciation, especially the last advances of ice about 25,000 to 11,000 years ago (Figure 7). Advances of ice sheets out of the Great Lakes basins during the Pleistocene glaciations, of which the Wisconsin Glaciation was the latest, have sculpted the bedrock and the land surface, leaving characteristic landforms and depositing unlithified sediments. These sediments—till, outwash, and glaciolacustrine deposits—blanket the bedrock surface to depths of as much as several hundred feet and are important in understanding regional hydrogeology. Groundwater in the shallow, water table aquifer and the deep, confined aquifer originally infiltrated from the surface through these unlithified sediments.

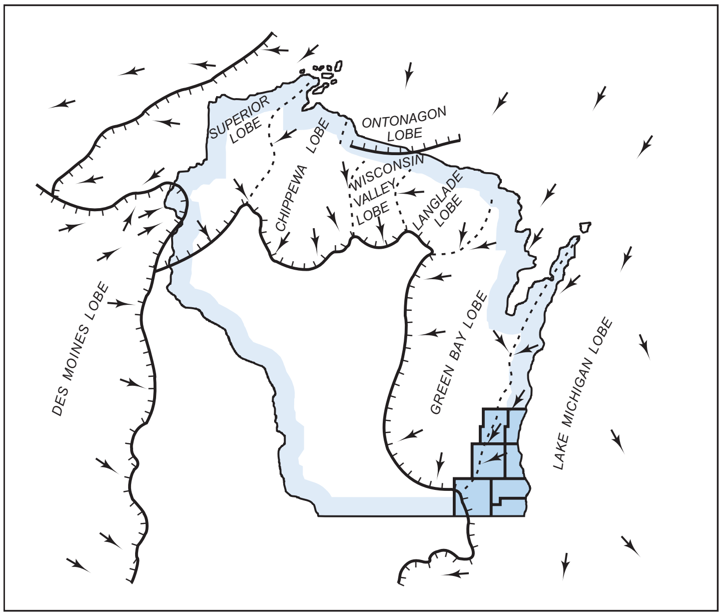
Before the last part of the Wisconsin Glaciation, early ice advances deposited glacial sediment, most of which is buried by deposits of later advances. These early ice advances are partly responsible for the deep valleys carved into the bedrock surface, of which the best known is the Troy Valley (Alden, 1918; Batten and Conlon, 1993; Green, 1968). This valley, now completely filled with glacial deposits, was presumably scoured out and refilled many times and may have been an outlet for Lake Michigan at one time (Clayton, 2001).

The characteristic glacial landforms in Southeastern Wisconsin and their associated deposits were created by two lobes of the Wisconsin ice sheet: the Green Bay Lobe, which advanced from the northwest, and the Lake Michigan Lobe, which advanced from the east in this region (Figure 7). Until 11,000 years ago, ice in these lobes advanced and melted back repeatedly, in response to climate fluctuations. At the location of farthest advance of the ice sheets, and other locations where the ice margin was stationary for some time, deposits accumulated in ridges called moraines. These moraines are the major topographic features in Southeastern Wisconsin. A region of hummocky topography, the Kettle Moraine, was formed where ice of the Green Bay and Lake Michigan Lobes met. Some distance behind the belts of moraines, elongated hills called drumlins were sculpted beneath the ice.

The advances of the ice lobes over uneven bedrock topography, and the landforms they created, resulted in a wide range in the thickness of glacial deposits covering the bedrock. This thickness, represented as depth to bedrock on Map 13, ranges from zero to more than 500 feet and is commonly between 50 and 150 feet. This map was prepared at one inch equals 4,000 feet scale, in digital form. Areas where outcrops occur and where bedrock is less than 25 feet deep are often found along an irregular buried bedrock ridge, a continuation of the prominent geologic feature of northeastern Wisconsin—called the Silurian escarpment. This ridge passes through

Figure 7

LOBES OF THE LARENTIDE ICE SHEET IN WISCONSIN DURING THE WISCONSIN GLACIATION



Source: Adapted from Clayton and others, 1991.

Southeastern Wisconsin from eastern Washington County southwest through the middle of Waukesha County. It is deeply dissected by buried pre-glacial bedrock valleys.

LITHOLOGY

Three major types of sediment were deposited during the Wisconsin Glaciation: till, outwash, and glaciolacustrine deposits. Till, which constitutes much of the surface material in glaciated areas and is thickest in moraines, is generally very poorly sorted sandy or clay silt containing cobbles and boulders. Till units were deposited directly from the ice sheet as it advanced or retreated, and their exact composition is characteristic of the particular ice lobe or advance. They typically exhibit moderate to low permeability, and surface water infiltrates slowly through them to the water table.

Another type of deposit, called outwash, consists mainly of sand and gravel with varying amounts of silt and clay. This sediment originated from the ice but was transported away from the ice margin by meltwater and is therefore well sorted and stratified. In addition to filling deep bedrock valleys as the ice retreated, outwash often constitutes the core of drumlins and separates layers of till deposited by different ice advances. Outwash is typically highly permeable, and surface water infiltrates rapidly through it to the water table.

The third major type of glacial sediment, glaciolacustrine deposits, was deposited in meltwater lakes formed in front of the retreating ice sheet. Some of these lakes remained to form the modern large lakes in Southeastern Wisconsin. In addition to local and regional glacial lakes, large lakes filled the basin of Lake Michigan at different times, and left deposits at different levels, up to 60 feet above the modern lake level. The glaciolacustrine units have a wide range of sediment characteristics, from laminated clays to stratified silty sands, and tend to have values of permeability ranging between those of till and outwash. They are often found at land surface, associated with peat deposits, or between till sheets deposited by different ice advances, and commonly interfinger with the other types of sediment.

MAJOR LITHOSTRATIGRAPHIC UNITS

The Pleistocene deposits in the Region consist of a complex sequence of deposits differing in origin, age, lithology, thickness, and areal extent. Mickelson and others (1984) recognized five lithostratigraphic units in Southeastern Wisconsin: Kewaunee, Horicon, Oak Creek, New Berlin, and Zenda Formations (see Table 18, next chapter).

Most of the area of the inland counties in Southeastern Wisconsin—Washington, Waukesha, and Walworth—is covered with glacial deposits of the Green Bay Lobe (Horicon Formation) and early advances of the Lake Michigan Lobe (New Berlin and Zenda Formations) (Figure 8) that occurred about 15,000 to 35,000 years ago (Clayton, 2001; Mickelson and Syverson, 1997). The till units associated with these earlier ice advances tend to be sandier and more permeable than the younger tills to the east. The till of the Zenda Formation is older, pink, and medium-grained, and only rarely occurs at the surface. The younger Horicon and New Berlin Formations

Map 13

GENERALIZED DEPTH TO BEDROCK IN THE SOUTHEASTERN WISCONSIN REGION

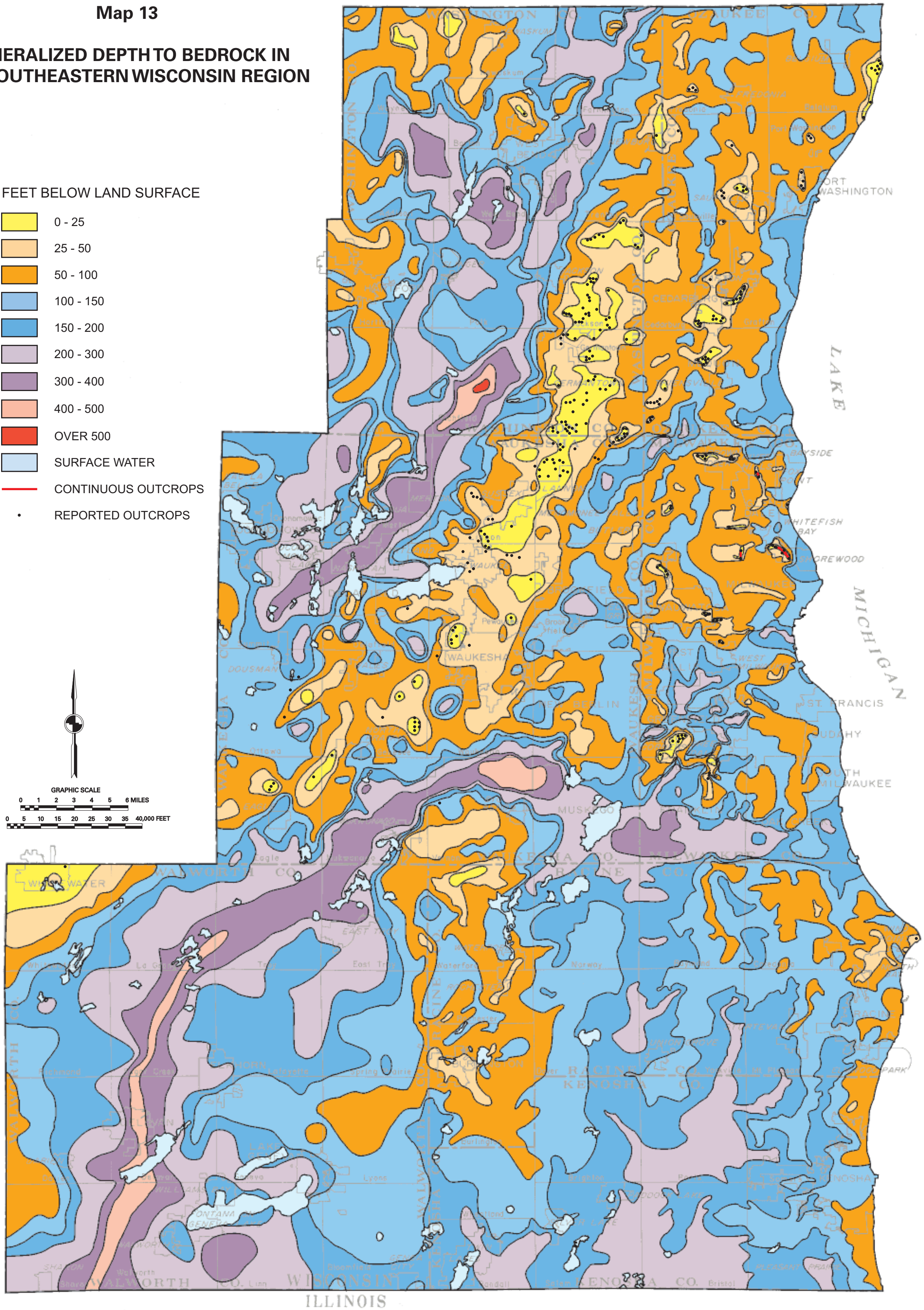
FEET BELOW LAND SURFACE

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- 200 - 300
- 300 - 400
- 400 - 500
- OVER 500
- SURFACE WATER
- CONTINUOUS OUTCROPS
- REPORTED OUTCROPS

GRAPHIC SCALE

0 1 2 3 4 5 6 MILES

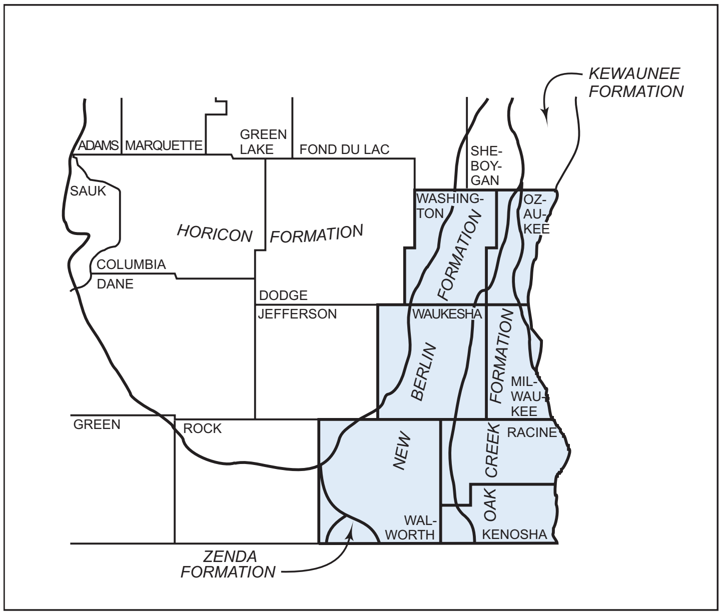
0 5 10 15 20 25 30 35 40,000 FEET



Source: University of Wisconsin - Extension, Wisconsin Geological and Natural History Survey, and SEWRPC.

Figure 8

DISTRIBUTION OF PLEISTOCENE LITHOSTRATIGRAPHIC UNITS IN SOUTHEASTERN WISCONSIN



Source: Adapted from Clayton and others, 1991.

contain yellowish-brown and coarse-grained tills; the New Berlin Formation usually overlies the Zenda Formation (Mickelson and others, 1984). The Kettle Moraine, formed along the junction of these two ice lobes, is a hummocky upland consisting mainly of outwash sediment that collapsed when underlying or adjacent ice melted (L. Clayton, WGNHS, and N. Ham, St. Norbert's College—verbal communications). Central Waukesha County is noted for its abundance of drumlins oriented in the direction of ice flow.

The lakeshore counties in Southeastern Wisconsin—Ozaukee, Milwaukee, Racine, and Kenosha—also contain units of the sandy till (Horicon and New Berlin Formations) left by earlier advances, but these are mostly buried by younger silty deposits (Kewaunee and Oak Creek Formations) from later advances of the Lake Michigan Lobe (Figure 8).

In all, there were three known major advances of the Lake Michigan Lobe, each of which laid down a distinctive type of till. The first advance of the Lake Michigan Lobe occurred about 15,000 to 35,000 years ago and deposited the sandy tills of the Zenda and New Berlin Formations. During the second major advance of the Lake Michigan Lobe about 13,000 to 14,500 years ago, a gray silty till of the Oak Creek Formation (Mickelson and others, 1984) was deposited, in three major morainic belts: the Valparaiso, Tinley and Lake Border systems, formed roughly parallel to the shoreline (Brown, 1990; Schneider, 1983; Simpkins, 1989). This silty, clayey till has a very low permeability, but contains lenses of gravelly outwash and sandy lake deposits. The third major advance of the Lake Michigan Lobe occurred from about 13,000 to 11,000 years ago, and deposited a reddish silty till (of the Kewaunee Formation) in a narrow band along the lakeshore north of Milwaukee and into Ozaukee County (Mickelson and others, 1984; Mickelson and Syverson, 1997). This till overlies the earlier gray clayey till and is also of very low permeability (Figure 8).

Twice during these advance periods, ice retreated briefly back east and north in the Lake Michigan basin, and two large proglacial lakes formed: glacial Lake Milwaukee and glacial Lake Chicago, respectively (L. Clayton, WGNHS, verbal communication; Hansel and Mickelson, 1988; Hansel and others, 1985; Schneider, 1983). The two later advances of the Lake Michigan Lobe ice overrode sediment from these lakes, causing the till that was then deposited to be much finer grained than that of the first advance. Clayey and sandy sediments from these proglacial lakes are common along the lakeshore, particularly in the vicinity of the Milwaukee estuary.

METHODS OF STUDY

Formal Pleistocene geology maps and county reports have been completed (Clayton, 2001; Mickelson and Syverson, 1997) or are in progress (Ham and Atting, in preparation; Schneider and others, in preparation) for all counties in the Southeastern Wisconsin planning region with the exception of Milwaukee County. Because of the extensive urbanization of Milwaukee County, conventional mapping methods were not applicable there. A compilation of the Pleistocene geology map for Milwaukee County, based on available data (among others Need, 1983; Rodenback, 1988) and extensive subsurface information, was prepared specifically for this project (Zaporozec and Eaton, 1996) to help determine hydrogeologic properties of glacial deposits. Advanced field maps were used to assess hydrogeologic properties of Pleistocene glacial sediment in Walworth County before mapping was completed.

Conventional methods of Pleistocene geology mapping combine for the published and in-progress reports extensive fieldwork with stereoscopic analysis of aerial photographs to delineate landforms. Solid-stem augering, sampling, and laboratory grain-size analysis of Pleistocene materials, along with identification of characteristic geographic features, enable the reconstruction of significant events during the most recent Wisconsin Glaciation. Lithostratigraphic units and constituent members are formally defined according to the North American Stratigraphic Code (American Commission on Stratigraphic Nomenclature, 1983). In each report, they are delineated in plan view and cross-sections, and published at a scale of 1:100,000.

The lithologic properties of Pleistocene materials, mapped according to methods described above, are critical to the study of groundwater resources on a regional basis. Recharge to the water table, and eventually, the deep confined aquifers percolates through the unsaturated zone at various rates depending on the vertical permeability of the Pleistocene materials. Any contaminants spilled on the ground surface that move through the soil zone will percolate down to the water table at roughly the same rates as water. Mapped Pleistocene units can therefore be regrouped according to their lithology and estimated permeability for the purposes of assessing the vulnerability of groundwater to contamination.

DETERMINATION OF HYDROGEOLOGIC PROPERTIES

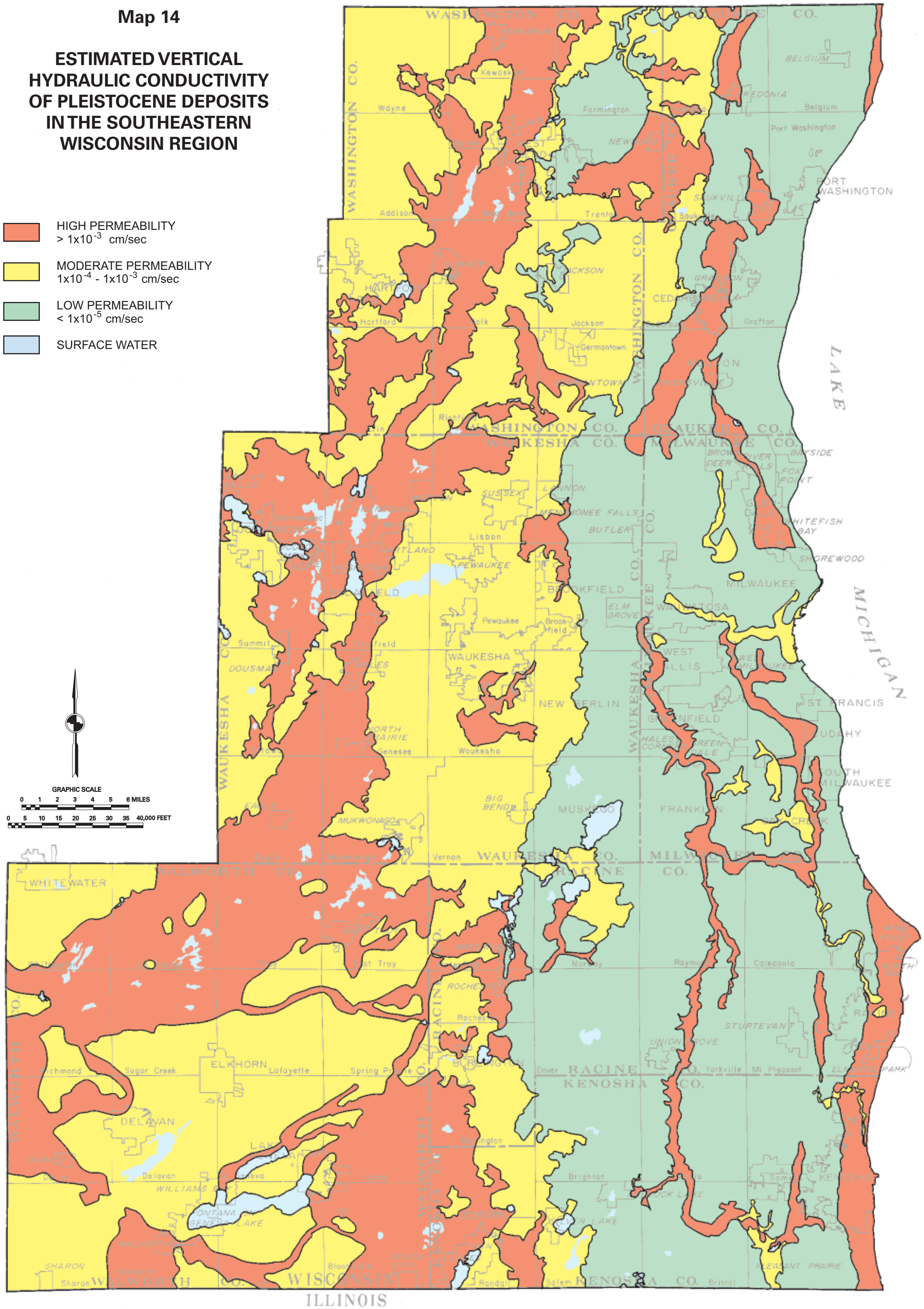
Coarse-grained deposits like sand and gravel are the most permeable units in the region, so all outwash deposits are considered high permeability units. Sandy till units and lacustrine sediments are generally fine-grained and less permeable, so they are considered moderate permeability units. Very silty and clayey till deposits are the least permeable units found in the Region, and they are considered low permeability units. In addition to Pleistocene units mapped at the land surface, subsurface information such as cross-sections and boring logs were used to estimate the vertical permeability of the unsaturated zone.

An extensive survey of the literature on hydraulic conductivity (permeability coefficient) of Pleistocene deposits enabled estimates of composite vertical hydraulic conductivity to be made for each of the types of deposits. Estimates of hydraulic conductivity for each of the three major types of glacial sediment (till, outwash and glaciolacustrine deposits) were used, along with their relative thickness above the water table, to calculate composite vertical hydraulic conductivity at locations along cross-sections or for different areas on the maps (Freeze and Cherry, 1979). For example, in areas where the water table is relatively deep, and thin till units are underlain by unsaturated sand and gravel, the much higher permeability of the sand and gravel increases the overall composite vertical permeability of the Pleistocene materials above the water table. Mapped Pleistocene units were combined into three classes of estimated permeability and generalized, eliminating units of small areal extent considered insignificant at the final mapping scale of 1:96,000 (Map 14).

Materials classified as high permeability units—sand, sand and gravel—were estimated to have a vertical hydraulic conductivity of $1x10^{-3}$ centimeters per second (cm/s) or greater, or approximately three feet per day (ft/day). Materials classified as moderate permeability units—sandy till, glaciolacustrine sediments—were estimated to have a vertical hydraulic conductivity in the range of $1x10^{-4}$ cm/s, or approximately 0.3 feet per day, to $1x10^{-5}$ cm/s, or approximately 0.03 feet per day. Materials classified as low permeability units—silty, clayey till—were estimated to have a vertical hydraulic conductivity of less than $1x10^{-5}$ cm/day, or approximately 0.03 feet per day. This distribution of hydrogeologic properties of glacial deposits is used in the assessment of contamination potential for Southeastern Wisconsin (see Chapter VII). These figures are very general and not intended to apply to any specific site. Because of the variability of Pleistocene deposits, it is essential that field work and hydrogeologic testing be undertaken to determine values at any specific location. Map 14 shows areas of relatively different permeabilities in all seven counties of Southeastern Wisconsin.

Map 14

ESTIMATED VERTICAL HYDRAULIC CONDUCTIVITY OF PLEISTOCENE DEPOSITS IN THE SOUTHEASTERN WISCONSIN REGION



Source: Wisconsin Geological and Natural History Survey.

Chapter V

BEDROCK GEOLOGY OF SOUTHEASTERN WISCONSIN

REGIONAL GEOLOGY

Knowledge of bedrock geology is important to land use, transportation, and other public facility and utility planning, especially water-supply planning. Moreover, bedrock geology is an important factor in quality of groundwater and in the assessment of groundwater contamination potential. The bedrock of Southeastern Wisconsin is separated into two major divisions: 1) younger, relatively flat-lying sedimentary rocks of the Paleozoic Era (younger than 570 million years), and 2) older predominantly crystalline rocks of Precambrian age (Table 18).

The Paleozoic rocks are of primary importance to understanding the water resources of Southeastern Wisconsin because they form the major aquifers that provide municipal, industrial, and private water supplies for the Region. They consist of a sequence of sedimentary rocks—dolomite, shale, and sandstone—that range from Cambrian to Devonian in age (Table 18). The Paleozoic rocks are nearly flat-lying, but dip gently to the east from the Wisconsin Arch into the Michigan Basin, and thicken significantly from west to east. An older crystalline basement of Precambrian crystalline rock, primarily granite and quartzite, underlies the Paleozoic sedimentary sequence. The distribution of the major stratigraphic units is shown on the bedrock geologic map (Map 15).

Devonian strata, the youngest Paleozoic rock in Wisconsin, are present only along a narrow band parallel to the Lake Michigan shoreline from Milwaukee to the north. They constitute the westernmost occurrence of Devonian strata in the Michigan Basin. The Silurian dolomites are at the bedrock surface throughout most of the Region. The Ordovician-age Maquoketa Formation (shale) and Sinnipee Group (dolomite) underlie the western edge of the Region (Map 15). The remaining Ordovician rock units, the St. Peter formation and the Prairie du Chien Group, and the Cambrian sandstone sequence are not exposed at the bedrock surface, but are encountered in deep wells throughout the Region.

Bedrock geology of Southeastern Wisconsin, as described in this chapter, is based upon existing publications, file material, and unpublished field notes of the Wisconsin Geological and Natural History Survey. The general bedrock geology of the Region shown on Map 15 was excerpted from the official bedrock geological map of Wisconsin (Mudrey and others, 1982). New interpretation of well records resulted in redefinition of the western edge of the Maquoketa Formation, which is included in Map 15. The cross-sections (Figures 9 and 10), bedrock surface elevation map (Map 16), and depth-to-bedrock map (Map 13 in Chapter IV) were specifically prepared for this study.

Table 18

GEOLOGIC COLUMN FOR BEDROCK AND GLACIAL DEPOSITS IN SOUTHEASTERN WISCONSIN

Geologic Time	Rock Unit		Lithologic Description
QUATERNARY			
Recent	Undifferentiated		Soil, muck, peat, alluvium, colluvium, beach sediment
Pleistocene *(all units include lake and stream sediment in addition to till)*	Kewaunee Formation		Brown to reddish-brown, silty and clayey till
	Horicon Formation		Coarser, brown, sandy till with associated sand and gravel
	Oak Creek Formation		Fine-textured, gray clayey till; lacustrine clay, silt, and sand
	New Berlin Formation		Upper: medium-textured. gravelly sandy till; Lower: outwash sand and gravel
	Zenda Formation		Medium-textured, pink, sandy till; limited distribution
PALEOZOIC			
Devonian	Antrim Formation		Gray, silty shale; thin; limited distribution
	Milwaukee Formation		Shaly dolomite and dolomitic siltstone
	Thiensville Formation		Dolomite and shaly dolomite
Upper Silurian	Waubakee Formation		Dense, thin-bedded, gray, slightly shaly dolomite
	Racine Formation		Finely crystalline dolomite; locally shaly beds and dolomite reefs
	Waukesha Formation		Cherty, white to buff, medium bedded, shaly dolomite
	Brandon Bridge beds		Pink to green shaly dolomite with shaly beds
	Lower Silurian beds (undifferentiated)		Dolomite and shaly dolomite
Ordovician	Neda Formation		Brown hematitic shale and oolite; occurs sporadically
	Maquoketa Formation		Green to gray dolomitic shale; locally layers of dolomite, fossiliferous
	Sinnipee Group	Galena Formation	Cherty dolomite with shaly dolomite at the base
		Decorah Formation	Shaly dolomite with fossils; thin or absent
		Platteville Formation	Dolomite and shaly dolomite
	Ancell Group	Glenwood Formation	Blue to green shale or sandy dolomite; thin or absent
		St. Peter Formation	Predominantly medium-grained quartz sandstone
	Prairie du Chien Group	Shakopee Formation	Light gray to tan dolomite or dolomitic sandstone; locally absent
		Oneota Formation	Massive, light gray to tan, cherty, sandy dolomite; locally absent
Cambrian	Trempealeau Group	Jordan Formation	Fine- to medium-grained quartz sandstone; locally absent
		St. Lawrence Formation	Tan to pink silty dolomite; locally absent
	Tunnel City Group		Fine- to medium-grained sandstone and dolomitic sandstone; locally absent
	Elk Mound Group	Wonewoc Formation	Medium- to coarse-grained, tan to white, quartz sandstone
		Eau Claire Formation	Fine- to medium-grained sandstone; local beds of green shale
		Mt. Simon Formation	Coarse- to medium-grained sandstone; lower beds very coarse and pebbly
PRECAMBRIAN	Undifferentiated		Granite or quartzite

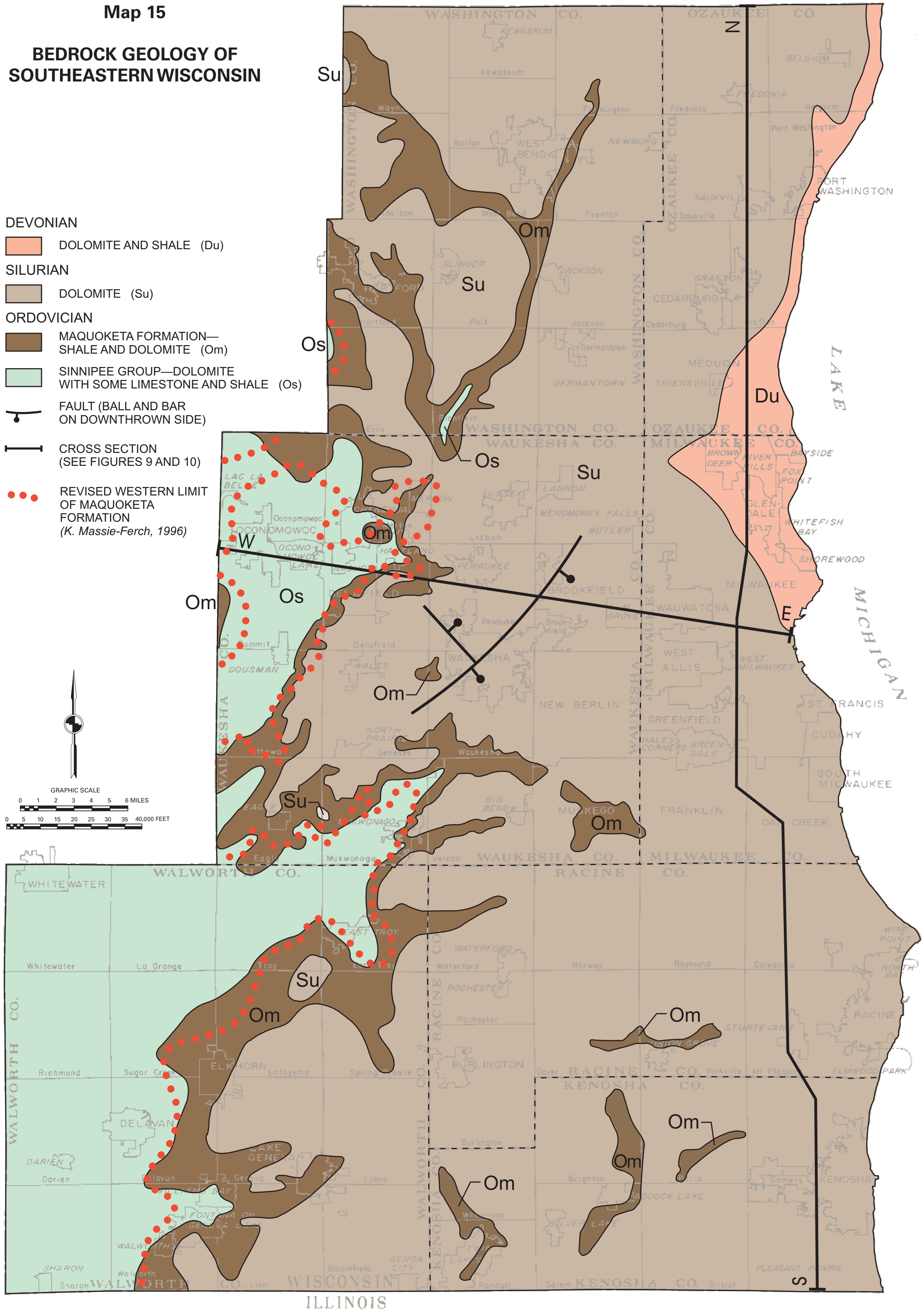
Source: University of Wisconsin–Extension, Wisconsin Geological Natural History Survey.

DEVONIAN ROCKS

The youngest rocks in Southeastern Wisconsin are the Devonian limestone, dolomite, and shale. Because of the eastward regional dip of the beds, Devonian rocks are exposed only in a small area in eastern Milwaukee and Ozaukee Counties. These rocks were described in detail in Mikulic (1977), Mikulic and Kluessendorf (1988), and Rovey (1990). Rovey (1997) used rock cores recovered from the MMSD tunnel project as new reference sections for the Devonian Thiensville Formation and the Upper Silurian Waubakee Formation.

Map 15

BEDROCK GEOLOGY OF SOUTHEASTERN WISCONSIN



Source: Mudrey, Brown, and Greenberg, 1982, and Wisconsin Geological and Natural History Survey.

The Devonian consists, from the top, of the Antrim Shale, the Milwaukee Formation, and the Thiensville Formation (Table 18). The Thiensville Formation ranges from 55 to 75 feet in thickness and grades from shaly dolomite at the base to clean dolomite at the top. The Milwaukee Formation consists of about 60 feet of shaly dolomite and dolomitic siltstone, and locally in eastern Milwaukee County it is overlain by up to 13 feet of a gray, silty mudstone of the Antrim Formation (formerly Kenwood Shale). Because of limited extent and thickness, the Devonian rocks are not a major source of municipal water supply. For purposes of regional aquifer definition, they are combined with the underlying Silurian rocks.

SILURIAN ROCKS

The Silurian section in Southeastern Wisconsin consists of up to 600 feet of dolomite, subdivided into five formations. These are, from the top, the Waubakee Formation, the Racine Formation, the Waukesha Formation, the Brandon Bridge beds, and the undifferentiated "lower Silurian beds" (Table 18). The Waubakee Formation consists of dense, laminated to thin-bedded, slightly shaly, gray dolomite and is present only in Ozaukee and eastern Milwaukee County. It varies from 60 to 100 feet in thickness, and is unconformably overlain by the Devonian Thiensville Formation. Locally, reefs developed in the underlying Racine Formation project through the Waubakee Formation and are overlain directly by the Thiensville Formation.

The Racine formation is on average about 170 feet thick in the Milwaukee area, but can reach as much as 290 feet where reefs are developed. The nonreef facies of the Racine Formation is well-bedded, finely crystalline, light olive-gray dolomite, with some shaly beds. Reefs occur locally within the Racine Formation, and consist of massive, coarsely crystalline, porous, fossiliferous, mottled gray to brownish-gray dolomite (Mikulic and Kluessendorf, 1988). The reefs are up to 100 feet thick and over 990 feet in diameter, and grade laterally into typical nonreef Racine dolomite. The contact between the nonreef Racine facies and the overlying Waubakee Formation is gradational.

The Waukesha Formation consists of locally cherty, white to buff-colored, medium-bedded, shaly dolomite. In the southern part of the Region, at Racine and Burlington, the Brandon Bridge beds consist of light pink to green shaly dolomite interbedded with maroon shaly beds in the lower half. The Brandon Bridge beds thin to the north and are not present north of Waukesha (Mikulic, 1977). In Milwaukee County, the Brandon Bridge beds and the Waukesha Formation together range from 45 to 80 feet in thickness. These two units are sometimes called in the literature the Manistique Formation.

The lower part of the Silurian section is not exposed in Southeastern Wisconsin and has not been extensively studied because few rock cores exist. The "lower Silurian beds" are approximately 175 feet thick in Milwaukee County. The beds consist of dolomite similar to that of other Silurian formations and are probably equivalent to the Byron and Mayville Formations of northeastern Wisconsin.

Rovey (1990) and Rovey and Cherkauer (1994a; 1994b) subdivided the Devonian and Upper Silurian strata into informal members and described 11 stratigraphic units and their facies changes. Rovey and Cherkauer (1994b) described the Byron and Mayville Formations as distinctly different hydrostratigraphic units, which extend from Illinois and increase in thickness toward the north, with little lithologic changes. The upper unit, the Byron Formation, is described as a fine-grained mudstone and the lower unit, the Mayville Formation, as a coarser-textured packstone.

ORDOVICIAN ROCKS

The Ordovician rocks of Southeastern Wisconsin consist from, from the top, of the Neda Formation (shale), the Maquoketa Formation (shale and dolomite), the Sinnipee Group (dolomite), the Ancell Group (sandstone), and the Prairie du Chien Group (dolomite). The Ancell and Prairie du Chien Groups are not exposed at the bedrock surface, and are known only from well cuttings and logs. A complete description of these rocks in adjacent northeastern Illinois and a discussion of their lithostratigraphy is provided by Buschbach (1964). The stratigraphy and composition of the principal formation of the Ancell Group, the St. Peter Sandstone, is described in Mai and Dott (1985).

Neda Formation

The upper Ordovician Neda Formation is a layer of brown hematitic shale and oolite, which occurs sporadically at the Ordovician-Silurian boundary in eastern Wisconsin and is conformable and gradational with the underlying Maquoketa Formation (Paull and Emerick, 1991). Where present, the Neda Formation can be up to 50 feet thick.

Maquoketa Formation

The Maquoketa Formation underlies the Silurian dolomite and is exposed at the bedrock surface in the western part of the Region (Map 15). It consists predominantly of green to gray shale, dolomitic shale, and dolomite. It is approximately 130 feet thick in Kenosha County and thickens to the north and east. The Fort Atkinson Member is a continuous dolomite unit consisting of coarse, dark brown to brown shaly dolomite up to 50 feet thick in the middle of the Maquoketa Formation, between the Brainard and Scales Members, which are predominantly shale.

Sinnipee Group

The Sinnipee Group consists of dolomite, shaly dolomite, and minor shale, and is divided into three formation (Table 18). The uppermost one, the Galena Formation, consists of cherty dolomite with 15 to 20 feet of shaly dolomite at the base. Total thickness of the Galena Formation is 275 feet in Kenosha County. The middle unit, Decorah Formation is thin or locally absent in Southeastern Wisconsin, represented by five feet or less of shaly dolomite in Waukesha County (Choi, 1995). The lower formation of the Sinnipee Group, the Platteville Formation, consists of dolomite and shaly dolomite, and reaches a thickness of 95 feet in Kenosha County. It thins to the north and west to 60 feet in thickness at Fort Atkinson in Jefferson County.

Ancell Group

The Ancell Group includes the Glenwood and St. Peter Formations (Table 18). The Glenwood Formation consists of 20 feet or less of dolomitic sandstone, blue-green shale, or sandy dolomite. The Glenwood Formation is locally variable in thickness and lithology and is not always present in Southeastern Wisconsin (Mai and Dott, 1985). The St. Peter Formation is present throughout the Region, and is subdivided into two members. The upper Tonti Member is a pure quartz sandstone, ranging in thickness from less than 50 feet to locally greater than 250 feet. The lower Readstown Member is variable in character, consisting of white to red sandstone, conglomerate (consisting of shale, chert, sandstone, and/or dolomite clasts), red to brown shale, or any combination of these rock types, in a matrix of fine to coarse sand or clay. The Readstown Member is not continuous, and is best developed in areas where maximum erosion of the underlying formations took place prior to Ancell Group deposition.

Prairie du Chien Group

The Prairie du Chien Group is subdivided into two formations (Table 18). The upper one, the Shakopee Formation, consists of light gray to tan sandy dolomite (the Willow River Member) and a thin (15 feet or less) discontinuous dolomitic sandstone (the New Richmond Member). The New Richmond Member is not always recognizable in well cuttings, and is not well defined in Southeastern Wisconsin. The lower formation, the Oneota Formation, consists of massive, light gray to tan, commonly cherty dolomite. The base of the Oneota Formation becomes sandy and is gradational with the underlying Coon Valley Member of the Cambrian Jordan Formation. The Prairie du Chien Group is not exposed at the bedrock surface in Southeastern Wisconsin, and is known in the subsurface in parts of Racine, Kenosha, and Walworth Counties, having been removed by pre-St. Peter erosion to the north. Where present, the Prairie du Chien Group is generally less than 70 feet thick (Mai and Dott, 1985).

CAMBRIAN ROCKS

The Cambrian rocks of Southeastern Wisconsin consist predominantly of sandstone, with minor dolomite and shale. Although the Cambrian sandstones are an important aquifer that supplies water to many deep municipal wells in the Region, these rocks have not been adequately studied due to the scarcity of good samples. Their stratigraphy is not known in detail. The Cambrian is subdivided into three major divisions, the Trempealeau Group, the Tunnel City Group, and the Elk Mound Group (Table 18). The Cambrian section thickens from northwest to southeast, ranging in thickness from around 700 feet in western Waukesha County to around 2,400 feet near Zion, Illinois, south of Kenosha.

Trempealeau Group
The Trempealeau Group consists of the Jordan and St. Lawrence Formations (Table 18). The Trempealeau Group is eroded by the pre-St. Peter unconformity in much of Southeastern Wisconsin. Where not eroded, the Trempealeau Group varies from 70 to 150 feet in total thickness. In its outcrop area of western Wisconsin, the Jordan Formation can be subdivided into five members on the basis of grain size and composition. These members are not easily recognized in the subsurface of Southeastern Wisconsin. The Jordan Formation in Southeastern Wisconsin is predominantly fine- to medium-grained quartz sandstone, commonly with some dolomitic cement. The Coon Valley Member at the top of the Jordan Formation is a sandy dolomite that grades into the overlying Oneota Formation. The St. Lawrence Formation is tan to pink sandy or silty dolomite, becoming more dolomitic to the south, where it is known as the Potosi Dolomite in Illinois (Buschbach, 1964).

Tunnel City Group
The Tunnel City Group consists of fine- to medium-grained sandstone and dolomitic sandstone, which varies in color from light brown to green, depending on glauconite content. In its outcrop area of western Wisconsin, the Tunnel City group is divided into the Lone Rock and Mazomanie Formations. In Southeastern Wisconsin these formations are not easily recognized in well cuttings, and the Tunnel City Group is treated as a single unit varying from 50 to 80 feet in thickness. It is equivalent to the Franconia Formation of northern Illinois (Buschbach, 1964). The Tunnel City Group is not present in Milwaukee County due to erosion.

Elk Mound Group
The Elk Mound Group is the lowermost division of the Paleozoic sedimentary section. It is divided into the Wonewoc, Eau Claire, and Mount Simon Formations (Table 18). The lowest one, the Mount Simon sandstone, directly overlies the Precambrian crystalline rock basement.

Wonewoc Formation
The formation is a medium- to coarse-grained, tan to white quartz sandstone. It is generally poorly cemented, but may be locally cemented by dolomite or silica. Where present, the Wonewoc Formation is easily distinguished from the overlying Tunnel City Group and the underlying Eau Claire Formation by coarser grain size, color, and absence of glauconite. The lower contact of the Wonewoc Formation is an erosional surface that locally cuts into the underlying Eau Claire Formation. Total thickness of the Wonewoc and Eau Claire Formations together varies from 160 to 200 feet from north to south across the Region. In adjacent northern Illinois, the Wonewoc Formation is represented by two stratigraphic units, the Ironton and Galesville Formations (Buschbach, 1964). These units are considered members of the Wonewoc Formation in western Wisconsin (Ostrom, 1967), but the division is only recognized locally in Southeastern Wisconsin.

Eau Claire Formation
This formation consists of fine- to medium-grained sandstone with local beds of green to black shale and dolomite. Dolomite cement, pyrite, and fossils are commonly present. The Eau Claire Formation thickens to the south into northern Illinois, and shale and dolomite content increases to the south as well (Buschbach, 1964). It is easily distinguished from the overlying Wonewoc and underlying Mount Simon Formations by finer grain size and glauconite content.

Mount Simon Formation
The Mount Simon Formation consists predominantly of coarse- to medium-grained sandstone, with coarser layers commonly containing pebbles. It is generally poorly cemented, but locally may be cemented by dolomite or silica. In Southeastern Wisconsin, red, black, or green shale beds can be present within the Mount Simon Formation. The lower beds are commonly very coarse and pebbly, locally becoming conglomerate near the Precambrian

contact. The Mount Simon Formation thickens to the south and east. The maximum complete section penetrated in Southeastern Wisconsin is 1,306 feet in Waukesha County; a test well at Zion in northeastern Illinois penetrated 1,800 feet.

PRECAMBRIAN ROCKS

The Precambrian crystalline basement of Southeastern Wisconsin is poorly known. Only 22 wells have reached the Precambrian and recovered identifiable samples. The most common recovered rock types, presumably 1,760 million years old or younger, are granitic rocks and quartzite resembling the Waterloo and Baraboo quartzites exposed to the west (Smith, 1978). The Precambrian is encountered at a depth of 77 feet in western Waukesha County, and dips to the south and east (Figure 9), reaching a depth of 3,460 feet in the Zion, Illinois well. The Precambrian basement forms the lower boundary of the extensive and important lower Paleozoic sandstone aquifer.

STRUCTURAL GEOLOGY

The area of Southeastern Wisconsin has largely remained tectonically inactive for a billion years and the structural deformations are minimal there. The cross-sections in Figures 9 and 10 show diagrammatically the stratigraphic formations and their regional dip, and the regional dip of the Precambrian surface. The cross-section lines are shown on Map 15.

Faults shown on the cross-sections are inferred from the differences in elevation of formation boundaries, both in wells shown on the sections presented in Figures 9 and 10 and by comparison with wells located within the several miles of the sections. There are no wells shown on the sections that actually cross a fault trace. Because most large faults in Southeastern Wisconsin are nearly vertical, it is rare that a well will cross a fault trace. There is only one well (in the City of Waukesha) supported by drill cuttings that is known to be drilled through a fault trace.

The west-east section (Figure 9) crosses a major fault zone, the Waukesha Fault, which passes through Waukesha County and trends northeastward into Lake Michigan (partly shown on Map 15). The Waukesha Fault is a potentially important hydrologic feature because it offsets major formation and aquifer boundaries, and may significantly influence deep groundwater flow systems. Although the existence of the Waukesha Fault in Southeastern Wisconsin has been recognized for some time (Foley and others, 1953), its location and linear extent have been, until recently, poorly defined due to limited data from bedrock wells and only one significant exposure. Sverdrup and others (1997) used gravity data from geophysical surveys conducted in the early 1980s to trace the Waukesha Fault from the Waukesha-Walworth county line to Port Washington in Ozaukee County.

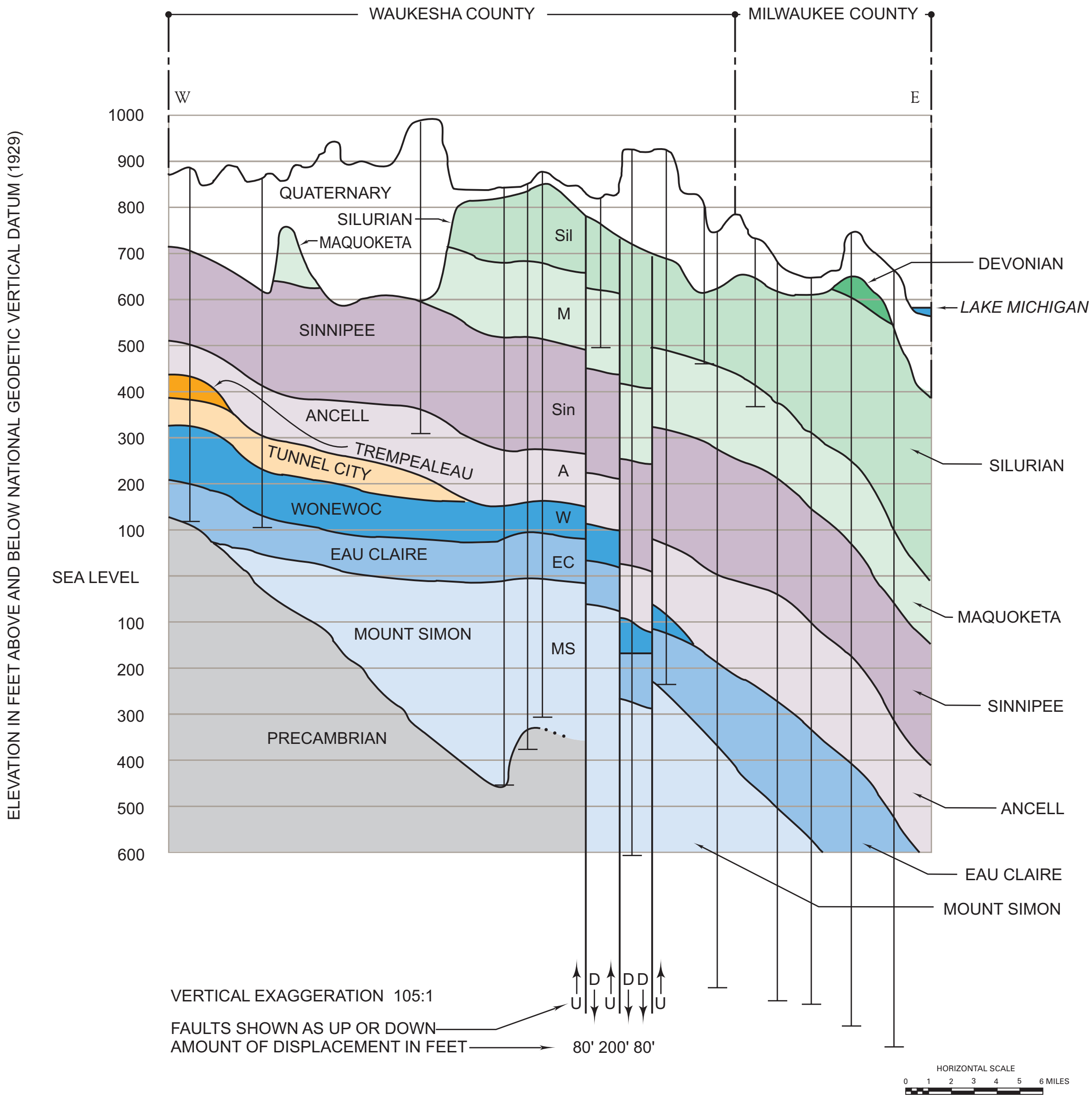
The north-south section (Figure 10) crosses several east-west faults. The lateral extent of these faults are at present poorly known, and they are not shown on Map 15. These faults also displace lithologic contacts and may significantly influence deep groundwater movement. Additional work is needed to map out the apparently complex structural and stratigraphic facies geometry of the Paleozoic rocks to enable realistic modeling of the deep groundwater flow system.

CHARACTERISTICS OF THE BEDROCK SURFACE

Southeastern Wisconsin was differentially eroded before the deposition of Pleistocene material and the contact between bedrock and Pleistocene deposits is irregular. The shape of the bedrock surface and the relationship of the bedrock surface to the land surface are portrayed on Map 16, and Map 13 in Chapter IV. Map 16 shows the actual shape of the bedrock surface and its elevation above sea level based on the most recent available data in the seven counties of Southeastern Wisconsin. Map 13 (see Chapter IV) is more complex, because it shows the depth to bedrock below the land surface, and takes into account the many hills and valleys caused by glacial moraines and rivers. Differences between these two maps are caused by the differences in thickness of unlithified glacial deposits that form the land surface.

Figure 9

GEOLOGIC CROSS SECTION OF SOUTHEASTERN WISCONSIN, WEST—EAST

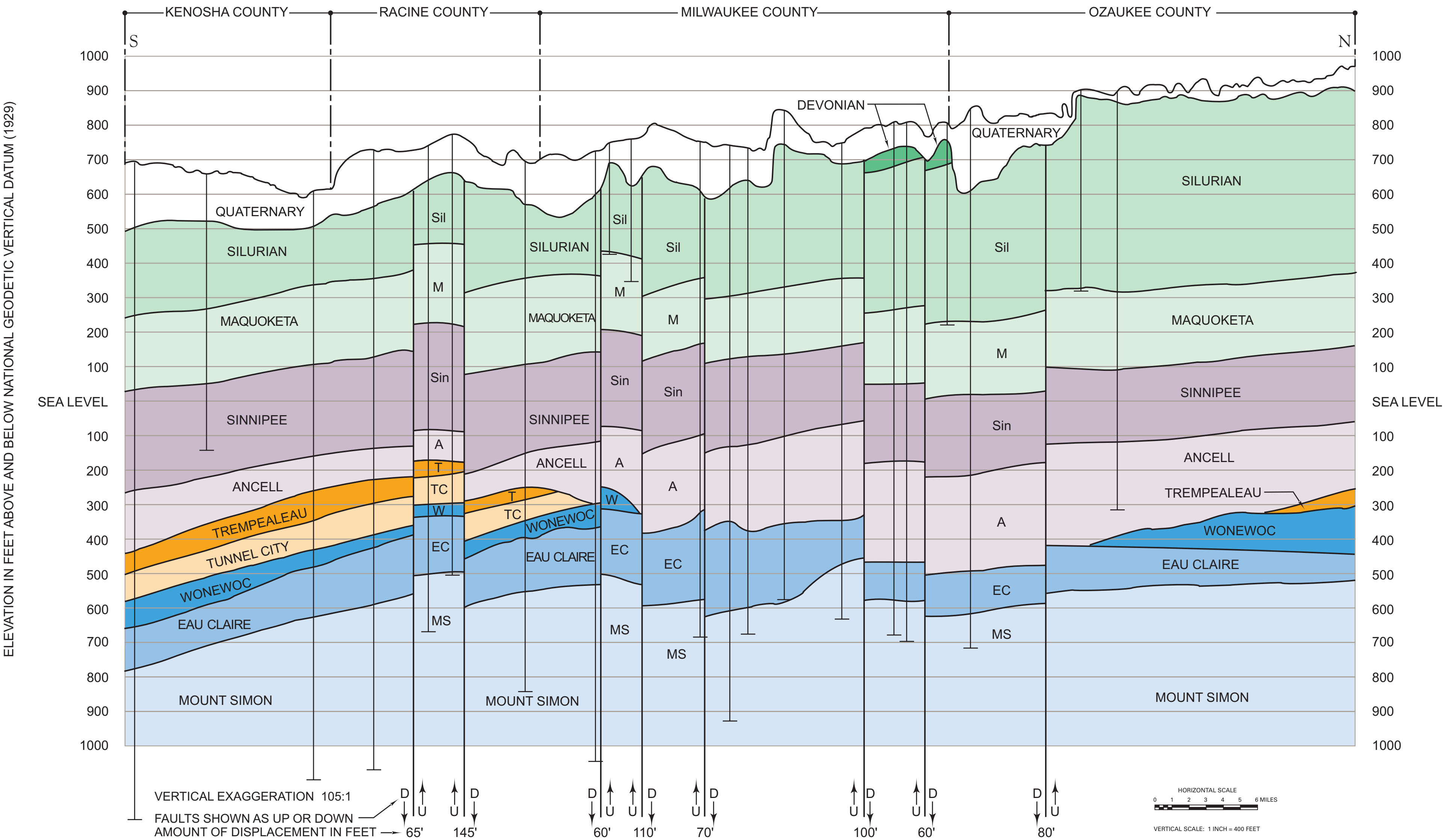


W–E	DENOTES LINE OF GEOLOGIC SECTION ON MAP 15	T	TREMPEALEAU GROUP
	WELL USED AS CONTROL POINT	TC	TUNNEL CITY GROUP
	QUATERNARY GLACIAL DEPOSITS		ELK MOUND GROUP
Dev	DEVONIAN UNDIFFERENTIATED	W	WONEWOC FORMATION
Sil	SILURIAN UNDIFFERENTIATED	EC	EAU CLAIRE FORMATION
M	MAQUOKETA FORMATION	MS	MOUNT SIMON FORMATION
Sin	SINNIPEE GROUP	PC	PRECAMBRIAN
A	ANCELL GROUP		

Source: Roger M. Peters, 1997.

Figure 10

GEOLOGIC CROSS SECTION OF SOUTHEASTERN WISCONSIN, SOUTH—NORTH



S–N DENOTES LINE OF GEOLOGIC SECTION ON MAP 15

WELL USED AS CONTROL POINT

QUATERNARY GLACIAL DEPOSITS

Dev DEVONIAN UNDIFFERENTIATED

Sil SILURIAN UNDIFFERENTIATED

M MAQUOKETA FORMATION

T SINNIPEE GROUP

TC ANCELL GROUP

Sin TREMPEALEAU GROUP

A TUNNEL CITY GROUP

ELK MOUND GROUP

W WONEWOC FORMATION

EC EAU CLAIRE FORMATION

MS MOUNT SIMON FORMATION

Source: Roger M. Peters, 1997, and SEWRPC.

The bedrock surface, as shown in Map 16, was shaped over hundreds of millions of years before the most recent Wisconsin Glaciation, which began only about 25,000 years ago, and is described in Chapter IV of this report. Before then, the land surface probably looked much like the bedrock geology surface in Map 16. Much as they do now, rivers and streams coursed over the landscape, carving out valleys and hills in the pre-glacial bedrock surface. Differential erosion caused softer or fault-weakened rock to weather away and more resistant rock to form highlands. To complicate the situation, ice sheets and meltwater of ancient glacial periods, about which little is known, probably repeatedly deepened and filled early river valleys in the bedrock.

The Wisconsin Glaciation, ending in the Region about 11,000 years ago, completely transformed the landscape. As described in Chapter IV, ice from the Green Bay and Lake Michigan Lobes planed off and scoured parts of the bedrock highlands, and meltwater deepened, then filled deep bedrock valleys with hundreds of feet of glacial deposits. In addition, a massive amount of silty, clayey glacial sediment (till) was brought to Southeastern Wisconsin by the ice sheets from the northern Great Lakes region, and deposited on top of the bedrock surface in morainal ridges. Areas that had been low points in the landscape were built up into highlands, and a completely different network of streams and rivers, and new large lakes has carved out different drainage patterns ever since. The thickness of these unlithified, mostly glacial sediments is portrayed in Map 13 (Chapter IV) as the depth to bedrock.

Bedrock Elevation

The most striking features of the bedrock surface, shown in Map 16, are several deep buried valleys, the bottoms of which are between 750 feet and 350 feet above sea level. These buried valleys were part of a drainage system that covered much of the Region and parts of Jefferson, Rock, and Dane Counties (Map 17). The valleys have been eroded down into the softer Maquoketa shale or underlying formations, and their development may have been influenced by faulting. The shape of the bottom of these bedrock valleys is poorly known because of their depth. There are only a few wells penetrating the deepest parts of the valleys. Although the valleys were probably originally formed by pre-glacial rivers, it is likely that subsequent glacial ice deepened and reshaped them. Therefore, possible closed pockets of low elevations appear on Map 16.

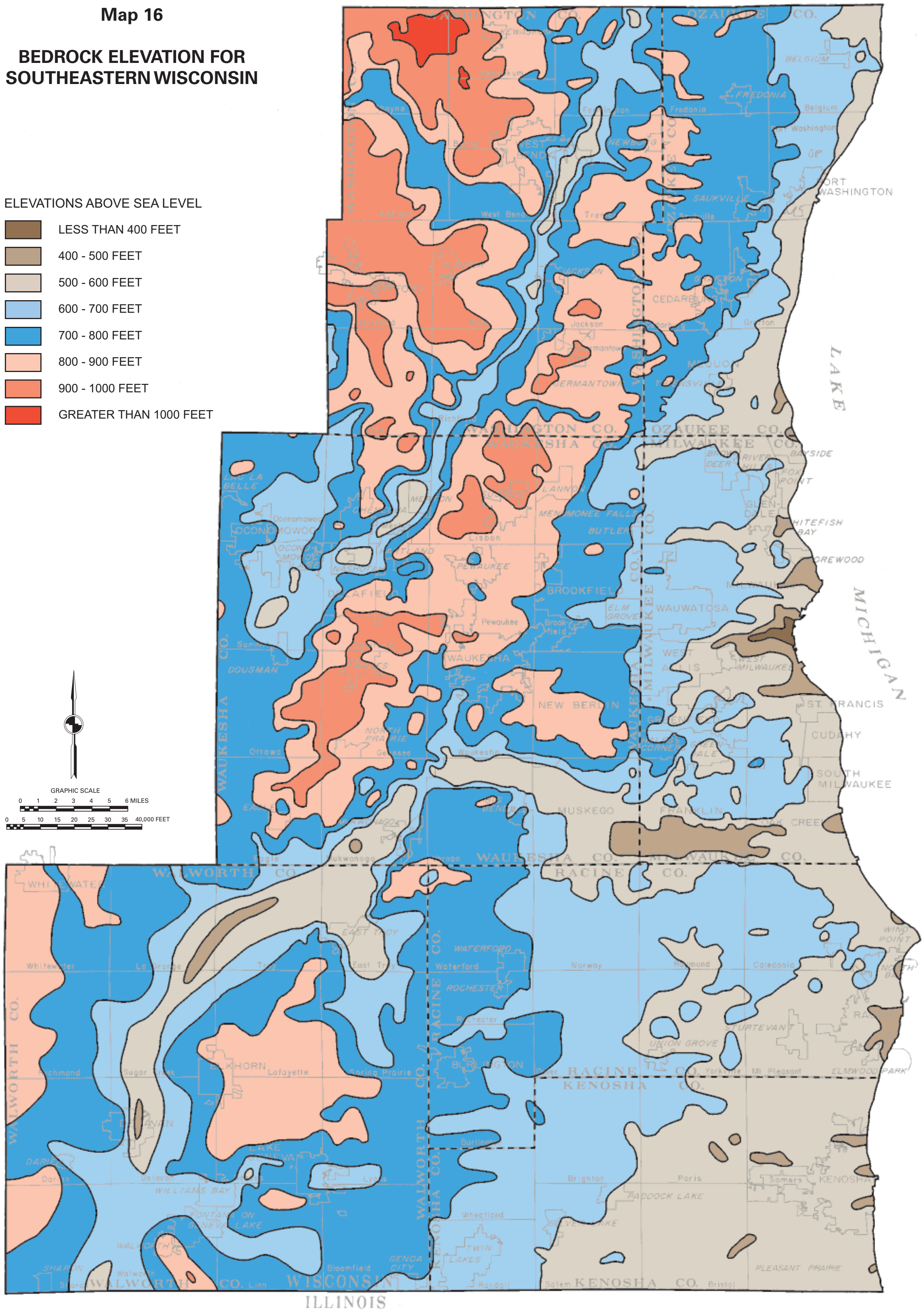
The northern valley extends from northeastern Washington County southwest through northwestern Waukesha County to southern Jefferson County. The valley in southern Washington County cuts through the Silurian dolomite and Maquoketa shale into the Sinnipee Group (Young and Batten, 1980). In Jefferson County, the valley turns west and joins the buried ancestral Rock River valley. At Lake Koshkonong the valley turns south and continues through Rock County into Illinois. The continuity of this valley system in some locations is uncertain because of the lack of wells reaching bedrock.

In the southern half of the Region, a long valley curves from southern Milwaukee and Waukesha Counties south through Walworth County into Illinois. The deepest part of the valley in Walworth County was named the Troy Valley by Alden (1904). The valley in southern Milwaukee County likely served as an outlet for Lake Michigan during glacial periods (L. Clayton, verbal communication). Information gathered in 1964 and 1965 (Green, 1968) and in 1996 (Map 16) indicates that the southern valley is not a single, continuous valley. Instead, two distinct valleys that trend in nearly opposite directions are probably separated by a pre-glacial bedrock drainage divide. The position of this divide is unclear because there is not enough control points to define it clearly. Green (1968) placed the divide northwest of Elkhorn in Walworth County. Bedrock data and elevation map compiled in 1996 (Map 16) indicate another possible location of the divide more to the north, between Mukwonago and Waukesha in southern Waukesha County.

Test-hole, well-construction, and seismic data collected from 1986 through 1991 (Batten and Conlon, 1993) showed that the part of the pre-glacial valley south of Waukesha is narrower and shallower than previously thought. These data indicated that the valley was filled with an unsorted mixture of clay, sand, and gravel. No apparent continuous layers of sand and gravel were found. Batten and Conlon (1993) estimated that the thickness of saturated glacial deposits ranges from 100 to 400 feet.

Map 16

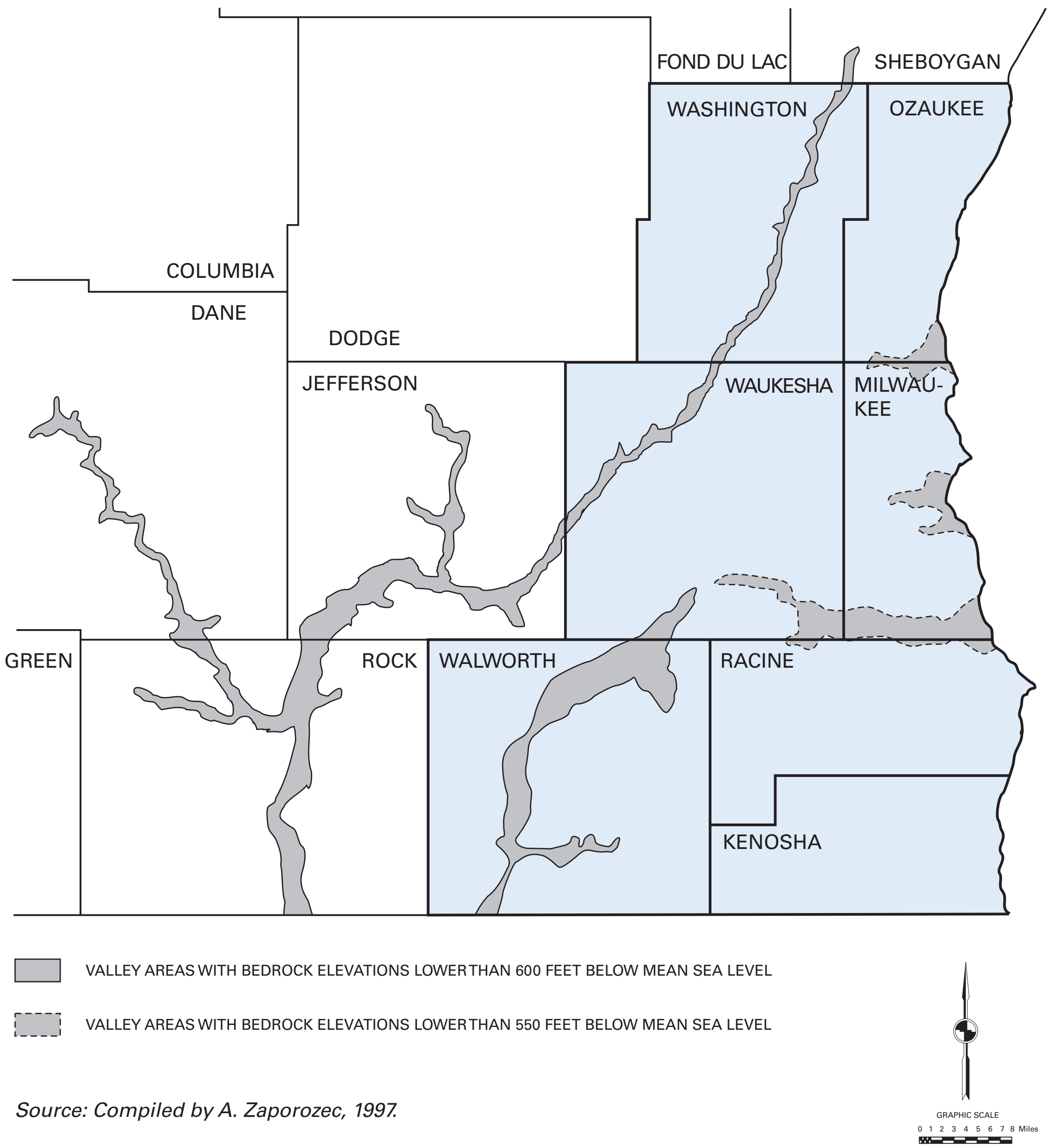
BEDROCK ELEVATION FOR SOUTHEASTERN WISCONSIN



Source: Wisconsin Geologic and Natural History Survey.

Map 17

APPROXIMATE EXTENT OF MAJOR PRE-GLACIAL BEDROCK VALLEYS IN SOUTHEASTERN WISCONSIN



Source: Compiled by A. Zaporozec, 1997.

The bedrock surface on either side of these deep valleys rises to a maximum elevation of 1,000 feet in Washington County, and between 800 and 950 feet in central Waukesha and Walworth Counties. This is a buried continuation of the Silurian escarpment known from northeastern Wisconsin. From these elevations, the bedrock surface gradually slopes down towards Lake Michigan through Ozaukee, Milwaukee, Racine, and Kenosha Counties. Near the lakeshore, the bedrock elevation ranges from 400 to 550 feet above sea level, which is below the level of Lake Michigan (580 feet). There are a number of drainage channels carved into the bedrock at the lakeshore, the most prominent of which are located along the county line between Ozaukee and Milwaukee Counties and at the Milwaukee harbor estuary. These two, together with the one in southern Milwaukee county, are part of another pre-glacial drainage network on the opposite side of the pre-glacial subcontinental divide.

These bedrock valleys draining eastward play an important role in the modern lake/groundwater interactions. The bedrock surface is particularly irregular in southern Milwaukee County (ranging over 100 feet in elevation within 500 feet distance), perhaps because of the existence of reefs in the Silurian dolomite formations.

Depth to Bedrock

Map 13 (Chapter IV) shows the approximate depth to bedrock and broadly resembles Map 16. Areas located over the deep bedrock valleys described earlier (Map 17) are where the bedrock is farthest from the land surface. Thicknesses of glacial materials in these buried valleys range from 250 feet to more than 450 feet. The areas where bedrock is closest to the land surface trend from northeast to southwest, from southeastern Washington County through northeastern Waukesha County (Map 13 of Chapter IV); bedrock generally is found there at depths less than 25 feet. Numerous outcrops and large quarries are found in the Silurian dolomite, which is the uppermost bedrock formation there. Elsewhere along the same general trend, bedrock lies at depths of less than 50 feet; for example, at the Kettle Moraine in Waukesha County, the City of Whitewater in Walworth County, and parts of Washington and Ozaukee Counties.

In most of the rest of Southeastern Wisconsin, depth to bedrock ranges between 50 and 250 feet (Map 13 of Chapter IV). This wide range of depth to bedrock is in large part caused by the many end moraines deposited during the last glacial period and the erosion of river valleys since then. For example, there are only a few outcrops or areas where bedrock is less than 50 feet deep in Racine and Kenosha Counties because of the thickness of glacial deposits. But numerous outcrops are in Milwaukee and Ozaukee Counties, where the Milwaukee, Menomonee, and Root Rivers and their tributaries have formed deep valleys in these same glacial deposits. In some cases, isolated outcrops have been reported in areas where overall bedrock surface is more than 25 feet deep.

Map 13 (Chapter IV) shows generalized depth to bedrock in Southeastern Wisconsin based on the most recent available information, but density of well data varies quite widely, and many depth range boundaries are dashed because of this uncertainty. Depth-to-bedrock information for specific localities on this map needs to be verified by onsite drilling.

Chapter VI

HYDROGEOLOGY OF SOUTHEASTERN WISCONSIN

GROUNDWATER RESOURCES

Groundwater is a vital natural resource of Southeastern Wisconsin. Groundwater not only sustains lake levels and wetlands and provides the perennial base flow of the streams, but also is a major source of water supplies. In general, the Region has an adequate supply of groundwater to support its growing population, agriculture, commerce, and a viable, diverse industry. However, overproduction and water shortages may occur in areas of concentrated development and intensive water demand, especially in the sandstone aquifer and in selected areas served by the shallow aquifers in the middle and eastern parts of the Region. The amount, recharge, movement, and discharge of the groundwater is controlled by several factors, including precipitation, topography, drainage, land use, soil, and the lithology and water-bearing properties of rock units ranging in age from Quaternary to Precambrian (see Table 18). The stratigraphy, lithology, and structure of these geologic units is described in Chapter V.

Groundwater Use

The importance of groundwater as a source of water supply in Southeastern Wisconsin can be shown by analyzing water-use data. According to estimates by the U.S. Geological Survey (Ellefson and others, 1997), water users in the Region withdrew about 311 million gallons per day (mgd) of water from surface and groundwater sources in 1995, not including water used for thermoelectric-power production (see Table 19). From this amount, 218 mgd, or about 70 percent, was withdrawn from surface water sources, primarily Lake Michigan; and 93 mgd, or about 30 percent, from groundwater. Most water was used for public supplies (84 percent), self-supplied industry (6.3 percent), and private domestic supplies (5.4 percent); agricultural and commercial users took the remaining 4.3 percent (B. Ellefson, USGS, personal communication, 1997).

Although the water use in the Region fluctuates somewhat, it has been relatively stable since 1979, when the USGS started to publish detailed water use data for individual counties (Lawrence and Ellefson, 1982; Ellefson and others, 1987; 1993; 1997). The total water use averaged around 313 mgd for the period 1979-1995; and groundwater portion of the total water use for this period varied from 22 to 30 percent, averaging 26 percent (see Table 20).

But the portion of ground and surface water in the total water use is changing. From 1985 to 1995, the use of groundwater increased 29 percent, from 72 to 93 mgd, while the use of surface water dropped almost 12 percent, from 256 to 226 mgd (see Table 20). In the same period, groundwater use increased more than 50 percent in Walworth and Racine Counties, primarily because of the population growth in suburban areas and rural

Table 19

ESTIMATED USE OF WATER IN SOUTHEASTERN WISCONSIN: 1995
(IN MILLION GALLONS PER DAY)

County Name	Public[a]		Industrial		Commercial		Irrigation		Agricultural		Domestic		Total	
	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW	SW	GW
Kenosha	14.75	0.42	0.49	- -	- -	0.13	- -	0.05	0.02	0.17	- -	1.76	15.26	2.53
Milwaukee	166.49	4.52	8.15	4.32	- -	0.94	- -	0.39	- -	0.02	- -	0.07	174.64	10.26
Ozaukee	1.35	4.28	- -	0.42	- -	1.65	0.04	0.01	0.03	0.28	- -	0.98	1.42	7.62
Racine	25.52	2.93	0.75	2.45	- -	0.02	0.30	1.15	0.01	0.04	- -	4.51	26.58	11.10
Walworth	- -	7.35	- -	0.89	- -	1.61	0.04	0.24	0.07	2.20	- -	2.17	0.11	14.46
Washington	- -	8.55	- -	0.12	- -	0.42	0.01	0.02	0.06	0.58	- -	2.64	0.07	12.33
Waukesha	- -	25.45	- -	1.92	- -	1.02	0.02	1.62	0.03	0.26	- -	4.78	0.05	35.05
Total	208.11	53.50	9.39	10.12	- -	5.79	0.41	3.48	0.22	3.55	- -	16.91	218.13	93.35
Percent of Total	79.5	20.5	48.1	51.9	- -	100.0	10.5	89.5	5.8	94.2	- -	100.0	70.0	30.0

[a]*Includes water delivered to residents, industry, and commerce within the served area. SW = surface water, GW = groundwater.*

Source: B.R. Ellefson, U.S. Geological Survey, 1997.

Table 20

TRENDS IN REPORTED WATER USE IN SOUTHEASTERN WISCONSIN: 1979-1995
(IN MILLION GALLONS PER DAY)

County Name	1979			1985			1990			1995		
	SW	GW	Total	SW	GW	Total	SW	GW	Total	SW	GW	Total
Kenosha	17.81	3.42	21.23	17.87	2.54	20.41	20.41	2.56	22.97	15.26	2.53	17.79
Milwaukee	172.47	10.18	182.65	213.26	9.91	223.17	184.96	6.17	191.13	174.64	10.26	184.90
Ozaukee	1.19	6.66	7.85	1.15	6.33	7.48	1.43	6.66	8.09	1.42	7.62	9.04
Racine	22.55	7.69	30.24	22.55	7.28	29.83	29.32	8.85	38.17	26.58	11.10	37.68
Walworth	0.14	9.89	10.03	1.16	9.14	10.30	0.08	16.07	16.15	0.11	14.46	14.57
Washington	0.15	10.11	10.26	0.06	9.37	9.43	0.08	9.76	9.84	0.07	12.33	12.40
Waukesha	0.02	33.37	33.39	0.12	27.84	27.96	0.04	30.78	30.82	0.05	35.05	35.10
Total	214.33	81.32	295.65	256.17	72.41	328.58	236.32	80.85	317.17	218.13	93.35	311.48
Percent of Total	72.5	27.5	100.0	78.0	22.0	100.0	74.5	25.5	100.0	70.0	30.0	100.0

NOTE: The trends are based on currently available data, but the sources of information and accuracy of data may vary from one reporting period to another. The USGS obtains most of water-use data from files of state agencies, and makes estimates for categories for which data are not reported (private domestic and agricultural uses). Water used for thermoelectric power is not included.

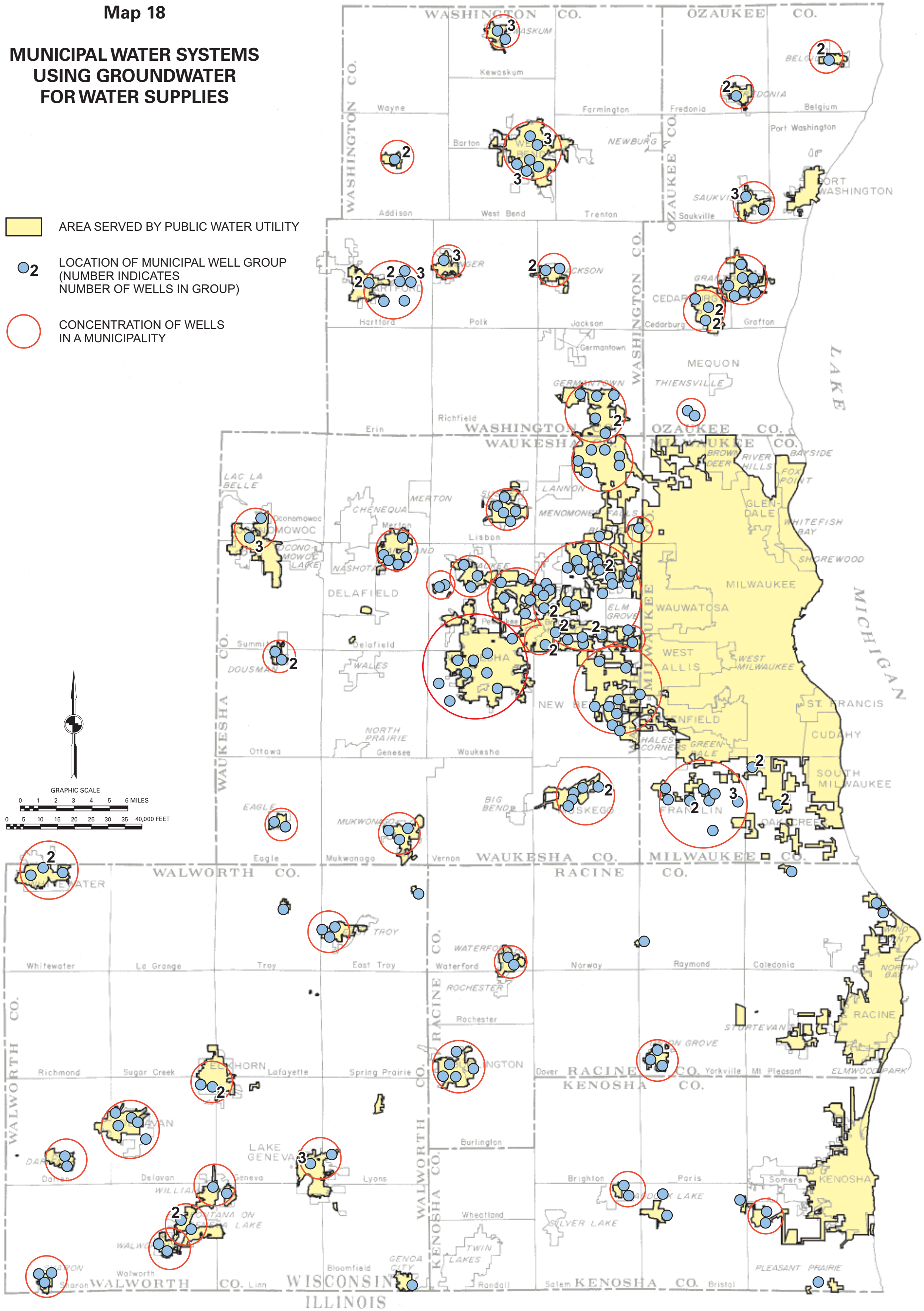
Source: Lawrence and Ellefson, 1982; Ellefson and others, 1987, 1993, 1997.

subdivisions, which rely on wells for water supply. Substantial increases in groundwater use were also recorded in Ozaukee (20 percent), Washington (32 percent),and Waukesha (25 percent) counties. Groundwater use in Milwaukee County increased slightly (3.5 percent). Groundwater use in Kenosha County did not change from 1985 to 1995.

In 1995, approximately 85 percent of the resident population of the Region, 1.8 million people, were served by public water systems, with about 75 percent of these people provided water from Lake Michigan. Although groundwater is not the primary source of water supply in the Region, it is an important source of water supply for most communities (see Map 18). According to the Wisconsin Department of Natural Resources (DNR), there were 78 municipal community water systems and 244 privately owned community water-supply systems serving the Region's population in 1995 (R. Baumeister, DNR, personal communication, 1997). Community water-supply

Map 18

MUNICIPAL WATER SYSTEMS USING GROUNDWATER FOR WATER SUPPLIES



Source: Wisconsin Geological and Natural History Survey and SEWRPC.

systems are defined as those systems that have at least 15 service connections used by year-round residents or those that regularly serve at least 25 year-round residents. Privately owned systems typically include residential subdivisions, apartments, condominiums, mobile home parks, and institutions.

In 1995, the majority of municipal water systems (68 percent) were supplied by groundwater, especially those west of the subcontinental divide; and all of the 244 privately owned community systems relied on groundwater as a source. Groundwater was also a primary source of water for agriculture, and the sole source of domestic water supplies in nonserviced areas, self-supplied commercial water supplies, and public water supplies in the inland counties of Walworth, Washington, and Waukesha (see Table 19). In 1995, Walworth and Washington Counties were almost entirely supplied by groundwater while in Ozaukee and Waukesha Counties groundwater constituted more than 80 percent of the total supply (see Figure 11). Locations of high-capacity wells used for municipal, industrial, irrigation, and community water supplies are included in Appendix B.

Groundwater Availability

Recharge to groundwater is derived almost entirely from precipitation. Much of the groundwater in shallow aquifers originates from precipitation that has fallen and infiltrated within a radius of about 20 or more miles from where it is found. The deeper sandstone aquifers are recharged by downward leakage of water through the Maquoketa Formation from the overlying aquifers or by infiltration of precipitation beyond the western edge of the Region where the sandstone aquifer is not overlain by the Maquoketa Formation and is unconfined.

On the average, precipitation annually brings about 32 inches of water to the surface area of the Region. For the area of the counties that primarily use groundwater as a source of supply (Ozaukee, Washington, Waukesha, and Walworth) that would translate into about 2,800 mgd of water. It is estimated that approximately 80 percent of that total is lost by evapotranspiration (Cotter and others, 1969). Of the remaining water, part runs off in streams and part becomes groundwater. It is likely that the average annual groundwater recharge to shallow aquifers varies from less than 3 percent of annual precipitation in parts of lakeshore counties, where there are poorly permeable soils and glacial deposits, to perhaps 10 to 15 percent of annual precipitation in parts of inland counties, where near-surface geologic conditions are more favorable for recharge.

To document the utilization of the shallow aquifers in the Region, it may be assumed, for example, that, on the average, 10 percent of the annual precipitation reaches groundwater. Then, the average groundwater recharge in the four above-mentioned counties was about 280 mgd. Their estimated daily use of groundwater in 1995 was 69.5 mgd, which is about 25 percent of the total amount of groundwater assumed to be recharged in that year. This indicates that there is an adequate annual groundwater recharge to satisfy water demands on the shallow aquifer system in these counties for years to come on an areawide basis. However, the availability on a localized area basis will vary depending upon usage, pumping system configuration, and groundwater flow patterns.

The situation is different for the deep aquifers where withdrawals of groundwater cause supply/demand imbalance in areas of concentrated use of groundwater, which has resulted in the declining potentiometric surface and mining of groundwater. For example, Professor Douglas Cherkauer of the University of Wisconsin–Milwaukee (Cherkauer, personal communication, 1999), estimated that the demand on groundwater from the deep sandstone aquifer in Waukesha County is greater than the available supply (see Table 21).

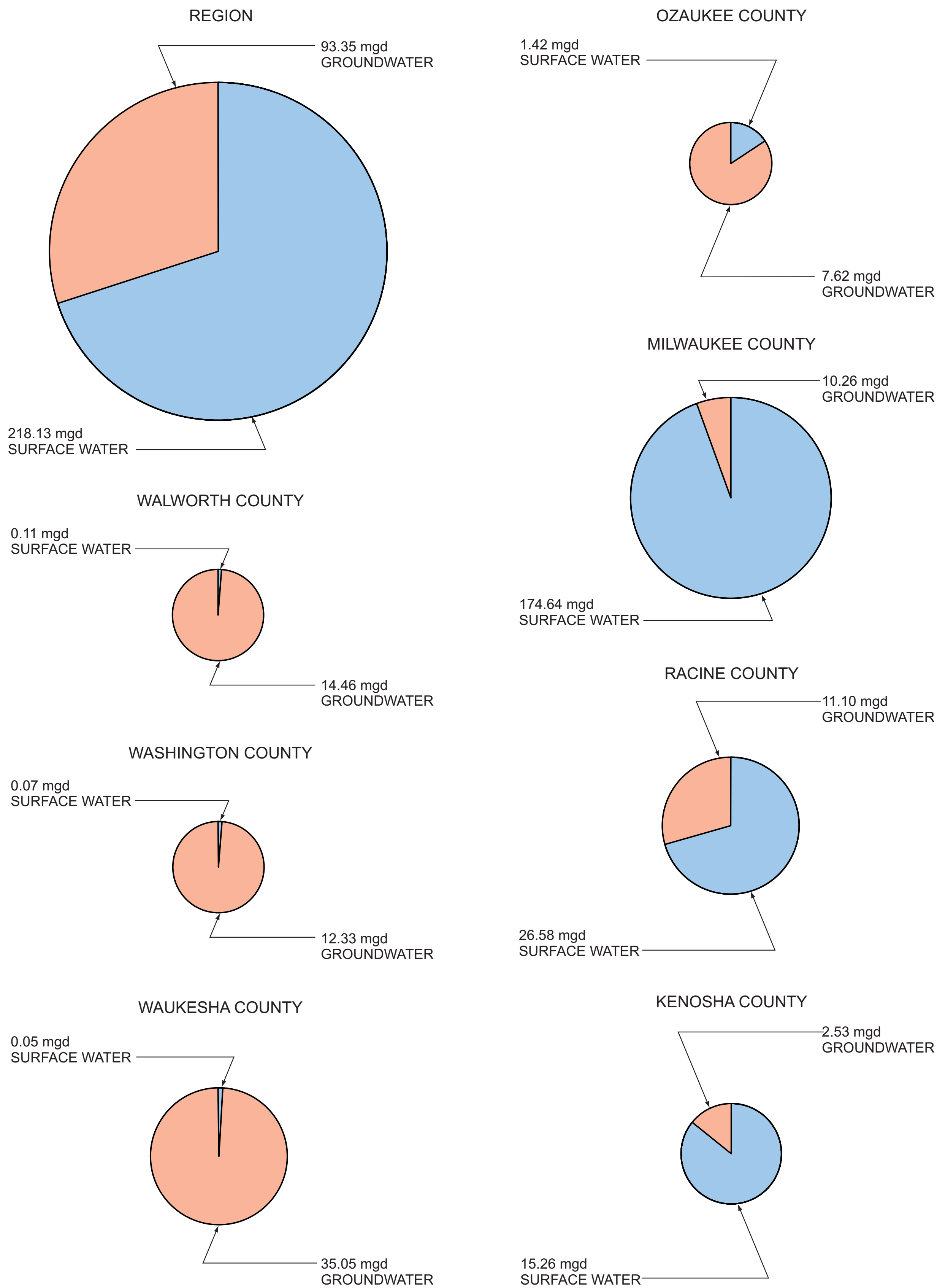
To satisfy future water demands in the Region, coordinated regional water resource management is needed, which would optimize the conjunctive use of all ground and surface water. Without such integrated management, water shortages would be inevitable in areas of concentrated withdrawals of groundwater from deep aquifers and likely from some limited portion of the shallow aquifers.

MAJOR AQUIFERS AND HYDROGEOLOGIC UNITS

Individual rock units within the Region differ widely in their ability to yield water to wells (see Table 22). From the standpoint of groundwater occurrence, all rocks that underlie the Region can be classified either as aquifers or as confining beds. An aquifer is a rock unit that will yield water in a useable quantity to a well or spring. A

Figure 11

USE OF SURFACE WATER AND GROUNDWATER WITHIN SOUTHEASTERN WISCONSIN BY COUNTY: 1995



NOTE: WATER USES IN THE FIGURE INCLUDE PUBLIC WATER SUPPLY, INDUSTRIAL, COMMERCIAL, IRRIGATION AND OTHER AGRICULTURAL, AND INDIVIDUAL PRIVATE WATER USES.

Source: U.S. Geological Survey.

Table 21

ESTIMATES OF AVAILABLE GROUNDWATER IN WAUKESHA COUNTY

Aquifer	Recharge Area (square miles)	Estimated Recharge Rate (inches per year)	Average Daily Recharge (mgd)	Average Daily Demand (mgd)
Shallow	400	3.1	59	3.5
Deep	100	3.1	14.8	31.5

Source: D.S. Cherkauer, 1999.

Table 22

HYDROGEOLOGIC UNITS OF SOUTHEASTERN WISCONSIN

Geologic Age	Rock Unit		Hydrogeologic Unit	Water Yield
Quaternary	Undifferentiated		Sand and gravel aquifer	Small to large yields; thick sections yield several hundred gallons per minute
Devonian	Antrim Fm. [1]		Semi-confining unit	Yields little water
	Milwaukee Fm. [1]			
	Thiensville Fm.[1]		Silurian dolomite aquifer	Small to large yields (10s – 100s gpm) depending upon lithology and number and size of solution channels and fractures. Main water-producing units: Thiensville, basal member of Racine, and Mayville (Rovey and Cherkauer, 1994a)
Silurian	Waubekee Fm.[1]			
	Racine Fm.[2]			
	Waukesha Fm.[2]			
	Brandon Bridge beds [2]			
	Byron Fm.[2]			
	Mayville Fm.[2]			
Ordovician	Maquoketa Fm. [2]		Confining unit	Yields little or no water
	Sinnipee Group	Galena Fm.	Galena-Platteville aquifer	Yields little water where overlain by Maquoketa Formation. Commonly yields a few tens of gpm west of Maquoketa
		(Decorah Fm.) [3]		
		Platteville Fm.		
	Ancell Group	(Glenwood Fm.) [3]	Upper sandstone aquifer	Moderate to large yields (100-500 gpm)
		St. Peter Fm.		
	Prairie du Chien Group	Shakopee Fm. [2]		Small yields (10s of gpm)
		Oneota Fm. [2]		
Cambrian	Trempealeau Group	Jordan Fm. [2]		Moderate yields (100s gpm)
		St. Lawrence Fm. [2]	Semi-confining unit	Yields little water
	Tunnel City Group			Yields little water
	Elk Mound Group	Wonewoc Fm. [2]	Lower sandstone aquifer	Moderate to large yields (100s – 1,000s of gpm)
		Eau Claire Fm.		
		Mt. Simon Fm.		
Precambrian	Undifferentiated		Confining bed	Yields little or no water

NOTE: Fm. = Formation; gpm = gallons per minute; for description, see Chapter V; [1] only in eastern Milwaukee and Ozaukee Counties; [2] not always present in the entire Region; [3] thin or locally absent. Aquifer units are shaded.

Source: A. Zaporozec, 1997.

confining bed, such as shale or siltstone, is a rock 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 great depths, reaching a thickness in excess of 1,500 feet in the eastern parts of the Region. For purposes of this report, rock units within the Region have been grouped into five aquifers, two confining beds, and two semi-confining beds (see Figure 12). The aquifers are, in descending order, the Quaternary sand and gravel, Silurian dolomite, Galena-Platteville, upper sandstone, and lower sandstone (see Table 22). The confining beds are the Maquoketa Formation and the Precambrian crystalline rock. The shaly Antrim Formation and siltstone and shaly dolomite of the Milwaukee Formation constitute the uppermost semi-confining bed; and silty dolomite and fine-grained dolomitic sandstone of the St. Lawrence Formation/Tunnel City Group, the lower semi-confining bed in 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 bedrock aquifers. Water-table conditions generally prevail in the Quaternary deposits and Silurian dolomite aquifer above the Maquoketa Formation and in the Galena-Platteville aquifer west of the Maquoketa Formation (see Map 19). These shallow aquifers provide water for most private domestic wells and some municipal wells. In 1996, approximately 200 registered wells were in use for water supply by water utilities in the Region. Of these, 61 percent were supplied by groundwater from the shallow aquifers.

In the deep sandstone aquifer beneath the Maquoketa Formation, the water can be under artesian pressure. Deep high-capacity wells in the eastern 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, except in the northern parts of Washington and Ozaukee Counties and the western part of Waukesha and Walworth Counties. 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, common within the Region in the late 1880s, ceased flowing at the beginning of the 1900s, and the potentiometric 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 four feet per year in the Milwaukee-Racine-Kenosha area and five feet per year around the City of Waukesha since the beginning of record in the late 1940s.

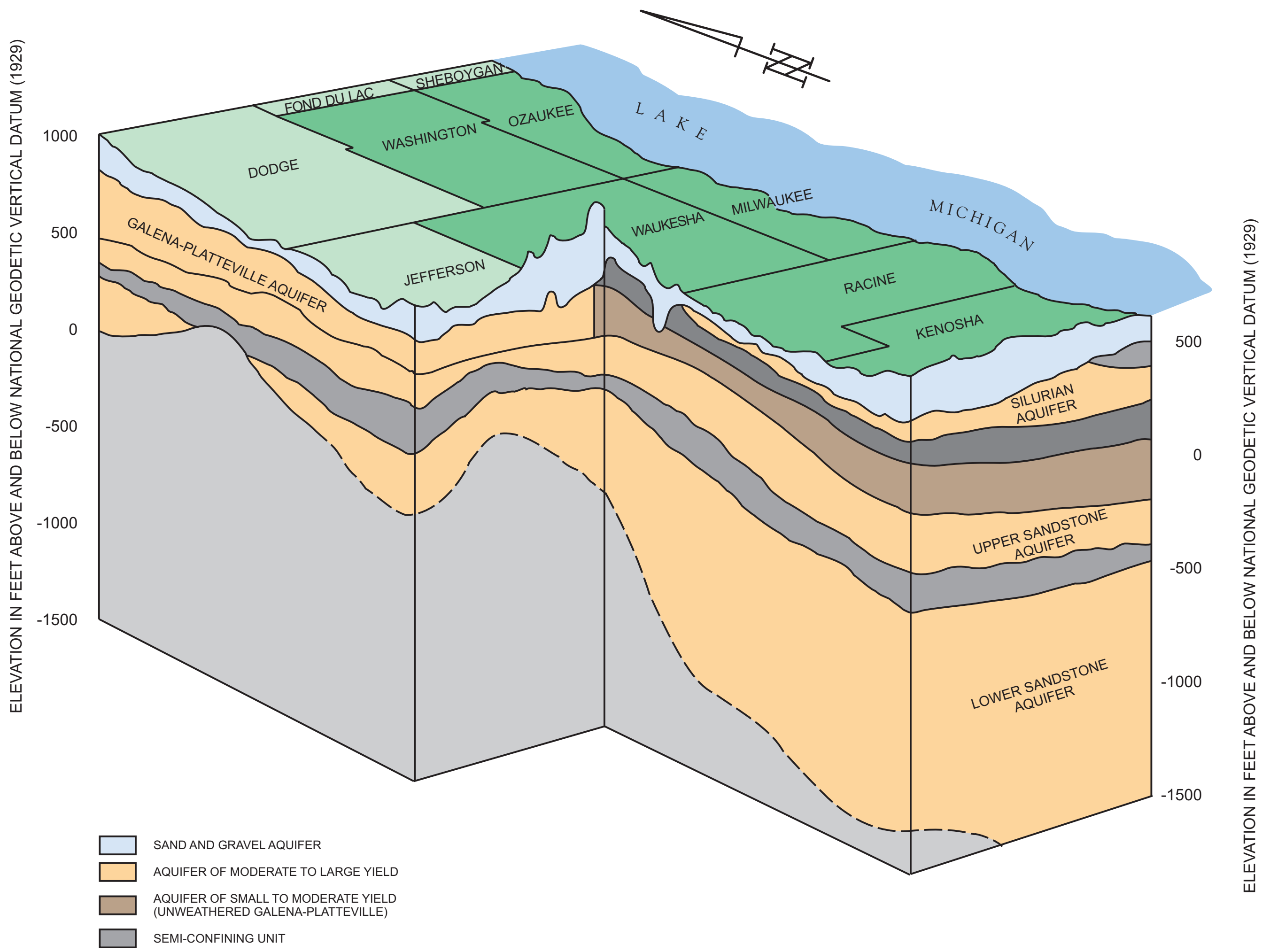
For purposes of this study, the aquifers in Southeastern Wisconsin are divided into shallow and deep. Shallow aquifers are the primary focus of this study. The shallow aquifer system comprises two or three aquifers, depending on its location relative to the Maquoketa shale bedrock subcrop (see Map 19). Where the Maquoketa formation is present, the shallow aquifer system consists of the Silurian dolomite aquifer and the overlying sand and gravel aquifer. There, 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, Galena-Platteville aquifer, and upper sandstone aquifer, and its lower boundary is the St. Lawrence semi-confining unit (see Figure 12). The U.S. Geological Survey subdivision of the sandstone aquifer into the upper and lower sandstone aquifer (Kammerer, 1995) is used in this definition of the shallow aquifer system in the Region.

The following are descriptions of the areal extent and lithology of aquifers and confining units mentioned earlier in this report, from top to bottom.

Sand and Gravel Aquifer
Groundwater availability from the Quaternary deposits is directly proportional to the amount of permeable, well-sorted sand and gravel within the glacial drift. The sand and gravel aquifer can be found primarily in the western part of the Region (see Map 19), the eastern part is mostly underlain by fine-grained till with a few sand and gravel deposits (see Chapter IV).

Figure 12

AQUIFER SYSTEMS IN SOUTHEASTERN WISCONSIN



Source: Eaton, 1997, Mai and Dott, 1985; Peters, 1997; Young, 1992.

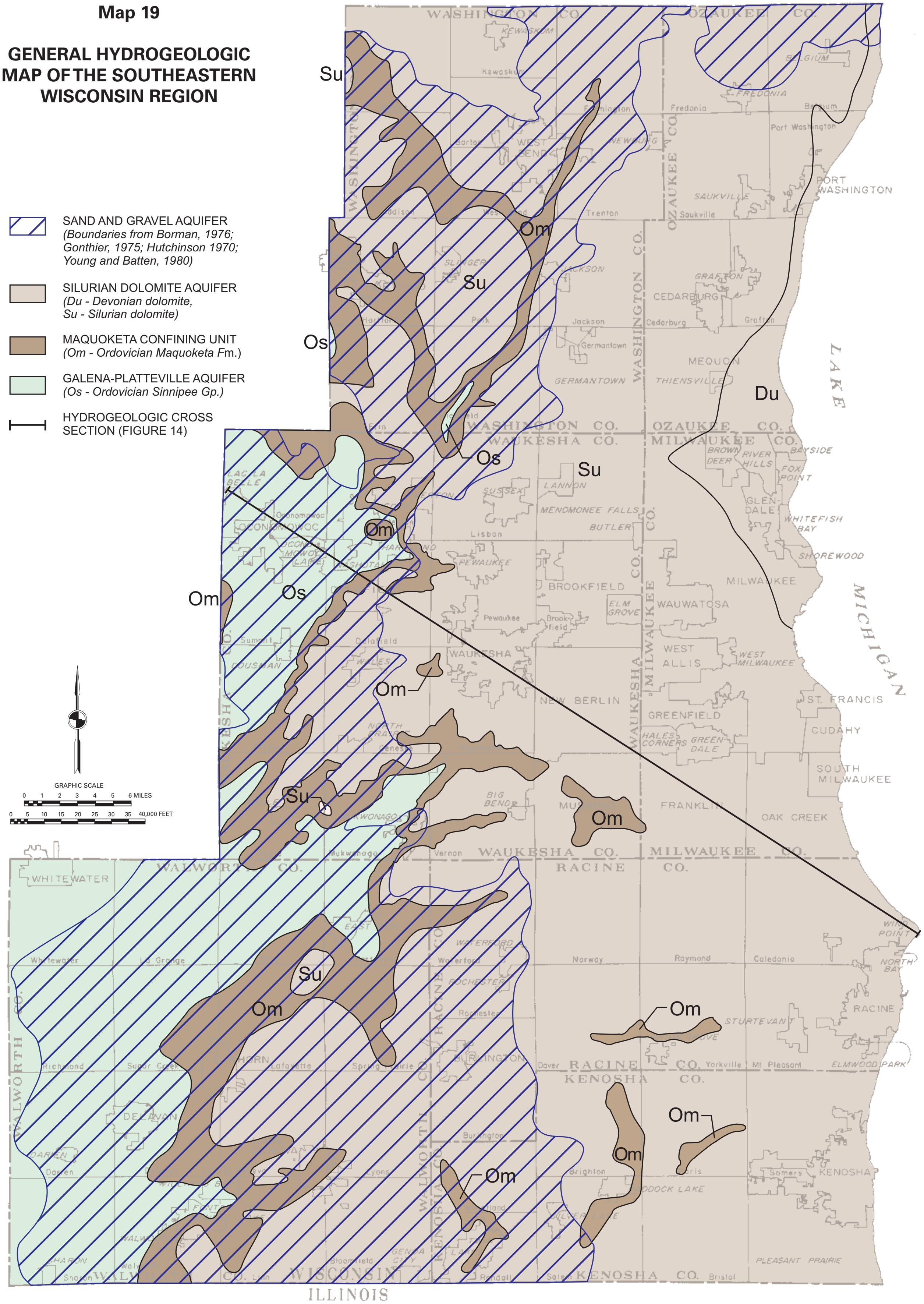
The sand and gravel aquifer consists primarily of layers or lenses within alluvial and glacial deposits and is extremely variable in thickness. It is not as continuous as the bedrock aquifers. The sand and gravel aquifer occurs as broad outwash deposits, isolated lenses within less permeable deposits, stream terraces, valley fill directly overlying bedrock, and other materials deposited by water or glacier (Kammerer, 1995). Important features are highly productive layers of sand and gravel in segments of buried bedrock valleys in Washington, Waukesha, and Walworth Counties, which can yield large amounts of water to wells.

The extent to which the sand and gravel aquifer is used for water supply depends upon the quality and availability of groundwater from underlying or adjacent aquifers. The aquifer is mostly unconfined and its yields vary widely. The sand and gravel aquifer is extensively used in Washington, Waukesha, and Walworth Counties (see Map 19) where properly constructed wells finished in this aquifer can produce from 100 to more than 1,000 gallons per minute (gpm).

The sand and gravel aquifer is connected hydrologically with the Silurian dolomite aquifer. Water moves freely between the aquifers, which generally are considered to be a single hydrologic unit referred to as the shallow aquifer.

Map 19

GENERAL HYDROGEOLOGIC MAP OF THE SOUTHEASTERN WISCONSIN REGION



Source: A. Zaporozec, 1996.

Devonian Semi-Confining Unit

The small, narrow area of Devonian dolomite and shale along Lake Michigan, extending from northern Ozaukee County to the middle of Milwaukee County (see Map 19), is considered to be part of the Silurian dolomite aquifer. However, the Devonian dolomite is not uniform, and a number of recent studies (Nader, 1990; Rovey, 1983; Rovey and Cherkauer, 1994a) indicated that its three units (Antrim, Milwaukee, and Thiensville Formations) can be differentiated hydraulically. Recent data from the deep tunnel construction project in Milwaukee County show that the upper part of the Devonian (Antrim and Milwaukee formations) may act as a semi-confining unit. The Thiensville Formation is the uppermost unit of the Silurian dolomite aquifer.

Rovey (1983, 1990) differentiated the Silurian and Devonian Formations hydraulically. He found that the basal, coarse-grained units in both the Silurian and Devonian dolomite (Mayville and Thiensville Formations, respectively) are more permeable than other units. An abrupt increase in permeability was especially apparent at the boundary between the top of Silurian dolomite and the Devonian Thiensville Formation. Nader (1990) used sensitivity analyses for his modeling of the groundwater Lake Michigan hydraulic connection to show that the Devonian Thiensville Formation, where present, contributes approximately 85 percent of the total amount of water discharged from the Silurian dolomite aquifer to Lake Michigan, although it makes up less than 15 percent of the aquifer's total thickness.

Silurian Dolomite Aquifer

The Silurian dolomite aquifer is present only in eastern Wisconsin. It was formerly referred to as the Niagara dolomite aquifer, named after the main Silurian formation in Wisconsin. The Silurian dolomite is the uppermost bedrock aquifer in most of the Region and the primary source of most domestic water supplies and many high-capacity wells in the area underlain by the Maquoketa Formation. Wells tapping this aquifer generally yield from 10 to 100 gpm and are commonly between 100 and 400 feet deep. Water in the aquifer, although confined locally where overlain by clayey till, is generally under water table conditions. The aquifer is often hydraulically connected to the sand and gravel aquifer.

Character of the Silurian dolomite aquifer is far from uniform. It comprises 11 stratigraphic units with distinctly different lithology. Most of the stratigraphic units are fine-grained mudstones but porous coarse-grained packstones are also present (Rovey and Cherkauer, 1994a). Therefore, the dolomite has dual permeability. The relatively thin, coarse-grained units retained the original, intergranular permeability. They are separated by more extensive, lower-conductivity units (Rovey, 1990; Schulze-Makuch, 1996), where secondary permeability (dependent on fracturing) prevails. This secondary permeability is best developed in the upper part of the aquifer (Young and Batten, 1980).

Recent studies by Rovey and Cherkauer (1994a, b) dispute the traditional view that groundwater flow in the Silurian dolomite aquifer in Southeastern Wisconsin is almost entirely dependent on fracturing and the accompanied enlargement of fractures by dissolution (for example, Gonthier, 1975; Sherill, 1979). Rovey and Cherkauer (1994b) argue that the Silurian dolomite aquifer can behave as a porous medium even though most of its section is fracture-dominated, and suggest that "wherever the porous stratigraphic units are present in this aquifer, they generally control the local-scale bulk hydraulic conductivity."

The possibility that fractures are not the sole source of the variability of well yields from the Silurian aquifer, although they may contribute to it, was raised in some of the previous studies. For example, Young and Batten (1980) suggested that, in addition to greater hydraulic conductivity caused by interconnecting fractures, joints, and solution openings, the wide variation in well yields is a result of the "particular stratigraphic section of the aquifer exposed in each well and the lithologic variations in the dolomite, both vertically and horizontally." Rovey and Cherkauer (1994a) analyzed more than 300 injection-pressure tests done for the deep tunnel project in Milwaukee County and correlated the test results with local stratigraphy. They concluded that hydraulic conductivity varied by approximately 1,000 times among stratigraphic units and that the higher values consistently occurred in three thin, but regionally continuous, coarse-grained units: the Thiensville Formation, Romeo—the basal member of the Racine Formation, and Mayville Formation. These three units carry between 68 and 90 percent of the groundwater discharge to Lake Michigan (Cherkauer and Mikulic, 1992; Mueller, 1992), even though they comprise only about 30 percent of the total thickness of the Silurian aquifer. In the western part of the aquifer, where the Thiensville Formation has been eroded, the relative importance of the joints and solution openings increases (Cherkauer, personal communication, 1999).

Maquoketa Confining Unit
This unit underlies the Silurian dolomite aquifer and is exposed at the bedrock surface only in the western part of the Region (see Map 19). Rock in this unit, which is primarily shale with some dolomite, forms a continuous, low-permeability layer that restricts vertical groundwater flow between the Silurian dolomite aquifer and the underlying sandstone aquifer. Weathered zones near the top of the Maquoketa Formation may yield small amounts of water, but few wells are open exclusively to it (Kammerer, 1995).

Galena-Platteville Aquifer
The Galena-Platteville aquifer consists mainly of the middle Ordovician dolomite with some thin shale beds and chert (Kammerer, 1995). Generally, the aquifer is only moderately permeable and is considered a minor aquifer (Young, 1992a). Because of the easterly dip in the bedrock units (see Figure 12), the Galena-Platteville aquifer is the uppermost bedrock aquifer in the western part of the Region where the Maquoketa Formation confining unit is absent (see Map 19). It is an important source of domestic water supplies in this area and can yield up to 100 gpm to wells. In this area, the aquifer is commonly unconfined, its permeability is due to fracturing and weathering (Young, 1976), and groundwater is generally considered to be in hydrologic connection with the immediately overlying sand and gravel aquifer. Beneath the Maquoketa shale (see Figure 12), however, the dolomite is probably unweathered, and therefore less permeable, and yields little water to wells. Young (1992b) considered the Galena-Platteville to be part of the Maquoketa confining unit where overlain by Maquoketa shale.

Upper Sandstone Aquifer
The upper sandstone aquifer includes sandstone and dolomite of the Ancell and Prairie du Chien Groups of Ordovician age and of the upper Cambrian Jordan Formation (see Table 22). The Prairie du Chien Group is present only in parts of Racine, Kenosha, and Walworth Counties and the Jordan sandstone is eroded by the pre-St. Peter sandstone unconformity in much of the Region. Therefore, these two units are not a major source of groundwater in the Region. The St. Peter sandstone of the Ancell Group is present throughout the Region and contributes moderate yields (100-400 gpm) to wells. The aquifer is confined beneath the Maquoketa Formation. Locally, in southwestern Washington County, the St. Peter Formation lies directly on the Precambrian surface and constitutes the entire sandstone aquifer thickness, even though it could be as thin as 200 feet in places.

St. Lawrence Semi-Confining Unit
There is little specific information on the hydraulic characteristics or geometry of the silty dolomites and dolomitic sandstone of the St. Lawrence Formation and the Tunnel City Group, which constitute this unit. However, J.T. Krohelski of the U.S. Geological Survey identified them in his study of Brown County as a confining unit because data for that area indicated that their permeability is probably an order of magnitude lower than the overlying and underlying sandstones (Krohelski, 1986). They have also been identified as a confining unit in Minnesota and Iowa (Young, 1992b). Where present, they are treated as a single unit that locally restricts groundwater flow between the upper and lower sandstone aquifers. The unit is not continuous throughout the Region because it is thin or absent because of pre-St. Peter erosion (Young, 1992b).

Lower Sandstone Aquifer
The lower sandstone aquifer is composed of the thick sedimentary sequence of Cambrian sandstone. In Brown County, Krohelski (1986) called it the Elk Mound aquifer after the Cambrian Elk Mound Group. The aquifer is wedge-shaped and its thickness and water yields generally increase to the southeast (see Figure 12), primarily because of the increasing thickness of its most extensive, basal unit, the Mount Simon Formation (see Table 22). These Cambrian sandstones are absent only on local highs of the Precambrian basement. There are only a few wells in Southeastern Wisconsin that fully penetrate this aquifer. However, the lower sandstone aquifer is an important source of water for municipalities and industries because even wells only penetrating upper portions of the aquifer generally yield more than 1,000 gpm. The aquifer is generally confined, and its permeability is dependent on the size and interconnection of pores between grains.

Precambrian Basement
Precambrian crystalline rock, mostly granite, underlies the Cambrian sedimentary sequence. Its characteristics are poorly known because only a very few wells reach the Precambrian surface in Southeastern Wisconsin (see Chapter V). The Precambrian basement is not a source of water supply in the Region. It is assumed to have a very low permeability and forms the lower boundary of the important lower sandstone aquifer.

GROUNDWATER RECHARGE, MOVEMENT, AND DISCHARGE

The flow of groundwater in the subsurface is a complex three-dimensional process determined largely by land-surface topography near the water table and lithology in the deeper portions of the flow system. Water enters groundwater flow systems in recharge areas and moves through them toward discharge areas. In recharge areas, the flow of groundwater is downward; in discharge areas, the flow is upward. Between these two areas, groundwater flow is essentially horizontal. An idealized concept of groundwater flow in profile (see Figure 13) shows groundwater moving from recharge areas to discharge areas. One of the most significant differences between recharge areas and discharge areas is that the areal extent of discharge areas is generally much smaller than that of recharge areas. Regional recharge occurs primarily in upland areas or topographic high points, but local recharge can occur anywhere. Discharge from aquifers occurs at low points in the land surface such as rivers and lakes, or to wells. Recharge areas, from which flow paths originate and diverge, are the locations of groundwater divides, across which there is no horizontal flow.

The pattern of groundwater flow from a recharge to a discharge area constitutes a dynamic flow system, which incorporates several superimposed elements (see Figure 13). Depending on the drainage basin topography and the thickness of the aquifer system, groundwater flow systems may have local, intermediate, and regional components. If the surface topography has well-defined local relief, such as in many parts of the Region, a series of local shallow groundwater flow systems can form. If the aquifer systems are large and deep enough, deeper, intermediate, and regional flow systems may develop. There may be a series of local and intermediate flow systems between the regional recharge and discharge areas (see Figure 13). This idealized description of flow systems assumes steady-state flow, without extensive pumping of groundwater from deep wells. Nevertheless, it provides a starting point for analysis of regional groundwater flow in the Region.

The time it takes groundwater to move from a recharge area to a discharge area may range from a few days in the zone closest to the discharge area to thousands of years (millennia) for water that moves from the central part of a major recharge area through the deeper parts of the groundwater flow system (Heath, 1983). Flow paths that penetrate into the deepest portions of the aquifer system generally have the longest travel time from recharge to discharge areas (see Figure 13).

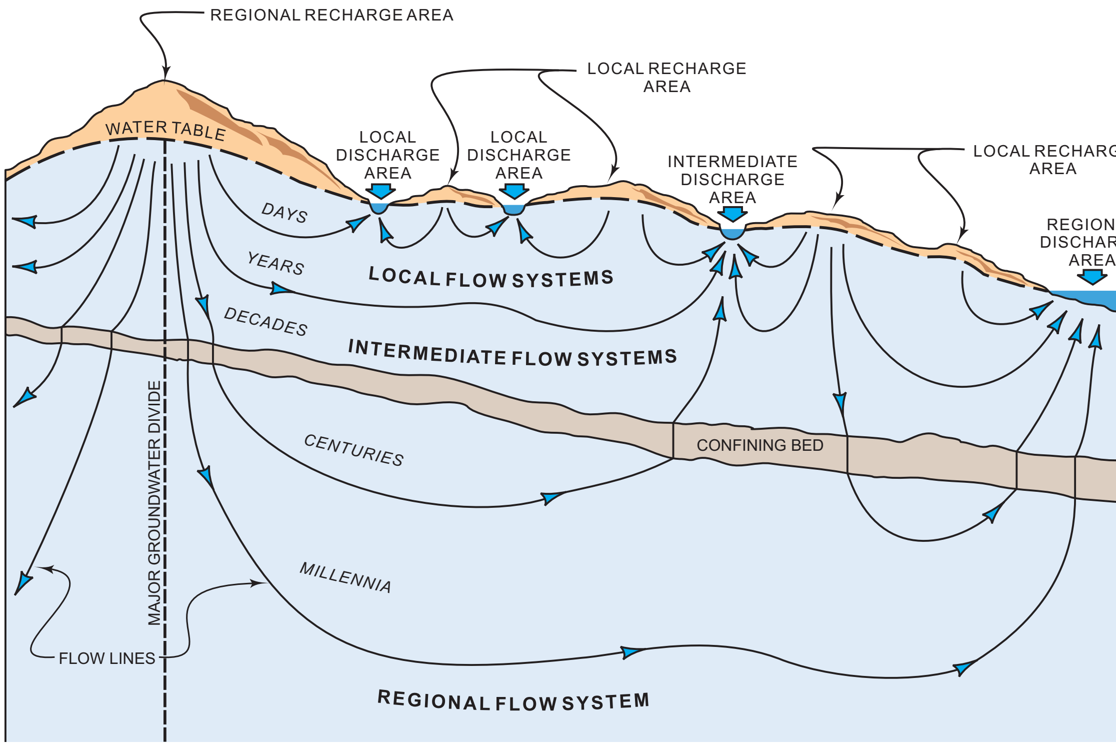
Much of the movement and discharge of groundwater in the Region occurs in local, unconfined, shallow flow systems within a few miles of points of recharge (Young, 1992a). Depth of the local systems probably does not exceed 200 feet. Groundwater in semi-confined or confined aquifers moves in intermediate or regional flow systems within the bedrock, where the flow is deeper and slower, and crosses much longer distances from recharge areas to discharge points (Lake Michigan or deep wells in the eastern part of the Region).

Shallow Groundwater Flow

Water Table
Water levels in wells open to a shallow aquifer represent the water table, which is the upper, free surface of the shallow, unconfined aquifer. The water table generally is a subdued replica of the land surface and is higher beneath topographic highs and lower, but nearer land surface, under topographic lows. It is generally in hydrologic connection with major surface-water features such as lakes and rivers. Where bedrock is close to the land surface (such as in southeastern Washington County and northeastern and central Waukesha County—see Map 13 in Chapter IV), the water table is found within the Silurian dolomite; otherwise, it is found in the unlithified Pleistocene materials overlying bedrock. Although depth to the water table commonly is less than 50 feet in most of the Region (see Map 20), depths may be 100 to 200 feet beneath the highest ridges. The flow patterns of shallow groundwater, or groundwater just below the water table, are shown on the map of regional water-table elevations (see Map 21). These maps were prepared at a scale of one inch equals 4,000 feet scale in digital form.

Figure 13

IDEALIZED GROUNDWATER FLOW SYSTEMS UNDER STEADY-STATE CONDITIONS



Source: A. Zaporozec, 1996.

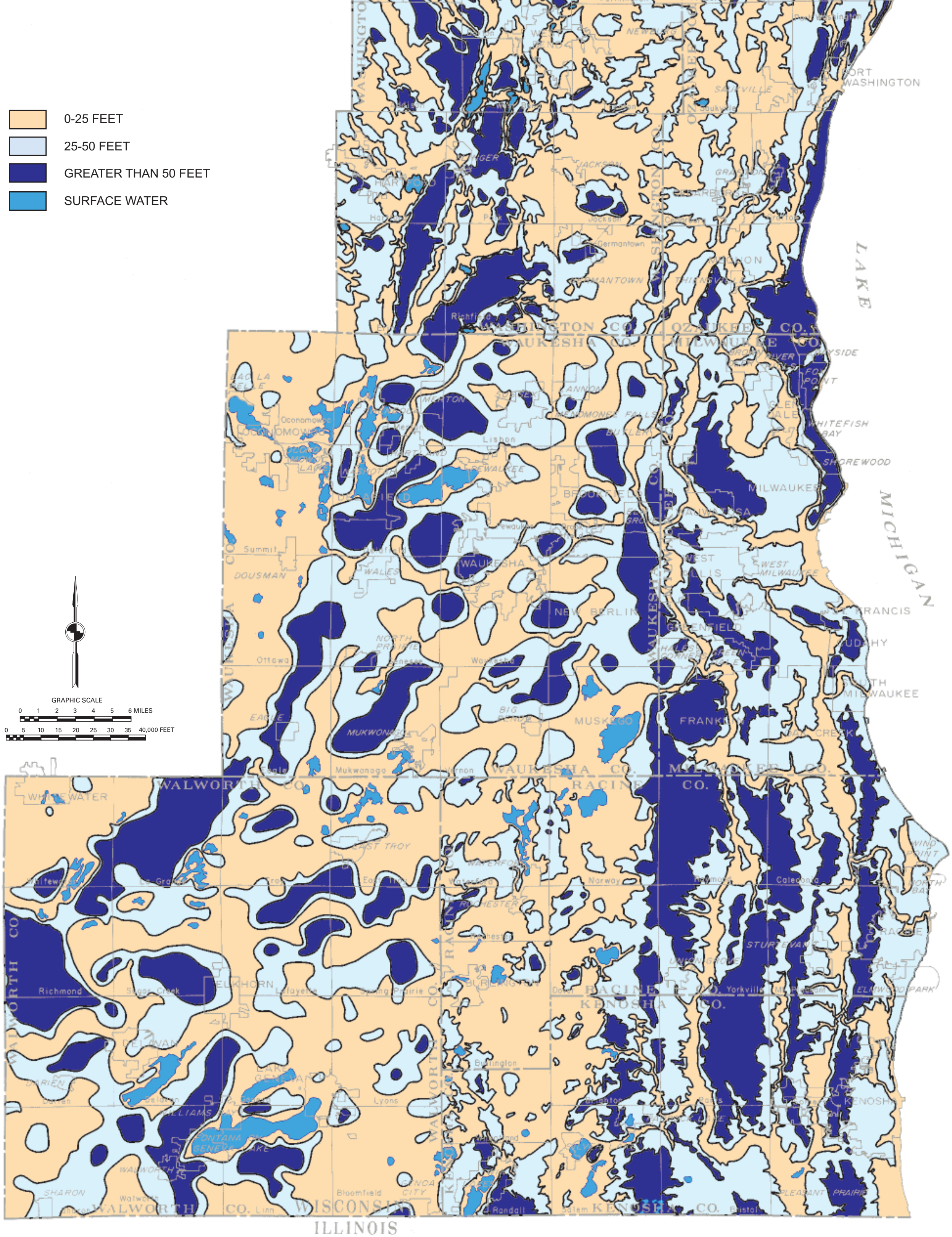
The water table map is based on elevations measured above mean sea level (msl) of static water levels in wells open to shallow aquifers; elevations of streams, lakes, and wetlands; and topography. Well constructor's reports for domestic wells, as filed with the Wisconsin Department of Natural Resources (DNR), were examined and checked against each other, together with data from all the Wisconsin Geological and Natural History Survey (WGNHS) geological logs, and the most representative and reliable water levels were used for construction of the water table contours. Data from these reports were supplemented by elevations of perennial rivers, lakes, wetlands, and groundwater seepage areas that intersect the water table. These features are independent data points and provide good control for well water level measurements that are taken at different times of year and in different years. The water table naturally fluctuates over time, due to changes in storage and available recharge during wet or dry periods.

It was beyond the scope of this study to field-check the locations and water level measurements reported on DNR well constructor's reports that were used to construct the water table map. The map does not reflect local details in the water table because the contour lines were generalized and interpolated from the nearest data points, and natural fluctuations in the water table can be as much as 15 feet. For this reason, the map should not be considered definitive for site-specific groundwater investigations.

The water table is not necessarily the top of the uppermost saturated zone because in many areas there can be "perched" conditions or seasonally saturated soil due to the lithology of the unlithified Pleistocene materials. In dense, clayey, or silty sediment, infiltrating water can be held in pore spaces constituting a local saturated zone, even though there may be dry sediment separating this perched water from the true, more widespread water table below. These conditions probably are most often in the clayey till with strong downward gradients to the bedrock. This is a common situation in the eastern part of the Region, which is underlain by near-surface clayey silt tills dating from the late Wisconsin glaciation. This area also contains lakes and streams that have at least a partial seal

Map 20

DEPTH TO WATER TABLE IN THE SOUTHEASTERN WISCONSIN REGION



Source: Wisconsin Geological and Natural History Survey and SEWRPC.

Map 21

GENERALIZED WATER TABLE ELEVATION IN THE SOUTHEASTERN WISCONSIN REGION

AVERAGE WATER-TABLE ELEVATION IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM 1929 (CONTOUR INTERVAL 20 FEET)

SUPPLEMENTAL CONTOUR (INTERVAL 10 FEET)

WELL DATA POINT (DATA HAVE NOT BEEN FIELD CHECKED)

SURFACE WATER POINT

GENERAL DIRECTION OF SHALLOW GROUNDWATER FLOW

GROUNDWATER DIVIDE

PRIMARY DIVIDE

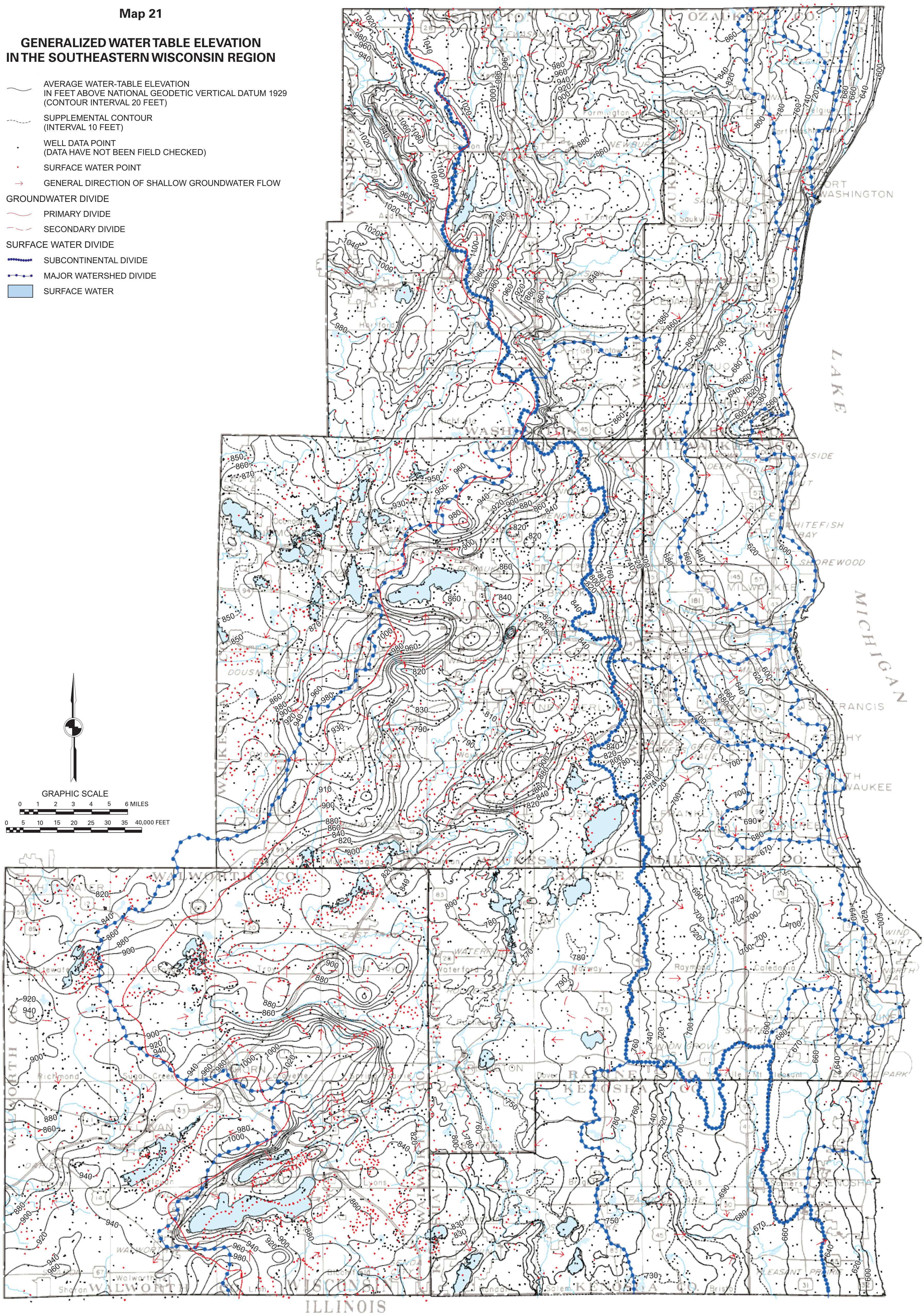
SECONDARY DIVIDE

SURFACE WATER DIVIDE

SUBCONTINENTAL DIVIDE

MAJOR WATERSHED DIVIDE

SURFACE WATER



Source: Wisconsin Geological and Natural History Survey and SEWRPC.

between their bottom sediment and the underlying aquifer. Some smaller streams, ponds, and lakes in this area also do not intersect the water table and are found many tens of feet above the true water table. However, in other places, such as the Cedarburg Bog in western Ozaukee County, there can be a local mounding in the water table, which is in hydrologic connection with surface water in the Bog (Ladwig, 1981).

Water Table Elevations and Groundwater Divides

Water table elevations range from a maximum of more than 1,100 feet above mean sea level in the Kettle Moraine in western Washington County to less than 590 feet above mean sea level along the shore of Lake Michigan. The water table is below 560 feet elevation above mean sea level around Mequon, where it has been lowered by pumping from the concentration of many subdivision wells finished in the Silurian dolomite aquifer.

The highest elevations in the water table form a ridge, which winds from northwestern Washington County through central and southwestern Waukesha County and central Walworth County. This narrow ridge represents the major water table divide, from which shallow groundwater flows east to Lake Michigan or the Fox River basin, and west to the Rock River basin. In Washington County, it coincides roughly with the subcontinental surface-water divide, from which surface water flows east to the St. Lawrence river basin and west to the upper Mississippi River basin (see Map 21).

In the remaining counties in the Region, the major groundwater divide is about 10 to 20 miles west of the subcontinental surface water divide. In Waukesha County, the major groundwater divide follows the trend of the Kettle Moraine topographic high, which corresponds to a secondary surface-water divide between the Fox River and the Rock River. In Walworth County, the major groundwater divide also approximates this secondary watershed divide. Shallow groundwater east of the major groundwater divide in Waukesha and Walworth Counties and west of the subcontinental surface-water divide in Racine and Kenosha Counties, generally discharges to the Fox River, which in turn eventually empties into the Mississippi River.

In addition to the major water table divide, there are several secondary groundwater divides wherever there are high areas in the water table. For example, secondary groundwater divides are found in southeastern Waukesha County and in western Racine and Kenosha Counties to the east of the Fox River. In Kenosha County, this divide closely parallels the watershed divide between the Fox River and the Des Plaines River. Other secondary groundwater divides traverse western Waukesha County and northern Walworth County (see Map 21).

General Directions of Flow

Groundwater in the shallow aquifer system generally moves from beneath topographic high areas to nearby lakes and streams, and provides much of the water (base flow) in the streams. Shallow groundwater flow is downgradient (from higher elevations to lower elevations) and generally perpendicular to the water table contour (equipotential) lines. The flow arrows on Map 21 represent the general direction of groundwater movement in the Region. The major and secondary groundwater flow divides delineate basins—analogous to surface watersheds—in which groundwater flows to a common discharge area, such as a major lake or river. In the inland counties, where water table gradients are steep, local directions of groundwater flow are relatively clear. In the lakeshore counties, where the water table gradient is low, local flow directions are not as obvious, but regional flow is predominantly toward Lake Michigan.

In Washington County, the major water table divide trends north-south in the western half of the county and usually is within a few miles of the subcontinental surface-water divide. West of the major divide, shallow groundwater flows generally toward the west and toward the streams and rivers that drain this area to the northwest, west, and southwest. East of the divide, shallow groundwater flow is mainly east or toward the Milwaukee River, Cedar Lake, and Cedar Creek, and the Menomonee River.

In Ozaukee County, groundwater is generally flowing to the east or southeast towards the Milwaukee River and Lake Michigan. The predominant natural discharge of the Silurian dolomite aquifer in Ozaukee County is into Lake Michigan. However, in the Thiensville-Mequon area, heavy pumping from many subdivision and irrigation wells has reversed the natural hydraulic gradient so that lake water has been induced to flow into the aquifer along the three miles of shoreline north of Virmond Park (see Map 21). Cherkauer and Zvibleman (1981) studied this area in the late 1970s and documented that drawdown from pumping had lowered the water table more than 50 feet near the center of the heavy pumping located about 1.5 miles inland from Lake Michigan. The resultant cone of depression, shown on Map 21, has water levels below 540 feet elevation, consistently below the elevation of Lake Michigan surface (580 feet, on average).

Bues (1983) studied the expansion of the cone of depression through time, and showed that the cone of depression was already well developed in 1974 and that very little lateral expansion had occurred from 1974 to 1982. She concluded that the shape and expansion of the cone is controlled primarily by bedrock topography. Two ridges border the cone, one major one on the south side and one minor one on the north side. These ridges are apparent on Map 13 (Chapter IV). Subsequent incorporation of Rovey's stratigraphic model (Rovey, 1983; 1990) indicates that the shape of the cone may be also controlled by saturation of the Thiensville Formation, which is the primary aquifer in eastern Mequon. When pumping dewaters this aquifer, water levels drop rapidly within the underlying Racine Formation. The cone of depression is enhanced by dewatering of the Thiensville Formation and is elongated to the east-northeast due to fracture-induced anisotropy.

In Waukesha County, shallow groundwater west of the major groundwater divide discharges to large nearby lakes and their outlet the Oconomowoc River, or to the Bark and Scuppernong Rivers. East of the major water table divide, shallow groundwater discharges to Pewaukee Lake and the Fox River; east of the secondary groundwater divide, it discharges to Muskego Lake and flows into Milwaukee County. Locally, large, deep pits and quarries divert groundwater flow from its original direction. For example, a gravel pit just north of the City of Waukesha captures groundwater that would otherwise discharge into the Fox River (see Map 21). In Walworth County, shallow groundwater west of the major groundwater divide flows toward the City of Whitewater and to the Turtle Creek watershed. Shallow groundwater to the east of the major groundwater divide flows to either Lake Beulah and Sugar Creek or Lakes Como and Geneva.

In the remaining lakeshore counties of Milwaukee, Racine, and Kenosha, the prevalent direction of groundwater flow is to the east, toward Lake Michigan, which is the major regional discharge area. In Milwaukee County, some shallow groundwater locally discharges into Lincoln Creek, Menomonee River, and Root River (see Map 21). In Racine and Kenosha Counties, the direction of flow depends on the position of the secondary divide running north-south through the counties. West of the secondary groundwater divide, groundwater flows toward the Fox River and its tributaries Honey Creek, New Munster Creek, Peterson Creek, and Basset Creek, or in southern Kenosha County, toward Lakes Elizabeth, Marie, Silver, and Camp. East of the secondary divide, groundwater discharges into the Root River Canal in Racine County and the Des Plaines River in Kenosha County. In the easternmost tier of townships, the direction of groundwater flow is to the east, towards Lake Michigan (see Map 21).

Regional Groundwater Flow

The vast majority of wells only penetrate the shallow water table aquifer, which is dominated by local flow systems. Although many thousands of shallow wells have been located to enable a reliable analysis of the shallow flow systems, only 400 deep wells provide information on the deeper confined and semi-confined aquifers. In addition, it has long been the practice of well drillers in Southeastern Wisconsin to construct deep wells so that their open intervals extend over many hundreds of feet and several different bedrock formations below the Maquoketa confining unit. Water levels in these wells represent a composite of hydraulic heads from two high-yielding units—the upper and lower sandstone aquifers—and several lower-yielding units discussed earlier in this chapter. Furthermore, water levels in these wells have changed considerably in the eastern part of the Region from the time of well construction. However, recent water level measurements are difficult to obtain in many of these wells. Therefore, the analysis of deep regional flow systems is somewhat limited by these considerations.

Earlier in the 20th century, the potentiometric surface in the deep confined aquifers was much higher, causing artesian, even flowing, conditions in deep wells. Before development of water supplies from the deep confined aquifers, vertical hydraulic gradients were upward causing groundwater flow through the Maquoketa confining unit. Some of the groundwater originating west of the Maquoketa Formation subcrop area (see Map 22) infiltrated to the deep sandstone aquifer and slowly flowed from west to east toward Lake Michigan.

Map 22

POTENTIOMETRIC SURFACE OF THE LOWER SANDSTONE AQUIFER: 1996

900 POTENTIOMETRIC SURFACE IN FEET ABOVE NATIONAL GEODETIC VERTICAL DATUM (1929) CONTOUR INTERVAL 50 FEET; DASHED WHERE APPROXIMATE

850 PREDEVELOPMENT POTENTIOMETRIC SURFACE *(From Young, 1976)*

ESTIMATED LOCATION OF REGIONAL POTENTIOMETRIC DIVIDE (UNCERTAIN)

GENERAL DIRECTION OF GROUNDWATER FLOW

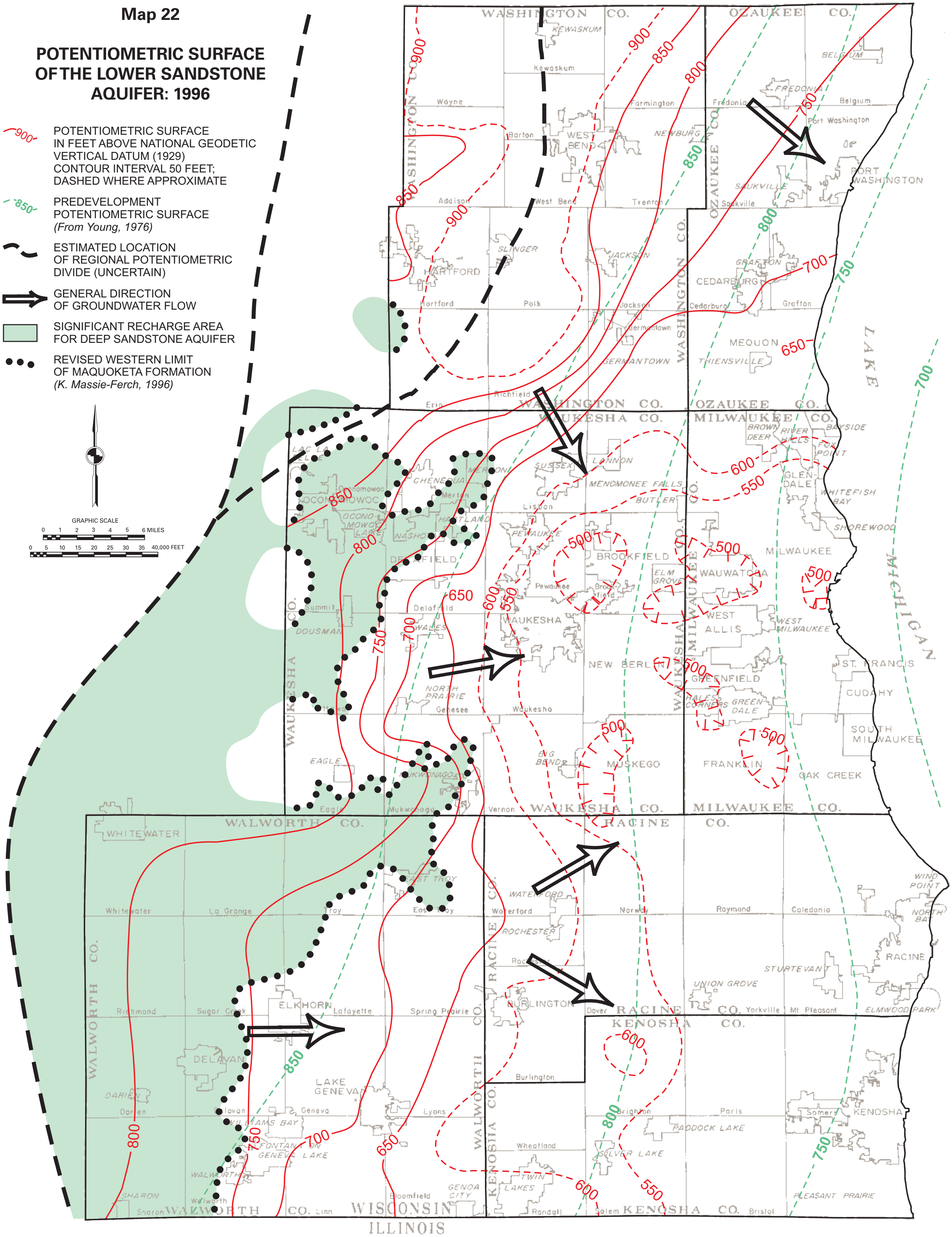
SIGNIFICANT RECHARGE AREA FOR DEEP SANDSTONE AQUIFER

REVISED WESTERN LIMIT OF MAQUOKETA FORMATION *(K. Massie-Ferch, 1996)*

GRAPHIC SCALE

0 1 2 3 4 5 6 MILES

0 5 10 15 20 25 30 35 40,000 FEET



Source: T. T. Eaton, 1996; Young, 1976.

Since the beginning of the 20th century, increasing groundwater pumpage from deep high-capacity wells has caused a decline in pressure in the deep sandstone aquifers, resulting in a reversal of vertical hydraulic gradient. Water levels, particularly in deep wells in eastern Waukesha and Milwaukee Counties, are much lower than the regional water table (see Maps 21 and 22), thus inducing downward flow through the Maquoketa in this area. The deep sandstone aquifers now discharge primarily to the many deep wells in the Region.

Vertical Aspect of Flow

Because of the great thickness of the aquifers in Southeastern Wisconsin, the vertical component of regional flow is an important element in understanding regional hydrogeology. A northwest-southeast hydrogeologic cross section, from Lac La Belle in northwest Waukesha County to Wind Point on Lake Michigan in Racine County, shows the current flow field interpreted from available well data (see Figure 14). Before development of water supplies from the deep sandstone aquifer, the major discharge area of the deep regional flow system in Southeastern Wisconsin was primarily Lake Michigan. Today, deep wells are the major discharge points in the east-central part of the Region. Local flow systems in the water table aquifer above the Maquoketa confining unit probably have not changed significantly because of rapid recharge occurring on an annual or semi-annual basis.

The analogy with the idealized groundwater flow system is limited because of the assumptions it is based on. The idealized groundwater flow system in Figure 13 illustrates steady-state conditions, where over a given time period, discharge equals recharge. This is not the case today in some areas of Southeastern Wisconsin where extensive development of the deep sandstone aquifer (with centuries- or millennia-scale flow systems) has occurred in the last 100 years, resulting in discharge exceeding recharge. In other areas, away from the major pumping centers, where limited deep aquifer development has taken place, flow systems probably resemble the idealized profile.

On the hydrogeologic cross section (see Figure 14), showing present-day conditions, intermediate and regional flow systems are not apparent because of the predominantly downward hydraulic gradient caused by pumping from the deep sandstone. Pumping from deep wells along the cross section has modified the flow field from the probable west-east flow pattern, which existed under pre-development conditions. Although most of the recharge originating from the land surface contributes to local flow systems, which then discharge into nearby rivers and lakes, some of the flow arrows show downward flow through the Maquoketa confining unit. This illustrates that this confining unit is not completely impermeable and the downward hydraulic gradient between the shallow and deep aquifer system causes significant leakage, and hence recharge, from the water table to the deep confined sandstone aquifers.

Potentiometric Surface and Regional Potentiometric Divide

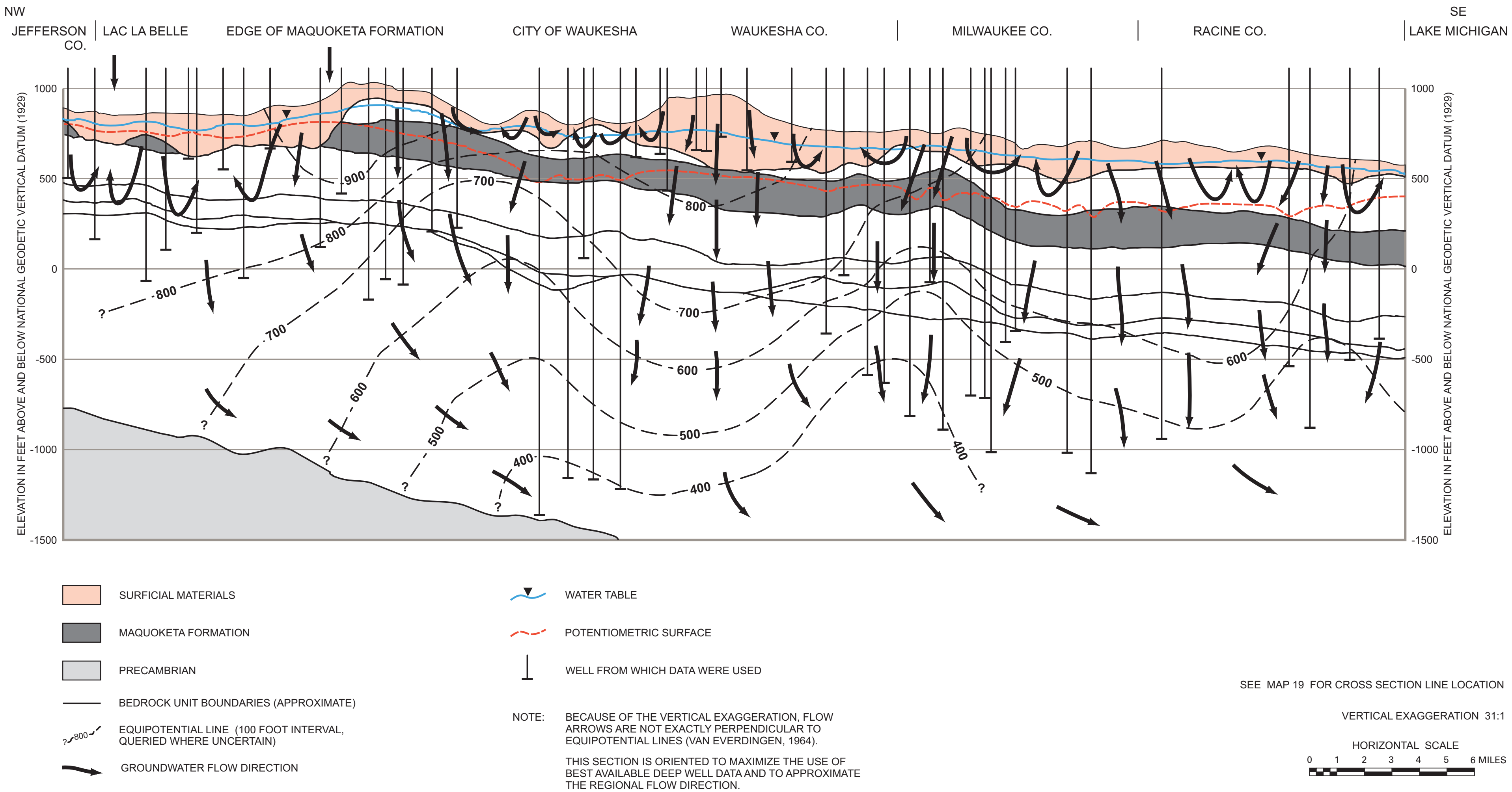
Elevations in the potentiometric surface range from a maximum in western Washington County to a minimum in eastern Waukesha, Milwaukee, Racine, and Kenosha Counties (see Map 22). Elevations of the potentiometric surface are approximate because of a limited number of current water-level measurements and the limited scope of the study.

Contours in the eastern part of the Region are dashed because water level data are known to be out of date. Modern static water levels have been drawn down to less than 350 feet above mean sea level in some locations. Nevertheless, the relative trends in the potentiometric surface of the lower sandstone aquifer are believed to be accurate.

The hydraulic head in the deep sandstone aquifer increases toward the western edge of the Region as shown in the potentiometric surface map (see Map 22). Farther west, in Dodge and Jefferson Counties, the hydraulic head decreases as one approaches the Rock River valley (not shown), a major deep regional flow discharge area. The area in between, just west of the Region, has the highest heads in the sandstone aquifer and forms the regional potentiometric divide. The location of this regional divide is uncertain, particularly in the north, where it is believed to pass either west of Washington County or through the western parts of Washington and Waukesha Counties (see Map 22). The southern part of this divide (west of the seven-county Region) corresponds to findings of recent studies of the Illinois State Water Survey (Visocky, 1993, 1997), which show the regional

Figure 14

SCHEMATIC HYDROGEOLOGIC CROSS SECTION FROM LAC LA BELLE, WAUKESHA COUNTY TO WIND POINT, RACINE COUNTY



Source: T.T. Eaton, 1997

potentiometric divide in Boone County, Illinois. Historical water-level data collected for this project are not adequate to characterize the exact location of this regional divide, nor whether the divide has moved since pre-development time. The position of the regional divide has major implications on recharge to the lower sandstone aquifer, and further future investigation is needed in this regard.

Another west-east regional potentiometric divide (not shown on Map 22) exists between the Chicago metropolitan area cone of depression and the Waukesha-Milwaukee cone of depression. The exact location of this divide cannot be confirmed without field measurements of current water levels in wells open to the lower sandstone aquifer. Concentrated pumpage in Waukesha-Milwaukee and Chicago areas has created deep cones of depression, and the Chicago cone of depression probably diverts some groundwater from Kenosha County. The older studies showed this divide in central Kenosha County (for example, Hutchinson, 1970). Young (1992b) put this divide even farther to the north, running west-east through the middle of Racine County. A secondary west-east potentiometric divide may separate the Waukesha-Milwaukee and Racine-Kenosha pumping areas, as indicated in the older studies (Foley and others, 1953).

Groundwater in the lower sandstone aquifer generally moves eastward from the regional potentiometric divide (see Map 22), paralleling the regional eastward dip of the Paleozoic rocks, and is confined under the Maquoketa Formation. Cones of depression on the potentiometric surface, caused by pumping from high-capacity wells in the eastern Waukesha and western Milwaukee Counties and in the metropolitan areas of Racine and Kenosha, divert and capture groundwater from great distances and change the original direction of regional groundwater flow.

Significant Recharge Areas of the Lower Sandstone Aquifer

As noted earlier, pre-development recharge area of the deep sandstone aquifers was restricted to the region bounded on the east by the Maquoketa Formation and on the west by the north-south trending groundwater divide extending just beyond the western boundaries of the Region (see Map 22). Upward vertical gradients through the Maquoketa confining unit, as demonstrated by the artesian conditions encountered in deep wells earlier in the 20th century, prevented any significant recharge elsewhere. Since then, reversed hydraulic gradients caused by the drawing down of the potentiometric surface have induced leakage, or recharge, from the shallow water table aquifer through the Maquoketa confining unit to the lower sandstone aquifer. This is illustrated by the predominantly downward flow arrows through the Maquoketa Formation along the modern-day hydrogeologic cross section (see Figure 14). Although geochemical data have not been collected and interpreted for this study, geochemical analysis of groundwater in the upper part of the deep sandstone aquifer has shown evidence of downward flow through the Maquoketa Formation in Dodge and Fond du Lac Counties (Weaver and Bahr, 1991).

Young (1992b) estimated that the permeability of the Maquoketa confining unit is approximately five orders of magnitude smaller than the Silurian or the deep sandstone aquifer, and thus, vertical flow is considerably restricted where this unit is present. Therefore, part of this study included a remapping of the western edge of the Maquoketa Formation in Southeastern Wisconsin (shown on Map 22; see also Chapter V). Despite the probable induced recharge through this confining unit in areas of extensive deep groundwater development, it is likely that the majority of groundwater in the deep sandstone aquifers originally recharged in the area west of the edge of the Maquoketa Formation. On a regional basis, therefore, the major recharge area of the deep sandstone aquifer lies between the edge of the Maquoketa Formation and the regional potentiometric divide along the western boundary of the Region (see Map 22).

As illustrated in the idealized groundwater flow system diagram (see Figure 13), recharge areas are characterized by downward flow and divergent flow paths. Data compiled as part of this study are not sufficient to definitively show downward flow in areas west of the edge of the Maquoketa confining unit. As indicated by the local flow systems at the left end of the hydrogeologic cross section (see Figure 14), available static water levels in wells penetrating the deep sandstone are within 20 feet of static water levels in wells completed in the shallow Galena-Platteville aquifer. To better define the vertical flow direction as well as the western extent of the recharge area, bounded by the regional potentiometric divide, new data on the vertical gradients in the deep aquifers need to be collected in the adjoining counties of Rock, Jefferson, and Dodge. Existing wells may not be deep enough to provide such data, in which case new deep test wells may need to be drilled for packer testing. Such field work would be similar to a study that defined the potentiometric divide between the Wolf and Fox Rivers near Green Bay (Batten and Bradbury, 1996).

CONCLUDING STATEMENT

Because of the emphasis of this study on the shallow aquifer system, the collection and interpretation of data was accordingly focused, and issues concerning the deep sandstone aquifer were addressed only to a limited extent. The shallow and deep aquifers in the Region are hydraulically connected, and there is a need to address the deeper aquifer system in more detail.

Existing information on the framework of the deep aquifer system and confining units within the Region is rather sparse. Available data show that the geometry and lithology of the bedrock units are complex and indicate the need to treat this question three dimensionally. New interpretation of existing subsurface geologic data and collection of new data could help better define the major lithologic and facies variations, complex system of deep bedrock valleys, and structural features such as faults (for example, the "Waukesha fault"—see Chapter V), all of which are important for understanding regional hydrogeology.

Although much information and data on the shallow aquifers has been collected and analyzed for this study, there is still a need for more information that would enable the integration of the shallow and deep systems in a regional plan. Better knowledge is needed on the distribution and rates of groundwater recharge in the Region. Also, the available information necessary to better define the important recharge areas for the shallow system needs to be interpreted.

Recently, local water supply managers expressed concern over the declining potentiometric surface in the deep sandstone aquifer due to increasing pumpage from municipal and industrial wells, and suggestions for regionwide water supply planning have emerged. Interrelations of the aquifer systems and related management issues can best be addressed with a three-dimensional groundwater model of the Region. To develop a three-dimensional model, data are needed to define the potential boundary condition for the model, for example, a regional potentiometric divide west of the Region. Also needed are better determinations of the western extent of the recharge area, vertical flow directions, static and pumping water levels for deep wells in Southeastern Wisconsin and northeastern Illinois, and existing pumpage records for high-capacity wells.

Chapter VII

GROUNDWATER QUALITY AND PROTECTION

GROUNDWATER QUALITY

Knowledge of the chemical character of groundwater and its variations is necessary for effective planning, management, and protection of groundwater resources. The systematic collection of information on groundwater chemistry provides the basis for determining existing groundwater quality conditions and for forecasting probable future water quality conditions. The data available for the Region are not adequate for fully describing existing groundwater quality and identifying trends in such quality but do provide much useful information. Data on the quality of groundwater within the Region were summarized from publications of the U.S. Geological Survey, the Wisconsin Geological and Natural History Survey, the Wisconsin Department of Natural Resources, University of Wisconsin student theses, and the Southeastern Wisconsin Regional Planning Commission itself.

Background Quality

The chemical composition of groundwater largely depends on the composition and physical properties of the soil and rocks it has been in contact with, the residence time of the water, and the antecedent water quality. The chemical composition of groundwater in the Region is primarily a result of its movement through the interaction with Pleistocene unconsolidated materials and Paleozoic rocks, which all contain large amounts of dolomite, $CaMg(CO_3)_2$, that is dissolved by water passing through the materials and rocks. In general, groundwater quality tends to be relatively uniform within a given aquifer, both spatially and temporally, but major differences in groundwater quality within the Region can be observed. The current quality of groundwater in both the shallow and deep aquifers underlying the Region is generally good and suitable for most uses, although localized water quality problems occur at some areas.

Groundwater in the Region contains all the major ions that commonly dominate the composition of natural waters: calcium (Ca^{2+}), magnesium (Mg^{2+}), and sodium (Na^{+}) cations and bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}) and chloride (Cl^{-}) anions. The areal distribution and predominance of these major ions can be used to classify the groundwater into hydrochemical facies, i.e., the chemical type of water. Groundwater may be classified as a calcium-magnesium-bicarbonate(Ca-Mg- HCO_3) type in most of the Region. Water chemistry in the shallow and deep aquifer systems is very similar. The most pronounced geochemical changes occur in the confined parts of the deep aquifer system (Siegel, 1989). From the western edge of the Maquoketa shale east toward Lake Michigan, water chemistry changes sequentially from Ca-Mg-HCO_3 to Ca-Na-SO_4-C1 to Na-SO_4-Cl type.

However, not much is known about the specific chemical composition of groundwater in the Region and its variations because it has not been studied in any detail. Besides general statewide or regional overviews

(Kammerer, 1981, 1984, 1995; Siegel, 1989; U.S. Geological Survey, 1988) there is only one unpublished study of water quality in the Silurian dolomite aquifer in eastern Wisconsin (Wilson, 1985) that provides some detail.

In a project for the Water Resources Management Program of the University of Wisconsin-Madison, Wilson in 1985 characterized the regional distribution of groundwater composition in the Silurian dolomite aquifer by means of trilinear diagrams (Zaporozec, 1972). According to his classification, the distribution of cations and anions in this aquifer shows the influence of increasing sodium (Na^+), sulfate (SO_4^{2-}), and chloride (Cl^-) concentrations as groundwater migrates from recharge areas in the west toward the Lake Michigan discharge areas in the east. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are the dominant cations, and bicarbonate (HCO_3^-) is the dominant anion in Walworth and Washington Counties (both more than 90 percent of the total cations and anions, respectively). Groundwater in Ozaukee and Waukesha Counties is of transitional type, with the increasing proportion of SO_4^{2+} and Cl^-. Groundwater in Racine County contains a larger proportion of Na^+, SO_4^{2+}, and Cl^-. In Kenosha County, groundwater is of Na+K-Ca-Mg-HCO_3-SO_4-Cl type; with Na^++K^+ as the predominant cations (more than 50 percent) and combined SO_4^{2+} and Cl^- approaching 50 percent of total anions.

Groundwater Age

Analysis of the isotopic composition of the groundwater and carbon-14 dating can be used to estimate the age of groundwater. These analyses indicate that the source of much of the groundwater in the Region was precipitation near the ice margin and recharge from glacial meltwater below the ice sheets. Isotopic analyses indicate that the groundwater in the Pleistocene Oak Creek Formation underlying southeastern Waukesha, southern Milwaukee, and eastern Racine Counties was probably not older than 15,000 years, which is the maximum age of the formation. Using radiocarbon dating, Simpkins and Bradbury, (1992) determined that the age ranged from 7,039 to 9,817 years. Siegel (1989) reported that the age of water in the Cambrian-Ordovician aquifer system, derived from carbon-14 dating, gradually increases eastward from 6,000 years in the recharge area to 40,000 years near Lake Michigan.

Dissolved Solids

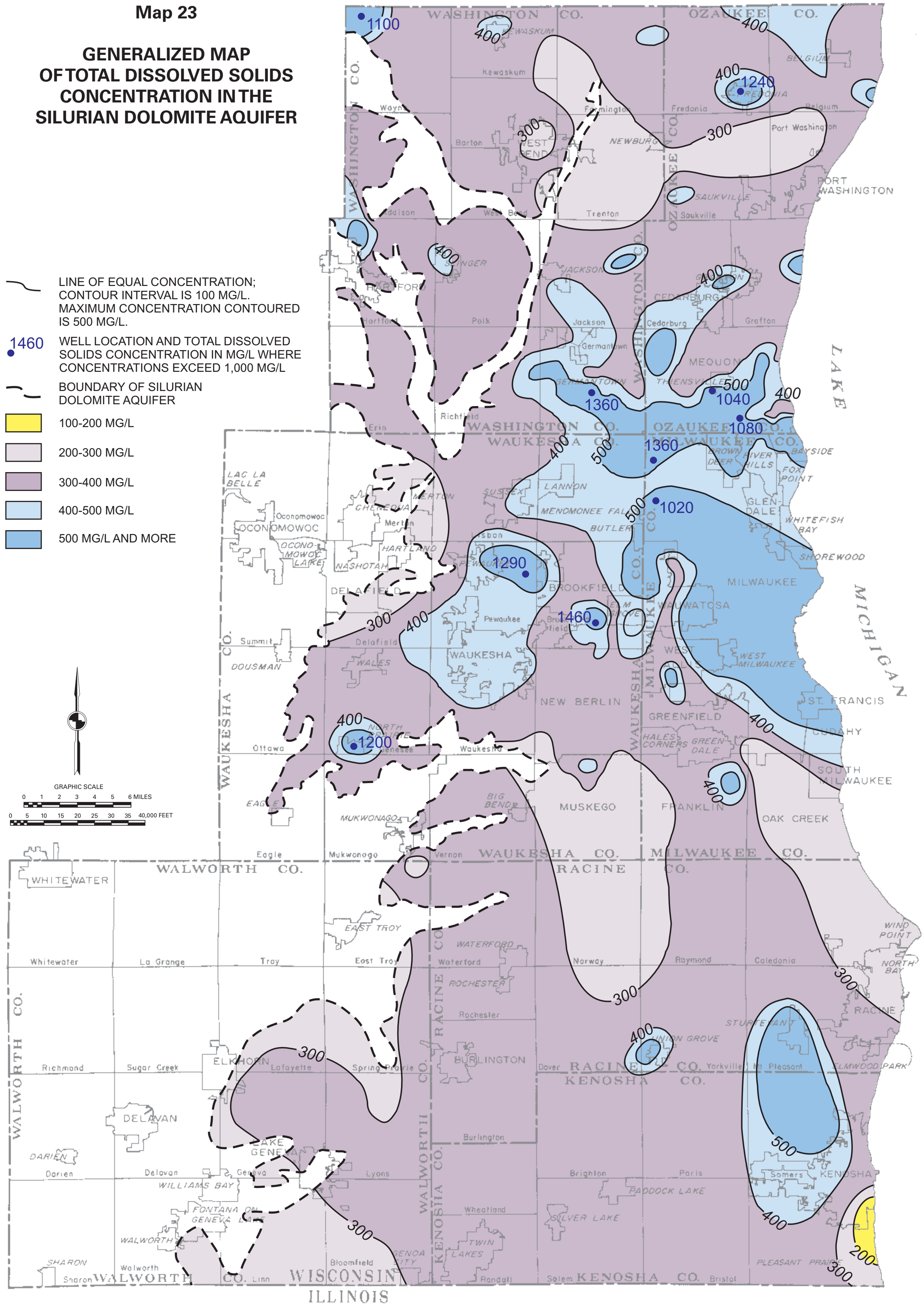
Dissolved-solids concentration and hardness are good initial indicators of water quality. Concentrations of dissolved solids are primarily in the 300 to 400 milligrams per liter (mg/l) range within the Region. The recommended maximum concentration for drinking water of 500 mg/l is exceeded only locally in isolated areas, primarily in the east-central part of the Region. The dissolved-solids concentration generally increases from west to east—generally in the direction of groundwater movement—and with depth and increased thickness of the aquifers. Available data show negligible differences between individual aquifers:

- Sand and gravel aquifer: generally 300 to 400 mg/l; locally more than 400 mg/l (Devaul, 1975a);
- Silurian dolomite aquifer: generally 100 to 300 mg/l along the Lake Michigan shore; 400 to 500 mg/l in Ozaukee, Milwaukee, and eastern Waukesha County; otherwise mostly 300 to 400 mg/l (Devaul, 1975b); and
- Sandstone aquifer: generally 300 to 400 mg/l in the west and increasing toward the east to more than 600 mg/l; 200 to 300 mg/l in western Waukesha and northern Walworth and Racine Counties (Devaul, 1975c).

Map 23 was compiled from maps in county and other reports (Borman, 1976; Gonthier, 1975; Kammerer, 1995; Wilson, 1985; Young and Batten, 1980). It shows the distribution of dissolved-solids concentration in the Silurian dolomite aquifer—the prevalent shallow aquifer in the Region. The map also shows those wells that available data indicate have concentrations above 1,000 mg/l. Water containing high dissolved solids is occasionally reported by drillers of new deep wells. Water containing more than 1,000 mg/l of dissolved solids is considered saline water (Ryling, 1961). The highest concentration of dissolved solids documented within the Region was a composite

Map 23

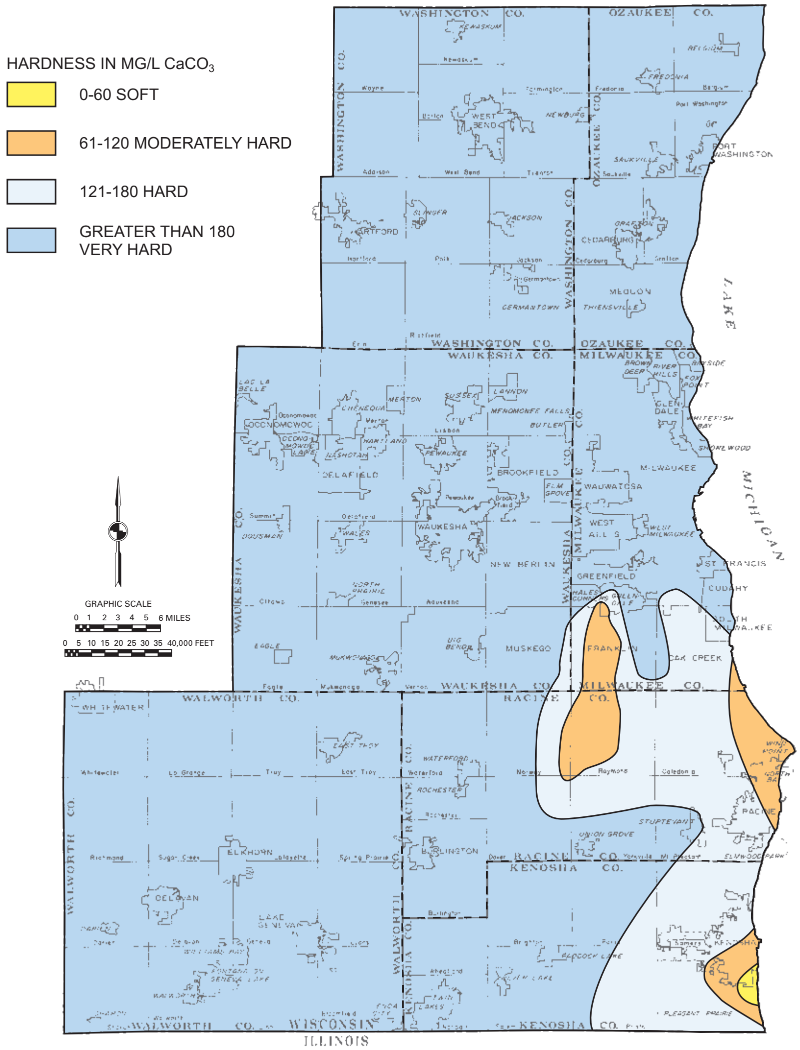
GENERALIZED MAP OF TOTAL DISSOLVED SOLIDS CONCENTRATION IN THE SILURIAN DOLOMITE AQUIFER



Source: Compiled from Borman, 1976; Devaul, 1975b; Gonthier, 1975; Wilson, 1985; Young and Batten, 1980.

Map 24

AREAL DISTRIBUTION OF HARDNESS OF GROUNDWATER IN THE SHALLOW AQUIFERS OF SOUTHEASTERN WISCONSIN



Source: Wisconsin Geological and Natural History Survey.

sample from the well tapping the Silurian dolomite, Galena-Platteville dolomite, and St. Peter Sandstone aquifers in northeastern Milwaukee County: ML 413 – 6,690 mg/l.

Hardness

Hardness is generally high due to the dominance of Ca/Mg cations in groundwater of the Region (Map 24). Hardness is reported in terms of equivalent concentration of calcium carbonate ($CaCO_3$), in milligrams per liter. No national or state standards for hardness are given, but water with a hardness of less than 100 mg/l $CaCO_3$ is generally considered as suitable for domestic uses. Water having more than 180 mg/l $CaCO_3$ is considered very hard, and softening is required for most purposes. Hardness in the Silurian dolomite aquifer generally ranges from180 mg/l to 360 mg/l $CaCO_3$ (Kammerer, 1995). The hardest water is found in northern Milwaukee County and northeastern Waukesha County with values exceeding 360 mg/l.

Hardness in excess of 360 mg/l, or even 500 mg/l $CaCO_3$ is common in wells in the Villages of Brown Deer and Menomonee Falls, and the Cities of Brookfield, Glendale, and Milwaukee. Wells ML 408 and ML 413 in the Village of River Hills have measured hardness exceeding 1,500 mg/l. The eastern parts of Racine and Kenosha Counties have water containing less than 180 mg/l of hardness, with less than 120 mg/l in the northeastern corner of Racine County and southeastern corner of Kenosha County.

Trace Elements

Concentrations of some constituents, normally found in trace amounts, exceeded accepted limits in some areas of the Region and may limit the usefulness of groundwater for certain purposes. Siegel (1989) suggested that, in particular, barium concentrations may exceed the limit of one mg/l in a 30-mile broad band running through the western part of Washington County, most of Waukesha County, eastern Walworth County, and western Racine and Kenosha Counties. The higher barium concentrations probably are due to a zone of reducing conditions in the confined aquifer system, extending from northeastern Illinois to Wisconsin. Radium concentrations (^{226}Ra and ^{228}Ra combined) in some parts of the confined deep aquifer system may exceed the current drinking water standard. The sources of the high radium concentrations in the groundwater are probably related to the occurrence of uranium and thorium in the matrix of sandstones (Siegel, 1989).

Water Quality Concerns

Some water quality problems are caused by natural factors, which cannot be controlled. For example, the abundant dolomite material in the Region releases calcium and magnesium, which form about one-half of all ions in groundwater and are the principal components of hardness. Therefore, hardness is objectionably high in groundwater in most of the Region (see Map 24), and softening is required for almost all water uses.

Deep aquifers in some parts of the Region contain saline water, that is, water with dissolved solids concentrations greater than 1,000 mg/l. But saline water also can occur in the shallow aquifer system through hydraulic connection between the deep and shallow aquifer systems. Ryling (1961) documented the dissolved solids levels in excess of 1,000 mg/l in southeastern Ozaukee County and northeastern Milwaukee County. Kammerer (1995) reported several areas in southwestern Ozaukee, northeastern Waukesha, and northern Milwaukee Counties, where saline water is suspected or has been found to be beneath the shallow aquifer system. Some locations of wells in the shallow aquifer system containing more than 1,000 mg/l of dissolved solids are shown on Map 23. Available data are insufficient to define the extent of areas of saline water.

Naturally occurring radioactivity in groundwater, including radium and radon, has become a concern in Wisconsin in recent years. The State initiated several studies to examine the occurrence and extent of these naturally occurring contaminants. Radon does not appear to be a problem in the shallow aquifer of Southeastern Wisconsin. A radon study currently under way indicates only one private well in Walworth County with radon content greater than 1,000 picocuries per liter (WDNR, 1995). The source of radium in groundwater is the naturally occurring radium content of certain types of rock. There are a number of water supply systems in the Region which reported one or more exceedances of the current five picocuries per liter EPA standard for radium (combined Radium-226 and Radium-228). Those systems serve all or portions of the Cities of Brookfield, New Berlin, Pewaukee, and Waukesha, and the Villages of Eagle, Mukwonago, Pewaukee, and Sussex in Waukesha County; the Villages of Union Grove and Waterford in Racine County; the Cities of Delavan and Elkhorn in Walworth County; and several water supply systems serving special purpose units of government or institutions (WDNR, 2002). It should be noted that the standard exceedances in these systems can vary from one occurrence to repeated occurrences.

Although most of the exceedances of the radium standard have occurred in wells open to Cambrian sandstone formations, hydraulic connection between the deep and shallow aquifer systems and the upward migration of groundwater in some areas can bring the water with elevated concentrations of radium into shallow aquifers. Hahn (1984) documented 21 radium-standard violations in community water systems in Southeastern Wisconsin, primarily in Waukesha, Racine, and Kenosha Counties. Additional exceedances in seven private wells have also been reported (Koth, 1985). Radium can be removed from groundwater by water softening methods (synthetic zeolite ion exchange, reverse osmosis, or lime-soda ash softening) or reduced in concentration by blending with water of low radium content.

Another naturally occurring element, arsenic (As), is also a concern because some municipal and private water supplies exceed a new federal standard of 10 micrograms per liter. Municipal wells that have reported one or more past exceedances include those serving the Village of Grafton in Ozaukee County; the Cities of Elkhorn and Whitewater, and the Village of Williams Bay in Walworth County; and the Cities of Pewaukee and Muskego in Waukesha County (WDNR, 2002).

Contaminants resulting from human activities, causing groundwater quality problems in the Region, include bacteria, nitrate, pesticides, and volatile organic compounds (VOCs). The first three can affect water quality of water in private wells, but generally they do not cause major problems in the Region.

The coliform bacteria test has traditionally been used to measure the sanitary condition of well water. Although coliform bacteria usually do not cause disease, their presence in well-water samples may be an indication that more harmful bacteria also exist in a well. Bacteria can be introduced into wells from septic tanks, leaking sewer pipes, feedlots, or manure pits and piles. Their presence usually indicates an improperly constructed well or a well too shallow for local conditions, such as thin soil or fractured bedrock. Bridson and others (1995) reported that coliform bacteria have been detected in, on the average, 25 percent of samples collected from private wells in the Region. However, this bacterial contamination may not always be caused by the coliform bacteria but by insects present in well caps.

In Wisconsin, nitrate-nitrogen is the most commonly found groundwater contaminant that exceeds the State drinking water standard of 10 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. A data summary (Bridson and others, 1995) indicates that nitrate contamination is a relatively minor problem in the Region. Nitrate-nitrogen exceeded the standard in 3.7 percent of 1,245 samples collected and the exceedance rate ranges from zero in Milwaukee County to 7.5 percent in Walworth County. The highest exceedance rate was found in the Darien Township, Walworth County, where more than 18 percent of samples exceeded 10 mg/l of nitrate-nitrogen.

Pesticide contamination of groundwater results from field applications, spills, misuse, or improper storage and disposal of pesticides. In 1992 the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) initiated a rural well sampling program for testing of atrazine, the most widely used triazine herbicide in Wisconsin for weed control, primarily in corn. Triazine was detected in 63 of the 263 samples collected by DATCP in all of the counties within Southeastern Wisconsin, except Milwaukee (Bridson and others, 1995). However, none of the samples exceeded the State drinking water standard.

The presence in certain locations of volatile organic chemicals (VOCs) is also a cause of concern. Sources of VOCs are landfills, leaking underground storage tanks (LUST), and spills of hazardous substances. Available data from drinking water sampling conducted in 1985 (Koth, 1985) indicated that VOCs were detected in two systems in Ozaukee County (one over the health advisory limit), one system in Washington County, four in Waukesha County (one over the health advisory limit), and three in Walworth County (one over the health advisory limit). Forty-seven private and noncommunity wells were tested in Washington, Waukesha, and Walworth Counties and VOCs were detected in six of them, with one over the health advisory. The Wisconsin Department of Natural Resources (WDNR) has recently tested all municipal water systems in the State and a large number of noncommunity and private wells for VOCs.

Investigation of the cases of existing contamination was not part of this study. However, during the contamination source inventory, conducted by the Commission, data were obtained from the WDNR on areas of special well casing requirements, which indicate the presence of contaminants. The special well casing requirement program was created under *Wisconsin Administrative Code* NR 812 to provide additional protection of drinking water in areas where aquifers have known contamination. Special well casing requirement areas, based on detected or suspected contaminants, designated by WDNR in the Region in 2002 are listed in Table 23 and the locations of the special well casing requirement areas are shown on Map 25. The most often found contaminants were VOCs and bacteria. Other contaminants included petroleum products, nitrates, and landfill leachate.

SOURCES OF GROUNDWATER CONTAMINATION

Potential sources of groundwater contamination are many and varied because, in addition to some natural processes, such as dissolved and particulate matter in precipitation, decay of organic matter, natural radioactivity and dissolution of arsenic-containing minerals, many types of facilities or structures and many human activities may eventually contribute to groundwater quality problems. This section characterizes the activities and practices that may affect groundwater quality in the Region and outlines the nature of contamination that may result from such activities. It also describes the nature and extent of potential groundwater contamination sources in the Region. No attempt has been made, however, to rank quantitatively the various potential contamination sources in the Region. For the purposes of this study, the sources that were considered to have potential to create contamination problems in the Region are summarized according to their location in Table 24.

In 1997 and 1998, the Commission and the Wisconsin Geological and Natural History Survey, in cooperation with the Wisconsin Departments of Natural Resources, Agriculture, Trade and Consumer Protection, and Transportation, conducted, as a part of this study, an inventory of potential sources of contamination in order to assess their extent and potential impact on groundwater. No attempt was made to include all possible human activities that may affect groundwater quality in the Region, as listed in Table 24. The primary emphasis of the inventory was on the clusters of on-site sewage disposal systems, landfills, leaking underground storage tanks, and abandoned wells. Also identified were wastewater sludge application sites, agricultural activities (major farm animal operations, fertilizer and pesticide storage facilities) and other potential sources of contamination, such as the stockpiles of salt for highway de-icing, salvage yards, and bulk fuel storage sites. The sources of contamination that were specifically inventoried for this study, are shown in bold in Table 24. Because of the nature of the sources of groundwater contamination, the location and number of each source can change over time. Thus, for the most up-to-date inventory data, it is recommended that the agency noted as the source of information be contacted.

On-site Sewage Disposal Systems

Private wastewater systems are used to dispose of sanitary wastes in the unsewered areas. A conventional on-site system consists of a septic tank and a soil absorption field. Most solids, called septic sludge, settle at the bottom of the tank where they are partially digested by bacteria. The liquid waste, called septic tank effluent, flows from the tank to the soil absorption field where it is purified as it moves through the soil. If these systems are properly installed in suitable soils and located a sufficient distance from a water supply source, most contaminants are removed or attenuated before they can reach the water supply. However, local groundwater contamination may occur in areas of concentrated suburban or rural residential development where individual on-site systems are densely spaced. This may be of most concern where older systems are in place, which may not meet current design criteria. Specifically, the amount of nitrate and chloride may not be significantly reduced.

In addition to conventional on-site systems, newer alternative on-site sewage disposal systems designed to overcome certain types of soil limitations are in use in the Region. Such systems include “mound-type systems,” which pump septic tank effluent through a distribution piping system placed in sand or other fill material on top of the natural soil. Other types of soil absorption systems include in-ground pressure distribution systems and at-grade systems. In addition, holding tanks to temporarily store wastewater prior to pumping out to a tank truck and transport to a sewage treatment plant are used.

With regard to the use of on-site sewage disposal systems in the study area, it is important to note that during early 1999, draft revisions of the *Wisconsin Administrative Code* governing the installation, maintenance,

Table 23

SELECTED CHARACTERISTICS OF THE SPECIAL WELL CASING REQUIREMENT AREAS IN SOUTHEASTERN WISCONSIN: 2001

Identification Number[a]	Location	Contaminant Found	Soil Type	Geologic Formation	Casing Recommendation
			Washington County		
1	Town of Wayne Sections 26, 27, 34, and 35	Gasoline	Loam	Pleistocene sand and gravel, alluvial sand	150 feet
2	Town of Barton Section 27 SE ¼	VOC	Mucky peat, loam	Alluvial sand and silt, outwash sand and gravel	60 feet into bedrock
3	Town of Barton Sections 3, 4, 9, and 10	VOC	Loam, silt loam, mucky peat	Gravel; gravelly, silty sand; peat and muck	To base of Maquoketa shale
4	Town of West Bend Sections 15 and 16	VOC	Silt loam, loam	- -	Casing to base of Maquoketa shale
5	Town of West Bend Section 27 SE ¼	Methane gas	Silt loam, loam	Sand and gravel	Bedrock well
6	Town of Polk Section 20 SE ¼	VOC	Loam, gravel pit	Outwash sand and gravel	210 feet
7	Town of Jackson Sections 21, 22, 27, and 28	Bacteria, nitrate	Loam, silt loam	Clayey, sandy silt; lacustrine silt and sand	120 feet, plus sampling
8	Town of Jackson Section 27 NE ¼ , Section 28 NE ¼	Bacteria, nitrate	Silt loam	- -	220 feet
9	Town of Richfield Sections 12 and 13	Gasoline	Silt loam, silty clay loam	- -	100 feet into bedrock
10	Town of Richfield Section 36 SE ¼	Gasoline	Silt Loam, silty clay loam	- -	220 feet
11	Town of Germantown Sections 9 and 10	Gasoline	Silt loam	Gravelly, clayey, sandy silt	200 feet
12	Town of Germantown Sections 9 and 10	Bacteria, nitrate, gasoline	Silt loam	Gravelly, clayey, sandy silt	80 feet
13	Village of Germantown Section 22	Bacteria	Silt loam	Clayey silt; silt, sand, and clay	60 feet
14	Village of Germantown Sections 29 and 30	Gasoline	Sand loam, silt loam, mucky peat	- -	150 feet
15	Village of Germantown Section 31 SW ¼	Gasoline	Loam	- -	220 feet
			Ozaukee County		
16	Town of Cedarburg Section 14 SW ¼	VOC, petroleum, gasoline	Silt loam	- -	130 feet
17	City and Town of Cedarburg Sections 22, 23, and 26	VOC	Loam, silt loam	- -	Special sampling
18	Village and Town of Grafton Section 25	VOC	Silt loam	- -	Special sampling
19	Village of Thiensville Sections 14,15, 22, and 23	VOC	Loam	Outwash sand and gravel	160 feet
20	Village of Thiensville Section 22, 23	VOC	Loam	Outwash sand and gravel	140 feet
			Waukesha County		
21	Town of Merton Section 19	VOC	Silt loam	Gravelly sand	Top of bedrock
22	Village of Sussex and Town of Lisbon Sections 22, 25, 26, 34, 35, and 36	Bacteria, gasoline	Silt loam	Sandy till; gravelly sand; silt, clay	100 to 220 feet or special approval
23	Town of Lisbon within 0.5 mile of quarry or rock outcrops	Bacteria	- -	- -	100 feet or special approval

Table 23 (continued)

Identification Number[a]	Location	Contaminant Found	Soil Type	Geologic Formation	Casing Recommendation
Waukesha County (continued)					
24	Town of Lisbon Section 1 NE ¼	Gasoline	Silt loam	- -	220 feet
25	Village of Menomonee Falls Section 6, NW ¼	Gasoline	Silt loam	- -	220 feet
26	Villages of Menomonee Falls and Lannon within 0.5 mile of quarries or rock outcrops	Bacteria	- -	- -	100 feet or special approval
27	City of Pewaukee Sections 1 and 2	Bacteria	Silt loam, loam	Sandy till, gravelly sand	100 feet
28	City of Pewaukee Section 12 SE ¼	Bacteria	Silt loam	Sandy till	135 feet
29	Town of Delafield Sections 21, 22, 27, and 28	Leachate, VOC	Loam, silt loam	Gravelly sand, sandy till	To base of Maquoketa shale
30	Town of Genesee Sections 23, 24, 25, and 26	Bacteria	Silt loam, loam, muck	Sandy till; peat; silt, clay	200 feet
Milwaukee County					
31	Village of River Hills Section 6 SE ¼	Naturally occurring tar and asphaltum	Silt loam	Top of Silurian Dolomite	200 feet if tar and Asphaltum are present
32	City Franklin Section 6 NE ¼	Petroleum	Silt loam	Silty till	Greater than 40 feet into bedrock
Walworth County					
33	Town of East Troy Sections 10 and 11	Bacteria, detergents	Silt loam	- -	80 feet
34	Town of East Troy Sections 15, 16, and 21	Leachate	Loam, silt loam	- -	To top of bedrock

NOTE: VOC = Volatile Organic Compound.

[a]*See Map 25.*

Source: Wisconsin Department of Natural Resources.

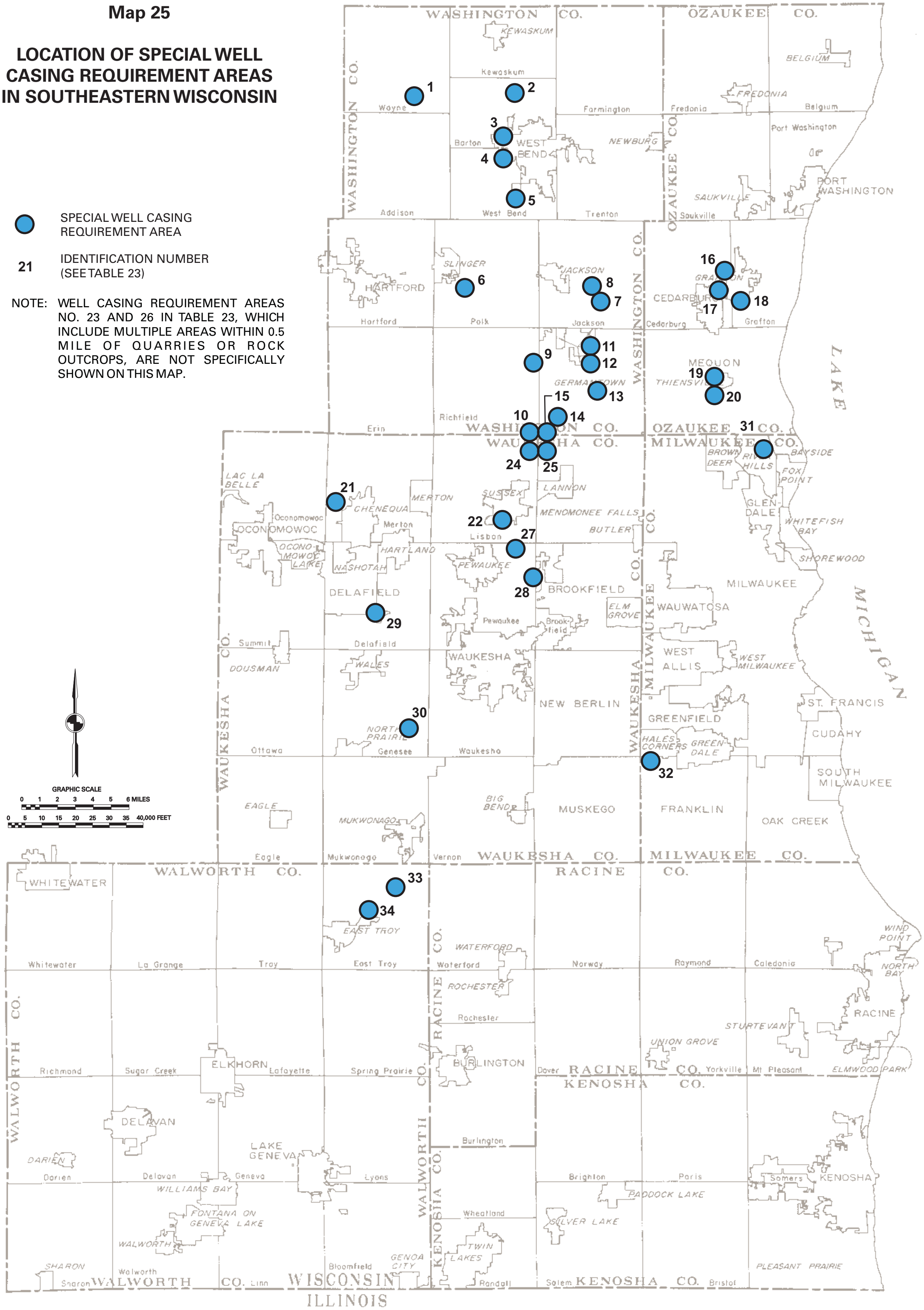
regulation, and inspection of new on-site sewage disposal systems were being considered and presented for public review. The proposal would completely revise Chapter Comm 83 and would, accordingly, revise related chapters of the *Wisconsin Administrative Code*. Chapter Comm 83, *Wisconsin Administrative Code*, is a health and safety code, which regulates private sewage systems statewide. As of August 1999, these proposed rule revisions were under review.[1]

It is estimated that more than 216,000 persons were served by individual on-site systems within the Region as of 1990. However, the potential contamination sources inventory focused on areas of clustered on-site sewage

[1]*During 2000, the Wisconsin Legislature amended Chapter Comm 83 and adopted new rules governing on-site sewage disposal systems. These rules, which had an effective date of July 1, 2000, increased the number of types of on-site sewage disposal systems that legally could be used from four to nine. The Wisconsin Department of Commerce envisions that other systems also will be approved in the future. These new rules significantly alter the existing regulatory framework and will increase the area in which on-site sewage disposal systems may be utilized. The new rules included a provision that allows counties the option of waiting three years before implementing the new on-site sewage disposal system rules and permitting the use of the new types of systems.*

Map 25

LOCATION OF SPECIAL WELL CASING REQUIREMENT AREAS IN SOUTHEASTERN WISCONSIN



Source: Wisconsin Department of Natural Resources.

Table 24

HUMAN ACTIVITIES THAT MAY CREATE GROUNDWATER QUALITY PROBLEMS IN SOUTHEASTERN WISCONSIN

Originating On the Land	Originating Below Land Surface
Above-ground storage tanks (bulk fuel storage)	Above Water Table
Accidental spills	Animal waste storage facilities
Agricultural activities:	**Landfills**
Animal feedlots	Leakage:
Fertilizer and pesticide storage, mixing, and loading	**Underground storage tanks**
Fertilizer and pesticide application	Underground pipelines
Irrigation return flow	Sewers
Silage and crop residue piles	**On-site sewage disposal systems**
Dumps	Surface wastewater impoundments
Highway de-icing, including material **storage sites**	Sumps, dry wells
Waste spreading or spraying (sewage, **sludge**, septage, whey)	Waste disposal in dry excavations
Stockpiles (chemicals and waste)	Below Water Table
Infiltration of contaminated surface water or precipitation	Ground water development:
Salvage yards	**Improperly abandoned wells and holes**
Application of fertilizers and pesticides to urban lawns and gardens	Improper well construction
Urban runoff	Overpumping
	Drainage or disposal wells
	Waste disposal in wet excavations

NOTE: Items in **bold** have been specifically inventoried for this report.

Source: Wisconsin Geological and Natural History Survey and SEWRPC.

disposal systems, defined as areas with more than 32 housing units per U.S. Public Land Survey section, as shown on Map 26. On-site systems tend to be concentrated in western Kenosha and Racine Counties, and Walworth, Waukesha, and Washington Counties. These parts of the Region tend to overlie relatively permeable soils, especially in the major river valleys. Therefore, clustered on-site systems in these areas are a potential source of contamination to the groundwater. However, for those sites that are located in the eastern half of the Region on less permeable soils, groundwater contamination is not as great concern.

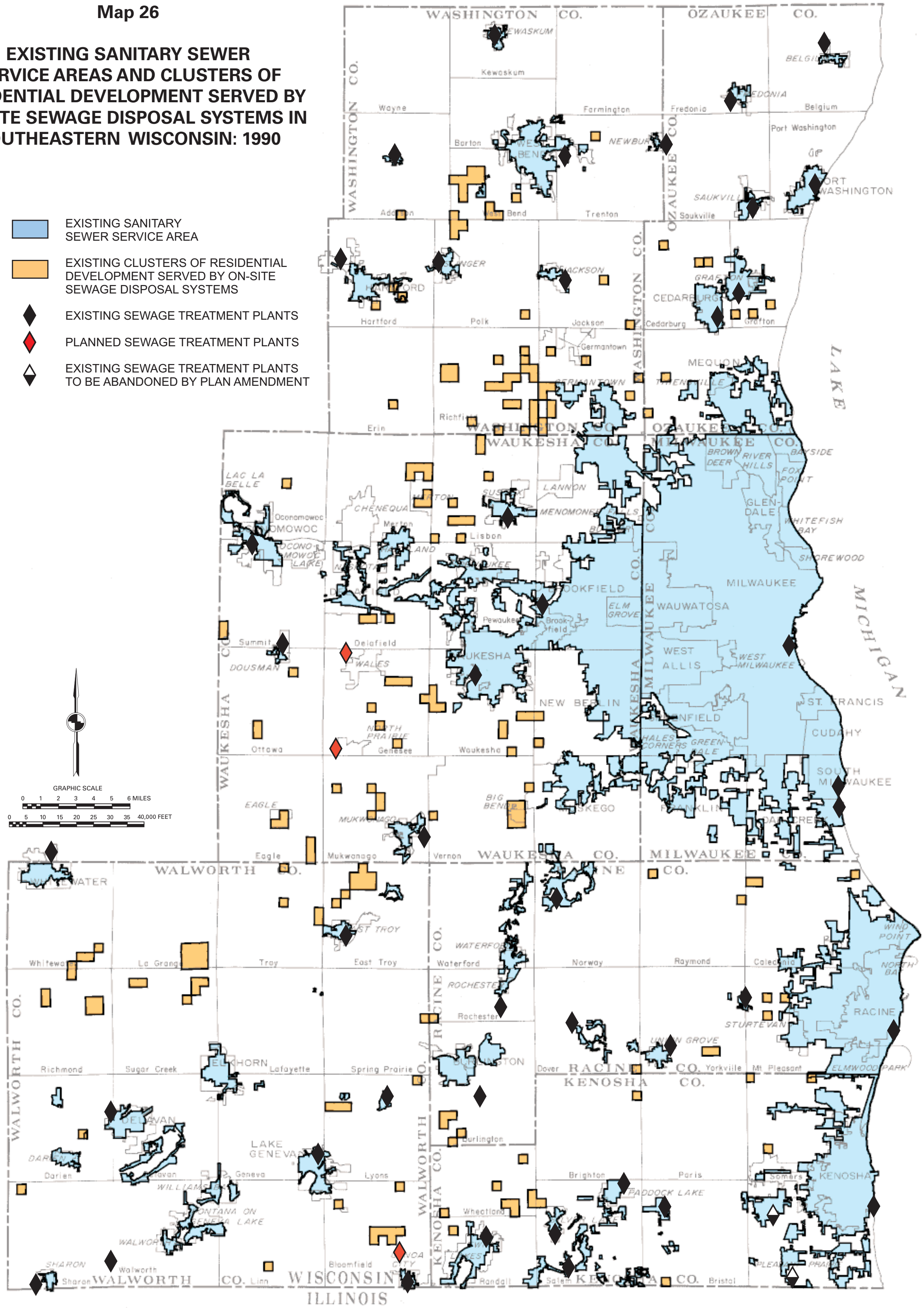
Land Disposal of Solid Waste

Solid waste disposal is an important potential groundwater contamination source. Continuous or intermittent contact between deposited waste and water produces a liquid called leachate, which contains high concentrations of potential contaminants. Landfill leachate is defined as a contaminated liquid characterized by high concentrations of dissolved chemicals, high chemical and biological oxygen demand, and high hardness. Its composition is extremely variable, and is a function of the composition of waste and the volume of water. The threat to groundwater from solid waste disposal sites depends on the nature of leachate, the availability of moisture, the type of soil through which the leachate passes, and the hydrogeology of the site. Because the Region lies in a humid climatic zone, most waste disposal sites will eventually produce leachate. Disposal site success depends on how leachate production and movement is managed either by engineering design or by locating the site in a more protective environment.

Based upon a 1998 inventory, there were 14 active and 173 inactive landfills, including 13 inactive landfills that once received hazardous materials in the Region. Nine abandoned landfills are classified as Superfund sites. All landfills are shown on Map 27, summarized in Table 25, and listed in Appendix D. Most of the landfills are concentrated in Milwaukee and Waukesha Counties, with others located near the major population centers of Racine and Kenosha Counties. However, several landfills also exist in the western portions of the Region. It is these landfills that could pose the most concern to the groundwater supply, because the western part of the Region

Map 26

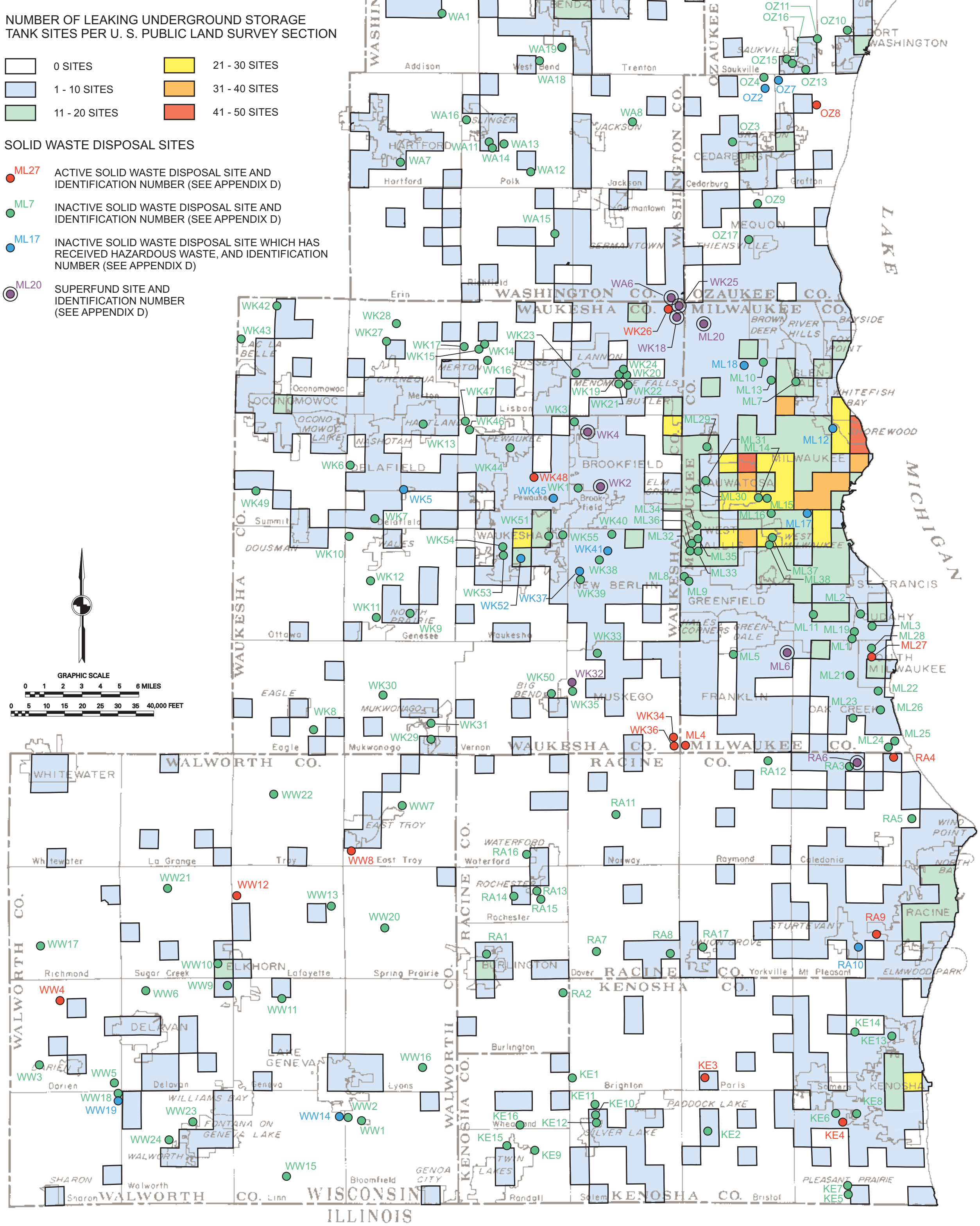
EXISTING SANITARY SEWER SERVICE AREAS AND CLUSTERS OF RESIDENTIAL DEVELOPMENT SERVED BY ON-SITE SEWAGE DISPOSAL SYSTEMS IN SOUTHEASTERN WISCONSIN: 1990



Source: SEWRPC.

Map 27

SOLID WASTE DISPOSAL AND LEAKING UNDERGROUND STORAGE TANK SITES IN SOUTHEASTERN WISCONSIN: 1995-1998



NOTE: Because of the nature of these sites, the inventory information changes periodically. The Wisconsin Department of Natural Resources should be contacted for the most recent data.

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 25

SOLID WASTE DISPOSAL SITES IN SOUTHEASTERN WISCONSIN: 1998

County	Active Sites	Inactive Sites	Inactive Sites with Hazardous Waste	Inactive Superfund Sites	Total Number of Sites
Kenosha	2	14	0	0	16
Milwaukee	2	31	3	2	38
Ozaukee	1	14	2	0	17
Racine	2	13	1	1	17
Walworth	3	19	2	0	24
Washington	0	19	0	1	20
Waukesha	4	41	5	5	55
Total	14	151	13	9	187

NOTE: Because of the nature of the disposal site facilities noted, the number, location, and status changes periodically. The Wisconsin Department of Natural Resources should be contacted for the latest inventory information.

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 26

LEAKING UNDERGROUND STORAGE TANK SITES IN SOUTHEASTERN WISCONSIN: 1995

County	Number of Active Sites	Number of Closed Sites
Kenosha	120	31
Racine	168	52
Walworth	95	23
Waukesha	313	152
Washington	100	26
Ozaukee	82	28
Milwaukee	847	328
Total	1,725	640

NOTE: Because of the nature of the storage tank sites noted, the number, location, and status changes periodically. The Wisconsin Department of Natural Resources should be contacted for the latest inventory information.

Source: Wisconsin Department of Natural Resources and SEWRPC.

principally overlies sand and gravel. This material is very porous and more susceptible to downward movement of contaminants compared to the heavier clays associated with the eastern part of the Region.

The sites shown on Map 27 have been documented based upon Wisconsin Department of Natural Resources (WDNR) and SEWRPC files. In addition, there are other known solid waste disposal sites for which only limited information is available. Some of these sites are still under review by the WDNR. Because of the nature of these facilities, the inventory information changes periodically. The WDNR maintains an up-to-date inventory of the landfill sites. It is recommended that WDNR be contacted for the most recent inventory data.

Underground Storage Tanks

Storage and transmission of a wide variety of fuels and chemicals are inherent in many industrial, commercial, agricultural, and individual activities. Petroleum and petroleum products are the most common potential contaminants. Throughout the Region, underground storage tanks for gasoline, oil, and other liquids were installed during the 1950s and 1960s and have now reached or exceeded their expected 20- to 30-year life. The large volume and high concentration of hazardous materials that can leak or can be released from a storage tank or associated piping in a small area creates an on-site, and sometimes off-site, contamination risk. The majority of the existing tanks are in urban areas and, as a result, are relatively close to municipal water supply wells. Leaks in petroleum-product conveyance and transmission lines also are a potential source of groundwater contamination.

Based upon a review of Wisconsin Department of Natural Resources (WDNR) file data, as of 1995 there were approximately 1,725 underground storage tank sites within in the Region, where there has been a release of contaminants (see Table 26). In addition, there were about 640 “closed” sites within the Region, where response and remedial actions were completed. Of all the leaking underground storage tank (LUST) sites within the State, about 30 percent were within the Region. WDNR classified these sites as high and medium in priority. Additionally, other sites also exist, which the WDNR has inventoried as a low priority, with minor potential for contamination.

The majority of the sites was located in the eastern half of the Region with the highest concentration in Milwaukee County (see Map 27). The WDNR’s classification system considers LUST to be a high priority when it is known that the site is causing contamination to the groundwater, or where there is a high potential for such contamination. Additionally, those sites that are assigned a medium priority, have known soil contamination or a potential for groundwater contamination. Map 27 shows the density of leaking underground storage tanks of the high- and medium-priority sites per square mile. Because of the nature of these potential contamination sites, the number and location are subject to frequent change. The Wisconsin Department of Natural Resources should be contacted for the most recent inventory data.

Land Application of Liquid Waste and Sewage Sludge

Sludge and biosolids are organics, by-products of treated wastewater. Most of the land application of such materials in Southeastern Wisconsin involves biosolids which are treated residuals from sewage treatment plants that can be used beneficially. They are composed mostly of water and organic matter. Both industrial sludges or residual solids and municipal biosolids may contain hazardous chemicals and metals removed by the wastewater treatment process. Metals often found in biosolids at variable concentrations include arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. The types and concentrations of metals found in sludge depend upon the source of the wastewater. Other constituents of sludge that may have an impact on the groundwater are nitrate, chloride, and pathogenic bacteria and viruses.

The land application of municipal sludge is regulated under Chapter NR 204 and 40 CFR Part 503. Industrial sludges are also applied in the Region although the majority of the wastewater biosolids is domestic sewage sludge. Industrial sludge is regulated under Chapter NR 214. Wastewater biosolids must meet the requirements of the above regulations before being land applied. The requirements include ceiling concentrations for contaminants, pathogen reduction requirements, and vector reduction options. As of 1999, WDNR had approved 3,450 sites for storage and land application of wastewater and sludge in the Region. Most of the sites were located in Walworth (1,175 sites) and Washington (1,065 sites) Counties, although Ozaukee (408 sites), Waukesha (400 sites), Racine (275 sites), and Kenosha (127 sites) Counties have hundreds of sites as well. The number and location of these sites is constantly changing and the Wisconsin Department of Natural Resources should be contacted for the latest information on the approved sites.

A large majority of the sludge and wastewater land applications being conducted in the Region involve the spreading of public and private sewage treatment plant biosolids. However, some land application of wastewater from other sources such as vegetable processing and dairy operation by-products (whey), septage and, in some cases, holding tank waste are also practiced. Sludge and wastewater are only applied to agricultural land in the Region. Biosolids are land-applied to improve the structure of the soil, or as a fertilizer to supply nutrients to crops and other vegetation in the soil. Land application in the Region is done by spreading, spraying, injection, or incorporation of sewerage sludge onto or below the surface of the land to take advantage of the soil enhancing qualities of the biosolids. Almost all of the sludge and wastewater is injected or incorporated into the soil, although there are some spray irrigation systems.

Contamination of groundwater from land application of sludge and wastewater depends upon the concentration of contaminants, application rate, physical and chemical soil properties, amount of precipitation, and distance to the water table. Coarse-textured soils, a shallow water table, and high rates of precipitation favor ground-water contamination. Currently, the wastewater biosolids are applied in such a manner that there should be no impact on the groundwater. All of the municipal residuals that are land-applied in Southeastern

Table 27

POTENTIAL AGRICULTURAL SOURCES OF GROUNDWATER CONTAMINATION IN SOUTHEASTERN WISCONSIN

County	Major Livestock Operations (1999)						Agricultural Chemical Storage Facilities (1995)
	Type of Animals						
	Dairy	Poultry	Swine and Dairy	Waterfowl	Mixed	Number of Operations	
Kenosha	- -	- -	- -	- -	- -	- -	1
Milwaukee	- -	- -	- -	- -	- -	- -	3
Ozaukee	- -	- -	- -	- -	- -	- -	4
Racine	- -	- -	- -	2	- -	2	7
Walworth	- -	1	1	- -	- -	2	8
Washington	1	1	- -	--	1	3	3
Waukesha	1	- -	- -	- -	- -	1	10
Total	2	2	1	2	1	8	36

NOTE: Because of the nature of the facilities noted, the number, location, and status changes periodically. The Wisconsin Departments of Natural Resources and Agriculture, Trade, and Consumer Protection should be contacted for the latest inventory information.

Source: Wisconsin Department of Agriculture, Trade, and Consumer Protection and Wisconsin Department of Natural Resources.

Wisconsin have been treated to meet the appropriate quality parameters. The type of soil, application rate, distance to bedrock and groundwater, slopes, porosity of the soils, percolation rates, solum depth, and distance to lakes, streams, ponds, and other water sources are evaluated for every site approved for land application prior to application.

Major Livestock Operations

Major livestock operations are not common in the Region. In 1999, there were seven farm operations with more than 1,000 animal units: two in Racine, Walworth, and Washington Counties, each; and one in Waukesha County (see Table 27). These farm operations are shown on Map 28 and listed in Table E-1, Appendix E. In addition, there was one other livestock operation in Washington County that required a WDNR Wisconsin Pollution Discharge Elimination System Permit. The principal contaminants associated with animal farm operations and feedlots are nitrogen, phosphorus, chloride, oxygen-demanding material, and microorganisms. Feedlots may also cause objectionable odor. The potential for groundwater contamination will depend on the volume of waste produced at a given site, waste handling practices, and general farm operations. Typically, animal waste is stored in a storage facility such as a manure pile, lagoon, or holding tank, and then periodically applied to the land as a source of plant nutrients. Unless livestock manure is applied to sandy soils that are prone to rapid internal drainage, most nutrient loss, especially phosphorus, occurs by erosion from overland runoff, and presents the greatest potential environmental threat to surface waters.

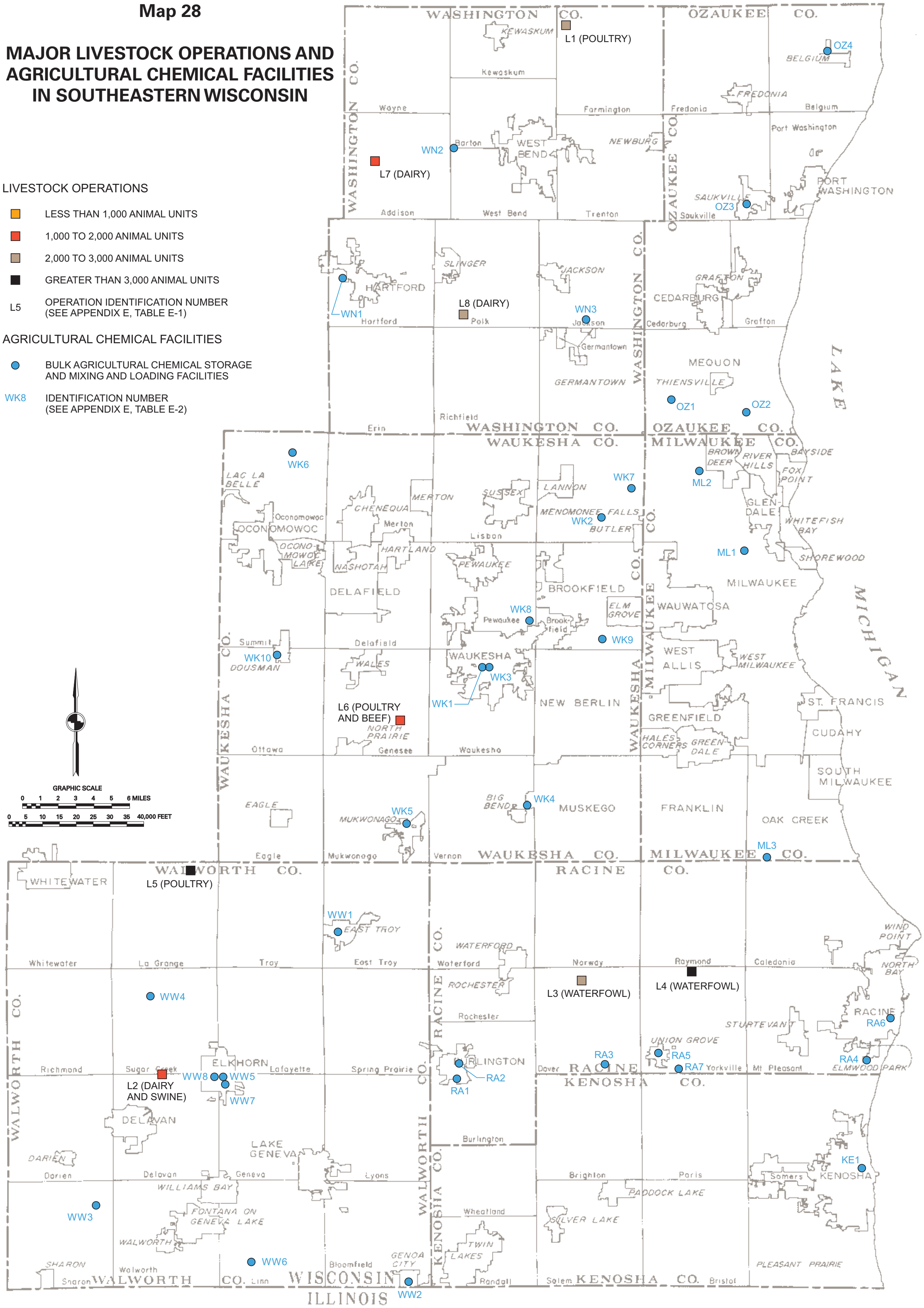
The WDNR regulates livestock operations with greater than 1,000 Animal Units through the Wisconsin Pollution Discharge Elimination System (WPDES) permit program. One animal unit (AU) is equivalent to a single mature beef unit weighing 1,000 pounds, e.g., 100,000 chickens equal 1,000 animal units. Proper plant nutrient management plays a critical role in assuring that large livestock operations manage the large volumes of animal waste they generate, and minimizes detrimental effects on the environment. Because of the nature of these facilities, the number and location changes periodically. It is recommended that the Wisconsin Department of Natural Resources be contacted for up-to-date information.

Agricultural Chemical Facilities

There were 36 bulk agricultural chemical (fertilizers and pesticides) storage and loading facilities in the Region in 1995, as shown on Map 28 and listed in Table 27. Selected information on these sites is included in Appendix E (Table E-2). Commercial fertilizers include a variety of types and concentrations of nitrogen, phosphorus, potassium, and trace elements, most of which are intended to improve plant growth and market value. While both

Map 28

MAJOR LIVESTOCK OPERATIONS AND AGRICULTURAL CHEMICAL FACILITIES IN SOUTHEASTERN WISCONSIN



Source: Wisconsin Department of Natural Resources and SEWRPC.

nitrogen and phosphorus may contribute to eutrophication of surface waters, the nitrogen component of fertilizer has generated the most concern regarding groundwater quality.

Storage and handling of large amounts of agricultural chemicals in a small area presents a potential for contamination of groundwater in case of an accident or mismanagement. However, there are no documented cases of contamination resulting from operations of these facilities in the Region at this time.

Salvage Yards

Salvage yards are another minor potential source of contamination. The danger of groundwater contamination increases if the sites handle hazardous materials from various automotive parts and accessories, such as grease, oil, solvents, and battery acids. Well-operated salvage yards present a minimal threat to groundwater. As of 1995, there were a reported 197 salvage yard sites scattered throughout the Region, as shown on Map 29 and Table 28 and listed in Appendix F (Table F-1). The majority of these sites are located in Milwaukee County and eastern Waukesha County.

Salt Storage Facilities

Salt storage, road salting, and snow dumping are all common practices used in the Region in relation to road de-icing and improvement of winter driving conditions. These activities may contribute to high salt concentrations in both groundwater and surface water. Of these activities, salt storage in uncovered piles appears to be the most critical with respect to potential groundwater contamination. Rainfall can dissolve the salt, which may then seep into shallow aquifers.

As of 1995, there were a reported 147 salt-storage facilities in the Region, shown on Map 29, summarized by county in Table 28, and listed in Table F-2, Appendix F. Nearly all of these facilities are covered. About 55 percent of these sites are located in counties with a dense network of highways such as Milwaukee and Waukesha. The Wisconsin Department of Natural Resources has reported documented cases of groundwater contamination due to past salt storage and handling practices. However, current design and maintenance of storage facilities minimizes the potential for infiltration of salt into groundwater.

Temporary Solid and Hazardous Waste Storage Sites

Temporary storage of solid and hazardous waste represents a minor threat to the groundwater. If the waste is handled correctly and regularly transferred to a long-term facility, contamination from these areas should not be significant. As of 1997, there were 31 such temporary storage facilities located in the Region, as shown on Map 30, summarized in Table 28, and listed in Appendix G (Table G-1). Two-thirds of these facilities are in Milwaukee and Waukesha Counties.

Bulk Fuel Storage Facilities

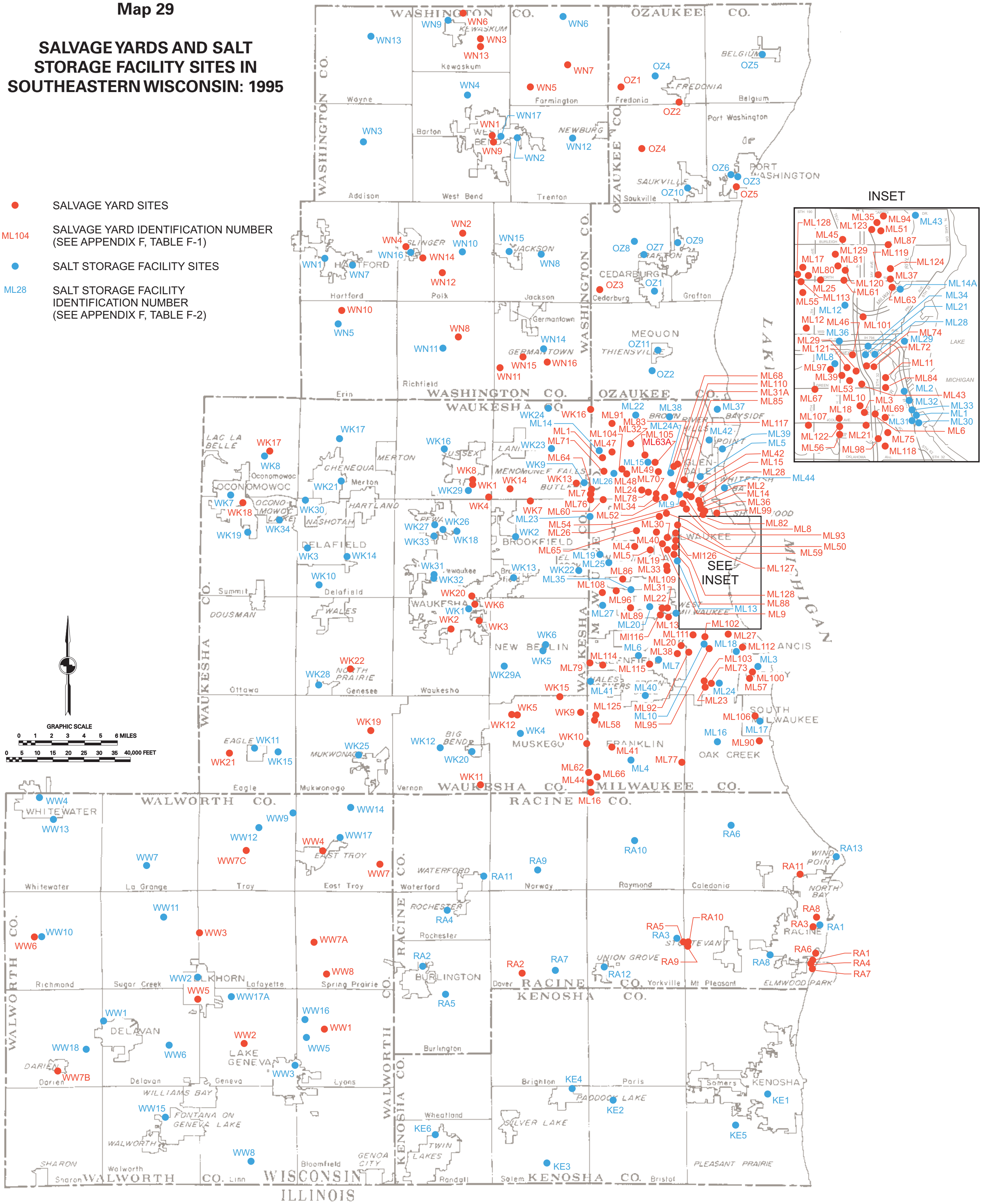
Bulk fuel storage sites are a potential source of groundwater contamination in the event of a spill or leak at the storage facility. As of 1995, there were 59 reported bulk fuel storage sites in the Region, as shown on Map 30, summarized in Table 28, and listed in Appendix G (Table G-2). Should a spill or leak occur, sites overlying sand and gravel materials would cause the greatest threat to contamination of the groundwater. In other areas, such incidents could also be potential sources of contamination to both the groundwater and surface water. Installation of containment structures under and around the storage tanks minimizes the risk of contamination due to ruptures or spills.

Spills of Hazardous Materials

Approximately 1,200 accidental or unintentional spills of hazardous materials are reported in Wisconsin every year, with nearly one-third of these spills occurring within the Region. An undetermined number of additional spills and illegal dumping of hazardous materials go unreported. Fortunately, many spills are small and can be cleaned up quickly before much of the substance can reach the groundwater. The types of spills varied, and have included substances such as fuel, mineral spirits, mineral oil, heating oil, hydraulic fluid, transformer fluid, chlorinated solvents, lubricants, hydrocarbons, as well as other unknown substances. By far, petroleum products are the contaminants most commonly involved in spills. The sites are scattered throughout the Region, but most of

Map 29

SALVAGE YARDS AND SALT STORAGE FACILITY SITES IN SOUTHEASTERN WISCONSIN: 1995

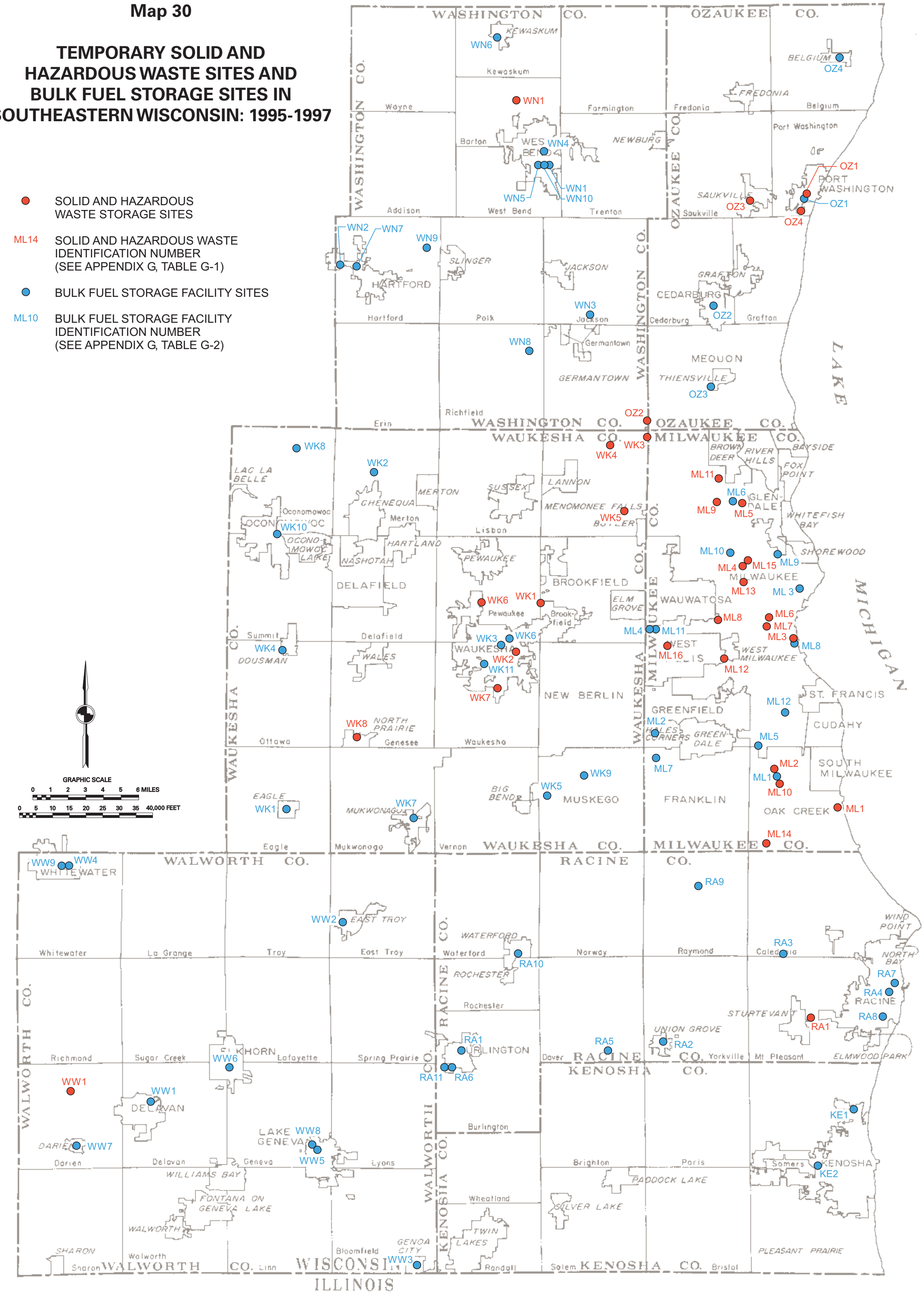


Source: Wisconsin Department of Transportation and SEWRPC.

Map 30

TEMPORARY SOLID AND HAZARDOUS WASTE SITES AND BULK FUEL STORAGE SITES IN SOUTHEASTERN WISCONSIN: 1995-1997

- SOLID AND HAZARDOUS WASTE STORAGE SITES
- ML14 SOLID AND HAZARDOUS WASTE IDENTIFICATION NUMBER (SEE APPENDIX G, TABLE G-1)
- BULK FUEL STORAGE FACILITY SITES
- ML10 BULK FUEL STORAGE FACILITY IDENTIFICATION NUMBER (SEE APPENDIX G, TABLE G-2)



Source: Wisconsin Departments of Natural Resources and Transportation and SEWRPC.

Table 28

MISCELLANEOUS POTENTIAL SOURCES OF GROUNDWATER CONTAMINATION IN SOUTHEASTERN WISCONSIN: 1995 AND 1997

County	Salvage Yards (as of 1995)	Salt Storage Facilities (as of 1995)	Temporary Solid and Hazardous Waste Storage Sites (as of 1997)	Bulk Fuel Storage Facilities (as of 1995)
Kenosha	0	6	0	2
Milwaukee	131	46	16	12
Ozaukee	5	11	4	4
Racine	11	13	1	11
Walworth	11	19	1	9
Washington	17	17	1	10
Waukesha	22	35	8	11
Total Number	197	147	31	59

NOTE: Because of the nature of the facilities noted, the number, location, and status changes periodically. The Wisconsin Departments of Natural Resources and Transportation should be contacted for the latest inventory information.

Source: Wisconsin Departments of Natural Resources and Transportation.

them have occurred along highways and within urban areas near storage tanks. The spills that required a major cleanup effort have been primarily centered around urban areas, with most occurring in the eastern portion of the Region, which tends to be underlain by clay tills with restricted permeability. Sites located on more permeable soils in the western half of the Region would be more susceptible to groundwater contamination. Spills of hazardous materials are also a potential hazard to surface waters, especially if the contaminant enters the storm sewer system.

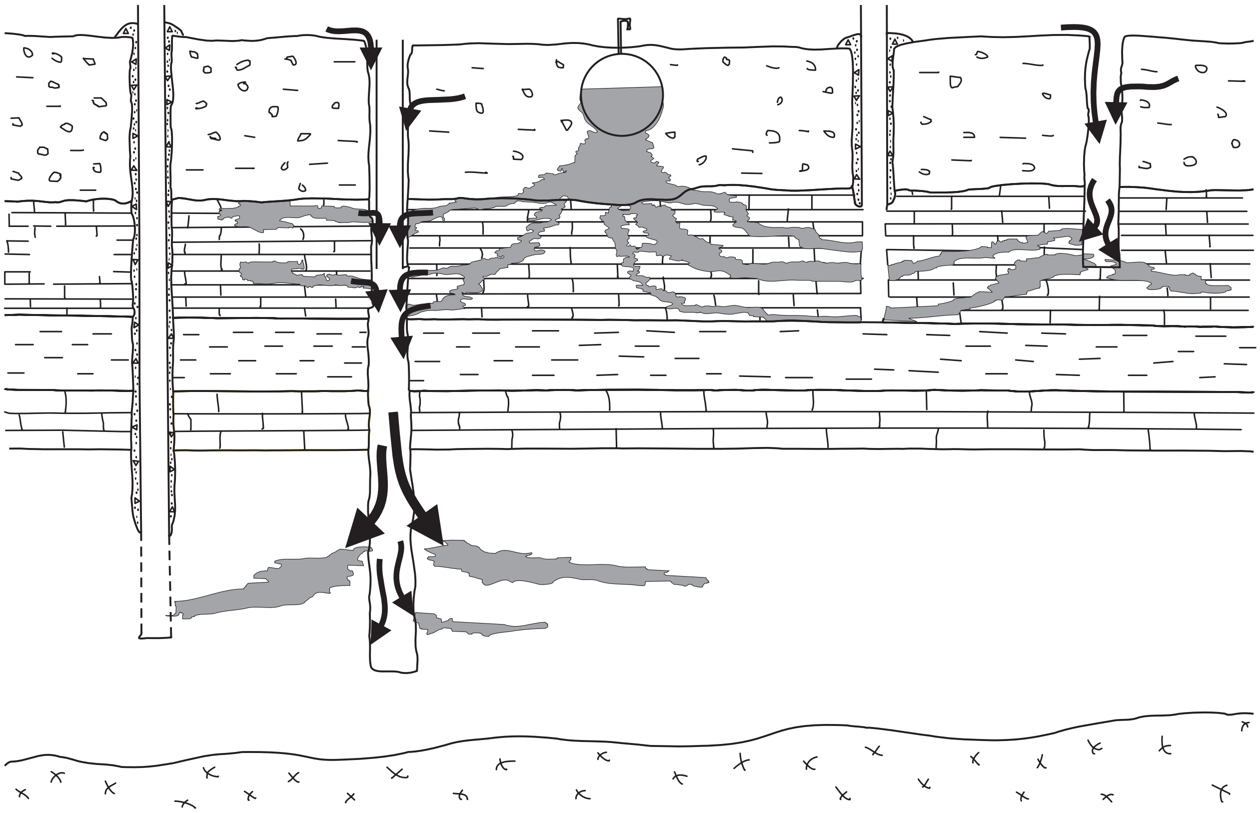
Improperly Abandoned Wells

One of the most important, yet overlooked, sources of groundwater contamination are old wells that are no longer used, but have not been properly sealed when abandoned. Proper well abandonment means filling the well from the bottom up with cement grout or bentonite (WDNR, 1994). The locations of old wells are often long-forgotten, and buildings or roads may have been built over the top of open boreholes. These wells can serve as a means for transmission of contaminants from the land surface to an aquifer and can permit contaminated water to migrate freely from one aquifer to another (Figure 15). This is particularly critical in Southeastern Wisconsin where the open intervals of most wells penetrate many different aquifer units. Even in areas where groundwater contamination potential is ordinarily considered low because of favorable soil and geological properties, such as Milwaukee and eastern Waukesha Counties, large numbers of improperly abandoned or unaccounted-for old wells create a significant threat to groundwater quality. In addition, an abandoned well can become a convenient receptacle for disposal of trash or a safety hazard.

Figure 15 illustrates the possible pathways that contaminants can take through improperly abandoned wells to threaten water quality in multiple aquifer systems. Wells B and D are improperly abandoned or poorly grouted wells, which enable contaminants from the land surface or from leaking underground storage tanks to migrate either to shallow production wells (C) in the upper aquifer or to deep production wells (A) in lower aquifers. If deep wells such as B are improperly abandoned or poorly grouted, they provide a conduit for contaminants to migrate below confining units, such as the Maquoketa shale, and contaminate deep sandstone aquifers normally considered well protected from surface activities.

Figure 15

AQUIFER CONTAMINATION THROUGH IMPROPERLY ABANDONED WELLS



Source: Adapted from DiNovo and Jaffe, 1984.

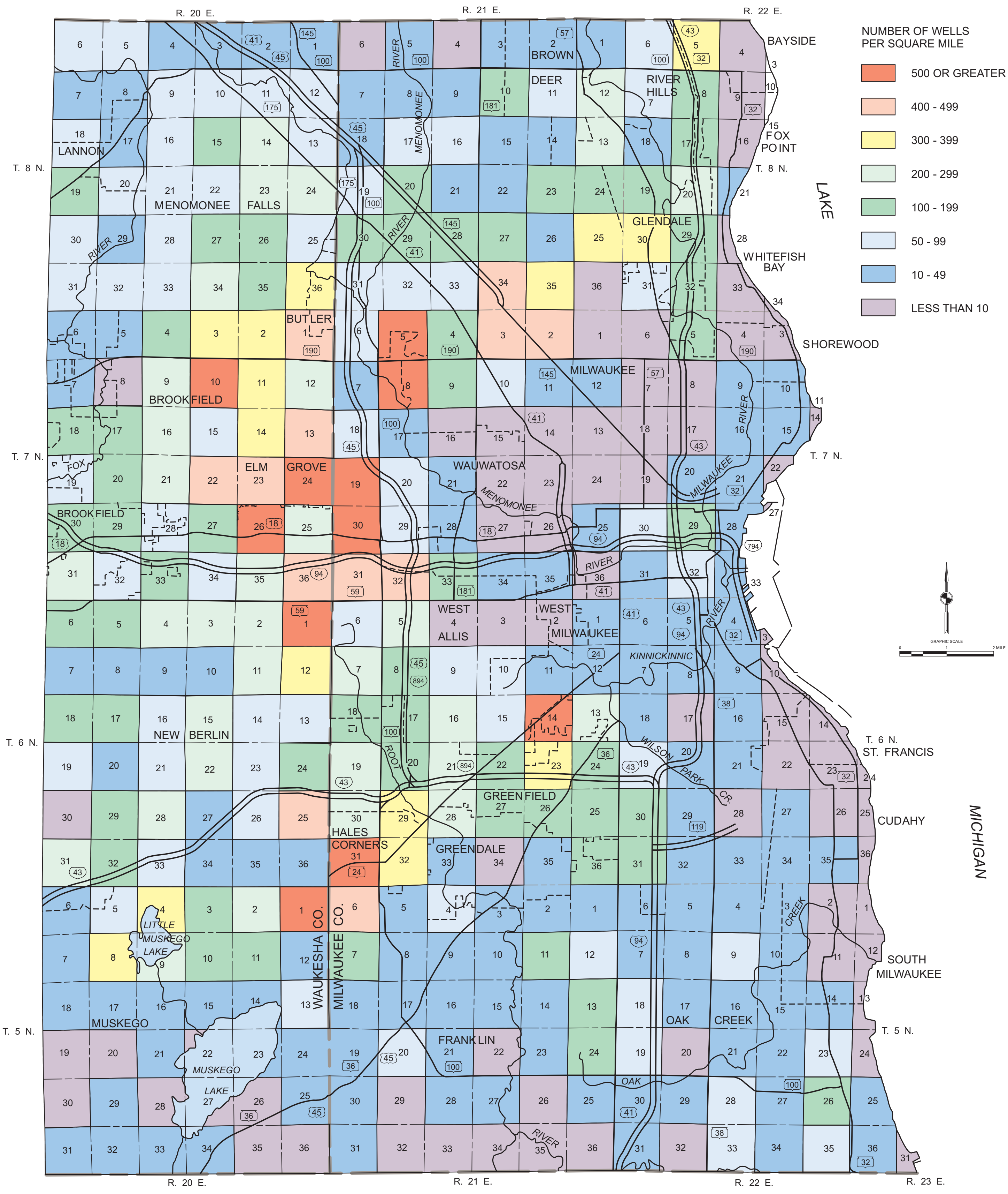
More than 100,000 private domestic and other wells have been drilled in Southeastern Wisconsin since the turn of the century, particularly before municipal water supply systems were established. Since 1936, well drillers have submitted Well Constructor's Reports (WCRs) for most of these wells to the Wisconsin Department of Natural Resources, and these WCRs are subsequently filed and sorted by reported location at the Wisconsin Geological and Natural History Survey (WGNHS). Densities of wells drilled between 1936 and 1979 in Milwaukee County and the easternmost townships in Waukesha County based on these records are illustrated in Map 31. Densities of wells for which records exist range from less than 10 per square mile in central and southern parts of Milwaukee County to more than 500 per square mile along the Milwaukee-Waukesha county line. Sections with at least 300 old well or boring records per square mile are located primarily in Brookfield, Wauwatosa, and Hales Corners.

Most of Milwaukee County was converted to municipal water supply by 1963, as shown on Map 32. Thus, Map 31 represents a reasonable count of potentially improperly sealed wells with records. However, the areas in Milwaukee County with relatively low densities of well records undoubtedly contain many wells drilled prior to 1936, for which no records exist. In eastern Waukesha County, numerous wells have been drilled since 1979, and numbers of WCRs and boring records per section shown on Map 31 probably are a significant underestimate of the total number of wells actually drilled.

Recently, the WDNR has introduced well abandonment forms, which should be submitted when unused, abandoned wells are properly sealed. The WDNR maintains files of these forms. Unfortunately, it is not possible to match well abandonment records with the original WCRs. Map 31 can be used to prioritize areas with high

Map 31

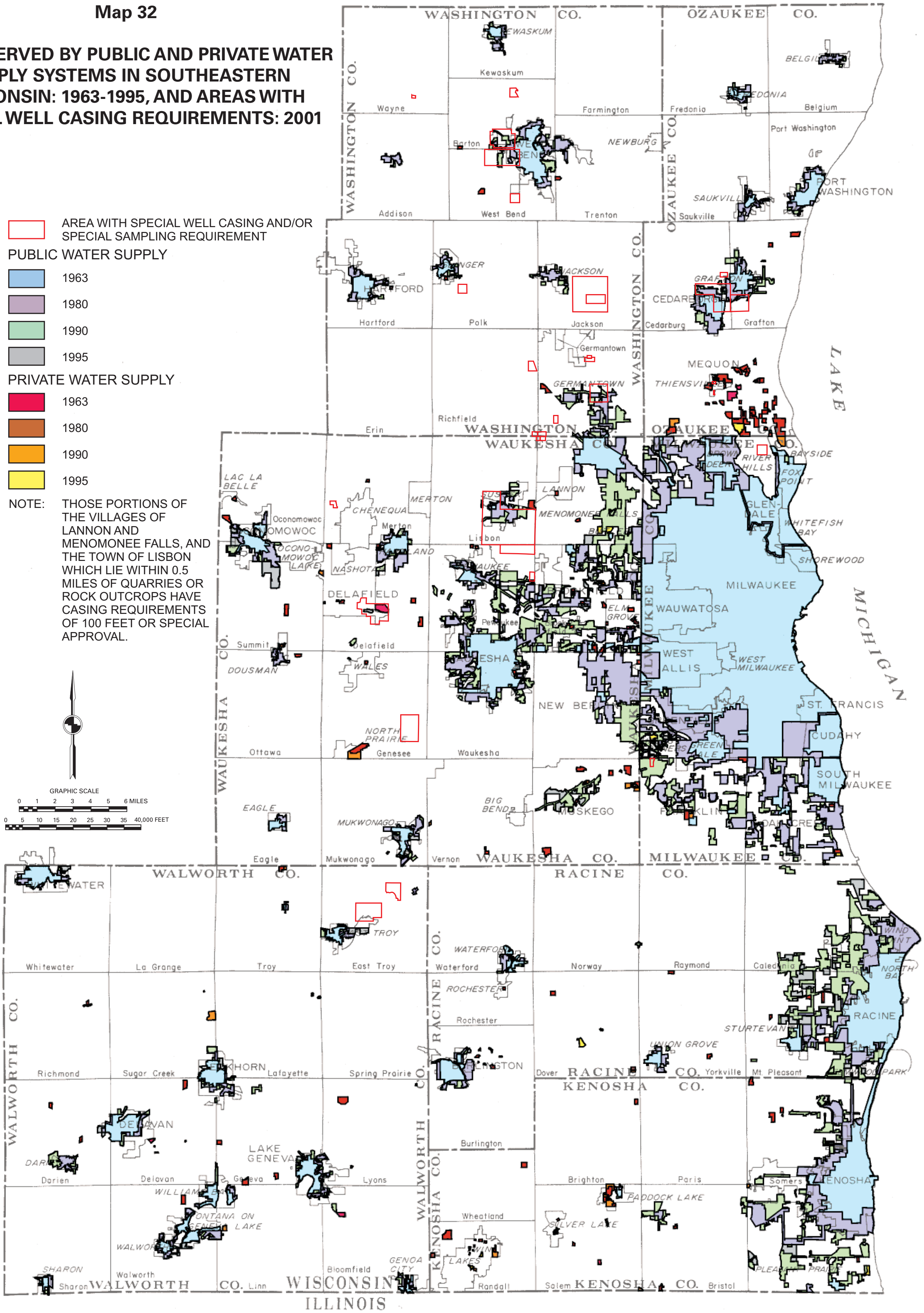
DENSITY OF WELL CONSTRUCTOR REPORTS AND BORING RECORDS, MILWAUKEE AND EASTERN WAUKESHA COUNTIES: 1936 - 1979



Source: Wisconsin Geological and Natural History Survey

Map 32

AREAS SERVED BY PUBLIC AND PRIVATE WATER SUPPLY SYSTEMS IN SOUTHEASTERN WISCONSIN: 1963-1995, AND AREAS WITH SPECIAL WELL CASING REQUIREMENTS: 2001



Source: Wisconsin Department of Natural Resources and SEWRPC.

probabilities of improperly abandoned wells for the WDNR well abandonment program, keeping in mind that for most areas this represents an underestimate of total wells drilled.

It is difficult to accurately estimate the number of improperly abandoned wells in Southeastern Wisconsin. As municipal water supply service areas expanded (Map 32), existing private domestic wells may have been sealed, or remain improperly abandoned, or are used for a secondary purpose, such as lawn watering, for which owners may or may not have been granted a permit. By comparing numbers from various sources, the WDNR has estimated that four areas: Milwaukee County; eastern Waukesha County, including the City of Waukesha; eastern Racine County; and eastern Kenosha County, have the most abandoned wells (Peter Wood, WDNR Southeast Region, written communication, 1997). The WDNR has estimated that Milwaukee County had up to 8,000 improperly abandoned wells; eastern Waukesha County, including the City of Waukesha, up to 3,000 improperly abandoned wells; and eastern Racine County and eastern Kenosha County about 1,000 improperly abandoned wells each.

The existence of unused, abandoned wells represents a significant contamination threat to both shallow and deep groundwater. It is not an intention of this report to show an accurate, absolute number of such wells, but rather to point out improperly abandoned wells as a serious problem in the Region, which has to be directly addressed in any regional water resource planning effort.

Aquifer Storage and Recovery Considerations

During the late 1990s, there has been an interest expressed by some water utilities in the concept of aquifer storage and recovery (ASR) as a water supply management practice. ASR is a practice of pumping water into confined aquifers for storage purposes at low demand times with recovery of that water to meet peak demands. The City of Oak Creek has conducted demonstrations using this concept since 1999. In that case, treated water from the City's Lake Michigan water supply treatment plant was stored in the deep sandstone aquifer and later pumped from the aquifer for experimental purposes, with the water eventually being distributed into the City water supply system once testing indicated safe water quality conditions. Other communities in the State are also evaluating this practice as a potential management tool since there is a potential to minimize the need for new supply sources and constructed storage. The practice is now being evaluated by the Wisconsin Department of Natural Resources with regard to potential water quality problems and management potential.

It is not envisioned that treated wastewater or stormwater would be allowed to be discharged into aquifers due to contamination concerns. Thus, only treated drinking water is currently being considered.

APPROACH TO THE EVALUATION OF VULNERABILITY OF GROUNDWATER TO CONTAMINATION FOR THE REGION

Processes Affecting the Fate and Transport of Contaminants in the Subsurface

The potential for groundwater contamination depends on the attenuation processes that take place between the source of contamination and the aquifer. Attenuation of most contaminants, as they travel through the unsaturated zone and groundwater system, is affected by a variety of naturally occurring chemical reactions and biological and physical processes that often cause the contaminant to change its physical state or chemical form. These changes may lessen the severity of contamination or amounts of contaminants. Once contaminants reach the saturated zone (an aquifer), fewer processes attenuate contaminant concentrations than in the unsaturated zone. Although the importance of these processes in attenuation of contaminants is well recognized, predicting how much attenuation will take place in a particular environment is still difficult (Aller and others, 1987). The degree of attenuation that occurs depends upon: (1) the grain size and physical and chemical characteristics of the material through which the contaminant passes, (2) the time the contaminant is in contact with the material through which it passes, and (3) the distance which the contaminant has traveled. However, attenuation processes can be bypassed completely if a contaminant is introduced directly into an aquifer.

Evaluation System
Many methods have been developed to evaluate the groundwater contamination potential. The most commonly used ones are the overlay methods combining several major physical factors considered most important for the evaluation of a given area. The factors typically include soil characteristics, lithology and thickness of the unsaturated zone, and depth to water. The methods often rely on a numerical rating system to assess the importance and relationship of individual parameters. A numerical rating is assigned to each of the selected parameters, and the final numerical score is calculated for each hydrogeologic setting present in the area by summing the numerical scores of the individual parameters (Aller and others, 1987).

The system for the evaluation of contamination potential in the Region is based on the following five parameters:

1. **S**oil characteristics.
2. **U**nsaturated zone thickness.
3. **P**ermeability of vertical sequences in the unsaturated zone.
4. **R**echarge to groundwater, represented by soil percolation.
5. **A**quifer characteristics.

In the approach used for this report, the evaluation of the physical environment in the Region was separated into three independent components according to the intended use or activity and the fate of contaminants in the subsurface:

1. Evaluation of the capacity of soils to attenuate contaminants.
2. Evaluation of the contamination potential of shallow groundwater.
3. Evaluation of the contamination potential of deeper aquifers.

Each of these components can be mapped separately, and the maps can be used individually or combined into a composite map. Using three independent components makes the system use-specific. However, at this point, the third component—the contamination potential of deeper aquifers—can be considered only generally, limited to currently available information. Components 1 and 2 are presented on Map 12 in Chapter III and Map 33.

The capacity of soils to attenuate contaminants have been evaluated by the Soil Contamination Attenuation Model (SCAM), using seven physical and chemical characteristics of soils. The system evaluates the ability of the soil solum (the A and B horizons) to attenuate potential contaminants resulting from activities above and within the soil zone. It was developed by F.W. Madison in 1985 and it is described in Chapter III of this report.

The evaluation of the contamination potential of shallow groundwater is based on three parameters: thickness of the unsaturated zone, permeability of vertical sequences in the unsaturated zone, and estimated annual soil percolation rate as an approximation of recharge. This component of the system evaluates the capacity of the subsurface environment to attenuate contaminants resulting from activities within the unsaturated zone or contaminants that penetrated the soil zone as described in the next section.

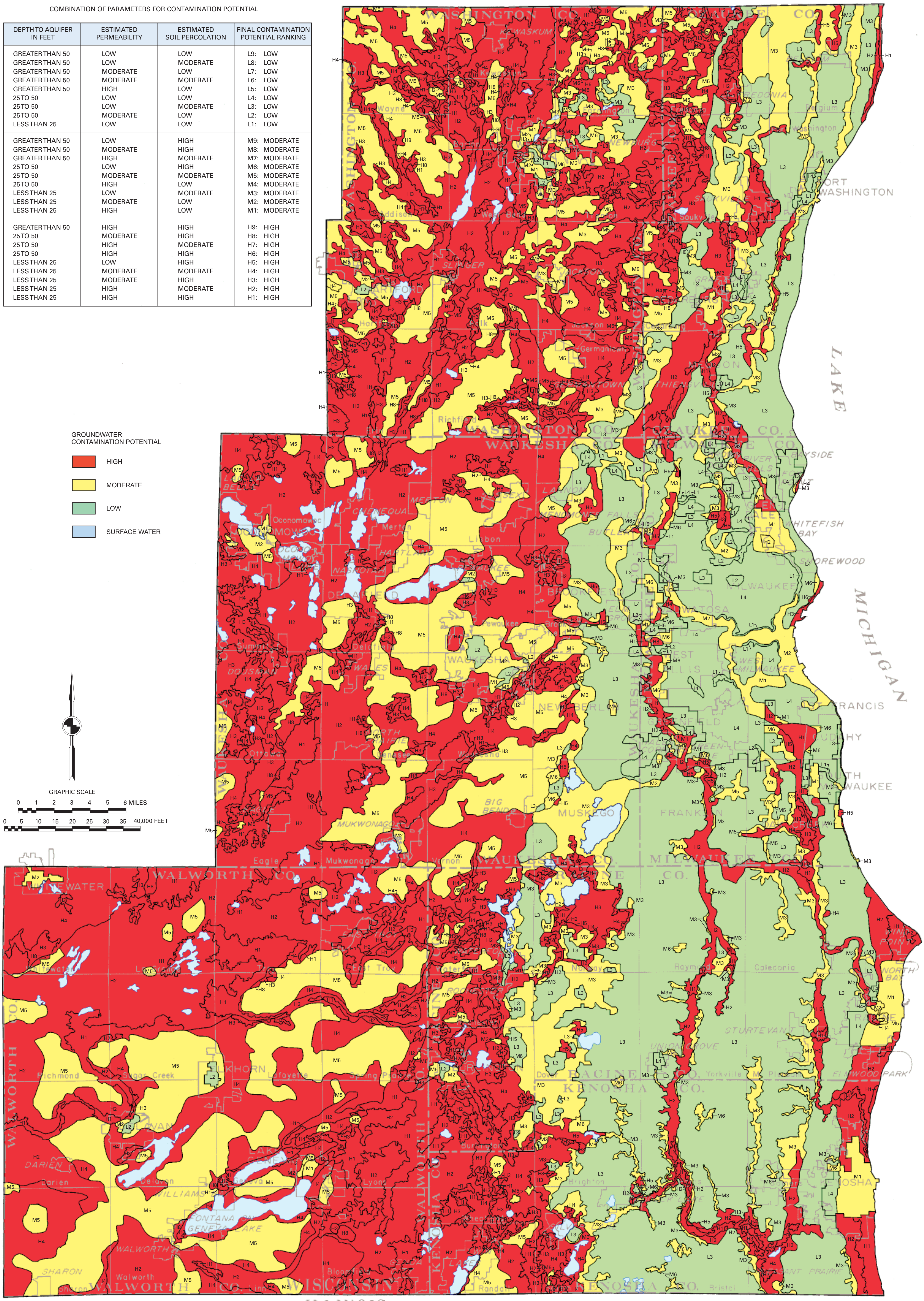
The contamination potential of the deeper aquifers is based upon consideration of the geologic and groundwater-flow characteristics, such as bedrock lithology; presence of the Maquoketa shale unit; location, extent and character of the recharge areas; and general direction of groundwater flow. This component of the system helps evaluate the general movement of contaminants that reach the deep groundwater-flow systems and also helps define protection zones related to water supply sources.

Map 33

GROUNDWATER CONTAMINATION POTENTIAL OF SHALLOW AQUIFERS IN THE SOUTHEASTERN WISCONSIN REGION

COMBINATION OF PARAMETERS FOR CONTAMINATION POTENTIAL

DEPTH TO AQUIFER IN FEET	ESTIMATED PERMEABILITY	ESTIMATED SOIL PERCOLATION	FINAL CONTAMINATION POTENTIAL RANKING
GREATER THAN 50	LOW	LOW	L9: LOW
GREATER THAN 50	LOW	MODERATE	L8: LOW
GREATER THAN 50	MODERATE	LOW	L7: LOW
GREATER THAN 50	MODERATE	MODERATE	L6: LOW
GREATER THAN 50	HIGH	LOW	L5: LOW
25 TO 50	LOW	LOW	L4: LOW
25 TO 50	LOW	MODERATE	L3: LOW
25 TO 50	MODERATE	LOW	L2: LOW
LESS THAN 25	LOW	LOW	L1: LOW
GREATER THAN 50	LOW	HIGH	M9: MODERATE
GREATER THAN 50	MODERATE	HIGH	M8: MODERATE
GREATER THAN 50	HIGH	MODERATE	M7: MODERATE
25 TO 50	LOW	HIGH	M6: MODERATE
25 TO 50	MODERATE	MODERATE	M5: MODERATE
25 TO 50	HIGH	LOW	M4: MODERATE
LESS THAN 25	LOW	MODERATE	M3: MODERATE
LESS THAN 25	MODERATE	LOW	M2: MODERATE
LESS THAN 25	HIGH	LOW	M1: MODERATE
GREATER THAN 50	HIGH	HIGH	H9: HIGH
25 TO 50	MODERATE	HIGH	H8: HIGH
25 TO 50	HIGH	MODERATE	H7: HIGH
25 TO 50	HIGH	HIGH	H6: HIGH
LESS THAN 25	LOW	HIGH	H5: HIGH
LESS THAN 25	MODERATE	MODERATE	H4: HIGH
LESS THAN 25	MODERATE	HIGH	H3: HIGH
LESS THAN 25	HIGH	MODERATE	H2: HIGH
LESS THAN 25	HIGH	HIGH	H1: HIGH



Source: Wisconsin Geological and Natural History Survey and SEWRPC, 1997.

EVALUATION OF CONTAMINATION POTENTIAL OF SHALLOW GROUNDWATER

Description of the Evaluation Method

Vulnerability of shallow groundwater in any given area of Southeastern Wisconsin is essentially dependent on three parameters: distance from the land surface to the aquifer, properties of materials through which contaminants have to pass to reach the aquifer, and rates at which such contaminants can travel. The uppermost bedrock aquifer in Southeastern Wisconsin is almost uniformly dolomite, so differences in the type of bedrock are not a significant factor.

The first parameter, distance from land surface to the shallow aquifer, was assessed in this study according to the position of the water table. If the water table is below the top of a bedrock or sand and gravel aquifer, then the most vulnerable areas are considered to be those where the top of the bedrock or sand and gravel is located closest to the land surface. Otherwise, distance to the aquifer is depth to the water table. The second parameter—properties of materials—was assessed by estimating vertical permeability of the materials in the unsaturated zone. The third parameter—travel time—was the most difficult to assess, and in the case of soluble contaminants, is best represented by groundwater recharge, which is a complex process. However, for contamination potential mapping, the most important aspect of recharge is direct infiltration or soil percolation, which can be estimated or mapped based on soil classification.

Source maps used to generate the maps of contamination potential are listed in Table 29. The first parameter is commonly represented by contoured maps of the depth to bedrock and depth to the water table. Maps of the second and third parameters are derived from existing maps such as Pleistocene geology maps or soil classification maps (Table 29).

Vertical permeability of the unsaturated zone was estimated from Pleistocene geology maps, geologic cross sections, water table elevations, and existing field data on hydraulic conductivity of Pleistocene materials in Wisconsin. Materials were assigned estimated hydraulic conductivities by type of material over a range of 1×10^{-7} to 1×10^{-2} centimeters per second (cm/s). Geologic cross sections were then used to estimate overall vertical permeability of each Pleistocene map unit above the water table by weighting the conductivity of each material type by its thickness in profile (Freeze and Cherry, 1979). Finally, generalized Pleistocene geology map units were classified into three categories of estimated vertical permeability, as shown in Table 30.

Soil percolation rates were estimated by analyzing water budgets for different soil textures in several subwatersheds with different land uses, using a modified U.S. Environmental Protection Agency (EPA) method of calculating leachate generation from landfills (Eaton, 1995). The results were generalized to three classes of soil percolation, and applied on a regional basis using the U.S. Natural Resources Conservation Service (formerly Soil Conservation Service) Hydrologic Soil Group (HSG) classification (USDA Soil Conservation Service, 1986) and a similar soil classification for attenuation of contaminants developed at WGNHS (Cates and Madison, 1991). Urban areas were assigned a low percolation rating regardless of soil, due to the extent of impervious surfaces. Estimated values of soil percolation are presented in Table 31, and represent approximately from less than 9 percent to more than 19 percent of annual precipitation, which is about 32 inches per year in Southeastern Wisconsin.

Mapping Method

For the evaluation and mapping of contamination potential of shallow groundwater a two-step procedure was developed, using a geographic information system (GIS) computerized analysis. The four maps listed in Table 29 were superimposed, using a GIS, to evaluate contamination potential for different areas. The digital intersection of these maps results in a new network of polygons, each having four attributes corresponding to the classes of the component maps. Subsets of these polygons can then be selected using Boolean logic to evaluate the contamination potential of different areas. Because each map has only three classes, this GIS operation can be more readily understood as a conceptual two-step procedure using three by three matrices.

Table 29

COMPONENT MAPS FOR CONTAMINATION POTENTIAL ASSESSMENT OF SOUTHEASTERN WISCONSIN

- Depth to bedrock (contoured)
- Depth to the water table (contoured)
- Permeability of the unsaturated zone (derived)
- Soil percolation (derived)

Source: Wisconsin Geological and Natural History Survey.

Table 30

VERTICAL PERMEABILITY OF PLEISTOCENE UNITS IN SOUTHEASTERN WISCONSIN

Class	Material	Estimated Permeability
High	Sand and gravel/outwash	More than 1 x 10^{-3} cm/s
Moderate	Sandy silt till/glaciolacustrine	Less than 1 x 10^{-3} to more than 1 x 10^{-5} cm/s
Low	Silt and clayey silt till	Less than 1 x 10^{-5} cm/s

Source: Wisconsin Geological and Natural History Survey.

Table 31

ESTIMATED VALUES OF SOIL PERCOLATION RATE IN SOUTHEASTERN WISCONSIN

Percolation Class	HSG	Soil Texture	Estimated percolation
High	A	Fine sand/sandy loam	>6 inches per year
Moderate	B	Silty loam/loam	3-6 inches per year
Low	C,D	Clay loam/clay	< 3 inches per year

Source: Wisconsin Geological and Natural History Survey.

Table 32

INITIAL VULNERABILITY MATRIX

Estimated Permeability of Unsaturated Zone	Depth to Aquifer: Water Table or Bedrock or Sand and Gravel Aquifer		
	<25 Feet	25-50 Feet	>50 Feet
High Permeability	H	H	M
Moderate Permeability	H	M	L
Low Permeability	M	L	L

Source: Wisconsin Geological and Natural History Survey.

In the first step, a GIS coverage of three classes of estimated vertical permeability of materials in the unsaturated zone is digitally combined with three classes of the depth to aquifer to produce the initial vulnerability matrix (Table 32). Depth to aquifer is represented by mapped ranges of depth to either the water table, or bedrock, or sand and gravel aquifers. Three classes were considered: zero to 25 feet, 25 to 50 feet, and greater than 50 feet. In assessing the depth to aquifer parameter, the most vulnerable situation—i.e., the shallowest depth—is selected, depending on the position of the water table. Since in practice, it is difficult to map areas of buried sand and gravel aquifers, the assumption was made that any area classified as highly permeable contains a sand and gravel aquifer less than 25 feet below the surface, and moderate to low permeability areas do not. A qualitative rating of High (H), Moderate (M), or Low (L) was symmetrically distributed in the body of the matrix such that cross-referencing permeability (left column) and depth to aquifer (top row) provided a High (H), Moderate (M), or Low (L) initial vulnerability of the shallow aquifer. This allowed an initial vulnerability rating to be assigned to any area on the basis of aquifer depth and estimated permeability.

The second step involved digital combination of the initial vulnerability ratings of High, Moderate, or Low from Table 32 with three classes of the final parameter, the estimated soil percolation (Table 33). Cross-referencing the columns and rows of this matrix provided the final contamination potential ranking of High (H), Moderate (M), or Low (L) in the body of the matrix (Table 33) for each area under consideration.

The two-step matrix procedure was designed to conceptually illustrate the Boolean logic operations that are actually used to select the final contamination potential rankings using the GIS-assisted analysis. The GIS procedures perform the operations on all the polygons in the mapped area at the same time, rather than individually as the matrices assume.

Table 33

CONTAMINATION POTENTIAL MATRIX

Initial Vulnerability (Table 32)	Estimated Soil Percolation Rate		
	< 3 Inches per Year	3-6 Inches per Year	> 6 Inches per Year
High	M	H	H
Moderate	L	M	H
Low	L	L	M

Source: Wisconsin Geological and Natural History Survey.

Table 34

COMBINATIONS OF PARAMETERS FOR CONTAMINATION POTENTIAL MAPPING

Depth to Aquifer	Estimated Permeability	Estimated Soil Percolation	Final Contamination Potential Ranking
>50 Feet	Low	Low	L9: Low[a]
>50 Feet	Low	Moderate	L8: Low[a]
>50 Feet	Moderate	Low	L7: Low[a]
>50 Feet	Moderate	Moderate	L6: Low[a]
>50 Feet	High	Low	L5: Low[a]
25-50 Feet	Low	Low	L4: Low
25-50 Feet	Low	Moderate	L3: Low
25-50 Feet	Moderate	Low	L2: Low
<25 Feet	Low	Low	L1: Low
>50 Feet	Low	High	M9: Moderate[a]
>50 Feet	Moderate	High	M8: Moderate[a]
>50 Feet	High	Moderate	M7: Moderate[a]
25-50 Feet	Low	High	M6: Moderate
25-50 Feet	Moderate	Moderate	M5: Moderate
25-50 Feet	High	Low	M4: Moderate[a]
<25 Feet	Low	Moderate	M3: Moderate
<25 Feet	Moderate	Low	M2: Moderate
<25 Feet	High	Low	M1: Moderate
>50 Feet	High	High	H9: High[a]
25-50 Feet	Moderate	High	H8: High
25-50 Feet	High	Moderate	H7: High[a]
25-50 Feet	High	High	H6: High[a]
<25 Feet	Low	High	H5: High
<25 Feet	Moderate	Moderate	H4: High
<25 Feet	Moderate	High	H3: High
<25 Feet	High	Moderate	H2: High
<25 Feet	High	High	H1: High

[a]*Not present in Southeastern Wisconsin.*

Source: Wisconsin Geological and Natural History Survey.

Since there are three classes for each of the three characteristics considered in this procedure, there are 27 possible different combinations of these classes, as shown in Table 34. One of the three final contamination potential rankings: High, Moderate, or Low, is assigned to each combination on the basis of the two-step procedure using the matrices in Tables 32 and 33. This results in an "averaging" of the vulnerability factors associated with each parameter. For instance, in the case of depth to aquifer greater than 50 feet, low permeability, and low soil percolation, the Boolean logic operation would take the form: "Select all polygons such that depth to water table >50 ft *or* depth to bedrock >50 ft *or* permeability not equal to H; then select from that subset all polygons such that permeability = L *and* soil percolation = L."

Because of the "*or*" operators in the first part of the Boolean logic operations and in Table 32, the resulting sets of polygons meeting each combination of vulnerability criteria are not always mutually exclusive. Therefore, the GIS-assisted analysis procedure of selecting each of these subsets causes some reclassification, and the order of selection for contamination potential ranking is important. All combinations corresponding to a Low ranking must be selected first, then all combinations corresponding to a Moderate ranking, and finally all combinations corresponding to a High ranking, in the same order as presented in Table 34.

Once ranked, the resulting sets of polygons—or map areas—are represented in different colors: red for High, yellow for Moderate, and green for Low, to indicate areas of differing vulnerability of the shallow aquifer. Labels corresponding to the letter-number designation of each final contamination potential ranking—such as L1, M1, or H1—were used to identify the different areas on the map (Map 33). However, not all of the possible combinations of parameters occur in the study area (Table 34).

Labeling each polygon enables the user of the map to identify the reasons for which any area was ranked, by referring to Table 34. All final rankings are understandable in terms of the three original groundwater vulnerability factors previously identified—depth to aquifer, vertical permeability of materials in the unsaturated zone, and soil percolation. As with any GIS polygon intersection operation, small meaningless "sliver" polygons were generated in this assessment, and polygons smaller than 0.25 square mile were deleted for the final published map.

Any method for assessing and mapping of contamination potential should be evaluated. However, developing a conclusive verification procedure is difficult. The distribution of actual groundwater contamination is more a consequence of various land use activities or spill events than of any geologic or hydrogeologic factors. Furthermore, available data on groundwater quality tend to be concentrated at contamination sites and would not be representative of groundwater quality on a regional basis. For these reasons, correlative analyses would be misleading. Conclusive verification of the method used was beyond the scope of this study. Nevertheless, the correspondence of high contamination potential areas with local geologic, hydrogeologic, and soil characteristics conducive to groundwater vulnerability, and vice versa, provide a level of confidence in the internal consistency of the method. This method, however, is not a replacement for site-specific field studies, but rather is intended to be used as a guide to the conduct of such studies and as a sound basis for more general land use and facility planning.

CONTAMINATION POTENTIAL ANALYSIS

A comprehensive assessment of the vulnerability of groundwater to contamination in the Region has not been carried out previously to this study. Previous studies either dealt with a part of the Region or a single contamination source, or were done at a limited Statewide scale. In 1971, in the first study that addressed the potential for contamination of groundwater in the Region, Ketelle (1971) investigated geologic factors important to determine the suitability of land for liquid waste disposal. In that study, four general maps were used to develop the final suitability map: soil permeability, thickness of surficial deposits, nature of surficial deposits, and nature of the bedrock. In 1979, Sherrill (1979) constructed a map of contamination potential in the Silurian dolomite aquifer at the scale 1:250,000, based on three factors: the relative permeability of unconsolidated materials, the thickness of those materials, and the depth to the water table. In 1987, the Wisconsin Department of Natural Resources completed a statewide map of groundwater contamination susceptibility at the scale of 1:1,000,000 (Schmidt and Kessler, 1987). Five factors were considered in the preparation of the map: soil characteristics, depth to the water table, characteristics of surficial deposits, depth to bedrock, and type of bedrock.

In order to comprehensively assess the contamination potential of groundwater in the Region, this study has developed the aforementioned evaluation system, which is designed to specifically assess the potential for contamination of shallow groundwater; that is, the threat of contamination to the water table aquifer. As already noted, this threat to groundwater quality varies according to possible sources of contamination. The subsurface environment can provide three levels of protection against such sources. In general, for contaminants spilled at the land surface, the soil layer itself provides the first barrier to groundwater contamination. For contaminants that have penetrated the soil layer or for shallow subsurface sources of contamination such as on-site sewage disposal systems and leaking underground storage tanks, the nature of the unlithified geology and hydrogeology, as assessed in the groundwater contamination potential system, form the next barrier. If the shallow aquifer becomes contaminated, this constitutes a possible contamination source for deeper aquifers, because of the hydrologic interconnection of aquifer systems. The nature of the deeper bedrock geology and groundwater-flow systems constitute the final barrier to more extensive, deep groundwater contamination.

The contamination potential of groundwater in Southeastern Wisconsin is described at all three levels in the following sections. It is important to note, however, that any of the three barriers to groundwater contamination can be bypassed by various mechanisms. For instance, in areas where numerous leaking underground storage tanks, quarries, or gravel pits exist, it is clearly inappropriate to use the soil contaminant attenuation map to assess contamination potential, because contaminants from these sources have already bypassed the soil barrier. In addition, soils have only a limited capacity to attenuate contaminants. If there is a large spill of a contaminant, such as rupture of a high-volume petroleum storage tank, it is likely that the soil attenuation capacity at that location will be quickly overwhelmed. Furthermore, where there is reason to believe that numerous improperly abandoned wells exist, as previously noted, the contamination potential map for shallow groundwater may be misleading, because improperly abandoned wells are direct conduits that bypass the second barrier created by the unlithified geology and hydrogeology.

Potential for Contamination By Surface Sources

Since the first barrier to groundwater contamination is the soil, the threat of groundwater contamination from surface sources in Southeastern Wisconsin depends on the nature of soils and their ability to attenuate or neutralize contaminants (Chapter III). Map 12 shows the distribution of soils with differing attenuation properties based on a system described in Chapter III. The better the soil attenuation rating for a given area, the more likely it is that the soil can help neutralize small contaminant spills before they reach the groundwater, thus reducing the contamination threat to groundwater from surface activities. Conversely, the lower the soil attenuation rating, the greater the contamination threat to groundwater from surface activities.

The system for evaluating the ability of soils to attenuate contaminants is designed to assess soils in their natural, undisturbed state. There are some areas in all counties where soils may have been extensively modified, in which case mapped attenuation ratings may not be accurate. Over time, soil properties change as land is put into intensive agricultural production and eroded, or land use changes from rural to suburban or urban uses. Therefore, soil properties for attenuating contaminants must be verified by field examination for any specific area.

Map 12 indicates that more than one-half of the land area of the Region is covered by soils that have good and best potential for attenuating contaminants, and thus may be considered less susceptible to contamination from surface sources and well suited for a variety of land uses. These soils appear to be fairly evenly distributed across the Region on upland till surfaces. Areas where soils are best suited for attenuating contaminants, and therefore, contamination potential is the lowest, have good loamy or clayey soil texture; and thick, well-drained soils. Soils with best attenuation potential cover about six percent of the total land area of the Region (Appendix C) and are found mostly in Walworth County. Some examples are large areas located southwest of Lake Geneva and along the western boundary in Walworth County. Soils with good attenuation potential cover about 49 percent of the land area of the Region (Appendix C).

Approximately 43 percent of the land area of the Region is covered by soils with poor—marginal and least—attenuation potential (Appendix C). Soils that have the least attenuation potential, and thus, may be considered most susceptible to contamination by surface sources, account for about 16 percent of the total land area of the Region. Areas where soil attenuation is least tend to be concentrated in terminal moraine areas, where the surface drainage has been extensively disrupted by glacial debris, and in areas of poorly drained organic soils in land depressions with standing water and near lakes and rivers (Map 12). For example, the Fox River valley and the Bark River valley in Waukesha County, the Cedarburg Bog in Ozaukee County, the lowlands near Wind Lake in Racine County, and the upper valleys of Honey, Sugar, and Turtle Creeks in Walworth County are all examples of this setting. Other major areas of least soil attenuation are sandy soils in the Kettle Moraine in Waukesha and Walworth Counties and sandy soils along the Lake Michigan shoreline.

Due to their disturbance, soils have not been mapped in the urban areas of Milwaukee County, so it is not possible to determine attenuation potential for that area, which is shown in gray on Map 12.

Contamination Potential of Shallow Aquifers

The contamination potential of shallow groundwater, as mapped in this study, is illustrated for the Southeastern Wisconsin Region on Map 33. This map was compiled in digital form by County at a scale of one inch equals 4,000 feet. Areas of differing relative contamination potential are shown in red (high contamination potential), yellow (moderate contamination potential), and green (low contamination potential). Groundwater vulnerability factors used in assigning contamination potential rankings can be identified by using the map labels to refer to the table (Table 34) presented adjacent to the map. The map indicates that approximately one-half of the land area of the Region has a high potential for contamination of shallow aquifers, especially in the inland counties. Therefore, there is a need for careful planning of activities that may affect shallow aquifers.

The most noticeable feature of the regional groundwater contamination potential map is the west-east dichotomy between primarily high and moderate contamination potential areas in the west and primarily low contamination potential areas in the east. This is a reflection of the heavy influence of the Pleistocene glacial materials on groundwater vulnerability. The inland counties are dominated by sandier sediment and the lakeshore counties are dominated by less permeable silty sediment. Depth to the groundwater table is also an important groundwater vulnerability factor, which accounts for most of the additional variations in contamination potential.

Inland Counties

In the inland counties of the Region—Washington, Waukesha, and Walworth—a large portion of the land area (65 percent) has a high contamination potential (Map 33). Moderate contamination potential areas constitute 30 percent, and low contamination potential areas five percent of the total land area of these counties (Table 35).

Of the three inland counties, Walworth County has the largest area with high contamination potential: 71 percent of the county land area. Areas most vulnerable to contamination are those that have shallow depths to groundwater and high permeability (H2), or those underlain by outwash deposits with shallow depths to aquifer and high or moderate soil percolation (H3, H4). Many of these areas are found in valleys, such as the Fox River valley, where the water table is close to the surface. Much of the areas of northeastern Waukesha and southeastern Washington Counties are vulnerable to groundwater contamination because the bedrock aquifer is close to the surface. In addition, some upland areas, particularly in the Kettle Moraine, have high contamination potentials (H1, H2) because estimated permeabilities are high due to the presence of extensive sand and gravel deposits.

The moderate contamination potential classification (primarily M5), is attributable to shallow to average depth to groundwater, moderate permeability, and moderate soil percolation (see Table 34). M1 and M2 areas are found primarily in areas of urban development, where low soil percolation compensates for shallow depth to the aquifer. M3 areas are found primarily in eastern Waukesha and Washington Counties, where low permeability compensates for shallow depth to aquifer. Areas of low contamination potential labeled L1 and L2 are found in urban areas due mainly to low soil percolation. Some areas in eastern Washington and Waukesha Counties have low contamination potential rankings (L3) due to the low permeabilities of the soils.

Lakeshore Counties

The situation in the lakeshore counties of the Region—Ozaukee, Milwaukee, Racine, and Kenosha—is somewhat different. The three classes of contamination potential are more evenly distributed; and there is not the sharp distinction between the high and the low contamination potential areas as in the inland counties. Although areas with low contamination potential prevail, with 53 percent of the total land area of the three counties in this category, the areas with moderate and high contamination potential account for 19 percent and 28 percent, respectively, of the total land of the three counties (Table 35).

In the western parts of Racine and Kenosha Counties and in western and central Ozaukee County, the high contamination potential areas—approximately 33 percent of the total land area in each County—resemble those of the inland counties, with labels of H2 (primarily), H3, and H4. However, closer to the lakeshore, areas of high and moderate contamination potential are limited to river valleys and portions of the shoreline, with labels of H1 and H2 indicating shallow depth to aquifer.

The moderate contamination potential areas in the lakeshore counties are mostly labeled M3 and, in Milwaukee and Racine Counties, also M2. This is because moderate and low soil percolation and permeability compensates for shallow depths to aquifer (see Table 34). The central urban areas of Racine and Kenosha are classified as moderate contamination potential because of the low soil percolation (primarily M1).

The large area of low contamination potential in the lakeshore counties—53 percent of the total land area of these counties—is due to the ridges of the lakeshore moraines constituted of silty till. These areas are labeled mostly L3 and L4 indicating low permeabilities, low to moderate soil percolation, and moderate depths to aquifer. Ranking of large areas of Milwaukee County as low contamination potential—72 percent of the total land area (Table 35)—is influenced by low soil percolation in this mostly urban area with large portions of impervious surfaces.

Table 35

ACREAGE OF CONTAMINATION POTENTIAL AREAS BY COUNTY

County	High Potential		Moderate Potential		Low Potential	
	Acreage	Percent	Acreage	Percent	Acreage	Percent
Lakeshore Counties						
Kenosha	57,111	32.5	26,723	15.2	92,014	52.3
Milwaukee	18,390	11.9	24,751	15.9	112,094	72.2
Ozaukee	50,482	33.7	39,828	26.4	60,156	39.9
Racine	68,190	31.9	37,985	17.7	108,269	50.4
Subtotal	194,173	27.9	129,287	18.6	372,533	53.5
Inland Counties						
Walworth	254,384	71.1	102,755	28.7	809	0.2
Washington	184,134	66.4	86,561	31.2	6,737	2.4
Waukesha	209,009	58.3	105,727	29.5	43,697	12.2
Subtotal	647,527	65.2	295,043	29.7	51,243	5.1
Total	841,700	49.8	424,330	25.1	423,776	25.1

Source: Wisconsin Geological and Natural History Survey and SEWRPC.

Summary

Areas most vulnerable to contamination constitute approximately one-half of the land area of the Region (Table 35) and are located primarily in the inland counties, especially in Walworth County. Generally, the lakeshore counties contain more areas with low contamination potential, which are more suitable for the location of activities that may affect shallow groundwater. These areas cover about 25 percent of the total land area of the Region, primarily in the eastern one-third of the Region. These areas can be found in the eastern one-third of Kenosha and Racine Counties, in the majority of Milwaukee County, and in eastern Ozaukee County. The remaining 25 percent of the land area of the Region has moderate contamination potential (Table 35).

Contamination potential of shallow groundwater varies widely across the Region depending on the presence of the various combinations of the factors determining groundwater vulnerability. Mapped rankings of contamination potential can be misleading under specific circumstances such as improperly abandoned wells or open quarries, which can provide direct access to shallow aquifers. The groundwater contamination potential maps are intended to be used in conjunction with an inventory of potential contamination sources as an aid to sound land use and water quality management planning.

Contamination Potential of Deeper Aquifers

The vulnerability of the deeper aquifers of Southeastern Wisconsin to contamination is more difficult to assess; and a complete evaluation of such vulnerability was beyond the scope of this study, which is focused on the shallow groundwater system. In general, the greater thickness of overburden and the first two barriers to contamination—the soil layer and the underlying unlithified geologic conditions, provide effective shield against contamination of the deeper aquifers. In addition, the deeper aquifers are protected by the ability of shallow aquifers to dilute contaminants. The possibility of contamination of deeper aquifers, however, is very real, although very difficult to detect, and may be impossible to reverse. In addition, the importance of the deeper aquifers as a source of municipal and industrial water supply within the Region cannot be understated. In some cases, these aquifers represent the only practical source of such supply.

A conceivable contamination scenario is the discharge of a large amount of liquid, such as petroleum, in an area where the shallow aquifer is relatively thin, unprotected, and directly interconnected with the deeper aquifers. A more insidious possibility is a smaller surface spill in the immediate vicinity of an old, forgotten deep well or open borehole that has not been properly abandoned (Figure 15). Another contamination scenario is the drilling of a deep borehole through a shallow contaminated aquifer into the deeper aquifers. Contaminated shallow groundwater can contaminate the deeper aquifers through the borehole before a casing is installed. Other than the possibility of deep open boreholes, if the shallow aquifer is indeed significantly contaminated in a given area, the potential that such contamination will eventually reach the deeper aquifers depends on the nature of the deep bedrock lithology and the direction of flow between aquifers. These factors can be considered to be the third and final barrier to deep groundwater contamination.

Unfortunately, the nature of the deep bedrock lithology of the Region is not well understood at present, particularly with regard to the distribution of different units and the importance of regional faulting. A major confining unit plays the most significant role in the protection of the deeper aquifers: the Maquoketa Formation (see Chapters V and VI), which is continuous over most of the Region, except for the western half of Walworth County and the westernmost parts of Waukesha County. The location of the western edge of this important bedrock unit has been refined as part of this study, and is illustrated on Map 15 in Chapter V. In general, in areas to the west of this edge, where the Maquoketa Formation is absent, the deeper aquifers are more vulnerable to contamination. However, the variability of lithology of the Maquoketa Formation is not known in detail. The dominant lithology is shale, which is relatively impermeable, but significant proportions of the thickness of this unit in some areas may be dolomite, which is much more permeable.

The other factor that determines vulnerability of the deeper groundwater to contamination is the direction of flow in deep groundwater systems. In the very thick deep aquifers, groundwater flow is three-dimensional, depending on differences of pressure and gradient. Under steady state, nonpumping conditions gradients are downward in recharge areas and upward in discharge areas (see Figure 13 in Chapter VI) . If there is a source like a contaminated shallow aquifer in a regional recharge area, such as to the west of the Maquoketa confining unit, then deeper aquifers can be contaminated. However, downward gradients can also be caused by pumping from the deeper aquifers and can induce leakage from shallow to deep aquifers through the Maquoketa confining unit (Figure 15). If areas of downward gradients between aquifers near pumping centers coincide with locations of more permeable, dolomitic lithology in the Maquoketa shale, contaminants can penetrate into deeper aquifers over time. For this reason, protective measures for the deep aquifer recharge areas, as well as measures to avoid potential contamination routes through the confining unit, should be an important consideration in land use and water quality manage-ment planning.

GROUNDWATER QUALITY PROTECTION

Groundwater is a valuable resource in the Region. It serves as the source of supply for approximately 700,000 persons, or about 37 percent of the population of the Region, including the entire rural population. Unfortunately, certain land uses and facility development activities can result in contamination of groundwater. About one-half of the total land area of the Region is highly vulnerable to groundwater contamination (Table 35). Cleaning contaminated groundwater can be costly and, in some cases, almost impossible. Therefore, the prevention of contamination before it occurs is a prudent step that should be taken in the development of the Region.

This section identifies specific areas, which should be afforded high priority for groundwater protection efforts.

Special Management Areas

Groundwater quality protection can be pursued either by addressing particular sources of contamination, or by focusing on specific areas that require special attention, in which all the existing or potential sources of contamination are of concern. Considering the high contamination potential present in certain areas of the Region, the second option provides a more effective approach. These specific areas, sometimes called special management areas, can be delineated and designated for special groundwater protection measures (Born and others, 1987).

Special management areas can be divided into three categories:

1. Naturally vulnerable areas.
2. Potential problem areas.
3. Wellhead protection areas.

Naturally Vulnerable Areas

Areas vary in terms of their vulnerability to groundwater contamination. Certain locations are naturally more susceptible to contamination than others because the soils, unlithified materials, or bedrock do not provide adequate protection, and the potential exists for a rapid movement of contaminants into groundwater. To identify these locations, the most vulnerable categories from the soil attenuation potential map (Map 12 in Chapter III) and groundwater contamination potential map (Map 33) were combined, as shown on Map 34. The areas where these two categories overlap each other have no significant potential for the attenuation of contaminants and require special attention because certain land uses, accidents, or mishandling of hazardous materials may create serious contamination problems.

The critical recharge areas are another type of naturally vulnerable area. These are the recharge areas of the deeper aquifers located in areas of high groundwater contamination potential. These areas were delineated by superimposing the category of the high contamination potential from Map 33 on the significant recharge areas of lower sandstone aquifer (Map 22 in Chapter VI) and are shown by crosshatching on Map 34. If a contaminant is released in a critical recharge area, resulting contamination may eventually spread to large areas of the deep aquifer, as well as the overlying aquifers. The remaining portion of the deep aquifer recharge area, as shown on Map 15 in Chapter V, is considered as a naturally vulnerable area.

Delineating naturally vulnerable areas does not mean that the introduction of contaminants in other areas should be of no concern. The delineation is intended to focus needed management efforts on especially critical areas, and permits screening and priority-setting for areas that most need protection. By delineating the most vulnerable areas, it is possible to relate the stringency of protection controls to the severity of the threat of groundwater contamination.

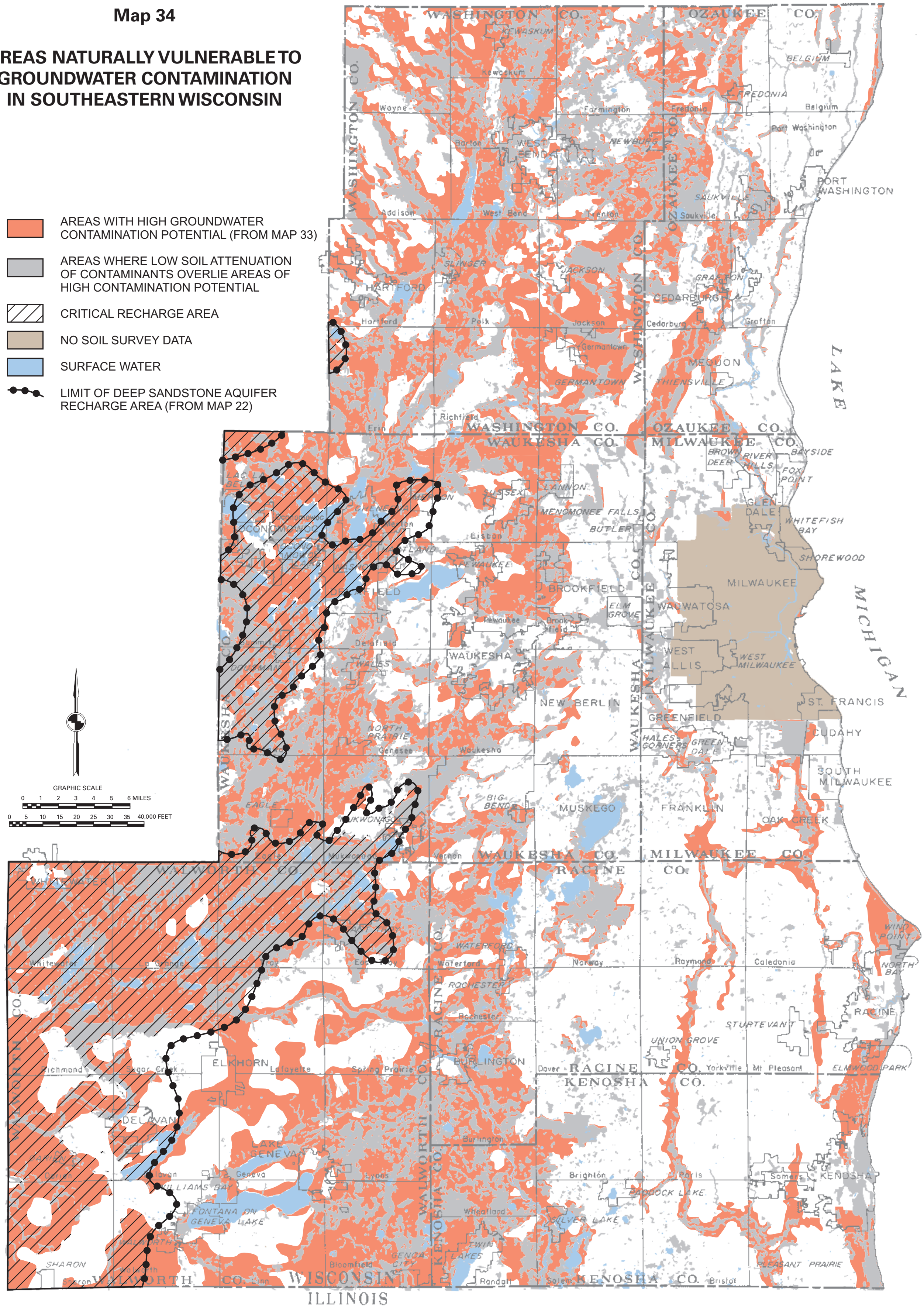
Finally, naturally vulnerable areas also include dominant recharge areas in the shallow aquifer system. Recharge to the Galena-Platteville aquifer and the upper sandstone aquifer takes place within the recharge area for the lower sandstone aquifer. Recharge to the Silurian dolomite aquifer will be dominantly where highly permeable layers (Thiensville and Mayville) subcrop or where traces of fracture zones reach the surface (in the areas of shallow depth to bedrock). Recharge to the sand and gravel aquifer is controlled by hydraulic conductivity of glacial materials and topography. Further information necessary to define the important recharge areas for the shallow aquifer system and their vulnerability to groundwater contamination has to be collected and interpreted.

Potential Problem Areas

Potential problem areas are places where potentially contaminating sources are located in the naturally vulnerable areas or places where contaminants have already entered groundwater. Overlaying the most vulnerable categories from the soil and groundwater contamination potential map (Map 12 and Map 33, respectively) with maps showing the location of individual potential contamination sources would indicate areas of highest contamination potential. This is not intended to suggest, however, that such places are the only areas in which groundwater quality problems may occur. All inventoried contamination sources, as shown on Maps 26 through 30, have a potential to create groundwater contamination problems. The potential problem area map would only show the areas of greatest concern, because of the high potential for contaminants to reach the groundwater system if released into the soil or underlying materials. A map of potential problem areas can be easily prepared and used as a guide in the identification of areas that should be given a high priority in regional and local groundwater management planning. The potential problem areas can be determined by overlaying the map of naturally vulnerable areas (Map 34) by maps of identified contamination sources (Maps 26, 27, 28, 29, 30, and 32).

Map 34

AREAS NATURALLY VULNERABLE TO GROUNDWATER CONTAMINATION IN SOUTHEASTERN WISCONSIN



Source: *Wisconsin Geological and Natural History Survey and SEWRPC.*

Potential problem areas, including the naturally vulnerable area, are located primarily in the western part of the Region, where in general, there is only a very limited potential for attenuating contaminants due to natural soil and geologic conditions, and where most of the recharge area of the deep sandstone aquifer is classified as having a high contamination potential (Map 34). This is the primary area that should be given the highest priority in any future planning efforts.

At present, the known existing sources of contamination, as determined in the contamination source inventory, do not present a widespread threat to groundwater quality. The major anthropogenic sources of groundwater contamination in the Region include abandoned landfills containing hazardous waste materials, leaking underground storage tanks, uncontrolled spills, improperly abandoned wells, and clusters of on-site sewage disposal systems. There are a few landfills, agricultural chemical storage facilities, and major farm animal operations located in the naturally vulnerable areas. Construction and operational procedures at these sources should be examined to determine if potential threat to groundwater quality exists and if control measures are needed. Most of the special well casing requirement areas, in which contamination of shallow aquifers may have already occurred, are located in the most vulnerable areas of the Region.

Wellhead Protection Areas

Drinking-water supplies may be protected by delineating wellhead protection (WHP) areas, in which potentially contaminating land uses are regulated. This type of planning is most appropriate for protecting municipal wells sunk into the shallow aquifers of the Region. Wellhead protection areas identify the land areas contributing groundwater to a well and are determined by hydrogeologic analysis. The WDNR is the regulatory State agency for developing and implementing the Wisconsin Wellhead Protection Plan. The first part of the plan is mandatory. *Wisconsin Administrative Code* NR 881 requires that a WHP plan be developed and submitted to the WDNR for any municipal water supply well constructed after May 1, 1992. The second part of the plan, applicable to any public water supply well approved prior to May 1, 1992, is voluntary. In 1996, the WDNR completed the delineation of WHP areas for all municipalities in the State using the EPA-approved calculated fixed radius method. This simple method results in a circular WHP area around each well and is a good first approximation of the WHP area (US EPA, 1987). However, more advanced delineations are desirable, to provide more accurate WHP areas. The capability to prepare greatly improved WHP area delineations will be developed under a regional aquifer performance modeling program initiated for Southeastern Wisconsin in 1999 under a cooperative project involving the Wisconsin Geological and Natural History Survey, the U.S. Geological Survey, and the Southeastern Wisconsin Regional Planning Commission, in cooperation with the water utilities of the Region.

Protection Alternatives

Clearly, the public officials and citizens of the Region will have to decide how to proceed with groundwater protection efforts and which protective measures and areas should receive priority. The following alternatives provide an example of actions, not in priority order, which can be included in groundwater quality protection planning efforts (Born and others, 1987).

- <u>Preventive versus Remedial Actions</u>
  Determination of the degree to which preventive versus remedial actions are to be relied upon is among the first of the decisions to be made when selecting groundwater protection strategies.

- <u>All Contamination Sources versus Selectivity</u>
  The second important determination relates to the scope of the management initiatives. Groundwater protection strategies targeted at all contaminating sources or targeted at the most critical sources would be evaluated.

- <u>General Focus versus Special Management Areas</u>
  The third important determination to be made is whether to deal with contaminating sources wherever they occur, or whether to focus on special management areas and deal, for example, with sources located in naturally vulnerable areas first.

- Long-Term versus Short-Term Actions
  The element of time plays an important role in the determination involved. Identification should be made of any actions, short-term in nature, that can be implemented before long-term actions are in place.

Other actions that may be included in a subregional groundwater protection planning effort include:

- Develop a regional aquifer three-dimensional model.
- Develop informational and educational programs relating to major potential contamination sources.
- Initiate discussions of groundwater protection efforts with business, industry, governmental units, and the public.
- Undertake a wellhead protection program in cooperation with the Wisconsin Department of Natural Resources and local municipalities.
- Incorporate groundwater protection as an element of land use planning.
- Develop protection strategies for special management areas.

CONCLUSIONS AND RECOMMENDATIONS

Although variations in the groundwater quality of the aquifers underlying the Region can be expected, the chemical composition of groundwater and its variations, both areally and within aquifers, are not well defined. Available groundwater quality data also are insufficient to define the extent of areas that may be affected by saline water from deeper aquifers, or the extent of groundwater with elevated radioactivity. Therefore, water quality data should continue to be obtained by Federal, State, and local agencies and other sources in a coordinated manner and should continue to be compiled and analyzed in order to fully address the groundwater quality issues in the Region. Eventually, such data can be used in conjunction with groundwater modeling for recommendations on future groundwater resource management. This study was focused on shallow aquifers and the contamination potential of deep aquifers was addressed only perfunctorily. A study of the interactions of the shallow and deep aquifer systems and of the contamination potential of deep aquifers should be undertaken as part of the future regional groundwater protection plan planning program.

Improperly abandoned wells constitute a significant threat to groundwater quality in the Region. Inventory of well drilling records for the Milwaukee-Waukesha metropolitan area indicated that a large number of abandoned wells exists in this area and the metropolitan areas of Racine and Kenosha. Results of these inventories could be used to prioritize areas with high probabilities of improperly abandoned wells for the Wisconsin Department of Natural Resources Well Abandonment Program. This problem should be fully documented and adequately addressed at the regional scale.

Data collected by WDNR for the Special Well Casing Requirement Program indicate that there are places in the Region where contaminants have already entered the groundwater. Additional areas of suspected contamination should be identified, the extent of contamination determined, and proper measures recommended to minimize potential problems.

To avoid potential contamination problems, maps of soil potential for attenuating contaminants and of groundwater contamination potential developed for this study should be used as a guide for locating new, potentially contaminating land uses and facilities and for estimating their impacts on groundwater. The maps are suited for system-level land use and water quality planning. However, the maps should not be used directly for locating such facilities but rather for general planning of such facilities and other land uses and for decisions which areas should be studied more closely. Detailed, site-specific studies are necessary before any new, potentially contaminating facility is located.

Although the existing contamination of shallow groundwater in the Region is not widespread and the existing contamination sources do not pose an unmanageable problem at this time, approximately one-half of the Region's land has been classified as having a high potential for groundwater contamination. Therefore, there is a need to incorporate the data included herein as one element in regional and local land use and water quality planning programs to prevent problems before they develop. This will enable the citizens of the Region to preserve the existing high quality of groundwater in the Region.

APPENDICES

Appendix A

REFERENCES

Alden W.C., 1904, The Delavan lobe of the Lake Michigan glacier of the Wisconsin stage of glaciation and associated phenomena. U.S. Geological Survey Professional Paper 34, 99 p.

Alden W.C., 1906, Description of the Milwaukee quadrangle. U.S. Geological Survey Geological Atlas of the United States, Milwaukee Special Folio, no. 140, p. 11-12.

Alden, W.C., 1918, The Quaternary geology of southeastern Wisconsin. U.S. Geological Survey Professional Paper 106, 356 p.

Aller, L. and others, 1987, DRASTIC: a standardized system for evaluating ground water pollution potential using hydrogeologic settings. U.S. Environmental Protection Agency, Ada, OK, EPA/600/2-87-036, 455 p.

American Commission on Stratigraphic Nomenclature, 1983, North American Stratigraphic Code. American Association of Petroleum Geologists Bulletin, vol. 67, no. 5, p. 841-875.

Batten W.G. and Bradbury K.R., 1996, Regional groundwater flow system between the Wolf and Fox Rivers near Green Bay, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 75, 28 p.

Batten, W.G. and Conlon, T.D., 1993, Hydrogeology of glacial deposits in a preglacial bedrock valley, Waukesha County, Wisconsin: U.S. Geological Survey Water-Resources Investigations Report 92-4077, 15 p.

Bonestroo, Rosene, Anderlik & Associates, Inc., 1996, Southeastern Wisconsin, sandstone aquifer screening model report. BRA, Mequon, WI, 62 p.

Borman, R.G., 1976, Ground-water resources and geology of Walworth County, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 34, 45 p.

Borman, R.G. and Trotta, L.C., 1976, Ground-water resources and geology of Jefferson County, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 33, p. 6.

Born, S.M., Yanggen, D.A., and Zaporozec, A., 1987, A guide to groundwater quality planning and management for local governments. Wisconsin Geological and Natural History Survey Special Report 9, 91 p.

Bridson, M.S., Bohn, M.F., and Madison, F.M., 1994, Evaluation of groundwater susceptibility assessment systems in Dane County: Wisconsin Geological and Natural History Survey Open-File Report 1994-3, 52 p.

Bridson, M.S., Bohn, M.F., and Warzecha, C.J., 1995, Wisconsin private well water quality. Wisconsin Dept. of Health and Social Services Report, 31 p. + appendices and figures.

Brown, S.E., 1990, Glacial stratigraphy and history of Racine and Kenosha Counties, Wisconsin. M.S. Thesis–Geology, University of Wisconsin-Madison, 173 p.

Bues, D.J., 1983, The relationship between Lake Michigan and a shallow dolomite aquifer at Mequon, Wisconsin. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 180 p.

Buschbach, T.C., 1964, Cambrian and Ordovician strata of northeastern Illinois. Illinois State Geological Survey Report of Investigations 218, 90 p.

Cates, K. and Madison, F., 1991, Worksheet #11: Site evaluation, Farm-A-Syst. University of Wisconsin-Extension, Madison, WI, G3536-11W.

Chamberlin, T.C., 1877, Geology of eastern Wisconsin. Geology of Wisconsin, Vol. II, Survey of 1873-1877, pt. II, chap. II, p. 141-170.

Cherkauer, D.S. and Carlson, D.A., 1997, Interaction of Lake Michigan with a layered aquifer stressed by drainage. Ground Water, vol. 35, no. 6, p. 981-989.

Cherkauer, D.S. and Hensel, B.R., 1986, Groundwater flow into Lake Michigan from Wisconsin. Journal of Hydrology, vol. 84, no. 1/2, p. 261-271.

Cherkauer, D.S. and Mikulic D., 1992, Development of a hydrostratigraphical model for the interaction of ground water with Lake Michigan in southeastern Wisconsin. Final report to the University of Wisconsin. Sea Grant Institute, 84 p.

Cherkauer, D.S. and Zvibleman, B., 1981, Hydraulic connection between Lake Michigan and a shallow ground-water aquifer. Ground Water, vol. 19, no. 4, p. 376-381.

Choi, Y.S., 1995, Stratigraphy and sedimentology of the Middle Ordovician Sinnipee Group, eastern Wisconsin. M.S. Thesis-Geology, University of Wisconsin-Madison, 229 p.

Clayton, L., 2001, Pleistocene geology of Waukesha County, Wisconsin: Wisconsin Geological and Natural History Survey Bulletin 99, 33 p.

Clayton, L., Attig, J.W., Mickelson, D.M., and Johnson, M.D., 1991 (rev. 1992), Glaciation of Wisconsin. Wisconsin Geological and Natural History Survey Educational Series 36, 4 p.

Cline, D.R., Geology and ground-water resources of Dane County, Wisconsin. U.S. Geological Survey Water-Supply Paper 779-U, plate 5.

Cotter, R.D., Hutchinson, R.D., Skinner, E.L., and Wentz, D.A., 1969, Water resources of Wisconsin, Rock-Fox River Basin. U.S. Geological Survey Hydrologic Investigations Atlas HA-360, 4 plates.

Devaul, R.W., 1975a, Dissolved-solids concentrations of water in the sand-and-gravel aquifer, Wisconsin. Wisconsin Geological and Natural History Survey State Maps 35, scale 1:1,000,000.

Devaul, R.W., 1975b, Dissolved-solids concentrations of water in the Niagara aquifer, Wisconsin. Wisconsin Geological and Natural History Survey State Maps 37, scale 1:1,000,000.

Devaul, R.W., 1975c, Dissolved-solids concentrations of water in the sandstone aquifer, Wisconsin. Wisconsin Geological and Natural History Survey State Maps 36, scale 1:1,000,000.

DiNovo, F. and Jaffe, M., 1984, Local groundwater protection–Midwest region.American Planning Association, Chicago, IL, p. 38.

Drescher, W.J., 1948, Results of pumping tests on artesian wells in the Milwaukee-Waukesha area, Wisconsin. U.S. Geological Survey in cooperation with Wisconsin Geological and Natural History Survey, 22 p.

Drescher, W.J., Dreher, F.C., and Brown, P.N.,1953, Water resources of the Milwaukee area, Wisconsin. U.S. Geological Survey Circular 247, 42 p.

Eaton, T.T., 1995, Estimating groundwater recharge using a modified soil-water budget method. 40th Annual Midwest Groundwater Conference, Columbia, MO, Program and Abstracts, Missouri Department of Natural Resources, p. 35.

Ellefson, B.R., Fan, C.H., and Ripley, J.L., 1997, Water use in Wisconsin, 1995. U.S. Geological Survey Open-File Report 97-356, 1 plate.

Ellefson, B.R., Rury, K.S., and Krohelski, J.T., 1987, Water use in Wisconsin, 1985. U.S. Geological Survey Open-File Report 87-699, 1 plate.

Ellefson, B.R., Sabin, T.J., and Krohelski, J.T., 1993, Water use in Wisconsin, 1990. U.S. Geological Survey Open-File Report 93-118, 1 plate.

Entine, L., 1992, Getting to know your stream, 2—Streambank Habitat. Dane County Extension, p. 24.

Foley, F.C., Walton, W.C., and Drescher, W.J., 1953, Ground-water conditions in the Milwaukee-Waukesha area, Wisconsin. U.S. Geological Survey Water-Supply Paper 1229, 96 p.

Freeze, R.A. and Cherry, J.A., 1979, Groundwater. Englewood Cliffs, NJ, Prentice-Hall, 604 p.

Gonthier, J.B., 1975, Ground-water resources of Waukesha County, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 29, 46 p.

Gonthier, J.B., 1979, Water-table map of Waukesha County, Wisconsin. U.S. Geological Survey Water-Resources Investigations Open-File Report 79-43, map 1:100,000, 1 sheet.

Green, J.H., 1968, The Troy Valley of southeastern Wisconsin. U.S. Geological Survey Professional Paper 600-C, p. 135-139.

Green, J.H. and Hutchinson, R.D., 1965, Ground-water pumpage and water-level changes in the Milwaukee-Waukesha area, Wisconsin, 1950-61. U.S. Geological Survey Water-Supply Paper 1809-I, 19 p.

Hahn, N.A., Jr., 1984, Radium in Wisconsin groundwater and removal methods for community water systems. Wisconsin Dept. of Natural Resources, 125 p.

Ham, N. and Attig, J.W., in press, Pleistocene geology of Walworth County, Wisconsin. Wisconsin Geological and Natural History Survey Bulletin.

Hansel, A.K. and Mickelson, D.M., 1988, A reevaluation of the timing and causes of high lake phases in the Lake Michigan Basin. Quaternary Research, Vol. 29, University of Washington, p. 113-128.

Hansel, A.K., Mickelson, D.M., Schneider, A.F., and Larsen, C.E., 1985, Late Wisconsinan and Holocene history of the Lake Michigan Basin. In Quaternary Evolution of the Great Lakes, P.F. Karrow and P.E. Calkin, eds., Geological Association of Canada Special Paper 30, p. 39-53.

Heath, R.C., 1983, Basic ground-water hydrology. U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Hutchinson, R.D., 1970, Water resources of Racine and Kenosha Counties, southeastern Wisconsin. U.S. Geological Survey Water-Supply Paper 1878, 63 p.

Kammerer, P.A., Jr., 1981, Ground-water quality atlas of Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 39, 39 p.

Kammerer, P.A., Jr., 1984, An overview of ground-water quality data in Wisconsin. U.S. Geological Survey Water-Resources Investigations Report 83-4239, 58 p.

Kammerer, P.A., Jr., 1995, Ground-water flow and quality in Wisconsin's shallow aquifer system. U.S. Geological Survey Water-Resources Investigations Report 90-4171, 42 p.

Ketelle, M.J., 1971, Hydrogeologic considerations in liquid waste disposal, with a case study in southeastern Wisconsin. SEWRPC Technical Record, Vol. 3, No. 3, 39 p.

Koth, M.A., 1985, The safety of Wisconsin's drinking water. Wisconsin Dept. of Natural Resources PUBL-WS-006 85, p. 10-12.

Krohelski, J.T., 1986, Hydrogeology and ground-water use and quality, Brown County, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 57, 41 p. + 2 plates.

Ladwig, K.J., 1981, Ground-water flow between the shallow glacial aquifer and the Cedarburg Bog wetland area, Ozaukee County, Wisconsin. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 148 p.

Lawrence, C.L. and Ellefson, B.R., 1982, Water use in Wisconsin, 1979. U.S. Geological Survey Water Resources Investigations 82-444, 98 p.

Lawton, D.R., 1979, Ground-water conditions in a shallow dolomite aquifer in northeastern Milwaukee and southeastern Ozaukee Counties, Wisconsin. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 153 p.

Mai, H. and Dott, R.H., Jr., 1985, A subsurface study of the St. Peter Sandstone in southern and eastern Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 47, 24 p.

Mandle, R.J. and Kontis, A.L., 1992, Simulation of regional ground-water flow in the Cambrian-Ordovician aquifer system in the northern Midwest, United States (Regional Aquifer-System Analysis report). U.S. Geological Survey Professional Paper 1405-C, 97 p.

Mickelson, D.M. and K.M. Syverson, in press, Pleistocene geology of Ozaukee and Washington Counties, Wisconsin. Wisconsin Geological and Natural History Survey Bulletin 91, 56 p.

Mickelson, D.M., Clayton, L., Baker, R.W., Mode W.N., and Schneider, A.F., 1984, Pleistocene stratigraphic units of Wisconsin. Wisconsin Geological and Natural History Survey Miscellaneous Paper 84-1, 15 p. + appendices.

Mikulic, D.G., 1977, A preliminary revision of the Silurian stratigraphy of southeastern Wisconsin. In Geology of Southeastern Wisconsin, K.G. Nelson, ed., 41st Annual Tri-State Field Conference Guidebook. Wisconsin Geological and Natural History Survey Other Contributions 5, p. A6-A34.

Mikulic, D.G. and Kluessendorf, J., 1988, Subsurface stratigraphic relationships of the Upper Silurian and Devonian rock of Milwaukee County, Wisconsin. Wisconsin Geological and Natural History Survey, Geoscience Wisconsin, Vol. 12, p. 1-23.

Mudrey, M.G. Jr., Brown, B.A., and Greenberg, J.K., 1982, Bedrock geologic map of Wisconsin. Wisconsin Geological and Natural History Survey, 1 sheet, scale 1:1,000,000, full color.

Mueller, S., 1992, Three-dimensional digital simulation of the ground-water contribution to Lake Michigan from the Silurian aquifer of southeastern Wisconsin. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 231 p.

Nader, D.C., 1990, Three-dimensional digital simulation of the ground-water–Lake Michigan hydraulic connection. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 159 p.

Need, E.A., 1983, Quaternary stratigraphy of the lower Milwaukee and Menomonee River valleys, Milwaukee, Wisconsin. In Late Pleistocene history of southeastern Wisconsin, D.M. Mickelson and L. Clayton, eds., Wisconsin Geological and Natural History Survey, Geoscience Wisconsin, Vol. 7, p. 24-42.

Ostrom, M.E., 1967, Paleozoic stratigraphic nomenclature for Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 8, 1 plate.

Paull, R.A. and Emerick, J.A., 1991, Genesis of the Upper Ordovician Neda Formation in eastern Wisconsin. In Ordovician-Silurian boundary of the Neda Formation, M.G. Mudrey, Jr., ed., Wisconsin Geological and Natural History Survey, Geoscience Wisconsin, Vol. 14, p. 23-52.

Rodenback, S.A., 1988, Merging Pleistocene lithostratigraphy with geotechnical and hydrogeologic data–examples from eastern Wisconsin. M.S. Thesis-Geology, University of Wisconsin-Madison, 286 p.

Rovey, C.W., II, 1983, Computer modeling of the interaction between Lake Michigan and the dolomite aquifer at Mequon, Wisconsin. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 271 p.

Rovey, C.W., II, 1990, Stratigraphy and sedimentology of Silurian and Devonian carbonates, eastern Wisconsin, with implications for ground-water discharge into Lake Michigan. Ph.D. Thesis-Geosciences, University of Wisconsin-Milwaukee, 427 p.

Rovey, C.W., II, 1997, Proposed reference sections and correlation of Upper Silurian and Devonian strata, eastern Wisconsin. Geoscience Wisconsin, Vol. 16, p. 37-46.

Rovey, C.W., II and Cherkauer, D.S., 1994a, Relation between hydraulic conductivity and texture in a carbonate aquifer: observations. Ground Water, vol. 32, no. 1, p. 53-62.

Rovey, C.W., II and Cherkauer, D.S., 1994b, Relation between hydraulic conductivity and texture in a carbonate aquifer: regional continuity. Ground Water, vol. 32, no. 2, p. 227-238.

Ryling, R.W., 1961, A preliminary study of the distribution of saline water in the bedrock aquifers of eastern Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 5, 23 p.

Schmidt, R. and Kessler, K., 1987, Groundwater contamination susceptibility in Wisconsin. Wisconsin Geological and Natural History Survey Other Contributions 9, map 1:1,000,000, full color.

Schneider, A.F., 1983, Wisconsinan stratigraphy and glacial sequence in southeastern Wisconsin. In Late Pleistocene history of southeastern Wisconsin, D.M. Mickelson and L. Clayton, eds., Wisconsin Geological and Natural History Survey, Geoscience Wisconsin, Vol. 7, p. 59-83.

Schneider, A.F., Mickelson, D.M., and Brown, S.E., in preparation, Pleistocene geology of Racine and Kenosha Counties, Wisconsin. Wisconsin Geological and Natural History Survey Bulletin.

Schulze-Makuch, D., 1996, Facies-dependent scale behavior of hydraulic conductivity and longitudinal dispersivity in the carbonate aquifer of southeastern Wisconsin. Ph.D. Thesis-Geosciences, University of Wisconsin-Milwaukee, 342 p.

Sherrill, M.G., 1979, Contamination potential in the Silurian dolomite aquifer, eastern Wisconsin. U.S. Geological Survey Water Resources Investigations 78-108 (4 maps on 2 plates).

Sherrill, M.G. and Erickson, J.R., 1979, Water-table map of Walworth County, Wisconsin. U.S. Geological Survey Water-Resources Investigations Open-File Report 79-42, map 1:100,000, 1 sheet.

Sherrill, M.G. and Schiller, J.J., 1979a, Water-table map of Kenosha County, Wisconsin. U.S. Geological Survey Water-Resources Investigations Open-File Report 79-39, map 1:100,000, 1 sheet.

Sherrill, M.G. and Schiller, J.J, 1979b, Water-table map of Racine County, Wisconsin. U.S. Geological Survey Water-Resources Investigations Open-File Report 79-41, map 1:100,000, 1 sheet.

Sherrill, M.G., Schiller, J.J., and Erickson, J.R., 1979, Water-table map of Milwaukee County, Wisconsin. U.S. Geological Survey Water-Resources Investigations Open-File Report 79-40, map 1:100,000, 1 sheet.

Siegel, D.I., 1989, Geochemistry of the Cambrian-Ordovician aquifer system in the northern Midwest, United States (Regional Aquifer-System Analysis report). U.S. Geological Survey Professional Paper 1405-D, 76 p.

Simpkins, W.W., 1989, Genesis and spatial distribution of variability in the lithostratigraphic, geotechnical, hydrogeological, and geochemical properties of the Oak Creek Formation in southeastern Wisconsin. PhD. Thesis–Geology, University of Wisconsin-Madison, 857 p.

Simpkins, W.W. and Bradbury, K.R., 1992, Groundwater flow, velocity, and age in a thick, fine-grained till unit in southeastern Wisconsin. Journal of Hydrology, vol. 132, p. 283-319.

Skinner, E.L. and Borman, R.G., 1970, Water resources of Wisconsin, Lake Michigan Basin. U.S. Geological Survey Hydrologic Investigations Atlas HA-432, 4 plates.

Smith, E.I., 1978, Introduction to Precambrian rocks of south-central Wisconsin. Wisconsin Geological and Natural History Survey, Geoscience Wisconsin, Vol. 2, p. 1-17.

Southeastern Wisconsin Regional Planning Commission, 1966, A comprehensive plan for the Root River watershed. SEWRPC Planning Report No. 9, chap. IV, p. 61-66.

Southeastern Wisconsin Regional Planning Commission, 1969, A comprehensive plan for the Fox River (Ill.) watershed. SEWRPC Planning Report No. 12, vol. I, chap. V, p. 75-87; chap. X, p. 233-248; chap. XI, p. 249-265.

Southeastern Wisconsin Regional Planning Commission, 1970-1971, A comprehensive plan for the Milwaukee River watershed. SEWRPC Planning Report No. 13, vol. 1, chap. VI, p. 102-103, 117-125; chap. X, p. 267-285; chap. XI, p. 287-310; vol. 2, chap. VI, p. 343-367.

Southeastern Wisconsin Regional Planning Commission, 1976, A comprehensive plan for the Menomonee River watershed. SEWRPC Planning Report No. 26, vol. 1, chap. V, p. 123-129, 146-154; chap. VII, p. 292-320.

Southeastern Wisconsin Regional Planning Commission, 1981, Refining the delineation of the environmental corridors in southeastern Wisconsin. SEWRPC Technical Record, Vol. 4, No. 2, p. 1-21.

Southeastern Wisconsin Regional Planning Commission, 1983, A comprehensive plan for the Pike River watershed. SEWRPC Planning Report No. 35, p. 67, 105, and 117-119.

Sverdrup, K. A., Kean, W.F., Herb, S., Brukardt, S.A., and Friedel, R.J., 1997, Gravity signature of the Waukesha Fault, southeastern Wisconsin. Wisconsin Geological and Natural History Survey, Geoscience Wisconsin, Vol. 16, p. 47-54.

Thompson, D.B., 1981, Hydrogeology of the Niagara dolomite aquifer and its interaction with Lake Michigan at Wind Point, Wisconsin. M.S. Thesis-Geosciences, University of Wisconsin-Milwaukee, 108 p.

U.S. Army Corps of Engineers, 1964. A survey report for flood control on the Milwaukee River and tributaries, U.S. Army Engineer District, Chicago,.

U.S. Department of Agriculture, Soil Conservation Service, 1970a, Soil survey, Ozaukee County, Wisconsin. U.S. Government Printing Office, Washington, DC, 92 p. + tables and maps.

U.S. Department of Agriculture, Soil Conservation Service, 1970b, Soil survey, Kenosha and Racine Counties, Wisconsin. U.S. Government Printing Office, Washington, DC, 113 p. + tables and maps.

U.S. Department of Agriculture, Soil Conservation Service, 1971a, Soil survey, Walworth County, Wisconsin. U.S. Government Printing Office, Washington, DC, 107 p. + tables and maps.

U.S. Department of Agriculture, Soil Conservation Service, 1971b, Soil survey, Washington County, Wisconsin. U.S. Government Printing Office, Washington, DC, 105 p. + tables and maps.

U.S. Department of Agriculture, Soil Conservation Service, 1971c, Soil survey of Milwaukee and Waukesha Counties, Wisconsin. U.S. Government Printing Office, Washington, DC, 177 p. + tables and maps.

U.S. Department of Agriculture, Soil Conservation Service, 1986 (2nd ed.), Urban hydrology for small watersheds. USDA Soil Conservation Service Technical Release 55.

U.S. Environmental Protection Agency, 1987, Guidelines for delineation of wellhead protection areas. U.S. EPA, Office of Ground-Water Protection, Washington, DC, chapters paginated separately.

U.S. Geological Survey, 1988, Wisconsin ground-water quality. In National Water Summary 1986–Hydrologic events and ground-water quality, D.W. Moody and others, compilers, U.S. Geological Survey Water-Supply Paper 2325, p. 531-537.

Van Everdingen, R.O., 1964, Distortion of groundwater flow patterns in sections with exaggerated vertical scale. Journal of Hydrology, vol. 2, p. 11-14.

Visocky, A., 1993, Water-level trends and pumpage in the deep bedrock aquifers in the Chicago region, 1985-1991. Illinois State Water Survey Circular 177, p. 26.

Visocky, A., 1997, Water-level trends and pumpage in the deep bedrock aquifers in the Chicago region, 1991-1995. Illinois State Water Survey Circular 182, p. 26.

Weaver, T.R. and Bahr, J.M., 1991, Geochemical evolution in the Cambrian-Ordovician sandstone aquifer, eastern Wisconsin, 2. Correlation between flow paths and ground-water chemistry. Ground Water, vol. 29, no. 4, p. 510-515.

Weidman, S. and Schultz, A.R., 1915, The underground and surface water supplies of Wisconsin. Wisconsin Geological and Natural History Survey Bulletin 35, 639 p.

Wilson, J.D., 1985, Hydrogeology of the Silurian dolomite aquifer. Independent Study Project, Water Resources Management Program, University of Wisconsin-Madison, unpublished report, p. 16-22.

Wisconsin Agricultural Statistics Service, 1989, Snow & frost, Wisconsin 1978-88. U.S. Dept. of Agriculture, Wis. Agr. Statistics Service, Madison, p. 30.

Wisconsin Department of Natural Resources, 1994, Well abandonment. Wisconsin Dept. of Natural Resources PUBL-WS-016 94 rev.

Wisconsin Department of Natural Resources, 1995, Fiscal year 1995--Groundwater quality monitoring plan. Wisconsin Dept. of Natural Resources, p. 14.

Wisconsin Department of Natural Resources, 2002, Water Supply System Reporting Data, 1980 to 2001.

Young, H.L., 1976, Digital-computer model of the sandstone aquifer in southeastern Wisconsin. Southeastern Wisconsin Regional Planning Commission Technical Report No. 16, 42 p.

Young, H.L., 1992a, Summary of ground-water hydrology of the Cambrian-Ordovician aquifer system in the northern Midwest, United States (Regional Aquifer-System Analysis report). U.S. Geological Survey Professional Paper 1405-A, 55 p.

Young, H.L., 1992b, Hydrogeology of the Cambrian-Ordovician aquifer system in the northern Midwest, United States (Regional Aquifer-System Analysis report). U.S. Geological Survey Professional Paper 1405-B, 99 p. + 1 plate.

Young, H.L. and Batten, W.G., 1980, Ground-water resources and geology of Washington and Ozaukee Counties, Wisconsin. Wisconsin Geological and Natural History Survey Information Circular 38, p. 17.

Young, H.L., MacKenzie, A.J., and Mandle, R.J., 1989, Simulation of ground-water flow in the Cambrian-Ordovician aquifer system in the Chicago-Milwaukee area of the northern Midwest. In Regional aquifer systems of the United States (L.A. Swain and A.I. Johnson, eds.)--Aquifers of the Midwestern area, American Water Resources Association Monograph 13, p. 39-72.

Zaporozec, A., 1972, Graphical interpretation of water-quality data. Ground Water vol. 10, no. 2, p.32-43.

Zaporozec, A. (ed.), 1985, Groundwater protection principles and alternatives for Rock County, Wisconsin. Wisconsin Geological and Natural History Survey Special Report 8, p. 34-36.

Zaporozec, A. and Eaton, T.T., 1996, Ground-water resource inventory in urbanized areas. American Institute of Hydrology Proceedings, Conference on Hydrology and Hydrogeology of Urban and Urbanizing Areas, Proceedings, p. RM21-RM32.

Appendix B

SIGNIFICANT HYDROLOGIC DATA POINTS IN SOUTHEASTERN WISCONSIN, BY COUNTY

Table B-1

SIGNIFICANT HYDROLOGIC DATA POINTS IN WASHINGTON/OZAUKEE COUNTIES

DATA POINTS

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
Climatic Data					
Precipitation Stations - map symbol ▲					
Washington:					
CD 1	479050	West Bend	1913-date	NCDC	
CD 2	473453	Hartford 2 W	1938-date	NCDC	
CD 3	473058	Germantown	1943-date	NCDC	
Ozaukee:					
CD 4	476764	Port Washington	1929-date	NCDC	
Ground Water Data					
Observation Wells - map symbol: active ● discontinued ●					
Washington:					
OW 1		West Bend City Well #1	1946-64	USGS	WN 3
OW 2		Hartford City Well #3	1946-64	USGS	WN 2
Ozaukee:					
OW 3		Wayside, County Hwy. LL N	1968-94	USGS	OZ 42
Municipal Wells - map symbol ▲			Installed		
Washington:					
MW 1	87934	Kewaskum Village Well #4	1989	DNR	WN 939
MW 2	87915	Kewaskum Village Well #1	1928	DNR	WN 17
MW 3	87916	Kewaskum Village Well #2	1947	DNR	WN 18
MW 4	87917	Kewaskum Village Well #3	1983	DNR	WN 914
MW 5	87931	Allenton Sanitary District #1 Well #2	1985	DNR	WN 920
MW 6	87899	Allenton Sanitary District #1 Well #1	1961	DNR	WN 143
MW 7	87929	West Bend City Well #13	1973	DNR	WN 72
MW 8	87928	West Bend City Well #12	1985	DNR	WN 700
MW 9	87927	West Bend City Well #11	1978	DNR	WN 699
MW 10	87921	West Bend City Well #4	1931	DNR	WN 22
MW 11	87926	West Bend City Well #9	1969	DNR	WN 70

MW 12	87925	West Bend City Well #8	1966	DNR	WN 89
MW 13	87922	West Bend City Well #5A	1944	DNR	WN 23
MW 14	87924	West Bend City Well #7	1966	DNR	WN 354
MW 15	87923	West Bend City Well #6	1957	DNR	
MW 16	GM798*	West Bend City Well #10	1969	DNR	WN 424
MW 17	87904	Hartford City Well #4	1917	DNR	WN 13
MW 18	87905	Hartford City Well #6	1933	DNR	WN 7
MW 19	87907	Hartford City Well #9	1952	DNR	WN 29
MW 20	87908	Hartford City Well #10	1960	DNR	WN 52
MW 21	87909	Hartford City Well #11	1966	DNR	WN 90
MW 22	87906	Hartford City Well #8	1953	DNR	WN 34
MW 23	87911	Hartford City Well #13	1979	DNR	WN 907
MW 24	87912	Hartford City Well #14	1979	DNR	WN 900
MW 25	87910	Hartford City Well #12	1969	DNR	WN 428
MW 26		Slinger Village Well #5		USGS	WN 983
MW 27	87920	Slinger Village Well #4	1959	DNR	WN 42
MW 28	87918	Slinger Village Well #2	1921	DNR	
MW 29	87919	Slinger Village Well #3	1931	DNR	
MW 30	87914	Jackson Village Well #3	1979	DNR	WN 905
MW 31	87930	Jackson Village Well #1	1949	DNR	WN 25
MW 32	87913	Jackson Village Well #2	1968	DNR	WN 149
MW 33	87902	Germantown Village Well #3	1967	DNR	WN 351
MW 34	87933	Germantown Village Well #5	1987	DNR	WN 938
MW 35	87901	Germantown Village Well #2	1964	DNR	WN 79
MW 36	87903	Germantown Village Well #4	1975	DNR	WN 797
MW 37	87932	Germantown Village Well #6	1986	DNR	WN 918
MW 38	87900	Germantown Village Well #1	1954	DNR	WN 30

Ozaukee:

MW 39	83707	Fredonia Village Well #2	1963	DNR	OZ 71
MW 40	83700	Belgium Village Well #2	1974	DNR	
MW 41	83699	Belgium Village Well #1	1970	DNR	
MW 42	83717	Saukville City Well #4	1979	DNR	OZ 470
MW 43	83706	Fredonia Village Well #1	1939	DNR	OZ 24
MW 44	83714	Saukville Village Well #1	1940	DNR	OZ 23
MW 45	83715	Saukville Village Well #2	1962	DNR	OZ 45
MW 46	83716	Saukville Village Well #3	1972	DNR	OZ 54
MW 47	83704	Cedarburg City Well #4	1965	DNR	OZ 78
MW 48	83718	Cedarburg City Well #6	1985	DNR	OZ 483
MW 49	83701	Cedarburg City Well #1	1923	DNR	OZ 16
MW 50	83703	Cedarburg City Well #3	1956	DNR	OZ 27
MW 51	83705	Cedarburg City Well #5	1967	DNR	OZ 89
MW 52	83711	Grafton Village Well #4	1965	DNR	OZ 79
MW 53	83708	Grafton Village Well #1	1938	DNR	OZ 25
MW 54	83712	Grafton Village Well #5	1970	DNR	OZ 13
MW 55	83713	Grafton Village Well #6	1973	DNR	OZ 368
MW 56	83709	Grafton Village Well #2	1952	DNR	OZ 21
MW 57	83710	Grafton Village Well #5	1958	DNR	OZ 39
MW 58	01090	Grafton Village Well #7		DNR	OZ 559
MW 59	83644	Mequon City Well #1 (Lac du Cours #1)	1964	DNR	OZ 73
MW 60	83645	Mequon City Well #3 (Lac du Cours #3)	1974	DNR	OZ 362
MW 61	01104	Mequon City Well #4 (Grasslyn Rd.)	1993	DNR	
MW 62	83637	Mequon City Well #5 (Whitman Pl. #1)	1971	DNR	OZ 47

Industrial High-Capacity Wells - map symbol

Washington:

IN 1	65207	Wissota Sand & Gravel Co., Inc. Well	1967	DNR	WN 144
IN 2	65202	Libby, McNeill, & Libby Well (Seneca Foods Corp.)		DNR	WN 867
IN 3	65205	Rockfield Canning Co. Well (Seneca Foods Corp.)	1948	DNR	WN 27
IN 4	65201	Libby, McNeill, & Libby Well (Seneca Foods Corp.)	1961	DNR	WN 54

Ozaukee:

IN 5	56803	Krier Preserving Co. Well	1958	DNR	OZ 32
IN 6	56809	Heatwolf Foundry Well		DNR	OZ 468
IN 7	22003	Simplicity Mfg. Co. well	1972	DNR	OZ 52
IN 8	56810	Freeman Chemical Corp. Well #1		DNR	OZ 507
IN 9	56804	Fromm Labs, Inc. Well		DNR	OZ 467
IN 10	56805	Fromm Labs, Inc. Well #3	1971	DNR	OZ 49
IN 11	56808	Cedarburg Ind. Center		DNR	OZ 18
IN 12	56811	R.E. Breaudoin & Son, Inc. Well #1		DNR	OZ 501

Irrigation High-Capacity Wells - map symbol

Washington:

IR 1	87808	West Bend Country Club Well	1930	DNR	WN 35
IR 2	87810	West Bend Country Club Well	1940	DNR	WN 66
IR 3	87831	West Bend Country Club Well	1969	DNR	WN 892
IR 4	34003	Kettle Hills Golf Course Well #1	1986	DNR	WN 935

Ozaukee:

IR 5	22004	Squires Golf, Inc.		DNR	OZ 469
IR 6	22006	Wayside Nurseries, Inc. Well		DNR	OZ 462
IR 7	83604	Ozaukee Country Club Well	1960	DNR	OZ 43
IR 8	83605	Ozaukee Country Club Well #1	1965	DNR	OZ 285
IR 9	22005	North Shore Country Club Well	1964	DNR	OZ 75
IR 10	83659	Gebhardt Farms	1981	DNR	OZ 472
IR 11	22002	Harold Hahn Well	1966	DNR	OZ 72

Other High-Capacity Wells - map symbol

Washington:

HC 1	90123	Wayne Elementary School Well	1964	DNR	WN 74
HC 2	34002	Gieringer Well	1967	DNR	WN 73
HC 3	90156	Farmington Elementary School Well	1966	DNR	WN 416
HC 4	90102	St. Lawrence Catholic Church Well	1962	DNR	WN 77
HC 5	87816	Cedar Lake Home Well #9	1978	DNR	WN 896
HC 6	87806	Society of Southern Wisconsin Synod Well	1956	DNR	WN 36
HC 7	87807	Cedar Lake Home of the Aged	1968	DNR	WN 415
HC 8	FX361*	Eastwood Trail Water Trust Well		DNR	
HC 9	BO721*	Walsh Subdivision 1		DNR	
HC 10	BO723*	Walsh Subdivision 2		DNR	
HC 11	BO717*	Bartlein Mobile Home Park Well		DNR	
HC 12	87811	Pike Lake State Park Well	1971	DNR	WN 68

HC 13	87815	Pike Lake Campground Well #2	1969	DNR	WN 65
HC 14	BO720*	Wheel Estates Mobile Home Park Well		DNR	
HC 15	FX358*	Wheel Estates Mobile HomePark Well		DNR	
HC 16	65209	Yahara Materials, Inc. Well #8	1987	DNR	WN 936
HC 17	90294	Kettle Moraine Lutheran High School Well	1977	DNR	WN 895
HC 18	87804	Heiliger Hugel Ski Club Well #1	1965	DNR	WN 88
HC 19	34001	L. Teweles Seed Co. Well		DNR	WN 866
HC 20	90428	St. Hubert Parish Well		DNR	WN 992
HC 21	90223	Richfield Elementary School Well	1970	DNR	WN 67
HC 22	65203	Merget Sand & Gravel Well #2	1951	DNR	WN 28
HC 23	65208	Wisconsin Electric Power Co. Well	1981	DNR	WN 909
HC 24	87824	Hill Top Homes Mobile Home Park Well #1	1985	DNR	WN 931
HC 25	87825	Hill Top Homes Mobile Home Park Well #2	1985	DNR	WN 919
HC 26	87826	Hill Top Homes Mobile Home Park Well #3	1985	DNR	WN 932
HC 27	87827	Hill Top Homes Mobile Home Park Well #4	1987	DNR	WN 937
HC 28	87828	Hill Top Homes Mobile Home Park Well #5	1985	DNR	WN 933
HC 29	87829	Hill Top Homes Mobile Home Park Well #6	1985	DNR	WN 934
HC 30	87830	Hill Top Associates Well		DNR	WN 991
HC 31	BO714-5*	Maple Terrace Mobile Home Park Well (2 wells)		DNR	
HC 32	01034	Level Valley Dairy Co.l	1949	DNR	WN 19
HC 33	FX362*	Park Avenue Water Trust Well		DNR	
HC 34	BO716*	Carriage Hills Apartments Well		DNR	
HC 35	87823	Karthauser & Sons, Inc. Well #1	1984	DNR	WN 917

Ozaukee:

HC 36	BO587*	New Tribes Institute		DNR	
HC 37	83607	Ozaukee County Courthouse	1968	DNR	OZ 88
HC 38	BO630*	Dairyland Mobile Home Park Well	1985	DNR	OZ 497
HC 39	83610	StoneCraft, Inc. Well	1973	DNR	OZ 451
HC 40	BO594*	Cherry Wood Apartments Well		DNR	
HC 41	BO588*	Pioneer Grafton Mobile Home Park Well		DNR	
HC 42	BO589*	Pioneer Grafton Mobile Home Park Well		DNR	
HC 43	90167	Our Savior Evangelical Lutheran Church Well		DNR	OZ 85
HC 44	90320	Milwaukee Area Technical College Well	1975	DNR	OZ 452
HC 45	83657	Villa Du Parc Subdivision Well #5	1978	DNR	OZ 475
HC 46	83652	Deer Trail Estates Well #2		DNR	OZ 511
HC 47	83639	Villa Du Parc Subdivision Well	1963	DNR	OZ 76
HC 48	83640	River Oak Country Club Estates Well #2	1969	DNR	OZ 349
HC 49	01177	Country Club of Wisconsin		DNR	OZ 543
HC 50	83606	Mequon Colony Estates Well	1966	DNR	OZ 86
HC 51	90046	Oriole Lane Elementary School Well		DNR	OZ 463
HC 52	83601	School Sisters of Notre Dame (Concordia College)	1957	DNR	OZ 33
HC 53	00521	Woodridge Estates Subdivision Well		DNR	
HC 54	01059	Westchester Lakes Subdivision Well		DNR	
HC 55	00728	Westchester Lake Subdivision Well #1		DNR	OZ 519
HC 56	00859	Lake Bluff Apartments Well #1	1990	DNR	OZ 525
HC 57	BO608*	Laurel Lakes 608		DNR	
HC 58	BO612*	Linden Lane Apartments 117		DNR	
HC 59	BO619*	Laurel Lakes 508		DNR	
HC 60	BO623*	Linden Lane Apartments 141		DNR	
HC 61	01099	Laurel Acres Well	1956	DNR	OZ 30
HC 62	FX327*	Grand Avenue Apartments Well		DNR	
HC 63	BO621*	Heidel Road Apartments 139		DNR	
HC 64	BO628*	Heidel Road Apartments 152		DNR	
HC 65	BO586*	Williamsburg 220		DNR	

HC 66	BO617*	Williamsburg 209		DNR	
HC 67	BO618*	Williamsburg 206		DNR	
HC 68	83630	Alberta Subdivision Well, Thiensville	1968	DNR	OZ 87
HC 69	83627	Century Estates #2, Thiensville	1960	DNR	OZ 44
HC 70	83628	Century Estates #3, Thiensville	1965	DNR	OZ 77
HC 71	83629	Century Estates #4, Thiensville	1968	DNR	OZ 347
HC 72	01072	Pine Ridge Estates Well	1979	DNR	OZ 477
HC 73	BO610*	Village Glen Apartments Well		DNR	
HC 74	00424	Bonnywell Village Apartments Well		DNR	
HC 75	83622	Village Heights Well		DNR	
HC 76	BO609*	River Garden Apartments Well		DNR	
HC 77	90067	Calvary Lutheran Church/School Well		DNR	OZ 450
HC 78	90263	Theinsville-Mequon High School Well	1959	DNR	OZ 41
HC 79	00729	Stonefield Subdivision Well		DNR	
HC 80	00522	River Ridge Subdivision Well		DNR	
HC 81	83656	River Ridge Subdivision Well		DNR	
HC 82	83642	River Glen Subdivision Well	1977	DNR	OZ 456
HC 83	83646	River Glen Subdivision Well		DNR	
HC 84	00907	Chateau Park Well		DNR	OZ 510
HC 85	83624	Huntington Park Well #2	1979	DNR	OZ 478
HC 86	83623	Huntington Park Well #1	1979	DNR	OZ 457
HC 87	83625	Huntington Park Well #3	1980	DNR	OZ 459
HC 88	83648	Huntington Park Well #4	1987	DNR	OZ 508
HC 89	01093	Brighton Ridge Subdivision Well		DNR	
HC 90	00523	Mequon Trail Subdivision Well #1	1990	DNR	OZ 514
HC 91	00524	Mequon Trail Subdivision Well #2	1990	DNR	OZ 529
HC 92	BA126*	Mequon on the Square and Mequon Ranch		DNR	
HC 93	90262	Theinsville-Mequon School Well (Wilson School)	1958	DNR	OZ 34
HC 94	90136	Steffen Middle School Well	1967	DNR	OZ 83
HC 95	83649	Riverlake Subdivision Well		DNR	
HC 96	83618	Country Terrace Condominiums Well	1973	DNR	OZ 455
HC 97	BO629*	Mequon Park Apartments Well	1973	DNR	OZ 454
HC 98	83650	River Trail Estates Well		DNR	
HC 99	BO599*	North Shore Heights Well		DNR	
HC 100	90196	Rangeline Elementary School Well		DNR	OZ 466
HC 101	90197	Mequon Middle School Well	1969	DNR	OZ 350
HC 102	00860	Gazebo Hills Well #2		DNR	OZ 516
HC 103	00903	Gazebo Hills Well #1		DNR	OZ 515
HC 104	01107	Knightsbridge Subdivision Well		DNR	
HC 105	00886	Mequon Business Park Well #2		DNR	OZ 526
HC 106	00908	Mequon Business Park Well #1	1990	DNR	OZ 512
HC 107	90178	Donges Bay Elementary School	1965	DNR	OZ 82
HC 108	83614	Greenbriar Meadows Well		DNR	OZ 465
HC 109	83619	Range Line Hills Subdivision Well #1 (Mequon)	1973	DNR	OZ 366
HC 110	83632	Range Line Valley Subdivision Well #2 (Mequon)	1978	DNR	OZ 491
HC 111	83655	Columbia Reserve Subdivison Well		DNR	
HC 112	83631	Range Line Valley Subdivision Well #1 (Mequon)	1976	DNR	OZ 414
HC 113	83615	Mequon Care Center Well		DNR	OZ 345
HC 114	83616	Mequon Care Center Well #2	1976	DNR	OZ 431
HC 115	72701	Kohl's Food Stores Well	1968	DNR	OZ 355
HC 116	83620	Mequon Water Trust Well	1955	DNR	OZ 28
HC 117	00902	Wyngate Subdivision Well #2		DNR	OZ 533
HC 118	83626	Concord Place Condominium Well	1979	DNR	OZ 458
HC 119	83608	Apple Orchard Condominium Well	1971	DNR	OZ 48
HC 120	AJ779*	Beechwood Farms Estates Well		DNR	
HC 121	CW500*	Beechwood Farms Estates Well		DNR	

HC 122	FX328*	Haddenstone Subdivision Well		DNR	
HC 123	83633	Cedar Ridge Condominium Well		DNR	
HC 124	83634	Cedar Ridge Condominium Well #2	1985	DNR	OZ 479
HC 125	83654	Kenilworth Subdivision Well	1988	DNR	OZ 506
HC 126	83643	Park Place Subdivision Well	1979	DNR	OZ 460
HC 127	83647	Park Place Subdivision Well #2	1987	DNR	OZ 498
HC 128	83653	Vintage Estates Well #1	1987	DNR	OZ 503
HC 129	01214	Vintage Estates Well		DNR	OZ 560
HC 130	BO598*	Ravine Farms Home Owners Association	1976	DNR	OZ 436
HC 131	83609	Cedar Gables Association Well	1967	DNR	OZ 367
HC 132	83611	Heritage Estates Apartments Well	1973	DNR	OZ 369
HC 133	90262	Greenbrier Apartments Well No. 1	1973	DNR	OZ 464
HC 134	90136	Greenbrier Apartments Well No. 2	1973	DNR	OZ 50

Surface Water Data

Surface Water Stations -map symbol

			Period of Record	Record. Agency	Data Type
Rock-Fox River Basin					
Washington:					
SW1	5423800	E. Branch Rock R. tributary near Slinger	1960-93	USGS	Crest stage
Lake Michigan Basin					
Washington:					
SW2	4086340	N. Branch Milwaukee R. near Fillmore	1968-81, 1993-94	USGS	Discharge
Ozaukee:					
SW3	4086500	Cedar Creek near Cedarburg	1930-70, 1973-81, 1983-87,	USGS	Crest stage
			1990-date	USGS	Discharge
SW4	4086600	Milwaukee R. near Cedarburg	1981-date	USGS	Discharge
SW5	4087050	Little Menomonee R. near Freistadt	1958-93	USGS	Crest stage
SW6	4086360	Milwaukee R. at Waubeka	1968-81	USGS	Discharge
SW7	4086400	Milwaukee R. tributary near Fredonia	1962-81	USGS	Crest stage

*Wis. Unique Well Numbers

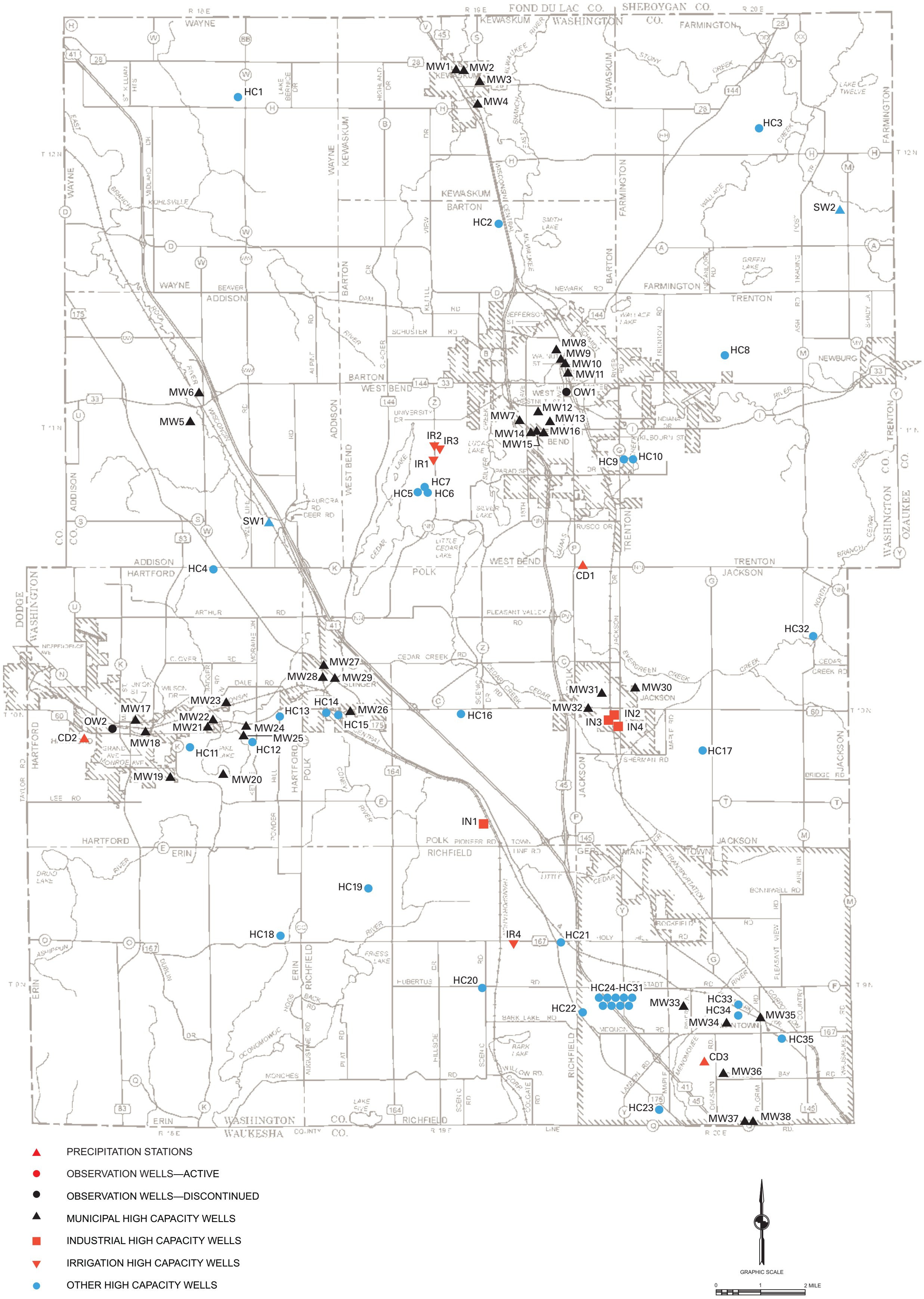
Agencies:

DNR	Wisconsin Department of Natural Resources, Madison, WI
NCDC	National Climatic Data Center, Asheville, NC (also: WGNHS, State Climatologist Office, Madison)
USGS	U.S. Geological Survey, Madison WI
WGNHS	Wisconsin Geological and Natural History Survey, Madison, WI

Source: Wisconsin Geological and Natural History Survey, 1996.

Map B-1

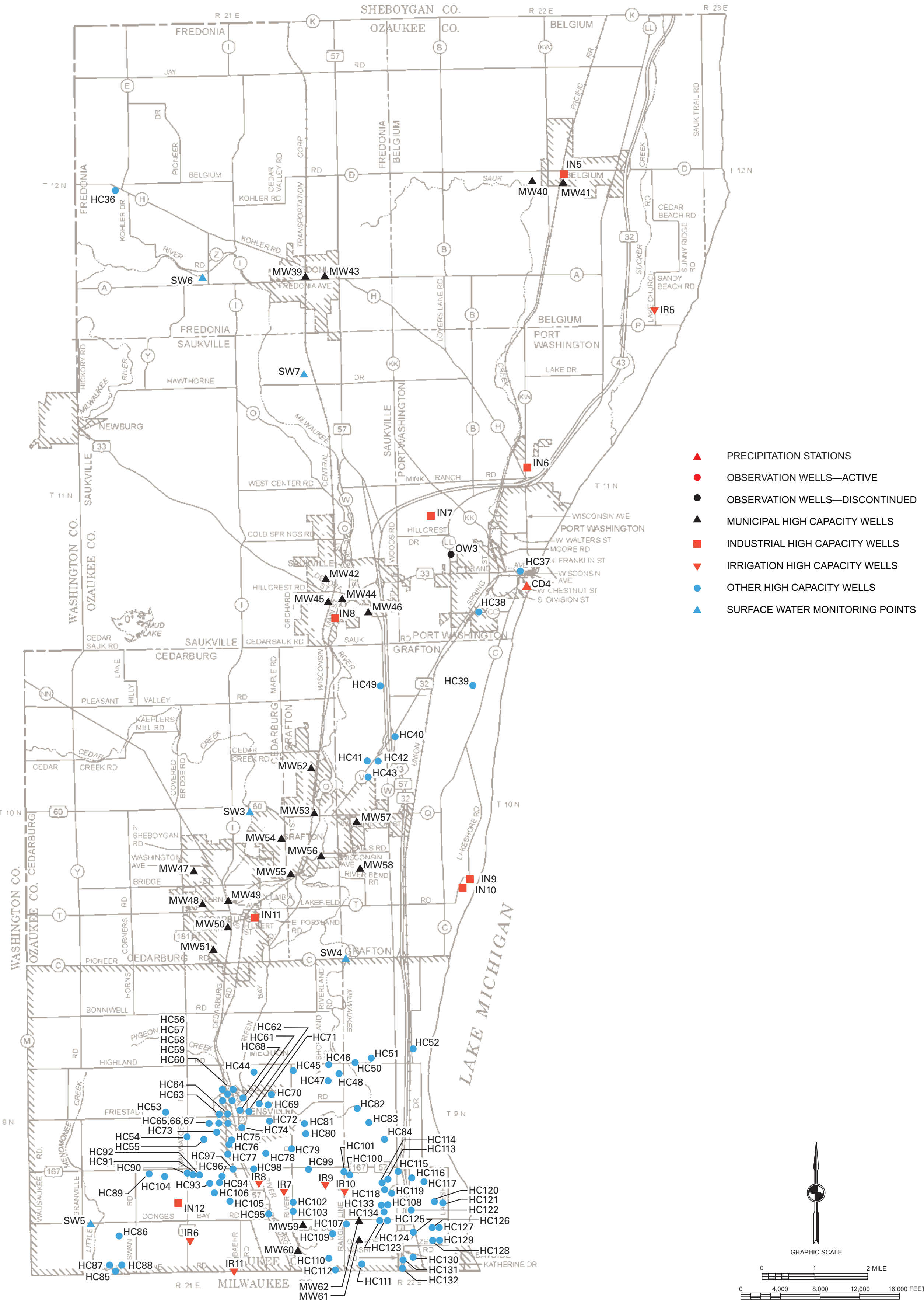
SIGNIFICANT HYDROLOGIC DATA POINTS IN WASHINGTON COUNTY



Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Map B-2

SIGNIFICANT HYDROLOGIC DATA POINTS IN OZAUKEE COUNTY



Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Table B-2

SIGNIFICANT HYDROLOGIC DATA POINTS IN WAUKESHA COUNTY

DATA POINTS

Climatic Data

Precipitation Stations - map symbol ▲

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
CD 1	476200	Oconomowoc	1938-date	NCDC	
CD 2	478937	Waukesha - Carroll College	1890-date	NCDC	
CD 3	478316	Sullivan (Jefferson Co.)	1994-date	NCDC	

Ground Water Data

Observation Wells - map symbol: active ● discontinued ●

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
OW 1	WK 20	C.W. Aeppler, Oconomowoc	1946-date	USGS	WK 20
OW 2	WK 50	L. Held, Menomonee Falls	1952-1993	USGS	
OW 3	WK 6	Waukesha City Well #2 (Baxter St.)	1995-date	USGS	WK 6
OW 4	WK14	New Tribes Mission, Waukesha	1946-1990	USGS	WK 14
OW 5	WK1301	Unused test hole, Waukesha	1992-date	USGS	WK 1301
OW 6	WK 31	W.M. Foss, Waukesha	1947-date	USGS	

Municipal Wells - map symbol ▲ *Standby/emergency well

Map No.	Identif. Number	Name (Location)	Installed	Record. Agency	WGNHS Log No.
MW 1	88153	Oconomowoc City Well #4	1963	DNR	
MW 2	88150	Oconomowoc City Well #1	1899	DNR	WK 104
MW 3	88151	Oconomowoc City Well #2	1911	DNR	WK 105
MW 4	88152	Oconomowoc City Well #3	1942	DNR	WK 106
MW 5	88125	Dousman Village Well #1	1971	DNR	WK 862
MW 6	88126	Dousman Village Well #2	1983	DNR	WK 1517
MW 7	88127	Dousman Village Well #3	1983	DNR	WK 1515
MW 8	88129	Hartland VillageWell #1*	1931	DNR	
MW 9	88132	Hartland Village Well #3	1973	DNR	WK 1104
MW 10	88133	Hartland Village Well #5	1983	DNR	WK 1526
MW 11	88131	Hartland Village Well #4	1971	DNR	WK 864
MW 12	88130	Hartland Village Well #2	1956	DNR	WK 150
MW 13	88158	Sussex Village Well #2	1961	DNR	WK 180
MW 14	88157	Sussex Village Well #1	1972	DNR	WK 888
MW 15	88180	Sussex Village Well #4		DNR	
MW 16	01491	Sussex Village Well #5		DNR	WK 1352
MW 17	88159	Sussex Village Well #3	1970	DNR	WK 726
MW 18	88134	Menomonee Falls City Well #2	1931	DNR	WK 4
MW 19	88135	Menomonee Falls City Well #3	1956	DNR	WK 148
MW 20	88138	Menomonee Falls City Well #6	1977	DNR	WK 1288
MW 21	88137	Menomonee Falls City Well #5	1967	DNR	WK 758
MW 22	88136	Menomonee Falls City Well #4	1960	DNR	WK 176
MW 23	88179	Menomonee Falls City Well #7	1988	DNR	
MW 24	88154	Pewaukee Village Well #2	1955	DNR	WK 137
MW 25	88155	Pewaukee Village Well #3	1969	DNR	WK 723
MW 26	88156	Pewaukee Village Well #4	1978	DNR	WK 1233

MW 27 00893	Pewaukee S.D.#3 (Highland Coop #1)	1914	DNR	WK 28
MW 28 00894	Pewaukee S.D.#3 (Highland Coop #2)	1988	DNR	WK 1528
MW 29 01086	Pewaukee S.D.#3 (Blue Mound)	1992	DNR	WK 1568
MW 30 00598	Pewaukee S.D.#3 Well #3	1989	DNR	WK 1309
MW 31 00526	Pewaukee S.D.#3 Well #4	1989	DNR	WK 1325
MW 32 88175	Pewaukee S.D.#3 Well #1	1974	DNR	WK 1249
MW 33 88176	Pewaukee S.D.#3 Well #2	1980	DNR	WK 1516
MW 34 01221	Menomonee Falls City Well #8	1992	DNR	
MW 35 88124	Butler Village Well	1965	DNR	WK 243
MW 36 88102	Brookfield City Well #4	1960	DNR	WK 178
MW 37 88103	Brookfield City Well #5*	1960	DNR	WK 210
MW 38 88109	Brookfield City Well #11	1965	DNR	WK 237
MW 39 88108	Brookfield City Well #10	1965	DNR	WK 238
MW 40 88118	Brookfield City Well #20*	1971	DNR	
MW 41 88115	Brookfield City Well #17	1968	DNR	WK 710
MW 42 88119	Brookfield City Well #21	1972	DNR	WK 894
MW 43 88116	Brookfield City Well #18	1970	DNR	WK 827
MW 44 88172	Brookfield City Well #24	1988	DNR	WK 1312
MW 45 88110	Brookfield City Well #12	1965	DNR	WK 240
MW 46 88111	Brookfield City Well #13	1965	DNR	
MW 47 88112	Brookfield City Well #14	1965	DNR	WK 234
MW 48 88106	Brookfield City Well #8	1964	DNR	
MW 49 88107	Brookfield City Well #9	1966	DNR	WK 701
MW 50 00896	Brookfield City Well #25	1992	DNR	WK 1347
MW 51 01219	Brookfield City Well #27	1992	DNR	WK 1348
MW 52 88105	Brookfield City Well #7*	1962	DNR	WK 217
MW 53 88104	Brookfield City Well #6	1962	DNR	WK 213
MW 54 88117	Brookfield City Well #19	1971	DNR	WK 867
MW 55 88122	Brookfield S.D. #4 Well #5	1977	DNR	WK 1286
MW 56 88123	Brookfield S.D. #4 Well #6	1978	DNR	WK 1130
MW 57 88010	Elm Grove Village Well		DNR	
MW 58 88120	Brookfield City Well #22	1973	DNR	WK 897
MW 59 88101	Brookfield City Well #3	1959	DNR	WK 166
MW 60 88113	Brookfield City Well #16	1966	DNR	WK 766
MW 61 8814	Brookfield City Well #5	1967	DNR	WK 860
MW 62 88121	Brookfield City Well #23*	1976	DNR	
MW 63 88099	Brookfield City Well #1*	1948	DNR	
MW 64 88100	Brookfield City Well #2*	1939	DNR	
MW 65 00895	Brookfield City Well #26	1991	DNR	WK 1340
MW 66 00906	Brookfield S.D. #4 Well #4	1991	DNR	WK 1341
MW 67 88178	Brookfield S.D. #4 Well #3	1989	DNR	WK 1304
MW 68 88170	Brookfield S.D. #4 Well #1	1960	DNR	WK 175
MW 69 88171	Brookfield S.D. #4 Well #2	1960	DNR	WK 174
MW 70 88169	Waukesha City Well #10	1979	DNR	
MW 71 88160	Waukesha City Well #1	1935	DNR	WK 8
MW 72 88162	Waukesha City Well #3	1930	DNR	WK 7
MW 73 88163	Waukesha City Well #4	1945	DNR	WK 5
MW 74 88164	Waukesha City Well #5	1955	DNR	WK 125
MW 75 88168	Waukesha City Well #9	1972	DNR	WK 887
MW 76 88165	Waukesha City Well #6	1959	DNR	WK 168
MW 77 88166	Waukesha City Well #7	1963	DNR	WK 194
MW 78 88167	Waukesha City Well #8	1967	DNR	WK 756
MW 79 88144	New Berlin City Well #3	1966	DNR	WK 350
MW 80 88142	New Berlin City Well #1	1964	DNR	WK 233
MW 81 88145	New Berlin City Well #4	1966	DNR	WK 235
MW 82 88143	New Berlin City Well #2	1965	DNR	WK 763

MW 83	88148	New Berlin City Well #7	1977	DNR	
MW 84	88147	New Berlin City Well #6	1972	DNR	WK 890
MW 85	88146	New Berlin City Well #5	1970	DNR	WK 855
MW 86	01105	New Berlin City Well #9		DNR	
MW 87	88149	New Berlin City Well #8	1984	DNR	
MW 88	88061	Muskego City Well #3	1975	DNR	WK 1247
MW 89	88062	Muskego City Well #4	1976	DNR	WK 1248
MW 90	88174	Muskego City Well #2	1978	DNR	WK 1289
MW 91	88173	Muskego City Well #1		DNR	
MW 92	88067	Kristen Downs Subdivision Well #1, Muskego	1977	DNR	WK 1142
MW 93	88068	Kristen Downs Subdivision Well #2, Muskego	1982	DNR	WK 1143
MW 94	88091	Ethan Allen School for boys (3 wells)		DNR	
MW 95	88140	Mukwonago Village Well #3	1960	DNR	WK 353
MW 96	88139	Mukwonago Village Well #2	1941	DNR	WK 36
MW 97	88141	Mukwonago Village Well #4	1980	DNR	WK 1513
MW 98	88128	Eagle Village Well #2	1979	DNR	WK 1232
MW 99	88127	Eagle Village Well #1	1953	DNR	WK 117

Industrial High-Capacity Wells - map symbol

IN 1	65611	Carnation Milk Co.	1963	DNR	WK 222
IN 2	65626	Carnation Milk Co.		DNR	
IN 3	65616	Central Ready Mix Concrete	1970	DNR	WK 859
IN 4	65602	Dale Dawson	1950	DNR	WK 114
IN 5	65622	Friday Canning Corp.	1975	DNR	WK 1245
IN 6	65609	Best Block Co.	1959	DNR	WK 167
IN 7	65624	Pabst Farms Dairy	1942	DNR	WK 119
IN 8	65627	Pabst Farms Dairy	1924	DNR	WK 121
IN 9	65620-1	Wis. Electric Power (2 wells)	1974	DNR	WK 899, 1250
IN 10	65612-3	Johnson T. & Sons (2 wells)	1962	DNR	WK 227
IN 11	65614	Milwaukee Electric Tool Co. Well	1964	DNR	WK 229
IN 12	65615	Milwaukee Electric Tool Co. Well #2	1971	DNR	WK 712
IN 13	65605	W.A. Krueger & Co.	1958	DNR	WK 161
IN 14	65605	Beatrice Cheese, Inc.		DNR	
IN 15	65623	Beatrice Cheese, Inc.	1958	DNR	WK 164
IN 16	65630-31	Grede Foundry (2 wells)	1925, 1944	DNR	WK 15, 12
IN 17	74028	Purity Bottling (Artesia)	1927	DNR	WK 16
IN 18	65618	AT&T Communications SPVR Facil.		DNR	
IN 19	65619	AT&T Communications SPVR Facil.	1971	DNR	WK 866
IN 20	65625	Anamax Corporation	1977	DNR	WK 1253
IN 21	65629	Muskego Industrial Park		DNR	

Irrigation High-Capacity Wells - map symbol

IR 1	34309	Koepke Farms Well #1	1964	DNR	WK 349
IR 2	34335	Koepke Farms Well #2	1977	DNR	WK 1146
IR 3	34349	Koepke Farms Well #3	1988	DNR	WK 1303
IR 4	34333	Runyard Farms, Inc.		DNR	
IR 5	34301	Oconomowoc Golf Club	1961	DNR	WK 184
IR 6	34302	Oconomowoc Golf Club		DNR	
IR 7	34352	Chenequa Country Club		DNR	
IR 8	01539	Ironwood Golf Course		DNR	
IR 9	01178	Lied's Nursery		DNR	WK 1575
IR 10	34305	North Hills Country Club	1962	DNR	WK 212
IR 11	34306	North Hills Country Club	1963	DNR	WK 246
IR 12	34317	Wanaki Golf Course	1968	DNR	WK 711

IR 13	34318	Wanaki Golf Course		DNR	
IR 14	34314	Paganica Golf Course		DNR	
IR 15	34315	Paganica Golf Course		DNR	
IR 16	34316	Paganica Golf Course		DNR	
IR 17	34337	Continental Properties	1977	DNR	WK 1280
IR 18	34326	Pabst Farms Well #11	1977	DNR	WK 1125
IR 19	34342	Pabst Farms Well		DNR	
IR 20	34320	Pabst Farms Well #3	1974	DNR	WK 1258
IR 21	34327	Pabst Farms Well #10	1976	DNR	WK 1150
IR 22	34321	Pabst Farms Well #4	1975	DNR	WK 1107
IR 23	36322	Pabst Farms Well #5	1975	DNR	WK 1126
IR 24	34347	Pabst Farms Well #14	1985	DNR	WK 1310
IR 25	34326	Pabst Farms Well #9	1976	DNR	WK 1149
IR 26	34338	Pabst Farms Well #12	1980	DNR	WK 1523
IR 27	34323	Pabst Farms Well #6	1975	DNR	WK 1127
IR 28	34324	Pabst Farms Well #7	1976	DNR	WK 1128
IR 29	34354	Pabst Farms Well		DNR	
IR 30	00730	Pabst Farms Well #8	1976	DNR	WK 1124
IR 31	34325	Pabst Farms Well		DNR	
IR 32	34319	Blaney Farms, Inc.	1975	DNR	WK 1243
IR 33	34346	Robert Schuett	1985	DNR	WK 1295
IR 34	34350	Lurvey Sod Farms (2 wells)		DNR	
IR 35	34310	Nagawaukee Park		DNR	
IR 36	34312	Nagawaukee Park	1964	DNR	
IR 37	34311	Nagawaukee Park	1977	DNR	WK 231
IR 38	34334	Moor Downs Golf Course		DNR	WK 1283
IR 39	34348	Moor Downs Gold Course		DNR	
IR 40	34304	Mt. Zion Cemetery	1961	DNR	WK 187
IR 41	34332	Westmoor Country Club		DNR	
IR 42	34340	Westmoor Country Club	1949	DNR	WK 111
IR 43	34341	Westmoor Country Club	1957	DNR	WK 152
IR 44	34343	Kincaid Farms, Inc.	1983	DNR	WK 1527
IR 45	34352	Lurvey Sod Farms (2 wells)		DNR	
IR 46	34328	Merrill Hills Country Club	1966	DNR	WK 706
IR 47	34329	Merrill Hills Country Club		DNR	
IR 48	34330	Merrill Hills Country Club		DNR	
IR 49	34307	D. Carmichael & Sons		DNR	
IR 50	01336	New Berlin Hills Golf Course	1994	DNR	WK 1371
IR 51	34355	Muskego Lake Country Club		DNR	
IR 52	34308	Wallace Rieger		DNR	

Other High-Capacity Wells - map symbol

HC 1	88001	Redemptionist Fathers	1948	DNR	WK 40
HC 2	90268	Meadowview Elementary School	1963	DNR	WK 223?
HC 3	90311	Holy Trinity Evang. Lutheran School	1980	DNR	WK 1522
HC 4	88064	The Evergreens Condominiums	1983	DNR	WK 1510
HC 5	90165	North Lake Elementary School	1967	DNR	WK 765
HC 6	90358	Stonebank Elementary School		DNR	
HC 7	90137	Merton Elementary School		DNR	WK 1365
HC 8	90265	Swallow Elementary School	1975	DNR	WK 1109
HC 9	00469	Arrowhead School District		DNR	
HC 10	00470	Arrowhead School District		DNR	
HC 11	01188	Halquist Stone Co.	1993	DNR	WK 1567
HC 12	88014	Willow Springs Mobile Home Court	1965	DNR	WK 236
HC 13	88015	Willow Springs Mobile Home Court	1972	DNR	WK 1110

HC 14	90185	Hamilton High School	1961	DNR	WK 215
HC 15	90186	Hamilton High School		DNR	
HC 16	88027	Ausblick Ski Club	1970	DNR	WK 863
HC 17	90279	Richmond Elementary School Well #1	1975	DNR	WK 1108
HC 18	90381	Richmond Elementary School Well #2	1985	DNR	WK 1538
HC 19	88075	Omega Hills South Landfill		DNR	
HC 20	88076	Omega Hills South Landfill		DNR	
HC 21	88040	Menomonee Park, Lannon	1969	DNR	WK 719
HC 22	88041	Menomonee Park, Lannon	1970	DNR	WK 856
HC 23	01505	Halquist Stone Co.		DNR	WK 1572
HC 24	90117	Willow Springs Elementary School		DNR	
HC 25	01060	Lannon Mobile Home Park		DNR	
HC 26	01521-23	Shady Lane Greenhouses (3 wells)		DNR	
HC 27	88009	Kettle Moraine Hospital	1963	DNR	WK 244
HC 28	90377	Country Christian High School	1984	DNR	WK 1534
HC 29	90104	Summit Elementary School		DNR	
HC 30	90195	Nashotah House Episcopal Seminary		DNR	
HC 31	88093	Nashotah House Episcopal Seminary	1988	DNR	WK 1297
HC 32	90194	Nashotah House Episcopal Seminary		DNR	
HC 33	88055	Indian Mound Boy Scout Reservation	1957	DNR	WK 144
HC 34	90188	Oconomowoc Development Training Center		DNR	
HC 35	90455	Oconomowoc Development Training Center	1992	DNR	WK 1370
HC 36	88029-30,44	J & D Enterprises, Inc. (3 wells)		DNR	
HC 37	88069	Riverview Estates Apts. Well #1	1982	DNR	WK 1529
HC 38	88070	Riverview Estates Apts. Well #2	1983	DNR	WK 1532
HC 39	90491	Country Christian School		DNR	
HC 40	94480	Lake Country School		DNR	WK 1549
HC 41	88022-24	Country Aire Apartments (3 wells)		DNR	
HC 42	90160	University Lake School		DNR	
HC 43	90409	University Lake School		DNR	
HC 44	90410	University Lake School		DNR	
HC 45	88084-87	Nagawicka Shores Condominiums (4 Wells)	1986-1987	DNR	WK 1313-14
HC 46	74029	Lake Country Apartments		DNR	
HC 47	88004	St. John's Military Academy, Delafield	1929	DNR	WK 38
HC 48	88072	Knollcrest Housing, Delafield		DNR	WK 1537
HC 49	88057	Heritage Ridge Center		DNR	WK 1518
HC 50	90451	Lakeside School	1940	DNR	WK 39
HC 51	88073-4	Oakton Beach (2 wells)	1960	DNR	WK 116
HC 52	90107	Zion Elementary School		DNR	
HC 53	88021	Schoenstatt Sisters of Mary	1968	DNR	WK 707
HC 54	90039	Torhorst School		DNR	
HC 55	88007	Carmelite Monastery	1958	DNR	WK 163
HC 56	88028	Country Inn	1971	DNR	WK 865
HC 57	74035	Wisconsin Bell Well #2	1985	DNR	WK 1294
HC 58	88078-9	Wisconsin Bell (2 wells)	1985	DNR	WK 1540
HC 59	90175	Pheasant Hill Elementary School	1968	DNR	WK 764
HC 60	90216	Wisconsin Hills Elementary School	1969	DNR	WK 725
HC 61	90000	Brookfield Central High School		DNR	
HC 62	90001	Brookfield Central High School	1956	DNR	WK 158
HC 63	88020	Elmbrook Memorial Hospital	1966	DNR	WK 356
HC 64	90476	Brookfield Academy Liberty Hall		DNR	WK 1566
HC 65	90050	Fairview South Elementary School		DNR	
HC 66	90143	Burleigh Elementary School		DNR	
HC 67	74022	Kohl's Food Stores	1966	DNR	WK 357
HC 68	90105	Butler Elementary School		DNR	
HC 69	74021	Treasure Island, Brookfield	1964	DNR	WK 228

HC 70	88025	Wisconsin Memorial Park, Brookfield	1970	DNR	WK 857
HC 71	88016	Brookfield Fire Station #2	1965	DNR	WK 242
HC 72	90031	Brookfield East High School	1961	DNR	WK 185
HC 73	88031	Congregational Home, Brookfield	1973	DNR	WK 1239
HC 74	90209	Tonawanda Elementary School	1969	DNR	WK 721
HC 75	88052	Marion Heights Subdivision, Elm Grove	1944	DNR	WK 2
HC 76	88083	Meadows of the Grove Subdivision	1978	DNR	WK 1129
HC 77	88003	Sisters of Notre Dame	1972	DNR	WK 893
HC 78	74023	United Parcel Service, Elm Grove	1968	DNR	WK 716
HC 79	74038	Park III, Inc., Elm Grove		DNR	
HC 80	90134	Elmbrook Middle School	1957	DNR	WK 155
HC 81	88055	Squire Grove Condominiums Well #1	1972	DNR	WK 1105
HC 82	88063	Squire Grove Condominiums Well #2	1980	DNR	WK 1519
HC 83	90254-55	Elm Grove Lutheran School (2 wells)		DNR	
HC 84	94025	Allstate Insurance, Brookfield	1972	DNR	WK 893
HC 85	88053	Brookfield Hills Apartments	1969	DNR	WK 717
HC 86	88054	Brookfield Hills Apartments	1973	DNR	WK 1106
HC 87	88046	Old World Wisconsin Well #6	1980	DNR	WK 1237
HC 88	88071	Old World Wisconsin Well #9	1983	DNR	WK 1291
HC 89	88096	Old World Wisconsin Well #10	1987	DNR	WK 1315
HC 90	88012	Rainbow Springs Country Club		DNR	
HC 91	90325	Mukwonago Elementary School	1981	DNR	WK 1240
HC 92	90399	Prairie View School		DNR	
HC 93	88048-49	Prairie Village Subdivision (2 wells)	1978	DNR	WK 1290
HC 94	88050	Prairie Village Subdivision Well #3	1980	DNR	WK 1521
HC 95	90129	Hillside Elementary School		DNR	
HC 96	90172	Magee Elementary School (2 wells)	1967	DNR	WK 759
HC 97	90119	Kettle Moraine High School	1964	DNR	WK 230
HC 98	90299	Wales Elementary School		DNR	WK 1353
HC 99	74036-7	Lynndale Subdivision (2 weeks)	1955, 1954	DNR	WK 133, 136
HC 100	01082	Pleasant Meadows Apartments	1992	DNR	WK 1571
HC 101	90135	Glen Park Middle School		DNR	
HC 102	00820	New Berlin Parks & Rec. Dept.		DNR	
HC 103	90145	Herbert Hoover Elementary School		DNR	
HC 104	88017-8	New Berlin Memorial Hospital Well (2 wells)	1965, 1966	DNR	WK 248, 355
HC 105	90187	Cleveland Heights Elementary School		DNR	
HC 106	90016	New Berlin High School	1960	DNR	WK 186
HC 107	90166	Prospect Hill Elementary School	1967	DNR	WK 757
HC 108	90193	Eisenhower High School	1969	DNR	WK 720
HC 109	88094-5	Hale Park Meadows Subdivision (2 wells)	1973, 1976	DNR	WK 1102, 1846
HC 110	88059	Durham Meadows Subdivision Well #1	1972	DNR	WK 1122
HC 111	88060	Durham Meadows Subdivision Well #2	1977	DNR	WK 1144
HC 112	00878	Durham Meadows Subdivision Well		DNR	
HC 113	88056	Lake Lore Estates	1977	DNR	WK 1148
HC 114	88042	Tudor Oaks Retirement Community	1975	DNR	WK 1121
HC 115	90176	Bay Lane School (Muskego Middle School)	1968	DNR	WK 708
HC 116	90235	St. Paul Evang. Lutheran School		DNR	
HC 117	74026	Freedom Square Condo Assoc.	1973	DNR	WK 1512
HC 118	74027	Freedom Square Condo Assoc.	1972	DNR	WK 892
HC 119	88036	Pioneer Centre Subdivision Well	1973	DNR	WK 1103
HC 120	88034	Muskego Park		DNR	
HC 121	90004	Muskego Union High School	1957	DNR	WK 154
HC 122	90326	Big Bend Elementary School		DNR	
HC 123	90444	St. Joseph's Church & School		DNR	
HC 124	88081	The Meadows Subdivision Well #1	1979	DNR	WK 1284
HC 125	88082	Maynard Schuessler		DNR	

Surface Water Data

Surface Water Stations - map symbol ▲

Rock-Fox River Basin

			Period of Record	Record. Agency	Data Type
SW 1	4303340 88255400	Upper Nemahbin Lake, Outlet, near Delafield	1993-date	USGS	Quality
SW 2	05426100	Scuppernong Cr. near Wales	1962-1981	USGS	Crest-stage
SW 3	05543800	Fox R. at Watertown Rd., near Waukesha	1992-date	USGS	Discharge
SW 4	05543830	Fox R. at Waukesha	1963-date	USGS	Discharge
SW 5	05544200	Mukwonago R. at Mukwonago	1973-date	USGS	Discharge Quality
SW 6	05544300	Mukwonago R. trib. near Mukwonago	1960-1992	USGS	Crest-stage

Lake Michigan Basin

SW 7	04087030	Menomonee R. near Menomonee Falls	1974-date	USGS	Discharge

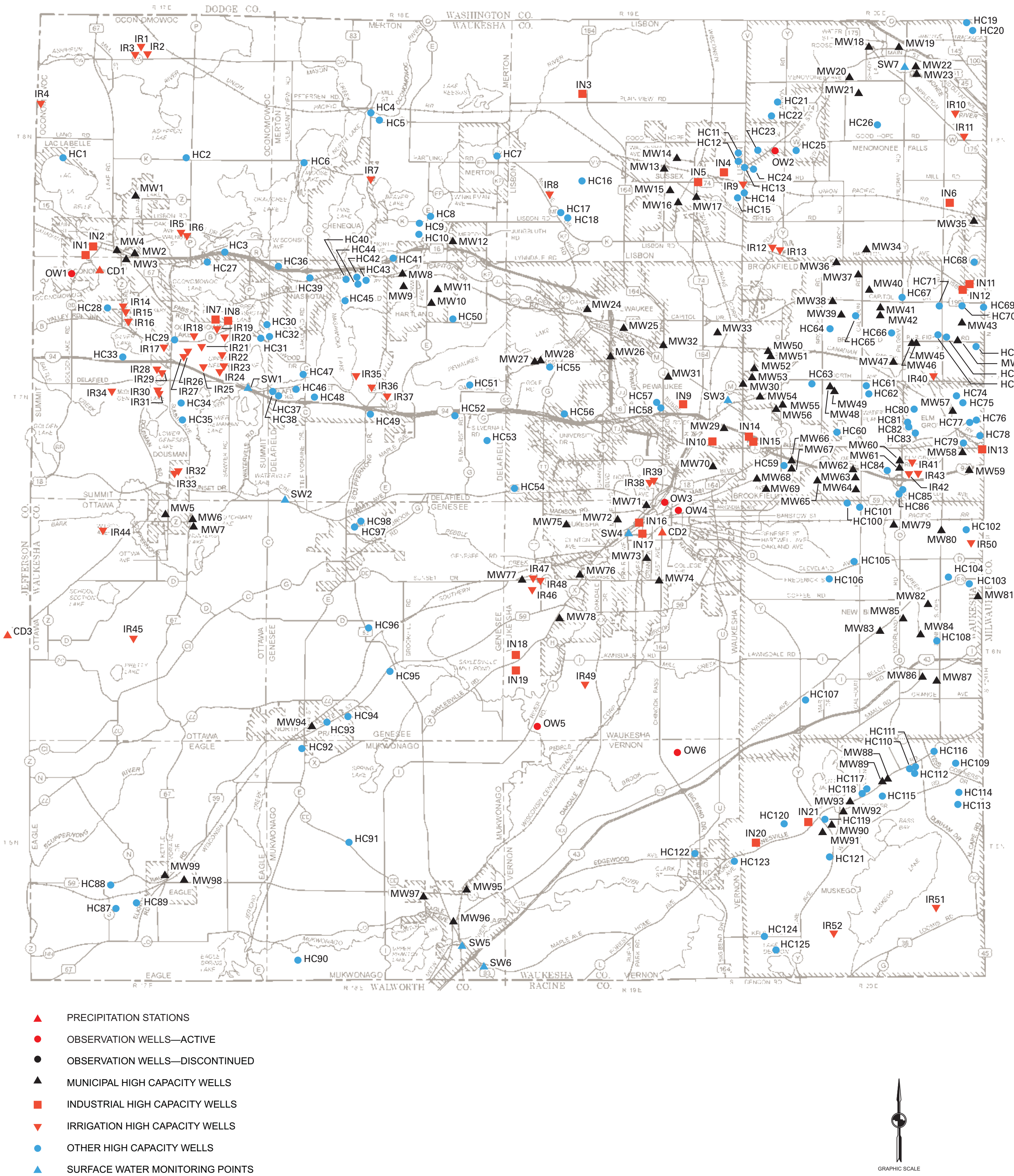
Agencies:

DNR	Wisconsin Department of Natural Resources, Madison, WI
NCDC	National Climatic Data Center, Asheville, NC (also: WGNHS, State Climatologist Office, Madison)
USGS	U.S. Geological Survey, Madison, WI
WGNHS	Wisconsin Geological and Natural History Survey, Madison, WI

Source: Wisconsin Geological and Natural History Survey, 1966.

Map B-3

SIGNIFICANT HYDROLOGIC DATA POINTS IN WAUKESHA COUNTY



Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Table B-3

SIGNIFICANT HYDROLOGIC DATA POINTS IN MILWAUKEE COUNTY

DATA POINTS

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.

Climatic Data

Precipitation Stations - map symbol

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
CD 1	475474	Milwaukee Mt. Mary College	1946-date	NCDC	
CD 2	475479	Milwaukee WSFO Airport	1927-date	NCDC	

Ground Water Data

Observation Wells - map symbol: active discontinued

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
OW 1	ML 118	A. Schaefer, Milwaukee	1946-date	USGS	
OW 2	ML 120	Nunn Bush Shoe Co., Milwaukee	1946-date	USGS	ML 120
OW 3	ML 45	Milwaukee Journal Building	1946-1982	USGS	ML 45
OW 4	ML 22	Allis-Chalmers Co., West Allis	1939-1980	USGS	ML 22
OW 5	ML 130	Greenfield Park, Milwaukee	1946-1981	USGS	
OW 6	ML 85	Old City Hall, Milwaukee	1974-date	USGS	ML 85
OW 7	ML 94	Whitnall Park(Well #2), Botanical Garden	1946-date	USGS	ML 94
OW 8	ML 148	Whitnall Park (old CCC well)	1946-date	USGS	
OW 9	ML 540	City of Oak Creek Well #4 (emerg.well)	1974-date	USGS	ML 540
OW 10	ML 431	Badger Meter Mfg. Co.	1966-1980	USGS	ML 431

Municipal Wells - map symbol

Map No.	Identif. Number	Name (Location)	Installed	Record. Agency	WGNHS Log No.
MW 1	ML 378	Wauwatosa City Well #11*	1955	WGNHS	*For
MW 2	ML 286	Wauwatosa City WEll #8*	1947	WGNHS	emergency
MW 3	ML 17	Wauwatosa City Well #6*	1930	WGNHS	use only
MW 4	82736	Franklin City Well #6	1968	DNR	
MW 5	82735	Franklin City Well #5	1975	DNR	ML 481
MW 6	82731	Franklin City Well #1 (Ind. Park)	1956	DNR	
MW 7	82740	Franklin City Well #9 (Franklin est.)	1974	DNR	ML 513
MW 8	82741	Franklin City Well 9A (Franklin est.)	1974	DNR	
MW 9	82733	Franklin City Well #3	1965	DNR	ML 516
MW 10	82734	Franklin City Well #4*	1975	DNR	ML 491
MW 11	82738	Franklin City Well #8	1978	DNR	ML 595
MW 12	82739	Franklin City Well #10 (form. 8A)	1978	DNR	ML 596
MW 13	83737	Franklin City Well #7	1967	DNR	
MW 14	82732	Franklin City Well #2 (Ind. Park)	1976	DNR	ML 592
MW 15	82745	Oak Creek City, Cedar Hills Subd. Well #1*	1963	DNR	ML 499
MW 16	82746	Oak Creek City, Cedar Hills Subd. Well #2*	1973	DNR	ML 500
MW 17	82742	Oak Creek City Well #1*	1956	DNR	ML 412
MW 18	82743	Oak Creek City Well #3*	1958	DNR	ML 454
MW 19	82624	Franklin City Well #14 (Country Gates Apts)	1974	DNR	ML 574
MW 20	82625	Franklin City Well #15 (Country Gates Apts)	1975	DNR	ML 497

MW 21	82626	Franklin City Well #12 (Whitnall Edge)	1979	DNR	ML 478
MW 22	82627	Franklin City Well #13 (Whitnall Edge)	1979	DNR	ML 715

Industrial High-Capacity Wells - map symbol

IN 1	82600	Mead Containers Co.		DNR	
IN 2	54827	Briggs & Stratton Good Hope Plant	1956	DNR	ML 415
IN 3	54815	Milwaukee Gear Co.	1953	DNR	ML 322
IN 4	54816	Oster Manufacturing Co. Well #1	1946	DNR	ML 161
IN 5	54817	Oster Manufacturing Co. Well #2	1951	DNR	ML 310
IN 6	54824	S.K Williams Co.	1968	DNR	ML 549
IN 7	54832	Falk Corporation	1958	DNR	ML 443
IN 8	54804	Briggs & Stratton Co.	1955	DNR	ML 351
IN 9	72402	WisCold	1955	DNR	ML 349
IN 10	54818	Kearney & Trecker Corp.	1953	DNR	ML 321
IN 11	54808	A.F. Gallun & Sons Corp.	1952	DNR	ML 138
IN 12	54828	Milwaukee Tallow & Grease Co.	1961	DNR	ML 492
IN 13	82618	Milwaukee Electric Power Co.	1969	DNR	ML 359
IN 14	54825-6	Kurth Malting Co. (2 wells)		DNR	ML 299
IN 15	54802	Babcock & Wilcox	1940	DNR	ML 103
IN 16	54803	Babcock & Wilcox	1949	DNR	ML 300
IN 17	54810	Kurth Malting Co. Well #1	1926	DNR	ML 104
IN 18	54811	Kurth Malting Co. Well #2		DNR	
IN 19	54812	Kurth Malting Co. Well #4	1954	DNR	ML 326
IN 20	54821	Venture Dyne Limited	1948	DNR	ML 225
IN 21	54805	Froedtert Grain & Malt Co. Well #1	1928	DNR	ML 106
IN 22	54806	Froedtert Grain & Malt Co. Well #2	1938	DNR	ML 107
IN 23	54807	Froedtert Grain & Malt Co. Well #3	1947	DNR	ML 226
IN 24	54814	Maynard Steel Casting Co.	1943	DNR	ML 80
IN 25	54829	Pelton Casteel Co.	1943	DNR	ML 81
IN 26	54801	Allis-Chalmers	1916	DNR	ML 95

Irrigation High-Capacity Wells - map symbol

IR 1	19709	Brown Deer Park & Golf Course	1935	DNR	ML 7
IR 2	19714	Brown Deer Park & Golf Course		DNR	ML 670
IR 3	19710	Tripoli Country Club		DNR	
IR 4	19711	Trammel Crow Co.		DNR	ML 742
IR 5	19713	Trammel Crow Co.		DNR	
IR 6	19705	Milwaukee Country Club Well #1	1964	DNR	ML 505
IR 7	19708	Milwaukee Country Club Well #2	1977	DNR	ML 593
IR 8	00781	Milwaukee Country Club Well #3		DNR	ML 677
IR 9	82602	Pinelawn Memorial Park		DNR	ML 602
IR 10	19703	Tuckaway Country Club	1962	DNR	ML 498
IR 11	19704	Tuckaway Country Club		DNR	
IR 12	82619	Whitnall Park Golf Course	1932	DNR	ML 93
IR 13	19706	Tuckaway Country Club Well #1	1968	DNR	ML 550
IR 14	19707	Tuckaway Country Club Well #2	1967	DNR	ML 546
IR 15	82614	Oakwood Golf Course	1969	DNR	ML 569
IR 16	00963	Oakwood Golf Course		DNR	ML 632

Other High-Capacity Wells - map symbol

HC 1	90006	Brown Deer High School		DNR	
HC 2	82630	Robert William Park Subdivision Well #1	1955	DNR	ML 337
HC 3	82631	Robert William Park Subdivision Well #2	1955	DNR	ML 385
HC 4	82603	McGovern Park	1935	DNR	ML 8
HC 5	90005	Bayside-Fox Point School	1957	DNR	ML 438
HC 6	82613	Bayside Nursing Home	1968	DNR	ML 568
HC 7	82622	Bayside Woods Condos Well #1	1978	DNR	ML 713
HC 8	82623	Bayside Woods Condos Well #2		DNR	
HC 9	82632	Northway Subdivision Water Coop Well #1	1953	DNR	ML 319
HC 10	82633	Northway Subdivision Water Coop Well #2	1953	DNR	ML 320
HC 11	82610	University Schools of Milwaukee Well #1	1960	DNR	ML 486
HC 12	90356	University Schools of Milwaukee Well #2	1985	DNR	ML 604
HC 13	90233	Indian Hill Elementary School		DNR	
HC 14	82634	Pelham Heath Subdivision Well #1	1956	DNR	ML 416
HC 15	82635	Pelham Heath Subdivision Well #2	1980	DNR	ML 716
HC 16	90249	Schlitz Audubon Center	1974	DNR	ML 608
HC 17	82601	Civil Defense Administration	1953	DNR	ML 312
HC 18	72403	Mayfair Shopping Center	1959	DNR	ML 455
HC 19	83604	Milwaukee County Zoo	1962	DNR	ML 511
HC 20	00539	UW Milwaukee, Dept of Geology		DNR	ML 676
HC 21	82608	Milwaukee County Museum	1962	DNR	ML 496
HC 22	90200	Jefferson Elementary School		DNR	
HC 23	90115	Edgewood Elementary School		DNR	
HC 24	82637	Whitnall Gardens Apartments	1967	DNR	ML 543
HC 25	90214	Whitnall Area Schools	1958	DNR	ML 448
HC 26	90213	Whitnall Middle School	1970	DNR	ML 571
HC 27	90183	Edgerton Elementary School	1966	DNR	ML 538
HC 28	82629	Blossom Heath Subdivision	1956	DNR	ML 414
HC 29	90034	Hales Corners Lutheran School		DNR	
HC 30	82611	Hales Corners Park	1964	DNR	ML 512
HC 31	82628	Village Brooke Condos	1979	DNR	ML 591
HC 32	82612	Forest Place Apartments	1968	DNR	ML 547
HC 33	82609	Wilson Park	1964	DNR	ML 508
HC 34	82615	Xaverian Missionary Fathers	1967	DNR	ML 545
HC 35	82616	Xaverian Missionary Fathers		DNR	
HC 36	82617	Xaverian Missionary Fathers		DNR	
HC 37	82621	Wehr Natural Center, Whitnall	1973	DNR	ML 352
HC 38	90336	Ben Franklin School		DNR	
HC 39	90394	Country Dale Elementary School		DNR	ML 650
HC 40	90114	Pleasant View Elementary School	1963	DNR	ML 506
HC 41	90097	Franklin Union High School	1962	DNR	ML 494
HC 42	90221	Forest Park Middle School	1970	DNR	ML 358
HC 43	82638	Security Acres Subdivision	1955	DNR	ML 421
HC 44	82639	Security Acres Subdivision	1956	DNR	ML 400
HC 45	82640	Milwaukee County House of Corrections	1948	DNR	ML 232
HC 46	82641	Milwaukee County House of Corrections	1956	DNR	ML 406
HC 47	90371	St. John's Evang. Lutheran School		DNR	
HC 48	90077	St. Matthews School		DNR	

Surface Water Data

Surface Water Stations - map symbol

Lake Michigan Basin

			Period of Record	Record. Agency	Data Type
SW 1	040869415	Lincoln Cr. at 47th St., Milwaukee	1993-date	USGS	Discharge
SW 2	04087000	Milwaukee R. at Milwaukee	1914-date	USGS	Discharge
			1964-date	USGS	Quality
SW 3	04087088	Underwood Cr. at Wauwatosa	1974-date	USGS	Discharge
SW 4	04087120	Menomonee R. at Wauwatosa	1961-date	USGS	Discharge
			1975-date	USGS	Quality
SW 5	04087170	Milwaukee R. at mouth	1985-date	USGS	Quality
SW 6	04087159	Kinnickinnic R. at S. 11th St., Milwaukee	1982-date	USGS	Discharge
SW 7	04087100	Honey Cr. at Milwaukee	1959-1994	USGS	Crest-stage
SW 8	04087204	Oak Cr. at South Milwaukee	1963-date	USGS	Discharge
SW 9	04087200	Oak Cr. near South Milwaukee	1958-1993	USGS	Crest-stage
SW 10	04087220	Root R. near Franklin	1963-date	USGS	Discharge

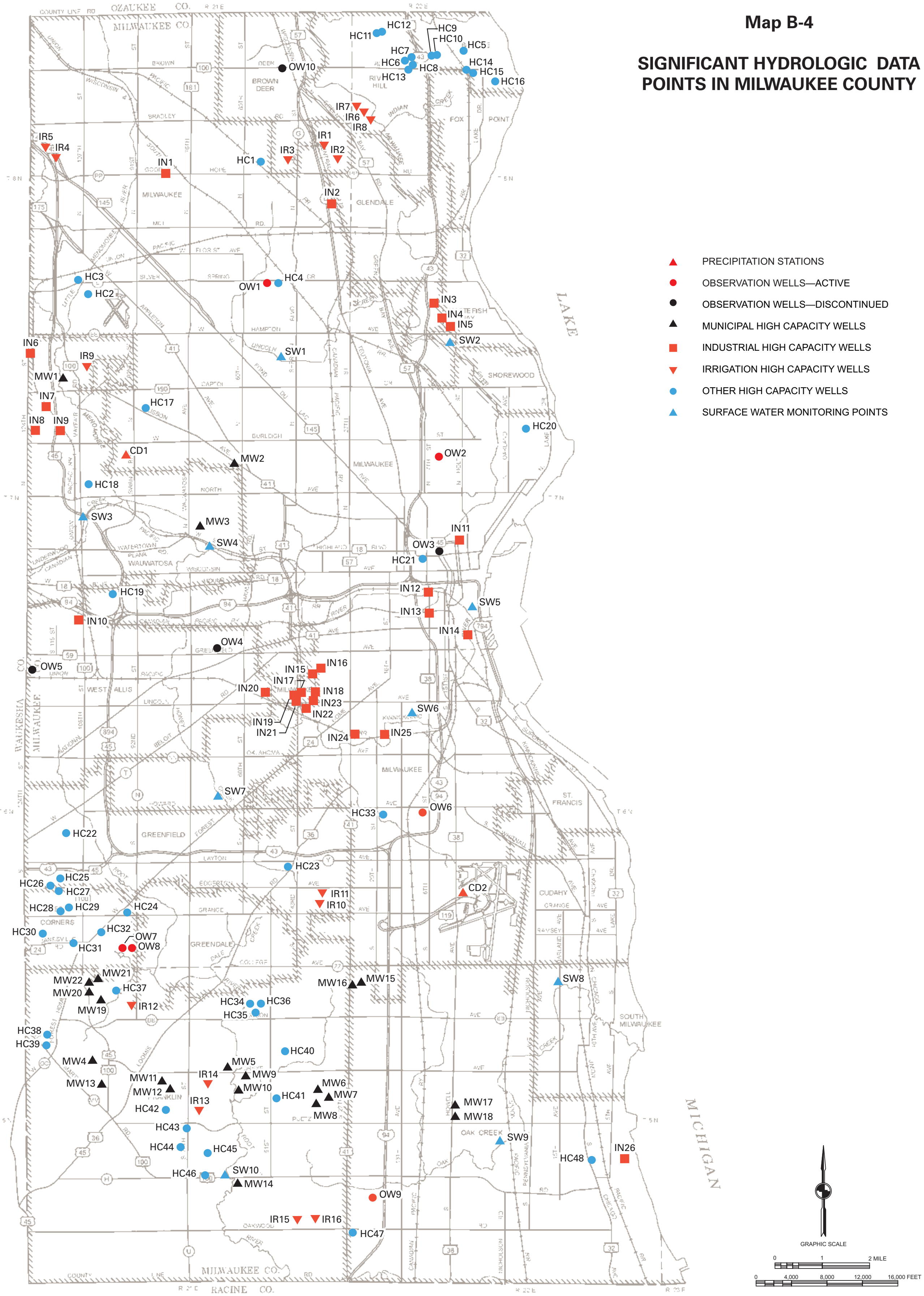
Agencies:

DNR	Wisconsin Department of Natural Resources, Madison, WI
NCDC	National Climatic Data Center, Asheville, NC (also: WGNHS, State Climatologist Office, Madison)
USGS	U.S. Geological Survey, Madison, WI
WGNHS	Wisconsin Geological and Natural History Survey, Madison, WI

Source: Wisconsin Geological and Natural History Survey, 1966.

Map B-4

SIGNIFICANT HYDROLOGIC DATA POINTS IN MILWAUKEE COUNTY



Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Table B-4

SIGNIFICANT HYDROLOGIC DATA POINTS IN WALWORTH COUNTY

DATA POINTS

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
		Climatic Data			
Precipitation Stations - map symbol ▲ (red)					
CD 1	479190	Whitewater (Jefferson Co.)	1942-date	NCDC	
CD 2	474457	Lake Geneva	1946-date	NCDC	
		Ground Water Data			
Observation Wells - map symbol: active ● (red) discontinued ● (black)					
OW 1	WW 908	Lulu Lake Preserve	1995-date	USGS	WW 908
OW 2	WW 9	Russel Stewart	1947-date	USGS	WW 9
OW 3	WW 37	Lake Geneva Water Works	1963-date	USGS	WW 37
OW 4	WW 83	Village of Fontana STP	1979-date	USGS	WW 83
OW 5	WW 1	Village of Genoa City Well #1	1946-1964	USGS	WW 1
Municipal Wells - map symbol ▲ (black)			Installed		
MW 1	87525	Whitewater City Well #6	1961	DNR	WW 106
MW 2	87524	Whitewater City Well #5	1944	DNR	WW 29
MW 3	87526	Whitewater City Well #7	1965	DNR	WW 539
MW 4	87527	Whitewater City Well #8	1977	DNR	WW 724
MW 5	87521	Town of Troy S.D. #1	1944	DNR	WW 51
MW 6	87505	East Troy Village Well #3	1951	DNR	WW 50
MW 7	87506	East Troy Village Well #5	1976	DNR	WW 736
MW 8	87507	East Troy Village Well #6	1981	DNR	WW 745
MW 9	87508	East Troy S.D. #3	1976	DNR	WW 723
MW 10	87509	Elkhorn City Well #4	1932	DNR	WW 39
MW 11	87510	Elkhorn City Well #5	1962	DNR	WW 127
MW 12	87511	Elkhorn City Well #6	1972	DNR	WW 735
MW 13	87499	Darien Village Well #1	1919	DNR	WW 47
MW 14	87500	Darien Village Well #2	1984	DNR	WW 903
MW 15	87501	Delavan City Well #2	1946	DNR	WW 61
MW 16	87502	Delavan City Well #3	1958	DNR	WW 185
MW 17	87503	Delavan City Well #4	1968	DNR	WW 68
MW 18	87504	Delavan City Well #5	1982	DNR	WW 832
MW 19	64401	Delavan City Well #6	1949	DNR	WW 766
MW 20	87528	Williams Bay Village Well #1	1930	DNR	WW 76
MW 21	87529	Williams Bay Village Well #2	1951	DNR	WW 55
MW 22	87516	Lake Geneva City Well #2	1927	DNR	WW 519
MW 23	87517	Lake Geneva City Well #3	1954	DNR	WW 67
MW 24	87518	Lake Geneva City Well #4	1970	DNR	WW 596
MW 25	00719	Lake Geneva City Well #5	1990	DNR	WW 923
MW 26	00723	Sharon Village Well #4	1990	DNR	WW 919
MW 27	87519	Sharon Village Well #1	1924	DNR	WW 35

MW 28	87520	Sharon Village Well #3	1979	DNR	WW 740
MW 29	00510	Fontana Village Well #1	1958	DNR	WW 63
MW 30	87512	Fontana Village Well #3	1989	DNR	WW 918
MW 31	87513	Fontana Village Well #2	1960	DNR	WW 96
MW 32	87522	Walworth Village Well #3	1958	DNR	WW 86
MW 33	87523	Walworth Village Well #4	1968	DNR	WW 590
MW 34	87514	Genoa City Village Well #2	1966	DNR	WW 540

Industrial High-Capacity Wells - map symbol

IN 1	66405	Hawthorne Melody Farms Dairy	1940	DNR	WW 33
IN 2	66406	Hawthorne Melody Farms Dairy	1946	DNR	WW 32
IN 3	66407	Larsen Company	1963	DNR	WW 129
IN 4	47215-6	David De Buck (2 wells)		DNR	
IN 5	47212	Kikkoman Foods Well #1		DNR	WW 753
IN 6	47217	Kikkoman Foods Well #2	1981	DNR	WW 827
IN 7	66403	Stewart Critten, Jr.		DNR	WW 769
IN 8	66404	"		DNR	WW 768

Irrigation High-Capacity Wells - map symbol

IR 1	33005	Jerry C. Kollwelter	1979	DNR	WW 935
IR 2	33003	Angus Dow Farm	1977	DNR	WW 734
IR 3	33016	Great Lakes Agric. Research Service	1989	DNR	WW 916
IR 4	33001	Curt Vanderveen	1958	DNR	WW 91
IR 5	33002	Curt Vanderveen	1958	DNR	WW 92
IR 6	33008	Curt Vanderveen	1979	DNR	WW 738
IR 7	33004	Daniel Boss	1977	DNR	WW 732
IR 8	33013	Evergreen Country Club	1994	DNR	WW 948
IR 9	33018	Merlyn Reum		DNR	
IR 10	00701	Kincaid Farms		DNR	
IR 11	33017	Big Foot Corp., Walworth		DNR	
IR 12	00771	Big Foot Farms		DNR	

Other High-Capacity Wells - map symbol

HC 1	87451-4	Rainbow Springs Aquaculture (5 wells)		DNR	
HC 2	87429	Timber Lee Christian Cntr. Well #10	1980	DNR	WW 741
HC 3	87405	Timber Lee Christian Cntr. Well #2	1963	DNR	WW 756
HC 4	87406	Timber Lee Christian Cntr. Well #6	1975	DNR	WW 730
HC 5	87407	Timber Lee Christian Cntr. Well #4	1963	DNR	WW 752
HC 6	87408	Timber Lee Christian Cntr. Well #3	1964	DNR	WW 751
HC 7	87409	Timber Lee Christian Cntr. Well #5	1966	DNR	WW 755
HC 8	87410	Timber Lee Christian Cntr. Well #1	1963	DNR	WW 757
HC 9	87404	Kettle Moraine State Forest		DNR	
HC 10	90331	B'nai B'rith Beber Camp	1981	DNR	WW 910
HC 11	90361	B'nai B'rith Beber Camp		DNR	
HC 12	87440-3	Camp Edwards (YMCA) (5 wells)	1985	DNR	WW 907
HC 13	87435-6	Salvation Army Camp (2 wells)	1950	DNR	WW 58
HC 14	90388	Stone Elementary School	1986	DNR	WW 915
HC 15	90222	Lakeview Elementary School	1970	DNR	WW 594
HC 16	90264	Tibbets Primary School	1975	DNR	WW 759
HC 17	87431	Willow Run Resort	1982	DNR	WW 840
HC 18	87422	Alpine Valley Resort	1964	DNR	WW 489
HC 19	87444	Alpine Valley Resort #3	1976	DNR	WW 721

HC 20	87423	Alpine Valley Resort #2	1976	DNR	WW 833
HC 21	87458	Alpine Valley Resort		DNR	
HC 22	87438-9	Lake Lawn Lodge (2 wells)	1985	DNR	WW 870, 911
HC 23	87418	ZWC Properties	1975	DNR	WW 765
HC 24	00874	Delavan Club Condos Well #1		DNR	WW 947
HC 25	00904	Delavan Club Condos Well	1992	DNR	WW 946
HC 26	87419	Country Estates Mobile Home Park Well #1	1973	DNR	WW 763
HC 27	87420	Country Estates Mobile Home Park Well #2	1972	DNR	WW 764
HC 28	87421	Country Estates Mobile Home Park Well #4	1976	DNR	WW 743
HC 29	90027	Lyons State Graded School	1960	DNR	WW 281
HC 30	90398	Mt Zion Christian School		DNR	
HC 31	87424	Americana Lake Geneva Resort Well #1	1967	DNR	WW 603
HC 32	87425	Americana Lake Geneva Resort Well #2	1967	DNR	WW 605
HC 33	87426	Americana Lake Geneva Resort Well #3	1968	DNR	WW 607
HC 34	87427	Americana Lake Geneva Resort Well #4	1968	DNR	WW 610
HC 35	87428	Americana Lake Geneva Resort Well #5	1970	DNR	WW 661
HC 36	00397-9	Geneva National Partners (3 wells)			
HC 37	00883-4	Geneva National Partners (2 wells)			
HC 38	90348	Williams Bay School Athletic Bldg.	1982	DNR	WW 829
HC 39	87414, 30	Interlaken Lodge and Village (2 wells)	1972, 1981	DNR	WW 729, 825
HC 40	87415-6	Christian League for the Handicapped (2 wells)	1962, 1973	DNR	WW 469, 770
HC 41	87433	Knollwood Subdivision-Cisco Beach Assoc.	1969	DNR	WW 591
HC 42	87417	P.K. Wrigley Estate	1975	DNR	WW 737
HC 43	87456	Lake Geneva Raceway	1963	DNR	WW 478
HC 44	87457	Lake Geneva Raceway		DNR	
HC 45	87401	Queen of Peace College	1951	DNR	WW 54
HC 46	90033	Star Center School	1961	DNR	WW 98
HC 47	73841	Nippersink Manor Resort		DNR	WW 753
HC 48	73842	Nippersink Manor Resort		DNR	WW 754
HC 49	73843	Nippersink Manor Resort	1961	DNR	WW 128
HC 50	00845-6	Fontana-Walworth Water Pol. Contr.(2 wells)		DNR	
HC 51	00937-8	Abbey Springs Condos (2 wells)		DNR	WW 937
HC 52	00944	Speckman Seed Farm		DNR	
HC 53	87411, 13	Girl Scouts of Milwaukee (2 wells)	1965	DNR	WW 443
HC 54	00472-3	Michael Fields Agr. Inst. (2 wells)	1990	DNR	WW 920 921

Surface Water Data

Surface Water Stations - map symbol ▲

Rock-Fox River Basin

			Period of Record	Record Agency	Data Type
SW 1	05545100	Sugar Cr. at Elkhorn	1962-date	USGS	Crest-stage
SW 2	05545200	White R. trib. near Burlington	1958-date	USGS	Crest-stage
SW 3	05545300	White R. near Burlington	1964-66, 1973-82	USGS	Discharge
SW 4	05431400	L. Turtle Cr. at Allens Grove	1962-date	USGS	Crest-stage
SW 5	05438283	Piscasaw Cr. near Walworth	1992-date	USGS	Discharge
SW 6	05548150	N. Branch Nippersink Cr.	1962-date	USGS	Crest-stage

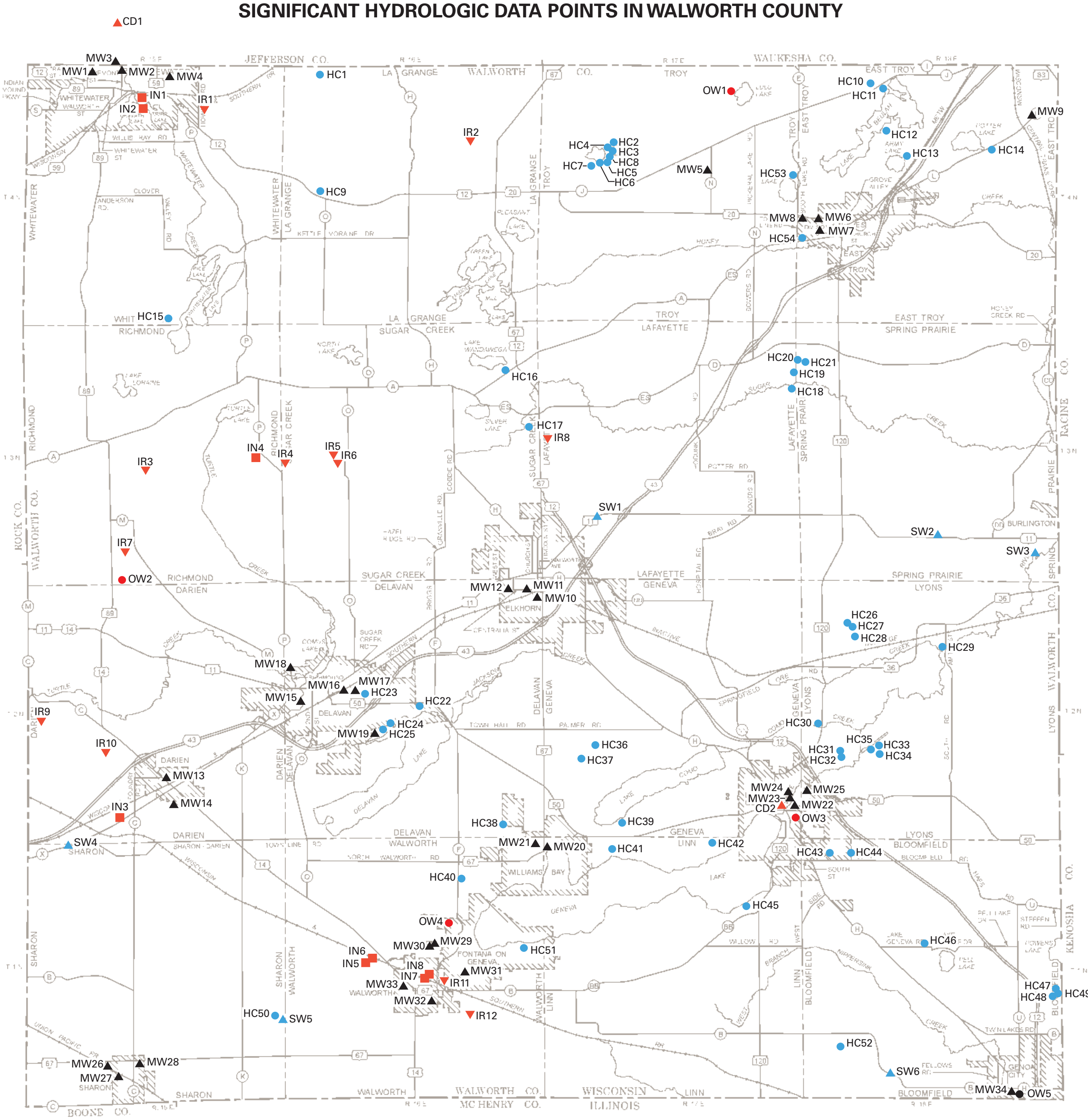
Agencies:

DNR	Wisconsin Department of Natural Resources, Madison, WI
NCDC	National Climatic Data Center, Asheville, NC (also: WGNHS, State Climatologist Office, Madison)
USGS	U.S. Geological Survey, Madison, WI
WGNHS	Wisconsin Geological and Natural History Survey, Madison, WI

Source: *Wisconsin Geological and Natural History Survey, 1966*.

Map B-5

SIGNIFICANT HYDROLOGIC DATA POINTS IN WALWORTH COUNTY



PRECIPITATION STATIONS

OBSERVATION WELLS—ACTIVE

OBSERVATION WELLS—DISCONTINUED

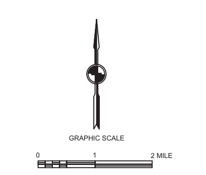
MUNICIPAL HIGH CAPACITY WELLS

INDUSTRIAL HIGH CAPACITY WELLS

IRRIGATION HIGH CAPACITY WELLS

OTHER HIGH CAPACITY WELLS

SURFACE WATER MONITORING POINTS



Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Table B-5

SIGNIFICANT HYDROLOGIC DATA POINTS IN RACINE/KENOSHA COUNTIES

DATA POINTS

Map No.	Identif. Number	Name (Location)	Period of Record	Record. Agency	WGNHS Log No.
		Climatic Data			
Precipitation Stations - map symbol					
Racine:					
CD 1	476922	Racine 1895-date		NCDC	
CD 2	478723	Union Grove	1941-date	NCDC	
CD 3	471205	Burlington	1945-date	NCDC	
Kenosha:					
CD 4	474174	Kenosha	1944-date	NCDC	
		Ground Water Data			
Observation Wells - map symbol: active / discontinued					
Racine:					
OW 1	RA 5	C.M.ST.P. & P. RR, Sturtevant	1946-1994	USGS	RA 5
OW 2	RA 62	Wayside Hwy. 11E	1985-date	USGS	RA 62
Kenosha:					
OW 3	KE 4	Sunset Ridge Memorial Park, Kenosha	1946-1983	USGS	KE 4
OW 4	KE 5	J. Bishop, Somers	1946-1979	USGS	KE 5
OW 5	KE 6	Petrifying Springs Park	1946-date	USGS	KE 6
OW 6	KE 19	Bong Air Force Base Test Hole #2	1963-1983	USGS	KE 19
OW 7	KE 21	Bong Recreational Area Well #2	1961-date	USGS	KE 21
OW 8	KE 46	St. Joseph Home for the Aged, Kenosha	1961-date	USGS	KE 46
OW 9	KE 288	Wayside Hwy. 45S	1972-date	USGS	KE 288
Municipal Wells - map symbol		*Emergency well	Installed		
Racine:					
MW 1	84881	Waterford Village Well #1	1913	DNR	
MW 2	84882	Waterford Village Well #2	1965	DNR	RA 351
MW 3	84875	North Cape S.D. #1	1956	DNR	RA 38
MW 4	84883	Caddy Vista S.D.	1955	DNR	RA 48
MW 5	84876	Crestview S.D. Well #1*	1955	DNR	RA 47
MW 6	84877	Crestview S.D. Well #2*	1972	DNR	RA 373
MW 7	84871	Burlington City Well #6*	1932	DNR	RA 35
MW 8	84872	Burlington City Well #7	1948	DNR	RA 27
MW 9	84873	Burlington City Well #8	1963	DNR	RA 339
MW 10	84874	Burlington City Well #9	1972	DNR	RA 374

MW 11	84884	Burlington City Well #10	1989	DNR	RA 385
MW 12	84878	Union Grove Village Well #3	1959	DNR	RA 57
MW 13	84879	Union Grove Village Well #4*	1965	DNR	RA 349
MW 14	84880	Union Grove Village Well #5	1978	DNR	RA 376

Kenosha:

MW 15	80504	Paddock Lake Village Well #1	1958	DNR	KE 25
MW 16	80505	Paddock Lake Village Well #2	1958	DNR	KE 23
MW 17	80499	Bristol Util. Distr. Well #1	1967	DNR	KE 291
MW 18	KE 357	Bristol Util. Distr. Well #2	1984	WGNHS	KE 357
MW 19	00714	Bristol Util. Distr. Well #3	1988	DNR	KE 307
MW 20	80502	Pleasant Prairie-Town Well #3*	1966	DNR	KE 285
MW 21	80503	Pleasant Prairie-Town Well #4*	1976	DNR	KE 314
MW 22	80501	Pleasant Prairie-Timber Ridge S.D.	1976	DNR	KE 301

Industrial High-Capacity Wells - map symbol

Racine:

IN 1	84812	Schneider National Trucking, Franksville	1989	DNR	RA 388
IN 2	84803	Johnson SC & Son, Wind Point	1960	DNR	RA 49
IN 3	00498	Johnson SC & Son, Racine		DNR	
IN 4	59201	Johnson SC & Son, Sturtevant	1954	DNR	RA 36
IN 5	59202	Johnson SC & Son, Sturtevant	1959	DNR	RA 63
IN 6	84809	B.R. Amon & Sons, Burlington		DNR	
IN 7	59214	Echo Lake Farm Produce Co. #1	1951	DNR	RA 392
IN 8	59215	Echo Lake Farm Produce Co. #2	1965	DNR	RA 394
IN 9	59216	Echo Lake Farm Produce Co. #3	1975	DNR	RA 393
IN 10	59217	Echo Lake Farm Produce Co. #4	1985	DNR	RA 419
IN 11	59203	Lavelle Industry, Burlington		DNR	
IN 12	59211	Foster-Forbes Glass Co., Burlington		DNR	
IN 13	59210	Nestle Chocolate, Burlington	1964	DNR	RA 325
IN 14	59212	Packaging Corp. of America, Burlington	1969	DNR	RA 358
IN 15	59213	Continental Can Co., Burlington	1971	DNR	RA 372
IN 16	59208	Maple Leaf Farms (form. C&D Duck Co.) #6	1964	DNR	RA 397
IN 17	59218	Maple Leaf Farms (form. C&D Duck Co.)	1961	DNR	RA 232
IN 18	59219	Maple Leaf Farms (form. C&D Duck Co.) #10	1987	DNR	RA 384
IN 19	59204	Maple Leaf Farms (form. C&D Duck Co.) #4 Abandoned	1954	DNR	RA 46
IN 20	59205	Maple Leaf Farms (form. C&D Duck Co.)	1962	DNR	RA 337
IN 21	59206	Maple Leaf Farms (form. C&D Duck Co.)	1962	DNR	RA 398
IN 22	59209	Maple Leaf Farms (form. C&D Duck Co.) #8	1966	DNR	RA 354
IN 23	59207	Maple Leaf Farms (form. C&D Duck Co.)	1968	DNR	RA 396

Kenosha:

IN 24	80428	Mann Brothers Sand & Gravel	1988	DNR	KE 306

Irrigation High-Capacity Wells - map symbol

Racine:

IR 1	25618	Wind Lake Produce Corp. #4	1957	DNR	RA 157
IR 2	25619	Wind Lake Produce Corp. #5	1965	DNR	RA 408
IR 3	25615	Klitz Bros. Sod Farm #1	1963	DNR	RA 298

IR 4	25627	Klitz Bros. Sod Farm #2	1977	DNR	RA 410
IR 5	25616	Gressel's Sod Ranch		DNR	
IR 6	25614	Jasperson Lyle & Buster	1964	DNR	RA 299
IR 7	25605	M. Sanfelippo	1958	DNR	RA 55
IR 8	25608	Wind Lake Produce Corp. #3	1963	DNR	RA 346
IR 9	25613	J. Stefanik	1963	DNR	RA 292
IR 10	25602	T. Kuehne		DNR	
IR 11	25626	Deak Sod Farms	1972	DNR	RA 411
IR 12	25603	Horner Sod Farms #3	1964	DNR	RA 342
IR 13	25601	Horner Sod Farms	1948	DNR	RA 31
IR 14	25604	W. Burkmeister & Son		DNR	
IR 15	25607	Wind Lake Produce Corp. #2	1959	DNR	RA 59
IR 16	25606	Wind Lake Produce Corp. #1	1949	DNR	RA 34
IR 17	25611	M. Sokie	1963	DNR	RA 345
IR 18	25623	F. Deak	1969	DNR	RA 357
IR 19	25610	E. Walter	1958	DNR	RA 58
IR 20	25617	Hawthorn Hills Inc.	1964	DNR	RA 344
IR 21	25612	Gressel's Sod Ranch	1963	DNR	RA 338
IR 22	25620	J. Moyer #1	1965	DNR	RA 401
IR 23	25621	J. Moyer #2	1966	DNR	RA 402
IR 24	25622	J. Lesser	1968	DNR	RA 356
IR 25	25624	H&H Fairway Ent., Golf Course	1969	DNR	RA 359
IR 26	25625	H&H Fairway Ent., Golf Course	1971	DNR	RA 371
IR 27	25629	Borzynski Farms Well #1	1984	DNR	RA 418
IR 28	00425	Borzynski Farms		DNR	
IR 29	00688	Borzynski Farms		DNR	

Kenosha:

IR 30	13404	Brighton-Dale County Park Well #1	1968	DNR	KE 294
IR 31	13405	Brighton-Dale County Park Well #2	1968	DNR	KE 292
IR 32	13407	Neumiller Farms		DNR	
IR 33	13403	E. Vincent	1968	DNR	KE 289
IR 34	13408	Breezy Hill Nursery		DNR	
IR 35	00965	Breezy Hill Nursery		DNR	
IR 36	00708	Spring Valley Country Club, Liberty Corners		DNR	
IR 37	13406	Thompson Strawberry Farm	1969	DNR	KE 295
IR 38	80405	Bristol Oaks Golf Course	1965	DNR	KE 282
IR 39	80406	Bristol Oaks Golf Course	1966	DNR	KE 284
IR 40	50401	J. Kamysz		DNR	
IR 41	50402	J. Kamysz	1946	DNR	KE 1

Other High-Capacity Wells - map symbol

Racine:

HC 1	90019	Lakeview School, Wind Lake		DNR	
HC 2	90043	Raymond Elementary School	1964	DNR	RA 341
HC 3	90083	Trinity Evangelical Lutheran Church		DNR	
HC 4	84802	T.A. Edison Technical Center, Franksville	1957	DNR	RA 53
HC 5	90164	Franksville Elementary School	1966	DNR	RA 347
HC 6	90148	W.A. Gifford Elementary School, Franksville	1966	DNR	RA 350
HC 7	90307	Prince of Peace Lutheran School, Racine		DNR	RA 423
HC 8	90280	Olympia-Brown Elementary School, Racine	1959	DNR	RA 60
HC 9	90139	Prairie School, Racine	1965	DNR	RA 348
HC 10	90217	Waterford Kindergarten School, Rochester		DNR	RA 391
HC 11	84801	St. Francis Monastery & College, Burlington	1950	DNR	RA 21

HC 12	00935	St. Francis Monastery & College, Burlington		DNR	
HC 13	00936	St. Francis Monastery & College, Burlington		DNR	
HC 14	84808	Browns Lake Resort Condos, Burlington		DNR	
HC 15	73061	Island View Condos, Burlington	1979	DNR	RA 303
HC 16	87446	Southern Wisconsin Center, Union Grove Well #1	1942	DNR	RA 15
HC 17	87447	Southern Wisconsin Center, Union Grove Well #2	1964	DNR	RA 16
HC 18	87448	Southern Wisconsin Center, Union Grove Well #3	1963	DNR	RA 66
HC 19	90334	Yorkville School		DNR	
HC 20	84805	Pavillion Apartments, Franksville		DNR	
HC 21	84806	Pavillion Apartments, Franksville		DNR	
HC 22	84807	Pavillion Apartments, Franksville		DNR	
HC 23	90439	True Life Pentacostal Church, Racine		DNR	RA 395
HC 24	84810	Ken Nue Car Wash, Racine		DNR	
HC 25	84811	Ken Nue Car Wash, Racine		DNR	
HC 26	90041	Racine School District #4	1961	DNR	RA 404
HC 27	90275	St. Bonaventure Prep. School, Sturtevant	1910	DNR	RA 405
HC 28	84804	Cozy Acres Subdivision, Racine	1948	DNR	RA 406
HC 29	00606	DNR Root River Facility, Racine		DNR	
HC 30	00607	DNR Root River Facility, Racine		DNR	
HC 31	00608	DNR Root River Facility, Racine		DNR	

Kenosha:

HC 32	00634	Wisconsin Electric Power Co., Paris		DNR	
HC 33	80410	R. Christian	1970	DNR	KE 312
HC 34	90154	St. Francis Xavier School, Brighton	1966	DNR	KE 283
HC 35	90074	Brighton Elementary School	1962	DNR	KE 26
HC 36	80401	Bong Recreational Area Well #1	1958	DNR	KE 24
HC 37	90225	Paris Consolidated Elementary School	1949	DNR	KE 327
HC 38	80411	Maplecrest Country Club		DNR	
HC 39	90303	Shoreland Lutheran High School, Somers	1978	DNR	KE 328
HC 40	80413-4	Eagle Chateau Apartments, Somers (2 wells)	1990	DNR	KE 309, 330
HC 41	80411	Somers Elementary School	1961	DNR	KE 30
HC 42	90192	Gateway Technical Institute, Kenosha	1968	DNR	KE 296
HC 43	80415	DNR Coho Release Site, Kenosha	1974	DNR	KE 311
HC 44	80416	Meadow View Village Apartments	1978	DNR	KE 302
HC 45	80418	Regis Landing Condos, Twin Lakes	1984	DNR	KE 354
HC 46	80420	Maple Leaf Manor, Twin Lakes	1984	DNR	KE 355
HC 47	90045	Lakewood School, Twin Lakes	1961	DNR	KE 167
HC 48	80412	Silver Lake County Park	1974	DNR	KE 299
HC 49	80419	Wocot Builders Apartments, Salem	1985	DNR	KE 361
HC 50	90218	Salem Consolidated Elementary School		DNR	
HC 51	90219	Salem Consolidated Elementary School	1970	DNR	KE 313
HC 52	80407	Camp Wonderland, Camp Lake		DNR	
HC 53	80408	Camp Wonderland, Camp Lake		DNR	
HC 54	80409	Camp Wonderland, Camp Lake		DNR	
HC 55	80417	Silvercrest Apartment, Silver Lake	1982	DNR	KE 353
HC 56	90234	Riverview Elementary School, Silver Lake	1971	DNR	KE 298
HC 57	90421	Riverview Elementary School, Silver Lake		DNR	
HC 58	80426	Carefree Estates Mobile Home, Trevor	1987	DNR	KE 359
HC 59	80427	Carefree Estates Mobile Home, Trevor	1987	DNR	KE 360
HC 60	90201	Wilmot Union High School	1962	DNR	KE 57
HC 61	90250	Trevor Elementary School		DNR	KE 324
HC 62	80404	Howard Johnson Motor Lodge, Bristol	1965	DNR	KE 281
HC 63	80422	Factory Outlet Center, Bristol		DNR	
HC 64	80423	Factory Outlet Center, Bristol		DNR	

HC 65	80424	Factory Outlet Center, Bristol	1986	DNR	KE 305
HC 66	80425	Factory Outlet Center, Bristol		DNR	
HC 67	80403	St. Joseph Home for the Aged, Kenosha	1960	DNR	KE 29
HC 68	90057	Prairie Lane School, Kenosha	1961	DNR	KE 54
HC 69	80500	Pheasant Prairie Industrial Park	1970	DNR	KE 274
HC 70	80429-30	Kenosha Tourist Center I94N (2 wells)	1962, 1970	DNR	KE 56, 297
HC 71	80421	Prairie Harbor Development Co.		DNR	

Surface Water Data

Surface Water Stations - map symbol ▲

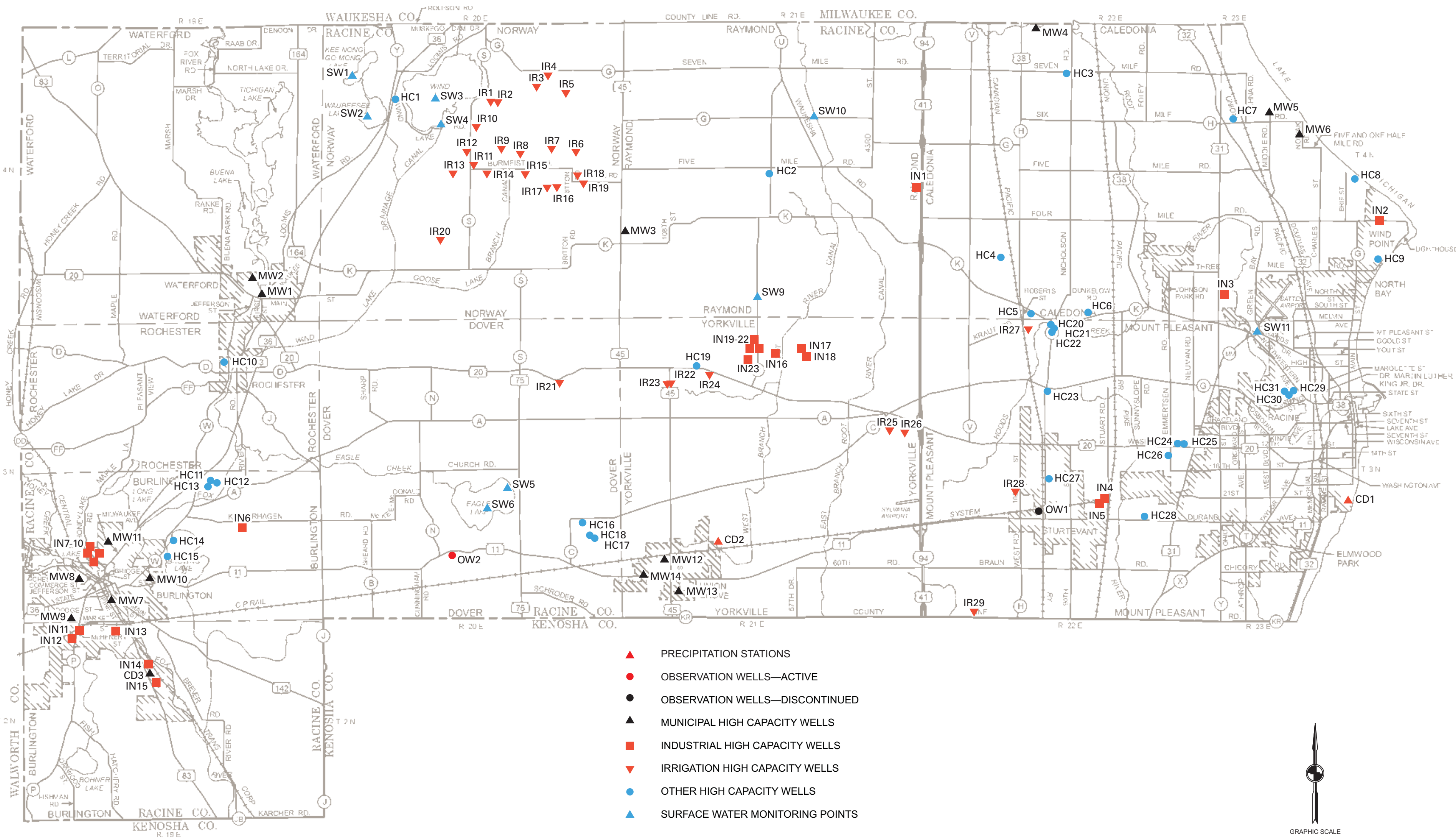
			Period of Record	Record. Agency	Data Type
Rock-Fox River Basin					
Racine:					
SW 1	4249370 88103400	Long (Kee Nong Go-Mong) Lake at Wind Lake	1988-1994	USGS	Stage Quality
SW 2	4248570 88101500	Waubeesee Lake at Wind Lake	1988-1994	USGS	Quality
SW 3	4249150 88083900	Wind Lake at Wind Lake	1985-1994	USGS	Quality
SW 4	4248480 88083100	Wind Lake Outlet at Wind Lake	1985-1994	USGS	Stage
SW 5	05544500	Eagle Lake near Kansasville	1936-1964, 1973-1977, 1993-1994	USGS	Stage
SW 6	4242070 88072400	Eagle Lake near Kansasville	1993-date	USGS	Quality
Kenosha:					
SW 7	05546500	Fox River at Wilmot	1939-1993	USGS	Discharge
SW 8	05545750	Fox River near New Munster	1993-date	USGS	Discharge
Lake Michigan Basin					
Racine:					
SW 9	04087230	W. Branch Root R. Canal Trib. nr. N. Cape	1962-1993	USGS	Crest stage
SW 10	04087233	Root R. Canal near Franklin	1963-date	USGS	Discharge
SW 11	04087240	Root River at Racine	1963-date	USGS	Discharge
Kenosha:					
SW 12	04087250	Pike Creek near Kenosha	1960-date	USGS	Crest stage
SW 13	04087257	Pike River near Racine	1971-date	USGS	Discharge
			1993-date	USGS	Quality Agencies:

DNR	Wisconsin Department of Natural Resources, Madison, WI
NCDC	National Climatic Data Center, Asheville, NC (also: WGNHS, State Climatologist Office, Madison)
USGS	U.S. Geological Survey, Madison, WI
WGNHS	Wisconsin Geological and Natural History Survey, Madison, WI

Source: Wisconsin Geological and Natural History Survey.

Map B-6

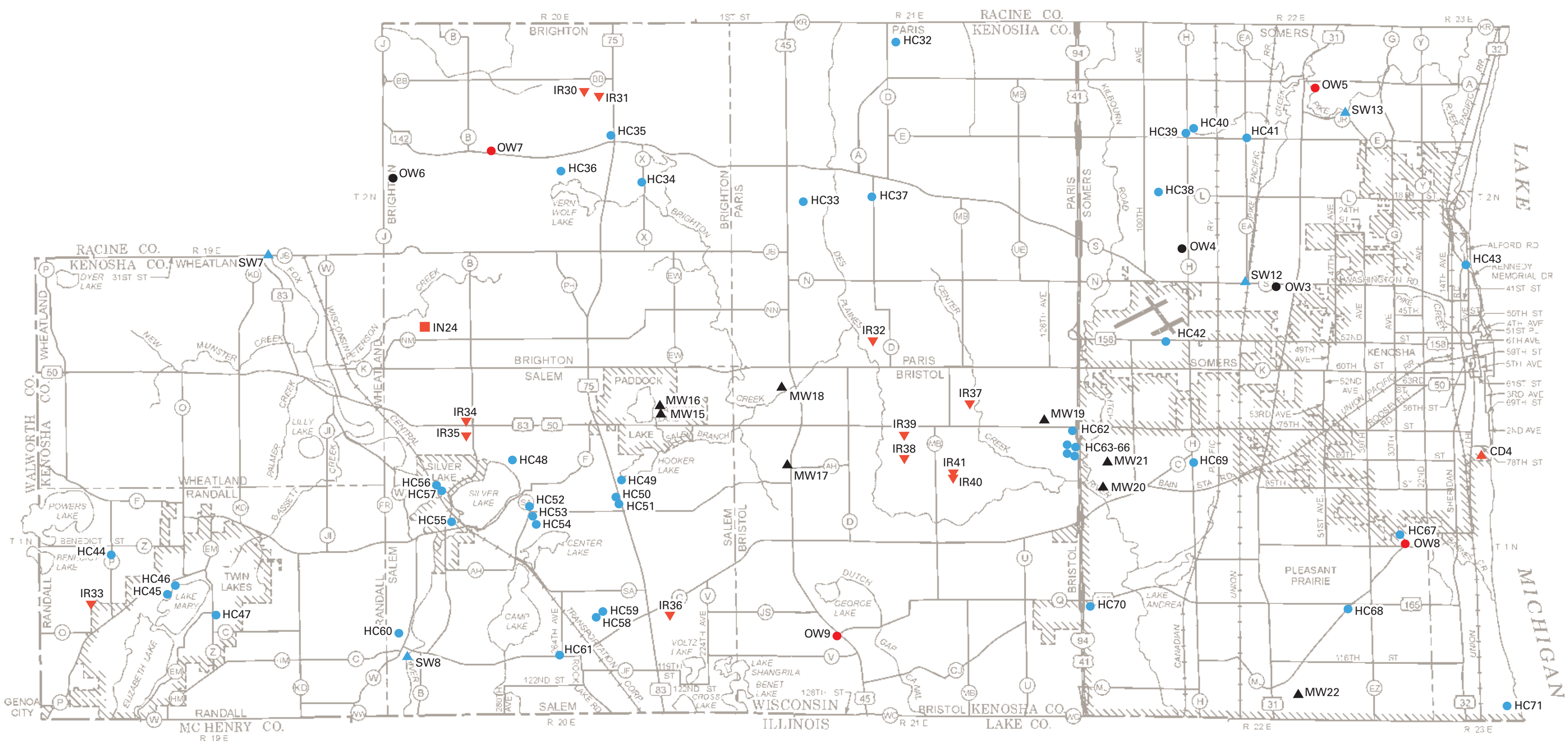
SIGNIFICANT HYDROLOGIC DATA POINTS IN RACINE COUNTY



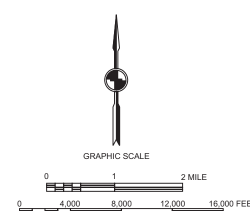
Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Map B-7

SIGNIFICANT HYDROLOGIC DATA POINTS IN KENOSHA COUNTY



- PRECIPITATION STATIONS
- OBSERVATION WELLS—ACTIVE
- OBSERVATION WELLS—DISCONTINUED
- MUNICIPAL HIGH CAPACITY WELLS
- IRRIGATION HIGH CAPACITY WELLS
- INDUSTRIAL HIGH CAPACITY WELLS
- OTHER HIGH CAPACITY WELLS
- SURFACE WATER MONITORING POINTS



Source: Wisconsin Department of Natural Resources and Wisconsin Geological and Natural History Survey.

Appendix C

SOIL SERIES IN SOUTHEASTERN WISCONSIN LISTED BY ATTENUATION POTENTIAL

Soils in the Region were evaluated as to their potential for attenuating contaminants (see Chapter III) and grouped, based on the numerical score, into four soil associations that reflect different attenuation potential.

Soils Potential to Attenuate Contaminants	Total Score	Percent of Total Land*
Least Potential	0-30	16
Marginal Potential	31-40	27
Good Potential	41-50	49
Best Potential	51	6

**The remaining two percent include miscellaneous areas which could not be categorized due to land use or lack of soils data.*

Soils that have similar soil profiles make up a soil series. However, soils of one series can differ in texture of the surface horizon or of the subsoil horizon. They can also differ in slope, stoniness, salinity, wetness, degree of erosion, and other characteristics that affect their use. On the basis of these differences, a soil series is divided into soil phases. As examples, a Hochheim loam, 2 to 6 percent slope, eroded, is a phase of the Hochheim series and a Casco sandy loam, 2 to 6 percent slope or a Casco loam, 6 to 12 percent slope are phases of the Casco series.

Soil phases will often receive different scores in the soil attenuation potential ranking but will remain in the same overall soil attenuation potential category (least, marginal, good, best). Occasionally, different phases will fall into more than one attenuation potential category. When this situation occurs, the portion of the soil phase that affects the scoring has been added in parentheses next to the soil series name. For example, the Aztalan series falls into two attenuation potential categories, least and marginal. Surface textural differences, sandy loam versus loam, affect the ranking of these soil phases. The coarser-textured, sandy loam soil ranks in the least potential category and the medium-textured, loam soil in the marginal category. Therefore, Aztalan (sandy loam) is listed in the least potential category and Aztalan (loam) is in the marginal category. In most situations, like the ones described, it is the difference in surface texture that creates the ranking differences, although variations in the subsoil, soil depth, and degree of erosion also affect the rank.

Soil complexes are also listed (i.e., Rodman-Casco complex). A soil complex consists of two or more soils that cannot be shown separately on the soil map because of their small size or intricate pattern. They are ranked on the basis of the lowest scoring soil series.

Least Potential (0 - 30)

Adrian
Aztalan (sandy loam)
Boyer (loamy sand, eroded)
Boyer complex
Casco-Rodman complex
Chelsea
Darroch (fine sandy loam)
Fabius
Gilford
Granby
Hochheim-Hennepin complex
Houghton
Keowns
*Knowles (silt loam, mottled subsoil)
Matherton (sandy loam)
Matherton (loam)
Matherton (silt loam)
Muskego
Mussey
Ogden
Palms
*Pella (silt loam, moderately shallow variant)
*Ritchey (silt loam, mottled subsoil variant)
Rodman-Casco complex
Rollin
Sebewa (silt loam)
Wallkill
Wasepi
Yahara

Acreage: 256,484
Percent of Total Land: 16%

bedrock <5 feet from surface

Marginal Potential (31 - 40)

Ashkum
Aztalan (loam)
Beecher
Blount
Boyer (loamy sand)
Boyer (sandy loam)
Brookston
Casco (sandy loam)
Casco (loam, eroded)
Casco (soils)
Casco-Fox
Casco-Miami
Colwood
Conover
Darroch (silt loam)
Drummer
Elburn
Elliot
Flagg (silt loam, mottled subsoil variant)
Fox (sandy loam)
Griswold (silt loam, mottled subsoil variant)
Hebron (sandy loam)
Hochheim-Sisson-Casco complex
Kane
Kendall
*Knowles (silt loam, eroded)
Lamartine
Lawson (silt loam, calcareous variant)
Lorenzo-Rodman complex
Manawa
Martinton
Matherton (loam, clayey substratum)
Mequon
Miami (sandy loam, sandy loam substratum, eroded)
Mundelein
Navan
Nenno
Oshtemo
Otter
Pella (silt loam)
Pistakee
Radford
*Ritchey (silt loam)
Sawmill
Sebewa (silt loam, clayey substratum)
Sisson (fine sandy loam, eroded)
Sisson-Casco-Hochheim complex
Virgil
Warsaw (sandy loam)
Warsaw (loam, eroded)

Acreage: 435,262
Percent of Total Land: 27%

Good Potential (41 - 50)

Casco (loam)
Dodge
Dorchester
Dresden
Fox (loam)
Fox (silt loam)
Grays
Griswold (silt loam)
Griswold (loam)
Hebron (loam)
Hennepin-Miami
Hochheim
Juneau
Kewaunee
*Knowles (silt loam)
Lawson (silt loam)
Lorenzo
Markham
Mayville
McHenry
Metea
Miami (sandy loam)
Miami (loam)
Miami (silt loam)
Montgomery
Morley
Ozaukee
Poygan
Ringwood
St. Charles
Saylesville
Sisson (fine sandy loam)
Theresa
Warsaw (loam)
Warsaw (silt loam)
Worthen
Zurich

Acreage: 794,407
Percent of Total Land: 49%

**bedrock < 5 feet from surface*

Best Potential (51+)

Flagg (silt loam)
Pecatonica
Plano
Symerton
Troxel
Varna
Warsaw (loam, clayey substratum)
Westville

Acreage: 91,422
Percent of Total Land: 6%

Miscellaneous Land Type Acreage: 44,481
Percent of Total Land: 2%

Total Acres: 1,622,056

Appendix D

SOLID WASTE DISPOSAL SITES IN SOUTHEASTERN WISCONSIN, BY COUNTY

Table D-1

SOLID WASTE DISPOSAL SITES IN KENOSHA COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
KE1	Town of Brighton	T2N, R20E, Section 31, SW, NW	Town of Brighton	Inactive
KE2	Town of Bristol	T1N, R21E, Section 17, NE, NW	Town of Bristol	Inactive
KE3	Town of Paris	T2N, R21E, Section 32, NW	Waste Management of Wisconsin, Pheasant Run	Active
KE4	Village of Pleasant Prairie	T1N, R22E, Section 9, E	Wisconsin Electric Power Company	Active; MON
KE5	Village of Pleasant Prairie	T1N, R22E, Section 33, SE, NE	City of Kenosha	Inactive
KE6	Village of Pleasant Prairie	T1N, R22E, Section 9, NE, NW	Harry Crow & Sons	Inactive
KE7	Village of Pleasant Prairie	T1N, R22E, Section 33, NE, NE	Village of Pleasant Prairie	Inactive
KE8	Village of Pleasant Prairie	T1N, R22E, Section 10, NE, NW	Ron's Rubbish	Inactive
KE9	Town of Randall	T1N, R19E, Section 23, NW, NW	Town of Randall	Inactive
KE10	Town of Salem	T1N, R20E, Section 8, SE, NW	Kenosha County Highway Department	Inactive
KE11	Town of Salem	T1N, R20E, Section 5, SE, SW	Town of Salem	Inactive
KE12	Village of Silver Lake	T1N, R20E, Section 8, NE, SW	Silver Lake Landfill	Inactive
KE13	Town of Somers	T2N, R22E, Section 24, NE, NW	Keno Trucking	Inactive
KE14	Town of Somers	T2N, R22E, Section 15, SE, SW	Town of Somers	Inactive
KE15	Village of Twin Lakes	T1N, R19E, Section 16, SW, SE	Village of Twin Lakes	Inactive
KE16	Town of Wheatland	T1N, R19E, Section 10, SE, SW	Town of Wheatland	Inactive

NOTES: 1. The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

2. The following abbreviation has been used:

MON = Site is being monitored.

[a]*See Map 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table D-2

SOLID WASTE DISPOSAL SITES IN MILWAUKEE COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
ML1	City of Cudahy	T6N, R22E, Section 34, W, SW	City of Milwaukee	Inactive
ML2	City of Cudahy	T6N, R22E, Section 27, NW, SE	City of Cudahy	Inactive
ML3	City of Cudahy	T6N, R22E, Section 35, NW	Ladish Corporation	Inactive
ML4	City of Franklin	T5N, R21E, Section 31, N, SW	Waste Management of Wisconsin, Metro	Active; MON
ML5	City of Franklin	T5N, R21E, Section 4, NE, SE	Milwaukee County Highway Department	Inactive
ML6	City of Franklin	T5N, R21E, Section 1, N, SE	Fadrowski Drum Disposal	Inactive; Superfund site
ML7	City of Glendale	T8N, R22E, Section 30, NW, NW	City of Glendale	Inactive
ML8	City of Greenfield	T6N, R21E, Section 18, NE, SW	City of Greenfield	Inactive
ML9	City of Greenfield	T6N, R21E, Section 18, NE, SW	Allis-Chalmers Corporation	Inactive
ML10	City of Milwaukee	T8N, R21E, Section 23, NE, NW	Village of Whitefish Bay	Inactive
ML11	City of Milwaukee	T6N, R22E, Section 29, NW, SW	Wisconsin Department of Trans-portaion, private contractors	Inactive
ML12	City of Milwaukee	T7N, R22E, Section 4, NW, SW	City of Milwaukee, Bluehole Landfill	Inactive; has received hazardous waste
ML13	City of Milwaukee	T8N, R21E, Section 26, NE, NE	City of Milwaukee	Inactive
ML14	City of Milwaukee	T7N, R21E, Section 26, SE, NW	City of Milwaukee	Inactive
ML15	City of Milwaukee	T7N, R21E, Section 26, SW, NE	Falk Corporation	Inactive
ML16	City of Milwaukee	T7N, R21E, Section 35, NE	City of Milwaukee, County Stadium	Inactive
ML17	City of Milwaukee	T7N, R22E, Section 31, NE	International Harvester, Cyanide Pits	Inactive; has received hazardous waste
ML18	City of Milwaukee	T8N, R21E, Section 22, SE, NW	Lakefield Sand and Gravel	Inactive; has received hazardous waste
ML19	City of Milwaukee	T6N, R22E, Section 34, SW	City of Milwaukee	Inactive
ML20	City of Milwaukee	T8N, R21, Section 8, N, NW	Moss-American	Inactive; Superfund site
ML21	City of Oak Creek	T5N, R22E, Section 10, SW, SW	City of Oak Creek	Inactive
ML22	City of Oak Creek	T5N, R22E, Section 14, NW, SE	City of South Milwaukee	Inactive
ML23	City of Oak Creek	T5N, R22E, Section 27, NE, NW	Gordon Derosso	Inactive
ML24	City of Oak Creek	T5N, R22E, Section 36, SW	Wisconsin Electric Power Company	Inactive
ML25	City of Oak Creek	T5N, R22E, Section 36, SW, NE	Wisconsin Electric Power Company	Inactive
ML26	City of Oak Creek	T5N, R22E, Section 23, NE, SE	James Manufacturing	Inactive
ML27	City of South Milwaukee	T5N, R22E, Section 2, SW	Falk Corporation	Active; MON
ML28	City of South Milwaukee	T5N, R22E, Section 2, NE, SW	Bucyrus-Erie Company	Inactive
ML29	City of Wauwatosa	T7N, R21E, Section 8, NE, SW	City of Milwaukee, Old Hartung Quarry	Inactive
ML30	City of Wauwatosa	T7N, R21E, Section 19, SE, SE	City of Wauwatosa	Inactive
ML31	City of Wauwatosa	T7N, R21E, Section 20, SE, NW	Milwaukee County Institutions	Inactive
ML32	City of West Allis	T6N, R21E, Section 7, NW, NE	City of West Allis	Inactive
ML33	City of West Allis	T6N, R21E, Section 7, NE, NE	N/A	Inactive
ML34	City of West Allis	T7N, R21E, Section 31, SE, SE	N/A	Inactive

Table D-2 (continued)

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
ML35	City of West Allis	T6N, R21E, Section 6, NE, SE	N/A	Inactive
ML36	City of West Allis	T6N, R21E, Section 6, SW, SE	Maynard Steel Casting Corporation	Inactive
ML37	Village of West Milwaukee	T6N, R21E, Section 2, NE, SE	Village of West Milwaukee	Inactive
ML38	Village of West Milwaukee	T6N, R21E, Section 2, SE	Wehr Steel	Inactive

NOTES: 1. The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

2. The following abbreviation has been used:

MON = Site is being monitored.
N/A = Data is currently not available.

[a]*See May 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table D-3

SOLID WASTE DISPOSAL SITES IN OZAUKEE COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
OZ1	Town of Belgium	T12N, R22E, Section 10, NE, NE	Town of Belgium	Inactive
OZ2	Town of Cedarburg	T10N, R21E, Section 2, NW, SE	City and Town of Cedarburg	Inactive; has received hazardous waste
OZ3	Town of Cedarburg	T10N, R21E, Section 21, SE, NE	Marvin Procknow	Inactive
OZ4	Town of Cedarburg	T10N, R21E, Section 2, NW, NE	Wisconsin Electric Power Company	Inactive
OZ5	Town of Fredonia	T12N, R21E, Section 32, NE, SE	Ozaukee County Highway Department	Inactive
OZ6	Town of Fredonia	T12N, R21E, Section 11, SW, SW	Town of Fredonia	Inactive
OZ7	Town of Grafton	T10N, R21E, Section 1, SE, NW	Town of Grafton	Inactive; has received hazardous waste
OZ8	Town of Grafton	T10N, R22E, Section 8, SW	Wisconsin Electric Power Company	Active; MON
OZ9	City of Mequon	T9N, R21E, Section 2, SW, SW	City of Mequon	Inactive
OZ10	City of Port Washington	T11N, R22E, Section 20, SE, SE	City of Port Washington	Inactive
OZ11	Town of Port Washington	T11N, R22E, Section 30, NW, NW	Town of Port Washington	Inactive
OZ12	Town of Port Washington	T11N, R22E, Section 4, SW, SW	N/A	Inactive
OZ13	Town of Saukville	T11N, R21E, Section 36, SW, SE	Town of Saukville	Inactive
OZ14	Town of Saukville	T11N, R21E, Section 5, NE, SW	Laubenstein Sales and Service, Inc.	Inactive
OZ15	Village of Saukville	T11N, R21E, Section 35, SW, NE	Freeman Chemical	Inactive
OZ16	Village of Saukville	T11N, R21E, Section 35, SW, NE	Village of Saukville	Inactive
OZ17	Village of Thiensville	T9N, R21E, Section 15, NE, SE	Village of Thiensville	Inactive

NOTES: 1. The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

2. The following abbreviation has been used:

MON = Site is being monitored.
N/A = Data is currently not available.

[a]*See Map 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table D-4

SOLID WASTE DISPOSAL SITES IN RACINE COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
RA1	City of Burlington	T3N, R19E, Section 29, NE, SE	Town of Burlington	Inactive
RA2	Town of Burlington	T2N, R19E, Section 1, SE, SE	Town of Burlington	Inactive
RA3	Town of Caledonia	T4N, R22E, Section 3, NW, SW	Caledonia Corporation	Inactive
RA4	Town of Caledonia	T4N, R22E, Section 1, N	Wisconsin Electric Power Company	Active; MON
RA5	Town of Caledonia	T4N, R23E, Section 19, NW, SE	Hillside Sand and Gravel	Inactive
RA6	Town of Caledonia	T4N, R22E, Section 3, NE, SE	Hunt's Disposal Landfill	Inactive; Superfund site
RA7	Town of Dover	T3N, R20E, Section 29, NW, SE	N/A	Inactive
RA8	Town of Dover	T3N, R20E, Section 25, SE, SW	Center for the Developmentally Disabled	Inactive
RA9	Town of Mt. Pleasant	T3N, R22E, Section 23, SE, NE	Kestrel Hawk Park	Active
RA10	Town of Mt. Pleasant	T3N, R22E, Section 27, SW, NE	Town of Mt. Pleasant	Inactive; has received hazardous waste
RA11	Town of Norway	T4N, R20E, Section 21, SW, NE	Town of Norway	Inactive
RA12	Town of Raymond	T4N, R21E, Section 2, SE, NE	Reclamation, Inc.	Inactive
RA13	Town of Rochester	T3N, R19E, Section 11, SE, NW	Town of Rochester	Inactive
RA14	Town of Rochester	T3N, R19E, Section 10, NW, SW	Racine County Highway Department	Inactive
RA15	Town of Yorkville	T3N, R19E, Section 11, NW, SE	Town of Yorkville	Inactive
RA16	Town of Waterford	T4N, R19E, Section 34, SE, NE	Town of Waterford	Inactive
RA17	Town of Yorkville	T3N, R21E, Section 29, SW, NW	Village of Union Grove	Inactive

NOTES: 1. The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

2. The following abbreviation has been used:

MON = Site is being monitored.
N/A = Data is currently not available.

[a]*See Map 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table D-5

SOLID WASTE DISPOSAL SITES IN WALWORTH COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
WW1	Town of Bloomfield	T1N, R18E, Section 7, NE, SE	City of Lake Geneva	Inactive
WW2	Town of Bloomfield	T1N, R18E, Section 7, SW, NW	Otto Jacobs	Inactive
WW3	Town of Darien	T2N, R15E, Section 29, NE, SE	Town of Darian	Inactive
WW4	Town of Darien	T2N, R15E, Section 9, NE, NE	Waste Management of Wisconsin, Mallard Ridge	Active
WW5	Town of Darien	T2N, R15E, Section 36, NW, SE	Town of Darian	Inactive
WW6	Town of Delavan	T2N, R16E, Section 5, SE, SW	City of Delevan	Inactive
WW7	Town of East Troy	T4N, R18E, Section 15, SW, SW	Town of East Troy	Inactive
WW8	Town of East Troy	T4N, R18E, Section 31, NW, NE	Troy Area Landfill	Active
WW9	City of Elkhorn	T2N, R16E, Section 1, NE, SE	City of Elkhorn	Inactive
WW10	City of Elkhorn	T3N, R16E, Section 36, SE, NW	City of Elkhorn	Inactive
WW11	Town of Geneva	T2N, R17E, Section 9, NW, NE	Walworth County Highway Department	Inactive
WW12	Town of LaFayette	T3N, R17E, Section 7, NE, SW	Mann Brothers Sand and Gravel	Active
WW13	Town of LaFayette	T3N, R17E, Section 13, NE, NW	Town of LaFayette	Inactive
WW14	Town of Linn	T1N, R17E, Section 12, SE, NE	Otto Jacobs	Inactive; has received hazardous waste
WW15	Town of Linn	T1N, R17E, Section 28, NE, SE	Gavins Construction Company	Inactive
WW16	Town of Lyons	T2N, R18E, Section 26, SW, SW	Town of Lyons	Inactive
WW17	Town of Richmond	T3N, R15E, Section 29, SE, NE	Town of Richmond	Inactive
WW18	Town of Sharon	T1N, R15E, Section 1, NE, NE	Pelishek Contracting, Inc.	Inactive
WW19	Town of Sharon	T1N, R15E, Section 1, NE, SE	Baker Landfill	Inactive; has received hazardous waste
WW20	Town of Spring Prairie	T3N, R18E, Section 21, SW, NW	Town of Spring Prairie	Inactive
WW21	Town of Sugar Creek	T3N, R16E, Section 9, SW, NE	Town of Sugar Creek	Inactive
WW22	Town of Troy	T4N, R17E, Section 16, NE, NW	Town of Troy	Inactive
WW23	Town of Walworth	T1N, R16E, Section 10, SE, SE	Village of Fontana	Inactive
WW24	Town of Walworth	T1N, R16E, Section 16, NW, SE	U.S. Gypsum	Inactive

NOTE: The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

[a]*See Map 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table D-6

SOLID WASTE DISPOSAL SITES IN WASHINGTON COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
WA1	Town of Addison	T11N, R18E, Section 14, SW, SW	Town of Addison	Inactive
WA2	Town of Barton	T11N, R19E, Section 1, SE, SE	N/A	Inactive
WA3	Town of Barton	T11N, R19E, Section 9, SE, NW	City of West Bend	Inactive
WA4	Town of Farmington	T12N, R20E, Section 33, NW, SE	Lazy Days Camp Ground	Inactive
WA5	Town of Farmington	T12N, R20E, Section 8, SE, NE	Town of Farmington	Inactive
WA6	Village of Germantown	T9N, R20E, Section 36, S	Waste Management of Wisconsin, Omega Hills North	Inactive; Superfund site
WA7	City of Hartford	T10N, R18E, Section 28, NW, SE	City of Hartford	Inactive
WA8	Town of Jackson	T10N, R20E, Section 15, SE, NW	Town of Jackson	Inactive
WA9	Town of Kewaskum	T12N, R19E, Section 1, NW, SE	Town of Kewaskum	Inactive
WA10	Town of Kewaskum	T12N, R19E, Section 6, NW, NW	Village of Kewaskum	Inactive
WA11	Town of Polk	T10N, R19E, Section 20, NW, SE	United Waste Systems	Inactive
WA12	Town of Polk	T10N, R19E, Section 34, NE, NE	LeRoy Schmidt Dump	Inactive
WA13	Town of Polk	T10N, R19E, Section 21, NE, SW	N/A	Inactive
WA14	Town of Polk	T10N, R19E, Section 20, S, SE	Town of Polk	Inactive
WA15	Town of Richfield	T9N, R19E, Section 13, SW, NW	Town of Richfield	Inactive
WA16	Village of Slinger	T10N, R19E, Section 18, SE, NW	Slinger Foundry	Inactive
WA17	Town of Trenton	T11N, R20E, Section 2, NW, SE	Town of Trenton	Inactive
WA18	Town of West Bend	T11N, R19E, Section 34, SE, NW	Town of West Bend	Inactive
WA19	Town of West Bend	T11N, R19E, Section 26, NE, SE	N/A	Inactive
WA20	Town of Wayne	T12N, R18E, Section 24, NE, SE	Town of Wayne	Inactive

NOTES: 1. The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

2. The following abbreviation has been used:

N/A = Data is currently not available.

[a]*See Map 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table D-7

SOLID WASTE DISPOSAL SITES IN WAUKESHA COUNTY: 1998

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
WK1	City of Brookfield	T7N, R20E, Section 19, SW, SE	City of Brookfield	Inactive
WK2	City of Brookfield	T7N, R20E, Section 20, SE, SE	Waste Management of Wisconsin, Brookfield Sanitary Landfill	Inactive; Superfund site
WK3	Town of Brookfield	T7N, R20E, Section 6, NE, SE, NW	Zaretzyke Dump	Inactive
WK4	Town of Brookfield	T7N, R20E, Section 5, SW, SW	Master Disposal Service Corporation	Inactive; Superfund site
WK5	City of Delafield	T7N, R18E, Section 27, NW, and Section 22, SW	Sanitary Transfer and Landfill	Inactive; has received hazardous waste
WK6	City of Delafield	T7N, R18E, Section 18, NE, SW	St. John's Military Academy	Inactive
WK7	Town of Delafield	T7N, R18E, Section 32, NW, SE	Ethan Allen School	Inactive
WK8	Town of Eagle	T5N, R17E, Section 26, SE, SW	Town of Eagle	Inactive
WK9	Town of Genesee	T6N, R18E, Section 27, NW, SE	Town of Genesee	Inactive
WK10	Town of Genesee	T6N, R18E, Section 6, SW, NW	Waukesha County Highway Department	Inactive
WK11	Town of Genesee	T6N, R18E, Section 29, SE, SE	Village of North Prairie	Inactive
WK12	Town of Genesee	T6N, R18E, Section 17, SE, SW	Town of Genesee	Inactive
WK13	Village of Hartland	T7N, R18E, Section 2, SW, NW	Village of Hartland	Inactive
WK14	Town of Lisbon	T8N, R19E, Section 17, NE, NW	N/A	Inactive
WK15	Town of Lisbon	T8N, R19E, Section 17, SW, NW	Town of Lisbon	Inactive
WK16	Town of Lisbon	T8N, R19E, Section 17, NW, SE	The Milwaukee Road	Inactive
WK17	Town of Lisbon	T8N, R19E, Section 18, SE, NW	Village of North Lake	Inactive
WK18	Village of Menomonee Falls	T8N, R20E, Section 1, NE, SE	Waste Management of Wisconsin (Lauer 1)	Inactive; Superfund site
WK19	Village of Menomonee Falls	T8N, R20E, Section 21, SE, SE	Industrial Waste Corporation	Inactive
WK20	Village of Menomonee Falls	T8N, R20E, Section 21, SE, SE	Manuel Robinson Landfill	Inactive
WK21	Village of Menomonee Falls	T8N, R20E, Section 28, E, NE	Mill Lands, Inc.	Inactive
WK22	Village of Menomonee Falls	T8N, R20E, Section 27, W, NW	Miller Brewing Landfill	Inactive
WK23	Village of Menomonee Falls	T8N, R20E, Section 19, SE, SW	Village of Menomonee Falls	Inactive
WK24	Village of Menomonee Falls	T8N, R20E, Section 21, SE, SE	Village of Menomonee Falls (Stribling)	Inactive
WK25	Village of Menomonee Falls	T8N, R20E, Section 1, N, NE	Waste Management of Wisconsin, Boundary Road Landfill	Inactive; Superfund site
WK26	Village of Menomonee Falls	T8N, R20E, Section 1, NW, NE	Waste Management of Wisconsin, Parkview	Active

Table D-7 (continued)

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
WK27	Town of Merton	T8N, R18E, Section 16, NW, NW	Town of Merton	Inactive
WK28	Town of Merton	T8N, R18E, Section 9, NW, NE	Village of Chenequa	Inactive
WK29	Town of Mukwonago	T5N, R18E, Section 35, NW, NE	Village of Mukwonago	Inactive
WK30	Town of Mukwonago	T5N, R18E, Section 16, SW, SW	Town of Mukwonago	Inactive
WK31	Village of Mukwonago	T5N, R18E, Section 26, S, NE	Town of Mukwonago	Inactive
WK32	City of Muskego	T5N, R20E, Section 18, E, NW	Waste Management of Wisconsin, Wauer/Muskego Sanitary Landfill	Inactive; Superfund site
WK33	City of Muskego	T5N, R20E, Section 5, NW, SE	Hilltop Restoration	Inactive
WK34	City of Muskego	T5N, R20E, Section 36, NE	Future Parkland Development, Inc.	Active
WK35	City of Muskego	T5N, R20E, Section 18, NE, SW	Waste Management of Wisconsin, Stone Ridge 3	Inactive
WK36	City of Muskego	T5N, R20E, Section 36, SE, NE	Superior Environmental Services, Emerald Park	Active
WK37	City of New Berlin	T6N, R20E, Section 18, SW, NE	Jaeger Sand and Gravel	Inactive; has received hazardous waste; under investigation
WK38	City of New Berlin	T6N, R20E, Section 8, NW, SE	N/A	Inactive
WK39	City of New Berlin	T6N, R20E, Section 18, NW, SE	Barrett Landfill	Inactive
WK40	City of New Berlin	T6N, R20E, Section 4, NE, NW	Industrial Waste Corporation	Inactive
WK41	City of New Berlin	T6N, R20E, Section 9, NW, NW	Bodus Landfill	Inactive; has received hazardous waste
WK42	Town of Oconomowoc	T8N, R17E, Section 4, SW, NW	City of Oconomowoc	Inactive
WK43	Town of Oconomowoc	T8N, R17E, Section 18, NW, NW	Sanitary Transfer and Landfill, Oconomowoc	Inactive
WK44	Village of Pewaukee	T7N, R19E, Section 9, NE, SE	Besnah Corporation	Inactive
WK45	Town of Pewaukee	T7N, R19E, Section 25, SW, NW	Johnson Sand and Gravel	Inactive; has received hazardous waste
WK46	Town of Pewaukee	T7N, R19E, Section 6, NW, SE	Town of Pewaukee	Inactive
WK47	Town of Pewaukee	T7N, R19E, Section 6, SW, NE	Town of Pewaukee	Inactive
WK48	Town of Pewaukee	T7N, R19E, Section 23, SE, NW	Wisconsin Electric Power Company	Active; MON
WK49	Town of Summit	T7N, R17E, Section 29, NW, and Section 20, SW	Town of Summit	Inactive
WK50	Town of Vernon	T5N, R19E, Section 13, SW, SW	Town of Vernon	Inactive
WK51	City of Waukesha	T6N, R19E, Section 2, SE, NE, and Section 1, SW, NW	City of Waukesha	Inactive

Table D-7 (continued)

Identification Number[a]	Civil Division	Location by U.S. Public Land Survey	Operator	Status
WK52	City of Waukesha	T6N, R19E, Section 10, SW, NW, SE	City of Waukesha	Inactive; has received hazardous waste
WK53	City of Waukesha	T6N, R19E, Section 9, SW, NE	Grede Foundry	Inactive
WK54	City of Waukesha	T6N, R19E, Section 9, NW, NE, and Section 4, SW, SE	Dresser Industries	Inactive
WK55	Town of Waukesha	T6N, R19E, Section 1, SW, NE	Wisconsin Electric Power Company	Inactive

NOTES: 1. The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

2. The following abbreviation has been used:

MON = Site is being monitored.
N/A = Data is currently not available.

[a]*See Map 27.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Appendix E

AGRICULTURAL SOURCES OF POTENTIAL CONTAMINATION IN SOUTHEASTERN WISCONSIN

Table E-1

LIVESTOCK OPERATIONS ISSUED A WPDES PERMIT IN SOUTHEASTERN WISCONSIN: 1999

Identification Number[a]	Site Name	County	Livestock Type	Number of Animals	Site Location
L1	Eggs-R-Us	Washington	Poultry	234,000 layers	9249 Wescott Road, Kewaskum Section 7, T12N, R20E
L2	Holt Brothers Farm	Walworth	Swine, dairy	50 calves 240 replacement cows 2,000 finishing hogs 600< finishing hogs 450 sows	6189 Amos Road, Elkhorn Section 4, T2N, R16E
L3	Maple Leaf Farms, Downey	Racine	Waterfowl	110,000 ducks	28430 Washington Avenue, Kansasville Sections 3&4, T3N, R20E
L4	Maple Leaf Farms, Main	Racine	Waterfowl	250,000 ducks	2319 Raymond Ave, Yorkville Sections 3&4, T3N, R21E
L5	S&R Egg Farms, La Grange	Walworth	Poultry	475,000 layers	N9416 Tamarack Rd, Whitewater Section 2, T4N, R16E
L6	S&R Egg Farms, Genesee	Waukesha	Poultry, beef	150,000 pullets 40 beef	S47 W29639 Hwy 59, Waukesha Section 26, T6N, R18E
L7	Sunset Farms, Inc.	Washington	Dairy	650 milk cows 450 hefers 200 steer 100 calves	6600 Sunset Drive, Allenton Section 17, T11N, R18E
L8	Lavern Schmidt Dairy Farm[b]	Washington	Dairy	60 milk cows 20 hefers	2745 Hwy. 164, Slinger Section 32, T10N, R19E

[a]*See Map 28.*

[b]*Failed to fulfill a Notice of Discharge issued in 1996. Has less than 1,000 animal units.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table E-2

BULK AGRICULTURAL CHEMICAL STORAGE AND MIXING/LOADING FACILITIES IN SOUTHEASTERN WISCONSIN: 1995

Identification Number[a]	Site Name	Location by U.S. Public Land Survey	Site Location	Operation Type
Kenosha County				
KE1	Koos, Inc. (Vigoro)	T2N, R23E, Section 30, NE 1/4, SW 1/4	4500 - 13th Court, Kenosha	DF, MB
Milwaukee County				
ML1	Happy Lawns	T7N, R22E, Section 1, SW1/4, SW1/4	4220 N. Teutonia Street, Milwaukee	BP
ML2	Hydrite Chemical	T8N, R21E, Section 15, NW1/4, NW1/4	7300 W. Bradley Road, Milwaukee	BP
ML3	PPG Industries	T5N, R22E, Section 32, SW1/4, SW1/4	10800 S. 13th Street, Oak Creek	BP
Ozaukee County				
OZ1	Walter Baehmann Farms	T9N, R21E, Section 29, NE 1/4, NW 1/4	9919 W. Mequon Road, Mequon	ML
OZ2	North Shore Country Club	T9N, R21E, Section 25, NE 1/4, SE 1/4	3100 W. Country Club Drive, Mequon	ML
OZ3	Saukville Feed Supplies	T11N, R21E, Section 35, NW 1/4, NE 1/4	313 W. Church Street, Saukville	BF
OZ4[b]	Kettle Lakes-Belgium[b]	T12N, R22E, Section 15, NE 1/4, SW 1/4	Elevator Avenue, Belgium	DF, ML
Racine County				
RA1	Cooperative Plus Inc. (formerly Burlington Consumers Cooperative)	T2N, R19E, Section 5, NW 1/4, NE 1/4	638 Kane Street, P.O. Box 220, Burlington	BF, DF, MB
RA2	Burlington Farmers Supply	T3N, R19E, Section 32, NW 1/4, NE 1/4	180 Commerce Street, Burlington	DF, MB
RA3	Conserve FS	T3N, R20E, Section 34, NE 1/4, NE 1/4	4304 S. Beaumont, P.O. Box 157, Kansasville	BF, BP, DF, MB
RA4	D.W. Davies & Company, Inc.	T3N, R23E, Section 31, NW 1/4. NE 1/4	3200 Phillips Avenue, Racine	BP
RA5	Cooperative Plus Inc. (formerly Farmers Grain and Supply)	T3N, R21E, Section 29, SW1/4, SW1/4	1007 State Street, Union Grove	BF, BP, DF, MB
RA6	S.C. Johnson, Waxdale	T3N, R23E, Section 16, NW 1/4, SW ¼	1525 Howe Street, Racine	BP
RA7	Cooperative Plus Inc.	T3N R21E, Section 33, SW ¼	17702 County Line Road, Union Grove	DF
Walworth County				
WW1	Cooperative Plus Inc. (formerly Burlington Consumers Cooperative)	T4N, R18E, Section 19, NW 1/4, SE ¼	N8265 Hwy N, East Troy	BF, BP, DF, MB
WW2	Cooperative Plus Inc. (formerly Burlington Consumers Cooperative)	T1N, R18E, Section 35, SE 1/4, SE ¼	407 Platt Street, Genoa City	BF, BP, DF, MB
WW3	Delong Company, Inc.	T1N, R15E, Section 11, NE 1/4, SE ¼	N1962 CTH K, Sharon	BF, BP
WW4	Millard Feed Mill	T3N, R16E, Section 9, NW 1/4, SW ¼	Route 2 W6406 CTH A, Elkhorn	BF, BP, DF, MB
WW5	Northern FS, Inc.	T2N, R17E, Section 6, NW 1/4, NW ¼	401 East Centralia, Elkhorn	BF, BP, DF, MB
WW6	Northern FS, Inc.	T1N, R17E, Section 29, NE 1/4, SE ¼	W4147 Highway B, P.O. Box 11, Zenda	BF, BP, DF, MB
WW7	Liquid Grow (formerly Elko Solutions, Inc.)	T2N, R17E, Section 6, SW 1/4, NW ¼	309 E. Centralia Street, P.O. Box 858, Elkhorn	BF, BP, DF, MB
WW8[b]	Cooperative Plus Inc. (formerly Walworth Consumers Cooperative)[b]	T2N, R16E, Section 1, NE 1/4, NE 1/4	230 S. Wisconsin Street, Elkhorn	BF, BP, DF, MB
Washington County				
WN1	Dodge County Cooperative	T10N, R18E, Section 19, NE 1/4, NE 1/4	7280 Highway 60W, Hartford	BF, DF, MB
WN2	Gundrum Brothers	T11N, R19E, Section 18, NW 1/4, NW 1/4	4894 Highway 33W, Nabob	BF, BP, DF, MB
WN3	Vogel Seed & Fertilizer, Inc.	T10N, R20E, Section 33,	1891 Spring Valley Road, Jackson	BF, BP, DF

Table E-2 (continued)

Identification Number[a]	Site Name	Location by U.S. Public Land Survey NW 1/4, SW 1/4	Site Location	Operation Type
Waukesha County				
WK1	All Green Corporation	T6N, R19E, Section 10, NW 1/4, NW 1/4	845 W. College, Waukesha	ML
WK2	American Landscape	T8N, R20E, Section 27, SE 1/4, SE 1/4	N60 W16073 Kohler Lane, Menomonee Falls	BF
WK3	Buckley Tree Service	T6N, R19E, Section 10, NW 1/4, NW 1/4	815 W. College Avenue, Waukesha	BF
WK4	Horn Brothers, Inc.	T5N, R19E, Section 13, NW 1/4, SE 1/4	S85 W22405 Buckett Street, Big Bend	DF
WK5	Horn Feeds, Inc.	T5N, R18E, Section 23, SE 1/4, SE 1/4	728 Clarendon Avenue, Mukwonago	BF, DF
WK6	Jefferson City Farmco Cooperative	T8N, R17E, Section 10, NE 1/4, NE 1/4	N87 W36145 Mapleton Street, Oconomowoc	BF, DF, MB
WK7	North Hills Country Club	T8N, R20E, Section 13, NE 1/4, SW 1.4	N73 W13430 Appleton Avenue, Menomonee Falls	ML
WK8	Tru Green Corporation	T7N, R19E, Section 25, NW 1/4, SE 1/4	N8 W22550 Johnson Drive, Box 1412, Waukesha	BF, MB
WK9	Westmoor Country Club	T7N, R20E, Section 34, SE 1/4, NE 1/4	400 S. Moorland Road, Brookfield	ML
WK10	Farm Better Services, Inc.	T6N, R17E, Section 3, SE 1/4, NW 1/4	132 W. Ottawa Avenue, P.O. Box 157, Dousman	BF

NOTE: The following abbreviations for the operation type were used:

BF = Liquid Bulk Fertilizer
BP = Liquid Bulk Pesticide
DF = Dry Bulk Fertilizer
MB = Minibulk Liquid Pesticide
ML = Mixing and Loading Site Only
WP = Liquid Bulk Wood Preservative (pesticide)

[a]*See Map 28.*

[b]*Bulk chemicals are no longer stored at this facility.*

Source: Wisconsin Department of Agriculture, Trade and Consumer Protection.

Appendix F

SALVAGE YARDS AND SALT STORAGE FACILITY SITES IN SOUTHEASTERN WISCONSIN

Table F-1

SALVAGE YARDS LOCATED IN SOUTHEASTERN WISCONSIN: 1995

Identification Number[a]	Site Name	Site Location
Milwaukee County		
ML1	A & R Salvage, Inc.	6939 W. Medford Avenue, Milwaukee, WI 53218
ML2	A1 Auto Recyclers	2140 W. Cornell Street, Milwaukee, WI 53209
ML3	A1 Auto Salvage	1561 S. 6th Street, Milwaukee, WI 53204
ML4	A1 Towing Company, Inc.	7605 W. Center Street, Milwaukee, WI 53222
ML5	AA Auto Recyclers	2239 N. 63rd Street, Wauwatosa, WI 53213
ML6	A Able Transmissions, Inc.	138 Becher Street, Milwaukee, WI 53204
ML7	A Auto, Inc.	5140 N.124th Street, Milwaukee, WI 53225
ML8	A B Rubbish & Salvage	5175 N. 27th Street, Milwaukee, WI 53209
ML9	ABC Salvage & Towing Company	2234 N. 48th Street, Milwaukee, WI 53208
ML10	ACE Trailer Rental, Inc.	1058 Wind Lake Road, Milwaukee, WI 53204
ML11	ACME Auto Salvage, Inc.	934 S. Barclay Street, Milwaukee, WI 53204
ML12	Action Imports	2848 Wells Street 103, Milwaukee, WI 53208
ML13	Advance Auto Salvage, Inc.	2375 S. 43rd Street, Milwaukee, WI 53219
ML14	Affordable Auto Salvage Company, Inc.	4485 N. Green Bay Avenue, Milwaukee, WI 53209
ML15	Al's Auto Body& Sales, Inc.	12300 W. Rohr Avenue, Milwaukee, WI 53225
ML16	Al's Auto Salvage, Inc.	10942 S. 124th Street, Franklin, WI 53132
ML17	American Recycling, Inc.	3015 W. Center Street, Milwaukee, WI 53210
ML18	Arteagas Stop and Save	1601 W. Becher Street, Milwaukee, WI 53215
ML19	Atlas Enterprises	2510 N. 52nd Street, Milwaukee, WI 53210
ML20	Augustine's Automotive Service	3320 W. Howard Avenue, Greenfield, WI 53221
ML21	Auto Ambulance	2255 S. 6th Street, Milwaukee, WI 53215
ML22	Auto Paradise Imports, Inc.	4905 W. Burnham Street, Milwaukee, WI 53219
ML23	Auto Paradise, Inc.	6102 S. 13th Street, Milwaukee, WI 53221
ML24	Bill's Towing & Salvage	7035 W. Tallmadge Place, Milwaukee, WI 53218
ML25	Bobbie's Auto Service & Towing	2419 W. Fond du Lac Avenue, Milwaukee, WI 53206
ML26	Bob's Auto & Truck Repair Center	4037 W. Fond du Lac Avenue, Milwaukee, WI 53216
ML27	Bowers Salvage & Towing Service	3244 S. Pine Avenue, Milwaukee, WI 53207
ML28	J. Brown Salvage	4915 N. 24th Street, Milwaukee, WI 53209
ML29	Bruce Street Auto Salvage, Inc.	1144 Bruce Street, Milwaukee, WI 53204
ML30	John Burbridge Auto	2440 N. 35th Street, Milwaukee, WI 53210
ML31	Burnham Auto Salvage, Inc.	4901 W. Burnham Street, Milwaukee, WI 53214
ML31A	C&W Salvage	4124 W. Fairmount Avenue, Milwaukee, WI 53209
ML32	Calumet Auto Salvage, Inc.	8501 W. Calumet Road, Milwaukee, WI 53224
ML33	Center City Auto Salvage, Inc.	999 N. 46th Street, Milwaukee, WI 53208
ML34	Chuck's Auto Salvage	4956 N. 60th Street, Milwaukee, WI 53218
ML35	Clark's Auto Salvage	3614 N. 2nd, Milwaukee, WI 53212
ML36	Cliff's Auto Repair and Salvage	4453 N. Green Bay Avenue, Milwaukee, WI 53209
ML37	Craig & Craig	2315 N. Booth Street, Milwaukee, WI 53212
ML38	The Cycle Empire, Inc	4001 Loomis Road, Greenfield, WI 53221
ML39	D&R Auto Repairs, Inc.	1202 W. National Avenue, Milwaukee, WI 53204
ML40	DNR Auto Repair	5722 W. Burleigh Street, Milwaukee, WI 53210
ML41	Denny's Auto Salvage	9919 W. Puetz Road, Franklin, WI 53132
ML42	Dotson & Sons Salvage	4951 N. 18th Street, Milwaukee, WI 53209
ML43	Durango Towing and Salvage	1128A S. 7th Street, Milwaukee, IW 53204
ML44	Durham Auto Salvage & Sales, Inc.	10568 S. 124th Street, Franklin, WI 53132
ML45	E&D Towing & Salvage	3290 N. Teutonia Avenue, Milwaukee, WI 53206
ML46	EZ Auto Salvage	923 S. 10th Street, Milwaukee, WI 53204
ML47	Eagle Salvage	7005 N. 102nd Street, Milwaukee, WI 53224
ML48	Ed's Auto Salvage	8611 W. Kaul Avenue, Milwaukee, WI 53225
ML49	Ed's Salvage	5734 W. Florist Avenue, Milwaukee, WI 53218
ML50	Edward's Salvage	4720 W. Capitol Drive, Milwaukee, WI 53216

Table F-1 (continued)

Identification Number[a]	Site Name	Site Location
Milwaukee County (continued)		
ML51	Ellis Boyd Salvage	3627 N. 1st Street, Milwaukee, WI 53206
ML52	Epple's Auto Salvage	4812 W. Hampton Avenue, Milwaukee, WI 53218
ML53	Esperanza Unida, Inc.	1329 W. National Avenue, Milwaukee, WI 53204
ML54	FJ Salvage	4769 N. 29th Street, Milwaukee, WI 53209
ML55	First Class Service	1952 N. 31st, Milwaukee, WI 53208
ML56	Frank's Salvage	1523 W. Lincoln Avenue, Milwaukee, WI 53215
ML57	Fryer Auto Salvage	3128 E. Grange, Cudahy, WI 53110
ML58	Gerovac Wrecking Company, Inc.	11401 W. Forest Home Avenue, Franklin, WI 53132
ML59	Grade A Auto Salvage	3100 W. Concordia Avenue, Milwaukee, WI 53216
ML60	Hampton Auto Salvage, Inc.	11840 W. Hampton Avenue, Milwaukee, WI 53225
ML61	Holmes Auto, Inc.	1309 W. Meinecke Avenue, Milwaukee, WI 53206
ML62	Hwy Forty Five Auto Salvage	10386 S. 124th Street, Franklin, WI 53132
ML63	Imperial Auto Parts & Service	425 E. North Avenue, Milwaukee, WI 53212
ML63A	J&J Salvage Auto Wrecking	6780 N. Industrial Road, Milwaukee, WI 53217
ML64	J&L Auto & Towing, Inc.	5300 N. 124th Street, Milwaukee, WI 53225
ML65	JSS Auto Salvage	7619 W. Lisbon Avenue, Milwaukee, WI 53222
ML66	Jaynes Drag Away Auto Salvage	11300 Oakwood Road, Franklin, WI 53132
ML67	Ken's Auto Salvage	2534 W. Greenfiled Avenue, Milwaukee, WI 53204
ML68	Kinnickinnic Auto Salvage, Inc.	3626 W. Mill Road, Milwaukee, WI 53209
ML69	Kinnickinnic Auto Salvage, Inc.	2003 S. Kinnickinnic Avenue, Milwaukee, WI 53207
ML70	Kipp Auto Service	5507 W. Hampton Avenue, Milwaukee, WI 53218
ML71	Labonty's	6117 N. 107th Street, Milwaukee, WI 53225
ML72	LaCroix Salvage	636 S. 6th Street, Milwaukee, WI 53204
ML73	Lake Auto Parts & Salvage	5659 S. 6th Street, Milwaukee, WI 53221
ML74	Lascelle Salvage	650 W. Pierce Street, Milwaukee, WI 53204
ML75	Last Ride Auto Recyclers	2324 S. Austin Street, Milwaukee, WI 53207
ML76	Lee's Auto Salvage, Inc.	5150 N. 124th Street, Milwaukee, WI 53225
ML77	Leschke Salvage	9605 S. 29th Street, Franklin, WI 53132
ML78	Leslie's Salvage	5321 N. 62nd Street, Milwaukee, WI 53218
ML79	Lesters and Sons	12015 W. Layton Avenue, Greenfield, WI 53228
ML80	Lev & Ed, Inc.	2431 N. 30th Street, Milwaukee, WI 53210
ML81	Macks Service Center	1711 W. Center Street, Milwaukee, WI 53206
ML82	Miki's Auto Salvage, Inc.	4385 N. Green Bay Avenue, Milwaukee, WI 53209
ML83	Mill Road Auto Salvage, Inc.	3800 W. Mill Road, Milwaukee, WI 53209
ML84	Mill Valley Recycling	1006 S. Barclay Street, Milwaukee, WI 53204
ML85	Milwaukee Cycle Salvage, Inc.	5754 N. Teutonia Avenue, Milwaukee, WI 53209
ML86	Mitchell Enterprises	403 N. 91st Street, Milwaukee, WI 53226
ML87	Modest John Salvage	3166 N. Buffum Street, Milwaukee, WI 53212
ML88	Murphy Towing	3421 W. Cherry Street, Milwaukee, WI 53208
ML89	N&S Towing, Inc.	1711 S. 83rd Street, West Allis, WI 53214
ML90	K. Nauman Auto	8560 Chicago Avenue, Oak Creek, WI 53154
ML91	Northwest Truck Parts, Inc.	8550 N. Grandville Road, Milwaukee, WI 53224
ML92	Oak Building Service, Inc.	4348 S. 27th Street, Milwaukee, WI 53221
ML93	Perry's Auto Service	2711 W. Atkinson Avenue, Milwaukee, WI 53209
ML94	Pinkey's Capital Auto Body	3859 N. Richards Street, Milwaukee, WI 53212
ML95	Quality Auto Body	4147 S. 6th Street, Milwaukee, WI 53221
ML96	Rauth Auto Parts & Salvage, Inc.	9802 W. Schlinger Avenue, West Allis, WI 53214
ML97	Recyclers Transport	1900 W. Bruce Street, Milwaukee, WI 53204
ML98	Richards Salvage	104 E. Clifford Street, Milwaukee, WI 53207
ML99	Richards Street Service	4101 N. Richards Street, Milwaukee, WI 53212
ML100	Rich's Auto Body & Salvage Co.	5020-5050 S. Nicholson Avenue, Cudahy, WI 53110
ML101	Road Patrol, Inc.	1347 N. 6th Street, Milwaukee, WI 53212
ML102	Road Runner Towing, Inc.	1109 E. Holt Avenue, Milwaukee, WI 53207
ML103	Roz Auto Salvages	5848 S. 13th Street, Milwaukee, WI 53221
ML104	Ruby Auto & Truck Parts Company	9000 W. Fond du Lac Avenue, Milwaukee, WI 53225
ML105	Rugg & Son Towing	6711 Spokane Street, Milwaukee, WI 53223
ML106	S&M Recycling	1200 Minnesota Avenue, South Milwaukee, WI 53172
ML107	Sam N Sonz	2728 W. Hayes Avenue, Milwaukee, WI 53215
ML108	Schaals Automotive Salvage	819 S. 111th Street, West Allis, WI 53214
ML109	Shels Service	4719 W. State Street, Milwaukee, WI 53208

Table F-1 (continued)

Identification Number[a]	Site Name	Site Location
Milwaukee County (continued)		
ML110	Sincock Auto Salvage	5178 N. 39th Street, Milwaukee, WI 53209
ML111	Southside Auto Salvage, Inc.	2108 E. Holt Avenue, Milwaukee, WI 53215
ML112	St. Francis Auto Wrecking, Inc.	4043 S. Pennsylvania Avenue, Milwaukee, WI 53207
ML113	Stevens Recycling	2217 N. 31st Street, Milwaukee, WI 53216
ML114	Suburban Services	11101 W. Layton Avenue, Greenfield, WI 53228
ML115	Sun Valley Auto Salvage	7225 Southridge Drive, Greenfield, WI 53221
ML116	Suttner Industries, Inc.	2393 S. 43rd Street, Milwaukee, WI 53219
ML117	The Auto Group	5520 N. Dexter Avenue, Glendale, WI 53209
ML118	Thunder Road	2629 S. Greeley Street, Milwaukee, WI 53207
ML119	Townsend Brothers Auto & Truck Repair	2452 N. 3rd Street, Milwaukee, WI 53212
ML120	Townsend Salvage	2716 N. 19th Street, Milwaukee, WI 53206
ML121	Triples Auto Parts, Inc.	450 S. 11th Street, Milwaukee, WI 53204
ML122	Trudeau Auto & Welding	2075 S. 15th Street, Milwaukee, WI 53204
ML123	Ulmer Jake Salvage	3210 N. Martin Luther King Jr. Drive, Milwaukee, WI 53212
ML124	Victor's Towing Truck	2538 N. Holton Street, Milwaukee, WI 53212
ML125	WC Eckert Salvage	7261 S. North Cape Road, Franklin, WI 53132
ML126	Waste and Recovery Material, LT	2424 N. 30th Street, Milwaukee, WI 53215
ML127	Willie Auto Salvage	3009 N. 37th Street, Milwaukee, WI 53206
ML128	Wright Auto	3507 W. Wright Street, Milwaukee, WI 53210
ML129	Young's Garage	1639 W. Hopkins Avenue, Milwaukee, WI 53206
Ozaukee County		
OZ1	Auto Parts and Recycling, Inc.	W4726 Hwy A, Fredonia, WI 53021
OZ2	Bradley Auto, Inc.	W3348 Meadow Lark Road, Fredonia, WI 53021
OZ3	Kirchhayn Auto Salvage, Inc.	1199 Western Avenue, Cedarburg, WI 53012
OZ4	Lakeland Metal Processing, Inc.	3909B Lakeland Road, Saukville, WI 53080
OZ5	Port Recycling, Inc.	728 Schmitz Drive, Port Washington, WI 53074
Racine County		
RA1	Chuck's Sheridan Auto, Inc.	3037 Capitol Avenue, Racine, WI 53403
RA2	Deback Salvage	26222 Durand Avenue, Kansasville, WI 53139
RA3	Erickson Nelson Service, Inc.	814 S Memorial Drive, Racine, WI 53403
RA4	Floyd and Sons, Inc.	1525 Durand Avenue, Racine, WI 53403
RA5	I-94 Auto Salvage Company	2118 N. Sylvania Avenue, Sturtevant, WI 53177
RA6	Martin Auto Salvage	2400 Racine Street, Racine 53403
RA7	Mason's Service, Inc.	3121 S. Memorial Drive, Racine, WI 53403
RA8	Mitchell's Salvage	1025 Geneva Street, Racine, WI 53404
RA9	Sturtevant Auto Sales & Service	2145 E. Frontage Road, Sturtevant, WI 53177
RA10	Thomas Hribar Truck and Equipment	1821 E. Frontage Road, Sturtevant, WI 53177
RA11	Town and Country Auto Truck & Salvage	1900 Three Mile Road, Racine, WI 53404
Walworth County		
WW1	Cocroft Auto	6988 Buckby Road, Lake Geneva, WI 53147
WW2	Como Auto Salvage	Route 5, Hwy H, Lake Geneva, WI 53147
WW3	D&E Auto Parts	N6396 Route 5, Elkhorn, WI 53121
WW4	East Troy Auto Recyclers, Inc.	2566 Energy Drive, East Troy, WI 53120
WW5	Eco, Inc.	10 E. Deere Road, Elkhorn, WI 53121
WW6	Firebird City	W9076 Hwy A, Delavan, WI 53115
WW7	Red's Auto Salvage	4332 High Drive, East Troy, 53120
WW7A	Buddy Short's Salvage	N6012 Hwy 120, Burlington, WI 53105
WW7B	Sisk Auto Part	Route 1, Wise Road, Darien, WI 53114
WW7C	Tri Troy Auto Parts	STH 20, Troy, WI 53120
WW8	Williams Salvage Yard	Route 10, Box 1765 Hwy 11, Burlington, WI 53105
Washington County		
WN1	Alexandra Jesse Trucking	121 Island Avenue, West Bend, WI 53095
WN2	Bartel Recycling	3640 Hwy C, West Bend, WI 53095
WN3	Bath Salvage	8715 Oak Drive, Kewaskum, WI 53040
WN4	Blaine Auto & Truck Parts	300 Storck Street, Slinger, WI 53086
WN5	Bradley Auto, Inc.	2026 Hwy A, West Bend, WI 53095
WN6	DAS Dons Auto Salvage	3382 E. Moraine Drive, Kewaskum, WI 53040
WN7	Dennis Sales and Service	8302 Orchard Valley Road, West Bend, WI 53095

Table F-1 (continued)

Identification Number[a]	Site Name	Site Location
Washington County (continued)		
- -[b]	GM Recycling	P.O. Box 143, Newburg, WI 53060
WN8	Glen Gotowitz Service	3753 Hwy 167, Richfield, WI 53076
WN9	Lynns Wastepaper Company, Inc.	131 Island Avenue, West Bend, WI 53095
WN10	Martin Implement	2350 Hwy 83 S, Hartford, WI 53027
WN11	Rocky's Automotive Service	W215 N11252 Appleton Avenue, Germantown, WI 53022
WN12	Tim Bell Transport	3178 Hillside Road, Box 306, Slinger, WI 53086
WN13	Voigt and Sons Salvage and Recycle	Route 3, 8701 Oak Drive, Kewaskum, WI 53040
WN14	Ralph Williams Service	3581 Hwy 175, Slinger, WI 53086
WN15	Zander Salvage	W188 N11910 Maple Road, Germantown, WI 53022
WN16	ZDS Salvage	N115 W16725 Bishop Drive, Germantown, WI 53022
Waukesha County		
WK1	A+ Foreign Auto and Truck Parts	W233 N5637 Hwy 164, Sussex, WI 53089
WK2	Advance Salvage	1239 S. West Avenue, Waukesha, WI 53186
WK3	B&M Auto Sales & Parts, Inc.	W227 S2698 Racine Avenue, Waukesha, WI 53186
WK4	Bira Salvage and Disposal	21995 Weyer Road, Pewaukee, WI 53072
WK5	DIX Salvage	W194 S7216 Cameron Court, Muskego, WI 53150
WK6	Elder's Service and Towing, Inc.	1523 Arcadian Avenue, Waukesha, WI 53186
WK7	Fritz's, Inc.	N48 W184747 Lisbon Road, Menomonee Falls, WI 53051
WK8	H&H Auto Parts & Salvage, Inc.	W233 N5639 Hwy 164, Sussex, WI 53089
WK9	Jack's Auto Salvage	S71 W13219 Tess Corners Drive, Muskego, WI 53150
WK10	Jack's Salvage	W126 S8557 N. Cape Road, Muskego, WI 53150
WK11	Joe's Truck & Auto Salvage	S107 W22645 River Avenue, Big Bend, WI 53103
WK12	Kohne Salvage	W200 S7203 Williams, Muskego, WI 53150
WK13	Larry's Auto & Truck Service, Inc.	N56 W13920 Silver Spring Drive, Menomonee Falls, WI 53051
WK14	R&H Recyclers	W204 N5213 Lannon Road, Menomonee Falls, WI 53051
WK15	RC Grimme Flatbed Service	15380 W. College Avenue, Muskego, WI 53150
WK16	Ron's Service & Auto Parts	W124 N9391 Boundary Road, Menomonee Falls, WI 53051
WK17	Stan Kaun Scrap Metal	N71 W35777 Mapleton Lake Drive, Oconomowoc, WI 53066
WK18	Tim's Auto Salvage	307 Forest Street, Oconomowoc, WI 53066
WK19	Vollmer Brothers, Inc.	S79 N29455 Frog Alley, Mukwonago, WI 53149
WK20	Waukesha Auto Parts & Salvage	1351 E. Main Street, Waukesha, WI 53186
WK21	Western Eagle Enterprises, Inc. (Eagle Auto Salvage)	S90 W38028 Hwy 59, Eagle, WI 53119
WK22	Williams Salvage	W305 S4990 Hwy 83, Mukwonago, WI 53149

[a] *See Map 29.*

[b] *Site not plotted on Map 29.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table F-2

SALT STORAGE FACILITY SITES IN SOUTHEASTERN WISCONSIN: 1995

Identification Number[a]	Responsible Party	Site Location
Kenosha County		
KE1	City of Kenosha, Street Division	6415 - 35th Avenue, Kenosha, WI
KE2	Kenosha County	19600 - 75th Street, Bristol, WI
KE3	Town of Salem Highway Department	11200 - 258th Court, Trevor, WI
KE4	Village of Paddock Lake	23201 - 62nd Street, Salem, WI
KE5	Village of Pleasant Prairie	8700 Green Bay Road, Pleasant Prairie, WI
KE6	Village of Twin Lakes	800 Burlington Avenue, Twin Lakes, WI
Milwaukee County		
ML1	Akzo Salt	1900 S. Harbor Drive, Milwaukee, WI
ML2	Akzo Salt	1531 S. Carferry Drive, Milwaukee, WI
ML3	City of Cudahy Department of Public Works	3555 E. Pabst Avenue, Cudahy, WI
ML4	City of Franklin	7811 W. Ryan Road, Franklin, WI
ML5	City of Glendale	5930 N. Glen Park Road, Glendale, WI
ML6	City of Greenfield	7325 W. Forest Home Avenue, Greenfield, WI
ML7	City of Greenfield	4551 S. 52nd Street, Greenfield, WI
ML8	City of Milwaukee Department of Public Works, Bureau of Sanitation	1912 W. Pierce Street, Milwaukee, WI
ML9	City of Milwaukee Department of Public Works, Bureau of Sanitation	2931 W. Cameron, Milwaukee, WI
ML10	City of Milwaukee Department of Public Works	4031 S. 6th Street, Milwaukee, WI
ML11	City of Milwaukee Department of Public Works	1333 N. 33rd Street, Milwaukee, WI
ML12	City of Milwaukee Department of Public Works	1600 N. 14th Street, Milwaukee, WI
ML13	City of Milwaukee Department of Public Works, Bureau of Sanitation	2363 S. 35th Street, Milwaukee, WI
ML14	City of Milwaukee Department of Public Works, Bureau of Sanitation	7222 W. Fond du Lac Avenue, Milwaukee, WI
ML14A	City of Milwaukee Department of Public Works, Bureau of Sanitation	1912 W. Pierce Street, Milwaukee WI
ML15	City of Milwaukee Department of Public Works	6732 N. Industrial Road, Milwaukee, WI
ML16	City of Oak Creek	8640 S. Howell Avenue, Oak Creek, WI
ML17	City of South Milwaukee	910 Marshall Avenue, South Milwaukee, WI
ML18	City of St. Francis	2125 E. Bolivar Avenue, St. Francis, WI
ML19	City of Wauwatosa	11100 W. Walnut Road, Wauwatosa, WI
ML20	City of West Allis Department of Public Works	6300 W. McGoech Avenue, West Allis, WI
ML21	CMC Heartland Partners	466 W. Canal Street, Milwaukee, WI
ML22	David J. Frank Landscape Contracting, Inc. (Northridge Shopping Center)	7700 W. Brown Deer Road, Milwaukee, WI
ML23	Delauca & Hartmann Construction	12001 W. Capitol Drive, Wauwatosa, WI
ML24	Milwaukee County Highway Department	5800 S. Howell Avenue, Milwaukee, WI
ML24A	Milwaukee County Highway Department	6271 N. Hopkins Street, Milwaukee, WI
ML25	Milwaukee County Highway Department	10190 Watertown Plank Road, Wauwatosa, WI
ML26	Metropolitan Maintenance and Landscaping	9300 W. Flagg Avenue, Milwaukee, WI
ML27	Metropolitan Maintenance and Landscaping	11020 W. Rogers Street, West Allis, WI
ML28	Morton Salt Company	501 W. Canal Street, Milwaukee, WI
ML29	Morton Salt Company	500 N. Harbor Drive, Milwaukee, WI
ML30	North American Salt Company	2225 S. Carferry Drive, Milwaukee, WI
ML31	North American Salt Company	2061 S. Harbor Drive, Milwaukee, WI
ML32	North American Salt Company	2175 S. Carferry Drive, Milwaukee, WI
ML33	North American Salt Company	1830 S. Carferry Drive, Milwaukee, WI
ML34	North American Salt Company	501 W. Canal Street, Milwaukee, WI
ML35	State Fair Park	Building 822, West Allis
ML36	Tews Company	1641 W. Mt. Vernon Avenue, Milwaukee, WI
ML37	Village of Bayside	101 E. Fairy Chasm Road, Bayside, WI
ML38	Village of Brown Deer	8717 N. 43rd Street, Brown Deer, WI
ML39	Village of Fox Point	7200 N. Santa Monica Boulevard, Milwaukee, WI
ML40	Village of Greendale	6351 Industrial Loop, Greendale, WI
ML41	Village of Hales Corners Department of Public Works	5635 S. New Berlin Road, Hales Corners, WI
ML42	Village of River Hills	7650 N. Pheasant Lane, Milwaukee, WI

Table F-2 (continued)

Identification Number[a]	Responsible Party	Site Location
Milwaukee County (continued)		
ML43	Village of Shorewood Department of Public Works	3801 N. Morris Boulevard, Shorewood, WI
ML44	Village of Whitefish Bay	155 W. Fairmount Avenue, Whitefish Bay, WI
Ozaukee County		
OZ1	City of Cedarburg	W59 N306 Johnson Avenue, Cedarburg, WI
OZ2	City of Mequon	10800 N. Industrial Drive, Mequon, WI
OZ3	City of Port Washington	333 N. Moore Road, Port Washington, WI
OZ4	Ozaukee County	Intersection of CTH I and STH 84, Fredonia, WI
OZ5	Ozaukee County	1000 Main Street, Belgium, WI
OZ6	Ozaukee County	410 S. Spring Street, Port Washington, WI
OZ7	Ozaukee County	1221 Hilltop Drive, Cedarburg, WI
OZ8	Town of Cedarburg	1293 Highway 143, Cedarburg, WI
OZ9	Village of Grafton	1300 Hickory Street, Grafton, WI
OZ10	Village of Saukville	600 S. Main Street, Saukville, WI
OZ11	Village of Thiensville	126 W. Freistadt Road, Thiensville, WI
Racine County		
RA1	City of Racine Department of Public Works	820 Racine Street, Racine, WI
RA2	Richard Pieters	824 Milwaukee Avenue, Burlington, WI
RA3	Racine County Highway Department	14200 Washington Avenue, Sturtevant, WI
RA4	Racine County Highway Department	31929 Academy Road, Burlington, WI
RA5	Town of Burlington	32288 Buschnell Road, Burlington, WI
RA6	Town of Caledonia	6922 Nicholson Road, Caledonia, WI
RA7	Town of Dover	4110 S. Beaumont Avenue, Kansasville, WI
RA8	Town of Mt. Pleasant	6126 Durand Avenue, Racine, WI
RA9	Town of Norway	4021 E. Wind Lake Road, Union Grove, WI
RA10	Town of Raymond	2563 - 76th Street, Franksville, WI
RA11	Town of Waterford	415 N. Milwaukee Street, Waterford, WI
RA12	Village of Union Grove	1015 State Street, Union Grove, WI
RA13	Village of Wind Point	215 E. Four Mile Road, Racine, WI
Walworth County		
WW1	City of Delavan	490 Richmond Road, Delavan, WI
WW2	City of Elkhorn	City Garage, 1st and N. Washington, Elkhorn, WI
WW3	City of Lake Geneva	191 Haskins Street, Lake Geneva, WI
WW4	City of Whitewater	303 N. Fremont Street, Whitewater, WI
WW5	R.W. Miller & Sons, Inc.	2604 Highway 120, Lake Geneva, WI
WW6	Town of Delavan	Town Hall Road, Delavan, WI
WW7	Town of La Grange	Rural Route 2, Whitewater, WI
WW8	Town of Linn	T1N R17E Sec. 28, Zenda, WI
WW9	Town of Mukwonago	1757 Town Line Road, East Troy, WI
WW10	Town of Richmond	Town Garage, Route 1, Delavan, WI
WW11	Town of Sugar Creek	Town Hall Garage, Route 2 Highway H, Elkhorn, WI
WW12	Town of Troy	2131 Highway N, Troy Center, WI
WW13	Town of Whitewater	Town Hall/W8590 Willis Ray Road, Whitewater, WI
WW14	Gregory Twelmeyer	768 Stewart School Road, East Troy, WI
WW15	Village of Fontana	Village Garage, Fontana, WI
WW16	Walworth County Highway Department	Fire No. 2604 STH 36, Town of Geneva, WI
WW17	Walworth County Highway Department	STH 24 one-half mile north of STH 20, East Troy, WI
WW17A	Walworth County Highway Department	W4097 CTH NN, Elkhorn, WI
WW18	Walworth County Highway Department	Intersection on CTH X and CTH K, Darien, WI
Washington County		
WN1	City of Hartford	710 W. Sumner Street, Hartford, WI
WN2	City of West Bend	251 Municipal Drive, West Bend, WI
WN3	Town of Addison	127 First Street, Allenton, WI
WN4	Town of Barton	3482 Town Hall Road, Kewaskum, WI
WN5	Town of Erin	1846 Highway 83, Hartford, WI
WN6	Town of Farmington	9422 Highway 144, Kewaskum, WI

Table F-2 (continued)

Identification Number[a]	Responsible Party	Site Location
Washington County (continued)		
WN7	Town of Hartford	3360 Highway K, Hartford, WI
WN8	Town of Jackson	3685 Division Road, Jackson, WI
WN9	Town of Kewaskum	9340 Highway 45, Kewaskum, WI
WN10	Town of Polk	3680 Highway 60, Slinger, WI
WN11	Town of Richfield	4128 Hubertus Road, Hubertus, WI
WN12	Town of Trenton	1071 Highway 33 East, West Bend, WI
WN13	Town of Wayne	6030 Highway H, Campbellsport, WI
WN14	Village of Germantown	W172 N12205 Fond du Lac Avenue, Germantown, WI
WN15	Village of Jackson	W204 N16660 S. Jackson Drive, Jackson, WI
WN16	Washington County Highway Department	Slinger Fairgrounds, Slinger, WI
WN17	Washington County Highway Department	620 E. Washington Street, West Bend, WI
Waukesha County		
WK1	Oliver Butterfield	1335 Ellis Street, Waukesha, WI
WK2	City of Brookfield	19450 Riverview Drive, Brookfield, WI
WK3	City of Delafield	111 W. Main Street, Delafield, WI
WK4	City of Muskego	W189 S8235 Mercury Drive, Muskego, WI
WK5	City of New Berlin	16550 W. National Avenue, New Berlin, WI
WK6	City of New Berlin	3805 S. Casper Drive, New Berlin, WI
WK7	City of Oconomowoc	630 S. Worthington Street, Oconomowoc, WI
WK8	City of Oconomowoc	6812 Brown Street, Oconomowoc, WI
WK9	Erickson, Charles	12975 Old Silver Spring Road, Butler, WI
WK10	Ethan Allen School	W323 S1050 Boys School Road, Delafield, WI
WK11	Pett Construction, Inc.	508 Kettle Moraine Drive, Eagle, WI
WK12	Titze, Leroy	W249 S8910 Center Drive, Big Bend, WI
WK13	Town of Brookfield	655 N. Janacek Road, Waukesha, WI
WK14	Town of Delafield	N14 W30782 Golf Road, Delafield, WI
WK15	Town of Eagle	S191 W35287 CTH NN, Eagle, WI
WK16	Town of Lisbon	N72 W24958 Good Hope Road, Sussex, WI
WK17	Town of Merton	W314 N7624 Highway 83, North Lake, WI
WK18	Town of Pewaukee	W240 N3065 Pewaukee Road, Pewaukee, WI
WK19	Town of Summit	2911 N. Dousman Road, Oconomowoc, WI
WK20	Village of Big Bend	W230 S9185 Nevins, Big Bend, WI
WK21	Village of Chenequa	5599 N. Highway 83, Chenequa, WI
WK22	Village of Elm Grove	900 Wall Street, Elm Grove, WI
WK23	Village of Menomonee Falls	N72 W15920 Good Hope Road, Menomonee Falls, WI
WK24	Village of Menomonee Falls	W164 N9183 Water Street, Menomonee Falls, WI
WK25	Village of Mukwonago	630 Highway NN, Mukwonago, WI
WK26	Village of Pewaukee	1000 Hickory Street, Pewaukee, WI
WK27	Village of Pewaukee	552 Hickory Street, Pewaukee, WI
WK28	Waukesha County Highway Department	Substation #2 126 Oakridge Drive, North Prairie, WI
WK29	Waukesha County Highway Department	N51 W23093 Lisbon Road, Sussex, WI
WK29A	Waukesha County Highway Department	Substation #5 20300 W. Lawndale Road, New Berlin, WI
WK30	Waukesha County Highway Department	Nashotah Substation, CTH R, Nashotah, WI
WK31	Waukesha County Highway Department	W25 N374 Grandview Boulevard, Pewaukee, WI
WK32	Waukesha County Highway Department	W254 N374 Grandview Boulevard, Waukesha, WI
WK33	Waukesha County Technical Institute	800 Main Street, Pewaukee, WI
WK34	Wold Construction Company, Inc.	612 N. Sawyer Road, Oconomowoc, WI

[a]*See Map 29.*

Source: Wisconsin Department of Transportation.

Appendix G

MISCELLANEOUS POTENTIAL SOURCES OF CONTAMINATION IN SOUTHEASTERN WISCONSIN

Table G-1

TEMPORARY SOLID AND HAZARDOUS WASTE STORAGE SITES IN SOUTHEASTERN WISCONSIN: 1997

Identification Number[a]	Site Name	Site Location	Location by U.S. Public Land Survey	Type of Storage Unit	Activity Code Status
Milwaukee County					
ML1	Cleansoils Wis, Inc.	9006 S. Fifth Avenue Oak Creek, WI 53154	T5N, R22E, Section 24, SE 1/4 of the NW 1/4	010	Inactive
ML2	Cleansoils Wis, Inc.	7045 S. Sixth Street Oak Creek, WI 53154	T5N, R22E, Section 5, SW 1/4 of the SE 1/4	010	Active
ML3	First Recovery Division of Ecoguard, Inc.	1414 S. Harbor Drive Milwaukee, WI 53207	T6N, R22E, Section 4, NE 1/4 of the NE 1/4	013	Active
ML4	Industrial Shredding Services	3495 W. Townsend Street Milwaukee, WI 53216	T7N, R21E, Section 12, NE 1/4 of the SW 1/4	010	Inactive
ML5	OSI Environmental, Inc.	3443 W. Mill Road Milwaukee, WI 53209	T8N, R21E, Section 25, NW 1/4 of the NE 1/4	011	Active
ML6	Aldrich Chemical Company, Inc.	940 W. St. Paul Avenue Milwaukee, WI 53233	T7N, R22E, Section 29, NW 1/4 of the SW 1/4	220, 222	Active, Active
ML7	Aldrich Chemical Company storage	230 S. Emmber Lane Milwaukee, WI 53233	T7N, R22E, Section 31, NE 1/4 of the NE 1/4	220	Active
ML8	Ashland Chemical Company, Division of Ashland, Inc..	1033 N. Hawley Road Milwaukee, WI 53208	T7N, R21E, Section 26, NW 1/4 of the SW 1/4	210	Inactive
ML9	Commerce Industrial Chemicals	5611 W. Woolworth Avenue Milwaukee, WI 53218	T8N, R21E, Section 26, NW 1/4 of the NW 1/4	210	Inactive
ML10	Delco Electronics Corporation	7929 S. Howell Avenue, Location A Oak Creek, WI 53154	T5N, R22E, Section 17, NE 1/4 of the NE 1/4	220	Inactive
ML11	EOG Disposal	5611 W. Hemlock Milwaukee, WI 53223	T8N, R21E, Section 14, SW 1/4 of the SW 1/4	210, 211	Active, Inactive
ML12	GE Medical Systems	4855 W. Electric Avenue Milwaukee, WI 53219	T6N, R21E, Section 2, NW 1/4 of the SE 1/4	220	Active
ML13	Master Lock	2600 N. 32nd Street Milwaukee, WI 53210	T7N, R21E, Section 13, NW 1/4 of the SE 1/4	220	Active
ML14	PPG Industries	10800 S. 13th Street Oak Creek, WI 53154	T5N, R22E, Section 32, NW 1/4 of the SW 1/4	220	Active
ML15	Tower Automotive Products, Inc.	3533 N. 27th Street Milwaukee, WI 53216	T7N, R21E, Section 12, NE 1/4 of the SE 1/4	222	Inactive
ML16	Van Waters & Rogers	1707 S. 101st Street West Allis, WI 53214	T6N, R21E, Section 5, SE 1/4 of the NW 1/4	220	Active
Ozaukee County					
OZ1	Aqua-Tech, Inc.	140 S Park Street Port Washington, WI 53074	T11N, R22E, Section 28, SW 1/4 of the SW 1/4	210	Inactive
OZ2	Cermatics	10014N 124W Wasaukee Mequon, WI 53092	T9N, R21E, Section 31, NW 1/4 of the NW 1/4	210	Active
OZ3	Cook Composites & Polymers Company	Railroad Street Saukville, WI 53080	T11N, R21E, Section 35, NW 1/4 of the NE 1/4	222	Active
OZ4	Superior Special Services	1275 Mineral Springs Drive Port Washington, WI 53074	T11N, R22E, Section 32, SW 1/4 of the SE 1/4	210, 215	Active, Inactive
Racine County					
RA1	SC Johnson & Son, Inc.	7512 Willow Road Mt. Pleasant, WI 53177	T3N, R22E, Section 22, SW 1/4 of the NE 1/4	220, 222	Active, Active

Table G-1 (continued)

Identification Number[a]	Site Name	Site Location	Location by U.S. Public Land Survey	Type of Storage Unit	Activity Code Status
Walworth County					
WW1	Waste Management of Wisconsin, Mallard Ridge tire storage	W8470 Hwy 11	T2N R15E, Section 9, E ½, Section 10	010	Active
Washington County					
WN1	An-Gun	7595 Otten Drive Barton, WI 53040	T12N, R19E, Section 34 NE 1/4	011	Active
Waukesha County					
WK1	Environmental Guardian, Inc.	1480 N. Springdale Road Waukesha, WI 53186	T7N, R19E, Section 1, NE 1/4 of the SE 1/4	010	Active
WK2	Tire Terminators	1250 E. Lincoln Avenue Waukesha, WI 53186	T6N, R19E, Section 2, NE 1/4 of the NE 1/4	011	Transitional
WK3	Advanced Environmental Tech Service	W124 N9451 Boundary Road Menomonee Falls, WI 53051	T8N, R20E, Section 1, NE 1/4 of the NE 1/4	210, 212	Active
WK4	Briggs & Stratton Corporation storage	W156 N9000 Pilgrim Road Menomonee Falls, WI 53051	T8N, R20E, Section 3, SE 1/4 of the SE 1/4	222	Inactive
WK5	MiSolv Corporation	N59 W14706 Bobolink Avenue Menomonee Falls, WI 53051	T8N, R20E, Section 26, NE 1/4 of the SE 1/4	210,212	Active, Active
WK6	GE Medical Systems	3114 N Grandview Boulevard Waukesha, WI 53188	T7N, R19E, Section 21, SW 1/4 of the SE 1/4	220	Inactive
WK7	Safety Kleen Corporation	2200 S West Avenue Waukesha, WI 53233	T6N, R19E, Section 15, NW 1/4 of the SE 1/4	210, 212	Active
WK8	Safety Kleen Coporation	113 Oak Ridge Drive, Lot 7 North Prairie, WI 53153	T6N, R18E, Section 32, SW 1/4 of the NE 1/4	216	Transitional

NOTE: The following codes describe the type of storage unit:

010 = Solid Waste - Storage Facility
011 = Solid Waste - Storage Container
013 = Solid Waste - Storage Tank Above Ground
210 = Hazardous Storage - Container Commercial
211 = Hazardous Waste Storage - Container Interim Licensed Commercial
212 = Hazardous Waster Storage - Tank Commercial
215 = Hazardous Waste - Waste Piles Interim Licensed Commercial
216 = Hazardous Waste - Miscellaneous Commercial
220 = Hazardous Waste - Container Noncommercial
222 = Hazardous Waste - Tank Noncommercial

The inventory data in this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Natural Resources should be contacted.

[a]*See Map 30.*

Source: Wisconsin Department of Natural Resources.

Table G-2

BULK FUEL STORAGE SITES IN SOUTHEASTERN WISCONSIN: 1995

Identification Number[a]	Name and Site Location	Location by U.S. Public Land Survey
Kenosha County		
KE1	C.H. Lockwood Oil 1552 - 22nd Avenue Kenosha, WI 53140	T2N, R23E, Section 18, NW 1/4 of the SW 1/4
KE2	Wisconsin Fuel & Heating 5724 - 59th Street Kenosha, WI 53144	T2N, R22E, Section 35, SW 1/4 of the SW 1/4
Milwaukee County		
ML1	Bio-Genesis Enterprizes 510 W. Rawson Avenue Oak Creek, WI 53154	T5N, R22E Section 8, NW 1/4 of the NE 1/4
ML2	Dahlman's Fuel Oil 6269 S. 108th Street Hales Corners, WI 53131	T6N, R21E, Section 31, NW 1/4 of the NE 1/4
ML3	Hometown Oil 1518 E. North Avenue Milwaukee, WI 53202	T7N, R22E, Section 21, NW 1/4 of the NE 1/4
ML4	Hometown Oil 430 S. Curtis Road West Allis, WI 53214	T7N, R21E, Section 31, NE 1/4 of the NW 1/4
ML5	Hometown Oil 1873 W. College Avenue Milwaukee, WI 53202	T5N, R21E, Section 6, NW 1/4 of the NE 1/4
ML6	Hopson Oil 6310 N. Sherman Boulevard Milwaukee, WI 53209	T8N, R21E, Section 26, NE 1/4 of the NE 1/4
ML7	Jacobus Oil 11221 W. Forest Home Avenue Hales Corners, WI 53131	T5N, R21E, Section 6, NW 1/4 of the SE 1/4
ML8	Jacobus Petroleum 1726 S. Harbor Drive Milwaukee, WI 53207	T6N, R22E, Section 4, SW 1/4 of the NE 1/4
ML9	North Side Oil 250 W. Capitol Drive Milwaukee, WI 53212	T7N, R22E, Section 5, SW 1/4 of the SE 1/4
ML10	Phillips 66 4302 W. Capitol Drive Milwaukee, WI 53216	T7N, R21E, Section 2, SE 1/4 of the SE 1/4
ML11	Radio Oil 435 S. 116th Street West Allis, WI 53214	T7N, R21E, Section 31, NE 1/4 of the NW 1/4
ML12	Signature Flight 4800 S. Howell Avenue Milwaukee, WI 53207	T6N, R22E, Section 28, NW 1/4 of the NW 1/4

Table G-2 (continued)

Identification Number[a]	Name and Site Location	Location by U.S. Public Land Survey
Ozaukee County		
OZ1	Becker Petroleum, Inc. 123 N. Park Street Port Washington, WI 53704	T11N, R22E, Section 28, SW 1/4 of the SW 1/4
OZ2	Filter Oil N51 W5358 Portland Road Cedarburg, WI 53012	T10N, R21E, Section 26, SW 1/4 of the SW 1/4
0Z3	Herbst Oil 230 Orchard Street Theinsville, WI 53092	T9N, R21E, Section 22, NE 1/4 of the SE 1/4
OZ4	Wester Oil 107 Lar Ann P.O. Box 3 Belgium, WI 53004	T12N, R22E, Section 14, SW 1/4 of the SW 1/4
Racine County		
RA1	Cooperative Plus, Inc. (formerly Burlington Consumers Cooperative) 400 Dodge Street Burlington, WI 53105	T2N, R19E, Section 32, SW 1/4 of the NE 1/4
RA2	Cooperative Plus, Inc. (formerly Farmers Grain and Supply) P.O. Box 365 Union Grove, WI 53182	T3N, R21E, Section 29, SW 1/4 of the SW 1/4
RA3	Franksville Oil Company 10210 Hwy K Franksville, WI 53126	T4N, R22E, Section 33, SW 1/4 of the SW 1/4
RA4	Jacobus Quick Flash 1100 W. 6th Street Racine, WI 53224	T3N, R23E, Section 9, SW 1/4 of the SW 1/4
RA5	Kenosha-Racine FS 4303 Beaumont Box 157 Kansasville, WI 53129	T3N, R20E, Section 34, NW 1/4 of the NE 1/4
RA6	Kruzan Oil 365 Market Street P.O. Box 585 Burlington, WI 53105	T2N, R19E, Section 6, NE 1/4 of the NE 1/4
RA7	W.H. Pugh Oil 200 Dodge Street Racine, WI 53402	T3N, R23E, Section 9, SW 1/4 of the NE 1/4
RA8	Franksville Oil (formerly Racine Consumers Cooperative) 1710 - 20th Street Racine, WI 53403	T3N, R23E, Section 20, SE 1/4 of the NE 1/4
RA9[b]	Jacobus Quick Flash (formerly Raymond Oil Company) 8810 W. Six Mile Road Franksville, WI 53126	T4N, R21E, Section 10, SW 1/4 of the SW 1/4

Table G-2 (continued)

Identification Number[a]	Name and Site Location	Location by U.S. Public Land Survey
Racine County (continued)		
RA10	Water Oil 411 S. 2nd Street P.O. Box 60 Waterford, WI 53185	T4N, R19E, Section 35, NE 1/4 of the SE 1/4
RA11	Wilson-Richtor Oil Market Street P.O. Box 116 Burlington, WI 53105	T2N, R19E, Section 6, NE 1/4 of the NE 1/4
Walworth County		
WW1	Austin Oil 115 Sunshine Avenue Delavan, WI 53115	T2N, R16E, Section 17, NW 1/4 of the NE 1/4
WW2	Cooperative Plus, Inc. (formerly Burlington Consumers Cooperative) 2021N Beulah Street Box 256 East Troy, WI, 53120	T4N, R18E, Section 19, NW 1/4 of the SE 1/4
WW3	Cooperative Plus, Inc. (formerly Burlington Consumers Cooperative) 408 Platt Street Genoa City, WI 53128	T1N, R18E, Section 35, SW 1/4 of the NE 1/4
WW4	Frawley Oil Company 622 Milwaukee Street Whitewater, WI 53190	T4N, R15E, Section 4, NE 1/4 of the SE 1/4
WW5	Lakeland Oil 846 Madison Street Lake Geneva, WI 53147	T2N, R17E, Section 25, NW 1/4 of the SW 1/4
WW6	Northern FS 401E Centralia Street Elkhorn, WI 53121	T2N, R17E, Section 6, NW 1/4 of the NW 1/4
WW7	Smith Petroleum 110 Market Street Box 355 Darien, WI 53114	T2N, R15E, Section 27, NE 1/4 of the SW 1/4
WW8	Swatek Sales 1050 Carey Street Lake Geneva, WI 53147	T2N, R17E, Section 26, SE 1/4 of the NE 1/4
WW9	Whitewater Oil Company 165 S. Wisconsin Whitewater, WI 53190	T4N, R15E, Section 4, NE 1/4 of the SW 1/4
Washington County		
WN1	Carter Oil Company 102 W Decorah West Bend, WI 53095	T11N, R19E, Section 14, SE 1/4 of the SE 1/4
WN2	Dodge County Cooperative 7280 Hwy 60 W Hartford, WI 53027	T10N, R18E, Section 18, SW 1/4 of the SW 1/4

Table G-2 (continued)

Identification Number[a]	Name and Site Location	Location by U.S. Public Land Survey
Washington County (continued)		
WN3	Filter Oil 2771 Division Road Jackson, WI 53037	T10N, R20E, Section 33, SE 1/4 of the NE 1/4
WN4	Kasten Oil Company 134 Wisconsin West Bend, WI 53095	T11N, R19E, Section 13, NW 1/4 of the NW 1/4
WN5	O'Connor Oil Company 108 W Decorah Road West Bend, WI 53095	T11N, R19E, Section 14, SE 1/4 of the SE 1/4
WN6	Strobel Oil 134 Clinton Kewaskum, WI 53040	T12N, R19E, Section 9, NW 1/4 of the SE 1/4
WN7	West Side Oil 800 State Street Hartford, WI 53027	T10N, R18E, Section 17, NE 1/4 of the SW 1/4
WN8	Wolf Brothers Fuel 1985 Hwy 175 Richfield, WI 53076	T9N, R., 19E, Section 12, SE 1/4 of the NW 1/4
WN9	E.H. Wolf & Sons 414 Kettle Moraine Drive Slinger, WI 53086	T10N, R18E, Section 12, SW 1/4 of the SW 1/4
WN10	Yahr Oil Company 106 W. Decorah Road West Bend, WI 53095	T11N, R19E, Section 14, SE 1/4 of the SE 1/4
Waukesha County		
WK1[b]	Hopson Oil (formerly Chapman Oil Company) P.O. Box 116 Eagle, WI 53119	T5N, R17E, Section 22, SW 1/4 of the NE 1/4
WK2	Corey Oil Company N7755 W315 Hwy 83 P.O. Box 26 North Lake, WI 53064	T8N, R18E Section 16, SE 1/4 of the NW 1/4
WK3	Don Dixon Oil Company 625E St. Paul Avenue Waukesha, WI 53186	T6N, R19E, Section 3, NE 1/4 of the NE 1/4
WK4	Dousman Oil Company 106 W. Ottawa Street Dousman, WI 53118	T6N, R17E, Section 3, NE 1/4 of the SW 1/4
WK5	Hopson Oil/Spaight Oil Company S84 W21172 Janesville Road Muskego, WI 53150	T5N, R20E, Section 18, SW 1/4 of the SW 1/4
WK6	Hopson Oil 1225 Whiterock Avenue Waukesha, WI 53186	T7N, R19E, Section 35, NE 1/4 of the SW 1/4
WK7	Horn Oil Company 728 Clarendon Avenue Mukwonago, WI 53149	T5N, R18E, Section 23, SE 1/4 of the SE 1/4

Table G-2 (continued)

Identification Number[a]	Name and Site Location	Location by U.S. Public Land Survey
Waukesha County (continued)		
WK8	Jefferson County Cooperative N87 W36145 Mapleton Oconomowoc, WI 53066	T8N, R17E, Section 10, NE 1/4 of the NE 1/4
WK9	Johnny's Petroleum S76 W17871 Janesville Road Muskego, WI 53150	T5N, R20E, Section 9, NE 1/4 of the SE 1/4
WK10	Lyon's Oil Company P.O. Box 698 37131 E Wisconsin Avenue Oconomowoc, WI 53066	T7N, R17E, Section 4, NE 1/4 of the NE 1/4
WK11	O'Rourke Distributing Company, Inc. 303 Sentry Drive Waukesha, WI 53186	T6N, R19E, Section 9, NE 1/4 of the NE 1/4

NOTE: The inventory data on this table is subject to periodic change due to the nature of the facilities. For the most recent data, the Wisconsin Department of Transportation should be contracted.

[a]*See Map 30.*

[b]*Bulk fuel is no longer stored at this facility.*

Source: Wisconsin Department of Transportation.