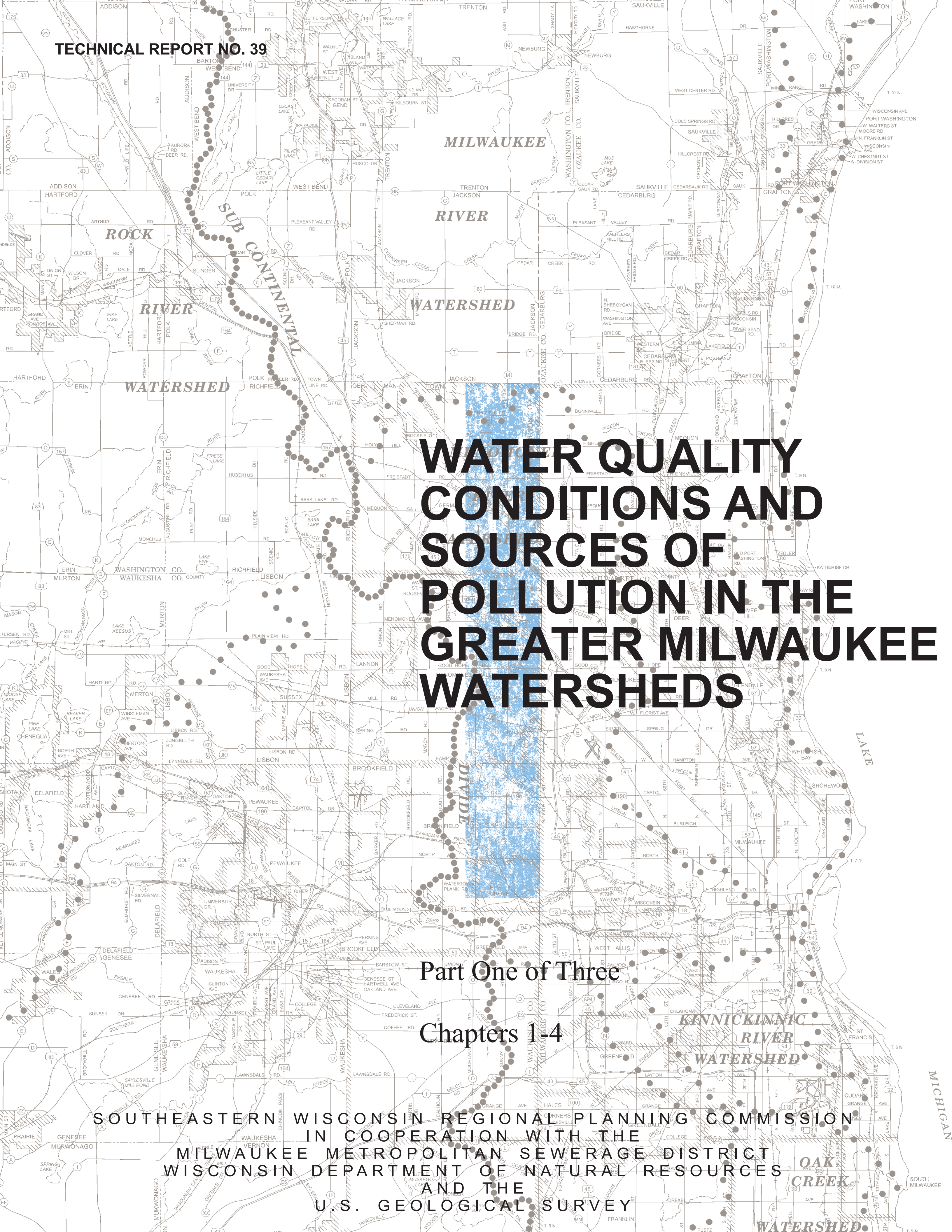
TECHNICAL REPORT NO. 39

WATER QUALITY CONDITIONS AND SOURCES OF POLLUTION IN THE GREATER MILWAUKEE WATERSHEDS

Part One of Three

Chapters 1-4



SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION
IN COOPERATION WITH THE
MILWAUKEE METROPOLITAN SEWERAGE DISTRICT
WISCONSIN DEPARTMENT OF NATURAL RESOURCES
AND THE
U.S. GEOLOGICAL SURVEY

Special acknowledgement is due Mr. Martin A. Aquino, Environmental Manager, City of Milwaukee Department of Public Works; Mr. Mark Baran, former Interim District Conservationist for Ozaukee County; Ms. Marsha B. Burzynski, Program and Planning Analyst, Wisconsin Department of Natural Resources; Mr. David E. Carpenter, retired Director of Planning and Development for Dodge County; Ms. Diane M. Georgetta, former Coordinator, Town and Country Resource Conservation and Development, Inc.; Ms. Elizabeth L. Gillen, Acting District Conservationist for Ozaukee County; Ms. Shannon K. Haydin, former Director, Sheboygan County Department of Planning and Resources; Ms. Judy Jooss, Representative, Town and Country Resource Conservation and Development, Inc.; Mr. Charles J. Krohn, former Regional Water Leader for the Wisconsin Department of Natural Resources; Mr. David Lynch, retired Ozaukee County Conservationist; Mr. Gary A. Mick, retired Director Milwaukee County Environmental Services; Mr. Stephen Poloncsik, Senior Staff Engineer, U.S. Environmental Protection Agency; and Ms. Gretchen Sawtelle, Executive Director, USDA Farm Services Agency, all of whom served on the Committee during much of the planning process.

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WATER QUALITY CONDITIONS AND SOURCES OF POLLUTION IN THE GREATER MILWAUKEE WATERSHEDS

Part One of Three
Chapters 1-4

Prepared by the

Southeastern Wisconsin Regional Planning Commission
In Cooperation with the
Milwaukee Metropolitan Sewerage District,
Wisconsin Department of Natural Resources,
and the
U.S. Geological Survey

The preparation of this report was financed in part by the Milwaukee Metropolitan Sewerage District and by the Wisconsin Department of Natural Resources and the U.S. Environmental Protection Agency under the continuing water quality management planning program conducted cooperatively by the Department and the Regional Planning Commission.

November 2007

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STATEMENT OF THE EXECUTIVE DIRECTOR

The information presented in this technical report provides an important basis for the formulation of the plan presented in SEWRPC Planning Report No. 50, *An Update to the Regional Water Quality Management Plan for the Greater Milwaukee Watersheds,* which was prepared pursuant to the provisions of Section 208 of the Federal Water Pollution Control Act under a collaborative program involving the Southeastern Wisconsin Regional Planning Commission, the Milwaukee Metropolitan Sewerage District (MMSD), and the Wisconsin Department of Natural Resources (WDNR). The objectives of that plan update were 1) to determine the current state of stream and lake water quality conditions within the Kinnickinnic, Menomonee, Milwaukee, and Root River watersheds, the Oak Creek watershed, the Milwaukee Harbor estuary, and the Lake Michigan Direct Drainage Area (collectively designated the “Greater Milwaukee Watersheds”), 2) to compare those conditions against established water use objectives and supporting water quality standards, 3) to explore alternative means of improving water quality through the abatement of both point and nonpoint sources of water pollution, and 4) to recommend the most cost-effective means of improving water quality over time.

The formulation of sound recommendations for the abatement of water pollution and the attainment of water use objectives requires, among other things, characterization of existing water quality conditions, identification of water quality trends over time, and definitive identification of all sources of water pollution. Accordingly, the Commission prepared this technical report as a companion report to Planning Report No. 50. This report consists of 1) a comprehensive review and analysis of observed water quality, fishery, and instream and riparian habitat data collected since the initial regional water quality management plan was published; 2) an inventory to identify the significant sources of water pollution within the Greater Milwaukee Watersheds and to establish the number, type, and location of those pollution sources; and 3) an inventory and simulation modeling to establish the type and amount of pollutants contributed by each source to the surface waters of the study area.

In addition to providing one of the bases for the preparation of the update to the regional water quality management plan, it is the hope of the Commission staff that this report will provide an important historical benchmark with respect to water quality conditions and sources of water pollution in the streams and lakes of the study area, including the nearshore area of Lake Michigan, a benchmark against which progress in water pollution abatement can be measured over the years ahead.

Respectfully submitted,

Philip C. Evenson

Philip C. Evenson
Executive Director

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Chapter I

INTRODUCTION

BACKGROUND

This report documents inventory data and associated analyses of water quality and sources of pollution used in an update to the regional water quality management plan for the "greater Milwaukee watersheds."[1] The plan update is for the design year 2020 and represents a major amendment to the regional water quality management plan for Southeastern Wisconsin.[2,3]

This report documents inventories and analyses conducted as part of the regional water quality management plan update effort. The regional water quality management plan update is designed largely to meet Wisconsin Department of Natural Resources (WDNR) needs in developing watershed-based, total maximum daily pollution loading, and possibly water quality standard use attainability analyses and reports consistent with the policies of the WDNR and U.S. Environmental Protection Agency (USEPA).

This report is intended to serve as a planning tool and, in addition to being a component of the regional water quality management plan update, it forms part of the cooperative and coordinated efforts by the Milwaukee Metropolitan Sewerage District (MMSD) and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) in MMSD's 2020 facilities planning effort. The approach to carrying out the MMSD facilities planning program and the regional water quality management plan update program has been developed cooperatively by the WDNR, the MMSD (including its facilities plan consultant team), and the SEWRPC and has

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[1]*The term "greater Milwaukee watersheds" is defined for purposes of this report as all five watersheds which lie entirely or partially in the greater Milwaukee area, as well as the Milwaukee Harbor estuary and a portion of nearshore Lake Michigan and its direct drainage area. The watersheds included are those of the Kinnickinnic River, Menomonee River, Milwaukee River, Oak Creek, and Root River.*

[2]*SEWRPC Planning Report No. 30,* A Regional Water Quality Management Plan for Southeastern Wisconsin—2000, *Volume One,* Inventory Findings, *September 1978; Volume Two,* Alternative Plans, *February 1979; and Volume Three,* Recommended Plan, *June 1979.*

[3]*SEWRPC Planning Report No. 50,* A Regional Water Quality Management Plan Update for the Greater Milwaukee Watersheds, *December 2007.*

been conceptually formalized under a February 19, 2003, Memorandum of Understanding among these agencies.[4] Under the approach envisioned, the coordinated, collaborative planning programs will lead to the preparation of an update to the regional water quality management plan for the greater Milwaukee watersheds, and support the facilities planning program for the MMSD sewerage systems.

STUDY AREA

The study area for the regional water quality management plan update consists of all five watersheds which lie entirely or partially in the greater Milwaukee area, as well as the Milwaukee Harbor estuary and a portion of nearshore Lake Michigan and its direct drainage area, as shown on Map 1.

The watersheds involved in the study are those of the Kinnickinnic River, Menomonee River, Milwaukee River, Oak Creek, and the Root River. These watersheds cover approximately 1,127 square miles. About 861 square miles of these watersheds are located within the seven-county Region for which SEWRPC has planning authority, representing about 32.0 percent of the Region. In addition, approximately 266 square miles of the greater Milwaukee watersheds, or about 23.6 percent of the study area, are located outside of the Region. This portion of the study area consists of the upper reaches of the Milwaukee River watershed, and is located in Dodge, Fond du Lac, and Sheboygan Counties. The watersheds in the study area are drained by approximately 1,010 miles of stream.

With regard to the Milwaukee Harbor estuary and nearshore Lake Michigan portion of the study area, it is important to make a physical distinction between the boundaries of the Milwaukee Harbor and the boundaries of the estuary itself. As shown on Map 2, the Milwaukee Harbor includes the outer harbor area—from the breakwater to the shoreline, excluding the anchorage area protected by the offshore breakwater south of E. Lincoln Avenue extended—and the inner harbor area—which includes those lower reaches of the Kinnickinnic, Menomonee, and Milwaukee Rivers that are maintained to depths which will accommodate navigation by deep draft commercial vessels. The inner harbor is approximately bounded by the Becher Street bridge on the Kinnickinnic River, S. 25th Street on the Menomonee River, and Buffalo Street extended on the Milwaukee River. The Milwaukee Harbor estuary itself includes the 3.1-mile reach of the Milwaukee River below the site of the former North Avenue dam, the 2.2-mile reach of the Menomonee River below the former Falk Corporation dam, and the 2.4-mile reach of the Kinnickinnic River below the Chase Avenue bridge along with the outer harbor to the breakwater structure. Thus defined, the Milwaukee Harbor estuary has a total length of stream of about 9.1 miles, and a total surface water area of approximately 1,630 acres, or about 2.5 square miles. A break wall shelters the Milwaukee Harbor area and is aligned from approximately one mile north to about 1.7 miles south of the mouth of the Milwaukee River. Lake Michigan water level conditions affect stages in each river in the Milwaukee Harbor estuary. The nearshore Lake Michigan area protected by the South Shore breakwater immediately south of the Milwaukee Outer Harbor is an important part of the study area. This area is protected by a breakwater structure extending from the Milwaukee Harbor about 12,500 feet south along the Lake Michigan shoreline and partially protecting the South Shore Yacht Club, South Shore Park, and Bay View Park.

The Lake Michigan direct drainage area, as shown on Map 1, is a limited area drained by a number of small streams, drainage swales, and storm sewers discharging directly to Lake Michigan. The largest drainage system is Fish Creek located on the border of Milwaukee and Ozaukee Counties. The portion of the nearshore area of Lake Michigan included in the study area extends from Fox Point in Milwaukee County to a point approximated by Three Mile Road extended in Racine County. The land area draining directly to the Lake in this reach is included in the study area.

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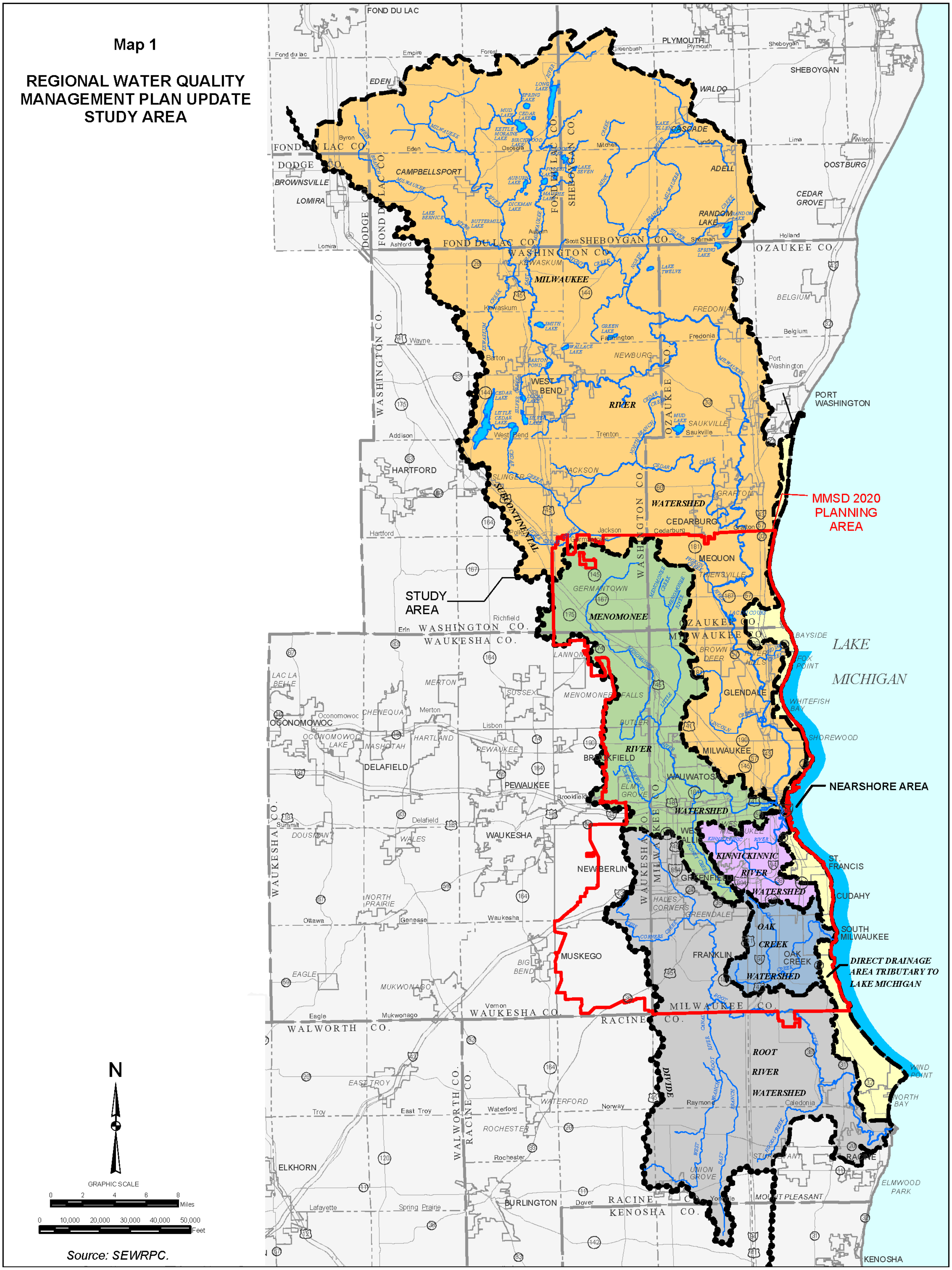
[4]"*Memorandum of Understanding between the Milwaukee Metropolitan Sewerage District (District), the Southeastern Wisconsin Regional Planning Commission (SEWRPC), and the Wisconsin Department of Natural Resources (DNR) for Cooperation in the Watershed Approach to Water Quality and Facilities Planning,*" *February 19, 2003.*

Map 1

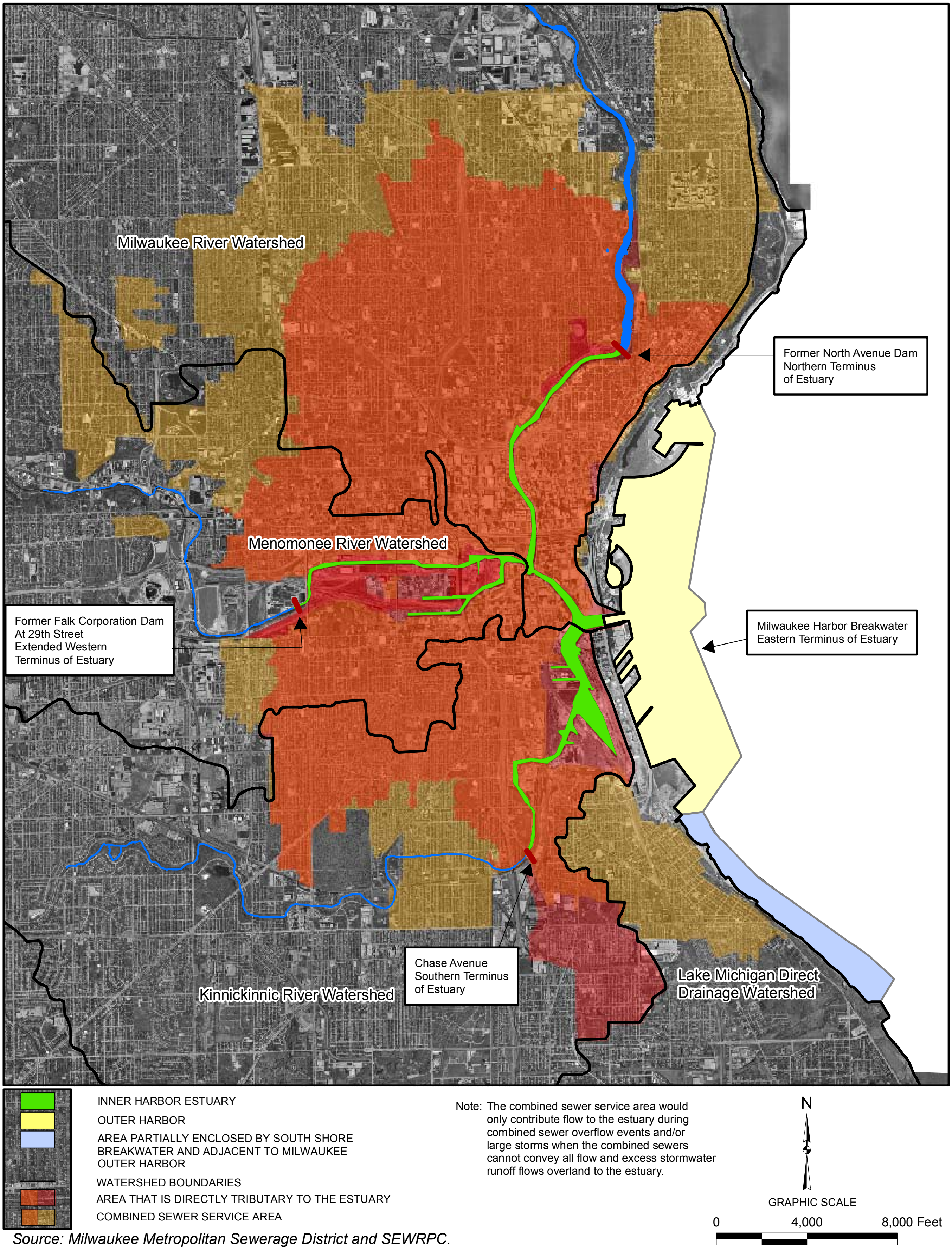
REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA



Source: SEWRPC.

Map 2

MILWAUKEE HARBOR ESTUARY



Note: The combined sewer service area would only contribute flow to the estuary during combined sewer overflow events and/or large storms when the combined sewers cannot convey all flow and excess stormwater runoff flows overland to the estuary.

Source: Milwaukee Metropolitan Sewerage District and SEWRPC.

UNITS OF GOVERNMENT

Civil Divisions

Superimposed on the irregular study area boundary as defined by watershed boundaries is a pattern of local political boundaries. As shown on Map 3, the watersheds lie primarily within Fond du Lac, Milwaukee, Ozaukee, Racine, Sheboygan, Washington, and Waukesha Counties with small portions in northern Kenosha and northeastern Dodge Counties. Eighty-eight civil divisions lie in part or entirely within the greater Milwaukee watersheds, as also shown on Map 3 and in Table 1. Geographic boundaries of the civil divisions are an important factor which must be considered in any watershed-based planning effort like the regional water quality management plan update program, since the civil divisions form the basic foundation of the public decision-making framework within which intergovernmental, environmental, and developmental problems must be addressed.

Special-Purpose Units of Government

Special-purpose units of government are of particular interest to the water quality management update planning program. Among these are the MMSD; the legally established, active town sanitary and utility districts created to provide various urban-related services, such as sanitary sewerage, water supply, and solid waste collection and disposal, to designated portions of rural towns with urban service needs; and inland lake protection and rehabilitation districts.

Milwaukee Metropolitan Sewerage District

The Milwaukee Metropolitan Sewerage District is directed by an appointed Commission. The MMSD includes all of Milwaukee County, except the City of South Milwaukee and portions of the City of Franklin. In addition, sewage conveyance and treatment services are provided to portions of Ozaukee, Racine, Washington, and Waukesha Counties. The District, which exists pursuant to the provisions of Section 200.23 of the *Wisconsin Statutes*, has a number of important responsibilities in the area of water resources management, including the provision of floodland management programs for most of the major streams within the District and the collection, transmission, and treatment of domestic, industrial, and other sanitary sewage generated in the District and its contract service areas.

The MMSD has defined a series of interrelated projects which were designed to carry out its sewage management responsibilities, and which are collectively referred to as the Milwaukee water pollution abatement program. These projects were developed through facilities planning programs which were subregional in nature, the latest of which was completed in 1998 and had a design year of 2010. The present MMSD initiative, which is being conducted in coordination with the regional water quality management plan update, seeks to amend and extend its sewerage facilities plan to a design year of 2020.

Town Sanitary and Utility Districts

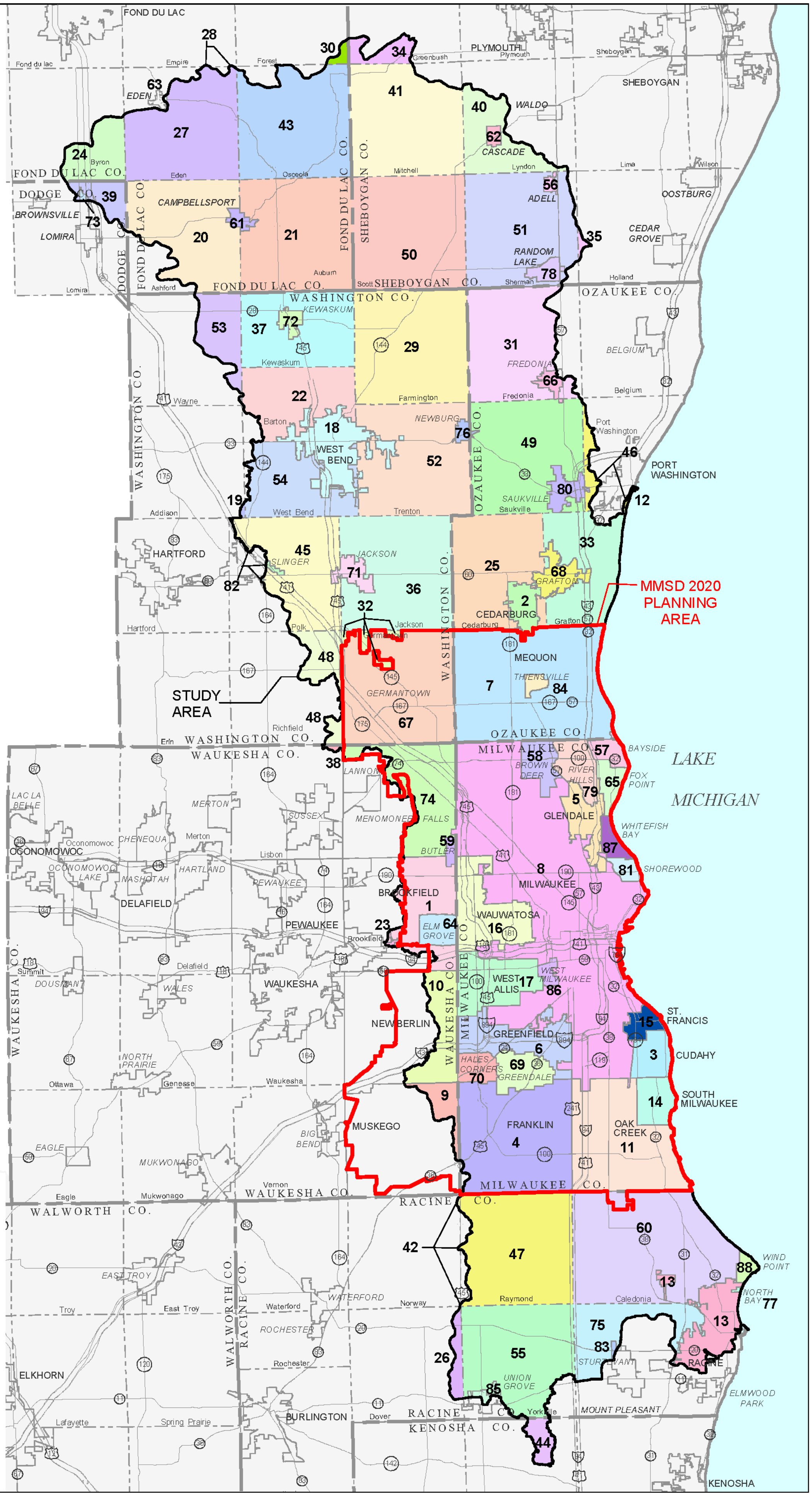
There are 11 active town sanitary and utility districts within the study area: the Brookfield Sanitary District No. 4 in the Town of Brookfield; the Caddy Vista Sanitary District, the Caledonia Utility District No. 1, the Crestview Sanitary District, and the North Park Sanitary District in the Town of Caledonia; the Lake Ellen Sanitary District in the Town of Lyndon; the Silver Lake Sanitary District in the Town of West Bend; the Town of Scott Sanitary District in the Town of Scott; the Wallace Lake Sanitary District in the Towns of Barton and Polk; the Waubeka Area Sanitary District in the Town of Fredonia; and the Yorkville Sewer Utility District No. 1 in the Town of Yorkville.

Inland Lake Protection and Rehabilitation Districts

Inland lake protection and rehabilitation districts are special-purpose units of government created pursuant to Chapter 33 of the *Wisconsin Statutes*. There are three such districts in the watershed: the Big Cedar Lake Protection and Rehabilitation District, the Little Cedar Lake Protection and Rehabilitation District, and the Silver Lake Protection and Rehabilitation District. Lake protection and rehabilitation district powers include 1) study of existing water-quality conditions to determine the causes of existing or expected future water-quality problems, 2) control of aquatic macrophytes and algae, 3) implementation of lake rehabilitation techniques, including

Map 3

CIVIL DIVISIONS WITHIN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA: 2000



1 City of Brookfield
2 City of Cedarburg
3 City of Cudahy
4 City of Franklin
5 City of Glendale
6 City of Greenfield
7 City of Mequon
8 City of Milwaukee
9 City of Muskego
10 City of New Berlin
11 City of Oak Creek
12 City of Port Washington
13 City of Racine
14 City of South Milwaukee
15 City of St. Francis
16 City of Wauwatosa
17 City of West Allis
18 City of West Bend
19 Town of Addison
20 Town of Ashford
21 Town of Auburn
22 Town of Barton
23 Town of Brookfield
24 Town of Byron
25 Town of Cedarburg
26 Town of Dover
27 Town of Eden
28 Town of Empire
29 Town of Farmington
30 Town of Forest
31 Town of Fredonia
32 Town of Germantown
33 Town of Grafton
34 Town of Greenbush
35 Town of Holland
36 Town of Jackson
37 Town of Kewaskum
38 Town of Lisbon
39 Town of Lomira
40 Town of Lyndon
41 Town of Mitchell
42 Town of Norway
43 Town of Osceola
44 Town of Paris
45 Town of Polk
46 Town of Port Washington
47 Town of Raymond
48 Town of Richfield
49 Town of Saukville
50 Town of Scott
51 Town of Sherman
52 Town of Trenton
53 Town of Wayne
54 Town of West Bend
55 Town of Yorkville
56 Village of Adell
57 Village of Bayside
58 Village of Brown Deer
59 Village of Butler
60 Village of Caledonia
61 Village of Campbellsport
62 Village of Cascade
63 Village of Eden
64 Village of Elm Grove
65 Village of Fox Point
66 Village of Fredonia
67 Village of Germantown
68 Village of Grafton
69 Village of Greendale
70 Village of Hales Corners
71 Village of Jackson
72 Village of Kewaskum
73 Village of Lomira
74 Village of Menomonee Falls
75 Village of Mt. Pleasant
76 Village of Newburg
77 Village of North Bay
78 Village of Random Lake
79 Village of River Hills
80 Village of Saukville
81 Village of Shorewood
82 Village of Slinger
83 Village of Sturtevant
84 Village of Thiensville
85 Village of Union Grove
86 Village of West Milwaukee
87 Village of Whitefish Bay
88 Village of Wind Point

NOTE: MAP REFLECTS YEAR 2000 CORPORATE LIMITS. THE TOWNS OF CALEDONIA AND MOUNT PLEASANT INCORPORATED TO VILLAGES IN THE YEAR 2005 AND 2003 RESPECTIVELY.

Source: SEWRPC.

Table 1

AREAL EXTENT OF COUNTIES, CITIES, VILLAGES, AND TOWNS IN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA: 2000

Civil Division	Area (square miles)	Percent of Total
Dodge County		
Village of Lomira	0.2	0.02
Town of Lomira	4.4	0.39
Subtotal	4.6	0.41
Fond du Lac County		
Village of Campbellsport	1.1	0.10
Village of Eden	0.1	0.01
Town of Ashford	28.9	2.56
Town of Auburn	35.8	3.18
Town of Byron	8.9	0.79
Town of Eden	29.7	2.63
Town of Empire	<0.1	<0.01
Town of Forest	0.8	0.07
Town of Osceola	33.5	2.97
Subtotal	138.8	12.31
Kenosha County		
Town of Paris	2.8	0.25
Subtotal	2.8	0.25
Milwaukee County		
City of Cudahy	4.8	0.43
City of Franklin	34.2	3.04
City of Glendale	6.0	0.53
City of Greenfield	11.5	1.02
City of Milwaukee	96.7	8.58
City of Oak Creek	28.5	2.53
City of South Milwaukee	4.9	0.44
City of St. Francis	2.6	0.23
City of Wauwatosa	13.2	1.17
City of West Allis	11.4	1.01
Village of Bayside	2.3	0.20
Village of Brown Deer	4.4	0.39
Village of Fox Point	2.9	0.26
Village of Greendale	5.6	0.50
Village of Hales Corners	3.2	0.28
Village of River Hills	5.3	0.42
Village of Shorewood	1.6	0.14
Village of West Milwaukee	1.1	0.10
Village of Whitefish Bay	2.1	0.19
Subtotal	242.3	21.46
Ozaukee County		
City of Cedarburg	3.7	0.33
City of Mequon	47.0	4.17
City of Port Washington	0.1	0.01
Village of Bayside	0.1	0.01
Village of Fredonia	1.3	0.12
Village of Grafton	4.1	0.36
Village of Newburg	0.1	0.01
Village of Saukville	2.9	0.26
Village of Thiensville	1.1	0.10

Table 1 (continued)

Civil Division	Area (square miles)	Percent of Total
Ozaukee County (continued)		
Town of Cedarburg	26.0	2.31
Town of Fredonia	28.1	2.49
Town of Grafton	19.5	1.73
Town of Port Washington	2.6	0.23
Town of Saukville	33.4	2.96
Subtotal	170.0	15.09
Racine County		
City of Racine	10.6	0.94
Village of Caledonia	45.6	4.05
Village of Mt. Pleasant	13.5	1.20
Village of North Bay	0.1	0.01
Village of Sturtevant	0.2	0.02
Village of Union Grove	0.7	0.06
Village of Wind Point	1.3	0.12
Town of Dover	2.6	0.23
Town of Norway	0.1	0.01
Town of Raymond	34.0	3.02
Town of Yorkville	29.9	2.65
Subtotal	138.6	12.31
Sheboygan County		
Village of Adell	0.6	0.05
Village of Cascade	0.8	0.07
Village of Random Lake	1.7	0.15
Town of Greenbush	3.7	0.33
Town of Holland	0.5	0.04
Town of Lyndon	12.6	1.12
Town of Mitchell	33.5	2.97
Town of Scott	36.5	3.24
Town of Sherman	32.6	2.90
Subtotal	122.5	10.87
Washington County		
City of Milwaukee	>0.1	>0.01
City of West Bend	12.6	1.12
Village of Germantown	34.4	3.05
Village of Jackson	2.5	0.22
Village of Kewaskum	1.4	0.12
Village of Newburg	0.8	0.07
Village of Slinger	0.3	0.03
Town of Addison	0.2	0.02
Town of Barton	18.0	1.60
Town of Farmington	36.8	3.26
Town of Germantown	1.8	0.16
Town of Jackson	34.2	3.03
Town of Kewaskum	22.9	2.03
Town of Polk	24.2	2.15
Town of Richfield	7.2	0.64
Town of Trenton	33.5	2.97
Town of Wayne	9.1	0.81
Town of West Bend	17.2	1.53
Subtotal	257.1	22.81

Table 1 (continued)

Civil Division	Area (square miles)	Percent of Total
Waukesha County		
City of Brookfield	13.5	1.20
City of Milwaukee	0.1	0.01
City of Muskego	3.9	0.35
City of New Berlin	9.9	0.88
Village of Butler	0.8	0.07
Village of Elm Grove	3.3	0.29
Village of Menomonee Falls	18.5	1.64
Town of Brookfield	0.2	0.02
Town of Lisbon	0.3	0.03
Subtotal	50.5	4.49
Total	1,127.2	100.00

NOTE: The Town of Mt. Pleasant incorporated as a Village in 2003, and the Town of Caledonia incorporated as a Village in 2005.

Source: SEWRPC.

aeration, diversion, nutrient removal or inactivation, dredging, sediment covering, and drawdown, 4) construction and operation of water-level-control structures, 5) control of nonpoint source pollution, and 6) creation, operation, and maintenance of a water safety patrol unit.

Other Agencies with Resource-Management Responsibilities Related to Water Quality

Superimposed upon these local and special-purpose units of government are those State and Federal agencies with important responsibilities for water quality management and resource conservation and management. These include the WDNR; the University of Wisconsin-Extension; the State Board of Soil and Water Conservation Districts; the U.S. Department of the Interior, U.S. Geological Survey; the USEPA; the U.S. Department of Agriculture, Natural Resources Conservation Service; and the U.S. Army Corps of Engineers.

LAND USE

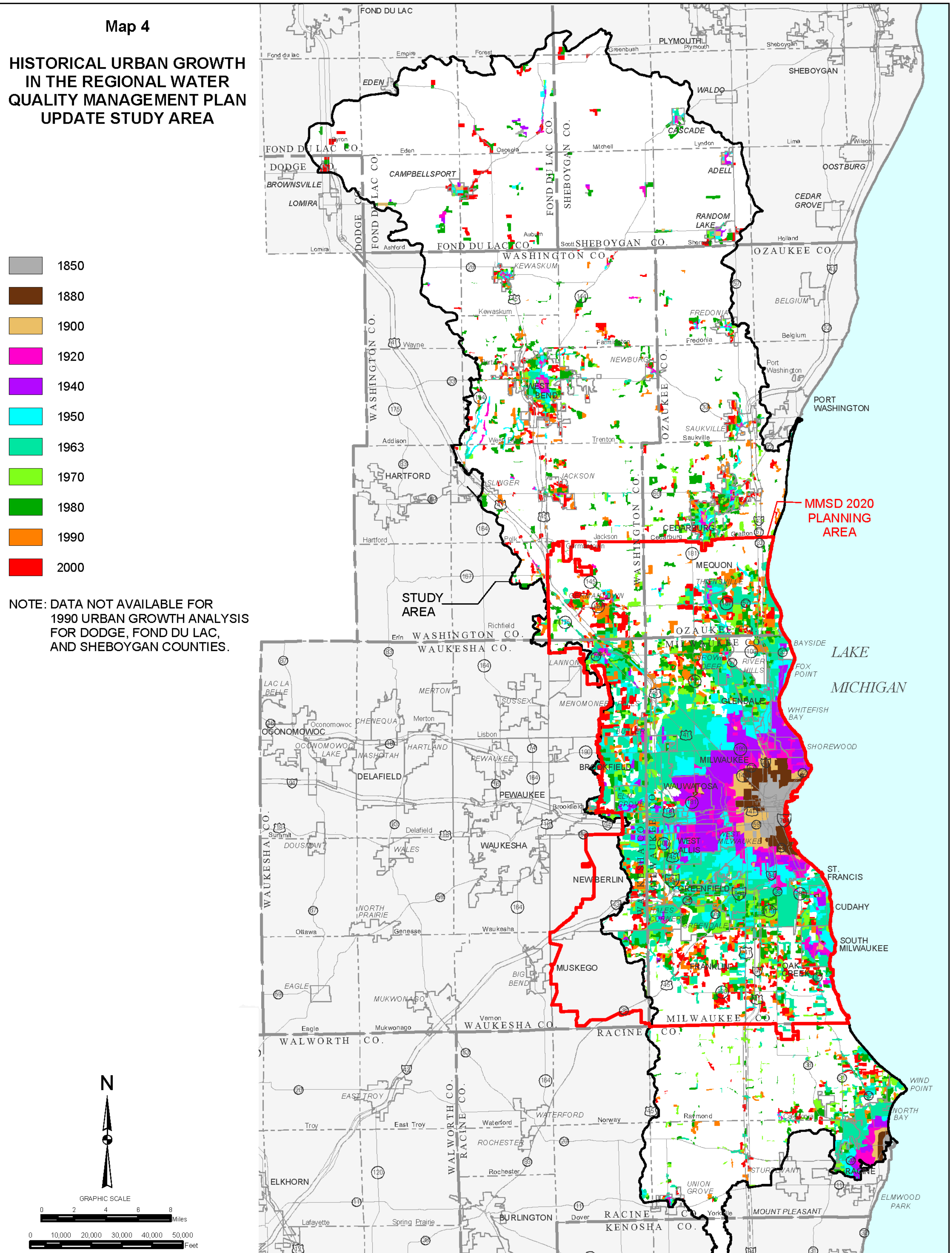
An important concept underlying the watershed planning effort is that land use development should be planned considering the ability of the underlying natural resource base to sustain such development. The type, intensity, and spatial distribution of land uses determine, to a large extent, the resource demands within a watershed. Water-resource demands can be correlated directly with the quantity and type of land use, as can water quality conditions. The existing land use pattern can best be understood within the context of its historical development. Thus, attention is focused here on historical, as well as existing, land use development.

Historical Growth Patterns

The movement of European settlers into the Southeastern Wisconsin Region began around 1830. Completion of the U.S. Public Land Survey in the Region in 1836 and the subsequent sale of public lands in Wisconsin brought an influx of settlers into the area. In 1850, the urban portions of the regional water quality management plan update study area was located at Cedarburg, Grafton, Milwaukee, Racine, and West Bend, along with many smaller settlements throughout the study area. Over the 100-year period from 1850 to 1950, urban development in the study area occurred in a pattern resembling concentric rings around existing urban centers, resulting in a relatively compact settlement pattern. After 1950, there was a significant change in the pattern and rate of urban development in the study area. While substantial amounts of development continued to occur adjacent to established urban centers, considerable development also occurred in isolated enclaves in outlying areas of the study area. Map 4 indicates a continuation of this trend during the 1990s, with significant development occurring adjacent to existing urban centers, but also with considerable development continuing to occur in scattered fashion in outlying areas. In Milwaukee and Waukesha Counties in the central portion of the study area, new

Map 4

HISTORICAL URBAN GROWTH IN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA



Source: SEWRPC.

urban development consists primarily of in-fill, which is the development of the last remaining lots and small subdivisions in an existing developed area, as well as redevelopment.

Table 2 summarizes the historic urban growth pattern in the study area for the period 1850 to 2000. The rate at which urban growth occurred in the study area increased gradually until 1940. After 1940, the rate of urban growth increased substantially, reaching a maximum average rate of approximately 4,500 acres converted to urban uses per year during the period 1950 to 1963. Since 1963, the average rate of urban growth in the study area has declined from this peak.

Land Use

The existing land use pattern within the study area is shown on Map 5, and the existing land uses are quantified by watershed in Table 3.

As indicated in Table 3, about 486,000 acres, or about 67 percent of the total study area, was still in rural uses in 2000, with agriculture and related open uses occupying about 304,000 acres, or about 42 percent of the total study area. In 2000, urban land uses occupied about 235,000 acres, or about 33 percent of the total study area. Residential land use accounted for over 113,000 acres, or about 16 percent of the total study area. Also of significance is the transportation, communication, and utilities land use category, which accounted for about 67,000 acres, or about 9 percent of the total study area.

Table 4 shows land use in those portions of the study area within the Southeastern Wisconsin Region for the years 1970, 1990, and 2000. During the period from 1970 to 2000, the amount of land devoted to agricultural and related uses declined from about 420 square miles to about 317 square miles. Much of this decrease resulted from the conversion of land from agricultural and related uses to urban uses. Over the same time period, the amount of land in urban land uses increased from about 259 square miles to about 347 square miles. In addition, the area represented by surface water increased from 10.1 square miles in 1970 to 11.5 square miles in 2000. This change represents the net effect of a number of changes, including refinements in watershed boundaries, changes in the water levels in inland lakes and ponds, and the construction of stormwater detention and infiltration basins. Over the same time period, the area represented by wetlands increased from 73.6 square miles to 78.2 square miles. This change represents the net effect of a number of changes, including reversion of prior-converted agricultural lands back to wetland, the creation or restoration of some wetlands, and the delineation of previously unidentified wetlands. The total area of the portion of the study area in the Region increased slightly by 0.5 square mile from 1970 to 2000. This increase represents the combined effects of refinements of watershed boundaries and the net effect of erosion and aggradation of land along the shore of Lake Michigan.

SURFACE WATER AND GROUNDWATER RESOURCES

Surface water resources, lakes and streams and their associated floodlands, form the most important element of the natural resource base of the regional water quality management plan update study area. Their contribution to the economic development, recreational activity, and aesthetic quality of the watersheds is immeasurable. Lake Michigan is a major source of water for domestic, municipal, and industrial users in the Greater Milwaukee watersheds. Understanding the interaction of the surface water and groundwater resources is essential to sound water resource planning. Surface water and groundwater are interrelated components of the hydrologic system.[5] Accordingly, both these elements of the hydrologic system are described herein. The groundwater resources of the watersheds are hydraulically connected to the surface water resources inasmuch as the former provide the base flow of streams. The groundwater resources constitute the major source of supply for domestic, municipal, and industrial water users located in the northern portion of the study area and those resources are discussed below.

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[5]*Thomas C. Winter, Judson W. Harvey, O. Lehn Franke, William M. Alley,* Ground water and surface water; a single resource*, USGS Circular 1139.*

Table 2

EXTENT OF URBAN GROWTH WITHIN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA: 1850-2000

Year	Extent of New Urban Development Occurring Since Previous Year (acres)[a]	Cumulative Extent of Urban Development (acres)[a]	Cumulative Extent of Urban Development (percent)[a]
1850	4,617	4,617	0.6
1880	5,063	9,680	1.3
1900	4,479	14,159	2.0
1920	11,101	25,260	3.5
1940	18,331	43,591	6.0
1950	21,651	65,242	9.0
1963	57,944	123,186	17.1
1970	18,966	142,152	19.7
1980	15,360	168,494	23.4
2000	10,177	202,632	28.1

[a]*Urban development, as defined for the purposes of this table, includes those areas within which houses or other buildings have been constructed in relatively compact groups, thereby indicating a concentration of urban land uses. Scattered residential developments were not considered in this analysis. The quantification of urban lands set forth in Table 3 includes scattered urban development.*

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

Lakes and Ponds

There are more than 120 named lakes and ponds greater than two acres in area within the regional water quality management plan update study area, of which 21 lakes are greater than 50 acres in area and are capable of supporting a variety of recreational uses.[6] The total surface area of these 21 lakes is 3,438 acres, or less than 1 percent of the total study area. More than 75 percent of the 3,438 acres is comprised of nine lakes all greater than 100 acres in size that include: Silver, Big Cedar, and Little Cedar Lakes in Washington County; Auburn, Kettle Moraine, and Long Lakes in Fond du Lac County; Mud Lake in Ozaukee County; and Ellen and Random Lakes in Sheboygan County. Ponds and other surface waters are present in relatively smaller proportions, totaling less than 200 acres in area throughout the study area. These lakes and smaller bodies of water provide residents of the regional water quality management plan update study area and persons from outside the study area with a variety of aesthetic and recreational opportunities and also serve to stimulate the local economy by attracting recreational users.

Rivers and Streams

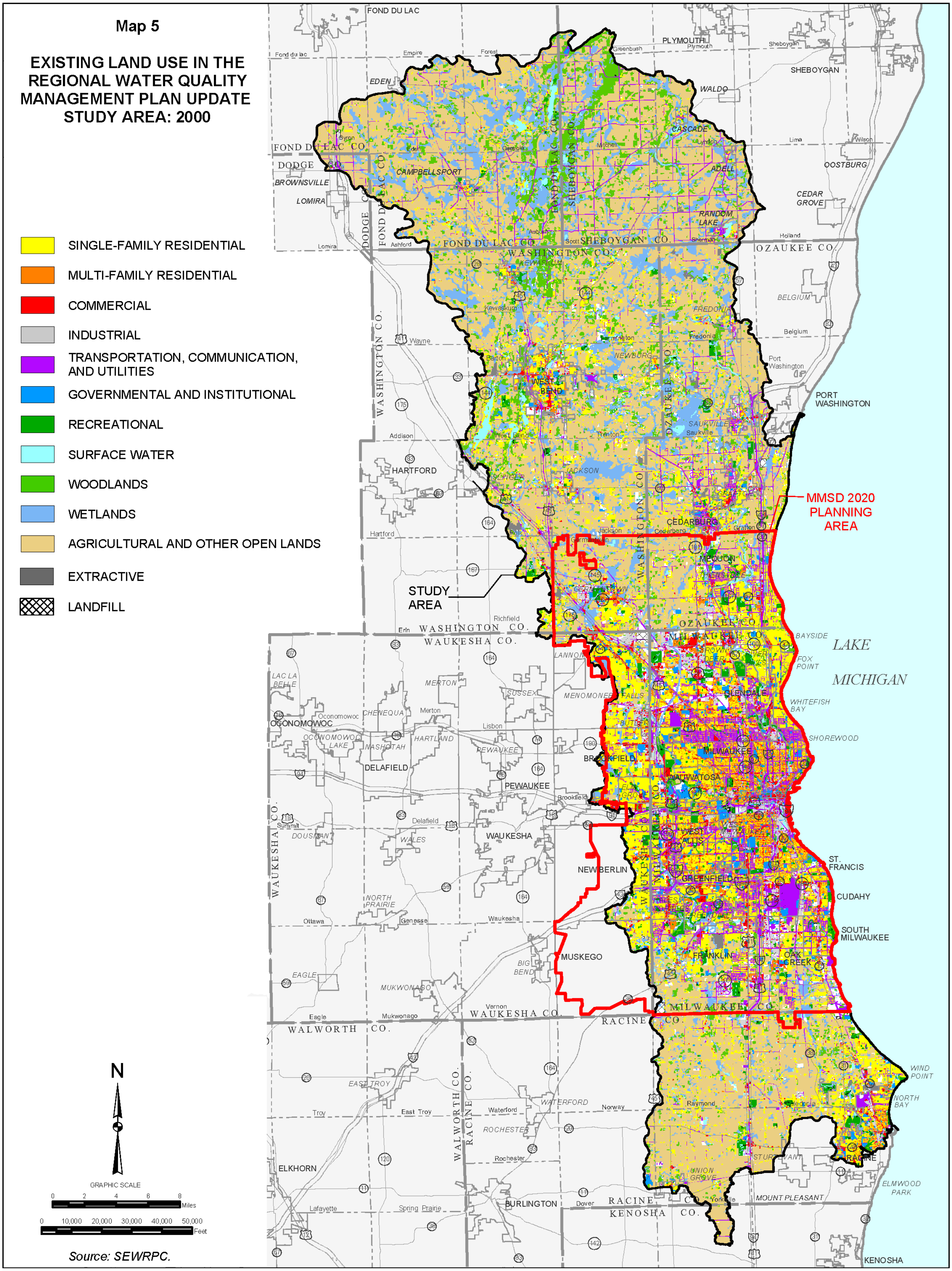
Water from rainfall and snowmelt flows into stream systems by one of two pathways; either directly flowing overland as surface water runoff or infiltrating into the soil surface and eventually flowing underground into streams as groundwater. Ephemeral streams generally flow only during the wet season. Streams that flow year-round are called perennial streams and are primarily sustained by groundwater during dry periods. The surface water drainage systems and the 1,010 miles of mapped streams are shown on Map 6 on a study area basis. More-detailed mapping and information on the stream system is presented in Chapters V through X of this report.

Viewed from above, the network of water channels that form a river system displays a branchlike pattern as shown in Figure 1. A stream channel that flows into a larger channel is called a tributary of that channel. The

[6]*Wisconsin Department of Natural Resources Publication No. PUBL WT 704-2001,* State of the Milwaukee River Basin*, August 2001; Wisconsin Department of Natural Resources Publication No. PUBL WT-700-2002,* State of the Root-Pike River Basin*, May 2002.*

Map 5

EXISTING LAND USE IN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA: 2000



Source: SEWRPC.

Table 3

EXISTING LAND USE IN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA: 2000[a,b]

Category	Watershed												Total	
	Lake Michigan Direct Drainage		Kinnickinnic River		Menomonee River		Milwaukee River		Oak Creek		Root River			
	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total	Acres	Percent of Total
Urban														
Residential	9,322	35.6	5,741	34.7	25,928	29.8	45,848	10.2	4,599	25.5	22,215	17.6	113,384	15.7
Commercial	520	2.0	913	5.8	3,510	4.0	4,045	0.9	638	3.5	1,812	1.4	11,438	1.6
Industrial	844	3.2	1,154	7.3	4,417	5.1	5,688	1.3	865	4.8	1,639	1.3	14,608	2.0
Transportation, Communication, and Utilities[c]	4,519	17.3	5,175	32.8	14,546	16.8	28,504	6.4	3,516	19.5	10,645	8.4	66,904	9.3
Governmental and Institutional	971	3.7	1,201	7.6	3,647	4.2	4,415	0.9	652	3.6	1,956	1.5	12,841	1.8
Recreational	1,200	4.6	646	4.1	3,409	3.9	6,593	1.5	555	3.1	3,361	2.7	15,763	2.2
Subtotal	17,376	66.4	14,560	92.3	55,457	63.8	95,093	21.2	10,825	60.0	41,628	32.9	234,938	32.6
Rural														
Agricultural and Related	2,801	10.7	70	0.4	14,978	17.3	219,168	48.9	2,919	16.2	64,012	50.6	303,948	42.1
Water	127	0.5	153	1.0	542	0.6	7,715	1.7	28	0.2	1,017	0.8	9,583	1.3
Wetlands	415	1.6	57	0.3	6,741	7.8	67,110	15.0	920	5.1	6,793	5.4	82,036	11.4
Woodlands	1,464	5.6	92	0.6	2,110	2.4	39,836	8.9	760	4.2	4,936	3.9	49,199	6.8
Landfill, Extractive, Unused, and Other Open Land	3,983	15.2	847	5.4	7,062	8.1	19,080	4.3	2,587	14.3	8,104	6.4	41,662	5.8
Subtotal	8,790	33.6	1,219	7.7	31,433	36.2	352,909	78.8	7,214	40.0	84,862	67.1	486,428	67.4
Total	26,166	100.0	15,779	100.0	86,890	100.0	444,802	100.0	18,039	100.0	126,490	100.0	721,366	100.0

[a]*As approximated by whole U.S. Public Land Survey one-quarter sections.*

[b]*As part of the regional land use inventory for the year 2000, the delineation of existing land use was referenced to real property boundary information not available for prior inventories. This change increases the precision of the land use inventory and makes it more usable to public agencies and private interests throughout the Region. As a result of this change, however, year 2000 land use inventory data are not strictly comparable with data from the 1990 and prior inventories. At the watershed and study area level, the most significant effect of the change is to increase the transportation, communication, and utilities categories, as a result of the use of narrower estimated right-of-ways in prior inventories. The treatment of streets and highways generally diminishes the area of adjacent land uses traversed by those streets and highways in the 2000 land use inventory relative to prior inventories.*

[c]*Off-street parking of more than 10 spaces is included with the associated land use.*

Source: SEWRPC.

Table 4

LAND USE IN THE SOUTHEASTERN WISCONSIN PORTION OF THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA : 1970-2000[a,b,c]

Category	1970		1990		2000[c]		Change 1970-2000	
	Square Miles	Percent of Total	Square Miles	Percent of Total	Square Miles	Percent of Total	Square Miles	Percent of Total
Urban								
Residential	123.5	14.4	152.4	17.7	169.0	19.7	45.5	36.8
Commercial	9.7	1.1	15.2	1.8	17.6	2.0	7.9	81.4
Industrial	14.7	1.7	18.5	2.1	21.6	2.5	6.9	46.9
Transportation, Communication, and Utilities[c]	77.1	9.0	84.8	9.9	96.0	11.2	18.9	24.5
Governmental and Institutional	17.1	2.0	18.7	2.2	19.4	2.2	2.3	13.5
Recreational	17.3	2.0	20.7	2.4	23.7	2.8	6.4	37.0
Subtotal	259.4	30.2	310.3	36.1	347.3	40.4	87.9	33.9
Rural								
Agricultural and Related	419.8	48.8	362.2	42.1	317.2	36.9	-102.6	-24.4
Water	10.1	1.2	11.2	1.3	11.5	1.3	1.4	13.9
Wetlands	73.6	8.6	75.6	8.8	78.2	9.1	4.6	6.2
Woodlands	42.2	4.9	43.4	5.1	43.6	5.1	1.4	3.3
Land, Extractive, Unused, and Other Open Lands	54.4	6.3	57.0	6.6	62.2	7.2	7.8	14.3
Subtotal	600.1	69.8	549.4	63.9	512.7	59.6	-87.4	-14.6
Total	859.5	100.0	859.7	100.0	860.0	100.0	0.5	- -

[a]As approximated by whole U.S. Public Land Survey one-quarter sections.

[b]As part of the regional land use inventory for the year 2000, the delineation of existing land use was referenced to real property boundary information not available for prior inventories. This change increases the precision of the land use inventory and makes it more usable to public agencies and private interests throughout the Region. As a result of the change, however, year 2000 land use inventory data are not strictly comparable with data from the 1990 and prior inventories. At the county and regional level, the most significant effect of the change is to increase the transportation, communication, and utilities category, as a result of the use of narrower estimated right-of-ways in prior inventories. The treatment of streets and highways generally diminishes the area of adjacent land uses traversed by those streets and highways in the 2000 land use inventory relative to prior inventories.

[c]Because data are unavailable for Dodge, Fond du Lac, and Sheboygan Counties for 1970 and 1990, these data include only those portions of the study area that are within the Southeastern Wisconsin Region.

[d]Off-street parking of more than 10 spaces are included with the associated land use.

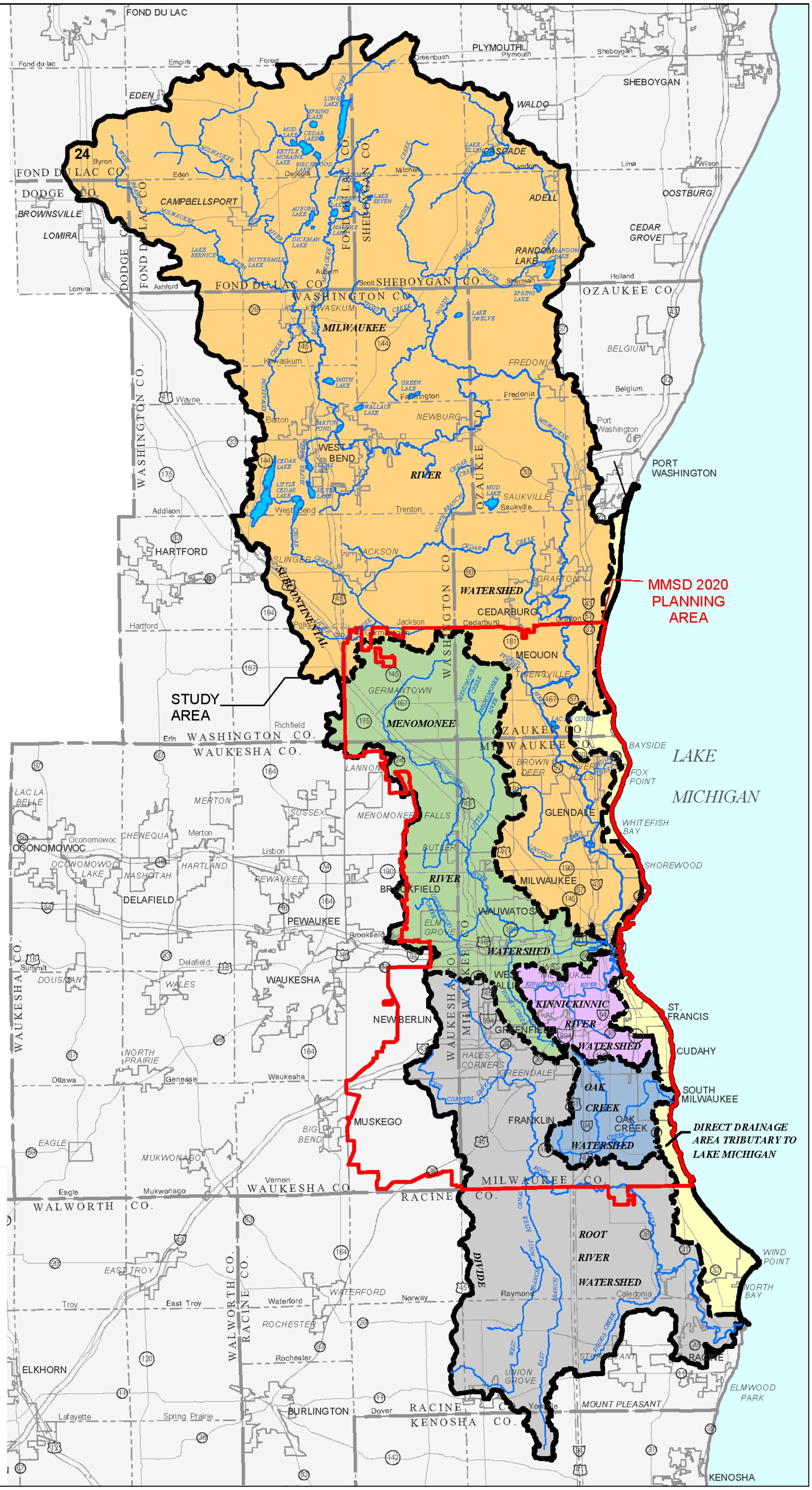
Source: SEWRPC.

entire area drained by a single river system is termed a drainage basin, or watershed. Stream size increases downstream as more and more tributary segments enter the main channel. A classification system based on the position of a stream within the network of tributaries, called stream order, was developed by Robert E. Horton and later modified by Arthur Strahler. In general, the lower stream order numbers correspond to the smallest headwater tributaries and are shown as the Order 1, or first-order, streams in Figure 1. Second-order streams (Order 2) are those that have only first-order streams as tributaries, and so on (Figure 1). As water travels from headwater streams toward the mouth of larger rivers, streams gradually increase their width and depth and the amount of water they discharge also increases. Over 80 percent of the total length of rivers and streams worldwide are headwater streams (first- and second-order), which is also the case in terms of the watersheds within the regional water quality management plan update study area.

To better understand stream systems and what shapes their conditions, it is important to understand the effects of both spatial and temporal scales. Streams can be theoretically subdivided into a continuum of habitat sensitivity to

Map 6

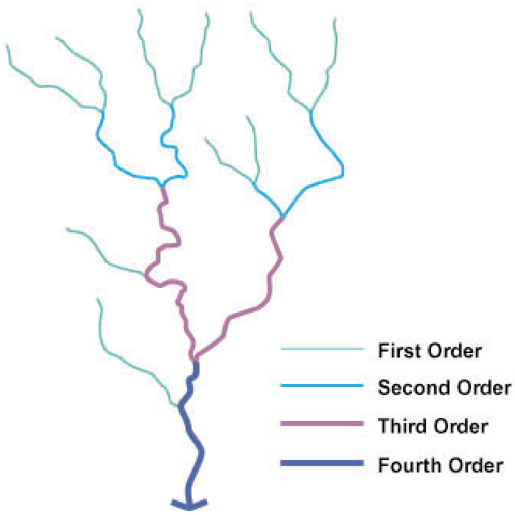
SURFACE DRAINAGE AND SURFACE WATER IN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA



Source: SEWRPC.

Figure 1

TYPICAL STREAM NETWORK PATTERNS BASED ON HORTON'S CLASSIFICATION SYSTEM



Source: Oliver S. Owen and others, Natural Resource Conservation: Management for a Sustainable Future.

disturbance and recovery time as shown conceptually in Figure 2.[7] Microhabitats, such as a handful-sized patch of gravel, are most susceptible to disturbance and river systems and watersheds, or drainage basins, are least susceptible. Furthermore, events that affect smaller-scale habitat characteristics may not affect larger-scale system characteristics, whereas large disturbances can directly influence smaller-scale features of streams. For example, on a small spatial scale, deposition at one habitat site may be accompanied by scouring at another site nearby, and the reach or segment does not appear to change significantly. In contrast, a large-scale disturbance, such as a debris flood, is initiated at the segment level and reflected in all lower levels of the hierarchy (reach, habitat, microhabitat). Similarly, on a temporal scale, siltation of microhabitats may disturb the biotic community over the short term. However, if the disturbance is of limited scope and intensity, the system may recover quickly to pre-disturbance levels.[8] In contrast, extensive or prolonged disturbances, such as the stream channelization practices of ditching and tile drainage, have resulted in longer-term impacts throughout the study area.

The most important fundamental aspects of stream systems are that 1) the entire fluvial system is a continuously integrated series of physical gradients in which the downstream areas are longitudinally linked and dependent upon the upstream areas and 2) that streams are intimately connected to their adjacent terrestrial setting, in other words the land-stream interaction is crucial to the operation of stream ecosystem processes. In this regard, land uses have a significant impact on stream channel conditions and associated biological responses.[9]

Groundwater Resources

Groundwater is a key element of the natural resource base that not only sustains lake levels and wetlands and provides the base flows of streams in the study area, but also comprises the major source of water supply in the northern portion of the study area.

Groundwater occurs within three major aquifers that underlie the study area. From the land's surface downward, they are: 1) the sand and gravel deposits in the glacial drift; 2) the shallow dolomite strata in the underlying

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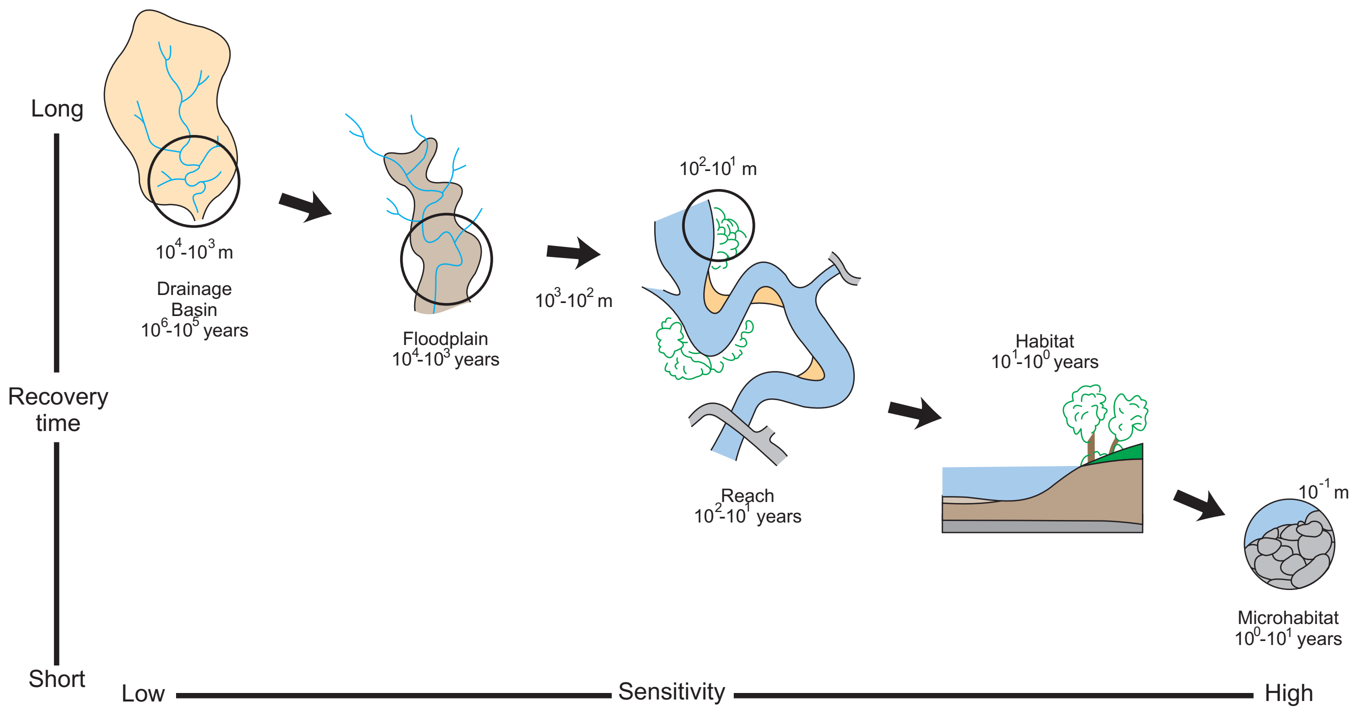
[7]*C.A. Frissell and others, "A Hierarchical Framework for Stream Classification: Viewing Streams in a Watershed Context,"* Environmental Management*, Volume 10, pages 199-214, 1986.*

[8]*G.J. Niemi and others, "An Overview of Case Studies on Recovery of Aquatic Systems From Disturbance,"* Journal of Environmental Management*, Volume 14, pages 571-587, 1990.*

[9]*Lizhu Wang and others, "Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams,"* Fisheries*, Volume 22, No. 6, June 1997; Jana S. Stewart and others, "Influences of Watershed, Riparian-Corridor, and Reach-Scale Characteristics on Aquatic Biota in Agricultural Watersheds,"* Journal of the American Water Resources Association*, Volume 37, No. 6, December 2001; Faith A. Fitzpatrick and others, "Effects of Multi-Scale Environmental Characteristics on Agricultural Stream Biota in Eastern Wisconsin,"* Journal of the American Water Resources Association*, Volume 37, No. 6, December 2001.*

Figure 2

RELATION BETWEEN RECOVERY TIME AND SENSITIVITY TO DISTURBANCE FOR DIFFERENT HIERARCHICAL SPATIAL SCALES ASSOCIATED WITH STREAM SYSTEMS



Source: *C.A. Frissell and others,": A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context,"* Environmental Management*, Vol. 10.*

bedrock; and 3) the deeper sandstone, dolomite, siltstone, and shale strata. Because of their proximity to the land's surface and hydraulic interconnection, the first two aquifers are commonly referred to collectively as the "shallow aquifer," while the latter is referred to as the deep aquifer. Within the study area, the shallow and deep aquifers are separated by the Maquoketa shale, which forms a relatively impermeable barrier between the two aquifers (Figure 3).

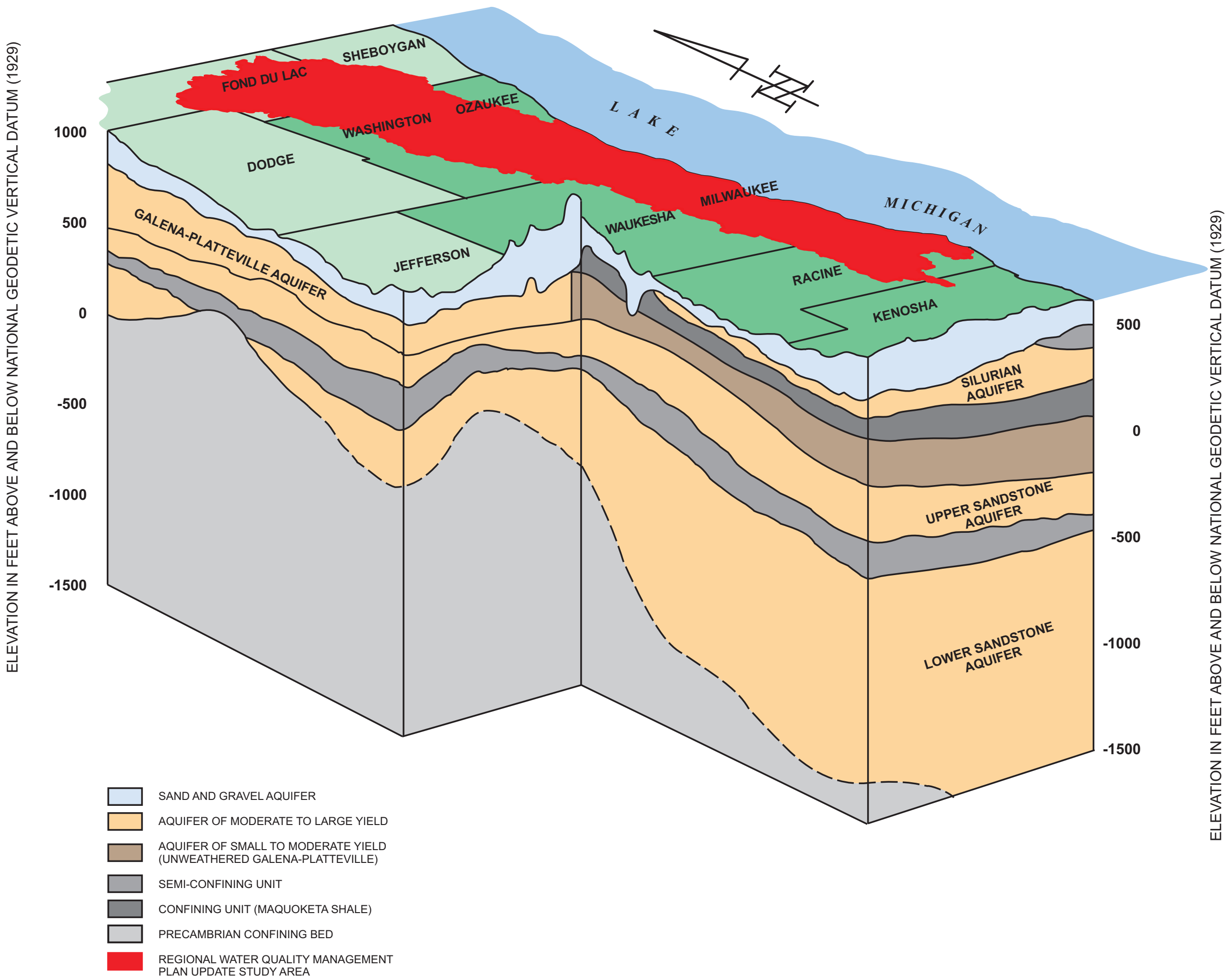
Recharge to the sand-and-gravel aquifer occurs primarily through infiltration of precipitation that falls on the land surface directly overlying the aquifer. Within the study area, the rate of recharge to the sand-and-gravel aquifer varies depending on the permeability of the overlying glacial till.

Recharge to the Silurian aquifer occurs primarily through infiltration of precipitation that seeps through the glacial drift above the aquifer. As with the sand-and-gravel aquifer, the rate of recharge varies with the permeability of the glacial drift. Some additional recharge to the Silurian aquifer occurs as lateral subsurface inflow from the west.

Recharge to the sandstone aquifer, located in the Cambrian and Ordovician strata, occurs in the following three ways: 1) seepage through the relatively impermeable Maquoketa shale; 2) subsurface inflow from natural recharge areas located to the west in Waukesha, Jefferson, and Dodge Counties; and 3) seepage from wells that are hydraulically connected to both the Niagara and the sandstone aquifers. Although the natural gradient of groundwater movement within the sandstone aquifer is from west to east, concentrated pumping which has occurred over the years has reversed the gradient so that groundwater now flows from the east toward a cone of depression located in the vicinity of the Milwaukee-Waukesha County line in the southern portion of the study area.

Figure 3

AQUIFER SYSTEMS IN SOUTHEASTERN WISCONSIN



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

Like surface water, groundwater is susceptible to depletion in quantity and to deterioration in quality as a result of urban and rural development. Consequently, water quality management planning must appropriately consider the potential impacts of urban and rural development on this important resource. Water quality management and land use planning must also take into account, as appropriate, natural conditions which may limit the use of groundwater as a source of water supply, including the relatively high levels of naturally occurring radium in groundwater in the deep sandstone aquifer, found in certain areas of the Region. Other considerations which may limit the uses of groundwater include decreasing aquifer levels and increasing concentrations of dissolved solids and other constituents.

Springs are areas of concentrated discharge of groundwater at the land surface. Alone, or in conjunction with numerous smaller seeps, they may provide the source of base flow for streams and serve as a source of water for lakes, ponds, and wetlands. Conversely, under certain conditions, streams, lakes, ponds, and wetlands may be sources of recharge that create springs. The magnitude of discharge from a spring is a function of several factors, including the amount of precipitation falling on the land surface, the occurrence and extent of recharge areas of relatively high permeability, and the existence of geologic and topographical conditions favorable to discharge of groundwater to the land surface.

SEWRPC, working with the U.S. Geological Survey, the Wisconsin Geological and Natural History Survey, the University of Wisconsin-Milwaukee, and the WDNR, recently completed two major groundwater studies for the Region that will be important resources for regional and local planning. These studies include a regional groundwater inventory and analysis and the development of a regional groundwater aquifer simulation model. The groundwater inventory and analysis findings are presented in SEWRPC Technical Report No. 37, *Groundwater Resources of Southeastern Wisconsin*. The aquifer simulation model will be documented in a SEWRPC technical report to be published in 2005.

REGIONAL WATER QUALITY MANAGEMENT PLAN

SEWRPC is, pursuant to State legislation, the official planning agency for the seven-county Southeastern Wisconsin Region. The Commission is charged by law with the duty of preparing and adopting a comprehensive plan for the development of the Region. SEWRPC is also the State-designated and Federally recognized areawide water quality management planning agency for Southeastern Wisconsin.

Pursuant to the provisions of section 208 of the Federal Clean Water Act, the Commission prepared and adopted an areawide water quality management plan for the Southeastern Wisconsin Region in 1979.[10] That plan was subsequently adopted by the Wisconsin Natural Resources Board and approved by the USEPA. That plan provided the necessary framework for the preparation and adoption of the 1980 MMSD facilities plan. Although certain elements of the areawide plan have been updated since 1979, and although many key recommendations of that plan have been implemented, the plan has now been updated to provide a needed framework for the preparation of the new MMSD facilities plan.

The previously cited initial regional water quality management plan was designed, in part, to meet the Congressional mandate that the waters of the United States be made to the extent practicable "fishable and swimmable." In accordance with the requirements of Section 208 of the Federal Clean Water Act, the plan provides recommendations for the control of water pollution from such point sources as sewage treatment plants, points of separate and combined sewer overflow, and industrial waste outfalls and from such nonpoint sources as urban and rural stormwater runoff.

An important amendment to the regional water quality management plan, adopted in 1987, addressed water quality issues in the Milwaukee Harbor estuary.[11] The estuary plan set forth recommendations to abate water pollution from combined sewer overflows, including a determination of the level of protection to be provided by such abatement, and from other point and nonpoint sources of pollution in the tributary watersheds, including recommendations for instream measures, that might be needed to achieve established water use objectives.

Since completion of the initial regional water quality management plan, SEWRPC and the WDNR have cooperatively conducted a continuing water quality management planning effort. That effort has been severely limited by fiscal constraints, however, with work confined largely to sanitary sewer service area planning, groundwater inventories and analyses, and selected plan implementation activities.

In 1995, SEWRPC completed a report documenting the implementation status of the regional water quality management plan as amended over the approximately first 15 years since the initial adoption of the plan. This

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[10]*SEWRPC Planning Report No. 30,* op. cit.

[11]*SEWRPC Planning Report No. 37,* A Water Resources Management Plan for the Milwaukee Harbor Estuary, *Volume 1,* Inventory Findings, *March 1987; Volume Two,* Alternative and Recommended Plans, *December 1987.*

report, SEWRPC Memorandum Report No. 93, *A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report*, March 1995, provides a comprehensive restatement of the regional water quality management plan as amended. The plan status report reflects implementation actions taken and plan amendments adopted since the initial plan was completed. The status report also documents, as available data permitted, the extent of progress which had been made toward meeting the water use objectives and supporting water quality standards set forth in the regional water quality management plan.

All of the regional water quality management planning efforts were conducted using the watershed as the primary planning unit. In addition to providing clear and concise recommendations for the control of water pollution, the adopted areawide plan provides the basis for the continued eligibility of local units of government for Federal and State grants and loans in partial support of sewerage system development and redevelopment, for the issuance of waste discharge permits by the WDNR, for the review and approval of public sanitary sewer extensions by that Department, and for the review and approval of private sanitary sewer extensions and large onsite sewage disposal systems and holding tanks by the Wisconsin Department of Commerce. The WDNR also permits large farm animal operations. However, these permits are not directly related to the regional water quality plan recommendations.

WISCONSIN DEPARTMENT OF NATURAL RESOURCES BASIN PLANNING

The WDNR conducts program management and planning for the Milwaukee River basin, comprised of the Kinnickinnic, Menomonee, and Milwaukee River watersheds and for the Root-Pike basin, which includes the Root River and Oak Creek watersheds, as well as the Pike River watershed. The Department has prepared state-of-the-basin plans for each basin.[12] These plans include resource management recommendations related to the WDNR programmatic activities, including surface water use objectives (classifications), sewerage system management, and related water resources programs. The regional water quality management plan updating program includes review, coordination, and a specific plan implementation strategy for integrating the current regional planning with the WDNR basin planning.

MILWAUKEE METROPOLITAN SEWERAGE DISTRICT FACILITY PLANNING

The MMSD is a special-purpose unit of government directed by an appointed Commission. The MMSD includes all of Milwaukee County, except the City of South Milwaukee and portions of the City of Franklin. In addition, sewage conveyance and treatment services are provided to portions of Ozaukee, Racine, Washington, and Waukesha Counties. The District, which exists pursuant to the provisions of Section 200.23 of the *Wisconsin Statutes*, has a number of important responsibilities in the area of water resources management, including the provision of floodland management programs for most of the major streams within the District and the collection, transmission, and treatment of domestic, industrial, and other sanitary sewage generated within the District and its contract service areas.

During 2002, the MMSD initiated work on a third-generation sewerage facilities planning effort. This effort is responsive to a court-ordered stipulation requiring the facilities plan to be completed by June 30, 2007, and is consistent with Section 201 of the Federal Clean Water Act. As the facilities planning program was conceptualized, the MMSD proposed to utilize the watershed approach to plan development consistent with evolving USEPA policies. That approach was further defined to be conducted cooperatively with a coordinated and integrated comprehensive regional water quality management planning effort. Such an approach is sound public planning practice, as well as being consistent with the requirements of Section 208 of the Federal Clean Water Act and evolving USEPA facilities planning guidance.

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[12] *Wisconsin Department of Natural Resources Publication No. PUBL WT 704-2001,* op. cit.*; Wisconsin Department of Natural Resources Publication No. PUBL WT-700-2002,* op. cit.

As previously noted, a cooperative approach to carrying out the MMSD facilities planning program and the regional water quality management plan update program has been developed by the WDNR, the MMSD, and the SEWRPC.

PURPOSE OF REPORT

Reliable engineering and planning data available on a uniform, areawide basis are essential to the formulation of watershed water resources management plans. This report documents current objectives and historic and existing conditions to provide a factual basis for updating the regional water quality management plan for the study area described above. To accomplish this, this report documents current water use objectives and supporting standards, describes existing water quality, sediment quality, and biological conditions, documents water quality trends, and identifies factors causing impairments or degradation to water quality. The inventories and analyses contained within this report will serve as a basis for developing elements of the update to the regional water quality management plan, including the point source pollution abatement and nonpoint source pollution abatement elements.

SCHEME OF PRESENTATION

The major findings of the regional water quality management planning study for the greater Milwaukee watersheds, Milwaukee Harbor, estuary, and the associated nearshore portions of Lake Michigan are presented in the planning report that documents the water quality management plan update.[13] This report complements the planning report and sets forth the basic concepts underlying the study and the factual findings of the extensive inventories and analyses conducted under the study. Toward these ends, the remainder of this report has been organized as follows: Chapter II, "Water Quality Definitions and Issues," provides an overview of technical issues related to water quality; Chapter III, "Data Sources and Methods of Analysis," describes the data sources and analytical procedures used to characterize the state of water quality and to evaluate the degree to which water use objectives are being met in the waters of the study area; Chapter IV, "Water Use Objectives and Water Quality Standards," describes the regulatory setting and recommended water use objective and supporting water quality standards for the waters of the study area; Chapters V through X, "Surface Water Quality Conditions and Sources of Pollution," in each of the six watersheds, present inventories and analyses of historic and existing water quality, sediment quality, and biological conditions, inventories of sources of water pollution, and describe riparian corridor conditions for each of the watersheds in the study area and for the Milwaukee Harbor Estuary and adjacent nearshore Lake Michigan Area; Chapter XI, "Groundwater Quality Conditions and Sources of Pollution in the Study Area," presents inventories and analyses for groundwater resources in the study area; and Chapter XII, "Summary and Conclusions," provides a summary of the information presented in this report.

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[13]*SEWRPC Planning Report No. 50,* op. cit.

Chapter II

WATER QUALITY DEFINITIONS AND ISSUES

WATER QUALITY AND POLLUTION: BACKGROUND

The term water quality refers to the physical, chemical, and biological characteristics of surface water and groundwater. Water quality is determined both by the natural environment and by human activities. The uses which can be made of the surface water resource are significantly affected by its quality, and, similarly, each potential use requires a certain level of water quality. Surface water uses may also be affected by the physical characteristics of the channels and by modifications in those characteristics.

Definition of Pollution

Pure water, in a chemical sense, is not known to exist in nature; foreign substances, originating from the natural environment or human activities, will always be present. Water is said to be polluted when those foreign substances are in such a form and so concentrated as to render the water unsuitable for any desired beneficial uses, such as the following: preservation and enhancement of fish and other aquatic life, water-based recreation, public water supply, industrial water and cooling water supply, wastewater disposal, and aesthetic enjoyment. This definition of pollution does not explicitly consider the source of the polluting substance, which may significantly affect the meaning and use of the term. For the purpose of this report, the causes of pollution are considered to be exclusively related to human activities—anthropogenic pollution—and; therefore, the sources are potentially subject to control through alteration of human activities. Examples of potentially polluting discharges to the surface waters that are related to human activities include discharges of treated effluent from municipal and private sewage treatment facilities, discharges from commercial and industrial establishments, and runoff from urban areas and agricultural lands. Substances derived from natural sources that are present in such quantities as to adversely affect certain beneficial water uses—natural pollution—will not be herein defined as pollution, but constitute a natural condition that impairs the usefulness of the water.

Types of Pollution

As defined above, water pollution is the direct result of human activities in the tributary watershed. Water pollution may be classified into one or more of the following eight categories in accordance with the nature of the substance that causes the pollution:

1. Toxic pollution, such as that caused by heavy metals and other inorganic and organic elements or compounds in industrial wastes, domestic sewage, or runoff, some of which may be toxic to humans and to other life.

2. Organic pollution, such as that caused by oxygen-demanding organic compounds—carbonaceous and nitrogenous—in domestic sewage and industrial wastes, which has a high oxygen demand and may deplete the dissolved oxygen content of the water, severely affecting fish and other aquatic life.

3. Nutrient pollution, or eutrophication, such as that caused by an overabundance of plant nutrient elements, such as nitrogen and phosphorus in urban or agricultural runoff and in domestic sewage; this type of pollution may cause unsightly, excessive plant growths which can, alternately, supersaturate the dissolved oxygen supply in a river or lake during the day due to photosynthesis and deplete the oxygen supply in water through respiration at night, and as a result of decay processes.

4. Pathogen or disease-related pollution, such as that caused by the presence of bacteria and viruses in domestic sewage or in runoff, which may transmit water-borne, infectious diseases from one person to another.

5. Thermal pollution, such as that caused by heated discharges, which may adversely affect aquatic flora and fauna.

6. Sediment pollution, such as that caused by erosion resulting from a lack of adequate soil conservation practices in rural areas and a lack of adequate runoff control from construction sites in urban areas. Such pollution results in instream sediment accumulations that have the potential to inhibit aquatic life, interfere with navigation, impede agricultural drainage, and increase flood stages.

7. Radiological pollution, such as that caused by the presence of radioactive substances in sewage or cooling water discharges, which may adversely affect human and animal life.

8. Aesthetic pollution, which may be associated in combination with any of the other forms of pollution, along with floating debris and unsightly accumulations of trash along streambanks and lakeshores.

All of the eight types of water pollution may occur in surface waters. Groundwater pollution is normally limited to toxic, nutrient, pathogen, and radiological pollution. With the exception of thermal and radiological pollution—the high concentrations of radium in the groundwater of the Region are from natural and not anthropogenic sources and, hence, are not defined as pollution in this chapter—all of the above types of pollution are known to occur, or to have occurred, in the watersheds of the Region as documented in the following chapters.

Emerging Pollutants

Over the last three decades, attention to chemical pollutants in water has focused mostly on conventional priority pollutants, such as nutrients, toxic metals, and pesticides. It is important to recognize that these groups of chemicals are not the only ones entering and potentially threatening the integrity of surface waters. Recently, attention has been paid to several groups of chemicals that have been detected in surface waters and that may pose risks to human health or aquatic life.

Pharmaceuticals and Personal Care Products

One large class of chemicals that has recently begun to receive attention consists of pharmaceuticals and active and inert ingredients of personal care products (PPCPs). This class encompasses thousands of substances that are ingested or externally applied, including prescription and over the counter drugs, fragrances, cosmetics, sun-screen agents, diagnostic agents, and nutritional supplements. These compounds are released into surface waters through human activity. Generally, they are excreted or washed off into sewer systems. As shown in Table 5, some may be fully or partially removed by wastewater treatment facilities; however, removal efficiencies can vary greatly by compound and among treatment plants. It is important to recognize that municipal wastewater treatment plants are not designed or engineered to remove these chemicals. In general, the removal efficiencies and the factors affecting the removal efficiencies of most PPCPs by wastewater treatment plants are poorly understood. In addition, in most instances where removal efficiencies have been determined, only the fate of the parent compound has been tracked. Metabolites and transformation products, which may exhibit biological

Table 5

PHARMACEUTICALS AND PERSONAL CARE PRODUCTS IDENTIFIED IN ENVIRONMENTAL SAMPLES OR KNOWN TO HAVE SIGNIFICANT EFFECTS ON AQUATIC ORGANISMS

Compound	Use	Removal Efficiency by WWTP (percent)[a]	Maximum Concentrations Detected (µg/l)[b]			Toxicological Data
			WWTP Influent	WWTP Effluent	Surface Water	
Acetaminophen	Analgesic/anti-inflammatory	High	- -	6.000	- -	*Daphnia* immobilization test EC_{50}[c] = 41-140 mg/l
Acetylsalicylic Acid	Analgesic/anti-inflammatory	81	- -	1.500	0.3400	*Daphnia* immobilization test EC_{50}[c] = 160-1,500 mg/l *Daphnia reproduction* test EC_{50}[c] = 61-68 mg/l
Betaxolol	Antihypertensive, antiglaucoma	80	- -	0.190	0.0280	- -
Bezafibrate	Lipid regulator	27-83	1.20	4.600	3.1000	- -
Biphenylol	Antiseptic, fungicide	High	2.60	- -	- -	- -
Bisoprolol	Antihypertensive	65	- -	0.370	2.9000	- -
Bleomycin	Antineoplastic	- -	- -	0.019	0.0170	- -
Carazolol	Antihypertensive, Antianginal, Antiarrhythmic	66	- -	0.120	0.1100	- -
Carbamazepine	Antiepileptic, Analgesic	7	- -	6.300	1.1000	- -
Chloramiphenol	Antibiotic	- -	- -	0.560	0.0600	- -
4-Chloro-3,5-xylenol	Antiseptic	- -	<0.10	<0.100	- -	- -
Chlorophene	Antiseptic	- -	0.71	- -	- -	- -
Clarithromycin	Antibiotic	- -	- -	0.240	0.0260	- -
Clenbuterol	Bronchiodilator	- -	- -	0.180	0.0500	- -
Clofibrate	Lipid Reguator	- -	- -	- -	- -	Algae growth inhibition tests EC_{10}[c] = 5.4 mg/l, EC_{50}[c] = 12 mg/l *Daphnia* acute toxicity test LC_{10}[d] = 17.7 mg/l, LC_{50}[d] = 28.2 mg/l *Daphnia* reproduction test LC_{10}[d] = 8.4 µg/l, LC_{50}[d] = 106 µg/l
Clofibric Acid	Metabolite of lipid regulators	15-51	2.00	9.700	0.8750	*Daphnia* immobilization test EC_{50}[c] = 106 mg/l Algae growth inhibition test EC_{50}[c] = 89 mg/l
Cyclophosphamide	Antieoplastic	- -	4.50	0.143	- -	- -
Diatrizoate (Na)	X-ray contrast media	- -	- -	- -	100.0000	- -
Diazepam	Psychiatric drug, muscle relaxant	- -	- -	0.040	- -	*Daphnia* immobilization test EC_{50}[c] = 4.3-14.0 mg/l
Diclofenac-Na	Analgesic/anti-inflammatory	9-75	1.80	2.100	1.2000	- -
Dimethylamino-phenazone	Analgesic/anti-inflammatory	38	- -	1.000	0.3400	- -

Table 5 (continued)

Compound	Use	Removal Efficiency by WWTP (percent)[a]	Maximum Concentrations Detected (µg/l)[b]			Toxicological Data
			WWTP Influent	WWTP Effluent	Surface Water	
Erhythromycin-H_2O	Antibiotic	- -	- -	6.000	1.7000	- -
17β-Estradiol	Hormone	64-99	- -	0.048	- -	- -
Estrone	Hormone	67-83	- -	0.076	- -	- -
17-α-Ethinyl estradiol	Oral contraceptive	78	- -	0.007	0.0043	Algae growth inhibition tests EC_{10}[c] = 54 µg/l, EC_{50}[c] = 840 µg/l *Daphnia* reproduction test EC_{10}[c] = 12.5 µg/l, EC_{50}[c] = 105 µg/l *Daphnia* acute toxicity test EC_{10}[c] = 3.2 mg/l, EC_{50}[c] = 5.7 mg/l Fathead Minnow mortality test LOEC[e] = 1 µg/l
Etofibrate	Lipid regulator	- -	- -	- -	- -	- -
Fenfluramine	Diet drug	- -	- -	- -	- -	- -
Fenofibrate	Lipid regulator	High	- -	0.030	0.1000	- -
Fenofibric Acid	Metabolite of fenofibrate	6-69	0.40	1.200	0.3500	- -
Fenoprofen	Analgesic/anti-inflammatory	- -	- -	- -	- -	- -
Fenoterol	Bronchiodilator	- -	- -	0.060	0.0610	- -
Fluoroquinolone carboxylic acids	Antibiotics	- -	- -	- -	- -	- -
Fluoxetine	Antidepressant (SSRI)	- -	- -	- -	- -	Elicits significant spawning in male mussels at about 150 µg/l and female mussels at 3,000 µg/l
Fluvoxamine	Antidepressant (SSRI)	- -	- -	- -	- -	Elicits significant spawning in male mussels at about 0.318 µg/l and female mussels at 31 µg/l
Gemfibrozil	Lipid regulator	16-69	0.30	1.500	0.5100	- -
Gentisic Acid	Metabolite of Acetylsalicylic acid	High	4.60	0.590	1.2000	- -
o-Hydroxyhippuric acid	Metabolite of Acetylsalicylic acid	High	6.80	- -	- -	- -
16α-Hydroxyestrone	Hormone	68	- -	0.005	- -	- -
Ibuprofen	Analgesic/anti-inflammatory	22-95	3.30	3.400	0.5300	Algae growth inhibition tests EC_{50}[c] = 7.1 mg/l Bluegill Sunfish LC_{50}[d] = 173, mg/l
Ifosfamide	Antineoplastic	Low	- -	2.900	- -	- -
Indomethacine	Analgesic/anti-inflammatory	71-83	0.95	0.600	0.2000	- -
Iohexol	X-ray contrast medium	- -	- -	- -	- -	- -
Iopamidol	X-ray contrast medium	- -	- -	15.000	- -	- -

Table 5 (continued)

Compound	Use	Removal Efficiency by WWTP (percent)[a]	Maximum Concentrations Detected (µg/l)[b]			Toxicological Data
			WWTP Influent	WWTP Effluent	Surface Water	
Iopromide	X-ray contrast medium	- -	- -	11.000	- -	- -
Iotrolan	X-ray contrast medium	- -	- -	- -	- -	- -
Ketoprofen	Analgesic/anti-inflammatory	48-69	0.50	0.380	0.2100	- -
Meclofenamic Acid	Analgesic/anti-inflammatory	- -	- -	- -	- -	- -
Menstranol	Hormone	- -	- -	0.004	- -	- -
Methylbenzylidene camphor	Sunscreen agent	- -	- -	- -	- -	Bioconcentrated in roach from German lakes
Metoprolol	Antihypertensive	83	- -	2.200	2.2000	- -
Musk ambrette[f]	Fragrances, cosmetics	- -	- -	- -	- -	Known to accumulate in fish and shellfish tissue
Musk xylene[f]	Fragrances, cosmetics	- -	0.15	0.036	0.0230	Known to accumulate in fish and shellfish tissue
Musk ketone[f]	Fragrances, cosmetics	- -	0.55	0.410	0.0230	Known to accumulate in fish and shellfish tissue
Musk moskene[f]	Fragrances, cosmetics	- -	- -	- -	- -	Known to accumulate in fish and shellfish tissue
Musk tibetene[f]	Fragrances, cosmetics	- -	- -	- -	- -	Known to accumulate in fish and shellfish tissue
Galaxolide (HHCB)[g]	Fragrances, cosmetics	- -	- -	- -	0.1520	Known to accumulate in fish and shellfish tissue
Tonalide (AHTN) [g]	Fragrances, cosmetics	- -	- -	- -	0.0880	Known to accumulate in fish and shellfish tissue
Celestolide (ADBI) [g]	Fragrances, cosmetics	- -	- -	- -	0.0080	Known to accumulate in fish and shellfish tissue
Musk xylene derivatives	Transformation products of nitro musks	- -	- -	0.250	- -	*Daphnia magna* toxicity tests showed EC_{50}[c] of 0.25 µg/l
Nadolol	Antihypertensive	- -	- -	0.060	0.0090	- -
Naproxen	Analgesic/anti-inflammatory	15-78	0.60	3.000	0.3900	- -
Norethisterone	Hormone	- -	- -	0.020	0.0170	- -
Paracetamol	Analgesic	>99	- -	- -	- -	Algae growth inhibition test EC_{50}[c] = 134 mg/l Algal acute toxicity test LC_{50}[d] = 29.6 mg/l *Daphnia* immobilization test EC_{50}[c] = 9.2-136 mg/l
Paroxetine	Antidepressant (SSRI)	- -	- -	- -	- -	Does not elicit spawning behavior in mollusks
Phenazone	Analgesic	33	- -	0.410	0.9500	- -
Progesterone	Hormone	- -	- -	- -	0.0060	- -
Propanolol	Antihypertensive	96	- -	0.290	0.5900	*Daphnia* immobilization test EC_{50}[c] = 2.6-31.0 mg/l *Daphnia* acute toxicity test LC_{50}[d] = 3.1-17.7 mg/l

Table 5 (continued)

Compound	Use	Removal Efficiency by WWTP (percent)[a]	Maximum Concentrations Detected (µg/l)[b] WWTP Influent	WWTP Effluent	Surface Water	Toxicological Data
Propyphenazone	Analgesic/anti-inflammatory	- -	- -	- -	- -	- -
Roxithromycin	Antibiotic	- -	- -	1.000	0.5600	- -
Salbutamol (albuterol)	Bronchiodilator	>90	0.17	- -	0.0350	- -
Salicylic acid	Metabolite of Acetosalicylic acid	90	- -	54.000	4.1000	*Daphnia* immobilization test EC_{50}[c] = 118 mg/l Algae growth inhibition test EC_{50}[c] > 100 mg/l
Sulfonamides[h]	Antibiotics	- -	- -	- -	- -	- -
Sulphamethoxazole	Antibiotic	- -	- -	2.000	0.4800	- -
Terbutaline	Bronchiodilator	67	- -	0.120	- -	- -
3,4,5,6-Tetrabromo-*o*-cresol	Antiseptic, fungicide	- -	<0.10	<0.100	- -	- -
Timolol	Antihypertensive	- -	- -	0.070	0.0100	- -
Tolfenamic acid	Analgesic/anti-inflammatory	- -	- -	1.600	- -	- -
Triclosan	Antiseptic	- -	- -	- -	0.1500	- -
Trimethoprim	Antibiotic	- -	- -	0.660	0.2000	- -
Verapamil	Cardiac drug, antihypertensive	- -	- -	- -	- -	*Daphnia* immobilization test EC_{50}[c] = 50-300 mg/l

[a]*Removal efficiencies can vary greatly depending on the design and operation of the wastewater treatment facility.*

[b]*Influent, effluent, and surface water concentrations are based on isolated observations that were made at different locations and times (i.e. for a given compound, the treatment plant influent and effluent and surface water concentrations are the maximum found in the literature and they may apply to the treatment plants and surface waters of three distinct locations.)*

[c]*Effective Concentration at which an effect is observed in a particular percentage of test organisms. For example, EC_{50} is the concentration required to produce an observable toxic effect in 50 percent of the test organisms. Similarly, EC_{10} is the concentration required to produce an observable toxic effect in 10 percent of the test organism.*

[d]*LC denotes lethal concentration, the concentration at which a particular percentage of test organisms experience lethal toxic effects. For example, LC_{50} is the concentration required to produce death in 50 percent of the test organisms. Similarly, LC_{10} is the concentration required to produce death in 10 percent of the test organism.*

[e]*LOEC denotes Lowest Observed Effects Concentration, the lowest concentration observed to induce toxic effects.*

[f]*These compounds are nitro musks, a class of synthetic musk introduced in the late 1800s.*

[g]*These compounds are polycyclic musks, a class of synthetic musk introduced in the 1950s.*

[h]*Sulfonamides constitute a large class of compounds.*

Source: C.G. Daughton and T.A. Ternes, "Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?", Environmental Health Perspectives *Vol. 107, Supplement 6, 1999, pp. 907-938; Environment Agency (UK),* Review of Human Pharmaceuticals in the Environment, *R&D Technical Report No. P390, 2000.*

activity, have not been included in these studies.[1] The persistence of PPCPs in the environment varies. Some of these compounds are relatively resistant to breakdown. Others are degraded relatively rapidly in the environment. Despite this, the constant release of many of these substances to the environment may make them effectively persistent. For most, there is a paucity of data on their fate in the environment.

Few data exist on the presence of PPCPs in surface waters. In general, they have been detected in most places that have been examined for their presence. A recent, nationwide study sampled 139 streams in 30 states for 95 compounds.[2] For any particular compound, 46 to 115 streams were sampled. The results showed that 80 percent of these streams had detectable concentrations of one or more of these compounds, with a median number of seven compounds detected per sample. While most attention to the presence of these substances in the environment is relatively recent, the presence of PPCPs in surface water is probably not a new development. Their presence in the environment has become more widely evident in the last decade due to improvements in chemical analytical methodologies lowering the limits of detection for many of these substances. It is likely that these compounds have been present in the environment for as long as they have been used commercially.

With some exceptions, the risks posed to humans and aquatic organisms by PPCPs are essentially unknown. Few data are available on the presence of most PPCPs or on the effects of exposure to humans and aquatic organisms. Because they may be continually exposed to these compounds over multiple generations, aquatic organisms are thought to have higher exposure risks than humans. Several reasons have been offered for concern about the presence of these substances in surface waters.[3] Many of these substances were purposefully designed to have biological effects at low concentrations. Epidemiological studies of the effects of exposure to many PPCPs at environmentally relevant concentrations have not been conducted and for many are not currently possible. Additive and synergistic effects of exposure to multiple substances are unknown. The effects of continual, life-long exposure to trace levels of toxicants constitute an unexplored area of toxicology. Finally, no data sets exist on long-term trends in concentrations of these substances. It is important to keep in mind that PPCP compounds represent a large number of chemical classes. There are potentially as many environmental effects of these compounds as classes of chemicals represented.

One issue of concern over PPCPs is that the presence of antibiotic drugs in surface and groundwater may contribute to the emergence and spread of resistance to antibiotics by disease-causing organisms. The selection for antibiotic-resistant bacteria and drug-resistant parasites has become a frequent occurrence.[4] This trend has been driven by the widespread use of antimicrobial drugs in a variety of applications.[5] In addition, disease-causing microbes can also acquire new antibiotic resistance genes from other, often nonpathogenic, species in the environment that have developed resistance through selection by antibiotics.[6] Antibiotic drugs in surface water

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[1]*C.G. Daughton and T.A. Ternes, "Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?"* Environmental Health Perspectives*, Volume 107, Supplement 6, 1999.*

[2]*D.W. Kolpin, E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D. Zaugg, L.B. Barber, and H.T. Buxton. "Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance,"* Environmental Science & Technology, *Volume 36, 2002, pp. 1201-1211.*

[3]*C. Daughton. "PPCPs as Environmental Pollutants", http://www.epa.gov/nerlesd1/chemistry/pharma/faq.htm, June 2001.*

[4]*J. Davies, "Inactivation of Antibiotics and the Dissemination of Resistance Genes,"* Science, *Volume 264, 1994, pp. 375-382.*

[5]*M.L. Cohen, "Epidemiology of Drug Resistance: Implications for a Post-Antimicrobial World",* Science, *Volume 257, 1992, pp. 1050-1055; H.C. Neu, "The Crisis in Antibiotic Resistance,"* Science*, Volume 257, 1992, pp. 1064-1072.*

[6]*J. Davies,* op. cit.

and groundwater may act as selective agents promoting the development and spread of resistance genes in disease-causing organisms.

Endocrine Disrupting Compounds

Endocrine disrupting chemicals are substances or mixtures of substances in the environment that alter the functioning of the endocrine system by interfering with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body and consequently cause adverse health effects in organisms or their progeny. These chemicals include natural and synthetic hormones, plant constituents, pesticides, compounds used in the plastics industry, and other industrial byproducts. Examples include halogenated organic compounds, such as polychlorinated biphenyls (PCBs), DDT and its derivatives, and polychlorinated dibenzo-dioxins (PCDDs); hormones found in medications and oral contraceptives; and surfactants, such as nonylphenol. Endocrine disrupting compounds often act by mimicking or antagonizing the actions of naturally occurring hormones. They can produce multiple effects through multiple mechanisms of action. It is important to note that for most associations between exposures to endocrine disrupting compounds and a variety of biological outcomes the mechanisms of action are poorly understood.[7]

Three sets of observations contribute to concerns about the presence of endocrine disrupting compounds in surface water and groundwater. First, adverse effects suggesting endocrine disruption have been observed in fish and wildlife in the environment. For example, male carp and rainbow trout exposed to wastewater treatment plant discharges had elevated levels of vitellogenin, the protein responsible for production of egg yolk in female fish.[8] Normally, this protein is not detected in male fish. Similarly, developmental abnormalities in snapping turtles, including missing tails and deformed limbs, have been attributed to exposures to a number of endocrine disrupting compounds, including PCBs, dioxins, and furans.[9] In addition, reproductive effects attributable to endocrine disrupting compounds have been reported in terrestrial animals that feed aquatically, including mink and otter[10] and herring gulls.[11]

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[7]*T. Damstra, S. Barlow, A. Bergman, R. Kaulock, and G. van der Kraak,* Global Assessment of the State-of-the-Science of Endocrine Disruptors, *World Health Organization International Programme on Chemical Safety, 2002.*

[8]*H. E. Bevans, S. L. Goodbred, J. F. Miesner, S. A. Watkins, T. S. Gross, N. D. Denslow, and T. Schoeb,* Synthetic Organic Compounds and Carp Endocrinology and Histology in Las Vegas Wash and Las Vegas and Callville Bays of Lake Mead, Nevada, 1992 and 1995. *U.S. Geological Survey, Nevada Basin and Range Study Unit, Carson City, NV, Water Resources Investigations Report 96-4266, 1996; C. E. Purdom, P. A. Hardiman, V. J. Bye, N. C. Eno, C. R. Tyler, and J. P. Sumpter, "Estrogenic Effects of Effluents from Sewage Treatment Works,"* Chemical Ecology*, Volume 8, pp. 275-285, 1994.*

[9]*C.A. Bishop, P. Ng, K.E. Pettit, S.W. Kennedy, J.J. Stegeman, R.J. Norstrom, and R.J. Brooks, "Environmental Contamination and Developmental Abnormalities in Eggs and Hatchlings of the Common Snapping Turtle (*Chelydra serpentina serpentina*) from the Great Lakes-St. Lawrence River Basin (1989-91),"* Environmental Pollution*, Volume 101, 1998, pp. 143-156.*

[10]*C.D. Wren, "Cause-Effect Linkages Between Chemicals and Populations of Mink* (Mustela vison*) and Otter (*Lutra canadensis*) in the Great Lakes Basin,"* Journal of Toxicology and Environmental Health*, Volume 33, 1991, pp. 549-585.*

[11]*G.A. Fox, "Epidemiological and Pathobiological Evidence of Contaminant-Induced Alterations in Sexual Development in Free-Living Wildlife," In: T. Colborn and C. Clement, (eds.)* Chemically-Induced Alterations in Sexual and Functional Development: The Wildlife/Human Connection*, Princeton, NJ: Princeton Scientific Publishing Co., 1992, pp. 147-158.*

Second, there appears to be an increase in incidents of certain endocrine-related diseases in humans that may be attributable to the presence of endocrine disrupting compounds in the environment. For instance, it has been suggested that chemicals that interfere with normal development of the reproductive system via an endocrine mechanism could be related to increases noted in human reproductive disorders, including lowered fertility, decreases in sperm count and quality, malformation of the male reproductive tract, and testicular maldescent.[12] A number of studies have linked reproductive tract abnormalities in male animals to exposure to endocrine disrupting compounds during gestation.[13] In addition, early onset of puberty has been attributed to exposures to polybrominated biphenyls[14] and phthalate esters.[15] There also appear to be associations between exposures to PCBs[16] and dioxins[17] and incidents of endometriosis. In all of these examples it is important to note that analysis of human data, by itself, has not provided firm evidence of direct causal relationships between low-level exposures to endocrine disrupting compounds and adverse health effects.

Third, endocrine disruption resulting from exposure to certain chemicals that are present in the environment has been observed in laboratory experimental animals. For example, exposure to environmentally relevant concentrations of nonylphenol was shown to retard testicular growth and induce production of vitellogenin in male rainbow trout.[18] Similarly, low doses of PCBs over an 18 month period resulted in impaired reproduction in mink.[19]

Mercury

Mercury is a heavy metal that can produce toxic effects in humans and wildlife. This chemical has been used for thousands of applications in industry, agriculture, medicine, and households. Common uses include dental fillings, electrical switches, batteries, lamps, thermometers, and pigments.

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[12] *R.M. Sharpe and N.E. Skakkebaek, "Are Oestrogens Involved in Falling Sperm Counts and Disorders of the Male Reproductive Tract?"* Lancet*, Volume 341, 1993, pp. 1392-1395.*

[13] *T. Damstra,* et al. op. cit.

[14] *H.M. Blanck, M. Marcus, B.E. Tolbert, C. Rubin, A.K. Henderson, V.S. Hertzberg, R.H. Zhang, and L. Cameron, "Age at Menarche and Tanner Stage in Girls Exposed* In Utero *and Postnatally to Polybromonated Biphenyl,"* Epidemiology*, Volume 11, 2000, pp. 641-647.*

[15] *I. Colon, D. Caro, C.J. Bourdony, and O. Rosario, "Identification of Phthalate Esters in the Serum of Young Puerto Rican Girls with Premature Breast Development,"* Environmental Health Perspectives*, Volume 108, 2000, pp. 895-900.*

[16] *I. Gerhard and B. Runnebaum, "Environmental Pollutants and Fertility Disorders. Heavy Metals and Minerals,"* Geburtshilfe Frauenheilkd, *Volume 52, 1992, pp. 383-396.*

[17] *P.R. Koninck, "The Pathophysiology of Endometriosis: Pollution and Dioxin,"* Gynecologic and Obstetric Investigation *Volume 47, 1999, pp. 47-49.*

[18] *S. Jobling, D.A. Sheahan, J.A. Osborne, P. Matthiessen and J.P. Sumpter, "Inhibition of Testicular Growth in Rainbow Trout (*Oncorhynchus mykiss*) Exposed to Estrogenic Alkylphenolic Chemicals,"* Environmental Toxicology and Chemistry*, Volume 15, Pp: 194-202, 1996.*

[19] *B. Brunstrom, B.O. Lund, A. Bergman, L Asplund, I. Athanassiadis, M. Athanasiadou, S. Jensen, and J. Ordberg, "Reproductive Toxicity in Mink* (Mustela vison*) Chronically Exposed to Environmentally Relevant Polychlorinated Biphenyl Concentrations,"* Environmental Toxicology and Chemistry*, Volume 20, 2001, pp. 2318-2327.*

Three forms of mercury occur in the environment: metallic mercury, mercury (II) cation, and methylmercury. Metallic mercury is volatile and can enter the atmosphere through evaporation. Over 95 percent of the mercury in the atmosphere consists of this form. It is insoluble in water and does not readily wash out of the atmosphere in precipitation. In the atmosphere, it can ionize to mercury (II). The mercury (II) cation is soluble in water and readily washes out of the atmosphere in precipitation. Methylmercury is the form that is commonly taken up by organisms. It is both volatile and soluble in water.

Deposition from the atmosphere is a major source of mercury in soil and waterbodies. In Wisconsin, sources to the atmosphere include energy production, lime production, and purposeful uses of mercury. Statewide, burning coal for energy production accounts for over 40 percent of the mercury inputs to the atmosphere. However, owing to the complex interaction between mercury emissions from in- and out-of-state sources and climatological conditions, the contribution to the atmosphere cannot be directly related to the amount of deposition of mercury on land and water surfaces. Mercury leaves the atmosphere through both dry deposition and as mercury (II) in solution in rain. Most of the mercury entering waterbodies ends up in the sediment. Microbial action in the sediment converts it to methylmercury.

Methylmercury from the sediment can enter the water column. In this form, methylmercury can be incorporated into organism tissue. There are two main routes through which methylmercury can enter organisms. In one route, it is assimilated into the organisms directly from solution through absorption across skin or respiratory tissues. In the other route, it is ingested in food. Once assimilated, methylmercury will accumulate in organism tissue, especially muscle, blood, and internal organs. An organism will accumulate methylmercury in its tissue any time it takes the contaminant up more rapidly than it can eliminate it. Tissue concentrations can be magnified as mercury moves through the food web. For instance, while the average tissue concentration of methylmercury in Wisconsin panfish is 0.19 parts per million (ppm), the average tissue concentration in Wisconsin walleye is 0.48 ppm. Larger and older organisms will contain higher tissue concentrations of methylmercury than smaller and younger organisms. Because it accumulates in tissue and is difficult for organisms to excrete, methylmercury can be biomagnified through the food chain. Tissue concentrations of the compounds will be fairly low in organisms at lower trophic levels, such as algae and plants. Organisms at each succeeding trophic level will have increasingly higher tissue concentrations. The highest concentrations of this contaminant will be found in the tissue of organisms at the top of the food chain, such as piscivorous fish. When an organism is not taking up methylmercury, its body burden of this contaminant will decline. The rate of this decline is species specific. For humans, the half-life of methylmercury in tissue is about 70 days. For freshwater fish species, the tissue half-life ranges from about six months to two years.[20]

Mercury has been shown to produce a number of toxic effects. Metallic mercury can cause neurological damage, kidney damage, and respiratory problems in humans. Methylmercury can cause neurological damage, miscarriage, stillbirth, mental retardation, and cognitive defects in humans. Pregnant women, infants, and young children are most at risk. High enough doses of methylmercury can cause mortality. Fish are generally less sensitive to mercury poisoning than humans. High doses can kill fish. Lower doses have been shown to reduce hatching success of walleye eggs.

The most common way that humans are exposed to methylmercury is through consumption of contaminated fish. Repeated ingestion is needed to produce toxic effects. The Wisconsin Department of Natural Resources (WDNR) has issued a general fish consumption advisory for fish caught from most of the surface waters of the State. These are shown in Table 6. In addition, the WDNR may issue more restrictive consumption advice for fish taken from particular waterbodies. This occurs when fish tissue from these waterbodies is found to contain higher concentrations of mercury. The tissue concentrations used for issuing these advisories are shown in Table 7.

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[20]*K. Huber,* Wisconsin Mercury Sourcebook (draft)*, Wisconsin Department of Natural Resources, 1997.*

Table 6

GENERAL FISH CONSUMPTION ADVISORY FOR MOST WATERS IN WISCONSIN[a]

Advisory	Sensitive Group[b]	All others
Unlimited Consumption	- -	Bluegill, sunfish, black crappie, white crappie, yellow perch, or bullheads
One Meal per Week	Bluegill, sunfish, black crappie, white crappie, yellow perch, or bullheads	Walleye, northern pike, smallmouth bass, largemouth bass, channel catfish, flathead catfish, or other species
One Meal per Month	Walleye, northern pike, smallmouth bass, largemouth bass, channel catfish, flathead catfish, white sucker, drum, burbot, sauger, sturgeon, carp, white bass, rock bass, or other species	- -
Do Not Eat	Muskellunge	- -

[a]On certain waters, the Wisconsin Department of Natural Resources issues more restrictive consumption advice due to higher levels of mercury or PCBs in fish.

[b]Sensitive group includes pregnant women, nursing mothers, women of childbearing age, and children under 15 years of age.

Source: Wisconsin Department of Natural Resources.

Table 7

FISH TISSUE CONTAMINANT CONCENTRATIONS FOR ESTABLISHING CONSUMPTION ADVISORIES

	Consumption Advisory Level					
Contaminant	No Advisory	Unlimited	One Meal per Week	One Meal per Month	One Meal per Two Months	Do Not Eat
Mercury (ppm)[a]	- -	<0.05	0.05-0.22	0.23-1.00	- -	>1.00
Total PCB (ppm)	- -	<0.05	0.06-0.20	0.21-1.00	1.10-1.90	>2.00
Dioxin and Furan Congeners (ppt)	<10	- -	- -	- -	- -	>10.00

[a]Values are for consumption by sensitive individuals consisting of pregnant women, nursing mothers, women of childbearing age, and children under 15 years of age.

Source: Wisconsin Department of Natural Resources.

Polychlorinated Biphenyls

Polychlorinated biphenyls are members of a family of 209 separate chemical compounds, referred to as congeners, formed by the substitution of chlorine atoms for hydrogen atoms on a biphenyl molecule. A particular PCB congener may have from one to ten chlorine atoms. These chemicals were used for numerous applications in industry and households. Common uses included insulators in electrical equipment and heating coils, lubricating oils, printing inks, adhesives, synthetic rubbers, and carbonless copy paper. While their manufacture in the United States ended in 1977, over half of all PCBs manufactured are still in use today.

PCBs have similar physical and chemical properties. They are highly stable compounds and tend to persist in the environment. They have high boiling points. While they are highly soluble in lipids, they have low solubility in water. They can also adsorb to sediment and other particles. The properties of any particular PCB compound are strongly influenced by the number of chlorine atoms in its molecule. Congeners containing fewer chlorine atoms are lighter, more volatile, more soluble in water, and more mobile in the environment than congeners containing more chlorine atoms. PCBs were commercially produced in mixtures referred to as arochlors. An individual arochlor consists of a mixture of many PCB compounds.

PCBs enter the environment through several routes. Some were released to air, water, or soil during their manufacture, use, and disposal. Others were released through accidental spills, leaks, or fires. Currently, PCBs enter the environment through hazardous waste sites, illegal or improper disposal of industrial wastes and consumer products, leaks from old electrical transformers, and burning of some wastes in incinerators. PCBs do not readily break down in the environment. They can travel long distances in the air and can be deposited at sites far away from where they were released.

PCBs can be taken up by small organisms and fish in water, amphibians, reptiles, birds, and mammals through contact with contaminated water or sediment or through ingestion of an organism carrying PCBs. The chemicals will build up in fatty tissue of organisms carrying them. Larger and older organisms will tend to have higher body burdens of PCBs than smaller and younger organisms of the same species. Tissue concentrations can be magnified as PCBs move through the food chain, reaching levels that may be many thousands of times higher than the concentration in water. Higher levels of PCBs will be found in the tissue of species at the top of the food chain, such as piscivorous fish. In addition, species, such as carp, that have high exposure to contaminated sediments will tend to have high body burdens of PCBs.

PCBs have been shown to produce a number of health effects. Acute toxic effects have been seen only at high doses. PCBs have been shown to induce tumors in laboratory animals. Animal studies and epidemiological studies have shown liver cancers and liver damage to be associated with PCB exposure. Developmental problems, especially related to learning and memory, have been seen in the children of women exposed to PCBs during pregnancy. Chloracne and rashes have also been associated with high levels of exposure to PCBs.

The available data indicates that PCB congeners differ in their toxicity and toxicological properties. PCB congeners have been assigned to groups based upon their presumed toxicity;[21] however, these assignments are based upon the congeners' abilities to induce toxic effects similar to those induced by dioxins through similar mechanisms as those responsible for dioxin toxicity. Those congeners which are known to have the ability to induce toxic effects similar to those induced by dioxins are referred to as dioxin-like congeners and are regarded as having the highest toxicity of PCB congeners. They have been assigned toxicity equivalence factors which compare their toxicity to that of 2,3,7,8-tetrachlorodibenzo-p-dioxin. These toxicity equivalence factors are shown in Table 8. It is important to note that these factors apply only to dioxin-like toxic effects and do not take into account any toxic effects related to other mechanisms of toxicity. Toxic effects unrelated to dioxin-like toxicity have been reported; however, less information is available on non-dioxin-like PCB congeners and their toxicology is not well understood.[22] The available toxicological information suggests that the typical effects of PCB exposure are caused by all congener classes, although the underlying mechanisms may be different.

The most common way that humans are exposed to PCBs is through consumption of contaminated fish. Repeated ingestion is needed to produce toxic effects. The WDNR has issued a general fish consumption advisory for fish caught from most of the surface waters of the State. This advisory is shown in Table 6. In addition, when tissue from fish caught in a particular waterbody is found to contain higher levels of PCBs, the WDNR issues more restrictive consumption recommendations, as shown in Table 7. PCBs can also be absorbed through the skin, if contaminated material is touched.

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[21]*Victor A. McFarland and Joan U. Clarke, "Environmental Occurrence, Abundance, and Potential Toxicity of Polychlorinated Biphenyl Congeners: Considerations for a Congener-Specific Analysis,"* Environmental Health Perspectives, *Vol. 81, 1989; Stephen Safe, "Toxicology, Structure-Function Relationships, and Human and Environmental Impacts of Polychlorinated Biphenyls: Progress and Problems,"* Environmental Health Perspectives, *Vol. 100, 1992.*

[22]*Tala R. Henry and Michael J. DeVito, "Non-dioxin-like PCBs: Effects and Consideration in Ecological Risk Assessment," U.S. Environmental Protection Agency Ecological Risk Assessment Support Center, June 2003.*

Table 8

TOXICITY EQUIVALENCY FACTORS (TEFS) FOR DIOXIN-LIKE PCB CONGENERS

Congener Number	TEFs[a]		
	Humans and Mammals	Fish	Birds
PCB-77	0.00010	0.000100	0.05000
PCB-81	0.00010	0.000500	0.10000
PCB-105	0.00010	<0.000005	0.00010
PCB-114	0.00050	<0.000005	0.00010
PCB-118	0.00010	<0.000005	0.00001
PCB-123	0.00010	<0.000005	0.00001
PCB-126	0.10000	0.005000	0.10000
PCB-156	0.00050	<0.000005	0.00010
PCB-157	0.00050	<0.000005	0.00010
PCB-167	0.00001	<0.000005	0.00001
PCB-169	0.01000	0.000050	0.00100
PCB-189	0.00010	<0.000005	0.00001

[a]TEF indicates the toxicity relative to 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). For example, a PCB congener with a TEF of 0.01 is considered to be one hundred times less toxic than 2,3,7,8-TCDD.

Source: World Health Organization.

Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are members of a large class of organic compounds containing two or more fused aromatic rings of carbon. Some of these compounds occur naturally in peat, lignite, coal, and crude oil. While a few of these compounds are manufactured as intermediates in the production of materials, like dyes, pigments, pesticides, and plasticizers and mixtures of some are manufactured to treat wood used for railroad ties and marine timbers, most PAHs are produced as byproducts due to incomplete combustion of organic material during industrial processes and other human activities.

PAHs exhibit a wide range of physical and chemical properties. In general, they tend to be solid at ambient temperatures. They tend to have low volatilities, high melting points, and high boiling points. Similarly, their solubilities in water are low. In general, the volatilities and water solubilities of these compounds tend to decrease with increasing molecular weight. They are soluble in lipids and nonpolar organic solvents. They tend to adsorb to particulate material. While they can undergo photodecomposition in the atmosphere and react with strong oxidizing agents, such as ozone and oxides of nitrogen and sulfur, PAHs are fairly stable compounds. Individual PAH compounds that contain more aromatic rings and have higher molecular weights tend to exhibit higher chemical stability. They are usually found in the environment as mixtures of compounds and are often associated with other contaminants, such as pesticides, heavy metals, and PCBs.

PAHs enter the environment through several routes. Often they are released to the atmosphere by combustion sources, usually sorbed to particulates. In the air they can travel long distances and can be deposited at sites far away from where they were released. They enter surface waters through atmospheric deposition, urban runoff, abrasion of asphalt, accidental spills, and release from creosote-treated wood. PAHs entering surface waters tend to accumulate in sediment.

PAHs can be taken up by small organisms and fish in water through contact with contaminated water or sediment or through ingestion of organism carrying PAHs. Organisms can absorb these compounds through the gastrointestinal tract, respiratory tissues, and the skin. The relative importance of direct uptake from water and uptake through ingestion of food is not known. Once assimilated, PAHs are widely distributed throughout organism tissues. They can be found in most organs, but accumulate especially in lipid-rich tissue. The metabolism of PAHs within organisms is rather complex. Some are converted to nontoxic forms. Others are converted to forms that bind to DNA. Organisms can excrete PAHs in feces and in urine. While turnover of some PAHs in organism bodies can be rapid, others persist in fatty tissue or remain bound to cellular DNA or RNA.

PAHs have been shown to produce a number of health effects in humans and other organisms. The acute toxicity of PAHs to humans tends to be fairly low. Fish, algae, and some invertebrates, such as *Daphnia,* show sensitivity to acute toxicity from these compounds. Some PAHs can damage DNA and are mutagenic. Some of these compounds are highly carcinogenic. In addition, the metabolic products of some PAHs are compounds that are toxic, mutagenic, or carcinogenic.

A number of PAHs have been listed as priority pollutants by the U.S. Environmental Protection Agency (USEPA). They are listed in Table 9.

The Relative Nature of Pollution

The determination of whether or not a particular surface water or groundwater resource is polluted is a function of the intended use of the water resource, in that the water may be considered to be polluted for some uses and not polluted for others. For example, a stream that contains a low dissolved oxygen level would be classified as polluted from the perspective of its use for sport fishing, since the survival and propagation of fishes depends upon an ample supply of dissolved oxygen. That same stream, however, may not be considered polluted when its water is used for industrial cooling. Water pollution, therefore, is a relative term, depending on the uses that the water is to satisfy and the quality of the water relative to the minimum requirements established for those uses or needs.

Water Quality Indicators

There are literally hundreds of parameters or indicators available for measuring and describing water quality; that is, the physical, chemical, and biological characteristics of water. A list of these indicators would include all of the physical and chemical substances in solution or suspension in water, all of the macroscopic and microscopic organisms in water, and the physical characteristics of the water itself. Only a few of these hundreds of indicators, however, are normally useful in evaluating wastewater quality and natural surface water quality and in indicating pollution. Selected indicators were employed in the regional water quality management plan update planning program to evaluate surface water quality by comparing it to supporting adopted water use standards, which in turn relate to specific water use objectives. These same indicators were also used to describe the quality of point discharges and diffuse source runoff and to determine the effect of those discharges on receiving streams. These indicators included: temperature; specific conductance; turbidity; hydrogen ion concentration (pH); and total dissolved solids (TDS), total suspended solids (TSS), chloride, dissolved oxygen, biochemical oxygen demand (BOD, or BOD_5 when referring to the five-day BOD test), fecal coliform bacteria, heavy metal, pesticide, and PCB, phosphorus, and nitrogen concentrations; and aquatic flora and fauna species distributions.[23] These latter are generally described in terms of biological or biotic indices, two of which are in general use within Wisconsin, namely, the Hilsenhoff Biotic Index (HBI)[24] and the Index of Biotic Integrity (IBI).[25] These indices are applied to stream systems as a means of assessing the quality of the habitat, and its associated fauna. The HBI is used primarily to assess the diversity and quality of benthic invertebrates, or the organisms that generally provide the

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[23]*For a more complete discussion of most of the cited indicators, including their significance in evaluating water quality, see Chapter V of SEWRPC Technical Report No. 17,* Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975, *June 1978.*

[24]*Wisconsin Department of Natural Resources Technical Bulletin No. 132,* Using a Biotic Index to Evaluate Water Quality in Streams, *1982.*

[25]*U.S. Department of Agriculture, National Forest Service General Technical Report No. NC-149,* Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin, *April 1982.*

Table 9

POLYCYCLIC AROMATIC HYDROCARBONS INCLUDED AMONG PRIORITY POLLUTANTS[a]

Priority Pollutants
Acenaphthene
Acenaphthylene
Anthracene
Benz(a)anthracene[b]
Benzo(a)pyrene[b]
Benzo(b)fluoranthene[b]
Benzo(g,h,i)perylene
Benzo(k)fluroanthene[b]
Chrysene[b]
Dibenz(g,h)anthracene[b]
Fluorene
Fluoranthene
Ideno(1,2,3-c,d)pyrene[b]
Naphthalene
Phenanthrene
Pyrene

[a]*As defined in Sec. 307(a) of the Clean Water Act.*

[b]*Considered Class 2 carcinogens by the U.S. Environmental Protection Agency.*

Source: U.S. Environmental Protection Agency.

food resources that support a fishery, while the IBI is typically applied to an assessment of the quality of the fishery and fish habitat.

Water Quality Parameters

The following subsections describe the major water quality indicators that were examined in order to characterize surface water quality as part of the regional water quality management plan update. In cases where surface water quality standards and criteria for those indicators exist, they are discussed in Chapter IV of this report.

Bacterial and Biological Parameters

Bacteria

The concentration of certain bacteria in water is measured in order to assess the quality of the water for drinking water supply and recreational uses. A variety of disease-causing organisms can be transmitted through water contaminated with fecal material. These organisms include bacteria, such as those causing cholera and typhoid fever; viruses, such as those causing poliomyelitis and infectious hepatitis; and protozoa, such as *Giardia* and *Cryptosporidium*. The major source of many of these to surface waters is contamination of the waters with fecal material.

It is not practical to test surface waters for all of these disease causing organisms. In fact, for many, rapid, inexpensive tests do not currently exist. Instead, the sanitary quality of surface water is assessed by examining samples for the presence and concentrations of organisms indicating fecal contamination. Two groups of bacteria are commonly examined in surface waters of the Greater Milwaukee watersheds: fecal coliform bacteria and *Escherichia coli* (*E. coli*). All warm-blooded animals have these bacteria in their feces. Because of this, the presence of high concentrations of fecal coliform bacteria or *E. coli* in water indicates a high probability of fecal contamination. While some strains of *E. coli* are associated with food poisoning, most strains of these two bacterial groups have a low probability of causing illness. Instead, they act as indicators of the possible presence of other pathogenic agents in water. While the presence of high concentrations of these indicator bacteria does not necessarily indicate the presence of pathogenic agents, they are generally found when the pathogenic agents are found.

As indicated above, fecal coliform bacteria are a group of bacteria found in the feces of warm-blooded animals. Fecal coliform bacteria are used to indicate the suitability of inland waters in Wisconsin for recreational uses. The State requires that counts of fecal coliform bacteria in waters of the State not exceed 200 cells per 100 milliliters (cells per 100 ml) as a geometric mean based on not less than five samples per month, nor exceed 400 cells per 100 ml in more than 10 percent of all samples during any month.[26]

E. coli is a species of fecal coliform bacteria. The USEPA recommends using either *E. coli* or enterococci as indicators of fecal pollution in recreational waters for freshwater systems. Agencies participating in the monitoring of beaches in the Wisconsin Beach Monitoring program use *E. coli* as the indicator of sanitary quality of the associated waters. Water quality advisories are issued for beaches whenever the concentration of *E. coli* in a

[26]*Chapter NR 102.04(5) of the* Wisconsin Administrative Code.

single sample exceeds 235 cells per 100 ml or whenever the geometric mean of at least five samples taken over a 30-day period exceeds 126 cells per 100 ml. Beaches are closed whenever the concentration of *E. coli* exceeds 1,000 cells per 100 ml.

*Chlorophyll-*a

Chlorophyll-*a* is a pigment found in all photosynthetic organisms, including plants, algae, and photosynthetic bacteria. Measurements of the concentration of chlorophyll-*a* are used as an estimate of the biomass of phytoplankton suspended in the water column. It is important to keep in mind that this is an estimate of the entire phytoplankton community. Chlorophyll-*a* concentration can vary based upon factors other than the total biomass of phytoplankton present, including which species are present, the amount of light available, the ambient temperature, and nutrient availability. High concentrations of chlorophyll-*a* are indicative of poor water quality, and are often associated with high turbidity, poor light penetration, and nutrient enrichment.

Chemical and Physical Parameters

Water Temperature

The temperature of a waterbody is a measure of the heat energy it contains. Water temperature drives numerous physical, chemical, and biological processes in aquatic systems. Processes affected by temperature include the solubility of substances in water, metabolic rates of organisms, and the toxicity of some substances. For example, the solubility of many solids in water increases as temperature increases. The opposite trend is seen for many gases. The solubility of these gases in water decreases as temperature increases.

Temperature is a major determinant of the suitability of waterbodies as habitat for fish and other aquatic organisms. Each species has a range of temperatures that it can tolerate and a smaller range of temperatures that are optimal for growth and reproduction. These ranges are different for different species. As a result, very different biological communities may be found in similar waterbodies experiencing different temperature regimes.

Solar heating strongly influences water temperature and factors that affect the incidence of light on waterbodies or light penetration in waterbodies can affect temperature. Water temperature follows a seasonal cycle, with lowest temperatures occurring during winter and highest occurring during summer. Discharges of groundwater or stormwater runoff and discharges from point sources can also affect water temperature.

Alkalinity

Alkalinity is a measure of the acid-neutralizing capacity of water. While several substances contribute to alkalinity, concentrations of alkalinity are often expressed as an equivalent concentration of calcium carbonate ($CaCO_3$). A waterbody's alkalinity is influenced by the types of minerals in the soil and underlying bedrock of the watershed. Groundwater contributions from aquifers containing limestone and dolomite also contribute alkalinity to waterbodies. Because much of the Southeastern Wisconsin Region is underlain by carbonate bedrock such as dolomite, alkalinity tends to be high in many of the Region's waterbodies.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) is the amount of oxygen required for the oxidation of organic material in water by microbial and chemical processes over a specified time interval. BOD serves as an indicator of the amount of organic material in the water. For most purposes, a five-day test period is used. Low concentration of BOD is an indicator of good water quality, while high concentration of BOD is an indicator of poor water quality. High concentrations of BOD in waterbodies tend to be associated with low concentrations of dissolved oxygen.

Natural sources of BOD to waterbodies include leaf fall and plant decay. Anthropogenic sources include a variety of point and nonpoint sources of water pollution. BOD concentrations in most discharges from point sources are subject to effluent limitations through the Wisconsin Pollution Discharge Elimination System (WPDES) permit program that limit the concentrations and amounts of BOD that can be discharged.

Chloride
Chlorides of commonly occurring elements are highly soluble in water and are present in some concentration in all surface waters. Chloride is not decomposed, chemically altered, or removed from the water as a result of natural processes. Because of this, it is referred to as a conservative substance. In the absence of additions of chloride to a waterbody, its concentration is generally related to the extent of dilution. As a result, increases in chloride concentration can indicate inputs of pollution to waterbodies.

Natural chloride concentrations in surface water are directly affected by leaching from underlying bedrock and soils, and by deposition from precipitation events. Higher concentrations can reflect pollution. Waterbodies in southeastern Wisconsin typically have very low natural chloride concentrations due to the limestone bedrock found in the Region. Limestone is primarily composed of calcium carbonate and magnesium carbonate, and, as such, is rich in carbonates rather than chlorides. Hence, the sources of chloride in southeastern Wisconsin are largely anthropogenic, including sources such as salts used on streets and highways for winter snow and ice control, salts discharged from water softeners, and salts from sewage and animal wastes.

High concentrations of chloride can affect aquatic plant growth and pose a threat to aquatic organisms. The effects of chloride contamination begin to manifest at about 250 mg/l and become severe at concentrations in excess of 1,000 mg/l.[27] For surface waters, Wisconsin has set forth two standards for chloride concentrations. The acute toxicity criterion for fish and aquatic life is 757 mg/l and chronic toxicity criterion for fish and aquatic life is 395 mg/l.

Dissolved Oxygen
The concentration of dissolved oxygen in water is a major determinant of the suitability of a waterbody as habitat for fish and other aquatic organisms because most aquatic organisms require oxygen in order to survive. Though tolerances vary by species, most organisms have minimum oxygen requirements.

Sources of dissolved oxygen to water include diffusion of oxygen from the atmosphere and photosynthesis by aquatic plants and suspended and benthic algae. Processes that remove dissolved oxygen from water include diffusion of oxygen to the atmosphere, respiration by aquatic organisms, and bacterial decomposition of organic material in the water column and sediment. Several factors can influence these processes, including the availability of light, the clarity of the water, the presence of aquatic plants, and the amount of water turbulence. Water temperature has a particularly strong effect for two reasons. First, the solubility of most gases in water decreases with increasing temperature. Thus as water temperature increases, the water is able to contain less oxygen. Second, the metabolic demands of organisms and the rates of process such as bacterial decomposition increase with increasing temperature. As a result, the demands for oxygen in waterbodies tend to increase as temperature increases.

Concentrations of dissolved oxygen in surface waters typically show a strong seasonal pattern. Highest concentrations usually occur during the winter. Concentrations decrease through the spring to reach a minimum during summer. Concentrations rise through the fall to reach maximum values in winter. This cycle is driven by seasonal changes in water temperature. Dissolved oxygen concentrations in some waterbodies may also show daily fluctuations in which high concentrations occur during daylight due to photosynthesis and lower concentrations occur during periods of darkness when photosynthesis ceases and respiration increases.

Supersaturation of water with dissolved oxygen occurs when the water contains a higher concentration of dissolved oxygen than is normally soluble at ambient conditions of temperature and pressure. Dissolved oxygen supersaturation can result from several causes including, the presence of waterfalls, discharge of water through dams, water temperature increases related to solar heating or discharge of industrial or power generation cooling

[27] *Frits van der Leeden, Fred L. Troise, and David Keith Todd,* The Water Encyclopedia, Second Edition, *Lewis Publisher, 1990.*

water effluent, and high levels of photosynthesis in waterbodies with high densities of aquatic plants, phytoplankton, or benthic algae. Dissolved oxygen supersaturation can cause a number of physiological conditions that are harmful or fatal to fish and other aquatic organisms.

Under Wisconsin's surface water quality criteria for warm water fish and aquatic life, concentrations of dissolved oxygen in continuous streams, unstratified lakes, and the upper layers of stratified lakes may not be lowered to less than 5.0 mg/l. For coldwater communities, concentrations of dissolved oxygen may not be lowered to less than 6.0 mg/l or 7.0 mg/l during the spawning season.

Hardness

Hardness is an indicator of the mineral content of water and measures the combined concentrations of ions of calcium, magnesium, and a variety of other metals. Because the relative concentrations of the constituents of hardness can vary, measurements of hardness are often reported as an equivalent concentration of milligrams per liter of calcium carbonate (mg/l as $CaCO_3$). General guidelines for classification of waters on the basis of hardness are: 0 to 60 mg/l as $CaCO_3$ is classified as soft; 61 to 120 mg/l as $CaCO_3$ as moderately hard; 121 to 180 mg/l as $CaCO_3$ as hard; and more than 180 mg/l as $CaCO_3$as very hard. High levels of hardness can make untreated water unusable for some uses. The toxicity of some metals to fish and other aquatic organisms can be affected by hardness, with higher metal concentrations being required to produce a toxic effect in harder water.

pH

The acidity of water is measured by pH. This is defined as the negative logarithm of the hydrogen ion (H^+) concentration. This is sometimes referred to as the standard pH unit or standard units. It is important to note that each unit on this scale represents a change of a factor of 10. Thus, the hydrogen ion concentration associated with a pH of 6.0 standard units is 10 times the concentration associated with a pH of 7.0 standard units. A pH of 7.0 standard units represents neutral water. Water with pH values lower than 7.0 standard units has higher hydrogen ion concentrations and is more acidic, while water with pH values higher than 7.0 standard units has lower hydrogen ion concentrations and is less acidic.

Many chemical and biological processes are affected by pH. The solubility and availability of many substances are influenced by pH. For example, many metals are more soluble in water with low pH. Different organisms are capable of tolerating different ranges of pH, with most preferring ranges between about 6.5 and 8.0. In addition, the toxicity of many substances to fish and other aquatic organisms can be affected by pH.

Several factors influence the pH of surface waters. Because of diffusion of carbon dioxide into water and associated chemical reactions, rainfall in areas that are not impacted by air pollution has a pH of about 5.6 standard units. The pH of rainfall in areas where air quality is affected by oxides of nitrogen or sulfur tends to be lower. The mineral content of the soil and bedrock underlying a waterbody has a strong influence on the waterbodies pH. Because much of the Southeastern Wisconsin Region is underlain by carbonate bedrock such as dolomite, pH in the Region's waterbodies tends to be between 7.0 and 9.0 standard units. Pollutants from point and nonpoint sources can affect a waterbodies pH. Photosynthesis by aquatic plants and algae can cause pH variations both on a daily and seasonal basis.

Secchi Depth

Secchi depth is a measure of water clarity in lakes. Readings are taken by lowering an eight-inch-diameter weighted, black and white disc into the water and measuring the depth at which it disappears from sight. Higher Secchi depths are observed in clearer water and generally indicate better water quality. Several factors can affect water clarity and Secchi depth. The presence and concentrations of some dissolved substances can impart color to water, reducing the depth to which light penetrates and lowering clarity. Particulate material suspended in the water can absorb or dissipate light, lowering water clarity.

Specific Conductance
Conductance is the measure of the ability of water to conduct an electrical current. Because temperature affects this ability, conductance values are corrected to a standard temperature of 25 degrees Celsius. This corrected value is referred to as specific conductance. It is reported in units of microsiemens per centimeter (μS/cm).

Pure water is a poor conductor of electrical currents and exhibits a low value of specific conductance. For example, distilled water produced in a laboratory has a specific conductance in the range of 0.5 to 3.0 μS/cm. The ability of water to carry a current depends on the presence of ions in the water, and on their chemical identities, total concentration, mobility, and electrical charge. Solutions of most inorganic compounds, such as salts, are relatively good conductors. As a result, specific conductance gives a measure of the concentration of the amount of dissolved solids in water, with higher values of specific conductance indicating higher concentrations of dissolved solids.

Suspended Materials
Suspended material in surface waters consists of particles of sand, silt, and clay; planktonic organisms; and fine organic and inorganic debris. The composition of suspended material varies with characteristics of the watershed and pollution sources.

Energy in water motions keeps particulate material suspended in water. Because the density of these particles is greater than the density of water, in the absence of water motions, such as flow or mixing, these particles will settle out of the water. The rate at which a particle settles is a function of its size, density, and shape. In general, larger and denser particles will settle more quickly than smaller and less dense particles. Flow and mixing will keep particles suspended, with stronger flow or mixing being required to keep larger or denser particles suspended. This has implications for suspended material in waterbodies. In streams, for example, higher concentrations and larger and denser particles are associated with higher water velocities—both in fast-moving sections of streams and during high flow periods. If water velocities are great enough, they may cause resuspension of sediment from the bed or erosion from the bed and banks of the stream. By contrast, deposition of suspended material may occur in slow-moving streams or during periods of low flow, with progressively smaller and lighter particles being deposited with decreasing water motions. The result of this is that concentrations of suspended material and the nature of the suspended particles in a waterbody vary, both spatially and over time.

Sources that contribute suspended material to waterbodies include sources within the waterbody and sources in the contributing watershed. Within a waterbody, resuspension of sediment in the beds of waterbodies and erosion of beds and banks can contribute suspended materials. Suspended materials can also be contributed by point and nonpoint pollution sources within the watershed. Examples of point sources include sewage treatment plants and industrial discharges. Concentrations of suspended materials in most discharges from point sources are subject to effluent limitations through the WPDES permit program that limit the concentrations and amounts of total suspended solids that can be discharged. A variety of nonpoint sources can also contribute suspended materials to waterbodies. Many best management practices (BMPs) for urban and rural nonpoint source pollution are geared toward reducing discharges of suspended materials.

High concentrations of suspended material can cause several impacts in waterbodies. High turbidity is a result of high concentrations of suspended material, with associated poor light penetration. This can result both in reductions in photosynthesis and increases in temperature in the waterbody. High concentrations of suspended material can clog the gills of fish and other aquatic organisms, stressing them physiologically—in some cases fatally. Deposition of sediments may alter the substrate, making it unsuitable as habitat for aquatic organisms or changing channel characteristics. In addition, as a result of physical and chemical interactions, other materials may adsorb to particles suspended in water. Examples include poorly soluble organic molecules, such as PCBs, PAHs, and pesticides; nutrients, such as phosphate and nitrate ions; metals, such as copper and zinc ions; and microorganisms, such as bacteria and viruses. As a result, some pollutants may be carried into, or transported within, waterbodies in association with suspended material.

Two measures of the concentration suspended materials are commonly used: TSS and total suspended sediment concentration (SSC). Both are based upon the amount of material retained when a sample is passed through a filter, though they differ in the details of sample handling and subsampling. It is important to note that these two measures are not comparable to one another.[28]

Nutrients

Nutrients are elements and compounds needed for plant and algal growth. They are often found in a variety of chemical forms, both inorganic and organic, which may vary in their availability to plants and algae. Typically, plant and algal growth and biomass in a waterbody are limited by the availability of the nutrient present in the lowest amount relative to the organisms' needs. This nutrient is referred to as the limiting nutrient. Additions of the limiting nutrient typically result in additional plant or algal growth. Phosphorus is usually, but not always, the limiting nutrient in freshwater systems. Under some circumstances nitrogen may act as the limiting nutrient.

Sources of nutrients to waterbodies include sources within the waterbody and sources in the contributing watershed. Within a waterbody, mineralization of nutrients from sediment, resuspension of sediment in the bed, and erosion of bed and banks can contribute nutrients. Nutrients can also be contributed by point and nonpoint pollution sources within the watershed. Examples of point sources include sewage treatment plants and industrial discharges. Concentrations of some chemical forms of nutrients in discharges from point sources are subject to effluent limitations through the WPDES permit program that limit the concentrations and amounts that can be discharged. A variety of nonpoint sources can also contribute nutrients to waterbodies. Many BMPs for urban and rural nonpoint source pollution are geared toward reducing discharges of nutrients. In addition, the decay of organic material that washes into a waterbody will contribute nutrients to that waterbody.

Nitrogen Compounds

A variety of nitrogen compounds are present in surface waters which act as nutrients to plants and algae. Typically, only a small number of forms of nitrogen are examined and reported in water quality sampling. Total nitrogen includes all of the nitrogen in dissolved or particulate form in the water. It does not include nitrogen gas, which is not usable as a nutrient by most organisms. Total nitrogen is a composite of several different compounds which vary in their availability to algae and aquatic plants and vary in their toxicity to aquatic organisms. Common constituents of total nitrogen include ammonia, nitrate, and nitrite. These are the forms that most commonly support algal and plant growth. In addition, a large number of nitrogen-containing organic compounds, such as amino acids, nucleic acids, and proteins commonly occur in natural waters. These compounds are usually reported as organic nitrogen.

Total and Dissolved Phosphorus

Phosphorus usually acts as the limiting nutrient in freshwater systems. Two forms of phosphorus are commonly sampled in surface waters: total phosphorus and dissolved phosphorus. Total phosphorus represents all the phosphorus contained in material dissolved or suspended within the water. Dissolved phosphorus represents the form that can be taken up and used for growth by algae and aquatic plants.

Metals

Concentrations of several heavy metals are used as water quality indicators. These metals produce a variety of toxic effects in humans, wildlife, fish, and other aquatic organisms with the toxic effects depending on the type of metal, its chemical form, its biological role, the type of organisms exposed to the metal, and the conditions of exposure. In addition to direct toxicity, these metals can bioaccumulate in the tissue of organisms with tissue concentrations being considerably higher than ambient concentrations in the environments. Tissue concentrations of some of these metals may be magnified as they are passed up the food web through trophic interactions.

[28] *J.R. Gray, G.D. Glysson, L.M. Turcios, and G.E. Schwartz,* Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data, *U.S. Geological Survey Water-Resources Investigations Report No. 00-4191, 2000.*

A number of sources can contribute heavy metals to surface waters. Natural sources include release of minerals from bedrock and soil during weathering and deposition from the atmosphere of metals derived from volcanic activity. Anthropogenic sources include atmospheric deposition of metals contributed to the atmosphere by vehicles and stationary combustion sources, discharges from point sources of water pollution, and urban and rural stormwater runoff. Particular sources vary among the metals.

In the greater Milwaukee watersheds, heavy metals whose concentrations in surface waters were regularly assessed include arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Surface water quality standards for these metals are presented in Chapter IV of this report.

Organic Compounds

Organic compounds constitute a general group of chemicals that contain carbon. While some are naturally produced by organisms, many are synthetic. There are hundreds of these chemicals that may be of interest for assessing water quality. Commonly assessed compounds belong to classes such as detergents, disinfectants, dye agents, flavoring agents, flame retardants, fragrances, insect repellants, plasticizers, and solvents. In addition, metabolites and transformation products of some of these substances may exhibit activity in the environment and may, therefore, be of interest.

These compounds can produce a variety of environmental impacts, including impacts to human health and impacts on fish and other aquatic organisms. This group represents a large number of chemical classes. There are potentially as many environmental effects of these compounds as classes of chemicals represented. Among the effects identified for members of this group are acute and chronic toxicity, carcinogenesis, and endocrine system disruption. Water quality criteria have been promulgated for some of these compounds. These are presented in Chapter IV of this report.

Pesticides

Pesticides are chemical and biological substances intended to control pest organisms. Specific pesticides have been developed and used for many types of organisms including insects, rodents, plants, algae, and fungi. These compounds are generally designed to be toxic to the target organisms. In addition, they can produce impacts on other organisms. Examples of unintended impacts attributed to exposure to pesticides include fish kills, reproductive failure in birds, and acute illness in humans.

Pesticides represent a large group of chemicals consisting of several classes of compounds. These classes of compounds all have their own modes of action, chemical properties, and biological effects. Many pesticides break down over time as a result of several chemical and microbiological reactions in soils. Others are resistant to breakdown and persistent in the environment. Some, such as chlorinated hydrocarbon insecticides, can bio-accumulate in the tissue of organisms with tissue concentrations being considerably higher than ambient concentrations in the environments. Tissue concentrations of some of these compounds may be magnified as they are passed up the food web through trophic interactions, with tissue concentrations increasing, often by orders of magnitude, at higher trophic levels.

Pesticides are registered for use in the United States by the USEPA and in Wisconsin by the Department of Agriculture, Trade, and Consumer Protection. Some pesticides that have been banned, such as DDT and its metabolites, are still found in environmental samples and tissue samples of aquatic organisms. Wisconsin has promulgated surface water quality criteria for some pesticides. These are presented in Chapter IV of this report.

Wet and Dry Weather Conditions: An Important Distinction

It is important to distinguish between instream water quality during dry weather (base flow) conditions and during wet weather (flood) conditions. In general, a water quality sample is assumed to represent dry weather conditions if 0.10 inch or less of rainfall was recorded in the 24 hours prior to the time of sampling, assuming that the precise time of sampling was known, or if such rainfall is recorded on the day of sampling in those cases where the precise time of sampling was not known. Dry weather instream water quality is assumed to reflect the quality of groundwater discharge to the stream plus the continuous or intermittent discharge of various point sources for example, industrial cooling or process waters, and leakage and discharge from sanitary sewers. While instream water quality during wet weather conditions includes the above discharges, the dominant influence, particularly during major rainfall or snowmelt runoff events, is likely to be the soluble and insoluble substances carried into the streams by direct land surface runoff. That direct runoff moves from the land surface to the surface waters by overland routes, such as drainage swales, street and highway ditches, and gutters, or by underground storm sewer systems.

In the past, water quality sampling and monitoring were most often conducted in dry weather, low-flow periods, such as might be expected in July, August, and September. This practice reflects a period in the development of the state-of-the-art of water quality control when continuous and relatively uniform discharges from point sources—primarily municipal sewage treatment plant and industrial wastewater outfalls—were the dominant sources of pollution addressed in pollution abatement efforts. The impact of these kinds of point sources of pollutants on stream water quality was most critical when stream flows were lowest. Accordingly, many of the available water quality monitoring studies for the streams in the study area and, therefore, many of the data presented in this report pertain to dry weather, low-flow conditions.

Significant progress has been made in the understanding and control of major point sources of pollution. Consequently, substances carried into the streams by land surface runoff during wet weather conditions are becoming increasingly important in terms of their impacts on water quality. In some situations, over half of the total contaminant load to a system can be transported into the surface water system by two or three major storms. Thus, wet weather conditions are likely to be as critical in terms of adverse water quality conditions as dry weather conditions.

SOURCES OF WATER POLLUTION

An evaluation of water quality conditions in a watershed must include an identification, characterization, and where feasible, quantification of known pollution sources. This identification, characterization, and quantification is intended to aid in determining the probable causes of the water pollution problems discussed earlier in this chapter.

Pollutants can reach the surface waters of the watershed by several pathways. First, pollutants may be discharged from discrete outfall points into surface waters of the watershed. Second, pollutants associated with the land may be transported to the stream system either in surface runoff associated with wet weather events or through dry weather pathways. Third, pollutants may be transported from their point of origin through the atmosphere to the watershed. These substances may then be carried into surface waters either through precipitation or dry deposition processes. Fourth, pollutants may be carried into surface waters through groundwater flow. Finally, pollutants sequestered in sediments within the waterbody may be released to the overlying surface waters.

Point Source Pollution

Point source pollution is defined as pollutants that are discharged to surface waters at discrete locations. Examples of such discrete discharge points include sewage treatment plant discharges, sanitary sewerage system flow relief devices, combined sewer overflows, and industrial discharges.

Private and Public Sewage Treatment Plants

Private and public sewage treatment plants remove pollutants from wastewater before it is discharged to surface water or groundwater. The processes utilized at these plants are not 100 percent efficient at removing pollutants from sewage. Thus, the effluent from these plants may contain residual amounts of several pollutants, including chlorine, suspended solids, nutrients, and oxygen demanding substances. In addition, these facilities are not engineered to remove some substances that may be present in sewage, such as pharmaceuticals and personal care products. All of the public and private sewage treatment plants in the study area are subject to a Wisconsin Department of Natural Resources permit under the WPDES permit program. That program requires treatment of wastewater to the levels determined to be necessary to meet the water use objectives.

Sanitary Sewer System Flow Relief Points

Raw sanitary sewage can enter the surface water system of a watershed either directly from sanitary sewer overflows or indirectly via flow relief devices to separate storm sewer systems. This direct or indirect conveyance of sanitary sewage to the surface water system of a watershed occurs through various types of flow relief devices as a result of one or more of the following conditions: inadequate sanitary sewage conveyance facilities, excessive infiltration and inflow of clear water during wet weather conditions, and mechanical and/or power failures at sanitary sewage pumping facilities. In order to prevent damage to residential dwellings or the mechanical elements of the conveyance system as a result of the aforementioned system failures, a sanitary sewage flow relief device may be provided. Since the promulgation of the regional water quality management plan and State and Federal clean water initiatives in the 1970s, it has been policy within the Region to reduce reliance on such devices as general sewerage system upgrades are implemented. Flow relief devices for which locations are available are mapped in Chapters V through X of this report.

Combined Sewer Overflows

Some portions of the Milwaukee Metropolitan Sewerage District's (MMSD) service area are served by combined sewers. These sewers convey sewage along with stormwater runoff from adjacent lands. During dry periods, combined sewers function much like sanitary sewers, conveying sewage to a sewage treatment plant. During wet weather, inflow of stormwater can sometimes cause the capacity of the combined sewer system to be exceeded. This can result in excess flow being discharged into nearby surface waters. This type of event is referred to as a combined sewer overflow (CSO). Effluent from CSOs generally contains a high proportion of stormwater.

Approximately 25 square miles of the MMSD's service area are served by combined sewers, located in the City of Milwaukee and the Village of Shorewood. The MMSD's current WPDES permit lists 117 CSO outfall locations. These discharge to the Kinnickinnic, Menomonee, and Milwaukee Rivers and to Lake Michigan. As part of the MMSD 1977 water pollution abatement program, an inline storage system or deep tunnel was recommended to be constructed to both convey and store both separate sewer flows and combined sewer flows. That system was constructed and became operational in early 1994. Since that time, the number of combined sewer overflows has been reduced from over 50 per year to between two and three per year. The associated water quality of CSOs also has greatly improved for a variety of water quality constituents, since the deep tunnel came online as shown in Figure 4. The discharge locations of the limited number of overflows which now occur are categorized as point sources of pollution to be considered in this report.

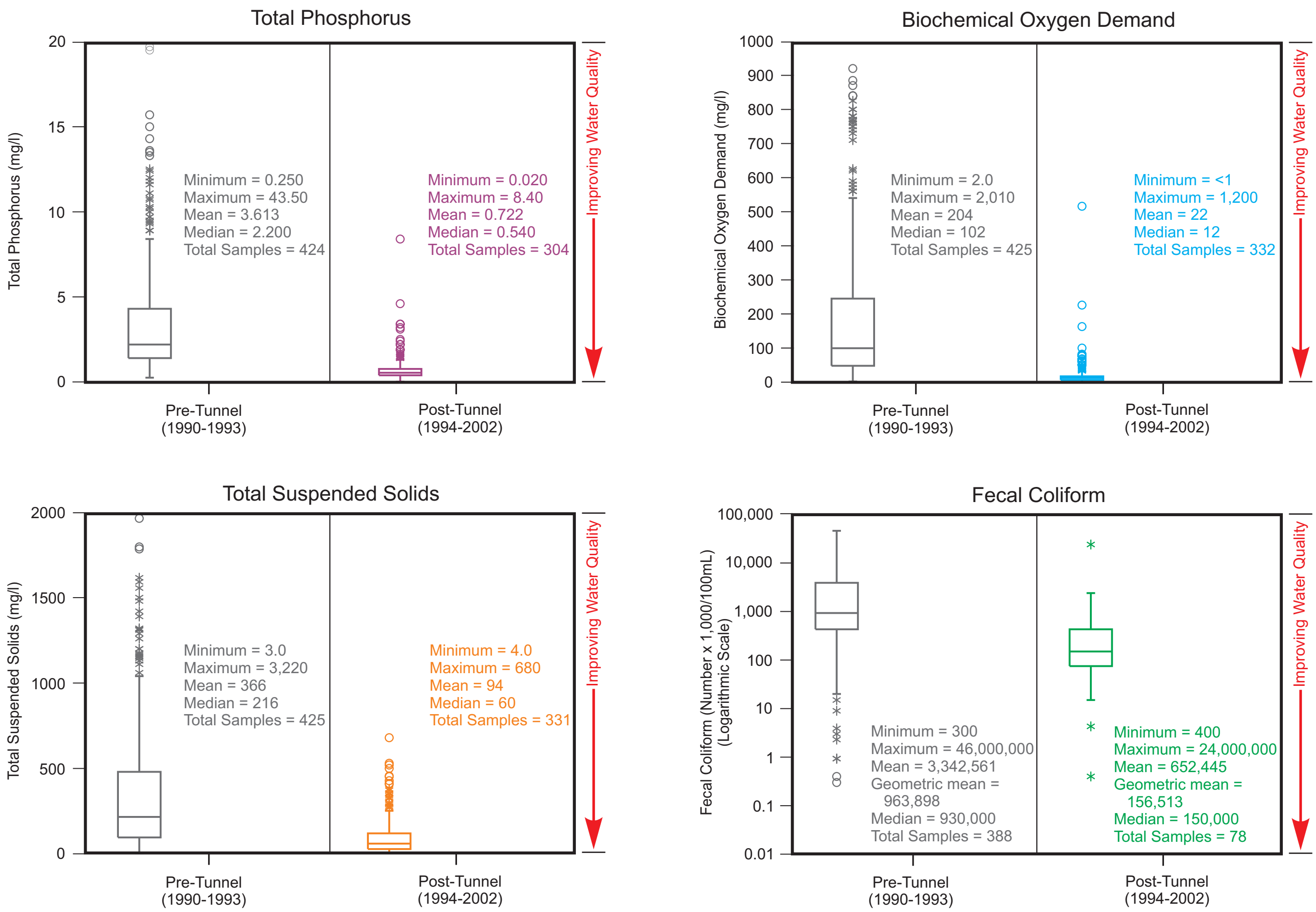
Industrial Discharges

A variety of commercial and industrial activities can result in point source discharges to surface waters. These discharges originate from several processes. Examples of effluents discharged from these processes include: water used for single-pass cooling processes (noncontact cooling water), condensate from air conditioners and steam tunnels; discharges from boilers; carriage water from dredging processes using pumps; process water from concrete products manufacturing; water removed during dewatering of pits, trenches, and nonmetallic mines; water used to pressure test or clean water pipelines; and water resulting from backwash or recharge of potable water treatment and conditioning systems. Depending on their source, these discharges may contain contaminants, such as suspended solids, heat, nutrients, residual chlorine, chemical oxygen demand, and oil and grease. In addition, the temperature, pH, and concentration of dissolved oxygen of the discharge may be different from that of the receiving water. Pretreatment of effluents to remove contaminants prior to discharge is required under the WPDES when concentrations of contaminants exceed effluent limitations. Most industrial discharges in the study area which have significant levels of pollutants in their wastewater have been connected to public sanitary sewer systems. The remaining industrial point sources are largely cooling water and uncontained process wastewater.

As the number, nature, and locations of industries present in the regional water quality management plan update study area changes, it is expected that number, nature, and locations of industrial discharges and the types and amounts of contaminants contained in these discharges may also change.

Figure 4

COMPARISON OF WATER QUALITY PARAMETERS IN COMBINED SEWER OVERFLOWS BEFORE AND AFTER THE INLINE STORAGE SYSTEM (DEEP TUNNEL) BEGAN OPERATION IN 1994



NOTE: The total phosphorus, total suspended solids, and biochemical oxygen demand graphs may contain values that exceed the maximum graph values; however, summary statistics for each water quality parameter were included. Fecal coliform summary statistics include nonlog transformed values, including a geometric mean value. See Figure 24 in Chapter III of this report for description of box plot symbols.

Source: Milwaukee Metropolitan Sewerage District and SEWRPC.

Nonpoint Source Pollution

Nonpoint source pollution, also referred to as diffuse source pollution, consists of various discharges of pollutants to the surface waters which cannot be readily identified as point sources. Nonpoint source pollution is transported from the rural and urban land (see Table 3 in Chapter I of this report for the distribution of land uses in the study area) areas of a watershed to the surface waters by means of direct runoff from the land via overland routes, via storm sewers and channels, and by interflow during and shortly after rainfall or rainfall-snowmelt events. Nonpoint source pollution also includes pollutants conveyed to the surface waters via groundwater discharge—base flows—which is a major source of stream flow between runoff events.

The distinction between point and nonpoint sources of pollution is somewhat arbitrary since a nonpoint source pollutant, such as sediment being transported in overland rainfall runoff, can be collected in open channels or in storm sewers and conveyed to points of discharge, such as a storm sewer outfall. Thus, for purposes of this report, nonpoint source pollution includes substances washed from the land surface or subsurface by rainfall and snowmelt runoff and then conveyed to the surface waters by that runoff, even though the entry into the surface waters may be through a discrete location, such as a drain tile or storm sewer outfall.

Nonpoint source pollution is similar in composition to point source pollution in that it can cause toxic, organic, nutrient, pathogenic, sediment, radiological, and aesthetic pollution problems.[29] Nonpoint source pollution is becoming of increasing concern in water resources planning and engineering as efforts to abate point source pollution become increasingly successful. The control of nonpoint source pollution is a necessary step in the process of improving surface waters to render such waters suitable for full recreational use and a healthy fishery.

Nonpoint source pollution generally differs from point source pollution in one important respect: nonpoint source pollution is transported to the surface water at a highly irregular rate because large portions of the overall transport occur during rainfall or snowmelt events. In the dry period after washoff events, potential nonpoint source pollutants gradually accumulate on the land surface as a result of human activities, becoming available for transport to the surface waters during the next runoff event.

For example, the stream hydrograph schematic as shown in Figure 5 shows how stream discharge typically responds to a rainfall event. Normal stream base flow is shown as the dashed line, which is usually mostly comprised of groundwater discharge. The amount of rainfall is shown as the solid orange line. Time is shown on the horizontal axis and water discharge passing one point on the stream is shown on the vertical axis. The stream discharge response to the rainfall event is shown as the solid blue line. The rising limb represents the increase in stormwater runoff volume and the crest represents the maximum runoff rate. The falling limb represents the decrease in runoff until base flow is achieved once more. Associated with this rise and fall of stream discharge are a rise and fall of pollutant loadings as shown in Figure 6, which compares stormwater water quality in the initial first flush (rising limb) versus a later time period (falling limb) of the storm hydrograph. In every case as shown in Figure 6, stormwater in the initial first flush contains significantly more pollutant load than in the later time period. These pollutant washoff processes were incorporated into the modeling of pollutant loads as detailed in Chapters V through X in this report.

The following activities, or effects of human activities, result in nonpoint source pollution: 1) dry fallout and washout of atmospheric pollution; 2) vehicle exhaust and lubricating oil and fuel leakage; 3) the gradual wear and disintegration of tires, pavements, structures, and facilities; 4) improper disposal of grass clippings and leaves; 5) improperly located and maintained onsite wastewater disposal systems; 6) poor soil and water conservation practices; 7) improper management of livestock wastes; 8) excessive use of fertilizers and pesticides; 9) debris, careless material storage and handling, and poor property maintenance; 10) construction and demolition activity; 11) application of deicing salts and sand; 12) streambank erosion; and 13) domestic and wild animal litter.

Residential Land Use

The concentration of people, domestic structures, and activities in residential areas and the alteration of the natural drainage and infiltration characteristics results in the production and release of nonpoint source water pollutants. Runoff from lawns, rooftops, driveways, sidewalks, and unused land is channeled through drainage ways and streets and is transported directly, as overland flow, or indirectly, through storm sewerage systems, to surface waters. Pollutant sources associated with residential land uses include street debris, fertilizers, pesticides, pet wastes, garbage and litter, vegetation, degraded surface coatings, such as paint particles, and detergent. Surface runoff from precipitation events and from urban activities within residential areas, such as lawn sprinkling or automobile washing release pollutants to the environment.

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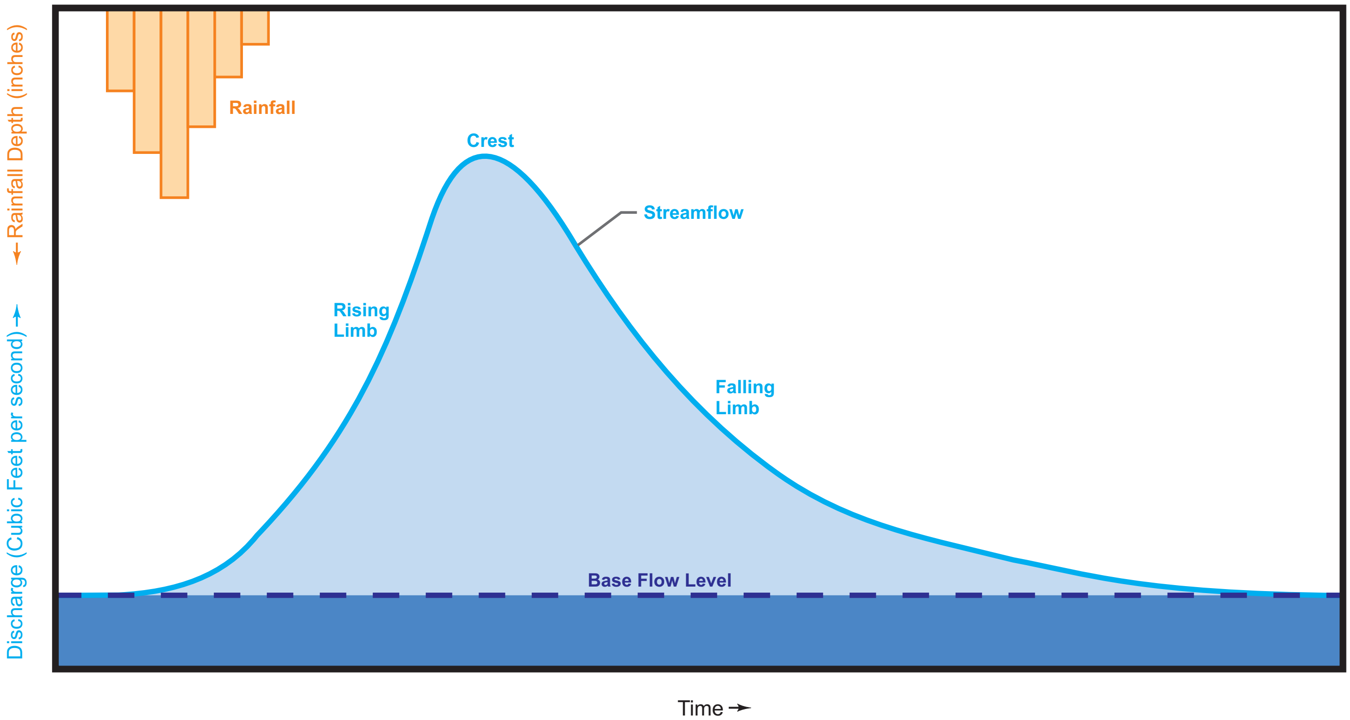
[29]*University of Wisconsin-Extension in cooperation with the Wisconsin Department of Natural Resources Nonpoint Source Program,* Urban Runoff-How Polluted Is It?, *revised 1995.*

Figure 5

HYDROGRAPH SCHEMATIC OF STREAMFLOW RESPONSE TO A RAINFALL EVENT



Source: SEWRPC.

Commercial Land Use

The high percentage of impervious area and attendant high runoff rates, together with the accumulation of litter and debris, make commercial land a significant contributor of nonpoint source pollutants. Rainfall and snowmelt runoff from rooftops, parking lots, buildings, alleys, streets, loading docks and work areas, and adjacent sidewalks and open areas contribute sediment, oxygen-demanding substances, dissolved substances, nutrients, toxic and hazardous substances, oil, grease, bacteria, and viruses to the streets and storm sewers which drain the commercial areas and discharge into the streams within the project study area. Another source of runoff is the washing of debris from work areas, sidewalks, and areas adjacent to storage areas. Excessive use of pesticides and fertilizers on grassed areas associated with commercial land use is also a source of nonpoint pollution.

Industrial Land Use

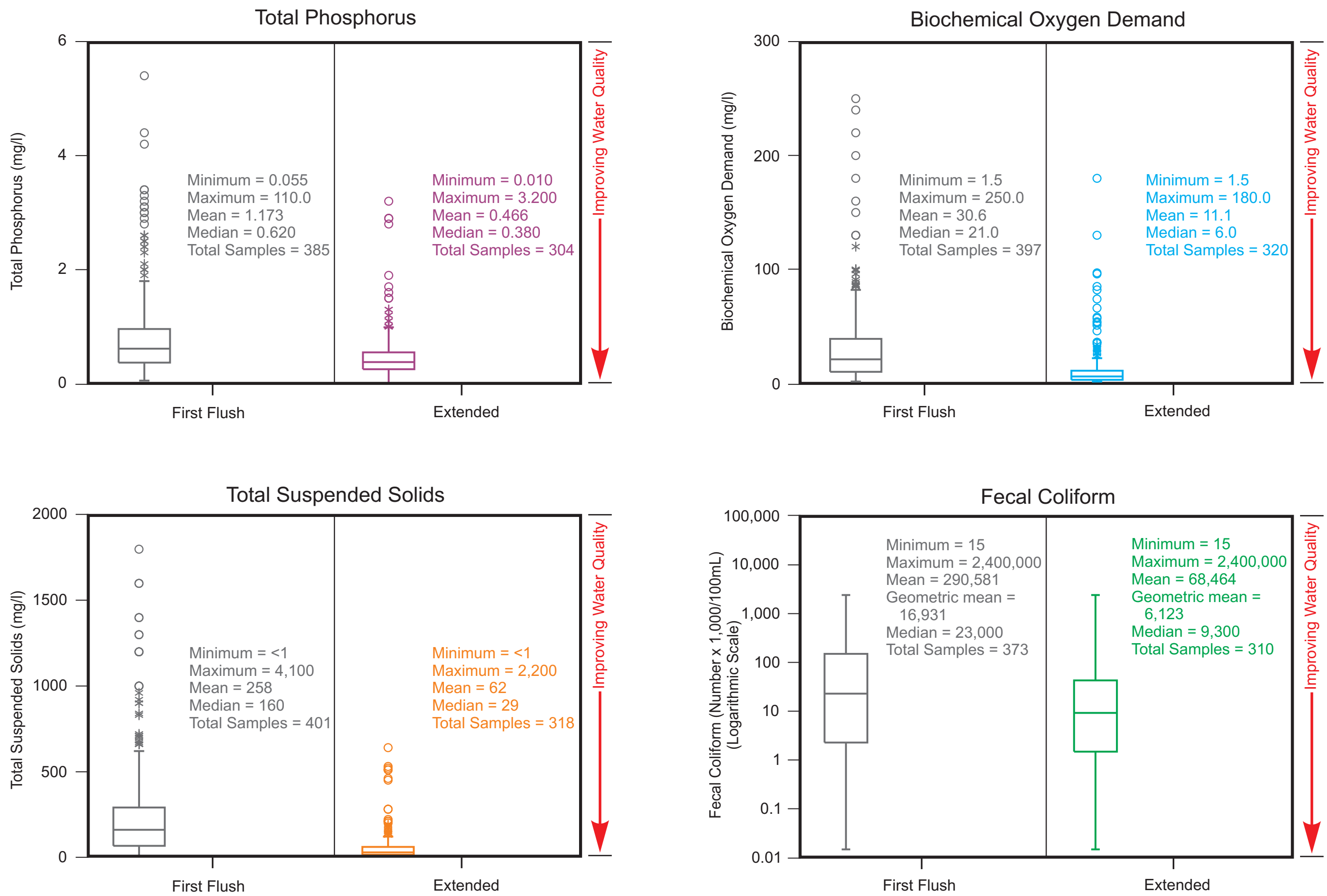
Runoff from industrial spills, production and distribution sites, automobile salvage yards, loading docks and work areas, material storage sites, industrial buildings and adjacent streets, parking lots, rooftops, lawns, sidewalks, and open areas transports fuels, oil, grease, wood, metals, paper, plastic, salt, sand and gravel, organic substances, fly ash, petroleum and chemical products, corrosives, waste chemicals, brush, garbage, rubber, acids, glass, ceramics, paint particles, glue, and solvents to streets, storm sewers, and large collector sewers. Many industrial operations do not have the indoor or covered storage capacity to house raw materials awaiting processing and, therefore, store the materials in outdoor bins or designated areas exposed to natural weathering processes, breakage, leakage, erosion, oxidation, heat, cold, and moisture which increase the degradation of the material and the potential for its removal and transport to surface waters by storm runoff or snowmelt.

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

Figure 6

COMPARISON OF WATER QUALITY PARAMETERS IN STORMWATER OUTFALLS BETWEEN FIRST FLUSH FROM A RAINFALL EVENT VERSUS AN EXTENDED PERIOD OF TIME AFTER THE SAME RAINFALL EVENT: 2000-2003



NOTE: The total phosphorus, total suspended solids, and biochemical oxygen demand graphs may contain values that exceed the maximum graph values; however, summary statistics for each water quality parameter were included. Fecal coliform summary statistics include nonlog transformed values, including a geometric mean value. See Figure 24 in Chapter III of this report for description of box plot symbols.

Source: Milwaukee Metropolitan Sewerage District and SEWRPC.

contaminants. Underground storage tanks for gasoline, oil, and other liquids that were installed during the 1950s and 1960s have now 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 in a small area creates an onsite, and sometimes offsite, contamination risk. Leaks in petroleum-product conveyance and transmission lines also are a potential source of groundwater contamination. The WDNR keeps an inventory of leaking underground storage tanks (LUST) that they have identified and categorized according to risk. LUST sites are identified as high priority when it is know that the site is causing contamination to groundwater, or where there is a high potential for such contamination. LUST sites that are ranked as medium priority, have known soil contamination problems or a potential for groundwater contamination.

Hazardous Spills

Industrial spills are an additional source of pollution to surface waters. Common to nearly all industrial activities is the storage of petroleum and chemical substances. Heavy loading of nutrients, oxygen-demanding substances, suspended and dissolved solids, toxic substances, and fecal coliform bacteria may be transported to surface waters by leaking oil drums; overflowing hoppers and bins of scrap metal saturated with cutting oils; punctured industrial waste hoppers; and spilled greases, fuels, process wastes, metals, synthetic organic chemicals, such as polychlorinated biphenyls, and other organic materials. The resulting pollution of the surface water resources by careless or improper handling of industrial substances can be catastrophic depending on the nature of those substances and the quantity and location of the spill.

Transportation Activities
Transportation activities contribute significant amounts of pollutants to surface waters as goods and people are moved by rail, air, bus, truck, or car. The terminals, transportation routes, and service and maintenance areas are all sites of pollutant buildup and potential release. Motor vehicle pollutants accumulate on freeways and expressways, highways, streets, and parking lots. Motor vehicles deposit fuel, oil and grease, hydraulic fluids, coolants, exhaust emissions—particulates and gases, tire rubber, litter, metals, asbestos, and nutrients on streets. Deicing salts, pavement debris, vegetation debris, animal wastes, litter, fertilizers, pesticides, chemicals, and material from adjacent land also accumulate on streets. Because the transportation-related urban surfaces are impervious and designed to drain very quickly, they play a particularly important role in the transport of pollutants.

Deicing Agent Usage
Initially, salts were used in conjunction with abrasives, such as sand or ashes to facilitate travel on snowy and icy highways. In many municipalities and counties and on State trunk and interstate highways implementation of bare pavement winter maintenance programs require liberal and frequent applications of straight salt in order to provide, wherever possible, consistently dry and, therefore, safer driving surfaces. Sodium chloride is the most commonly used deicing salt. The deicing salts dissolve to form solutions with lower freezing points than the freezing point for water. The application of deicing salts on highways during the winter may significantly affect the quality of runoff water. The salt applied to the highway must either be carried by surface runoff or must infiltrate the ground surface. Improper or excessive salt application may lead to groundwater or surface water contamination, soil contamination, damage to plants, damage to wildlife, increased corrosion, and possible human toxicity in extreme circumstances.

During cold weather months, deicing activities at airports may contribute pollutants to surface waters. Aircraft are deiced by applying chemical deicer fluids to critical surfaces. These fluids typically consist of glycol compounds, usually ethylene glycol or propylene glycol, and additives, such as surfactants, corrosion inhibitors, and flame retardants in aqueous solution. Runoff from snowmelt and precipitation can carry these substances into surface waters. There are two main issues of concern related to runoff containing deicing fluids. First, glycols can create high oxygen demands in receiving waters. Second, some constituents of deicing fluids are toxic to fish and other organisms. Ethylene glycol, in particular, is highly toxic to mammals and can be toxic to aquatic organisms. In addition, some additives such as urea and some surfactants and corrosion inhibitors are either toxic to aquatic organisms or can biodegrade to toxic compounds.

Recreational Activities
Certain outdoor recreational activities, which utilize large areas of the land and water, may constitute nonpoint sources of pollution by contributing pollutants to storm water runoff and snowmelt that are then carried to surface waters. Normally, outdoor recreational sites include large areas of land which are relatively well stabilized and act either as relatively modest source of pollutants or as pollutant-trapping mechanisms. For example, grass buffer strips along streams serve to remove pollutants from stormwater runoff and snowmelt through the sedimentation, filtration, and nutrient uptake effects of the vegetative cover. However, outdoor recreational sites may also include space and impervious areas for the conduct of such recreational pursuits as golf, tennis, swimming, and boating which may be sources of nonpoint pollution. The amount of pollutants contributed will depend upon such factors as the types of recreational facilities provided, the location and size of vegetated buffer areas and zones, the amount of fertilizers and pesticides used, the land management methods applied, the drainage efficiency of the site, and the location of the site with respect to adjacent lakes or streams. However, well-designed and managed recreational lands may serve as a means of resolving other nonpoint source pollution problems.

Construction Activities
The development and redevelopment of residential, commercial, industrial, transportation, and recreational areas can cause significant quantities of pollutants to be contributed to streams. Construction activities generally involve soil disturbance and destruction of stable vegetative cover; changes in the physical, chemical, and biological properties of the land surface; and attendant changes in the hydrologic and water quality characteristics of the site as an element of the natural system of surface and groundwater movement. The clearing and grading of construction sites subjects the soil to high erosion rates. Potential pollutants from construction activities include soil particles; pesticides; petroleum products, such as oils, grease, gasoline, and asphalt; solid waste materials, such as paper, wood, metal, rubber, garbage, and plastic; construction chemicals, such as paints, glues, solvents, sealants, acid, and concrete; and soil additives, such as lime, fly ash, and salt. The transportation of pollutants from construction sites to natural waters is by direct runoff of stormwater and snowmelt, leaching and groundwater infiltration, wind, soil slippage or landslide, and mechanical transfer on vehicles.

Chapter NR 216 of the *Wisconsin Administrative Code* requires that landowners of construction sites that will disturb one or more acres of land must apply for and obtain a Construction Site Storm Water permit. This permit requires the landowner to develop and implement a construction site erosion control plan and a stormwater management plan designed to prevent stormwater from becoming contaminated with pollutants. The permit also requires that weekly visual inspections of erosion control and stormwater management measures be conducted to assure that the plans are effective. The WDNR issues and administers these permits through the WPDES General Permits program.

Onsite Sewage Disposal Systems
An onsite sewage disposal system may be a conventional septic tank system; a mound system; an alternative system, such as an aerobic treatment unit or a sand filter; or a holding tank. Failure of an onsite sewage disposal system occurs when the soils surrounding the seepage area will no longer accept or properly stabilize the effluent, when the groundwater rises to levels which will no longer allow uptake of liquid effluent by the soils, or when age or lack of proper maintenance cause the system to malfunction. Hence, onsite disposal system failure may result from installation in soils with severe limitations for system use, improper design or installation of the system, or inadequate maintenance.

The pollution of surface water and groundwater from onsite sewage disposal systems potentially can be worsened by:

- The lack of resources for adequate inspection of systems, resulting in the continued use of systems that should be upgraded or replaced,

- The lack of public education on the proper operation and maintenance of private onsite sewage disposal systems, and

- Operation and maintenance abuses such as pumping from systems into ditches, puncturing tanks, and commercial haulers discharging effluent to surface waters.

During the year 2000, the Wisconsin Legislature amended Chapter Comm 83 of the *Wisconsin Administrative Code* and adopted new rules governing onsite sewage disposal systems. These rules, which had an effective date of July 1, 2000, increased the number of types of onsite 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 increase the area in which onsite sewage disposal systems may be utilized. Although Chapter Comm 83 treats onsite sewage disposal systems as waste treatment facilities comparable in effect to public sewage treatment plants, onsite systems still pose a greater risk for pollution of groundwater with nitrates, chlorides, and other soluble pollutants. The fact that these systems discharge directly to the groundwater system distinguishes them from public sewage treatment plants. In addition, there is a concern with regard to management and oversight of such systems, as was described above.

Improperly Abandoned Wells
One of the most important, yet overlooked, sources of groundwater contamination is 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. 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 allow contaminated water to migrate freely from one aquifer to another. 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 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.

CHANNEL CONDITIONS AND STRUCTURES

Channelization and Concrete-Lined Channels
Undegraded streams typically exhibit a high degree of heterogeneity in channel morphology and alignment within their channels, including variations of depths, widths, and flow patterns.[30] Patterns of flow in these streams can be quite complex, encompassing areas of both slow- and fast-moving water, areas of smooth, laminar flow, and areas of turbulent flow. Water depth can also vary, with deeper water usually found in areas of scour, such as along the outside of bends in the channel, and immediately downstream of areas with high water velocity, such as riffles. This heterogeneity also has a temporal component. Over time, long-term changes in the watershed produce gradual alterations in channel geometry. These long-term changes result from cyclical patterns of small scale streambank and streambed degradation, caused by scouring and erosion, and streambank and streambed aggradation caused by sedimentation.[31] Over long periods of time, the position and geometry of an undisturbed stream's channel can vary considerably.

While exceptions are common, low-gradient streams, such as those characteristic of southeastern Wisconsin, typically decrease in gradient from upstream to downstream. Several changes are seen along streams as stream gradient decreases. With decreasing gradient, the frequency and length of riffles decreases. The distinction among pools, riffles, and runs often becomes less clear.[32] Stretches of smooth-flowing water become longer and areas of obvious turbulence become less common. Meanders become the main source of longitudinal variability in stream velocity and channel form.

Channelization usually includes one or more of the following changes to the natural stream channel: channel straightening; channel deepening with ensuing lowering of the channel profile; channel widening; placement of a concrete invert and sidewalls, removal of dams, sills, or other obstructions to flow; and reconstruction of selected bridges and culverts. At times the natural channel may be relocated or completely enclosed in a conduit. These modifications to the natural channel generally yield a lower, hydraulically more efficient waterway, which results in lower flood stages within the channelized reach.

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[30]*P.V. Winger, "Physical and Chemical Characteristics of Warmwater Streams: A Review," In: L. A. Krumholz (ed.),* The Warmwater Streams Symposium*, American Fisheries Society, Bethesda, Maryland, 1981, pp. 32-44.*

[31]*V.R. Hasfurther, "The Use of Meander Parameters in Restoring Hydrologic Balance to Reclaimed Stream Beds," In: J.A.. Gore,* The Restoration of Rivers and Streams*, Butterworth Publishing, Boston, 1985*, *pp. 21-40.*

[32]*J.L. Funk, "Characteristics of Channels for Warmwater Fisheries," In: Soil Conservation Society of America,* Plants, Animals and Man. Proceedings of the 28th Annual Meeting of the Soil Conservation Society of America*, Ankeny, Iowa, 1973*, *pp. 55-61.*

Historically, streams and rivers have been channelized for a number of reasons. A major reason for the channelization of many streams in southeastern Wisconsin was to create more land area usable for agriculture, roads, or other purposes immediately adjacent to the stream. Other reasons for channelization of streams are related to stormwater control. Many streams were channelized in an attempt to improve the drainage of precipitation off land with a resulting improvement in stormwater control and reduction of flooding in the areas adjacent to the channelized sections. In addition, larger rivers were often channelized to make them more suitable for navigation. Finally, many streams were channelized and lined in order to reduce the potential for migration of the stream channel.

Channelization can produce a number of effects on the hydrology of a stream or river. Because straightening the channel reduces its total length without decreasing the elevation through which the stream must drop, channelization often results in an increase of the stream's gradient and an accompanying increase in the speed at which water moves downstream through the channel. This increase in stream velocity can have major effects on the stability of the channel. Unless the streambank is well-protected, the higher water velocity may result in erosion and degradation of the bank and an increase in the sediment load carried by the stream. The sediment mobilized by this degradation will be deposited downstream, covering coarse substrates and filling pools and holes in the bed.[33] As a result, the width of the channel will increase while the depth of the channel decreases. When the stream bank is well-protected, scouring of the existing channel can occur, leading to erosion of the streambed. This erosion, referred to as headcutting, tends to move from downstream to upstream. This will also lead to increased sediment loads and deposition of sediment downstream[34] and can result in an increase in channel width and a decrease in channel depth in the downstream reach. These changes in channel geometry tend to disrupt the pool-riffle structure of the stream, resulting in a decrease in heterogeneity in channel width and depth and flow patterns. In addition, the higher stream velocities that result from channelization hasten the conveyance of water through the stream. This can result in lower base flows during dry periods and flashier flows during high water events. These changes resulting from channelization reflect the stream's tendency to return to a more gradual slope and may be accompanied by effects in areas of the stream well upstream and downstream of the channelized section.[35] Finally, lining a channel with concrete significantly impairs the ability for the channel to interact with the groundwater. The ability of the stream to buffer itself through infiltration from the channel to the groundwater is almost completely eliminated and the maintenance of a longitudinally distributed base flow is disrupted because the concrete lining presents a barrier to groundwater inflow along the channel length, with baseflow from groundwater only allowed to enter the channel through drains in the concrete sides or bed.

While channelization can be an effective means of reducing flood damages, it may entail high aesthetic and ecological costs. Furthermore, because of decreased floodplain storage and increased streamflow velocities resulting from channelization, channel modifications tend to increase downstream flood discharges and stages, and, therefore, may cause new flood problems or exacerbate existing ones. It is possible, however, depending on the relative position of the channelized reach or reaches in the watershed stream system, for channelization to result in reduced downstream discharges. Channelization in the lower reaches of a watershed or subwatershed may provide for the rapid removal of runoff from the lower reaches prior to the arrival of runoff from the middle and upper portions of the watershed or subwatershed, thereby reducing peak discharges and stages in the lower reaches.

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[33]*L.W. Jackson and R.I. Beschta, "Influences of Increased Sand Delivery on the Morphology of Sand and Gravel Channels,"* Water Resources Bulletin, *Volume 20, 1984, pp.527-533.*

[34]*R. Newbury and M. Gaboury, "The Use of Natural Stream Characteristics for Stream Rehabilitation Works Below the Manitoba Escarpment," Manitoba Department of Natural Resources Fisheries Branch Report No. 87-25, 1987.*

[35]*N.R. Nunnally, "Application of Fluvial Relationships to Planning and Design of Channel Modifications,"* Environmental Management, *Volume 9, 1985, pp. 417-427.*

The changes in hydrology resulting from channelization can have profound effects on the suitability of a stream as habitat for fish and other aquatic organisms.[36] Increased stream velocity resulting from higher gradient may make the stream unsuitable as habitat for fish and invertebrate species that cannot tolerate fast-moving water.[37] Deposition of fine sediments over coarser substrates can adversely impact fish habitat and fish populations in warmwater streams.[38] It can reduce these substrates' food-producing capabilities and make the substrates unsuitable as spawning habitat for fish. In addition, many gamefish species require the deeper water found in pools as habitat. Sediment deposition in pools can reduce the size and number of these deeper habitats. The removal of large woody debris and boulders from the channel during channelization also reduces the amount of cover and food-producing areas available to gamefish.[39] Finally, the removal of vegetation from along the streambank that often accompanies channelization can result in a reduction in cover and food for wildlife.

Dams, Culverts, and Other Structures

Structures commonly found along streams in the regional water quality management plan update study area include dams, culverts, and bridges. The presence of these structures can result in a number of hydrological and ecological effects within a watershed.

Historically, dams have been built for a number of reasons, including: flood control; creation of reservoirs for water supply, recreation, fire control, and agricultural uses; capture of energy to run mills or electrical turbines; and increasing stream depth for navigation.

Functionally, there are two general types of dams: those that store water and those that do not. Water-storing dams create impoundments which hold water upstream. Some of this stored water may be released from the dam on a schedule determined by the operator of the dam. The amount and timing of this release is dependent upon the purposes of the dam. The size of a water-storing dam can be characterized by the amount of water stored in its impoundment. Nonwater-storing dams, or run of river dams, are designed either to raise the water level upstream or to divert flow for distribution away from the stream.

The effects that a dam has on a watercourse depends upon the type, size, and operation of the dam. The presence of a dam on a stream can produce several effects. Dams can change the pattern of sediment transport and distribution in a stream. Typically, suspended sediment is deposited in the reservoir upstream of a dam. This results in less sediment being transported to downstream reaches, and can ultimately lead to increases in erosion and armoring of the channel in downstream reaches. Water-quality characteristics in reservoirs often resemble those of lacustrine systems more than those of running water systems. For example, water temperature in a reservoir may be altered through solar insolation. This change may include temperature stratification of the reservoir. The location of where water is removed from the reservoir can lead to either higher or lower water temperatures in downstream reaches of the stream. In addition, oxygen and nutrients may be removed from water

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[36]*John Lyons and Cheryl C. Courtney, "A Review of Fisheries Habitat Improvement Projects in Warmwater Streams, with Recommendations for Wisconsin,"* Wisconsin Department of Natural Resources Technical Bulletin No. 169, *1990.*

[37]Ibid.

[38]*H.E. Berkman and C.F. Rabeni, "Effect of Siltation on Stream Fish Communities,"* Environmental Biology of Fishes, *Volume 18, 1987, pp. 285-294.*

[39]*D.D. McClendon and C.F. Rabeni, "Physical and Biological Variables Useful for Predicting Population Characteristics of Smallmouth Bass and Rock Bass in an Ozark Stream,"* North American Journal of Fisheries Management, *Volume 7, 1987, pp. 46-59; P.L. Angermeier and J.R. Karr, "Relationships Between Woody Debris and Fish Habitat in a Small Warmwater Stream"* Transactions of the American Fisheries Society, *Volume 113, 1984, pp. 716-726.*

in the reservoirs through biological processes similar to those found in lakes. The presence of a dam can also adversely impact aquatic organisms. Fish can be killed as they pass through or over dams. Finally, by posing a barrier to movement, dams can act to fragment populations of organisms and cut organisms off from habitat needed for feeding, cover, or reproduction.

The operation of a dam can also affect the hydrology and ecology of a stream. The patterns of water release determined by the operator can alter fundamental characteristics of flow in the stream, including the magnitudes and frequencies of peak flows, mean flows, and base flows; the timing or seasonality of peak and low flows; and the rate of change between high and low flows. These changes in flow patterns can cause changes in stream morphology and water quality downstream of the dam. Some of these downstream effects can be mitigated by changes in operations designed to more accurately mimic seasonal flow rates.

Depending on the size of the waterway opening and the characteristics of the approaches, bridges and culverts can be important elements in the hydraulics of a watershed, particularly with respect to localized effects. The constriction caused by a bridge and culvert under flood discharge conditions can result in a large backwater effect and thereby create upstream flood stages that are significantly higher, and an upstream floodland that is significantly larger, than would exist in the absence of the bridge or culvert.

Culverts can fragment populations of organisms by acting as obstructions to passage. High water velocities, low water depths, elevated outlets, and blocked outlet pools resulting from inappropriately designed or installed culverts can act as barriers to fish passage, effectively cutting fish off from habitat needed for feeding, cover, or reproduction. Over time, this can act to exclude fish from portions of the stream. Aquatic invertebrates may also be adversely impacted by the presence of culverts. For example, the presence of culverts was found to impede recolonization of upstream reaches by caddisflies.[40]

Streambank Conditions

Both physical characteristics and water quality parameters are pertinent to characterization of the stream habitat in each of the watersheds in the study area. The combination of this information (physical characterization and water quality) will provide insight as to the ability of the stream to support a healthy aquatic community, and to the presence of chemical and nonchemical stressors to the stream ecosystem. A description of the water quality parameters used in the regional water quality management update planning effort is set forth in the "Water Quality Indicators" section of this chapter. Physical characterization includes documentation of general land use; description of the stream type; summary of the riparian vegetation and streambank condition features; and measurements of instream parameters, such as width, depth, flow, and substrate.

Streambank condition is largely determined by bank stability, which is a measure of whether the stream banks are eroded (or have the potential for erosion). Steep banks are more likely to collapse and erode than are gently sloping banks. Signs of erosion include crumbling, unvegetated banks, exposed tree roots, and exposed soil. Eroded banks indicate problems resulting from sediment movement and deposition, and suggest scarcities of cover for stream organisms and organic input to streams.

Another important issue that affects streambank condition is the amount of vegetative protection afforded to the streambank and the near-stream portion of the riparian zone. The root systems of plants growing on stream banks help hold soil in place, thereby reducing the amount of erosion that is likely to occur. Evaluation of streambank condition provides information on the ability of the bank to resist erosion as well as information on the uptake of nutrients by the plants, the control of instream scouring, and stream shading. Banks that have full, natural plant growth provide better habitat for fish and macroinvertebrates than banks without vegetative protection or banks that are shored up with concrete or riprap. Evaluation of streambank condition can be made more effective by

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[40]*T.J. Blakely, J.S. Harding, and A.R. McIntosh, "Impacts of Urbanization on Okeover Stream, Christchurch, NZ," Council Report, University of Canterbury, Christchurch, New Zealand, 2003.*

comparing the vegetation present to the native vegetation for the region and stream type. In some regions, the introduction of exotic plants has resulted in the displacement of native vegetation. In areas of high grazing pressure from livestock or where residential and urban development activities disrupt the riparian zone, the growth of a natural plant community is impeded and can extend to the bank vegetative protection zone.

Maintenance of Instream Flow

The maintenance of adequate instream baseflow is essential to supporting aquatic and riparian habitat. The quantity of baseflow can be influenced by several factors, including 1) low flow conditions resulting from periods of drought, 2) the loss of groundwater recharge areas through the introduction of impervious surfaces in a watershed without mitigating features for infiltration of rainfall, and 3) loss of instream flow through consumptive withdrawals.

HABITAT AND RIPARIAN CORRIDOR CONDITIONS

Habitat and riparian corridor conditions are strongly influenced by the width and nature of the buffers adjacent to a waterbody and are an important best management practice with regard to protecting water from contamination by nonpoint source pollutants. There are many different kinds of buffers. While these buffers may be applied to a variety of situations and called different names, their functions are much the same—improve and protect surface water and groundwater; reduce erosion on cropland, streambanks, lakes, and wetlands; and provide protection and cover for plants, insects, fish, birds, amphibians and reptiles, and mammals. Types of buffers include, but are not limited to, riparian buffers that consist of streamside or lakeshore plantings of trees, shrubs, and grasses that can intercept contaminants from surface water runoff before they reach the waterbody to reduce the loads of pollutants entering the system. Filter strips or grassed waterways are also types of buffers that utilize strips of grass adjacent to or within areas of cropland to intercept or trap field sediment, organics, pesticides, and other potential pollutants, as well as to prevent gully erosion.

Buffers can be used for a variety of purposes from reducing water temperature entering streams to enhancing species diversity, and buffer size may vary widely, depending on the specific functions required for a particular buffer as shown in Figure 7. Researchers have generally found that buffers that have widths in the 15- to 30-foot range provide limited protection of aquatic resources under most conditions.[41] Under most circumstances, a minimum buffer width of about 50 to 100 feet is necessary to protect wetlands and streams. In general, minimum buffer widths in the 50- to 65-foot range would be expected to provide for the maintenance of the natural physical and chemical characteristics of aquatic resources. Buffer widths at the upper end of the 50- to 100-foot range seem to be necessary for the maintenance of the biological components of many wetland and stream systems. It is important to note, however, that site-specific conditions, such as slope, vegetation, and soil characteristics, can greatly influence the need for either wider or narrower buffers.

Primary and secondary environmental corridors and isolated natural resource areas, each of which is described below, have many beneficial functions related to water resource protection and preservation, including the provision of riparian buffer areas.

Primary and Secondary Environmental Corridors

One of the most important tasks completed under the regional planning effort has been the identification and delineation of those areas of the Region in which concentrations of recreational, aesthetic, ecological, and cultural resources occur, resources which should be preserved and protected. Such areas normally include one or more of the following seven elements of the natural resource base which are essential to the maintenance of both the ecological balance and natural beauty of the Region: 1) lakes, rivers, and streams and their associated shorelands and floodlands, 2) wetlands, 3) woodlands, 4) prairies, 5) wildlife habitat areas, 6) wet, poorly drained, or organic

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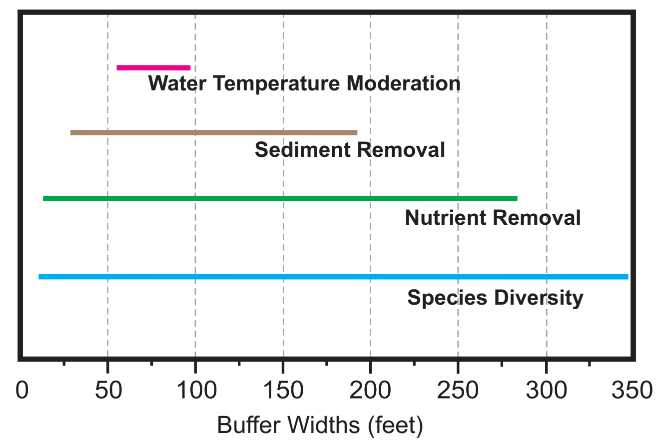
[41] *A.J. Castelle and others, "Wetland and Stream Buffer Size Requirements-A Review," Journal of Environmental Quality, Vol. 23, 1994.*

soils, and 7) rugged terrain and high-relief topography. While the foregoing elements comprise the integral parts of the natural resource base, there are five additional elements which, although not part of the natural resource base *per se*, are closely related to, or centered on, that base and are a determining factor in identifying and delineating areas with recreational, aesthetic, ecological, and cultural value: 1) existing park and open space sites, 2) potential park and open space sites, 3) historic sites, 4) significant scenic areas and vistas, and 5) natural and scientific areas. The delineation of these 12 natural resource and natural resource-related elements on a map results in a pattern of relatively narrow, elongated areas which have been termed "environmental corridors" by the Commission.[42]

Figure 7

RANGE OF BUFFER WIDTHS FOR PROVIDING SPECIFIC BUFFER FUNCTIONS



NOTE: Site-specific evaluations are required to determine the need for buffers and specific buffer characteristics.

Source: Adapted from A. J. Castelle and others, "Wetland and Stream Buffer Size Requirements-A Review," Journal of Environmental Quality, Vol. 23.

Primary Environmental Corridors

Primary environmental corridors include a wide variety of such important resource and resource-related elements and are at least 400 acres in size, two miles in length, and 200 feet in width. The primary environmental corridors in the regional water quality management plan update study area are primarily located along major stream valleys, around major lakes, and along the northern Kettle Moraine. These primary environmental corridors contain almost all of the best remaining woodlands, wetlands, and wildlife habitat areas in the study area, and represent a composite of the best remaining elements of the natural resource base.

Secondary Environmental Corridors

Secondary environmental corridors connect with primary environmental corridors, and are at least 100 acres in size and one mile in length. Secondary environmental corridors are generally located along the small perennial and intermittent streams within the regional water quality management plan update study area. Secondary environmental corridors also contain a variety of resource elements, often remnant resources from primary environmental corridors which have been developed for intensive urban or agriculture purposes. Secondary environmental corridors facilitate surface water drainage, maintain pockets of natural resource features, and provide corridors for the movement of wildlife, as well as for the movement and dispersal of seeds for a variety of plant species.

Isolated Natural Resource Areas

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 within the regional water quality management plan update study area. These natural areas, which are at least five acres in size, are referred to as isolated natural resource areas. Isolated natural resource areas may provide the only available wildlife habitat in an area, provide good locations for local parks and nature study areas, and lend unique aesthetic character or natural diversity to an area. These isolated natural resource areas should also be protected and preserved in their natural state whenever possible.

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[42]*A detailed description of the process of delineating environmental corridors in southeastern Wisconsin is presented in the March 18 issue (Volume 4, No. 2) of the* SEWRPC Technical Record, *May 1981*.

Natural Areas Habitat

Natural areas, as defined by the Wisconsin Natural Areas Preservation Council, are tracts of land or water so little modified by human activity, or sufficiently recovered from the effects of such activity, that they contain intact native plant and animal communities believed to be representative of the pre-European settlement landscape. Natural areas are classified into one of the following three categories:

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

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

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

Classification of an area into one of these three categories is based upon consideration of several factors. These factors include the diversity of plant and animal species and community types present; the structure and integrity of the native plant or animal community; the extent of disturbance by human activity, such as logging, grazing, water level changes, and pollution; the commonness of the plant and animal communities present; any unique natural features within the area; the size of the area; and the educational value. Natural areas form an element of the wildlife habitat base of the Study area.

BIOLOGICAL CONDITIONS

Warmwater and Coldwater Fish Communities

The majority of streams in the regional water quality management plan update study area are warmwater and generally low gradient, although some short moderate-gradient stretches with well-developed pool-riffle structure occur and there are some coldwater streams, primarily in the northern portions of the study area. The headwater area streams (first- and second-order) are generally too small to support sportfish on a permanent basis, but they are capable of supporting forage fish species. It is important to note that many headwater streams are frequently utilized during the spring high-water flow season by sport fishes, such as northern pike as spawning and juvenile rearing areas. Further downstream in the stream networks (third- through fifth-order) the streams are large enough to have the potential to hold fishable populations of sport fish species.

In Wisconsin, high-quality warmwater streams are characterized by many native species, darters, suckers, sunfish, and intolerant species (species that are particularly sensitive to water pollution and habitat degradation). Tolerant fish species are capable of persisting under a wide range of degraded conditions and are also typically present within high-quality warmwater streams, but they do not dominate. Tolerant species may also include nonnative fishes, such as carp, as well many native species, such as bullheads and creek chubs. Insectivores (fish that feed primarily on small invertebrates) and top carnivores (fish that feed on other fish, vertebrates, or large invertebrates) are generally common. Omnivores (fish that feed on both plant and animal material) are also generally common, but do not dominate. Simple lithophilous spawners which are species that lay their eggs directly on large substrate, such as clean gravel or cobble, without building a nest or providing parental care for the eggs are also generally common. Deformities, eroded fins, lesions, or tumors on fish species in high-quality streams are generally few to none, but they may be found to varying degrees in lower-quality streams.

Coldwater streams are characterized by water temperatures that remain cool throughout the year and by the presence of or the potential to support trout. In Wisconsin, coldwater streams have a maximum daily mean temperature below 72 degrees and a maximum instantaneous temperature below 77 degrees. These temperatures are typically maintained by groundwater inputs. Since the solubility of oxygen in water increases with decreasing water temperature, coldwater streams also tend to have higher concentrations of dissolved oxygen. Coldwater streams also tend to have lower productivity than warm water systems. Other species found in coldwater streams include mottled sculpin, blacknose dace, creek chub, and johnny darter. A variety of macroinvertebrate species are typically found in high quality coldwater streams, including mayflies, caddisflies, and stoneflies.[43]

Both the warmwater IBI[44] and coldwater IBI[45] were used to assess the fishery among warmwater and coldwater streams as appropriate to classify the fisheries and environmental quality throughout the Greater Milwaukee watersheds study area.

The warmwater IBI consists of a series of fish community attributes that reflect the characteristics of biotic assemblages: species richness and composition, trophic and reproductive function, and individual abundance and condition.[46] The Wisconsin IBI described here consists of 10 basic metrics, plus two additional metrics (termed "correction factors") that affect the index only when they have extreme values. Although the fish IBI is useful for assessing environmental quality and biotic integrity in warmwater streams, it is most effective when used in combination with additional data on physical habitat, water quality, macroinvertebrates, and other biota when evaluating a site.[47]

In contrast to warmwater streams, coldwater systems are characterized by few native species, with salmonids (trout) and cottids (sculpin) dominating, and they lack many of the taxonomic groups that are important in high-quality warmwater streams as summarized above. An increase in fish species richness in coldwater fish assemblages often indicates environmental degradation. When degradation occurs the small number of coldwater species are replaced by a larger number of more physiologically tolerant cool and warmwater species, which is the opposite of what tends to occur in warmwater fish assemblages. Due to the fundamental differences between warmwater versus coldwater streams a separate IBI was developed to assess the health of coldwater streams.[48] This coldwater IBI is based upon the following elements: number of intolerant species, percent of individuals that are tolerant, percent of all individuals that are top carnivore species, percent of all individuals that are native or exotic coldwater (coho salmon, chinook salmon, rainbow trout, brown trout) or coolwater species, and percent of salmonid individuals that are brook trout. Since brook trout are the only native stream-dwelling salmonid in the State of Wisconsin, the presence and abundance of brook trout dramatically improves the coldwater IBI scores.

Coldwater streams in the regional water quality management plan update study area that are designated as such in Chapter NR 102, "Water Quality Standards For Wisconsin Surface Waters," of the *Wisconsin Administrative Code* include Auburn Lake Creek, Chambers Creek, Gooseville Creek, Melius Creek, Nichols Creek, and Watercress Creek in the Milwaukee River Watershed. In addition, studies of Mole Creek indicate that it also exhibits coldwater stream characteristics, although it has not been officially designated as such in the *Administrative Code*.

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[43]*This report uses common names for flora and fauna. Scientific names corresponding to the common names are set forth in Appendix A.*

[44]*John Lyons, "Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin," United States Department of Agriculture,* General Technical Report NC-149, *1992.*

[45]*John Lyons, "Development and Validation of an Index of Biotic Integrity for Coldwater Streams in Wisconsin,"* North American Journal of Fisheries Management, Volume 16, May 1996.

[46]*John Lyons,* General Technical Report NC-149, op. cit.

[47]Ibid.

[48]*John Lyons, "Development and Validation of an Index of Biotic Integrity for Coldwater Streams in Wisconsin,"* op. cit.

Sportfish and Forage Fish Communities
Sportfish communities include those supporting game fish as well as those supporting panfish. By Wisconsin law, game fish are defined as all varieties of fish except rough fish and minnows. Rough fish include dace, suckers, carp, goldfish, redhorse, freshwater drum, burbot, bowfin, gar, and buffalo, among others. Minnows include mud minnow, madtoms, stonecat, killifish, stickleback, trout perch, darters, sculpins, and all species in the minnow family (except goldfish and carp).[49] "Panfish" is a common term applied to a broad range of smaller fish with a relatively short and usually broad shape and the term applies to the following fish species: yellow perch, bluegill, black crappie, white crappie, pumpkinseed, green sunfish, warmouth, and orangespotted sunfish.

Forage fish communities are a major food source for a variety of fishes in all healthy cold and warmwater stream and lake systems. Forage fishes are also often present in streams that are too small to permanently support sportfish communities, which tend to support the larger downstream fisheries communities. Forage fish are a complex combination of species that typically do not grow over six inches in length (e.g., minnows), as well as the young-of-year or juveniles of larger rough fish (e.g., white sucker) and sportfish (e.g., largemouth bass) species. Hence, all species of fishes serve as forage fish at some point in their life history, and they are vulnerable to predation by other fishes, until some individuals achieve a size large enough to reduce their vulnerability to predation, and sometimes become predators themselves.

Macroinvertebrates
Macroinvertebrates are animals without backbones that can be seen without a microscope. A number of different macroinvertebrate species spend all or part of their lives in aquatic environments. Major groups include mollusks, such as snails and mussels, crustaceans, such as crayfish and scud, and insects, such as mayflies, stoneflies, caddisflies, and dragonflies. The different species of macroinvertebrates found in aquatic habitats exhibit a variety of life cycles, habitat preferences, feeding modes, and preferences.

In streams, many macroinvertebrate species utilize particulate organic matter, such as leaves and twigs that enter the stream from the adjacent terrestrial environment as a source of energy and nutrients. This acts to pass much of the energy and nutrients in this material into the stream community's food web. In addition, many macroinvertebrate species serve as food for other organisms, including fish.

Macroinvertebrates are useful indicators of water quality because they spend much of their life in the waterbody, they are not highly mobile, they are easily sampled, and the references needed to identify them to a useful degree of taxonomic resolution are readily available. In addition, the differences among macroinvertebrate species in habitat preferences, feeding ecology, and environmental tolerances allows the quality of water and habitat in a waterbody to be evaluated based upon which groups are present and what their relative abundances are. The differences among macroinvertebrate species in feeding ecology are often represented through the classification of species into functional feeding groups based on the organisms' principal feeding mechanisms.[50] Several groups have been described. Scrapers include herbivores and detritivores that graze microflora and fauna attached to mineral, organic, or plant surfaces. Shredders include detritivores and herbivores that feed primarily on coarse particulate organic matter. Collectors feed on fine particulate organic matter. This group includes filterers which remove suspended material from the water column and gatherers which utilize material deposited on the substrate.

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[49] *Wisconsin Department of Natural Resources,* Guide to Wisconsin Hook and Line Fishing Regulations 2005-2006*, Effective April 1, 2005 through March 31, 2006.*

[50] *Kenneth W. Cummins, "Trophic Relations of Aquatic Insects,"* Annual Review of Entomology, *Volume 18, 1973; K.W. Cummins and M.J. Klug, "Feeding Ecology of Stream Invertebrates,"* Annual Review of Ecology and Systematics, *Volume 10, 1979.*

A variety of metrics have been developed and used for evaluating water quality based upon macroinvertebrate assemblages.[51] These include metrics based on taxa richness, trophic function, relative abundance of the dominant taxa, and diversity, as well as more complicated indices. Most work on these metrics has been done for stream systems, though some macroinvertebrate metrics are being developed for other aquatic environments (e.g., wetlands).[52]

Effects of Urbanization and Agriculture on Instream Biological Communities

Researchers evaluated 134 sites on 103 streams throughout the State of Wisconsin and have found that the amount of urban land use upstream of sample sites had a negative relationship with biotic integrity scores, and there appeared to be a threshold of about 10 percent directly-connected impervious cover where IBI scores declined dramatically.[53,54] Fish IBI scores were found to be good to excellent below this threshold, but were consistently rated as poor to fair above this threshold. They also found that habitat scores were not tightly associated with degraded fish community attributes in the studied streams. Wisconsin researchers also found that the number of trout per 100 meters in coldwater streams dramatically decreased at a threshold of 6 percent imperviousness, and no trout were observed in cold water streams in watersheds with greater than 11 percent imperviousness.[55] Wang and others also studied 47 small streams in 43 watersheds in southeastern Wisconsin to retrospectively analyze fisheries and land use data from between 1970-1990.[56] This allowed them to determine the historical changes in land uses as provided by SEWRPC and the changes in the fishery over the two decades. Streams that were already extensively urbanized as of 1970 had fish communities characterized as highly tolerant with low species richness. As these areas urbanized even more, the fish communities changed little since they were already degraded. In contrast, stream sites that had little urbanization (characterized by connected imperviousness) in 1970 that were urbanizing by 1990, showed decreases in the fishery community quality. This study further supported major differences at the 10 percent impervious cover threshold, with poorer fisheries quality generally reported for stream sites above this threshold. In addition, numerous studies over different ecoregions and using various techniques have revealed that as watersheds become highly urban, aquatic diversity becomes extremely degraded.[57]

In addition to increases in the amount of impervious land cover that are associated with urbanization, urban development has also often been accompanied by alteration, or loss of wetlands; disturbance or reductions in the

[51]*Richard A. Lillie, Stanley W. Szczytko, and Michael A. Miller,* Macroinvertebrate Data Interpretation Manual, *Wisconsin Department of Natural Resources, PUB-SS-965 2003, Madison, Wisconsin, 2003.*

[52]*Richard A. Lillie, "Macroinvertebrate Community Structure as a Predictor of Water Duration in Wisconsin Wetlands,"* Journal of the American Water Resources Association, *Volume 39, 2003, pp. 389-400.*

[53]*L. Wang, J. Lyons, P. Kanehl, and R. Gatti, "Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams,"* Fisheries*, Volume 22, 1997.*

[54]*Directly connected impervious area is area that discharges directly to the stormwater drainage system without the potential for infiltration through discharge to impervious surfaces or facilities specifically designed to infiltrate runoff.*

[55]*Personal communication, L. Wang, Wisconsin Department of Natural Resources.*

[56]*L. Wang, J. Lyons, P. Kanehl, R. Bannerman, and E. Emmons, "Watershed Urbanization and Changes In Fish Communities In Southeastern Wisconsin Streams,"* Journal of the American Water Resources Association*, Volume 36, No. 5, 2000.*

[57]*Center for Watershed Protection, Watershed Protection Research Monograph No. 1,* Impacts of Impervious Cover on Aquatic Systems, *March 2003.*

sizes of riparian corridors; stream channel modification, including straightening and lining with concrete; and occasional spills of hazardous materials. All of these factors contribute to degradation of fish communities and of aquatic diversity. The following list describes approaches to mitigating the adverse effects of these factors.

- The impacts of increased imperviousness can be mitigated through the provision of stormwater best management practices that promote infiltration of rainfall and runoff, thereby increasing stream baseflow and lowering water temperatures; that control peak rates of runoff; and that remove nonpoint source pollutants from runoff prior to discharge to receiving streams.

- While alteration and loss of wetlands occurred in the past, that trend has been changed in Wisconsin through enforcement of local shoreland and wetland zoning ordinances, navigable waters protection by the Wisconsin Department of Natural Resources under Chapter 30 of the *Wisconsin Statutes*, and application of wetland water quality standards under Chapter NR 103 of the *Wisconsin Administrative Code*.

- As noted above, the Regional Planning Commission has identified and delineated environmental corridors which function as riparian buffers.

- In some cases, such as the Milwaukee Metropolitan Sewerage District's Lincoln Creek environmental restoration and flood control project, it may be possible to partially reverse the effects of channel straightening and lining with concrete.

- Finally, although by their very nature the occurrence of hazardous spills is difficult to control, Chapter 292 of the *Wisconsin Statutes* establishes the legal basis for actions to mitigate the effects of such spills.

Researchers in Wisconsin have also found that the amount of agricultural land use upstream of sample sites had a negative relationship with biotic integrity scores, and there appeared to be a threshold of about 50 percent for agricultural land use where IBI scores declined dramatically.[58] A separate study looking at the effects of multi-scale environmental characteristics on agricultural stream biota in Eastern Wisconsin demonstrated a strong negative correlation between Fisheries IBI and increased proportion of agricultural land ranging from 0 to 80 percent within watersheds, which indicates that, as the percent of agricultural land increased, the resultant fishery community decreased in abundance and diversity.[59] This study also discovered a positive relationship between Fisheries IBI and increased riparian buffer vegetation width, which implies that, by analogy, the impacts of increased urban land use can also be mitigated by an increased riparian buffer that acts to protect the stream aquatic biota. A follow up study investigating the influence of watershed, riparian corridor, and reach scale characteristics on aquatic biota in agricultural watersheds found that land use within the watershed, the presence of riparian corridors, and fragmentation of vegetation were the most important variables influencing fish and macroinvertebrate abundance and diversity.[60] In addition, combined upland BMPs that included barnyard runoff

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[58] *L. Wang, J. Lyons, P. Kanehl, and R. Gatti, "Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams,"* Fisheries*, Volume 22, 1997.*

[59] *F. Fitzpatrick, B. Scudder, B. Lenz, and D. Sullivan, "Effects of Multi-Scale Environmental Characteristics on Agricultural Stream Biota in Eastern Wisconsin,"* Journal of the American Water Resources Association*, Volume 37, No. 6, 2001.*

[60] *J. Stewart, L. Wang, J. Lyons, J. Horwatich, and R. Bannerman, "Influence of Watershed, Riparian Corridor, and Reach Scale Characteristics on Aquatic Biota in Agricultural Watersheds,"* Journal of the American Water Resources Association*, Volume 37, No. 6, 2001.*

controls; manure storage; contour plowing and reduced tillage; and riparian BMPs that included streambank fencing, streambank sloping, and limited streambank riprapping were shown to significantly improve overall stream habitat quality, bank stability, instream cover for fishes, and fish abundance and diversity.[61] Improvements were most pronounced at sites with riparian BMPs. At sites with limited upland BMPs installed in the watershed there were no improvements in water temperature or the quality of fish community.

Figure 8

ALEWIFE (*Alosa pseudoharengus*)

Source: Shawn Good, Vermont Department of Fish & Wildlife.

Exotic Invasive Species

A noticeable feature of the waterbodies on the post-European-settlement landscape of southeastern Wisconsin is the large number of exotic organisms, that is, nonnative species of plants and animals that have become naturalized, or established and capable of reproducing. In cases where their introduction has caused or is likely to cause economic or environmental harm or harm to human health, exotic species may be considered invasive. Typically, populations of exotic invasive species can grow rapidly, due to both the high reproductive capacities of these organisms and the absence of predators, parasites, pathogens, and competitors from their new habitat. Once established in a waterbody, these species can rarely be eliminated. In addition, many of these species are capable of readily dispersing to other waterbodies. In many cases, this dispersal is aided by direct or indirect human intervention.

The presence of an exotic invasive species in a habitat can produce alterations in physical and biological characteristics of an aquatic habitat. For example, many of these species are capable of producing dense populations, which can crowd out native species. Similarly, feeding by some of these species can have marked impacts on water clarity. In addition, many of these species are strong competitors for nutrients, space, and other resources, allowing them to displace native species from habitats.

Fish

Alewife

The alewife (Figure 8) is a pelagic fish native to the Atlantic Ocean which has invaded the Great Lakes. The alewife was first detected in Lake Michigan in 1949. By 1953, it had spread throughout the Lake. During the late 1950s and early 1960s it went through explosive population growth, reaching nuisance levels by about 1957. By 1967, about 90 percent of the fish biomass in Lake Michigan consisted of alewife.[62]

Several aspects of the biology of alewife contribute to its potential to be a nuisance species. Alewives commonly form large schools. While they are primarily zooplanktivorous, they also feed on crustaceans, such as *Mysis* and *Diporeia,* and upon the eggs of other fish, crustaceans, and insects. In addition, they feed upon fish fry and larvae, including larval yellow perch.[63] Alewife populations in the Great Lakes are subject to periodic mass die-offs,

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[61]*L. Wang, J. Lyons, and P. Kanehl, "Effects of Watershed Best Management Practices on Habitat and Fish in Wisconsin's Streams,"* Journal of the American Water Resources Association*, Volume 38, No. 3, 2002.*

[62]*E.H. Brown, Jr., "Population Biology of Alewives,* Alosa pseudoharengus, *in Lake Michigan: 1949-1970,"* Journal of the Fisheries Research Board of Canada, *Volume 29, 1972, pp. 477-500.*

[63]*Doran M. Mason and Stephen B. Brandt, "Effects of Alewife Predation on Survival of Larval Yellow Perch in an Embayment in Lake Ontario,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 53, 1996, pp. 1609-1617.*

Figure 9

CARP (*Cyprinus Carpio*)

Source: Rob Cosgriff, Illinois Natural History Survey.

involving large portions of the population. For example, about 70 percent of the alewives in Lake Michigan died in the 1967 die-off.[64] The reasons for these mass die-offs are not well understood. They have been attributed to a number of factors, including osmotic stress associated with living in a freshwater habitat, weakened condition due to lack of forage during the winter, stress related to spawning, nutritional deficiency due to a low concentration of iodine in freshwater, and stress from the rapid temperature changes they experience when moving into nearshore areas to spawn.

Several problems are associated with the presence of alewives in Lake Michigan. The presence of alewives has had an adverse impact on a number of native species in the Lake. Declines in the abundances of emerald shiner, deepwater sculpin, bloater, and yellow perch have been attributed to competition from alewives.[65] In addition, alewife predation on lake trout fry may represent a serious impediment to lake trout rehabilitation in Lake Michigan.[66] Alewife mass die-offs cause aesthetic and hygienic problems as dead alewives accumulate and decay along the shoreline. In addition, the bodies of these fish can clog water intakes at power plants and water utilities during die-offs.

The main measure used to control alewife populations in Lake Michigan has been the introduction of a number of salmonid species, including coho salmon, chinook salmon, brown trout, and rainbow trout into the Lake. Large-scale stocking efforts began in the mid-1960s and continue to the present time. By the early 1980s, predation by salmonids had reduced alewife abundances in the Lake to much lower levels.

Since 1995, the alewife physiological condition in Lake Michigan has declined.[67] There are currently concerns about whether the size of the alewife population and the rate of alewife reproduction in Lake Michigan are adequate to support the salmon fishery.

Carp

The common carp (Figure 9), a native of Asia, is an aggressive exotic fish species that was deliberately introduced into Wisconsin waters in the last decades of the 19th century. By 1885 it was well established in the

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[64]*L. Wells and A. L. McLain, "Lake Michigan: Effects of Exploitation, Introductions, and Eutrophication on the Salmonid Community,"* Journal of the Fisheries Research Board of Canada, *Volume 29, 1972, pp. 889-898.*

[65]*L. Wells and A.L McLain,* Lake Michigan—Man's Effects on Native Fish Stocks and Other Biota, *Great Lakes Commission Technical Report No. 20, 1973.*

[66]*C.C. Krueger, D.L. Perkins, E.L. Mills, and J.E. Marsden, "Predation by Alewives on Lake Trout Fry in Lake Ontario: Role of an Exotic Species in Preventing Restoration of a Native Species,"* Journal of Great Lakes Research, *Volume 21, Supplement 1, 1995, pp. 458-469.*

[67]*C.P. Madenjian, G.L. Fahnenstiel, T.H. Johengen, T.F. Nalepa, H.A. Vanderploeg, G.W. Fleischer, P.J. Schneeberger, D.M. Benjamin, E.B. Smith, J.R. Bence, E.S. Rutherford, D.S. Lavis, D.M. Robertson, D.J. Jude, and M.P. Ebener, "Dynamics of the Lake Michigan Food Web, 1970-2000,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 59, 2002, pp. 736-753.*

Figure 10

BIGHEAD CARP (*Hypophthalmichtys nobilis*)

Source: John Lyons, Wisconsin Department of Natural Resources.

Figure 11

SILVER CARP (*Hypophthalmichtys molirix*)

Source: John Lyons, Wisconsin Department of Natural Resources.

State.[68] Tolerant of a wide range of ecological conditions, the common carp is most abundant in large, shallow lakes. It prefers warm waters with abundant aquatic vegetation and can survive in polluted waters with low dissolved oxygen concentrations and high temperatures. It is not usually found in clean, cold waters.

Carp populations can produce a number of changes in waterbodies. Through their feeding activity they destroy aquatic vegetation and resuspend sediment. This can lead to increases in temperature and decreases in light penetration and dissolved oxygen concentration. In addition, the resuspension of sediment may transfer nutrients to the water column, leading to increased algal growth. These changes may reduce the suitability of the waterbody as habitat for other, more desirable fish and wildlife species. The common carp has been implicated in the loss of certain types of waterfowl from waterbodies because the fish destroys important aquatic vegetation, such as wild rice and wild celery, which these birds rely on for food. The carp may also outcompete certain native fish species, such as black bass, largemouth bass, and pike for food and spawning areas.

Four other nonindigenous species of carp, bighead carp (Figure 10), black carp, grass carp, and silver carp (Figure 11), may pose risks to Lake Michigan and inland waters in the study area. All of these species are native to eastern China. Each has high reproductive capacity and is capable of rapid rates of population growth. Each species is capable of consuming large amounts of food, and can grow large in size. Each species is known to be capable of migrating distances in excess of several hundred miles in large river systems.

Grass carp were introduced into the United States in 1963 to control submerged aquatic vegetation in aquaculture ponds in Arkansas. Since then this species has spread to at least 45 states. It prefers large, slow flowing or standing waterbodies. Grass carp may be present in limited numbers in Lake Michigan. This species primarily feeds on aquatic vegetation, but is capable of using invertebrates and detritus as a food source. Like the common carp, it is destroys aquatic habitat utilized by native species and may contribute to eutrophication through resuspension of sediments.

Bighead and silver carp were imported into the United States in the early 1970s to remove algae and suspended material from aquaculture ponds in Arkansas. These species escaped from the aquaculture ponds some time in the late 1970s or early 1980s. By 1982, they had become established in the upper Mississippi River. They differ in their habitat preferences. Bighead carp prefer large rivers and lakes, while silver carp prefer standing or slow moving water typical of impoundments and river backwaters. While both are opportunistic feeders and capable of feeding on a number of prey, they typically feed on phytoplankton and zooplankton. Silver carp, in particular, are very efficient at straining suspended material from water. The presence of these species may have adverse effects

[68] *George C. Becker,* Fishes of Wisconsin*, University of Wisconsin Press, Madison, Wisconsin, 1983.*

Figure 12

ROUND GOBY (*Neogobius melanostomus*)

Source: Eric Engbretson, U.S. Fish and Wildlife Service.

on native species that are dependent upon plankton for their nutrition. Both of these species have been found in the Illinois River, within about 40 to 50 miles of the Chicago Sanitary and Ship Canal, which connects the Great Lakes basin to the Mississippi River basin. There is an existing electrical fish exclusion barrier that is intended to prevent bighead and silver carp from entering the Canal and a replacement barrier is under construction. They are currently being prevented from entering the Canal by the presence of two electrical fish exclusion barriers.

In North America, black carp is currently found only in aquaculture ponds in Arkansas, Louisiana, Mississippi, Missouri, North Carolina, Oklahoma, and Texas. It feeds primarily on mollusks and crustaceans. Should it escape into the wild, it could have an adverse impact on native species of mussels and snails.

Round Goby

The round goby (Figure 12) is a fish native to the Caspian Sea and Black Sea regions of Eurasia which has invaded the Great Lakes. It was first detected in 1990 in the St. Clair River which runs from Lake Huron to Lake St. Clair. By 1993 it was detected in Lake Michigan. Since then it has spread to all of the Great Lakes, several Great Lakes tributaries, and a few inland rivers.[69] It was most likely introduced in ballast water discharged from oceangoing ships.[70] This may also have facilitated its spread through the Great Lakes.

Several aspects of the biology of the round goby contribute to its status as a nuisance species. While this benthic dwelling fish prefers rocky or gravel substrates, it can live in a variety of aquatic habitats and tolerate a wide range of environmental and water quality conditions. Females show high fecundity and are able to spawn several times over the summer. Males aggressively defend spawning sites, making them unavailable to native species, such as mottled sculpin and logperch.[71] The diet of the round goby is dependent upon the size of the individual. Smaller gobies feed on a variety of benthic macroinvertebrates. Larger individuals feed heavily on zebra mussels, a food source unavailable to most native species of forage fish. Individuals of all sizes feed on fish eggs and fish fry.[72] Round goby feed most actively in the dark. Several native piscivorous fish species have been found to feed on round goby, including walleyes, smallmouth bass, and rock bass.[73]

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[69]*P.M. Charlebois, L.D. Corkum, D.J. Jude, and C. Knight, "The Round Goby (*Neogobius melanostomus*) Invasion: Current Research and Future Needs,* Journal of Great Lakes Research, *Volume 27, 2001, pp. 263-266.*

[70]*J.E. Marsden and D.J. Jude,* Round Gobies Invade North America*, Illinois-Indiana Sea Grant, http://www.seagrant.umn.edu/exotics/goby.htm, 1995.*

[71]*L.D. Corkum, A.J. MacInnes, and R.G. Wickett, "Reproductive Habits of Round Gobies,"* Great Lakes Research Review*, Volume 3, 1998, pp. 13-20.*

[72]*W.J. Ray and L.D. Corkum, "Predation of Zebra Mussels by Round Gobies,* Neogobius melanostomus,*"* Environmental Biology of Fishes, *Volume 50, 1997, pp. 267-273.*

[73]*D.J. Jude, J. Janssen, and G. Crawford, "Ecology, Distribution, and Impact of the Newly Introduced Round and Tubenose Gobies on the Biota of the St. Clair and Detroit Rivers," In: M. Munawar, T. Edsall, and J. Leach (editors),* The Lake Huron Ecosystem: Ecology, Fisheries and Management, *SPB Academic Publishing, Amsterdam, The Netherlands, 1995.*

Figure 13

RUFFE (*Gymnocephalus cernuus*)

Source: John Lyons, Wisconsin Department of Natural Resources.

Round gobies may pose several threats to the integrity of the ecosystems of the Great Lakes and other waterbodies. This species may outcompete and displace native forage fish. Because of their ecological similarities, sculpins may be particularly sensitive to competition from round gobies. In some locations where they have become established, round goby has been implicated as a cause of the decline of mottled sculpin populations.[74] The discovery that round goby has recently dispersed to deeper waters in Lake Michigan indicates that it may also displace other native forage fish species.[75] The presence of round goby might also result in an increased mobilization of bioaccumulative chemicals of concern into higher levels of the food web.[76] Suspension feeding organisms like zebra mussels tend to accumulate high body burdens of bioaccumulative chemicals, such as PCBs and mercury. The large role played by zebra mussels in the diet of larger gobies could provide a pathway for the movement of greater amounts of these chemicals into the bodies of the piscivorous fish at higher levels of the food web.

A second nonnative goby species, the tubenose goby was also detected in the St. Clair River in 1990. It has not spread as rapidly as the round goby and is currently not anticipated to have as strong an impact upon aquatic environments in North America as the round goby.

Ruffe

The ruffe (Figure 13) is a fish native to northern, central, and eastern Europe. It was detected in Lake Superior in the 1986. Since then it has spread along the southern shore of Lake Superior. In addition, it has begun to spread to other lakes in the Great Lakes. In 1995, ruffe were detected in Lake Huron near Alpena, Michigan. It is anticipated that ruffe may invade Lake Michigan in coming years.

Several aspects of the biology of the ruffe contribute to its potential to be a nuisance species.[77] Ruffe have broad ecological and physiological tolerances and tolerate a wide range of conditions. They are capable of rapid population growth. They exhibit low vulnerability to predation due to their cryptic coloration, prominent spines, and tendency to be most active during periods of twilight or dark. There are concerns that the presence of ruffe may produce adverse effects on native fish species, especially yellow perch. Ruffe has similar dietary and thermal preference to yellow perch and may be capable of outcompeting this species.[78]

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[74]*J.R.P. French, III and D.J. Jude, "Diets and Dietary Overlap of Nonindigenous Gobies and Small Native Fishes Co-inhabiting the St. Clair River, Michigan,"* Journal of Great Lakes Research, *Volume 27, 2001, pp. 300-311.*

[75]Ibid.

[76]*D.J. Jude, J. Janssen, and G. Crawford, 1995,* op. cit.

[77]*Derek H. Ogle, "A Synopsis of the Biology and Life History of Ruffe,"* Journal of Great Lakes Research, *Volume 24, 1998, pp. 170-185.*

[78]*Aimee H. Fullerton, Gary A. Lamberti, David M. Lodge, and Martin B. Berg, "Prey Preferences of European Ruffe and Yellow Perch: Comparison of Laboratory Results with Composition of Great Lakes Benthos,"* Journal of Great Lakes Research, *Volume 24, 1998, pp. 319-328.*

Figure 14

SEA LAMPREY (*Pteromyzon marinus*)

Source: Lee Emery, U.S. Fish and Wildlife Service.

Sea Lamprey

Sea lamprey (Figure 14) is a parasitic fish native to the Atlantic Ocean that has invaded the Great Lakes through man-made shipping canals. This species was first observed in Lake Ontario in 1838. Following the deepening of the Welland Canal in 1919, sea lamprey spread to the other Great Lakes. It was first detected in Lake Michigan in 1936. During the 1940s and 1950s, sea lamprey populations in Lake Michigan exploded. This contributed to the decline and collapse of populations of fish species that were the mainstay of the fisheries in the Lake, particularly lake trout.

Several aspects of the biology of the sea lamprey contribute to its status as a nuisance species. Spawning occurs in streams. Females show high fecundity, with some producing over 100,000 eggs.[79] Following hatching, the juveniles burrow into sand or silt substrate and feed on algae and detritus. They may remain in the substrate for several years. During late-summer, juveniles metamorphose into adults and enter the Lake. The adults feed by attaching with their mouths to the bodies of large fish, rasping a hole in the body wall with their tongue, and ingesting blood and body fluids. This continues until the lamprey is satiated or the victim dies. Young adult sea lamprey generally feed in deepwater areas. As they age they tend to migrate to the shallower, nearshore zones. Ultimately the adults enter streams to spawn.

The presence of sea lamprey in Lake Michigan has had a major impact on the Lake's fishery and ecosystem. Each adult sea lamprey can destroy up to 40 pounds of fish during its lifetime. This can have a considerable impact on fisheries stocks. For example, sea lamprey significantly contributed to the decline and collapse of native lake trout populations. Between 1940 and 1954, the commercial catch of lake trout from Wisconsin waters of Lake Michigan declined from about 2.5 million pounds per year to 56 pounds per year. In 1955, there was no commercial catch.[80] While the effects of the sea lamprey were not the only cause of this decline, its impact was a contributing factor. In addition, the destruction of predatory fish by sea lamprey is thought to have contributed to the rapid expansion of the exotic alewife in the Lake.[81]

The primary method used to control sea lamprey populations in Lake Michigan has been the application of lampricides, especially 3-trifluoromethyl-4-nitrophenol (TFM), to streams in which adults spawn. By 1966, this led to an estimated 80 to 90 percent decline in the abundance of adult sea lamprey in the Lake.[82] To reduce the cost of lampricidal treatments, a variety of other methods have also been used to limit or reduce sea lamprey reproduction, including methods that exclude adult sea lamprey from spawning areas, such as low-head barrier dams, stream velocity barriers, and electrical barriers; trapping of adults during spawning migration; and release of sterile males into the population.

[79] *George C. Becker, 1983,* op. cit.

[80] *L.W. Wiegert, "Sportfishing on Green Bay,"* Wisconsin Conservation Bulletin, *Volume 23(7), 1958, pp. 3-5.*

[81] *S.H. Smith, "Species Interactions of the Alewife in the Great Lakes,"* Transactions of the American Fisheries Society, *Volume 99, 1970, pp. 754-765.*

[82] *D.S. Lavis, M.P. Henson, D.A. Johnson, E.M. Koon, and D.J. Ollila, "A Case History of Sea Lamprey Control in Lake Michigan: 1979-1999,"* Journal of Great Lakes Research, *Volume 28 (Supplement 1), 2003, pp. 584-598.*

Figure 15

WHITE PERCH (*Morone americana*)

Source: John Lyons, Wisconsin Department of Natural Resources.

Figure 16

RUSTY CRAYFISH (*Orconectes rusticus*)

Source: University of Michigan Museum of Zoology, http://animaldiversity.org.

White Perch

White perch (Figure 15) is a fish native to estuaries and coastal areas of the Atlantic Ocean that invaded the Great Lakes through the Erie and Welland Canals in the 1950s. It was first detected in Lake Michigan in 1988. It also appears to have invaded some streams tributary to Lake Michigan.

The presence of white perch in Lake Michigan has the potential to have significant impacts on the Lake's food web and the abundance of some native species of fish. White perch exhibit considerable dietary overlap with native yellow perch.[83] This suggests that competition from white perch may have adverse effects on yellow perch populations. In addition, white perch are known to heavily predate eggs of walleye, white bass, and possibly other fish. During spring spawning season, eggs of walleye or white bass may comprise the entire diet of white perch.

Invertebrates

Rusty Crayfish

The rusty crayfish (Figure 16) is a crustacean originally native to streams in the Ohio River basin in Ohio, Kentucky, and Tennessee. It was introduced into Wisconsin waters in about 1960[84] and has since spread throughout the State. Its spread and introduction into waterbodies were probably facilitated by anglers using this crayfish as bait.

Several features of the biology of the rusty crayfish contribute to its status as a nuisance species. It feeds on aquatic macrophytes, benthic macroinvertebrates, detritus, fish eggs, and small fish. This species has a higher rate of metabolism than similarly sized crayfish of other species.[85] As a result of this metabolic difference, the rusty crayfish can have a high impact on other biota in waterbodies into which it has been introduced. For example,

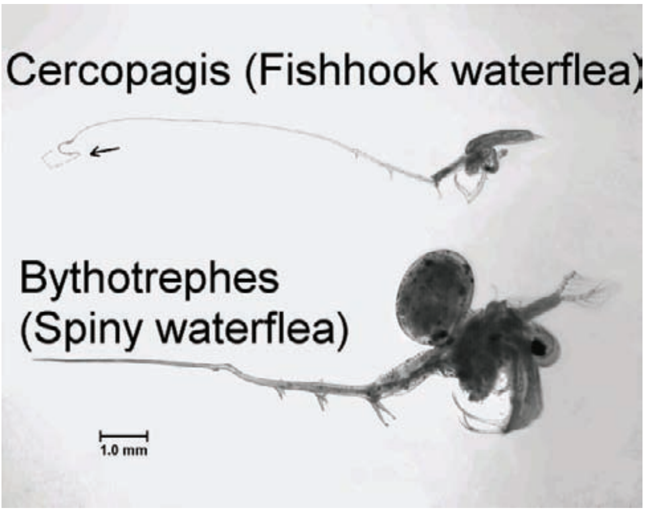
[83]*D.L. Parrish and F.J. Margraf, "Interactions Between White Perch (*Morone americana*) and Yellow Perch (*Perca flavescens*) in Lake Erie as Determined from Feeding and Growth,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 47, 1990, pp. 1779-1787.*

[84]*G.M. Capelli and J.J. Magnusson, "Morphoedaphic and Biogeographic Analyses of Crayfish Distribution in Northern Wisconsin,"* Journal of Crustacean Biology, *Volume 3, 1983, pp. 548-564.*

[85]*W.T. Momot, "Further Range Extensions of the Crayfish* Orconectes rusticus *in the Lake Superior Basin of Northwestern Ontario,"* Canadian Field-Naturalist*, Volume 106, 1992, pp. 397-399.*

Figure 17

FISHHOOK WATER FLEA (*Cercopagis pengoi*) AND SPINY WATER FLEA (*Bythotrephes longimanus*)



Source: NOAA, Great Lakes Environmental Research Laboratory.

through their feeding activities, rusty crayfish reduce the abundance and diversity of aquatic macrophytes.[86] Similarly, infestations of rusty crayfish tend to reduce the abundance and diversity of benthic macro-invertebrates.[87] The rusty crayfish exhibits highly aggressive behavior toward individuals from other crayfish species.[88] In addition, it is less susceptible to predation by fish than some native crayfish species.[89] As a result of these characteristics, rusty crayfish tend to displace native crayfish when they are introduced into waterbodies in Wisconsin.[90] Because environmentally sound methods to eradicate or control this species have not been developed and are unlikely to be developed in the near future,[91] measures to prevent the spread of this species to other waterbodies should be emphasized.

Spiny Water Flea

The spiny waterflea (Figure 17) is a small, predatory zooplanktonic crustacean native to the Black Sea and Caspian Sea areas of Eurasia which has invaded the Great Lakes. It was first detected in Lake Huron in 1984, and was probably introduced into this lake in ballast water discharged by an oceangoing vessel from Europe. It was detected in Lake Michigan in 1986. Since then, it has spread to all of the Great Lakes and a number of inland lakes in Michigan, Minnesota, and Ontario.

Several features of the biology of the spiny waterflea contribute to its status as a nuisance species. This species is a voracious predator of zooplankton. It is capable of rapid population growth, in part due to the fact that it normally produces eggs asexually. It can also produce resting eggs which sink to the substrate. These resting eggs can remain viable for years. Resuspension of these resting eggs by water movement can reintroduce this species to the water column. These resting eggs can also be dispersed to other waterbodies through water movement or transport in ballast water or live wells of small boats. In addition, the spiny waterflea has a caudal spine which can

[86] *D.M. Lodge and J.G. Lorman, "Reductions in Submerged Macrophyte Biomass and Species Richness by the Crayfish* Orconectes rusticus,*"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 44, 1987, pp. 591-597.*

[87] *W.T. Momot, 1992,* op. cit.

[88] *G.M. Capelli and B.J. Munjal, "Aggressive Interactions and Resource Competition in Relation to Species Displacement Among Crayfish of the Genus* Orconectes*,"* Journal of Crustacean Biology, *Volume 2, 1982, pp. 486-492.*

[89] *G.T. DiDonato and D.M. Lodge, "Species Replacements among* Orconectes *Crayfishes in Wisconsin Lakes: The Role of Predation by Fish,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 50, 1993, pp. 1483-1488.*

[90] *G.M. Capelli and B.J. Munjal, 1982,* op. cit.

[91] *A.M. Hill and D.M. Lodge, "Replacement of Resident Crayfish by an Exotic Crayfish: The Roles of Competition and Predation,"* Ecological Applications*, Volume 9, 1999, pp. 678-690.*

comprise as much as 70 percent of its body length. This spine makes the spiny water flea resistant to predation by fish that would normally feed on large zooplankton. The spiny waterflea also avoids predation by fish by migrating into deep water during the day, reducing its visibility.

Figure 18

ZEBRA MUSSEL (*Driessena Polymorpha*) ATTACHED ON NATIVE MUSSEL

Source: Randy Westbrooks, U.S. Geological Survey.

The presence of spiny waterflea may produce several impacts upon the ecological communities and food webs of the lakes it has invaded. Through its predation on zooplankton, spiny waterflea can produce major changes in the zooplankton community structure. In Lake Michigan, predation by spiny waterflea resulted in the collapse of the zooplankton species *Daphnia retrocurva* and *Daphnia pulicaria*,[92] species that were major food items for small and juvenile fish. Similar changes in zooplankton community structure and reductions in zooplankton species richness following the introduction of spiny waterflea have been reported from inland lakes.[93] Though some larger fish may consume spiny waterflea,[94] its long caudal spine discourages predation by smaller, zooplanktivorous fish and young fish generally do not utilize spiny waterfleas as food.[95] While it has been suggested that spiny water flea may ultimately lead to declines of forage and sportfish populations, the long-term impacts of the changes its presence has made to the food web and the long-term effects of the *Bythotrephes* invasion upon the fishery remain unknown. Finally, when spiny waterfleas are abundant, they may foul fishing lines and nets.

Recently a second exotic predatory crustacean zooplankter, the fishhook waterflea, has invaded the Great Lakes. This species was first detected in the Great Lakes in 1998. By 1999, it had been detected in Lake Michigan[96] Like the spiny waterflea, it is a native of the Caspian Sea region on Eurasia. Its biology is similar to that of the spiny waterflea. In addition, it also has a long caudal spine. It is currently anticipated that the effects of its presence will be similar to those of the spiny waterflea.

Zebra Mussel and Quagga Mussel

The zebra mussel (Figure 18) is a mollusk originally native to the Caspian Sea region of Eurasia which has invaded waters of the Great Lakes region. Zebra mussels were first detected in Lake St. Clair near Detroit in 1988,

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[92]*J.T. Lehman and C.E. Caceres, "Food-web Response to Species Invasion by a Predatory Invertebrate:* Bythothrephes *in Lake Michigan,"* Limnology and Oceanography, *Volume 38, 1993, pp. 879-891.*

[93]*Norman D. Yan and Trevor W. Pawson, "Changes in the Crustacean Zooplankton community of Harp Lake, Canada, Following Invasion by* Bythotrephes cederstroemi*,"* Freshwater Biology*, Volume 37, 1997, pp. 407-425.*

[94]*R.A. Coulas, H.J. MacIsaac, and W. Dunlop, "Selective Predation on an Introduced Zooplankter (*Bythotrephes cederstroemi*) by Lake Herring (*Coregonus artedii*) in Harp Lake, Ontario,"* Freshwater Biology, *Volume 40, 1998, pp. 343-355.*

[95]*D.R. Barnhisel and H.A. Harvey, "Size-Specific Fish Avoidance of the Spined Crustacean* Bythotrephes*: Field Support for Laboratory Predictions,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 52, 1995, pp. 768-775.*

[96]*P.M. Charlesbois, M.J. Rattenberg, and J.M. Dettmers, "First Occurrence of* Cercopagis pengoi *in Lake Michigan,"* Journal of Great Lakes Research, *Volume 27, 2001, pp. 258-261.*

and were probably introduced into this lake in ballast water discharged by an oceangoing freighter from Europe. Since then, this species has spread to all of the Great Lakes and has entered the Mississippi and Ohio Rivers. In addition, this mollusk has spread to a number of inland lakes. In 2003, the WDNR reported that zebra mussels had been detected in at least 47 inland lakes in the State, including 30 inland lakes in southeastern Wisconsin, as well as Lake Michigan, Lake Superior, and the St. Croix and Mississippi Rivers.[97]

Several features of the biology of the zebra mussel contribute to its status as a nuisance species. Adult zebra mussels colonize solid substrates in waters with concentrations of dissolved calcium greater than 15 mg/l.[98] These colonies can be very dense; beds of zebra mussels containing up to 100,000 mussels per square meter have been reported in Lake Erie.[99] Colonies of zebra mussel are able to grow by a few individuals colonizing small areas of hard substrate and others settling down on them. Female zebra mussels can produce large numbers of eggs which hatch to produce planktonic larvae called veligers. These veligers can be carried considerable distances by water currents and can be transported between waterbodies in boats, ballast water, or live wells before settling down on hard substrate to grow into adults. Zebra mussels feed by filtering suspended particles from the water column. Large adults have been observed to remove particles from over 1.5 liters per day.[100] These mollusks do not necessarily ingest all of the particles they remove from the water column. When particles are present in high concentrations or consist of unpalatable materials, they can be ejected in a mucilagenous secretion called pseudofeces. This results in suspended material being removed from the water column and transferred to sediment.

The presence of large infestations of zebra mussels typically produces several effects in North American waterbodies.[101] Because they prefer to attach to hard substrate, zebra mussels can clog water intakes, increasing operating costs for drinking water plants, power plants, industrial plants, and dams. The cost from this can be considerable. The Canadian government estimated that from 1991-2001 close to $44 million were spent on measures to keep water intakes of power generating plants free from zebra mussel and that the cumulative costs of damage in the Great Lakes to both the U.S. and Canada were in excess of $3 billion.[102] Because zebra mussels

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[97]*Wisconsin Department of Natural Resources, "Zebra Mussel Presence in Wisconsin Waters (Veligers and Adults)," http://dnr.wi.gov/org/water/wm/GLSWP/exotics/zmtable0404.pdf.*

[98]*E. Mellina and J.B. Rasmussen, "Patterns in the Distribution of Zebra Mussel (*Dreissena polymorpha*) in Rivers and Lakes in Relation to Substrate and Other Physiochemical Factors,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 51, 1994, pp. 1024-1036.*

[99]*F.L. Snyder, M.B. Hilgendorf, and D.W. Garton, "Zebra Mussels in North America: The Invasion and its Implications," Ohio Sea Grant, Ohio State University, Columbus, Ohio, http://www.sg.ohio-state.edu/f-search.html, 1997.*

[100]*Jin Lei, Barry S. Payne, and Shiao Y. Wang, "Filtration Dynamics of the Zebra Mussel,* Dreissena polymorpha, Canadian Journal of Fisheries and Aquatic Sciences, *Volume 53, 1996, pp. 29-37.*

[101]*A. Ricciardi, "Predicting the Impacts of an Introduced Species from its Invasion History: An Empirical Approach Applied to Zebra Mussel Invasions,"* Freshwater Biology, *Volume 48, 2003, pp. 972-981.*

[102]*Commission of the Environment and Sustainable Development, "A Legacy Worth Protecting: Charting a Sustainable Course in the Great Lakes and St. Lawrence River Basin,"* 2001 Report of the Commissioner on the Environment and Sustainable Development, *http://www.oaq-bvq.gc.ca/domino/reports.nsf/html/c101sec6e.html, 2001.*

remove suspended material from the water column, light penetration and water clarity tend to increase in lakes containing large numbers of these mollusks. In some instances this increase in light penetration can be enough to favor the presence of aquatic macrophytes over phytoplankton. Even when this does not happen, phytoplankton production and biomass tend to decline and macrophyte biomass tends to increase. Zooplankton biomass tends to decrease. These food web changes may result in less energy being available to support higher trophic levels, such as fish. The transfer of organic material to the sediment in pseudofeces can result in increases in benthic macroinvertebrate density and diversity. Similarly, since some waterfowl feed on zebra mussels, the density of waterfowl tends to increase in lakes with large zebra mussel populations. Because zebra mussels can accumulate organic pollutants in their tissues at concentrations hundreds of thousands of times the ambient concentration in the environment, this feeding by waterfowl can lead to pollutants being passed up the food chain.[103] Finally, the species richness and density of native mussel species tends to decline in waterbodies experiencing zebra mussel infestation.[104] This occurs both from competition between zebra mussels and native mussels for suspended food particles and from the tendency of zebra mussels to smother native mussels living in soft sediment by attaching to their shells and forming colonies.[105]

Recently the quagga mussel, a second species of Dreissenid mussel, was found to have invaded the Great Lakes. The first documented occurrence was in Lake Erie in 1989.[106] These mussels have been reported in Lake Michigan, including off the shore of Milwaukee near the Linwood Avenue water intake and at offshore reefs near Manitowoc and Sheboygan.[107] There have been no reports of quagga mussels being detected in inland lakes in Wisconsin. With the following exceptions, their biology is similar to that of the zebra mussel. Quagga mussels can utilize both hard and soft substrates. They are able to tolerate brackish water. They are less sensitive to temperature than zebra mussels. Because of this, quagga mussels feed all year long, including during the winter, a season during which zebra mussels are dormant. This all suggests that they may be able to thrive in places where zebra mussels are unable to. It is anticipated that the impacts of quagga mussels will be similar to those of zebra mussels.

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[103]*F.L. Snyder, M.B. Hilgendorf, and D.W. Garton, 1997,* op. cit.

[104]*A. Ricciardi, R.J. Neves, and J.B. Rasmussen, "Impending Extinctions of North American Freshwater Mussels (Unionoida) Following the Zebra Mussel (*Dreissena polymorpha*) Invasion,"* Journal of Animal Ecology, *Volume 67, 1998, pp. 613-619.*

[105]*W.R. Haag, D.J. Berg, D.W. Garton, and J.L. Farris, "Reduced Survival and Fitness in Native Bivalves in Response to Fouling by Introduced Zebra Mussel (*Dreissena polymorpha*) in Western Lake Erie,"* Canadian Journal of Fisheries and Aquatic Sciences, *Volume 50, 1993, pp. 13-19.*

[106]*E.L. Mills, G. Rosenberg, A.P. Spidle, M. Ludyanskiy, Y. Pilgin, and B. May, "A Review of the Biology and Ecology of the Quagga Mussel (*Dreissena bugensis*). A Second Species of Freshwater Dreissenid Introduced into North America,"* American Zoologist*, Volume 3, 19966, pp. 271-286.*

[107]*L.L. Hunt, "Invasion of the Quagga Mussels: A Food-chain Story,"* UWM News*, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin, April 12, 2004.*

Figure 19

CURLY-LEAF PONDWEED (*Potamogeton crispus*)

Source: Elizabeth Czarapata.

Plants

Curly-Leaf Pondweed

Curly-leaf pondweed (Figure 19) is an aquatic plant native to Europe and Asia that has invaded lakes in much of the United States. It was accidentally introduced into North American waters during the introduction of common carp in the late 19th century. By 1950 it had spread throughout much of the United States. Prior to the introduction of Eurasian water milfoil, curly-leaf pondweed was regarded as the most detrimental exotic aquatic plant that had been introduced into lakes in North America.

Several features of the biology of curly-leaf pondweed contribute to its status as a nuisance species. It has fairly broad environmental tolerances. It can grow in clear to turbid water and tolerates alkaline and brackish water.[108] It is tolerant of low light levels and well-adapted to cold water. This allows it to grow slowly under the ice during winter while other aquatic plants are dormant. It grows up early in the spring, often being the first plant to appear following ice out. It tends to form dense surface mats. These mats can interfere with recreational uses of the waterbody and can limit the growth of native aquatic plants. Typically, curly-leaf pondweed dies back in the middle of summer. Prior to die back, it forms propagules called turions consisting of hardened stem tips that disperse by water movement. Transfer of turions and transfer of plant fragments by boats can contribute to the spread of this plant between waterbodies.

Several problems are associated with the mid-summer die back of curly-leaf pondweed. This die back creates a sudden loss of habitat for fish and macroinvertebrates which can adversely impact their populations. Decomposition of dying pondweed can reduce dissolved oxygen concentrations in the waterbody and release nutrients which contribute to algal blooms and reduced water clarity. Rafts of dying pondweed can accumulate on shore, reducing aesthetic enjoyment of the waterbody.

Control of curly-leaf pondweed is usually accomplished through adjustment of water levels, manual harvesting, mechanical harvesting, herbicide application, or some combination thereof.

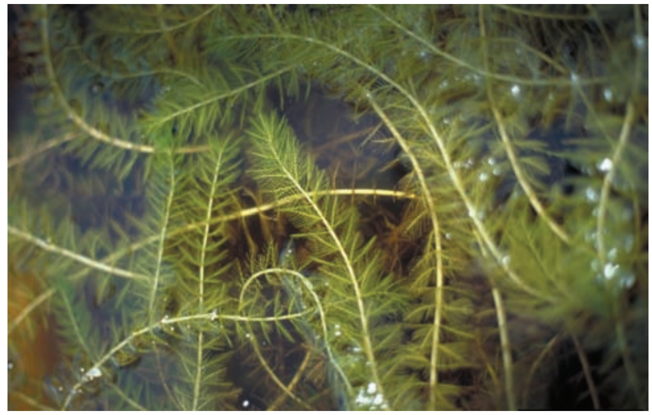
[108] *R.L. Stuckey, "Distributional History of Potamogeton crispus (Curly Pondweed) in North America," Bartonia, Volume 46, 1979, pp. 22-42.*

Eurasian Water Milfoil

Eurasian water milfoil (Figure 20) is an aquatic plant originally native to Europe, Asia, and North Africa that has invaded waterbodies in much of North America. It was first observed in a pond in the District of Columbia in 1942. Since then it has spread to waterbodies in most states in the United States and several Canadian provinces. This species most likely reached eastern North America through the aquarium trade when aquarium owners released the contents of aquaria into local waterbodies. Its spread has been facilitated by plant fragments clinging to boats moving between waterbodies. The waters of southeastern Wisconsin are heavily infested by this plant—Eurasian water milfoil has been reported in over 100 waterbodies in the Region.[109]

Figure 20

EURASIAN WATER MILFOIL (*Myriophyllum spicatum*)



Source: Alison Fox, University of Florida.

Several features of the biology of Eurasian water milfoil contribute to its status as a nuisance species. It is a perennial herbaceous submerged plant that forms systems of roots and runners in the sediment. Its shoot system can form dense branches at the surface. It begins its growth in the early spring, before other aquatic macrophytes have begun to grow. This along with its tendency to form dense stands allows it to shade out other vegetation. It can tolerate a wide range of conditions, including broad ranges of temperatures,[110] alkalinity,[111] and lake trophic status.[112] Most propagation of this species is vegetative through the growth of underground runners from the root system and through the growth of stem fragments into adult plants. Because of the latter method of propagations, shearing of plants by harvesting or boat propellers can facilitate the spread of this plant.

Several impacts are associated with the presence of Eurasian water milfoil in waterbodies in the study area. This species often outcompetes native aquatic plants and dominates the plant communities in lakes. This leads to reductions in the abundance and diversity of native aquatic plants.[113] Dense stands of Eurasian water milfoil can impede water circulation.[114] This can lead to reductions in dissolved oxygen, especially as organic material

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[109]*Wisconsin Department of Natural Resources, "Eurasian Water Milfoil in Wisconsin as of December 2002," http://dnr.wi.gov/org/water/wm/GLWSP/exotics/milfoil/charts/ewm2002_byname.pdf, 2002.*

[110]*C.S. Smith and J.W. Barko, "Ecology of Eurasian Water Milfoil,"* Journal of Aquatic Plant Management, *Volume 28, 1990, pp. 55-64.*

[111]*John D. Madsen, "Predicting the Invasion of Eurasian Watermilfoil into Northern Lakes," Technical Report A-99-2, U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, 1998.*

[112]Ibid.

[113]*J.D. Madsen, J.W. Sutherland, J.A. Bloomfield, L.W. Eichler, and C.W. Boylan, "The Decline of Native Vegetation Under Dense Eurasian Water Milfoil Canopies,"* Journal of Aquatic Plant Management, *Volume 29, 1991, pp. 94-99; A.S. Trebitz, S.A. Nichols, S.R. Carpenter, and R.C. Lathrop, "Patterns of Vegetation Change in Lake Wingra Following a* Myriophyllum spicatum *Decline,"* Aquatic Botany, *Volume 46, 1993, pp. 325-340.*

[114]*R.M. Smart and R. Doyle, "Ecological Theory and the Management of Submerged Aquatic Plant Communities," Information Exchange Bulletin A-95-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi, 1995.*

Figure 21

FLOWERING RUSH (*Butomus umbellatus*)

Source: Nick Proulx, Minnesota Department of Natural Resources and Dr. Thomas Slawski, SEWRPC.

decays.[115] Eurasian water milfoil provides relatively poor habitat for wildlife and other aquatic organisms. It offers less nutritional value to waterfowl,[116] supports lower diversity and abundance of macroinvertebrates,[117] supports lower fish abundance,[118] and promotes lower rates of fish growth[119] than native plant species. Finally, thick mats of this plant can limit boating, fishing, swimming, and aesthetic enjoyment of waterbodies, leading to increased costs for aquatic plant management.

Control of Eurasian water milfoil is usually accomplished through manual harvesting, mechanical harvesting, herbicide application, or some combination thereof. Aquatic milfoil weevil, an insect native to North America, is being evaluated for uses as a biological control agent.[120]

Flowering Rush

Flowering rush (Figure 21) is an aquatic plant native to Europe that has invaded waterbodies in North America. It was most likely introduced into North America as a garden ornamental. Since its introduction, flowering rush has spread through the northern tier of states and several Canadian provinces.

Several features of the biology of flowering rush contribute to its status as a nuisance species. Flowering rush grows well in wet places. It can form dense stands of plants. It is sensitive to water level changes and can invade areas not occupied by other plants, especially when lowering water levels expose new sites. Long-distance dispersal of flowering rush most likely occurs through escape from cultivation. Local dispersal is aided by this plant's ability to grow from fragments of existing plants. Because of this, flowering rush spread can be facilitated by plant fragments clinging to boats moving between waterbodies.

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[115]*R.A. Lillie and J. Budd, "Habitat Architecture of* Myriophyllum spicatum *L. as an Index to Habitat Quality for Fish and Macroinvertebrates,"* Journal of Freshwater Ecology, *Volume 7, 1992, pp. 113-125.*

[116]*S.G. Aiken, P.R. Newroth, and I. Wile, "The Biology of Canadian Weeds. 34.* Myriophyllum spicatum *L.,"* Canadian Journal of Plant Science, Volume *5, 1979, pp. 201-215.*

[117]*A. Keast, "The Introduced Aquatic Macrophyte,* Myriophyllum spicatum, *as Habitat for Fish and Their Invertebrate Prey,"* Canadian Journal of Zoology, *Volume 62, 1994, pp. 1289-1303.*

[118]Ibid.

[119]*R.A. Lillie and J. Budd, 1992,* op. cit.

[120]*L.L. Jester, M.A. Bozek, D. R. Helsel, and S.P. Sheldon, "*Euhrychiopsis lecontei *Distribution, Abundance and Experimental Augmentations for Eurasian Watermilfoil Control in Wisconsin Lakes,"* Journal of Aquatic Plant Management, *Vol. 38, 2000, pp. 88-97.*

Several impacts are associated with the presence of flowering rush in waterbodies. Flowering rush may be capable of aggressively displacing native vegetation,[121] including outcompeting cattails and willows.[122] This can lead to declines in native fish and wildlife. In addition, the dense stands formed by this species can interfere with boating and other recreational uses.

Purple Loosestrife
Purple loosestrife (Figure 22) is a plant originally native to Europe that has invaded wetlands and other habitats in northeastern North America. It was intentionally introduced into the Unites States in the early 19th century for use as a medicinal plant and garden ornamental. Since its introduction, it has spread throughout much of the northeastern United States and portions of Canada. Its spread into the Great Lakes area has been favored by its cultivation and sale as an ornamental and by the construction of inland waterways and canals in the 1880s.[123] While it was first detected in Wisconsin in the 1930s, it remained uncommon in the State until the 1970s.

Figure 22

PURPLE LOOSESTRIFE (*Lythrum salicaria*)

Source: Agriculture and Agri-Food Canada.

Several features of the biology of purple loosestrife contribute to its status as a nuisance plant. It is a hardy perennial. While it prefers moist soils, it can grow in a wide range of soil types and textures. In a mature plant, 30-50 erect shoots rise from persistent root stock.[124] Mature plants can be very prolific, producing over 2.5 million seeds per plant per year.[125] These seeds are very small and can be transported by water currents and animals. These seeds remain viable for several years and form a persistent seed bank that can maintain and regenerate the population.[126] This plant can also propagate itself vegetatively. No North American herbivores or pathogens are known to suppress purple loosestrife.[127]

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[121]*R.J. Staniforth and K.A. Frego, "Flowering Rush (*Butomus umbellatus*) in the Canadian Prairies,"* The Canadian Field-Naturalist, *Volume 94, 1980, pp. 333-336.*

[122]*L.C. Anderson, C.D. Zeis, and S.F. Alam, "Phytogeography and Possible Origins of* Butomus umbellatus *in North America,"* Bulletin of the Torrey Botanical Club, *Volume 101, 1974, pp. 292-296.*

[123]*D.Q. Thompson, R.L. Stuckey, and E.B. Thompson, "Spread, Impact, and Control of Purple Loosestrife in North American Wetlands," U.S. Fish and Wildlife Service, Jamestown, North Dakota, http://www.npwrc.usgs.gov/resource/1999/loosstrf/loosstrf.htm, 1987.*

[124]Ibid.

[125]*S.R.A. Shamsi and F.H. Whitehead, "Comparative Eco-physiology of* Epilobium hirsutum *L. and* Lythrum salicaria *L. 1. General Biology, Distribution and Germination,"* Journal of Ecology, *Volume 62, 1974, pp. 279-290.*

[126]*C.H. Welling and R.L. Becker, "Seed Bank Dynamics of* Lythrum salicaria *L.: Implications for Control of this Species in North America,"* Aquatic Botany, *Volume 38, 1990, pp. 303-309.*

[127]*D. Hight, "Available Feeding Niches in Populations of* Lythrum salicaria *L. (Purple Loosestrife) in the Northeastern United States,"* Proceedings of the International Symposium on Biological Control of Weeds, *Volume 7, 1990, pp. 269-278.*

Several problems result from the introduction of purple loosestrife into a watershed. This plant can invade a variety of habitats, including wetlands and the margins of lakes, rivers, and streams. Introduction is facilitated by disturbance to the habitat, such as water drawdown or exposed soil. Once established at a site, purple loosestrife outcompetes native plant species, forming a monoculture.[128] These monotypic stands can persist for long periods of time. Many in the northeastern United States have been self-replacing for over 20 years without apparent loss of vigor.[129] A result of this is that purple loosestrife infestation leads to reductions in the abundance and diversity of native plant species.[130] This reduces the amount of food and cover available for fish and wildlife.[131]

Purple loosestrife is controlled by manual removal and herbicide application. Biological control using a number of insect species is being actively investigated.[132]

Endangered and Threatened Species

The regional water quality management plan update study area contains several species of plants and animals that have been designated as endangered, threatened, or of special concern by the WDNR. Because the presence of particular endangered, threatened, and special concern species varies among the watersheds in the study area, these species will be discussed in Chapters V through X.

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[128] *T.K. Mal, J. Lovett-Doust, and L Lovett-Doust, "Time-Dependent Competitive Displacement of* Typha augustifolia *by* Lythrum salicaria*"* Oikos, *Volume 79, 1997, pp. 26-33.*

[129] *D.Q. Thompson, R.L Stuckey, and E.B. Thompson, 1987,* op. cit.

[130] *R.L. Stuckey, "Distributional History of* Lythrum salicaria *(Purple Loosestrife) in North America,"* Bartonia, *Volume 47, 1980, pp. 3-20.*

[131] *T.J. Rawinski and R.A. Malecki, "Ecological Relationships among Purple Loosestrife, Cattail, and Wildlife at the Montezuma National Wildlife Refuge,"* New York Fish and Game Journal, *Volume 31, 1984, pp. 81-87.*

[132] *Stephen D. Hight and John J. Dea, Jr., "Prospects for a Classical Biological Control Project Against Purple Loosestrife* (Lythrum salicaria)*,"* Natural Areas Journal, *Volume 11, 1991, pp. 151-157.*

Chapter III

DATA SOURCES AND METHODS OF ANALYSIS

INTRODUCTION

This chapter presents the data sources, and assessment methodology for evaluating surface water quality and quantity conditions, biological conditions, and sediment quality conditions in the streams and lakes for the greater Milwaukee watersheds study area, and also for characterizing groundwater quality conditions in the study area. An analysis of the ability of those conditions to support proposed water uses has been made, and the data are compared to historical data in order to assess the changes which have occurred in the conditions of surface water quality, sediment quality, and biological communities since the preparation of the original regional water quality management plan. More specifically, for each of the six major watersheds (Chapters V through X in this report) the following five basic questions were addressed:

- How have water quality conditions changed since 1975?
- How have toxicity conditions changed since 1975?
- What are the sources of water pollution?
- What is the current condition of the fishery?
- To what extent are the water use objectives and water quality standards being met?

SEWRPC has developed an extensive geographic information system database for the Southeastern Wisconsin Region that includes information on historical urban growth; land use; floodplains; wetlands; natural areas; critical species habitats; environmental corridors; sewer service areas; depth to bedrock; depth to water table; soil types; contamination attenuation potential of soils; groundwater contamination potential; watersheds, subwatersheds, and subbasins; and topography, that is updated periodically. A major update effort was carried out in the early 2000s in support of the preparation of new land use and transportation plans and other elements of the comprehensive plan for the Region.[1] The land use inventory information used in this report is generally based upon year 2000 conditions, the base year for the planning program, except in some instances where historical or newer inventory data was deemed important to present. This land use inventory was a vital component in assessing both water quality and modeled pollutant loading conditions among watersheds in this study area.

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[1] *SEWRPC Planning Report No. 48,* A Regional Land Use Plan For Southeastern Wisconsin: 2035*, June 2006; and SEWRPC Planning Report No. 49,* A Regional Transportation System Plan for Southeastern Wisconsin: 2035*, June 2006.*

In the case of water quality data, the baseline condition was established as the period from 1998 through 2001, supplemented by sampling data collected up to year 2004 where possible. This period adequately represents current baseline conditions in the study area and it also is representative of conditions within the MMSD planning area following the construction of major MMSD sewerage system facilities, including the Inline Storage System, which has significantly influenced water quality conditions.

BACKGROUND AND SCOPE OF WATER QUALITY STUDIES

A variety of data sources, based on field studies conducted during the period 1970 through 2004, were used to assess the historical and baseline water quality of surface waters in the regional water quality management plan update study area. These sources represent the efforts from a variety of Federal, State, and local agencies and organizations. The locations of water quality sampling stations within each watershed of the study area are discussed within Chapters V through X and shown on maps in those chapters.

Milwaukee Metropolitan Sewerage District Corridor Study Database

For those portions of the regional water quality management plan update study area that are within the study area for the Milwaukee Metropolitan Sewerage District's (MMSD) 2020 Facilities Plan, water quality data were obtained from the MMSD Corridor Study Database.[2] This database was compiled as part of a collaborative project between the MMSD, the Wisconsin Department of Natural Resources (WDNR), the Southeastern Wisconsin Regional Planning Commission (SEWRPC), the U.S. Geological Survey (USGS), the University of Wisconsin-Milwaukee, Marquette University, Wisconsin Lutheran College, and other organizations to ascertain the current state of water quality and ecological health in the stream corridors of the MMSD Planning area and provide data and tools with which to assess the potential success of future projects. The database was constructed and is maintained by the USGS.

The MMSD Corridor Study Database contains data taken from a number of types of surface water locations, including rivers, canals, estuaries, and lakes. In addition, the database contains data from samples taken in storm sewers, at municipal wastewater treatment plants, and at private industrial facilities. It contains over 2.7 million results from nearly 1.8 million sampling visits. The database was compiled from a number of legacy databases that were assembled either by the agencies using the data, such as the MMSD, or by agencies gathering data from multiple sources, such as the U.S. Environmental Protection Agency (USEPA) Storage and Retrieval (STORET) databases. The majority of the sources of data used to construct the MMSD Corridor Study Database were obtained from the USGS, USEPA, WDNR, and MMSD as shown in Table 10.

The MMSD Corridor Study Database contains data from samples taken within the 416-square-mile MMSD 2020 Facilities Plan study area shown on Map 1 in Chapter I of this report. This area includes the entirety of the Kinnickinnic River and Oak Creek watersheds and all but a small portion of the Menomonee River watershed. It also includes the lower portion of the Milwaukee River watershed, the upper portion of the Root River watershed, and those portions of the Lake Michigan Direct Drainage area within Milwaukee County and the City of Mequon. Data from Lake Michigan are not included in this database. Although somewhat incomplete, overall the database contained data from the period 1970 to 2002 (see Table 10). Certain types of data within the database are limited to specific time periods, with both the types of data and time periods varying among each of the greater Milwaukee watersheds, as indicated in Chapters V through X of this report. Where possible, supplemental data from various agencies were added to be inclusive up to year 2004 for sites both within and outside of the Corridor Database boundaries.

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[2]*Morgan A. Schneider, Michelle A. Lutz,* et. al., Water-Resources-Related Information for the Milwaukee Metropolitan Sewerage District Planning Area, Wisconsin, 1970-2002, *U.S. Geological Survey Water-Resources Investigation Report 03-4240, 2004.*

Table 10

DATA SOURCES AND TYPES INCLUDED WITHIN THE MILWAUKEE METROPOLITAN SEWERAGE DISTRICT CORRIDOR STUDY DATABASE: 2004[a]

Data Source Name	Agency Serving Data	Number of Sampling Sites	Number of Sampling Visits	Number of Results	Year of Earliest Sample	Year of Latest Sample
MMSD Water Quality	MMSD	50	24,137	586,749	1975	2001
MMSD Stream Evaluation	MMSD	4	216,422	216,422	1994	2001
MMSD Precipitation	MMSD	20	1,411,757	1,411,757	1993	2001
MMSD Sediment	MMSD	209	3,653	15,322	2000	2001
USGS Water Quality	USGS	96	8,918	107,181	1970	2002
USGS Streamflow	USGS	42	113,524	113,524	1970	2001
USEPA STORET Legacy	USEPA	324	6,268	26,930	1970	1998
USEPA STORET Modern	USEPA	18	515	2,120	1999	2001
WDNR Biology Database, Fish	WDNR	268	277	2,608	1970	2001
WDNR Biology Database, Habitat	WDNR	44	6,345	204,957	1991	2001
WDNR Milwaukee River Fish Database	WDNR	18	36	8,166	1996	2001
WDNR Sediment	WDNR	167	343	15,631	1984	1995
WDNR Macroinvertebrate Database	UWSP	189	328	5,729	1979	1999

NOTE: The following abbreviations have been used:

MMSD = Milwaukee Metropolitan Sewerage District
USGS = U.S. Geological Survey
USEPA = U.S. Environmental Protection Agency
WDNR = Wisconsin Department of Natural Resources
UWSP = University of Wisconsin-Stevens Point

[a]*This table summarizes the status of the database as of the year 2004. The database has been, and continues to be, updated periodically.*

Source: Morgan A. Schneider, Michelle A. Lutz, et al., Water-Resources-Related Information for the Milwaukee Metropolitan Sewerage District Planning Area, Wisconsin, 1970-2002, U.S. Geological Survey Water-Resources Investigation Report 03-4240, 2004.

These data were collected and analyzed over an approximately 30-year period for many different purposes using different field and laboratory methods. Thus, it was necessary to consider several factors as summarized below in the review, analysis, and interpretation of this extensive database:

- For some water quality indicators, data from samples collected or analyzed using different methods may not be strictly comparable. The majority of the water quality data used in this report were analyzed by one of three main analytical laboratories that include the MMSD Central Laboratory, USGS Wisconsin Water Science Center, and the Wisconsin State Laboratory of Hygiene. Where laboratory analysis methods differed among laboratories or changed over time within a laboratory, all efforts were made to convert these constituents and make them as comparable as possible prior to further analysis. These laboratories utilize standard methods for the examination of water and wastewater,[3] but there can be more than one USEPA-approved method for a particular constituent. To advance the state-of-the-art, the USEPA provides funding for validation studies for the development of new methods, but each new method has to meet or exceed the old method in performance. These validation studies are published and if the new method is approved then the State of Wisconsin has regulations that allow both methods to be used for most constituents.[4] This procedure can result in different methodologies being used among reporting laboratories.

[3]*American Public Health Association,* Standard Methods for the Examination of Water and Wastewater*, 20th Edition, United Book Press, Baltimore, Maryland, 1998.*

[4]*Personal communication, Ron Arneson, Laboratory Coordinator, Bureau of Integrated Science Services, Wisconsin Department of Natural Resources, February , 2006.*

- Laboratory analysis reporting levels were available for some but not all data, and they changed for constituents with the same database or agency source as well as among database sources. For example, the type of reporting limit varied between methods of detection, minimum detection limits, and laboratory reporting limits, among others. In addition, in some cases improvements in analytical techniques led to changes over time in the limits of detection and limits of quantitation for some water quality indicators.

- Sampling intervals differed. Some samples were collected as part of regular periodic sampling programs. Other data were collected in an event-driven manner targeting either high or low flow events. Still other data were collected as part of specific, short-term investigations. For some water quality parameters, these differences in sampling strategy can affect the validity of estimates of average concentrations, maximum concentrations, and loads and those limitations sometimes reduced the number of sites or sampling stations available for analysis.[5] These sampling constraints limited the number of stations that could be used to conduct more rigorous long-term trend analyses for each of the greater Milwaukee watersheds as part of this study.

Additional Sources of Water Quality Data
For sites within the study area that are outside of the MMSD 2020 Facilities Planning area, water quality data were obtained from a variety of sources, including Federal, State, and local agencies, such as the USGS, the WDNR, counties, and municipalities. Additional data were obtained from citizen monitoring organizations and were used where found to be adequate for the purpose of the study. Those organizations include the Water Action Volunteers Program operated by the University of Wisconsin-Extension, the Testing the Waters Program sponsored by Riveredge Nature Center, and the Self-Help Lake Monitoring Program sponsored by the WDNR.

It is important to note that these data were collected and analyzed over an approximately 30-year period for many different purposes using different field and laboratory methods. For example, while data collected by the USGS at some sampling stations represents long-term monitoring efforts, data collected at other stations are related to specific, short-duration studies. Similarly, some of the WDNR's sample sites represent ongoing stream baseline surveys, which are based on a five-year random sampling interval, while others represent shorter-term stream assessments or ambient water quality monitoring. In general, the same cautions regarding analysis and interpretation of the data from the Corridor Study Database listed above also apply to these data.

BACKGROUND AND SCOPE OF WATER QUANTITY STUDIES

The USGS has operated 40 streamflow stations on rivers and streams within the MMSD 2020 Facilities Plan study area distributed among each of the five major watersheds, including: nine stations in the Kinnickinnic River watershed, 19 stations in the Menomonee River watershed, seven stations in the Lower Milwaukee River watershed, two stations in the Oak Creek watershed, and three stations in the Root River watershed. There were an additional 21 streamflow stations in the remaining portions of the study area that included 18 stations in the Upper Milwaukee River watershed and three in the Root River watershed. In addition, special funding was acquired through the Great Lakes National Program Office for the establishment of nine temporary USGS gauges to supplement streamflow information for this study; six stations were located in the Upper Milwaukee River watershed and three stations in the Lower Root River watershed. These stations record water surface stage on a continuous basis. For these stations, the USGS has taken measurements of the volume of water passing a given stream cross-section in a given period of time to develop curves that can be used to estimate discharge from stage. In addition, the MMSD collected water surface elevation data at four sites in the 2020 Facilities Plan study area beginning in 1993, including three sites in the Milwaukee River watershed and one site in the Kinnickinnic River

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[5]*Dale M. Robertson, "Influence of Different Temporal Sampling Strategies on Estimating Total Phosphorus and Suspended Sediment Concentration and Transport in Small Streams,"* Journal of the American Water Resources Association, *Volume 39, 2003.*

watershed. Measured stage-discharge relationships were not established at those sites, thus, data from these stations cannot be used directly to estimate stream discharge. With the exception of the Lake Michigan direct drainage area, all of the watersheds in the MMSD 2020 Facilities Plan study area have at least one stream gauge where stream flow is computed. Most of the subwatersheds within these watersheds do not contain a stream gauge; however, in most cases, there is a stream gauge downstream in another watershed. Specific stream gauge locations are mapped and discussed in further detail for each of the watersheds in Chapters V through X of this report.

BACKGROUND AND SCOPE OF BIOLOGICAL CONDITIONS STUDIES

Fisheries data were obtained from databases constructed and maintained by the WDNR. Historical fishery sampling records were taken from the Master Fish File. More recent data were obtained from the National Biological Database. As a supplement to these data from the WDNR, data were obtained from stream fish monitoring under programs conducted by Wisconsin Lutheran College and the University of Wisconsin-Milwaukee. The locations of fisheries sampling sites are mapped and discussed in further detail for each of the watersheds in Chapters V through X of this report.

Surveys of stream macroinvertebrates were obtained from the WDNR through the BUG Monitoring Database constructed and maintained for the WDNR by the University of Wisconsin-Stevens Point.[6] Additional data were obtained from stream invertebrate monitoring conducted by Wisconsin Lutheran College[7] and by citizen monitoring programs where such data were judged to be adequate. Sample stations for macroinvertebrates are mapped and discussed in further detail for each of the watersheds in Chapters V through X of this report.

Toxicological data on contaminants in the tissue of fish and other aquatic organisms were obtained from the WDNR Fish and Sediment Contaminant Database. These data were available for a variety of species. Classes of contaminants sampled for include mercury, polychlorinated biphenyls (PCBs), and a variety of pesticides.

BACKGROUND AND SCOPE OF SEDIMENT QUALITY STUDIES

Information on contaminants in sediment was obtained from a number of sources. The WDNR provided data from its Fish and Sediment Contaminations Database. In addition, data from sediment studies conducted by the USGS were downloaded from the National Water Information System (NWIS). Classes of contaminants sampled for in these studies include PCBs, heavy metals, such as cadmium, lead and mercury, polycyclic aromatic hydrocarbons (PAHs), and a variety of pesticides.

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[6]*Stanley W. Szczytko, BUG Program Version 3.5, College of Natural Resources, University of Wisconsin Stevens Point, February 1995.*

[7]*R.C. Anderson,* Southeast Wisconsin's Menomonee River and Oak Creek Biological Evaluation, *Wisconsin Lutheran College Biology Department Technical Bulletin No. 1, January 2001; A.L. Ortenblad, D.A. Bohla, and R.C. Anderson,* Sustainability Through Biological Monitoring on the Root River Racine, Wisconsin, *Wisconsin Lutheran College Biology Department Technical Bulletin No. 4, December 2003.*

BACKGROUND AND SCOPE OF GROUNDWATER QUALITY STUDIES

The hydrogeology and water quality of aquifers in Southeastern Wisconsin have been the subject of many studies and reports, both published and unpublished, from the earliest reports by Alden[8] and Weidman and Schulz,[9] until today. These earliest reports, together with an even older report on artesian wells in eastern Wisconsin by Chamberlin,[10] are important sources of information on the original potentiometric levels and early well yields, dating back to the 1850s. Various county reports published by the Wisconsin Geological and Natural History Survey (WGNHS) and the USGS have described the general availability of groundwater in the counties comprising the regional water quality management plan update study area. 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. Later reports appraised the geology, groundwater resources, and water quality in Kenosha and Racine Counties, Waukesha County, and Ozaukee and Washington Counties. During the late 1970s, the USGS prepared water table maps for Kenosha, Milwaukee, Racine, and Waukesha Counties.

The first comprehensive studies of groundwater resources within the regional water quality management plan study area with respect to the needs of long-range planning programs were conducted by SEWRPC in cooperation with the USGS, the WGNHS, the University of Wisconsin-Milwaukee, the WDNR, and many of the water supply utilities serving the Region.[11] These studies included development of a regional groundwater aquifer simulation model and preparation of a report collating existing pertinent hydrogeological data about the Southeastern Wisconsin Region, supplemented by, and integrated with, additional fieldwork and mapping. The major objectives of the groundwater resources study included:

1. Mapping the contaminant attenuation capacity of the soils covering the planning area;

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

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

4. Evaluating and interpreting the hydrogeologic characteristics of the unsaturated zone and determining and mapping the contaminant attenuation potentials of the near-surface strata of the planning area;

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

6. Identifying and mapping the potential groundwater contamination sources within the planning area.

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[8]*W.E. Alden, "Description of the Milwaukee Quadrangle,"* U.S. Geological Survey Atlas of the United States, *Milwaukee Special Folio, no. 140, 1906.*

[9]*S. Wiedman and A.R. Schultz, "The Underground and Surface Water Supplies of Wisconsin,"* Wisconsin Geological and Natural History Survey Bulletin, *Vol. 35, 1915.*

[10]*T.C. Chamberlin,* Geology of Wisconsin, *Vol. II, 1877.*

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

ANALYSIS PROCEDURES

Surface Water Quantity Analysis
In order to compare the long-term volumes of flow at various locations in each watershed and to estimate the contribution of each tributary to the downstream volume, a flow fraction was calculated for each station for which flow data existed. This flow fraction represents a comparison of median flow at the station to the median flow at a long-term station (the reference station) in the downstream section of the mainstem of the river. For each station, the flow fraction was derived by calculating the median flow for the period of record. This number was then divided by the median flow from the reference station for the same time period. The median was used rather than the mean, because the median is less sensitive to outlier and extreme values. While this analysis ignores much of the variability contained within the data and does not take into account processes, such as evapotranspiration and interactions with groundwater, it does give a rough approximation of the relative magnitudes of average flow at various locations within a watershed.

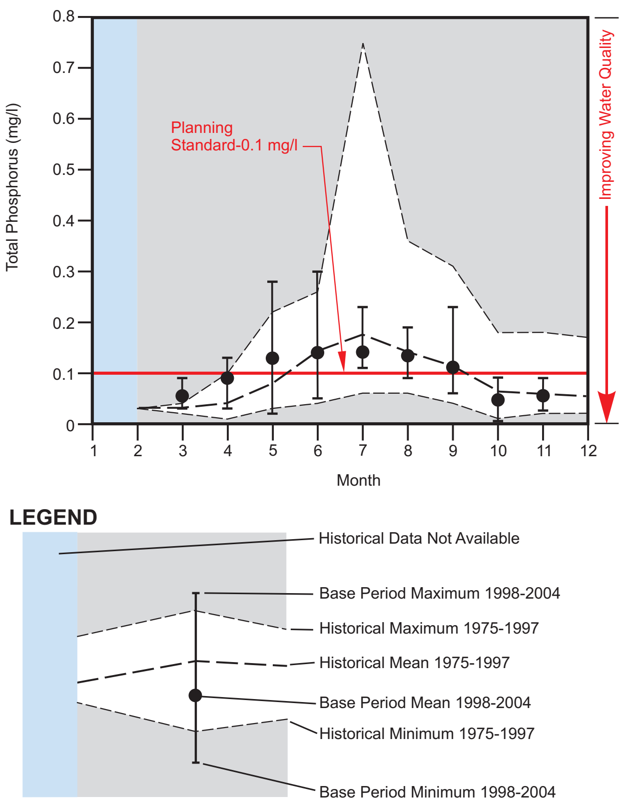
Surface Water Quality Analysis
Water Quality Indicators
There are hundreds of parameters, or indicators, available for measuring and describing water quality; that is, the physical, chemical, and biological characteristics of water. A list of these indicators would include all of the physical and chemical substances in solution or suspension in water, all of the macroscopic and microscopic organisms in water, and the physical characteristics of the water itself. Only a few of these hundreds of indicators, however, are normally useful in evaluating natural surface water quality and wastewater quality and in indicating pollution. Selected indicators were employed in the regional water quality management plan update planning program to evaluate surface water quality by comparing it to supporting adopted water use standards, which in turn relate to specific water use objectives. These same indicators were also used to describe the quality of point discharges and diffuse source runoff and to determine the effect of those discharges on receiving streams. These indicators included: biological indicators, such as fecal coliform bacteria, the bacterium *Escherichia coli,* and chlorophyll-*a*; chemical indicators, such as alkalinity, biochemical oxygen demand (BOD, or BOD_5 when referring to the five-day BOD test), chloride, dissolved oxygen, hardness, hydrogen ion concentration (pH), specific conductance, and temperature; suspended material, such as concentration of total suspended solids (TSS) or total suspended sediment; concentrations of nutrients, such as various chemical forms of phosphorus and nitrogen; and concentrations of contaminants, such as heavy metals, pesticides, and other organic compounds such as Polycyclic Aromatic Hydrocarbons (PAHs) and Polychlorinated Biphenyls (PCBs) in water, sediment, and aquatic organisms. For more complete descriptions of these constituents see Chapter II of this report.

Baseline and Historical Conditions Analysis
To evaluate baseline water quality conditions relative to historical conditions, baseline and historical conditions were graphically compared on a monthly basis. An example of this is shown in Figure 23. For each water quality parameter examined, the background of the graph summarizes the historical conditions. The white area in the graph shows the range of values observed during the period 1970-1997. The upper and lower boundaries between the white and gray areas show historical maxima and minima, respectively. Blue background indicates months for which no historical data were available. The dashed bold line plots the monthly mean value of the parameter for the historical period. Overlaid on this background is a summary of baseline conditions from the period 1998-2001 or in some cases 1998-2004. The circle shows the monthly mean value of the parameter for the current baseline condition time period. The bars extending from the dots show the monthly ranges of the maximum and minimum concentrations for the same time period. Where appropriate each graph includes a red arrow on the right side of the figure indicating the direction of improving water quality (see Figure 23).

Distributions of water quality data also were shown using box plots to illustrate changes among stations from upstream to downstream over several time periods from 1975 through 2004. Figure 24 shows an example of the symbols used in box plots, as well as the four time periods used for each graph that include 1975-1986, 1987-1993, 1994-1997, and 1998-2004, or most recent year of sampling. In this type of graph, the center line marks the location of the median—the point in the data above and below which half the instances lie. The length

Figure 23

EXAMPLE OF FIGURE SHOWING
HISTORICAL AND CURRENT (BASE PERIOD)
CONCENTRATIONS BY MONTH



NOTE: Most graphs will include a red line indicating a water quality standard, planning standard, or consumption advisory, where appropriate.

Source: SEWRPC.

of the box shows the range of the central 50 percent of the instances. This is known as the interquartile range. The "whiskers" extending from the box show the range of the instances that are within 1.5 box-lengths of the interquartile range from the box. Stars indicate outliers that are more than 1.5 box-lengths but less than three box-lengths from the box, and open circles indicate extreme values which lie outside the maximum range of the graph and represent the actual concentration value for each point. Box plots give a convenient means for comparing the features of distributions of all the data for a particular station and time period.

Trend Analysis

The data used for examination of long-term water quality trends within the MMSD planning area were taken from the MMSD Corridor Study database. This database contains data collected by the MMSD, the USGS, the USEPA, or the WDNR since 1970. In some cases, these data were supplemented with historical data taken by SEWRPC, if the stations were in the same locations.[12] Trend analysis was conducted using only those sites that had sufficiently long periods of record. Therefore, the number of stations available for long-term trend analysis varied among watersheds, as well as among water quality constituents as further summarized in Chapters V through X and in Appendix C, "Seasonal and Annual Trends in Water Quality Parameters Among Streams of the Greater Milwaukee Watersheds within Southeastern Wisconsin," of this report.

The data were examined for evidence of several kinds of trends: changes in the values of water quality parameters over time at a given location, changes in the values of water quality parameters at various locations along the length of streams, seasonal changes in the value of water quality parameters at a given location, and, for the Menomonee, Milwaukee, and Kinnickinnic Rivers, differences in the average values of water quality parameters between the upstream stations and the Milwaukee River Estuary. Trends over time were assessed at each sampling station through the use of separate linear regression analyses with the date as the independent variable and each of the individual water quality constituents as the dependent variable. These analyses were conducted both on a seasonal basis and on an annual basis. Data from the winter months were excluded from the annual trend analyses because MMSD did not conduct any sampling during the winter after 1986. Where necessary to meet the normality assumption of regression analysis, the water quality data were log-transformed prior to regression analysis. A trend was determined to exist when the results of an analysis showed that there was a statistically significant regression coefficient at a probability less than or equal to 0.05.

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[12]*SEWRPC Technical Report No. 17,* Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975, *Appendix D, "Physical, Chemical, and Bacteriological Stream Sample Analysis by the SEWRPC and the State Laboratory of Hygiene," June 1978.*

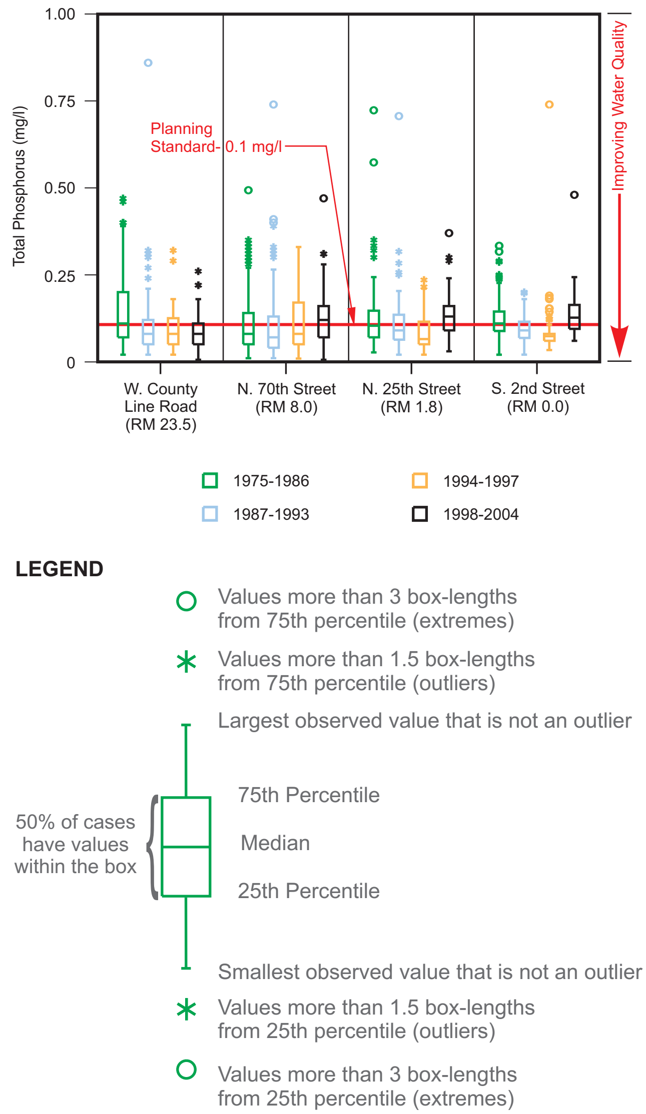
Trends along the length of a river were assessed through the use of linear regression analysis using river-mile as the independent variable and the water quality parameter as the dependent variable. These analyses were conducted on all data available from the sampling stations chosen for trend analysis. The sampling sites in the estuary were not included in these analyses. Again, in some cases the water quality data were log-transformed in order to meet the normality assumption of regression analysis, and a trend was determined to exist when the results of an analysis showed that there was a statistically significant regression coefficient at a probability less than or equal to 0.05.

Seasonal changes and trends were examined through graphical analysis and summarized in Appendix C. As described in detail in Chapters V through X of this report, when large amounts of data were available, seasonal differences were apparent in the summary graphs of historical and baseline water quality, an example of which is shown in Figure 23.

Differences in the average values of water quality parameters between the upstream stations and the estuary were assessed using analysis of variance (ANOVA). The period of record was divided into four intervals: 1975-1986, 1987-1993, 1994-1997, and 1998-2001. These intervals were chosen to reflect major changes in data collection procedures used by, and infrastructure available to, the MMSD. After 1986, the MMSD no longer conducted water quality sampling during the winter months. The first period was defined to reflect this change and the effect it has on comparability of the data. The second period was defined to represent water quality conditions before the Inline Storage System (i.e. the "Deep Tunnel") was brought online in 1994. The final two periods were defined for the purpose of making comparisons with the Inline Storage System in operation. The 1998-2004 period is also intended to represent baseline conditions. For each interval, ANOVAs were conducted for each water quality parameter for which sufficient data were available. Sites were classified as being in the estuary or upstream regions. This classification was used as the independent variable in the analysis and the water quality parameter was used as the dependent variable. Differences were determined to exist when the ANOVA showed that the differences between means were statistically significant at a probability less than or equal to 0.05.

Figure 24

EXAMPLE OF BOX-PLOT FIGURE SHOWING DISTRIBUTION OF WATER QUALITY CONCENTRATIONS AMONG STATIONS AND SPECIFIC TIME PERIODS FROM 1975-2004



NOTE: Most graphs will include a red line indicating a water quality standard, planning standard, or consumption advisory, where appropriate.

Source: SEWRPC.

A different procedure was used for examining water temperature data. These data were analyzed using a three-factor ANOVA with sampling site, time period, and season as the independent factors and water temperature as the dependent variable. This procedure can reveal both whether the average water temperature in the river has changed over time and whether differences exist in mean water temperature among sampling sites in a stream. It also has the advantage of separating out seasonal effects on temperature. In addition, the fact that it tests for the effects of interactions among factors on temperature allows for the examination of the question of whether water temperature at the sampling sites are behaving differently from one another with respect to seasons or time period. Because of limitations in the data set, two time periods were used for examining differences: 1985-1993 and 1994-2001. Because MMSD stopped sampling during the winter in 1987, data from the winter months were excluded from the analysis.

Analysis of Data from Lakes

In addition to the analyses described above, data from lakes in the regional water quality management plan update study area were examined to characterize their trophic status and to assess changes in trophic status over time.

Lakes are commonly classified according to their degree of nutrient enrichment—or trophic status. The ability of lakes to support a variety of recreational activities and healthy fish and other aquatic life communities is often correlated to the degree of nutrient enrichment which has occurred. There are three terms generally used to describe the trophic status of a lake: oligotrophic, mesotrophic, and eutrophic.

Oligotrophic lakes are nutrient-poor lakes. These lakes characteristically support relatively few aquatic plants and often do not contain very productive fisheries. Oligotrophic lakes may provide excellent opportunities for swimming, boating, and waterskiing. Because of the naturally fertile soils and the intensive land use activities, there are relatively few oligotrophic lakes in southeastern Wisconsin.

Mesotrophic lakes are moderately fertile lakes which may support abundant aquatic plant growths and productive fisheries. However, nuisance growths of algae and macrophytes are usually not exhibited by mesotrophic lakes. These lakes may provide opportunities for all types of recreational activities, including boating, swimming, fishing, and waterskiing. Many lakes in southeastern Wisconsin are mesotrophic.

Eutrophic lakes are nutrient-rich lakes. These lakes often exhibit excessive aquatic macrophyte growths and/or experience frequent algae blooms. If the lakes are shallow, fish winterkills may be common. While portions of such lakes are not ideal for swimming and boating, eutrophic lakes may support very productive fisheries.

Several numeric "scales," based on one or more water quality indicators, have been developed to define the trophic condition of a lake. Because the trophic state is actually a continuum from very nutrient poor to very nutrient rich, a numeric scale is useful for comparing lakes and for evaluating trends in water quality conditions. Care must be taken, however, that the particular scale used is appropriate for the lake to which it is applies. For lakes in the study area, the Wisconsin Trophic State Index (WTSI),[13] a refinement of the Carlson Trophic State Index (TSI)[14] designed to account for the greater humic acid content—brown water color—present in Wisconsin lakes, is presented. The WTSI has been adopted by the WDNR for use in lake management investigations.

The WTSI assigns a numerical trophic condition rating based on Secchi-disc transparency, total phosphorus, and chlorophyll-*a* concentrations. WTSI ratings that are less than 40 are characteristic of oligotrophic conditions. WTSI ratings between 40 and 50 are characteristic of mesotrophic conditions. WTSI ratings greater than 50 are characteristic of eutrophic conditions.

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

[14]*R. E. Carlson, "A Trophic State Index for Lakes,"* Limnology and Oceanography, *Vol. 22, pp. 361-369, 1977.*

Sources of Pollution Analysis
Commission staff obtained lists of discharge permits issued under the Wisconsin Pollution Discharge Elimination System (WPDES) that were effective in February 2003 for the study area. These lists included permits for discharges from public and private wastewater treatment plants, permits issued under the general permit program for discharges from industrial and related facilities, individual permits issued for discharges from industrial and related facilities, and permits for discharge of stormwater. For the purposes of this report, map locations of the permitted facilities as shown in Chapters V through X were determined based upon the address of the facility. The facilities were then assigned to the appropriate watershed based upon the location. In some instances, facility locations were located on aerial photographs and confirmed by site visits.

Pollution loadings were developed through watercourse modeling. The modeling procedures are described in Chapter V of SEWRPC Planning Report No. 50, *A Regional Water Quality Management Plan Update for the Greater Milwaukee Watersheds*. Data from three types of point sources were included in the model: public and private wastewater treatment facilities, facilities permitted to discharge noncontact cooling water under the WDNR's WPDES general permit program, and facilities with individual permits under the WDNR's WPDES individual permit program. Monitoring data for public and private wastewater treatment facilities were taken from compliance maintenance annual reports (CMARs) submitted to the WDNR. Monitoring data for facilities discharging under individual or noncontact cooling water permits were taken from discharge monitoring reports (DMRs) submitted to the WDNR. Nonpoint source pollutant loads were estimated through application of the water quality model.

Locations of sewage bypasses and overflows and data on bypass dates and volumes were obtained from two sources. Information on those sites within the MMSD 2020 Facilities Plan study area was provided by the MMSD. Information on sites outside of the MMSD 2020 Facilities Plan study area was provided by the WDNR. In some instances, bypass site locations were located on aerial photographs and confirmed by site visits.

Biological Conditions Analysis
Fishery Analysis
Both the warmwater IBI[15] and coldwater IBI[16] were used to assess the fishery among warmwater and coldwater streams as appropriate to classify the fisheries and environmental quality throughout the greater Milwaukee watersheds study area.

In Wisconsin, high-quality warmwater streams are characterized by many native species including cyprinids, darters, suckers, sunfish, and percids that typically dominate the fish assemblage. Intolerant species (species that are particularly sensitive to water pollution and habitat degradation) are also common in high-quality warmwater systems.[17] Tolerant fish species (species that are capable of persisting under a wide range of degraded conditions) are also typically present within high-quality warmwater streams, but they do not dominate. Insectivores (fish that feed primarily on small invertebrates) and top carnivores (fish that feed on other fish, vertebrates, or large invertebrates) are generally common. Omnivores (fish that feed on both plant and animal material) are also generally common, but do not dominate. Simple lithophilous spawners which are species that lay their eggs directly on large substrate, such as clean gravel or cobble, without building a nest or providing parental care for the eggs are also generally common.

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[15]*John Lyons, "Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin," United States Department of Agriculture,* General Technical Report NC-149, *1992.*

[16]*John Lyons, "Development and Validation of an Index of Biotic Integrity for Coldwater Streams in Wisconsin,"* North American Journal of Fisheries Management, *Volume 16, May 1996.*

[17]*John Lyons, "Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin,"* op. cit.

The warmwater IBI consists of a series of fish community attributes that reflect the characteristics of biotic assemblages: species richness and composition, trophic and reproductive function, and individual abundance and condition.[18] The Wisconsin IBI described here consists of 10 basic metrics, plus two additional metrics (termed "correction factors") that affect the index only when they have extreme values. These 12 metrics are given in Table 11. Although the fish IBI is useful for assessing environmental quality and biotic integrity in warmwater streams, it is most effective when used in combination with additional data on physical habitat, water quality, macroinvertebrates, and other biota when evaluating a site.[19] Hence, supplemental data from macroinvertebrate surveys were also evaluated where available.

In contrast to warmwater streams, coldwater systems are characterized by few native species, with salmonids (trout) and cottids (sculpin) dominating, and they lack many of the taxonomic groups that are important in high-quality warmwater streams as summarized above. An increase in fish species richness in coldwater fish assemblages often indicates environmental degradation. When degradation occurs the small number of coldwater species are replaced by a larger number of more physiologically tolerant cool and warmwater species, which is the opposite of what tends to occur in warmwater fish assemblages. Due to the fundamental differences between warmwater versus coldwater streams, a separate IBI was developed to assess the health of coldwater streams.[20] This coldwater IBI is based upon the following elements (see Table 11): number of intolerant species, percent of individuals that are tolerant, percent of all individuals that are top carnivore species, percent of all individuals that are native or exotic coldwater (coho salmon, chinook salmon, rainbow trout, brown trout) or coolwater species, and percent of salmonid individuals that are brook trout. Since brook trout are the only native stream dwelling salmonid in the State of Wisconsin, the presence and abundance of brook trout dramatically improves the coldwater IBI scores.

Stream Macroinvertebrate Analysis

The Commission staff used several metrics to classify macroinvertebrate communities and evaluate environmental quality in the streams of the greater Milwaukee watersheds study area. These metrics included the Hilsenhoff Biotic Index (HBI), the percentage of individuals in a macroinvertebrate sample belonging to the insect orders Ephemeroptera, Plecoptera, and Trichoptera (percent EPT), the number of genera in a macroinvertebrate sample belonging to the insect orders Ephemeroptera, Plecoptera, and Trichoptera, and the percentage of individuals in a macroinvertebrate sample belonging to particular functional feeding groups such as shredders or collectors. The HBI represents the average weighted pollution tolerance value of all arthropods present in a sample.[21] This is an index of organic pollution and is based on the response of the macroinvertebrate community to the combination of high organic loadings and decreased dissolved oxygen concentration. Two of the measures are based on the proportion of the community represented by the insect orders Ephemeroptera, Plecoptera, and Trichoptera. These taxa generally represent organisms that are less tolerant of organic pollution. The metrics used respond to a variety of stressors, including organic pollution, low dissolved oxygen, toxic contaminants, flow disruption, and thermal stress.[22]

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[18]*John Lyons,* General Technical Report NC-149, op. cit.

[19]Ibid.

[20]*John Lyons, "Development and Validation of an Index of Biotic Integrity for Coldwater Streams in Wisconsin,"* op. cit.

[21]*William L. Hilsenhoff, "Using a Biotic Index to Evaluate Water Quality in Streams,"* Wisconsin Department of Natural Resources Technical Bulletin No. 132, *1982; William L. Hilsenhoff, "An Improved Biotic Index of Organic Stream Pollution,"* Great Lakes Entomologist, *Volume 20, 1987.*

[22]*Richard A. Lillie, Stanley W. Szczytko, and Michael M. Miller,* Macroinvertebrate Data Interpretation Guidance Manual, *Wisconsin Department of Natural Resources PUB-SS-965-2003, 2003.*

Table 11

METRICS USED TO CALCULATE THE INDEX OF BIOTIC INTEGRITY (IBI) FOR WARMWATER AND COLDWATER STREAMS OF WISCONSIN

Index of Biotic Integrity (IBI)	Fish Community Attribute	Metric
Warmwater	Species Richness and Composition	Total number of native species Total number of darter species Total number of sucker species Total number of sunfish species Total number of intolerant species Percent of total individuals belonging to tolerant species
	Trophic and Reproductive Function	Percent of total individuals belonging to omnivorous species Percent of total individuals belonging to insectivorous species Percent of total individuals belonging to top carnivore species Percent of total individuals belonging to simple lithophilous spawning species
	Fish Abundance and Condition[a]	Number of individuals not belonging to tolerant species per 300 meters sampled
Coldwater[b]	Species Richness and Composition	Total number of intolerant species Percent of total individuals belonging to tolerant species
	Trophic and Physiological Condition	Percent of total individuals belonging to top carnivore species Percent of total individuals that are stenothermal, coolwater, and coldwater species (native or exotic) Percent of salmonid individuals belonging to brook trout species

[a]*These metrics are not normally included in the calculation of the IBI, but can lower the overall IBI score if they have extreme values (very low numbers of individuals or high percent DELT fish).*

[b]*Stocked trout should not be included in any of the metric calculations.*

Source: John Lyons, "Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin," United States Department of Agriculture, General Technical Report NC-149, *1992; John Lyons, "Development and Validation of an Index of Biotic Integrity for Coldwater Streams in Wisconsin," North American Journal of Fisheries Management, Volume 16, May 1996.*

The biological assessment rating for stream macroinvertebrate taxa is based upon modified rapid bioassessment protocol criteria for screening water quality that include the following benthic community attributes:[23] taxa richness (total number of families); percent dominance (percentage of the total number of individuals in the sample belonging to the numerically dominant family); Ephemeroptera, Plecoptera, and Trichoptera (EPT) index (total number of families belonging to the insect orders EPT); percent EPT (percentage of the total number of individuals in the sample belonging to the insect orders EPT); and the Family Biotic Index[24] (weighted average of tolerance values of the families present). These metrics respond to a variety of stressors, including organic pollution, low dissolved oxygen, toxic contaminants, flow disruption, and thermal stress.[25] The rating characterizes the state of stream sites as being nonimpaired, moderately impaired, or severely impaired based upon the composition of the benthic macroinvertebrate community. Nonimpaired sites are defined as comparable to

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[23]*New Jersey Department of Environmental Protection, Bureau of Freshwater and Biological Monitoring, http://www.state.nj.us/dep/www/bfbm/rbpintro.html, January 2004.*

[24]*W.L. Hilsenhoff, "Rapid Field Assessment of Organic Pollution with a Family-Level Biotic Index,"* Journal of the North American Benthological Society*, Volume, 1987, pp. 65-688.*

[25]*Richard A. Lillie,* et. al., op. cit.

undisturbed stream systems, and are characterized by maximum taxa richness, balanced taxa groups, and good representation of individuals belonging to species that are intolerant of pollution. Moderately impaired sites are characterized by reduced taxa richness, particularly among EPT taxa, accompanied by reduced community composition balance and reduction in the number of intolerant taxa. Severely impaired sites are characterized by macroinvertebrate communities dominated by a few very abundant taxa that are tolerant to poor water quality conditions.

Stream Habitat Condition Analysis

The Commission staff used a variety of physical habitat parameters, where available, to classify the quality and diversity of available habitat for fishes and other aquatic organism, in the streams of the Region. The WDNR has recently developed guidelines for evaluating habitat of wadable streams as part of their baseline monitoring protocol.[26] This protocol measures a variety of parameters that include stream flow, water depths, width, substrate composition, sinuosity, gradient, and amounts of pool and riffle habitat, among others. As part of the baseline monitoring protocol, these habitats assessments were executed for the same sites as the fisheries assessments were completed, which allows for direct comparisons between habitat and fisheries quality, where the data exist. Specific habitat assessment locations are mapped and discussed in further detail for each of the watersheds in Chapters V through X of this report.

The baseline monitoring program data were analyzed by SEWRPC staff using the Qualitative Habitat Evaluation Index (QHEI),[27] which integrates the physical parameters of the stream and adjacent riparian features to assess potential habitat quality. This index is designed to provide a measure of habitat that generally corresponds to those physical factors that affect fish communities and which are important to other aquatic life (i.e., macroinvertebrates and fishes). This index has been shown to correlate well with fishery IBI scores.

Riparian Corridor Condition Analysis

Riparian corridors along the rivers of the study area and their tributaries were delineated based on the presence of natural vegetation, as shown on year 2000 SEWRPC digital orthophotographs. The areas were mapped using a geographical information system (GIS). The riparian widths were classified based on the average distance between the edge of the stream channel and the exterior border. For each stream reach or segment evaluated, the average riparian width was evaluated for both the left and right bank and was placed into one of four categories:

1. 0-25 feet
2. 25-50 feet
3. 50-75 feet
4. Greater than 75 feet

Sediment Quality Analysis

Sediment Quality Standards

In addition to being present in water, many contaminants can potentially accumulate in stream and lake sediments. Based upon the potential for contaminants present in the sediment at particular sites to create biological impacts, the WDNR has developed proposed consensus-based sediment quality guidelines.[28] The consensus-based guidelines apply average effect-level concentrations from several guidelines of similar intent and are used

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[26]*Wisconsin Department of Natural Resources,* Guidelines for Evaluating Habitat of Wadable Streams*, Bureau of Fisheries Management and Habitat Protection, Monitoring and Data Assessment Section, June 2000.*

[27]*Edward T. Rankin,* The Quality Habitat Evaluation Index [QHEI]: Rationale, Methods, and Application*, State of Ohio Environmental Protection Agency, November 1989.*

[28]*Wisconsin Department of Natural Resources,* Consensus-Based Sediment Quality Guidelines: Recommendations for Use & Application–Interim Guidance, *WT-732 2003, December 2003.*

to predict the presence or absence of toxicity. Three criteria based on likely effects to benthic-dwelling organisms are proposed: threshold effect concentration (TEC), probable effect concentration (PEC), and midpoint effect concentration (MEC). TECs indicate contaminant concentrations below which adverse effects to benthic organisms are considered to be unlikely. PECs indicate contaminant concentrations at which adverse effects to the benthic organisms are highly probable or will be frequently seen. MECs are derived from TEC and PEC values for the purpose of interpreting the effects of contaminant concentrations that fall between the TEC and the PEC. The WDNR recommends their criteria be used to establish levels of concern for prioritizing sites for additional study. The threshold, midpoint, and probable effect concentrations for metals and for nonpolar organic compounds are shown in Tables 12 and 13, respectively. It is important to note that these guidelines estimate only the effects of contaminants on benthic macroinvertebrate species. Where noncarcinogenic and nonbioaccumulative compounds are concerned, these guidelines should be protective of human health and wildlife concerns. For bioaccumulative compounds, considerations of the protection of human health or wildlife may necessitate the use of more restrictive concentration levels.

The probable effect concentrations given in Tables 12 and 13 can also be used to derive mean PEC quotients for evaluating the toxicity of mixtures of contaminants in sediment to benthic organisms. A PEC quotient is calculated for each contaminant in each sample by dividing the concentration of the contaminant in the sediment by the PEC concentration for that chemical. The mean PEC quotient is then calculated by summing the individual quotients and dividing the sum by the number of PECs evaluated. This normalizes the value to provide comparable indices of contamination among samples for which different numbers of contaminants were analyzed. Results of evaluation of this method show that mean PEC quotients that represent mixtures of contaminants are highly correlated with incidences of toxicity to benthic organisms in the same sediments. Table 14 shows predicted incidences of toxicity for various mean PEC quotient values. The reliability of predictions of toxicity is greatest for mean PEC quotients calculated from total PAHs, total PCBs, and the metals arsenic, cadmium, chromium, copper, lead, nickel, and zinc. The WDNR has developed a proposed recommended procedure for calculating mean PEC quotients.[29] The analyses of sediment quality in Chapters V through X follow this procedure.

Groundwater Quality Analysis

The groundwater geology, water quality of groundwater, and sources of groundwater contamination in Southeastern Wisconsin, including the regional water quality management plan update study area, were recently reviewed in SEWRPC Technical Report No. 37 *Groundwater Resources of Southeastern Wisconsin*. The data, analyses, and conclusions presented in Chapter XI of this report represent a summary of the findings of that report as they pertain to the regional water quality management plan update study area.

SUMMARY

The assessment of water quality, water quantity, sediment quality, groundwater quality, and biological conditions requires a comparison of observed conditions to desired conditions. In addition, comparison of currently observed conditions to historical conditions facilitates the documentation of changes in conditions since the preparation of the original regional water quality management plan. This chapter described the sources of data and methods of analysis used in this report to assess the current state of water quality, water quantity, sediment quality, and biological conditions in the regional water quality management plan update study area.

For those portions of the study area that are within the MMSD 2020 Facility Plan study area, data were largely obtained from the MMSD Corridor Study database, a water quality database containing results from sampling conducted during the period 1970 to 2002 by a number of agencies, including the MMSD, the WDNR, the USGS, and the USEPA. Where possible, supplemental data from various agencies up to year 2004 were included for sites

[29]Ibid.

Table 12

CONSENSUS-BASED SEDIMENT QUALITY GUIDELINES FOR METALS USED AS SCREENING CRITERIA TO EVALUATE CONTAMINATION IN SEDIMENTS[a]

Substance	Threshold Effect Concentration (TEC)[b] (milligrams per kilogram, dry weight)	Midpoint Effect Concentration (MEC)[c] (milligrams per kilogram, dry weight)	Probable Effect Concentration (PEC)[d] (milligrams per kilogram, dry weight)
Silver	1.60	1.90	2.2
Arsenic	9.80	21.40	33.0
Cadmium	0.99	3.00	5.0
Chromium	43.00	76.50	110.0
Copper	32.00	91.00	150.0
Iron	20,000.00	30,000.00	40,000.0
Mercury	0.18	0.64	1.1
Manganese	460.00	780.00	1,100.0
Nickel	23.00	36.00	49.0
Antimony	2.00	13.50	25.0
Lead	36.00	83.00	130.0
Zinc	120.00	290.00	460.0

[a]*These freshwater sediment screening guidelines are derived from the following references: E.R. Long and L.G. Morgan,* The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program, *NOAA Technical Memorandum NOS-OMA-52, National Oceanic and Atmospheric Administration, Seattle, Washington, 1991; D.D. MacDonald, C.G. Ingersoll, and T.A. Berger, "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Aquatic Ecosystems,"* Archives of Environmental Contamination and Toxicology, *Volume 39, pp. 20-31, 2000; D.D. MacDonald and M. MacFarlane,* Criteria for Managing Contaminated Sediment in British Colombia (draft), *British Columbia Ministry of Environment, Lands, and Parks, Victoria, British Columbia, 1999; D. Persaud, R. Jaagumagi, and A. Hayton,* Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, *ISBN 0-7729-9248-7, Ontario Ministry of the Environment, Ottawa, Ontario, 1993; Wisconsin Department of Natural Resources,* Consensus-Based Sediment Quality Guidelines: Recommendations for Use and Application, *PUBL-WT-732-2003, 2003.*

[b]*Threshold Effect Concentrations (TECs) indicate contaminant concentrations below which toxicity to benthic organisms are considered to be unlikely. Water column species and wildlife are at a potential risk via biomagnification (food chain toxicity) if site-related sediment concentrations are at or above the TEC. It is also important to note that other known biomagnifiers (not included in this table) without screening numbers warrant case-by-case evaluation.*

[c]*Midpoint Effect Concentrations (MECs) are derived from TEC and PEC values for the purpose of interpreting contaminant concentrations that fall between the TEC and the PEC. The Wisconsin Department of Natural Resources recommends their use for establishing levels of concern for prioritizing sites for additional study.*

[d]*Probable Effect Concentrations (PECs) indicate contaminant concentrations at which toxicity to the benthic organisms are considered to by highly probable.*

Source: Wisconsin Department of Natural Resources.

both within and outside of the Corridor Database boundaries. For sites within the study area that are outside of the MMSD 2020 Facilities Planning study area, water quality data were obtained from a variety of sources, including Federal, State, and local agencies, such as the USGS, the WDNR, counties, and municipalities, as well as citizen monitoring organizations.

The data were assessed using a variety of analytical methods. Graphical analysis and related summary statistics were used to compare current conditions to historical conditions. The statistical procedures of ANOVA and linear regression were employed to examine the data for trends. A variety of indices, such as the Index of Biological Integrity and the WTSI were computed from the data to examine biological conditions, sediment quality, and lake trophic status. The results of these analyses are presented in Chapters V through X.

Table 13

CONSENSUS-BASED SEDIMENT QUALITY GUIDELINES FOR NONPOLAR ORGANIC COMPOUNDS USED AS SCREENING CRITERIA TO EVALUATE CONTAMINATION IN SEDIMENTS[a]

Substance	Threshold Effect Concentration (TEC)b,c (micrograms per kilogram, dry weight)	Midpoint Effect Concentration (MEC)b,d (micrograms per kilogram, dry weight)	Probable Effect Concentration (PEC)b,e (micrograms per kilogram, dry weight)
Polycyclic Aromatic Hydrocarbons (PAHs)			
Acenaphthene	6.70	48.00	89.00
Acenaphthylene	5.90	67.00	128.00
Anthracene	57.20	451.00	845.00
Benz(a)anthracene	108.00	579.00	1,050.00
Benzo(b)fluoranthene	240.00	6,820.00	13,400.00
Benzo(k)fluoranthene	240.00	6,820.00	13,400.00
Benzo(g,h,i)perylene	170.00	1,685.00	3,200.00
Benzo(a)pyrene	150.00	800.00	1,450.00
Benzo(e)pyrene	150.00	800.00	1,450.00
Chrysene	166.00	728.00	1,290.00
Dibenz(a,h)anthracene	33.00	84.00	135.00
Fluoranthene	423.00	1,327.00	2,230.00
Fluorene	77.40	307.00	536.00
Indeno(1,2,3-cd)pyrene	200.00	1,700.00	3,200.00
2-methylnaphthalene	20.20	111.00	201.00
Naphthalene	176.00	369.00	561.00
Phenanthrene	204.00	687.00	1,170.00
Pyrene	195.00	858.00	1,520.00
Total	1,610.00	12,205.00	22,800.00
Polychlorinated Biphenyls (PCBs)	60.00	368.00	676.00
Organochlorine Pesticides			
Aldrin	2.00	41.00	80.00
Benzohexachloride (BHC)	3.00	62.00	120.00
α-BHC	6.00	53.00	100.00
β-BHC	5.00	108.00	210.00
y-BHC (Lindane)	3.00	4.00	5.00
Chlordane	3.20	10.60	18.00
Dieldrin	1.90	32.00	62.00
Sum DDD	4.90	16.50	28.00
pp DDE	3.20	17.00	31.00
Sum o,p' + p,p' DDT	4.20	33.60	63.00
Sum DDD + DDE + DDT	5.30	289.00	572.00
Endrin	2.20	104.60	207.00
Heptachlor epoxide	2.50	9.30	16.00
Mirex	7.00	10.50	14.00
Toxaphene	1.00	1.50	2.00
Other			
Benzene	57.00	83.50	110.00
Benzoic Acid	6,500.00	- -	6,500.00
Benzyl Alcohol	570.00	650.00	730.00
Dibenzofuran	150.00	365.00	580.00
1,2-Dichlorobenzene	23.00	- -	23.00
1,4-Dichlorobenzene	31.00	60.50	90.00
Diethyl Phthalate	610.00	855.00	1,100.00
2,4-Dimethyl Phenol	290.00	- -	290.00
Dimethyl Phthalate	530.00	- -	530.00
Di-N-Butyl Phthalate	2,200.00	9,600.00	17,000.00
Di-N-Octyl Phthalate	580.00	22,790.00	45,000.00
2-Methylphenol	6,700.00	- -	6,700.00
Pentachlorophenol	150.00	175.00	200.00
Phenol	4,200.00	8,100.00	12,000.00
Toluene	890.00	1,345.00	1,800.00
2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)[f]	0.85	11.20	21.50
Tributyltin	0.52	1.73	2.94
1,2,4-Trichlorobenzene	8.00	13.00	18.00
Xylene	25.00	37.50	50.00

Table 13 Footnotes

[a]*These freshwater sediment screening guidelines are derived from the following references: Canadian Council of Ministers of the Environment (CCME), "Canadian Sediment Quality Guidelines for the Protection of Aquatic Life: Summary Tables,"* Canadian Environmental Quality Guidelines*, Canadian Council of Ministers of the Environment, Winnipeg, Canada, 1999; Canadian Council of Ministers of the Environment (CCME), "Canadian Sediment Quality Guidelines for the Protection of Aquatic Life-Update: Summary Tables," Canadian Council of Ministers of the Environment, Winnipeg, Canada, 2002; D.D. MacDonald, C.G. Ingersoll, and T.A. Berger, "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Aquatic Ecosystems,"* Archives of Environmental Contamination and Toxicology*, Volume 39, pp. 20-31, 2000; D.D. MacDonald and M. MacFarlane,* Criteria for Managing Contaminated Sediment in British Colombia (Draft)*, British Columbia Ministry of Environment, Lands, and Parks, Victoria, British Columbia, 1999; D. Persaud, R. Jaagumagi, and A. Hayton,* Guidelines for the Protection and Management of Aquatic Sediment Quality in Ontario, *ISBN 0-7729-9248-7, Ontario Ministry of the Environment, Ottawa, Ontario, 1993; Washington State Department of Ecology,* Sediment Management Standards*, Chapter 173-204,* Washington Administrative Code, *1991; Wisconsin Department of Natural Resources,* Consensus-Based Sediment Quality Guidelines: Recommendations for Use and Application*, PUBL-WT-732-2003, 2003.*

[b]*For nonpolar organic compounds (e.g. PAHs, organochlorine pesticides, PCBs), the guideline values are expressed on a dry weight basis normalized to a total organic carbon (TOC) level of 1 percent TOC. Organic carbon content of sediment is an important factor influencing the movement and bioavailability of nonpolar organic compounds between organic carbon in bulk sediment and sediment pore water and overlying surface water. For screening, comparison to guidelines, and comparison among sites, the values of these contaminants in sediments should be dry-weight normalized to 1 percent TOC.*

[c]*Threshold Effect Concentrations (TECs) indicate contaminant concentrations below which toxicity to benthic organisms are considered to be unlikely. Water column species and wildlife are at a potential risk via biomagnification (food chain toxicity) if site-related sediment concentrations of PCBs, organochlorine pesticides, or mercury are at or above the TEC. It is also important to note that other known biomagnifiers (not included in this table) without screening numbers warrant case-by-case evaluation.*

[d]*Midpoint Effect Concentrations (MECs) are derived from TEC and PEC values for the purpose of interpreting contaminant concentrations that fall between the TEC and the PEC. The Wisconsin Department of Natural Resources recommends their use for establishing levels of concern for prioritizing sites for additional study.*

[e]*Probable Effect Concentrations (PECs) indicate contaminant concentrations at which toxicity to the benthic organisms are considered to be highly probable.*

[f]*Units are nanogram of Toxic Equivalent to 2,3,7,8 TCDD activity per kilogram.*

Source: Ontario Ministry of the Environment and Wisconsin Department of Natural Resources.

Table 14

RELATIONSHIP BETWEEN MEAN PEC QUOTIENT AND INCIDENCE OF TOXICITY TO BENTHIC ORGANISMS IN FRESHWATER SEDIMENTS

Mean PEC Quotient	Average Incidence of Toxicity (percent)[a]
0.00	0.0
0.25	20.0
0.50	40.0
0.75	54.0
1.00	64.0
1.25	70.0
1.50	77.0
1.75	84.0
2.00	87.0
2.25	90.0
2.50	92.0
2.75	95.0
3.00	96.0
3.25	98.0
3.50	99.0
3.75	99.5
$\geq$4.00	100.0

[a]*Average incidence of toxicity computed from the regression equation $Y = 101.48(1-0.36^X)$, where Y is the incidence of toxicity and X is the mean PEC Quotient.*

Source: D.D. MacDonald, C.G. Ingersoll, and T.A. Berger, "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Aquatic Ecosystems," Archives of Environmental Contamination and Toxicology*, Vol. 39, 2000, pp. 20-31; Wisconsin Department of Natural Resources Publication No. PUBL-WT-732-2003,* Consensus-Based Sediment Quality Guidelines: Recommendations for Use and Application*, 2003.*

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Chapter IV

WATER USE OBJECTIVES AND WATER QUALITY STANDARDS

REGULATORY SETTING

Because the regional water quality management plan update is intended to address water quality problems and to assess the best means to attain water use objectives and water quality standards for the study area concerned, it is deemed important to review and summarize the existing and potential legal framework through which attainment of water quality goals may be sought at various levels of government.

The Clean Water Act and Federal Water Quality Management

The Federal approach to water quality management was broadened beginning with the passage of the Federal Water Pollution Control Act on June 30, 1948. With the passage of this Act, the Federal government began to take steps toward controlling and preventing pollution of the navigable waters of the United States. Initially, the Act was primarily directed at establishing a Federal grant-in-aid program for the construction of publicly owned wastewater treatment facilities. In the mid-1960s, requirements were added relating to the establishment of interstate water quality standards. The Act was substantially revised by the amendments of 1972, 1977, and 1987. The name of the statute was changed from the Federal Water Pollution Control Act to the Federal Clean Water Act at the time of the 1977 amendment. In general, the Act, as amended in 1972 and 1977, called for: 1) an increased emphasis on enhancing the quality of all of the navigable waters of the United States, whether interstate or intrastate, 2) an increased emphasis on planning and on examining alternative courses of action to meet stated water use objectives and supporting water quality standards, 3) waters of the United States to be made to the extent practicable "fishable and swimmable," 4) the provision of substantial Federal financial assistance to construct publicly owned wastewater treatment works, and 5) the development and implementation of areawide waste treatment management planning processes to assure adequate control of sources of pollutants within each state. The 1987 amendment to the Act called for 1) the development of control strategies for waters polluted by toxic substances, 2) a permitting program for stormwater discharges from municipalities of a certain size, certain industries, and construction sites, and 3) the establishment of a program to ultimately replace the Federal program of construction grants for sewage treatment facilities with revolving funds administered by the states. In the following sections, attention is focused on the most relevant portions of the Federal Clean Water Act.

Water Quality Standards and Effluent Limitations

Since 1965, the provisions of the Federal Water Pollution Control Act, and, later, the Clean Water Act, have required states to adopt water use objectives and supporting water quality standards for all interstate waters. The Act, as amended in 1972, incorporated by reference all existing interstate water quality standards and required, for the first time, the adoption and submittal of all intrastate water use objectives and supporting water quality standards for approval by the U.S. Environmental Protection Agency (USEPA). Wisconsin, through the Natural

Resources Board and the Wisconsin Department of Natural Resources (WDNR), has adopted the required interstate and intrastate water use objectives and supporting water quality standards. These objectives and standards as related to streams and watercourses in the regional water quality management plan study area are discussed in a subsequent section of this chapter.

In addition to water use objectives and standards, the Act requires the establishment of specific effluent limitations for all point sources of water pollution. Such limitations require the application of the best practicable water pollution control technology currently available, as defined by the USEPA Administrator. Also, the Act requires that any waste source which discharges to a publicly owned treatment works comply with applicable pretreatment requirements, also to be established by the USEPA Administrator. The Act established a requirement that publicly owned treatment works meet effluent limitations based upon a secondary level of treatment and through application of the best applicable waste treatment technology. In addition to these uniform or National effluent limitations, the Act provides that any waste source must meet any more stringent effluent limitations as required to implement any applicable water use objective and supporting standard established pursuant to any State law or regulation or any other Federal law or regulation.

Pollutant Discharge Permit System

The Clean Water Act establishes the National Pollutant Discharge Elimination System (NPDES). Under this system the USEPA Administrator or a state, upon approval of the USEPA Administrator, may issue permits for the discharge of any pollutant or combination of pollutants upon the condition that the discharge will meet all applicable effluent limitations or upon such additional conditions as are necessary to carry out the provision of the Act. All such permits must contain conditions to assure compliance with all of the requirements of the Act, including conditions relating to data collection and reporting. In essence, the Act stipulates that all discharges to navigable waters must obtain a Federal permit or, where a state is authorized to issue permits, a state permit. The intent of the permit system is to include in the permit, where appropriate, a schedule of compliance which will set forth the dates by which various stages of the requirements imposed in the permit shall be achieved. As described below, Wisconsin has an approved permit system operating under the NPDES.

The 1987 amendments to the Clean Water Act established a Federal program for permitting of stormwater discharges from municipalities and specific industries. The Phase I program applies to the specified industries and to municipalities with populations of 100,000 or more. Ultimately, every separate municipal stormwater management system will be required to obtain a permit, regardless of the size of the municipality. The program is administered by the USEPA and calls for the issuance of NPDES permits. Pollution from stormwater runoff is commonly characterized as diffuse, or nonpoint source, pollution. The Clean Water Act specifically exempts such pollution sources from the requirements of the NPDES program. However, because most urban stormwater runoff is discharged to receiving streams through storm sewers or other facilities which concentrate flows, the 1987 amendments designated urban stormwater pollution as a point source which could be regulated under the NPDES program. The Federal stormwater discharge permitting program requires: 1) control of industrial discharges utilizing the best available technology economically achievable, 2) control of construction site discharges using best management practices, and 3) municipal system controls to reduce the discharge of pollutants to the maximum extent practicable. The USEPA has delegated the administration of the Phase I stormwater discharge permitting program in the State of Wisconsin to the WDNR.

In October of 1999, the USEPA expanded the coverage of the stormwater discharge permitting regulations when it issued Phase II stormwater rules that apply to urbanized areas with populations between 50,000 and 100,000 persons and to construction sites that disturb five acres of land or more.[1] The Phase II program requires that regulated municipalities reduce nonpoint source pollution to the "maximum extent practicable" through implementations of a set of minimum control measures, including:

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[1]*As of October 2004, construction sites that disturb one acre of land or more are subject to the permitting regulations.*

- Public education and outreach;
- Public involvement and participation;
- Illicit discharge detection and limitation;
- Construction site stormwater runoff control;
- Post-construction stormwater management for new development and redevelopment; and
- Pollution prevention and good housekeeping for municipal operations.

In Wisconsin, the WDNR also administers the Phase II program.

Continuing Statewide Water Quality Management Planning Processes
The Clean Water Act stipulates that each state must have a continuing planning process consistent with the objectives of the Act. States are required to submit a proposed continuing planning process to the USEPA Administrator for approval. The Administrator is prohibited from approving any state discharge permit program under the pollutant discharge elimination system if that state does not have an approved continuing planning program. The state continuing planning process must result in water quality management plans for the navigable waters within the state. Such plans must include at least the following items: effluent limitations and schedules of compliance to meet water use objectives and supporting water quality standards; the elements of any areawide wastewater management plan prepared for metropolitan areas; the total maximum daily pollutant load to all waters identified by the state for which the uniform or national effluent limitations are not stringent enough to implement the water use objectives and supporting water quality standards; adequate procedures for the revision of plans; adequate authority for intergovernmental cooperation; adequate steps for implementation, including schedules of compliance with any water use objectives and supporting water quality standards; adequate control over the disposition of all residual waste from any water treatment processing; and an inventory and ranking in order of priority needs for the construction of waste treatment works within the state.

Areawide Waste Treatment Planning and Management
Section 208 of the Clean Water Act provides for the development and implementation of areawide waste treatment management plans. Such plans are intended to become the basis upon which the USEPA approves grants to local units of government for the construction of waste treatment works. The Act envisions that the Section 208 planning process would be most appropriately applied in the nation's metropolitan areas which, as a result of urban and industrial concentrations and other development factors, have substantial water quality control problems. Accordingly, the Act envisions the formal designation of a Section 208 planning agency for substate areas that are largely metropolitan in nature and the preparation of the required areawide water quality management plan by that agency.

Any areawide plan prepared under the Section 208 planning process must include the identification of both point and nonpoint sources of water pollution and the identification of cost-effective measures which will abate the pollution from those sources. The plans must also identify the appropriate management agency responsibilities for implementation.

On September 27, 1974, the seven-county Southeastern Wisconsin Region and the Southeastern Wisconsin Regional Planning Commission (SEWRPC) were formally designated as a Section 208 planning area and planning agency pursuant to the terms of the Clean Water Act. Following preparation of a detailed study design and after receiving a planning grant from the USEPA, SEWRPC started the planning program in July 1975. The initial program was continued through July 12, 1979, the date of formal adoption of the plan by SEWRPC. The plan adoption followed a series of public meetings and hearings and is fully documented in SEWRPC Planning Report No. 30, *A Regional Water Quality Management Plan for Southeastern Wisconsin*, Volume One, *Inventory*

Findings, Volume Two, *Alternative Plans*, and Volume Three, *Recommended Plan*. The plan was approved by the Wisconsin Natural Resources Board on July 25, 1979; by the Governor on December 3, 1979; and by the USEPA on April 30, 1980.

The original regional water quality management plan has been updated over time through an amendment and revision process. A status report on the plan as amended through 1993 is presented in SEWRPC Memorandum Report No. 93, *A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report*, March 1995. That report also identifies issues which remain to be addressed in the continuing planning process.

The Wisconsin Department of Natural Resources and State Water Quality Management

Responsibility for water quality management in Wisconsin is centered in the Wisconsin Department of Natural Resources. Pursuant to the State Water Resources Act of 1965, the WDNR acts as the central unit of State government to protect, maintain, and improve the quality and management of the groundwater and surface waters of the State. The only substantive areas of water quality management authority not located in the WDNR, or shared with other agencies, are: 1) the authority to regulate private sanitary sewer systems, private septic tank sewage disposal systems, and construction site erosion control for commercial sites, which are the responsibility of the Wisconsin Department of Commerce, 2) the establishment of groundwater standards under Chapter NR 140 of the *Administrative Code*, which is shared with the Wisconsin Department of Health and Social Services, 3) the development by the Wisconsin Department of Agriculture, Trade and Consumer Protection (DATCP) of a model shoreland management ordinance and of regulations for drainage districts and county land and water resource management plans, and 4) the authority to regulate highway construction site erosion control for projects administered by the Wisconsin Department of Transportation (WisDOT), which is the responsibility of WisDOT.

Water Use Objectives and Water Quality Standards

Section 281.15(1) of the *Wisconsin Statutes* requires that the WDNR prepare and adopt water use objectives and supporting water quality standards that apply to all surface waters of the State. Such authority is essential if the State is to meet the requirements of the Clean Water Act. Water use objectives and supporting water quality standards were initially adopted for interstate waters in Wisconsin on June 1, 1967, and for intrastate waters on September 1, 1968. Chapters NR 102 through NR 105 of the *Wisconsin Administrative Code* set forth the water quality standards for the surface waters of the State. The water use objectives and supporting water quality standards or criteria promulgated by the WDNR are described in a subsequent section of this chapter.

Pollutant Discharge Permit System

Sections 283.31(1) and 283.33 of the *Wisconsin Statutes* require a permit for the legal discharge of any pollutant into the waters of the State, including groundwaters. This State pollutant discharge permit system was established by the Wisconsin Legislature in direct response to the requirements of the Clean Water Act. While the Federal law envisioned requiring a permit only for the discharge of pollutants into navigable waters, in Wisconsin, permits are required for discharges from point sources of pollution to all surface waters of the State and, additionally, to land areas where pollutants may percolate or seep to, or be leached to, groundwater. The Wisconsin Pollutant Discharge Elimination System (WPDES) permitting program provides a major means for achievement of the basic goal of meeting the water use objectives for the receiving waters to the extent that the permits are consistent with the water quality management plans prepared pursuant to the terms of the Clean Water Act.

Rules relating to the WPDES are set forth in Chapter NR 200 of the *Wisconsin Administrative Code*, the current version of which became effective on June 1, 1985. The following types of discharges require permits under Chapter NR 200:

1. The direct discharge of any pollutant to any surface water.

2. The discharge of any pollutant, including cooling waters, to any surface water through any storm sewer system not discharging to publicly owned treatment works.

3. The discharge of pollutants other than from agricultural uses for the purpose of disposal, treatment, or containment on land areas, including land disposal systems such as ridge and furrow, irrigation, and ponding systems.

4. Discharge from an animal feeding operation where the operation causes the discharge of a significant amount of pollutants to waters of the State and the owner or operator of the operation does not implement remedial measures as required under a notice of discharge issued by the WDNR under Chapter NR 243, which deals with animal waste management.

Certain discharges are exempt from the permit system, as set forth under Chapter NR 200, including discharges to publicly owned sewerage works, discharges from vessels, discharges from properly functioning marine engines, and discharges of domestic sewage to septic tanks and drain fields, regulated under another chapter of the *Wisconsin Administrative Code*. Also exempted are the disposal of septic tank pumpage and other domestic waste, also regulated by another chapter of the *Wisconsin Administrative Code*; the disposal of solid wastes, including wet or semi-liquid wastes, when disposed of at a site licensed pursuant to another chapter of the *Wisconsin Administrative Code*; discharges from private alcohol fuel production systems; and discharges included under a general permit. The WPDES enables the accumulation of data concerning point sources of pollution and requires a listing of the treatment requirements and a schedule of compliance setting forth dates by which various stages of the requirements imposed by the permit shall be achieved.

As noted earlier in this chapter, the 1987 amendments to the Federal Clean Water Act established a Federal program for permitting stormwater discharges. The State of Wisconsin obtained certification from the USEPA which enabled the State to administer the stormwater discharge permitting program as an extension of the existing WPDES program. Section 283.33 of the *Statutes*, which provides authority for the issuance of stormwater discharge permits by the State, was enacted in 1993. The administrative rules for the State stormwater discharge permit program are set forth in Chapter NR 216 of the *Administrative Code*, which took effect on November 1, 1994. The most-current version of Chapter NR 216 became effective on August 1, 2004.

The following entities are required to obtain discharge permits under Chapter NR 216:

1. Municipal separate storm sewer systems (MS4) serving incorporated areas with a population of 100,000 or more.

2. The owners and operators of MS4 that were notified by WDNR prior to August 1, 2004, that their system was required to have a WPDES permit.

3. An MS4 within an urbanized area as defined by the U.S. Bureau of the Census.

4. An MS4 serving a population of 10,000 or more with a population density of 1,000 or more per square mile as determined by the U.S. Bureau of the Census.

5. Industries identified in Section NR 216.21.

6. Construction sites where one acre or more of land is disturbed, except those associated with agricultural land uses, those for commercial buildings regulated by the Wisconsin Department of Commerce under Chapter COMM 61 of the *Wisconsin Administrative Code,* and Wisconsin Department of Transportation projects which are subject to Chapter TRANS 401 of the *Wisconsin Administrative Code* and the WisDOT/WDNR liaison cooperative agreement.

CURRENT WATER USE OBJECTIVES AND STANDARDS

Water Use Objectives

As described in Chapter VII of SEWRPC Planning Report No. 50, *A Regional Water Quality Management Plan Update for the Greater Milwaukee Watersheds,* the Wisconsin Department of Natural Resources currently has developed standards, or criteria, for the following water use objectives or classifications relating to fish and aquatic life for the regional water quality management plan update study area watershed stream and lake system: 1) Great Lakes communities, 2) coldwater community, 3) warmwater sportfish community, 4) warmwater forage fish community, 5) limited forage fish, and 6) limited aquatic life. It is important to note that establishment of a stream water use objective other than coldwater or warmwater fish and aquatic life is not necessarily an indication of reduced water quality, since such stream reaches may be limited by flow or size, but may still be performing well relative to other functions. In addition, the WDNR has developed standards, or criteria, for two recreational use classifications: 1) full recreational use and 2) limited recreational use, and it has developed standards, or criteria, for public health and welfare and wildlife protection. For the purpose of the anti-degradation policy to prevent the lowering of existing water quality, the WDNR has classified some waters as outstanding or exceptional resource waters. These waters, listed in Chapters NR 102.10 and NR 102.11 of the *Wisconsin Administrative Code*, are deemed to have significant value such as valuable fisheries, hydrologically or geographically unique features, outstanding recreational opportunities, and unique environmental settings, and they are not significantly impacted by human activities. Any discharge that may be allowed to these waters can generally not be above background levels. These waters are considered "areas of special natural resource interest" for permitted activities under Chapter 30 of the *Wisconsin Statutes*.

The objectives or classifications for fish and aquatic life for all of the streams in the study area are set forth on Maps 7 through 12 and in Table 15. All of the fish and aquatic life categories are considered to be in the full recreational use category, except where a special variance is noted.

The fish and aquatic life and the recreational use objectives or classifications are those most directly related to the regional water quality management plan update. In addition, the WDNR has developed standards for wildlife and for public health and welfare. All streams are expected to meet the wildlife standards, or criteria. The public health and welfare standards, or criteria, vary only depending upon whether or not the surface water is used for public drinking water supply. Thus, there is no variation in the public health and welfare objectives or category for all the surface waters in the study area, except Lake Michigan.

For selected surface waters in the study area, the regional water quality management plan update has evaluated the potential for achieving a higher objective or classification than currently codified. The evaluations of alternative classifications are being largely done in response to changes in conditions since the last relevant *Administrative Code* sections were promulgated. This evaluation is being made to assist in future planning and management strategies and is not intended to be directed as a change to the current regulatory framework. Those surface waters where an auxiliary upgraded water use objective or classification has been evaluated in the planning process and the basis for the auxiliary recommendations are set forth in Table 15.

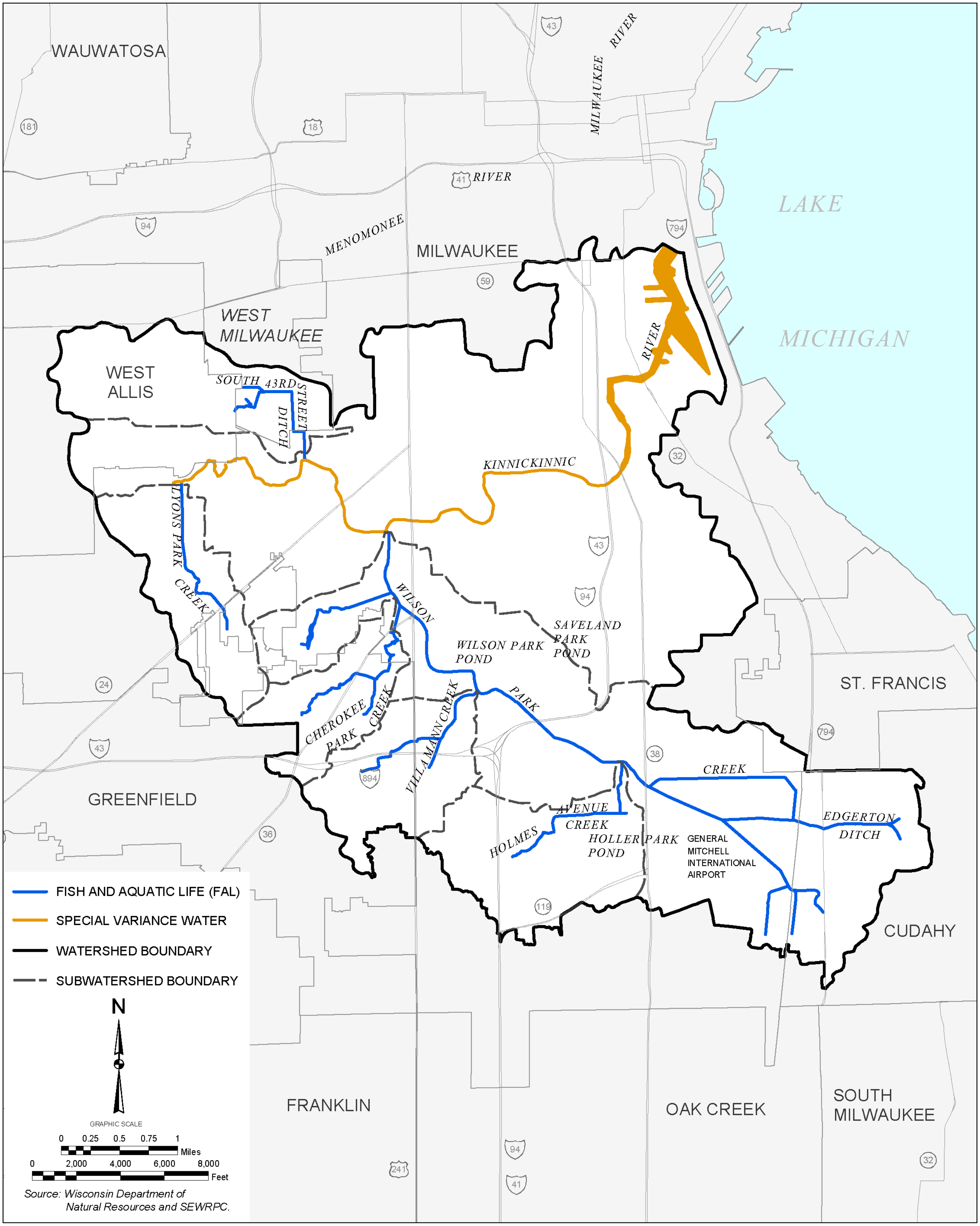
Chapter NR 103 of the *Wisconsin Administrative Code* establishes water quality-related rules for wetlands. The rules consist of 1) a set of standards intended to protect the water quality-related functions of wetlands and 2) implementation procedures for application of the water quality standards. Because the application of the rules set forth in Chapter NR 103 is site-specific and requires consideration of the specific activity proposed within or adjacent to a wetland, wetland water quality standards are not specifically addressed in this report. The procedures documented in Chapter NR 103 must be applied by the WDNR on a site-specific, case-by-case basis.

Water Quality Standards

The applicable water quality standards for all water uses designated in Southeastern Wisconsin are set forth in Table 16. The water quality standards are statements of the physical, chemical, and biological characteristics of the water that must be maintained if the water is to be suitable for the specified uses. Chapter 281 of the *Wisconsin Statutes* recognizes that different standards may be required for different waters or portions thereof. According to the Chapter, in all cases the "standards of quality shall be such as to protect the public interest, which includes the protection of the public health, and welfare and the present and prospective future use of such

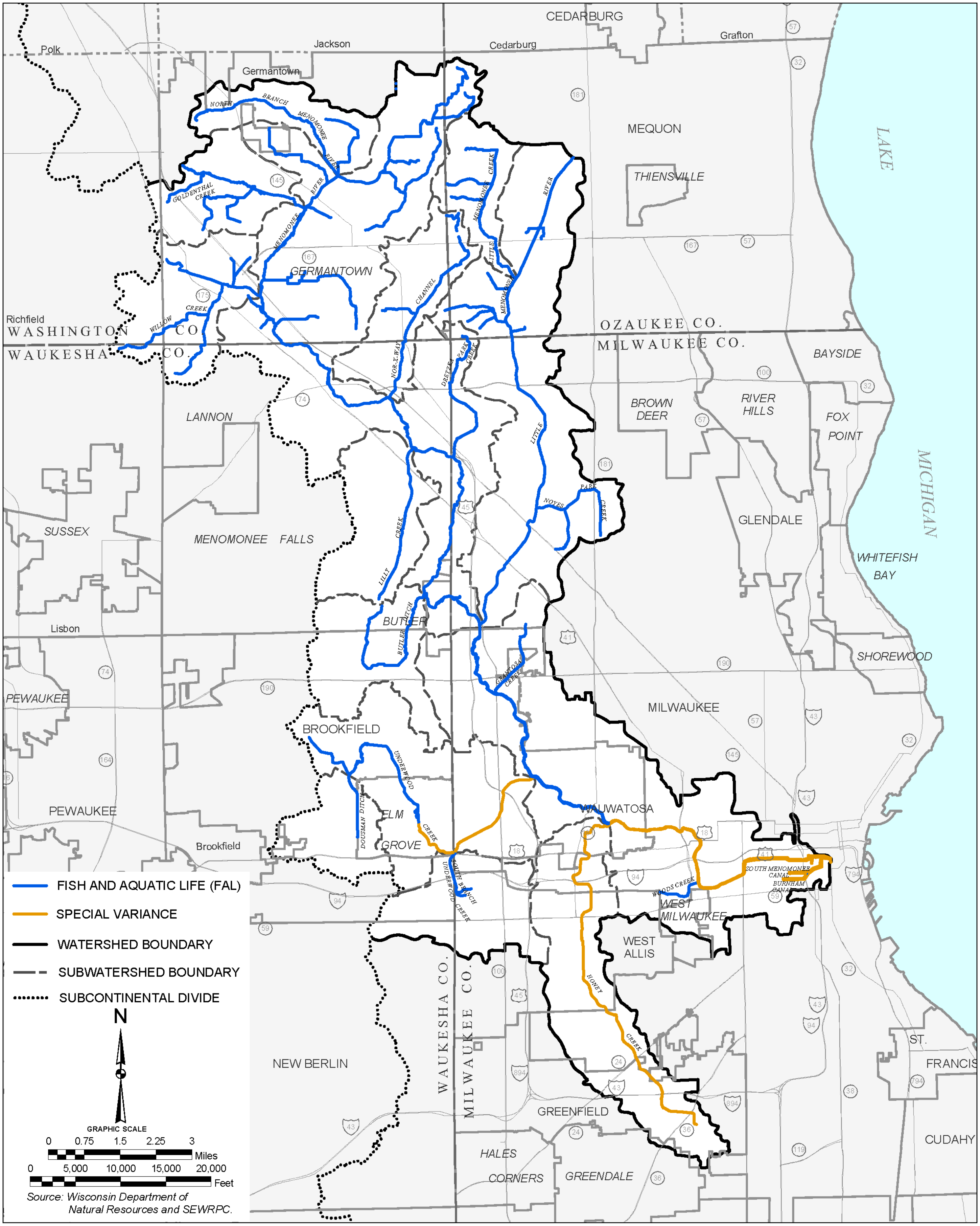
Map 7

CURRENT REGULATORY WATER USE CLASSIFICATIONS FOR SURFACE WATERS WITHIN THE KINNICKINNIC RIVER WATERSHED



Map 8

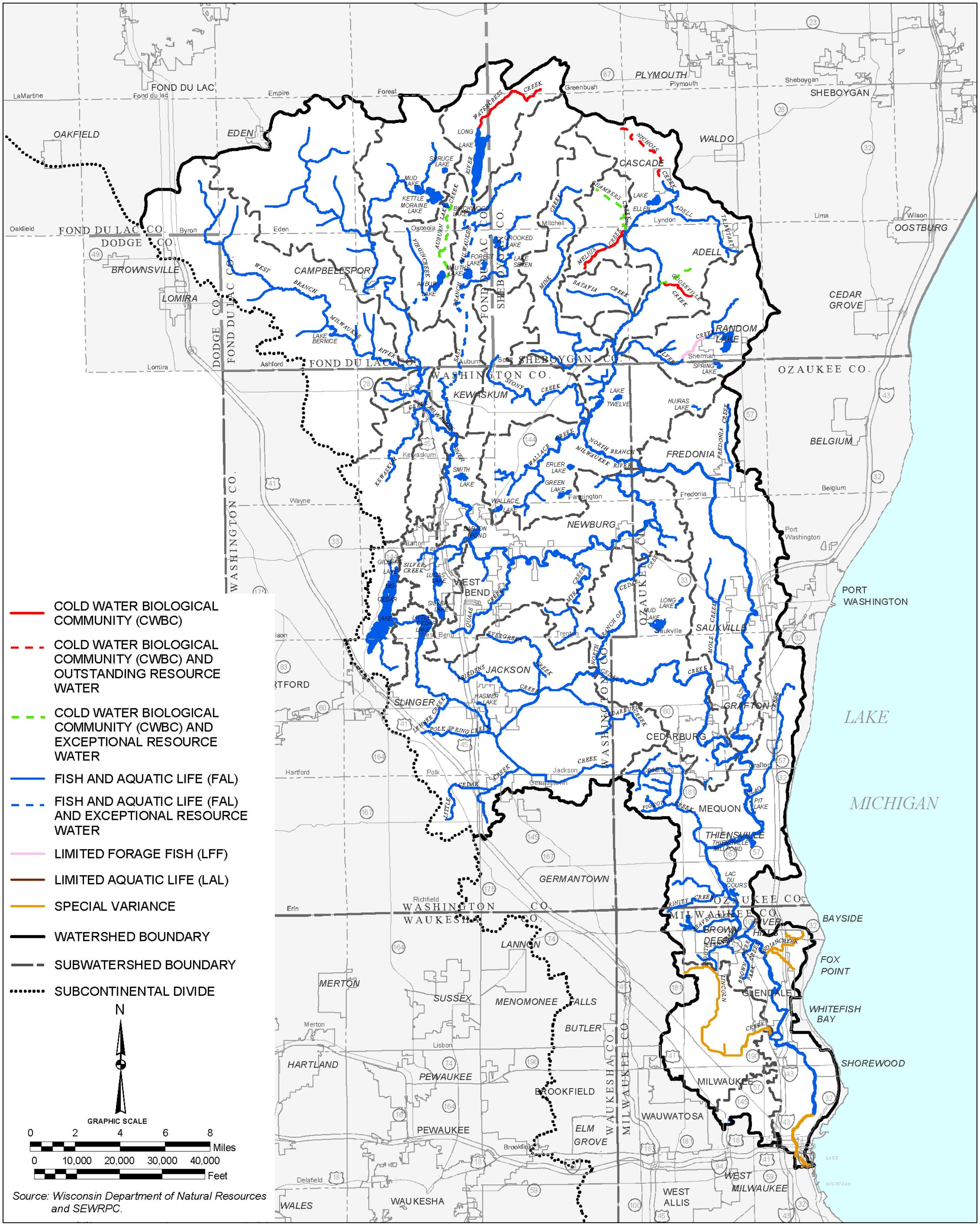
CURRENT REGULATORY WATER USE CLASSIFICATIONS FOR SURFACE WATERS WITHIN THE MENOMONEE RIVER WATERSHED



Source: Wisconsin Department of Natural Resources and SEWRPC.

Map 9

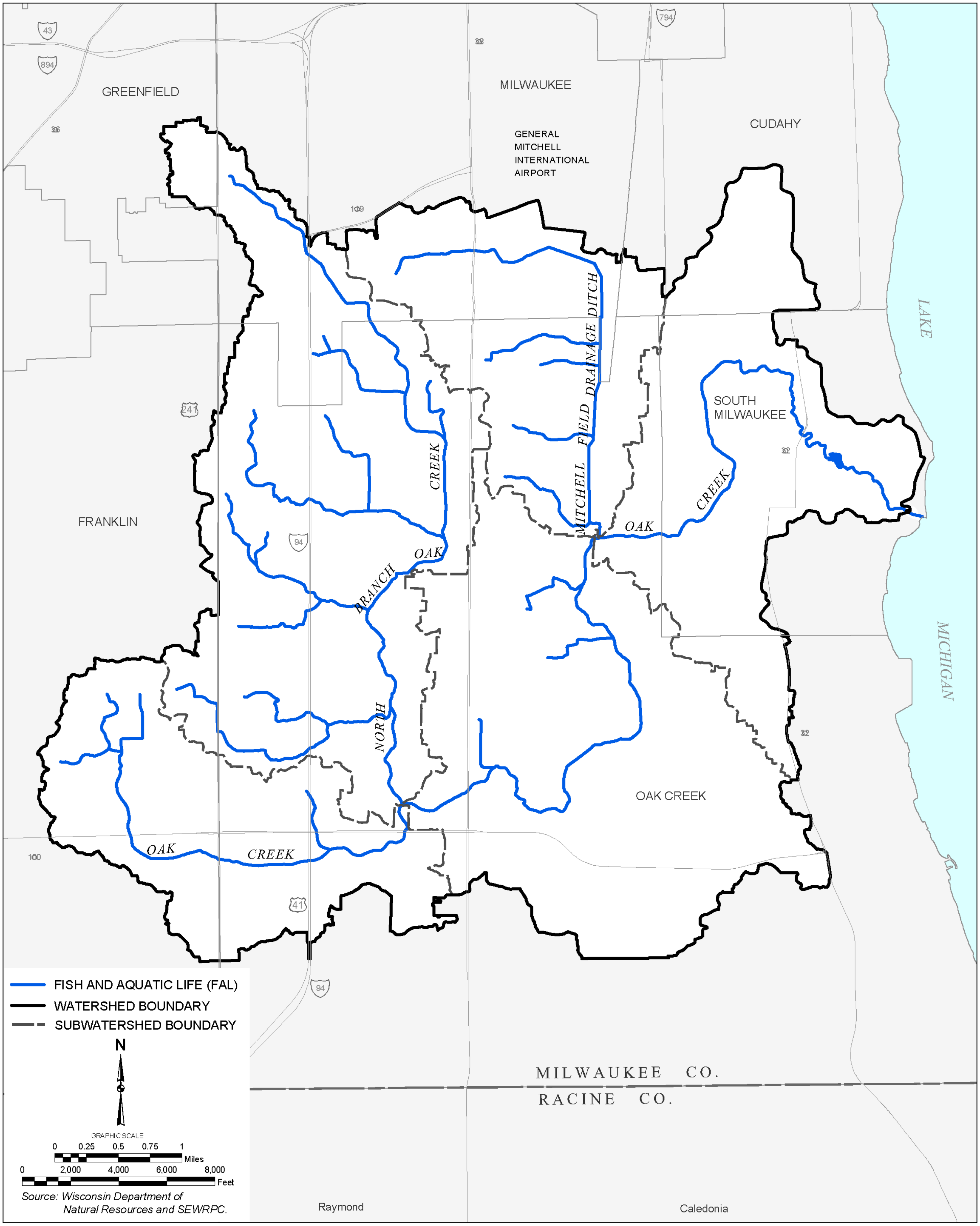
CURRENT REGULATORY WATER USE CLASSIFICATIONS FOR SURFACE WATERS WITHIN THE MILWAUKEE RIVER WATERSHED



Source: Wisconsin Department of Natural Resources and SEWRPC.

Map 10

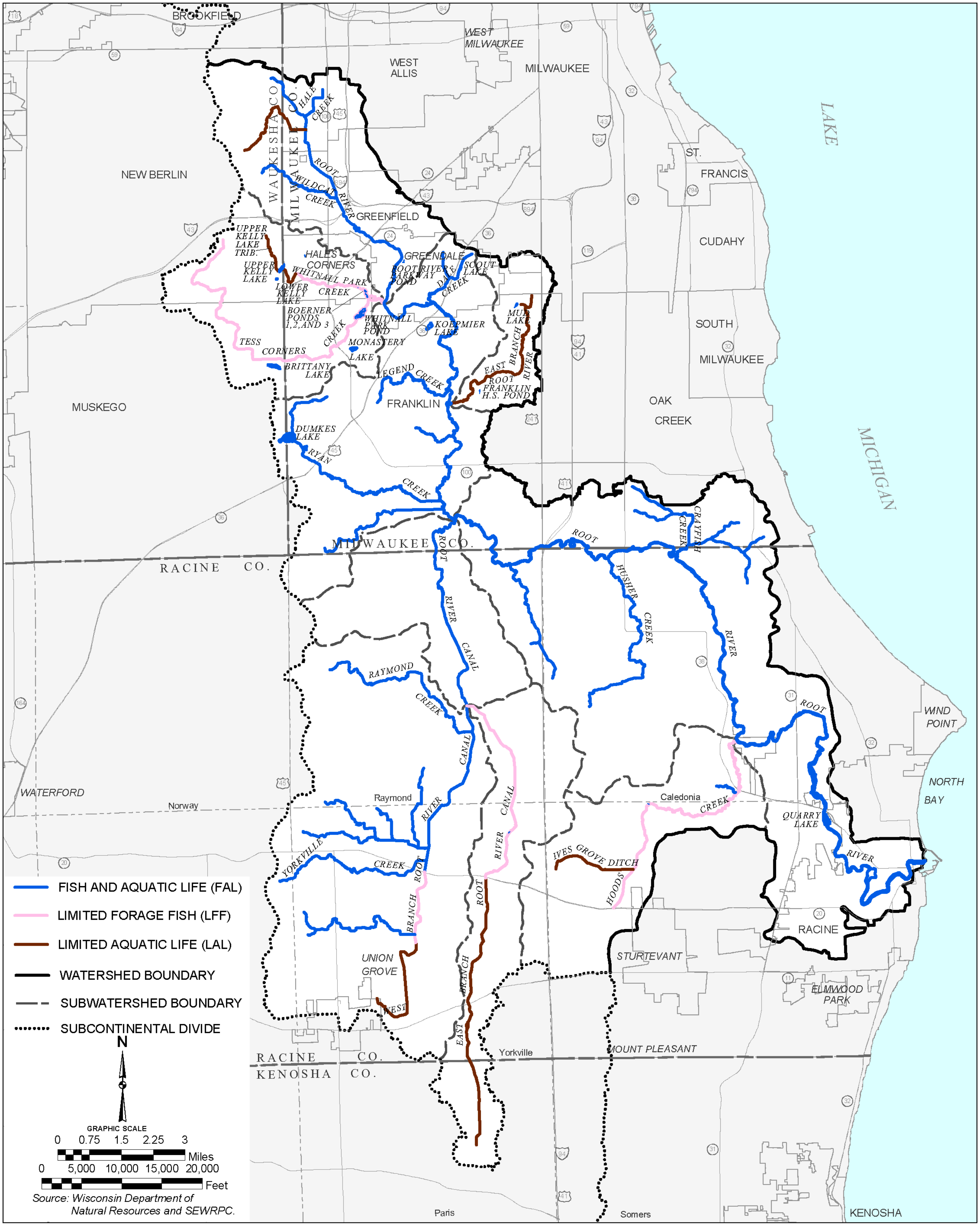
CURRENT REGULATORY WATER USE CLASSIFICATIONS FOR SURFACE WATERS WITHIN THE OAK CREEK WATERSHED



Source: Wisconsin Department of Natural Resources and SEWRPC.

Map 11

CURRENT REGULATORY WATER USE CLASSIFICATIONS FOR SURFACE WATERS WITHIN THE ROOT RIVER WATERSHED



Map 12

CURRENT REGULATORY WATER USE CLASSIFICATIONS FOR SURFACE WATERS WITHIN THE AREA TRIBUTARY TO LAKE MICHIGAN

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 15

REGULATORY AND AUXILIARY FISH AND AQUATIC LIFE WATER AND RECREATIONAL USE OBJECTIVES/DESIGNATED USES TO BE CONSIDERED FOR STREAMS IN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
KINNICKINNIC RIVER WATERSHED			
Kinnickinnic River Natural/Earthen Channel Reaches from Confluence with Milwaukee River to S. 6th Street (T6N R22E NE SW 8)	Variance Water[f] (NR 104.06(2)(a)(8))	**Variance Water** *FAL*[d]	Variance applies to all of the Kinnickinnic River
Kinnickinnic River Concrete Channel Reaches Upstream of S. 6th Street (T6N R22E NE SW 8) to Headwaters	Variance Water[f] (NR 104.06(2)(a)(8))	**Variance Water**	Variance applies to all of the Kinnickinnic River
Unnamed Creek (Cherokee Park Creek) (T6N R21E SE NE 13)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Edgerton Ditch) (T6N R22E SW NE 28)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Holmes Avenue Creek) (T6N R22E SE SE 20)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Lyons Park Creek) (T6N R21E SW NW 11)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (S. 43rd Street Ditch) (T6N R21E NW NW 12)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Villa Mann Creek) (T6N R22E NW NE 19)	FAL (DEF)[a]	**FAL**	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

2. FAL means Fish and Aquatic Life; DEF means no specific use classification is set forth in Chapter NR 102 of the *Wisconsin Administrative Code*; and COLD I indicates waters which have sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity; COLD II indicates waters which have some natural reproduction of trout, but require stocking to maintain a desirable sport fishery; COLD is used as an auxiliary use for planning purposes and may indicate either COLD I or COLD II; LFF means Limited Forage Fish Community; LAL means Limited Aquatic Life.

3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
KINNICKINNIC RIVER WATERSHED (continued)			
Unnamed Creek (Wilson Park Creek) Concrete or Enclosed Channel Reaches from Confluence with Unnamed Creek (Edgerton Ditch) (T6N R22E SE NW 27) to S. 6th Street (T6N R22E SW SE 20)	FAL (DEF)a	**FAL**	- -
Unnamed Creek (Wilson Park Creek) Natural/Earthen Channel Reaches from S. 6th Street (T6N R22E SW SE 20) to 20th Street (T6N R22E NW NE 19)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Wilson Park Creek) All Existing Concrete-Lined or Enclosed Reaches from S. 20th Street in the NW NE 19 T6N R22E to the Confluence with the Kinnickinnic River in the SE SE 12 T6N R21E	FAL (DEF)[a]	**FAL**	- -
MENOMONEE RIVER WATERSHED			
Burnham Canal (T7N R22E SW SE 29)	Variance Water[g] (NR 104.06(2)(b)(2))	**Variance Water** *FAL*[d]	- -
Honey Creek Natural Channel from Confluence with Menomonee River (T7N R21E NW NW 27) to Concrete Channel at Honey Creek Parkway (T7N R21E SW SE 28)	Variance Water[f] (NR 104.06(2)(a)(6))	**Variance Water** *FAL*[d]	Variance applies to all of Honey Creek

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

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3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
MENOMONEE RIVER WATERSHED (continued)			
Honey Creek Concrete or Enclosed Channel at Honey Creek Parkway (T7N R21E SW SE 28) to Natural Channel at IH 894 (T6N R21E SW SW 23)	Variance Water[f] (NR 104.06(2)(a)(6))	**Variance Water**	Variance applies to all of Honey Creek
Honey Creek Natural Channel from IH 894 (T6N R21E SW SW 23) to Headwaters	Variance Water[f] (NR 104.06(2)(a)(6))	**Variance Water** *LFF*[d]	Variance applies to all of Honey Creek
Lilly Creek	FAL (DEF)[a]	**FAL**	- -
Little Menomonee Creek	FAL (DEF)[a]	**FAL**	- -
Little Menomonee River	FAL (DEF)[a]	**FAL**	- -
Menomonee River from Confluence with Honey Creek (T7N R21E NW NW 27) to Confluence with Milwaukee River (T7N R22E SE SE 29)	Variance Water[f] (NR 104.06(2)(a)(7))	**Variance Water** *FAL*[d]	- -
Menomonee River Main Stem Upstream from Confluence with Honey Creek	FAL (DEF)[a]	**FAL**	- -
Nor-X-Way Channel Concrete Channel Reach	FAL (DEF)[a]	**FAL**	- -
Nor-X-Way Channel/ All-Natural Channel Reaches	FAL (DEF)[a]	**FAL**	- -
South Menomonee Canal (T7N R22E NE NW 32)	Variance Water[g] (NR 104.06(2)(b)(2))	**Variance Water** *FAL*[d]	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

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3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
MENOMONEE RIVER WATERSHED (continued)			
Southbranch of Underwood Creek from Confluence with Underwood Creek (T7N R21E NW SW 30) to Headwaters	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Butler Ditch) (T8N R20E SE NW 36)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Goldenthal Creek) (T9N R20E NW NW 22)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T7N R20E SE SE 15)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Wood Creek) (T7N R21E SW NW 36)	FAL (DEF)[a]	**FAL**	- -
Underwood Creek Concrete Channel from Confluence with Menomonee River (T7N R21E NW NE 20) to Juneau Boulevard (T7N R20E NE NW 25)	Variance Water[f] (NR 104.06(2)(a)(1))	**Variance Water** *FAL*[l]	- -
Underwood Creek from Juneau Boulevard (T7N R20E SE SW 24) to Headwaters	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Underwood Creek from T6N R21E S6 to Confluence with Underwood Creek	FAL (DEF)[a]	**FAL**	- -
Willow Creek	FAL (DEF)[a]	**FAL**	- -
Cedar Creek Subwatershed			
Cedar Creek	FAL (DEF)[a]	**FAL**	- -
Cedarburg Creek	FAL (DEF)[a]	**FAL**	- -
Evergreen Creek	FAL (DEF)a	**FAL**	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

2. FAL means Fish and Aquatic Life; DEF means no specific use classification is set forth in Chapter NR 102 of the *Wisconsin Administrative Code*; and COLD I indicates waters which have sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity; COLD II indicates waters which have some natural reproduction of trout, but require stocking to maintain a desirable sport fishery; COLD is used as an auxiliary use for planning purposes and may indicate either COLD I or COLD II; LFF means Limited Forage Fish Community; LAL means Limited Aquatic Life.

3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Cedar Creek Subwatershed (continued)			
Friedens Creek	FAL (DEF)[a]	**FAL**	- -
Jackson Creek	FAL (DEF)[a]	**FAL**	- -
Kressin Creek	FAL (DEF)[a]	**FAL**	- -
Lehner Creek	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
Little Cedar Creek	FAL (DEF)[a]	**FAL**	- -
North Branch Cedar Creek	FAL (DEF)[a]	**FAL**	- -
Polk Spring Creek	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T10N R19E NW NE 5)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T10N R20E NE NE 1)	FAL (DEF)[a]	**FAL**	- -
Milwaukee River East and West Branches Subwatershed			
Auburn Lake Creek (Lake Fifteen Creek) Downstream of Auburn Lake	FAL (DEF)[a]	**FAL**	Code lists as exceptional resource water (NR 102.11(1)(d) (8))
Auburn Lake Creek (Lake Fifteen Creek) Upstream of Auburn Lake	COLD II (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD II** *COLD I*[d]	Cold II designation in Wisconsin Trout Streams applies only to portions in S2-3 of T13N R19E Code lists as exceptional resource water (NR 102.11(1)(d) (8))
Kewaskum Creek	FAL (DEF)[a]	**FAL**	- -
Milwaukee River East Branch from Long Lake (T14N R19E NW SW 25) to STH 28 (T12N R21E SE NE 10)	FAL (DEF)[a]	**FAL**	Code lists as exceptional resource water (NR 102.11(1)(d) (39))
Milwaukee River East Branch from STH 28 (T12N R21E SE NE 10) to Confluence with Milwaukee River West Branch (T12N R19E SE SW 14)	FAL (DEF)[a]	**FAL**	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

2. FAL means Fish and Aquatic Life; DEF means no specific use classification is set forth in Chapter NR 102 of the *Wisconsin Administrative Code*; and COLD I indicates waters which have sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity; COLD II indicates waters which have some natural reproduction of trout, but require stocking to maintain a desirable sport fishery; COLD is used as an auxiliary use for planning purposes and may indicate either COLD I or COLD II; LFF means Limited Forage Fish Community; LAL means Limited Aquatic Life.

3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River East and West Branches Subwatershed (continued)			
Milwaukee River Main Stem	FAL (DEF)[a]	**FAL**	- -
Milwaukee River West Branch	FAL (DEF)[a]	**FAL**	- -
Myra Creek	FAL (DEF)[a]	**FAL**	- -
Quaas Creek	FAL (DEF)[a]	**FAL**	- -
Silver Creek	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R18E SW NE 28)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Lake Seven outlet)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Riveredge Creek)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T11N R19E NE NW 14)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T11N R20E SW SE 17)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T12N R19E NW NE 9)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T12N R19E SE NE 4)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T12N R20E NE SW 36)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R18E NW NE 26)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E NW NE 6)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E NW NE 17)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E NW SE 33)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E NW SE 6)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E SE NE 16)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E SE NW 18)	FAL (DEF)[a]	**FAL**	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

2. FAL means Fish and Aquatic Life; DEF means no specific use classification is set forth in Chapter NR 102 of the *Wisconsin Administrative Code*; and COLD I indicates waters which have sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity; COLD II indicates waters which have some natural reproduction of trout, but require stocking to maintain a desirable sport fishery; COLD is used as an auxiliary use for planning purposes and may indicate either COLD I or COLD II; LFF means Limited Forage Fish Community; LAL means Limited Aquatic Life.

3. All streams are classified as "Full Recreational Use," except that those designated as having a "variance water" designation are classified as "Limited Recreational Use."

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River East and West Branches Subwatershed (continued)			
Unnamed Creek (T13N R19E SE SW 34)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E SW NE 10)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R19E SW NE 14)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R17E SE NE 36)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R18E NW NE 27)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R18E NW SE 22)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R18E NW SW 14)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R18E SE NW 36)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R18E SE SE 36)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R19E NW NE 36)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R19E SE NW 36)	FAL (DEF)[a]	**FAL**	- -
Virgin Creek	FAL (DEF)[a]	**FAL**	- -
Watercress Creek	COLD II (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD II** *COLD I*[d]	- -
Milwaukee River North Branch Subwatershed			
Adell Tributary	FAL (DEF)[a]	**FAL**	- -
Batavia Creek	FAL (DEF)[a]	**FAL**	- -
Chambers Creek	COLD I (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD I**	Cold I designation in Wisconsin Trout Streams applies down to Hwy W Code lists as exceptional resource water (NR 102.11(1)(a))
Gooseville Creek (South Branch)	COLD II (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD II** *COLD I*[d]	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

2. FAL means Fish and Aquatic Life; DEF means no specific use classification is set forth in Chapter NR 102 of the *Wisconsin Administrative Code*; and COLD I indicates waters which have sufficient natural reproduction to sustain populations of wild trout at or near carrying capacity; COLD II indicates waters which have some natural reproduction of trout, but require stocking to maintain a desirable sport fishery; COLD is used as an auxiliary use for planning purposes and may indicate either COLD I or COLD II; LFF means Limited Forage Fish Community; LAL means Limited Aquatic Life.

3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River North Branch Subwatershed (continued)			
Gooseville Creek (North Branch and Main Stem to Milwaukee River)	COLD I (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD I**	Code lists as exceptional resource water (NR 102.11(1)(a))
Melius Creek	COLD II (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD II** *COLD I*[d]	- -
Mink Creek	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
North Branch Milwaukee River	FAL (DEF)[a]	**FAL**	- -
North Branch Milwaukee River (Nichols Creek)	COLD I (NR 102.04(3)(a) Wisconsin Trout Streams (1980)[b])	**COLD I**	Cold I designation in Wisconsin Trout Streams applies down to Hwy 28 in Cascade Code lists as outstanding resource water (NR 102.10(1)(d))
Silver Creek from Random Lake Sewage Treatment Plant Downstream to First Crossing of Creek Road	LFF (NR 104.07(2) Table 5 (40))	**LFF**	- -
Silver Creek, Except from Random Lake Sewage Treatment Plant Downstream to First Crossing of Creek Road	FAL (DEF)[a]	**FAL**	- -
Stony Creek	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
Unnamed Creek (T13N R20E NW NE 11)	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
Unnamed Creek (T12N R20E SE SE 2)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T12N R20E SW NW 8)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T12N R20E SW SW 3)	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
Unnamed Creek (T13N R20E SE NE 34)	FAL (DEF)a	**FAL** *COLD*[d]	- -

NOTES: 1. Text in italics = Auxiliary use objective to be considered as potential for management purposes.

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Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River North Branch Subwatershed (continued)			
Unnamed Creek (T13N R21E NE NW 11)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R21E NE NW 32)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R21E NW SE 27)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T13N R21E SE NE 23)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (T14N R21E SW NE 31)	FAL (DEF)[a]	**FAL**	- -
Wallace Creek	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
Milwaukee River South Branch Subwatershed			
Indian Creek Concrete Channel Upstream of IH 43 (T8N R22E NE SW 8) to Headwaters	Variance Water[f] (NR 104.06(2)(a)(5))	**Variance Water** *FAL*[d]	Variance applies to all of Indian Creek
Indian Creek Natural Channel from Confluence with Milwaukee River (T8N R22E NW NE 18) to IH 43 and Concrete Channel (T8N R22E NE SW 8)	Variance Water[f] (NR 104.06(2)(a)(5))	**Variance Water** *FAL*[d]	Variance applies to all of Indian Creek
Lincoln Creek Natural Channel from Confluence with Milwaukee River (T8N R22E NE SE 31) to Former Concrete Channel at Teutonia Avenue (T8N R22E NE SE 36)	Variance Water[f] (NR 104.06(2)(a)(9))	**Variance Water** *FAL*[d]	Variance applies to all of Lincoln Creek
Lincoln Creek Former Concrete Channel at Teutonia Avenue (T8N R22E NE SE 36) to Natural Channel at N. 32nd Street (T7N R21E NW NE 1)	Variance Water[f] (NR 104.06(2)(a)(9))	**Variance Water** *FAL*[k]	Variance applies to all of Lincoln Creek

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3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River South Branch Subwatershed (continued)			
Lincoln Creek Natural Channel at N. 32nd Street (T7N R21E NW NE 1) to Former Concrete Channel at W. Hampton Avenue (T8N R21E SE SE 34)	Variance Water[f] (NR 104.06(2)(a)(9))	**Variance Water** *LFF*[e]	Variance applies to all of Lincoln Creek
Lincoln Creek Former Concrete Channel at W. Hampton Avenue (T8N R21E SE SE 34) to Natural Channel Upstream of W. Silver Spring Drive (T8N R21E SW SW 26)	Variance Water[f] (NR 104.06(2)(a)(9))	**Variance Water** *LFF*[k]	Variance applies to all of Lincoln Creek
Lincoln Creek Natural Channel Upstream of W. Silver Spring Drive (T8N R21E SW SW 26) to Concrete Channel Upstream of Brynwood Country Club Pond (T8N R21E NE SW 15)	Variance Water[f] (NR 104.06(2)(a)(9))	**Variance Water** *LFF*[e]	Variance applies to all of Lincoln Creek
Lincoln Creek Concrete or Enclosed Channel Upstream of Brynwood Country Club Pond (T8N R21E NE SW 15) to Headwaters	Variance Water[f] (NR 104.06(2)(a)(9))	**Variance Water**	Variance applies to all of Lincoln Creek
Milwaukee River from Abandoned North Avenue Dam (T7N R22E NW NE 21) to Confluence with Lake Michigan	Variance Water[g] (NR 104.06(2)(b)(1))	**Variance Water** *FAL*[d]	- -
Milwaukee River from River Mile 47.5 to Abandoned North Avenue Dam (T7N R22E NW NE 21)	FAL (DEF)[a]	**FAL**	- -

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Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River South Branch Subwatershed (continued)			
Pigeon Creek (T9N R21E SW NW 23)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Beaver Creek) Natural Channel from Confluence with Milwaukee River (T8N R21E SE SW 1) to Concrete Channel (T8N R21E NW SW 1)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Beaver Creek) Concrete Channel Reach (T8N R21E SE SW 1) to North Ridge Lake Dam (T8N R21E SE SW 3)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Brown Deer Creek) (T8N R22E SW NW 7)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Fredonia Creek) T12N R21E NW NE 34)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Mole Creek) (T10N R21E NE NE 13)	FAL (DEF)[a]	**FAL** *COLD*[d]	- -
Unnamed Creek (Southbranch Creek) Natural Channel from Confluence with Milwaukee River (T8N R21E SW NW 12) to Concrete Channel at Churchill Road (T8N R21E NE SE 11)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Southbranch Creek) Concrete Channel Reaches (T8N R21E SE NW 12) to Headwaters	FAL (DEF)[a]	**FAL**	- -

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3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
Milwaukee River South Branch Subwatershed (continued)			
Unnamed Creek (Trinity Creek) (T9N R21E SE NE 35)	FAL (DEF)[a]	**FAL**	- -
Unnamed Creek (Ulao Creek) (T9N R21E NE NE 12)	FAL (DEF)[a]	**FAL**	- -
MINOR STREAMS AND DIRECT DRAINAGE AREA TRIBUTARY TO LAKE MICHIGAN			
Fish Creek	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Lake Michigan (T9N R22E 33)	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Lake Michigan (T4N R23E NW SW 22)	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Lake Michigan (T4N R23E NE SE 17)	FAL (DEF)[a]	**FAL**	- -
OAK CREEK WATERSHED			
Oak Creek	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Oak Creek (Mitchell Field Drainage Ditch) (T5N R22E SW NW 10)	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Oak Creek (North Branch Oak Creek) (T5N R22E SW SE 20)	FAL (DEF)[a]	**FAL**	- -
ROOT RIVER WATERSHED			
Root River	FAL (DEF)[a]	**FAL**	- -
Hoods Creek	LFF (NR 104.06(1) Table 4 (20))	**LFF** *FAL*[h]	LFF applies from STH 20 downstream to confluence with Root River
Unnamed Tributary to Hoods Creek (Ives Grove Ditch) (T3N R22E SW NW 9)	LAL (NR 104.06(1) Table 4 (20))	**LAL** **LFF**[e]	- -

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3. All streams are classified as “Full Recreational Use,” except that those designated as having a “variance water” designation are classified as “Limited Recreational Use.”

Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
ROOT RIVER WATERSHED (continued)			
Unnamed Tributary to Root River (T5N R22E SW SE 34)	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Root River (T4N R22E NW NW 3)	FAL (DEF)[a]	**FAL**	- -
Husher Creek (T4N R22E NE SW 5)	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Root River (T4N R21E NW SE 1)	FAL (DEF)[a]	**FAL**	- -
Root River Canal	FAL (DEF)[a]	**FAL**	- -
East Branch Root River Canal Upstream from STH 20	LAL (NR 104.06(1) Table 4 (5))	**LAL**	- -
East Branch Root River Canal from STH 20 Downstream to West Branch Root River Canal	LFF (NR 104.06(1) Table 4 (5))	**LFF**[e]	- -
West Branch Root River Canal	LFF & LAL (NR 104.06(1) Table 4 (30))	**LAL**[i]	Code lists 1. LAL from 67th Drive downstream to CTH C 2. LFF from CTH C downstream to STH 20
Unnamed Tributary to West Branch Root River Canal (T3N R21E NW SW 10)	FAL (DEF)[a]	**FAL**	- -
Ryan Creek	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Root River (T5N R21E SE NE 15)	LAL (NR 104.06(1) Table 4 (21))	**LAL** *FAL*[h]	LAL applies from the former Rawson Homes Sewage Treatment Plant to the Root River
Dale Creek	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to Root River (Tess Corners Creek) (T5N R21E NW NE 4)	LFF (NR 104.06(1) Table 4 (10))	**LFF** *FAL*[h]	Code lists sections upstream and downstream from USH 45 separately

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Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
ROOT RIVER WATERSHED (continued)			
Unnamed Tributary to Root River (Whitnall Park Creek, also known as Hales Corners Tributary) (T5N R21E NW NW 4) Upstream from the Former Hales Corners Sewage Treatment Plant (except for Upper Kelly Lake)	LAL (NR 104.06(1) Table 4 (7))	**LAL** *FAL*[h]	- -
Unnamed Tributary to Root River (Whitnall Park Creek, also known as Hales Corners Tributary) (T5N R21E NW NW 4) from the Former Hales Corners Sewage Treatment Plant Downstream to Whitnall Park Pond	LFF (NR 104.06(1) Table 4 (7))	**LFF** *FAL*[h]	- -
Unnamed Tributary to West Branch Root River Canal (Yorkville Creek) (T3N R21E SW SW 3)	FAL (DEF)[a]	**FAL**	- -
Unnamed Tributary to West Branch Root River Canal (Raymond Creek) (T4N R21E NW SE 26)	FAL (DEF)[a]	**FAL**	- -
Diffuse Surface Drainage from the Former New Berlin Memorial Hospital Sewage Treatment Plant to Root River Tributary (T6N R20E 12)	LAL (NR 104.06(1) Table 4 (12))	**LAL** *FAL*[j]	- -
Tributary to Root River Downstream from the Former New Berlin Memorial Hospital Sewage Treatment Plant (T6N R20E S12)	LAL (NR 104.06(1) Table 4 (12))	**LAL** **FAL**[j]	- -

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Table 15 (continued)

Watershed or Subwatershed and Stream Reach	Codified Use[a,b]	RWQMPU/2020 Facilities Plan Designated and Auxiliary Uses to Be Considered for Planning Purposes[c]	Comments
ROOT RIVER WATERSHED (continued)			
Unnamed Tributary to West Branch Root River Canal from Wastewater Treatment Plant in T4N R21E NE SW 34 to Confluence with West Branch Root River Canal	FAL (DEF)[a]	**FAL**	- -

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[a]*When no specific use classification is identified (DEF), FAL applies as the default classification, as defined in NR 102.13.*

[b]*Codified use is identical in the 2002 edition of Wisconsin Trout Streams.*

[c]*Pending further public input which may result in some revisions.*

[d]*Based upon: Wisconsin Department of Natural Resources,* The State of the Milwaukee River Basin: August 2001, *PUBL WT-704-2001.*

[e]*Considered by WDNR in 2001.*

[f]*These waters shall meet the standards for fish and aquatic life except that the dissolved oxygen shall not be lowered to less than 2 mg/L at any time, nor shall the membrane filter fecal coliform count exceed 1,000 per 100 ml as a monthly geometric mean based on not less than five samples per month nor exceed 2,000 per 100 ml in more than 10 percent of all samples in any month. This is interpreted to mean the current use is being achieved.*

[g]*These waters shall meet the standards for fish and aquatic life except that the dissolved oxygen shall not be lowered to less than 2 mg/L at any time, nor shall the membrane filter fecal coliform count exceed 1,000 per 100 ml as a monthly geometric mean based on not less than five samples per month nor exceed 89^{o}F at any time at the edge of the mixing zones established by the WDNR under s. NR 102.05(3).*

[h]*Based upon Wisconsin Department of Natural Resources,* The State of the Root-Pike River Basin: May 2002, *PUBL WT-700-2002.*

[i]*Recommended for the reach from CTH C to Southern Colony.*

[j]*Based upon best professional judgment of fisheries biologist.*

[k]*Based upon modifications in channel type completed or committed to by MMSD.*

[l]*Based upon resource objectives developed by WDNR and MMSD for use in the Milwaukee County Grounds Detention Basin Design Program.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

Table 16

APPLICABLE WATER USE OBJECTIVES AND WATER QUALITY STANDARDS (CRITERIA) AND GUIDELINES FOR LAKES AND STREAMS WITHIN THE REGIONAL WATER QUALITY MANAGEMENT PLAN UPDATE STUDY AREA

Water Quality Parameter	Combinations of Water Use Objectives Adopted for Planning Purposes[a]						Source
	Coldwater Community	Warmwater Sportfish and Forage Fish Communities	Limited Forage Fish Community (variance category)	Limited Aquatic Life (variance category)	Special Variance Category A[b]	Special Variance Category B[c]	
Recreational Use	Full	Full	Full	Full	Limited	Limited	- -
Maximum Temperature (^{o}F)[d]	Background	89.0	89.0	- -	89.0[e]	89.0	NR 102.04 (4)[f]
Dissolved Oxygen (mg/l)[d]	6.0 minimum 7.0 minimum during spawning	5.0 minimum	3.0 minimum	1.0 minimum	2.0 minimum	2.0 minimum	NR 102.04 (4) NR 104.02 (3)
pH Range (S.U.)	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0[e]	6.0-9.0[e]	NR 102.04 (4)[g] NR 104.02 (3)
Fecal Coliform (MFFCC)[h]							NR 102.04 (5) NR 104.06 (2)
Mean	200	200	200	200	1,000	1,000	
Maximum	400	400	400	400	2,000	- -	
Ammonia Nitrogen (mg/l)	- -[i]	- -[i]	- -[i]	- -[i]	- -[i]	- -[i]	NR 105 Tables 2c and 4b
Total Phosphorus (mg/l)							Regional water quality management plan[j]
Maximum for Streams	0.1[e]	0.1[e]	0.1[e]	0.1[e]	0.1[e]	0.1[e]	
Maximum for Lakes during Spring Turnover	0.02	0.02	0.02	0.02	- -	- -	
Chloride (mg/l)	1,000 maximum[e]	1,000 maximum[e]	1,000 maximum[e]	1,000 maximum[e]	1,000 maximum[e]	1,000 maximum[e]	Regional water quality management plan

[a]*NR 102.04(1) All waters shall meet the following minimum standards at all times and under all flow conditions: substances that will cause objectionable deposits on the shore or in the bed of a body of water, floating or submerged debris, oil, scum, or other material, and material producing color, odor, taste, or unsightliness shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant, or aquatic life.*

[b]*As set forth in Chapter NR 104.06(2)(a) of the* Wisconsin Administrative Code.

[c]*As set forth in Chapter NR 104.06(2)(b) of the* Wisconsin Administrative Code.

[d]*Dissolved oxygen and temperature standards apply to continuous streams and the upper layers of stratified lakes and to unstratified lakes; the dissolved oxygen standard does not apply to the hypolimnion of stratified inland lakes. However, trends in the period of anaerobic conditions in the hypolimnion of deep inland lakes should be considered important to the maintenance of their natural water quality.*

[e]*Not specifically addressed within the* Wisconsin Administrative Code*. These values are considered to apply for planning purposes only.*

[f]*NR 102.04(4) There shall be no temperature changes that may adversely affect aquatic life. Natural daily and seasonal temperature fluctuations shall be maintained. The maximum temperature rise at the edge of the mixing zone above the natural temperature shall not exceed 5^{o}F for streams. There shall be no significant artificial increases in temperature where natural trout reproduction is to be maintained.*

[g]*The pH shall be within the stated range with no change greater than 0.5 unit outside the estimated natural seasonal maximum and minimum.*

[h]*NR 102.04(5)(a) The membrane filter fecal coliform count may not exceed 200 per 100 ml as a geometric mean based on not less than five samples per month, nor exceed 400 per 100 ml in more than 10 percent of all samples during any month.*

[i]*J.E. McKee and M.W. Wolf,* Water Quality Criteria, 2nd edition, *California State Water Quality Control Board, Sacramento, California, 1963.*

[j]*U.S. Environmental Protection Agency,* Quality Criteria for Water, *EPA-440/9-76-023, 1976.*

Source: Wisconsin Department of Natural Resources and SEWRPC.

waters for public and private water supplies; propagation of fish and aquatic life and wildlife; domestic and recreational purposes; and agricultural, commercial, industrial, and other legitimate uses."[2]

It is recognized that under both extremely high and extremely low flow conditions, instream water quality levels can be expected to violate the established water quality standards for short periods of time without significantly damaging the overall health of the stream. It is important to note the critical differences in the application of standards for regulatory versus planning purposes. For the purpose of planning, the standards are often applied using a probabilistic approach, whereby the percent of time a given standard is violated is considered to allow assessment and resolution of water quality problems during high flow, as well as low flow conditions. The U.S. Environmental Protection Agency and the Wisconsin Department of Natural Resources, being regulatory agencies, utilize water quality standards as a basis for enforcement actions and compliance monitoring. This requires that the standards have a rigid basis in research findings and in field experience. SEWRPC and others use water quality standards as criteria to measure the relative merits of alternative plans.

Notwithstanding, there are minimum standards which apply to all waters. All surface waters must meet certain conditions at all times and under all flow conditions. Chapter NR 102 of the *Wisconsin Administrative Code* states that:

> "Practices attributable to municipal, commercial, domestic, agricultural, land development or other activities shall be controlled so that all waters including the mixing zone and the effluent channel meet the following conditions at all times and under all flow conditions:
>
> "(a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water shall not be present in such amounts as to interfere with public rights in the waters of the State.
>
> "(b) Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to interfere with public rights in the waters of the State.
>
> "(c) Materials producing color, odor, taste, or unsightliness shall not be present in such amounts as to interfere with public rights in the waters of the State.
>
> "(d) Substances in concentrations or combinations which are toxic or harmful shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant, or aquatic life."[3]

OTHER WATER QUALITY INDICATORS

In addition to the water quality standards set forth above, the WDNR has promulgated a number of additional standards and criteria for water quality and for other indicators associated with aquatic environments and resources. These other standards, criteria, and indicators are presented herein for completeness; however, in most cases, these substances are not being directly measured or quantified as part of the regional water quality management plan update. They will be considered only in a secondary manner as available data from other sources allows.

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[2]Wisconsin Statutes*, Section 281.15(1).*

[3]Wisconsin Administrative Code*, Chapter NR 102.04.*

Surface Waters

The WDNR has promulgated a number of standards and criteria for surface water quality in addition to the standards and criteria discussed above. Some of these standards and criteria are applicable to all surface waters of the State, while others are applicable only to surface waters with particular designated uses.

Standards for Public Health and Welfare

All surface waters of the State are required to meet the human threshold and human cancer criteria for public health and welfare. These criteria are set forth in Tables 17 and 18, respectively. The concentrations given in these criteria vary depending upon whether the surface water is used for public drinking water supplies and vary with the type of fish and aquatic life category designated for the waterbody. In addition, all surface waters providing public drinking water supplies or classified as Coldwater or warmwater sportfish communities are required to meet the threshold taste and odor criteria set forth in Table 19. For substances which impart tastes or odors to waters, the criteria consist of the concentrations listed in Table 19. For substances which impart tastes and odors to aquatic organisms, the criterion for a particular substance is computed by dividing the concentration listed in Table 19 by the aquatic life bioaccumulation factor as derived in Chapter NR 105.10 of the *Wisconsin Administrative Code* for the substance.

Standards for Wildlife

All surface waters of the state are required to be classified for wildlife uses. All surface waters of the state are required to meet the wildlife criteria set forth in Table 20.

Standards for Toxic Substances

Surface waters of the State are required to meet criteria for substances that produce acute or chronic toxic effects in fish or other aquatic organisms. The acute toxicity criterion is the maximum daily concentration of a substance which ensures adequate protection of a sensitive species of aquatic life from immediate toxic effects and will adequately protect the designated fish and aquatic life use of the surface water if not exceeded more than once every three years. The chronic toxicity criterion is the maximum four-day concentration of a substance which ensures adequate protection of a sensitive species of aquatic life from longer-term toxic effects and will adequately protect the designated fish and aquatic life use of the surface water if not exceeded more than once every three years.

The concentrations given in these criteria vary depending upon whether the surface water is used for public drinking water supplies and vary with the type of fish and aquatic life category designated for the waterbody. These standards fall into two groups. One group consists of substances producing effects that are not influenced by the ambient concentrations of other water quality constituents. The criteria for these substances are set forth in Table 21. The other group consists of substances producing effects that are influenced by the ambient concentrations of other water quality constituents, in most cases hardness, pH, or temperature. The criteria for these substances are set forth in Table 22. It is important to note that the criteria listed in Table 22 are for representative values of the water quality constituent(s) affecting the toxic effects of the substance listed. For most of these substances, the actual criteria are determined by equations set forth in Chapter NR 105 of the *Wisconsin Administrative Code*.

Biological Conditions

Biological conditions of waterbodies are generally described in terms of biological or biotic indices. While these indices have no regulatory status under Wisconsin law, they can be useful tools for assessing water quality. Two types of biotic indices are in general use: biotic indices that examine stream macroinvertebrate assemblages such as the Hilsenhoff Biotic Index (HBI) and biotic indices that examine fish assemblages such as the Index of Biotic Integrity (IBI). In general, biotic indices utilize differences among taxa of organisms in sensitivity to degraded environmental conditions to assess conditions at a particular site such as a stream reach. While the particular parameters used to compute biotic indices differ among indices, they are commonly based upon one or more community attributes that reflect the characteristics of biotic assemblages. Examples of these include species richness and composition, trophic and reproductive function, and individual abundance and condition. Water

Table 17

HUMAN THRESHOLD CRITERIA FOR PUBLIC HEALTH AND WELFARE FOR WATER QUALITY[a,b]

	Water Use Objectives				
	For Use As a Water Supply		Not Intended for Use As a Water Supply		
Substance	Warmwater Sportfish Communities (microgram per liter, except as noted)	Coldwater Communities[c] (microgram per liter, except as noted)	Warmwater Forage, Limited Forage, and Warmwater Sportfish Communities (microgram per liter, except as noted)	Coldwater Communities (microgram per liter, except as noted)	Limited Aquatic Life (microgram per liter, except as noted)
Arcolein	7.2	3.4	15	4.4	2,800
Antimony	10	10	2,220	2,200	2,200
Benzene	5	5	610	260	4,000
Bis(2-chloroisopropyl) ether	1,100	1,100	55,000	34,000	220,000
Cadmium	10	10	1,200	1,200	2,800
Chlordane[d] (nanogram per liter)	2.4	0.70	2.4	0.70	310,000
Chlorobenzene	100	100	4,900	1,600	110,000
Chromium (+3)	28,000	28,000	2,500,000	2,5000,000	5,600,000
Chromium (+6)	140	140	13,000	13,000	28,000
Cyanide, total	200	200	40,000	40,000	120,000
4,4'-DDT[d] (nanogram per liter)	3.0	0.88	3.0	0.88	2,800,000
1,2-Dichlorobenzene	600	600	6,400	1,900	500,000
1,3-Dichlorobenzene	1,400	710	3,300	1,000	500,000
cis-1,2-Dichloroethene	70	70	14,000	9,000	56,000
trans-1,2-Dichloroethene	100	100	24,000	13,000	110,000
Dichloromethane	5	5	95,000	72,000	328,000
2,4-Dichlorophenol	74	58	580	180	17,000
Dichloropropenes[e]	8.3	8.2	420	260	1,700
Dieldrin[d] (nanogram per liter)	0.59	0.17	0.59	0.17	280,000
2,4-Dimethylphenol	450	430	11,000	4,500	94,000
Diethyl phthalate	5,000	5,000	68,000	21,000	4,500,000
Dimethyl phthalate (milligram per liter)	241	184	1,680	530	56,000
4,6-Dinitro-o-cresol	100	96	1,800	640	22,000
Dinitrophenols[e]	55	55	2,800	1,800	11,000
2,4-Dinitrotoluene	0.51	0.48	13	5.3	110
Endosulfan	87	41	181	54	33,600
Ethylbenzene	700	700	12,000	3,700	560,000
Fluoranthene	890	610	4,300	1,300	220,000
Hexachlorobenzene[d]	0.075	0.022	0.075	0.022	4,500
Hexachlorocyclopentadiene	50	50	980	310	39,000
Hexachloroethane	8.7	3.3	13	3.7	5,600
γ-BHC (Lindane)[d]	0.20	0.20	0.84	0.25	1,900
Isophorone	5,500	5,300	180,000	80,000	1,100,000
Lead	10	10	140	140	2,240
Mercury[d]	0.0015	0.0015	0.0015	0.0015	336
Nickel	100	100	43,000	43,000	110,000
Pentachlorobenzened	0.46	0.14	0.47	0.14	4,500
Selenium	50	50	2,600	2,600	28,000
Silver	140	140	28,000	28,000	28,000
2,3,7,8-TCDD[d] (picogram per liter)	0.11	0.032	0.11	0.032	7,300
1,2,4,5-Tetrachlorobenzened	0.54	0.17	0.58	0.17	1,700
Toluene	1,000	1,000	76,000	26,000	1,200,000
1,1,1-Trichloroethane	200	200	270,000	110,000	2,000,000
2,4,5-Trichlorophenol	1,600	830	3,900	1,200	560,000

Table 17 Footnotes

[a]*Values set forth in Chapter NR 105 of the* Wisconsin Administrative Code.

[b]*All surface waters shall meet the human threshold and human cancer criteria specified in or developed pursuant to* Wisconsin Administrative Code *NR 105.08 and 105.09, respectively.*

[c]*For bioaccumulative chemicals of concern pursuant to NR 105.03 (9), criteria apply to all waters of the Great Lakes system.*

[d]*Indicates a bioaccumulative chemical of concern.*

[e]*The human threshold criteria for this chemical are applicable to each isomer.*

Source: Wisconsin Department of Natural Resources.

quality ratings associated with particular index scores are generally determined by calibrating the index against a series of reference sites. These calibrations usually are applicable only to specific geographical regions. It is important to note that habitat type can determine which particular biotic index is most appropriate to use in a given situation. For example, because water temperature has a strong influence on fish community composition different IBIs are generally used for warmwater and coldwater streams. The biotic indices used to assess biological conditions of streams in the regional water quality management plan update study are discussed in Chapter III of this report.

Sediments

The presence of contaminated sediments can have several effects on water quality. Contaminated sediments have been demonstrated to be toxic to benthic-dwelling organisms. Many sediment contaminants bioaccumulate in organism tissue and may be biomagnified as they are carried though the food web. Contaminated sediments can compromise human health both through direct exposure such as swimming and wading and consumption of contaminated fish and shellfish. Beneficial uses of waterbodies can also be compromised by the presence of contaminated sediment, leading, for example, to fish consumption advisories for waterbodies and reductions in sportfish populations.

A number of Federal laws have direct bearing on sediment quality or on the removal and disposal of contaminated sediment. These include the Clean Water Act, the Toxic Substances Control Act, the Coastal Zone Management Act, and the Rivers and Harbors Act of 1899. The Comprehensive Environmental Response, Compensations, and Liability Act of 1980 (CERCLA), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA), required that the USEPA and the Agency for Toxic Substances and Disease Registry (ATSDR) prepare a list of hazardous substances that pose the most significant threats for human health due to known or suspected toxicity and potential for human exposure.[4] Currently the list contains over 800 substances and 1,500 radionuclides. Many of these were first identified as hazardous under other statutes including, the Clean Water Act, the Clean Air Act, the Toxic Substances Control Act, and the Resource Conservation and Recovery Act.

Much of the regulation of contaminated sediment stems from impairment of designated water uses resulting from the presence of contaminants. For example, the remedial action plan for the Milwaukee Estuary cited several impairments related to those defined under the Great Lakes Water Quality Agreement. This agreement defined "Impairment of beneficial use(s)" to mean a change in the chemical, physical or biological integrity of the Great Lakes System sufficient to cause any of the following: restrictions on fish and wildlife consumption; tainting of fish and wildlife flavor; degradation of fish and wildlife populations; fish tumors or other deformities; bird or animal deformities or reproduction problems; degradation of benthos; restrictions on dredging activities; eutrophication or undesirable algae; restrictions on drinking water consumption, or taste and odor problems;

[4]*This list is located in 40 CFR, part 302.*

Table 18

HUMAN CANCER CRITERIA FOR PUBLIC HEALTH AND WELFARE FOR WATER QUALITY[a,b]

Substance	Water Use Objectives				
	For Use As a Water Supply		Not Intended for Use As a Water Supply		
	Warmwater Sportfish Communities (microgram per liter, except as noted)	Coldwater Communities[c] (microgram per liter, except as noted)	Warmwater Forage, Limited Forage, and Warmwater Sportfish Communities (microgram per liter, except as noted)	Coldwater Communities (microgram per liter, except as noted)	Limited Aquatic Life (microgram per liter, except as noted)
Acrylonitrile	0.57	0.45	4.6	1.5	130
Arsenic	0.185	0.185	50	50	50
α-BHC[d]	0.012	0.0037	0.013	0.0039	11
γ-BHC (Lindane)[d]	0.052	0.018	0.064	0.019	54
BHC, technical grade[d]	0.038	0.013	0.047	0.014	39
Benzene	5	5	140	45	1,300
Benzidine (nanogram per liter)	1.5	1.5	81	55	300
Beryllium	0.054	0.054	0.33	0.33	16
Bis(2-chloroethyl) ether	0.31	0.29	7.6	3.0	64
Bis(chloromethyl) ether (nanogram per liter)	1.6	1.6	96	79	320
Carbon tetrachloride	2.5	2.1	29	9.5	540
Chlordane[d] (nanogram per liter)	0.41	0.12	0.41	0.12	54,000
Chloroethene (vinyl chloride)	0.18	0.18	10	6.8	37
Chloroform (trichloromethane)	55	53	1,960	922	11,200
4,4'-DDT[d] (nanogram per liter)	0.22	0.065	0.22	0.065	206,000
1,4-Dichlorobenzene	14	12	163	54	2,940
3,3'-Dichlorobenzidine	0.51	0.29	1.5	0.46	154
1,2-Dichloroethane	3.8	3.8	217	159	770
Dichloromethane	5	5	2,700	2,100	9,600
Dieldrin[d] (nanogram per liter)	0.0091	0.0027	0.0091	0.0027	4,400
2,4-Dinitrotoluene	0.51	0.48	13	5.3	110
1,2-Diphenylhydrazine	0.38	0.31	3.3	1.04	88
Halomethanes[e]	55	53	1,960	922	11,200
Hexachlorobenzene[d] (nanogram per liter)	0.73	0.22	0.73	0.22	44,000
Hexachlorobutadiene[d]	0.59	0.19	0.69	0.2	910
Hexachloroethane	7.7	2.9	11	3.3	5,000
N-Nitrosodiethylamine (nanogram per liter)	2.3	2.3	150	140	460
N-Nitrosodimethylamine	0.0068	0.0068	0.46	0.46	1.4
N-Nitrosodi-n-butylamine	0.063	0.062	2.5	1.3	13
N-Nitrosodiphenylamine	44	23	116	34	13,000
N-Nitrosopyrrolidine	0.17	0.17	11	11	34
Polychlorinated biphenyls[d] (nanogram per liter)	0.01	0.003	0.01	0.003	9,100
2,3,7,8-TCDD[d] (picogram per liter)	0.014	0.0041	0.014	0.0041	930
1,1,2,2-Tetrachloroethane	1.7	1.6	52	22	350
Tetrachloroethene	5.8	4.6	46	15	1,300
Toxaphened (nanogram per liter)	0.11	0.034	0.14	0.034	63,600
1,1,2-Trichloroethane	6.0	6.0	195	87	1,200
Trichlororethene	5	5	539	194	6,400
2,4,6-Trichlorophenol	29	24	300	97	6,400

[a]*Values set forth in Chapter NR 105 of the* Wisconsin Administrative Code.

[b]*All surface waters shall meet the human threshold and human cancer criteria specified in or developed pursuant to NR 105.08 and NR 105.09, respectively.*

[c]*For bioaccumulative chemicals of concern pursuant to NR 105.03 (9), criteria apply to all waters of the Great Lakes system.*

[d]*Indicates a bioaccumulative chemical of concern.*

[e]*Human cancer criteria for halomethanes are applicable to any combination of the following chemicals: bromomethane (methyl bromide), chloromethane (methyl chloride), tribromomethane (bromoform), bromodichloromethane (dichloromethyl bromide), dichlorodifluoromethane (fluorocarbon 12), and trichlorofluoromethane (fluorocarbon 11).*

Source: Wisconsin Department of Natural Resources.

Table 19

THRESHOLD CONCENTRATIONS FOR PUBLIC HEALTH AND WELFARE FOR SUBSTANCES CAUSING TASTE AND ODOR IN WATER[a,b]

Substance	Threshold Concentration (microgram per liter)
Acenaphthene	20.00
Chlorobenzene	20.00
2-Chlorophenol	0.10
3-Chlorophenol	0.10
4-Chlorophenol	0.10
Copper	1,000.00
2,3-Dichlorophenol	0.04
2,4-Dichlorophenol	0.30
2,5-Dichlorophenol	0.50
2,6-Dichlorophenol	0.20
3,4-Dichlorophenol	0.30
2,4-Dimethylphenol	400.00
Hexachloropentiadiene	1.00
2-Methyl-4-Chlorophenol	1,800.00
3-Methyl-4-Chlorophenol	3,000.00
3-Methyl-6-Chlorophenol	20.00
Nitrobenzene	30.00
Pentachlorophenol	30.00
Phenol	300.00
2,3,4,6-Tetrachlorophenol	1.00
2,4,5-Trichlorophenol	1.00
2,4,6-Trichlorophenol	2.00
Zinc	5,000.00

[a]*Values set forth in Chapter NR 102 of the* Wisconsin Administrative Code.

[b]*All surface waters providing public drinking water supplies or classified as Coldwater or warmwater sportfish communities shall meet the taste and odor criteria specified in or developed pursuant to Section NR 102.14. For substances imparting tastes or odors to water, the criteria are the concentrations listed in the table. For substances imparting tastes or odors to aquatic organisms, the criteria is computed by dividing the concentration listed in the table (converted to mg/l) by the aquatic life bioaccumulation factor as derived in Section NR 105.10.*

Source: Wisconsin Department of Natural Resources.

beach closings; degradation of aesthetics; added costs to agriculture or industry; degradation of phytoplankton and zooplankton populations; and loss of fish and wildlife habitat.

The WDNR has not promulgated regulations setting chemical-specific numerical values for sediment quality. Rather, the approach has been to characterize sediment as either "clean" or "contaminated" and to assess the hazard posed to human health and welfare and the danger posed to the environment by its presence. For lower tier screening, the Department has, in the past, relied upon sediment quality criteria and guidelines developed by regulatory agencies in other jurisdictions for establishing clean-up objectives. For example, the Milwaukee Estuary Remedial Action Plan utilized the Ontario Sediment Quality Guidelines, the State of Washington Sediment Standards, the Netherlands Sediment Quality Objectives, the Canadian Marine Sediment Quality Guidelines, the USEPA Proposed Sediment Quality Guidelines, and guidelines developed by the National Oceanic and Atmospheric Administration's Status and Trends Program.[5] Currently, the Department uses guidelines from various sources for lower tier screening including the Ontario Provincial Sediment Quality Guidelines, the National Oceanic and Atmospheric Administration (NOAA) Guidelines, and the Assessment and Remediation of Contaminated Sediments (ARCS) Program Guidelines. In addition, the Department has developed proposed draft consensus-based sediment quality guidelines[6] that average effect-level concentrations from several guidelines of similar intent and are intended to be used to predict the presence or absence of toxicity to benthic organisms.

The WDNR has also established procedures for evaluating and prioritizing sites and facilities for remediation under the environmental repair, hazardous substance discharge, leaking underground storage tank, and superfund programs. These procedures are set forth in Chapter NR 710 of the *Wisconsin Administrative Code*. Finally, the Department has established regulations for sediment sampling and analysis, monitoring and disposal criteria for dredging projects. These are set forth in Chapter NR 347 of the *Wisconsin Administrative Code.*

[5]*Wisconsin Department of Natural Resources,* Milwaukee Estuary Remedial Action Plan: Progress Through January 1994*, 1994.*

[6]*Wisconsin Department of Natural Resources,* Consensus-Based Sediment Quality Guidelines: Recommendations for Use & Application – Interim Guidance*, WT-732 2003, December 2003.*

Groundwater

The WDNR has established standards for groundwater quality indicator parameters and for substances detected in or having a reasonable probability of entering the groundwater resources of the State. Standards have been issued for three groups of substances: indicator parameters, substances of public health concern, and substances related to public welfare. These standards are set forth in Tables 23, 24, and 25, respectively. For each groundwater quality indicator parameter, one criterion, a protective action limit, is established. Two criteria are set for each substance of concern: a preventive action limit and an enforcement standard.

Table 20

WILDLIFE CRITERIA FOR SURFACE WATER QUALITY[a,b]

Substance	Criteria
DDT and Metabolites (nanogram per liter)	0.011
Mercury (nanogram per liter)	1.3
Polychlorinated Biphenyls (nanogram per liter)	0.12
2,3,7,8-TCDD (picogram per liter)	0.003

[a] *Values set forth in Chapter NR 105 of the* Wisconsin Administrative Code.

[b] *All surface waters shall be classified for wildlife uses and shall meet the wildlife criteria specified or developed pursuant to* Wisconsin Administrative Code *NR 105.07.*

Source: Wisconsin Department of Natural Resources.

The preventive action limits have three major purposes. They are intended to be used to inform the WDNR of potential groundwater problems. In addition, they establish levels of contamination at which the Department is required to commence efforts to control contamination. Finally, they provide a basis for designing management criteria in administrative rulemaking.[7]

The enforcement standards establish concentrations used to initiate regulatory responses. It is important to note that Chapter NR 140 of the *Wisconsin Administrative Code* establishes procedures for granting exemptions when enforcement standards are attained or exceeded, in whole or in part, because of high background concentrations of substances.

In addition to groundwater quality standards, the WDNR has promulgated standards for drinking water supplies that include a number of substances for which groundwater quality standards have not been issued. For example, though no groundwater quality standard has been issued for radium, the standards for drinking water supplies set forth in Chapter NR 809 of the *Wisconsin Administrative Code* set a maximum contaminant limit for radium in drinking water of five picoCuries per liter. These standards will not be the focus of this report since they apply specifically to drinking water quality and not groundwater or surface water quality.

SUMMARY OF PUBLIC INVOLVEMENT ACTIVITY FINDINGS RELATED TO WATER USE OBJECTIVES

The water use objectives set forth on Maps 7 through 12 and in Table 15 were publicly presented on several occasions to the Citizens Advisory Council, the Watershed Officials Forum, and the Technical Advisory Committee for review and comment. In general, the water use objectives received support. The groups did suggest that for some waterbodies higher use objectives be considered as appropriate for planning purposes only. These higher use objectives for planning purposes have been incorporated and are set forth in Table 15.

[7] *With two exceptions, preventive action limits are established by determining values for background water quality based upon an averaging of a minimum of eight samples from each test well. The preventive action limit consists of the greater of either the minimum increase value from Table 23 or three standard deviations of the mean from the determination of background value added to the background value. For temperature, two preventive action limits are established in this manner: one above the background value and one below the background value. Those limits are computed by adding to, and subtracting from, the background value the greater of either the minimum increase value from Table 23 or three standard deviations of the mean. For pH, two preventive action limits are established at values one standard unit above and below the background value.*

Table 21

ACUTE AND CHRONIC TOXICITY CRITERIA FOR AQUATIC LIFE FOR SUBSTANCES UNRELATED TO WATER QUALITY[a]

Substance	Water Use Objectives: Acute Toxicity Criteria (micrograms per liter): Coldwater	Acute: Warmwater Sportfish, Warmwater Forage, and Limited Forage Fish	Acute: Limited Aquatic Life	Chronic Toxicity Criteria (micrograms per liter): Coldwater	Chronic: Warmwater Sportfish, Warmwater Forage, and Limited Forage Fish	Chronic: Limited Aquatic Life
Metals						
Arsenic (+3)[b]	339.8	339.8	339.8	148	152.2	152.2
Chromium (+6)[b]	16.02	16.02	16.02	10.98	10.98	10.98
Mercury (+2)[b]	0.83	0.83	0.83	0.44	0.44	0.44
Selenium [b,c]	- -	- -	- -	5	5	5
Anions						
Cyanide, Free	22.4	22.4	22.4	5.22	11.47	11.47
Chloride	757,000	757,000	757,000	395,000	395,000	395,000
Chlorine[e]	19.03	19.03	19.03	7.28	7.28	7.28
Pesticides						
γ-BHC (Lindane)	0.96	0.96	0.96	- -	- -	- -
Dieldrin	0.24	0.24	0.24	0.055	0.077	0.077
Endrin	0.086	0.086	0.086	0.036[d]	0.036[d]	0.036[d]
Toxaphene	0.73	0.73	0.73	- -	- -	- -
Chlorpyrifos	0.041	0.041	0.041	- -	- -	- -
Parathion	0.057	0.057	0.057	0.011	0.011	0.011

[a]*Values set forth in Chapter NR 105 of the* Wisconsin Administrative Code.

[b]*Values represent total recoverable form for each of these constituents.*

[c]*The United States Environmental Protection Agency disapproved Wisconsin's failure to adopt and submit to EPA a chronic aquatic life criterion for selenium as required by* 40 CFR 132.3(b). *Pursuant to the Great Lakes Guidance at* 40 CFR 132*, the corresponding Federal water quality criteria contained at* 40 CFR 132*, Tables 1 and 2 apply.*

[d]*The United States Environmental Protection Agency disapproved Wisconsin's chronic aquatic life criteria for endrin as being inconsistent with Tables 1 and 2 of the Great Lakes Guidance at* 40 CFR 132. *Pursuant to the Great Lakes Guidance, these criteria have been replaced by the corresponding Federal water quality criteria contained at* 40 CFR 132, *Tables 1 and 2.*

[e]*Values represent total residual form for chlorine.*

Source: Wisconsin Department of Natural Resources.

SUMMARY

This chapter has described the water use objectives and supporting water quality standards or criteria applicable to waterbodies in the regional water quality management plan update study area. The regulatory framework for this derives from the Clean Water Act and its amendments. This act, as amended, required the States to adopt water use objectives and supporting water quality standards or criteria for interstate and intrastate navigable waters, established effluent limitations for point source discharges, required permits for the discharge of any pollutants, and required permits for the discharge of stormwater under certain circumstances. The State of Wisconsin has adopted the required water use objectives and supporting water quality standards or criteria. These are set forth in Chapters NR 102-105 of the *Wisconsin Administrative Code*. In addition, the State has established a pollutant discharge permit system to meet the requirements of the Clean Water Act. This includes requiring permits for discharges from point sources to all surface waters of the State and land areas where pollutants may percolate or seep to or be leached to groundwater, as well as requiring permits for discharge of stormwater.

Table 22

ACUTE AND CHRONIC TOXICITY CRITERIA FOR AQUATIC LIFE FOR SUBSTANCES RELATED TO WATER QUALITY[a]

	Water Use Objectives					
	Acute Toxicity Criteria (micrograms per liter) at Various Hardness (milligrams $CaCO_3$ per liter) Levels[c]			Chronic Toxicity Criteria (micrograms per liter) at Various Hardness (milligrams $CaCO_3$ per liter) Levels		
Substances[b]	50	100	200	50	100	200
Cadmium						
All Surface Waters	- -	- -	- -	1.43[d]	2.46[d]	3.82[d,e]
Coldwater	1.97	4.36	9.65	- -	- -	- -
Warmwater Sportfish, Warmwater Forage and Limited Forage Fish	4.65	10.31	22.83	- -	- -	- -
Limited Aquatic Life	13.03	28.87	63.92	- -	- -	- -
Chromium (+3)						
All Surface Waters	1,022	1,803	3,181	- -	- -	- -
Coldwater	- -	- -	- -	48.86	86.21	152.1
Warmwater Sportfish	- -	- -	- -	74.88	132.1	233.1
All Other Surface Waters	- -	- -	- -	74.88	132.1	233.1
Copper[f]	7.29	14.00	26.90	5.16	9.33	16.87
Lead	54.73	106.92	208.90	14.33	28.01	54.71
Nickel[f]	261.0	469.2	843.3	29.02	52.16	93.76
Zinc	65.66	120.4	220.7	65.66	120.4	220.7

	Acute Toxicity Criteria (micrograms per liter) at Various pH (standard units) Levels[g]			Chronic Toxicity Criteria (micrograms per liter) at Various pH (standard units) Levels		
Substances[b]	6.5	7.8	8.8	6.5	7.8	8.8
Pentachlorophenol						
All Surface Waters	5.25	19.40	53.01	- -	- -	- -
Coldwater	- -	- -	- -	4.43	14.81	40.48
All Other Surface Waters	- -	- -	- -	5.33	12.82	48.70

	Acute Toxicity Criteria (milligram per liter) at Various pH (standard units) Levels			Chronic Toxicity Criteria (milligram per liter) at Various pH (standard units) Levels[i]		
Substances[b]	7.5	8.0	8.5	7.5	8.0	8.5
Ammonia (as N)						
Coldwater Categories 1 and 4[h]	13.28	5.62	2.14	- -	- -	- -
Coldwater Categories 2 and 3[h]	16.59	7.01	2.67	- -	- -	- -
Coldwater Category 5, Warmwater Sportfish, Warmwater Forage Fish, and Limited Forage Fish[h]	19.89	8.41	3.20	- -	- -	- -
Limited Aquatic Life	30.64	12.95	4.93	- -	- -	- -
Coldwater, Warmwater Sportfish (early life stages present), Warmwater Forage Fish (early life stages present)						
Temperature = 25° Celsius	- -	- -	- -	2.22	1.24	0.55
Temperature = 14.5° Celsius or less	- -	- -	- -	4.36	2.43	1.09
Warmwater Sportfish (early life stages absent), Warmwater Forage Fish (early life stages absent)						
Temperature = 25° Celsius	- -	- -	- -	2.22	1.24	0.55
Temperature = 7° Celsius or less	- -	- -	- -	7.09	3.95	1.77
Limited Forage Fish (early life stages present)						
Temperature = 27° Celsius or less	- -	- -	- -	5.54	3.09	1.38
Limited Forage Fish (early life stages absent)						
Temperature = 25° Celsius	- -	- -	- -	6.69	3.73	1.67
Temperature = 7° Celsius or less	- -	- -	- -	21.34	11.90	5.33
Limited Aquatic Life						
Temperature = 25° Celsius	- -	- -	- -	14.50	8.09	3.62
Temperature = 7° Celsius or less	- -	- -	- -	46.29	25.82	11.56

Table 22 Footnotes

[a]*Values set forth in Chapter NR 105 of the* Wisconsin Administrative Code.

[b]*Values represent total recoverable form for each of these constituents and applicable to all surface waters unless otherwise stated. The relation of actual toxicity criteria to water quality parameters are given in equations listed in Tables 2, 4, and 6 of NR 105.*

[c]*The acute toxicity criteria related to water quality are applicable to the following ranges in hardness concentration for each of the substances summarized below; 6-457 mg/l hardness for cadmium, 13-301 mg/l hardness for chromium (+3), 14-427 mg/l hardness for copper, 12-356 mg/l hardness for lead, 19-157 mg/l hardness for nickel, and 12-333 mg/l hardness for zinc.*

[d]*The chronic toxicity criteria values for cadmium for all surface waters are applicable to the range 18-175 mg/l hardness.*

[e]*This chronic toxicity criteria value is based upon a maximum hardness level of 175 mg/l.*

[f]*The United States Environmental Protection Agency disapproved Wisconsin's acute and chronic aquatic life criteria for copper and nickel as being inconsistent with Tables 1 and 2 of the Great Lakes Guidance at* 40 CFR 132. *Pursuant to the Great Lakes Guidance, these water quality criteria are replaced by the corresponding Federal water quality criteria contained at* 40 CFR 132, *Tables 1 and 2.*

[g]*The acute toxicity criteria related to water quality for pentachlorophenol is applicable to the pH range 6.6-8.8.*

[h]*Cold water categories 1-5 are applicable only to ammonia criteria. Cold water category 1 is the default category of coldwater classification. This category includes all fish. Cold water category 2 consists of inland lakes with populations of cisco, lake trout, brook trout, or brown trout, but no other trout or salmonid species. This category excludes data on genus* Oncorhynchus. *Cold water category 3 consists of inland lakes with populations of cisco, but no trout or salmonid species. This category excludes data on the genera* Oncorhynchus, Salmo, *and* Salvelinus. *Cold water category 4 consists of inland waters with brook trout, brown trout, or rainbow trout, but no whitefish or cisco. This category excludes data on genus* Prosopium. *Category 5 consists of inland waters with brook trout and brown trout, but not whitefish, cisco, or other trout or salmonid species. This category excludes data on genera* Prosopium *and* Oncorhynchus.

[i]*Values represent a 30-day chronic toxicity criterion.*

Source: Wisconsin Department of Natural Resources.

The WDNR has established water use objectives for fish and aquatic life uses and for recreational uses for streams and lakes in the regional water quality management plan update study area. These are set forth on Maps 7 through 12 and in Table 15. In addition, to assist in future planning and management strategies, the regional water quality management plan update has evaluated the potential for selected surface waters achieving a higher use objective or classification than currently codified. These auxiliary use objectives are set forth in Table 15.

The WDNR has also promulgated water quality standards in support of the water use objectives. Applicable regulatory standards and additional planning standards are set forth in Table 16. In addition, several other sets of standards and criteria apply to some or all of the waters of the study area. All surface waters of the State are required to meet the human health threshold and human cancer criteria set forth in Tables 17 and 18, respectively. Waters used for public drinking water supply or for Coldwater or warmwater sportfish uses are required to meet the taste and odor threshold criteria set forth in Table 19. All surface waters of the State are classified for wildlife uses and must meet the wildlife criteria set forth in Table 20. Surface waters in the State are required to meet the acute and chronic toxicity criteria for fish and aquatic life. The criteria for substances whose toxicity is not affected by other water quality parameters are set forth in Table 21. The criteria for substances whose toxicity is affected by other water quality parameters are set forth in Table 22.

While specific requirements have not been set regarding biological conditions, a number of biotic indices exist which can be useful in evaluating water quality and whether water use objectives are being achieved. These focus on fish or macroinvertebrates. In addition, sediment quality guidelines are available to evaluate whether contaminated sediment is contributing to impairment of beneficial water uses.

Wisconsin has also set regulatory standards for groundwater quality for indicator parameters, substances related to public health, and substances related to public welfare. These standards are set forth in Tables 23, 24, and 25, respectively.

Table 23

METHODOLOGY FOR ESTABLISHING PREVENTIVE ACTION LIMITS FOR INDICATOR PARAMETERS FOR GROUNDWATER QUALITY[a,b,c]

Parameter	Minimum Increase (milligrams per liter, except as noted)
Alkalinity	100
Biochemical Oxygen Demand (BOD_5)	25
Calcium	25
Chemical Oxygen Demand (COD)	14
Magnesium	25
Nitrogen Series	
Ammonia Nitrogen	2
Organic Nitrogen	2
Total Nitrogen	5
pH (standard units)[d]	1
Potassium	5
Sodium	10
Field Specific Conductance (micromohs per centimeter)	200
Temperature (^oF)[e]	10
Total Dissolved Solids (TDS)	200
Total Hardness	100
Total Organic Carbon (TOC)	1
Total Organic Halogen (TOC)	0.25

[a]*As set forth in Section NR 140.20 of the* Wisconsin Administrative Code.

[b]*Except as noted, the preventive action limit is calculated by adding whichever is greater, the value in the table or three times the standard deviation, to a value for background groundwater quality established by averaging a minimum of eight samples from each well.*

[c]*The preventive action limit is intended to inform the WDNR of potential groundwater contamination problems, establish levels of contamination at which the WDNR is required to commence efforts to control contamination, and provide a basis for the design of management criteria in administrative rules*

[d]*The preventive action limit for pH is set at 1 standard unit above or below the background pH.*

[e]*For field temperature, the preventive action limit shall be three standard deviations or 10^{o}F, whichever is greater, above or below the temperature of the background water quality.*

Source: Wisconsin Department of Natural Resources.

Table 24

GROUNDWATER QUALITY STANDARDS FOR SUBSTANCES OF PUBLIC HEALTH CONCERN[a]

Substance	Chemical Abstract Service Registry Number[b]	Enforcement Standard (micrograms per liter, except as noted)	Preventive Action Limit (micrograms per liter, except as noted)[c]
Acetone	67-64-1	1,000	200
Alachlor	15972-60-8	2	0.2
Aldicarb	116-06-3	10	2
Antimony	- -	6	1.2
Anthracene	120-12-7	3,000	600
Arsenic		10	1
Asbestos (million fibers per liter)	12001-29-5	7	0.7
Atrazine, total chlorinated residues[d]	- -	3	0.3
Bacteria, total coliform (number per 100 milliliters)[e]	- -	0	0
Barium (milligrams per liter)	- -	2	0.4
Bentazon	25057-89-0	300	60
Benzene	71-43-2	5	0.5
Benzo(b)fluoranthene	205-99-2	0.2	0.02
Benzo(a)pyrene	50-32-8	0.2	0.02
Beryllium	- -	4	0.4
Boron	7440-42-8	960	190
Bromodichloromethane	75-27-4	0.6	0.06
Bromoform	75-25-2	4.4	0.44
Bromomethane	74-83-9	10	1
Butylate	2008-41-5	67	6.7
Cadmium	- -	5	0.5
Carbaryl	63-25-2	960	192
Carbofuran	1563-66-2	40	8
Carbon disulfide	75-15-0	1,000	200
Carbon tetrachloride	56-23-5	5	0.5
Chloramben	133-90-4	150	30
Chlordane	57-74-9	2	0.2
Chloroethane	75-00-3	400	80
Chloroform	67-66-3	6	0.6
Chloromethane	74-87-3	3	0.3
Chromium	- -	100	10
Chrysene	218-01-9	0.2	0.02
Cobalt	7440-48-4	40	8
Copper	- -	1,300	130
Cyanazine	21725-46-2	1	0.1
Cyanide	57-12-5	200	40
Dacthal (milligrams per liter)	1861-32-1	4	0.8
1,2-Dibromoethane (EDB)	106-93-6	0.05	0.005
Dibromochloromethane	124-48-1	60	6
1,2-Dibromo-3-chloropropane (DBCP)	96-12-8	0.2	0.02
Dibutyl phthalate	84-74-2	100	20
Dicamba	1918-00-9	300	60
1,2-Dichlorobenzene	95-50-1	600	60
1,3-Dichlorobenzene	541-73-1	1,250	125
1,4-Dichlorobenzene	106-46-7	75	15
Dichlorodifluoromethane	75-71-8	1,000	200
1,1-Dichloroethane	75-34-3	850	85
1,2-Dichloroethane	107-06-2	5	0.5
1,1-Dichloroethylene	75-35-4	7	0.7
1,2-Dichloroethylene (cis)	156-59-2	70	7
1,2-Dichloroethylene (trans)	156-60-5	100	20
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	70	7

Table 24 (continued)

Substance	Chemical Abstract Service Registry Number[b]	Enforcement Standard (micrograms per liter, except as noted)	Preventive Action Limit (micrograms per liter, except as noted)[c]
1,2-Dichloropropane	78-87-5	5	0.5
1,3-Dichloropropene (cis/trans)	- -[f]	0.2	0.02
Di(2-ethylhexyl) phthalate	117-81-7	6	0.6
Dimethoate	60-51-5	2	0.4
2,4-Dinitrotoluene	121-14-2	0.05	0.005
2,6-Dinitrotoluene	606-20-2	0.05	0.005
Dinoseb	88-85-7	7	1.4
Dioxin (2,3,7,8-TCDD)	1746-01-6	0.00003	0.000003
Endrin	72-20-8	2	0.4
EPTC (*S*-ethyl dipropylcarbamothioate)	759-94-4	250	50
Ethylbenzene	100-41-4	700	140
Ethylene glycol (milligrams per liter)	107-21-1	7	0.7
Fluoranthene	206-44-0	400	80
Fluorene	86-73-7	400	80
Fluoride (milligrams per liter)	16984-48-8	4	0.8
Fluorotrichloromethane	75-69-4	3,490	698
Formaldehyde	50-00-0	1,000	100
Heptachlor	76-44-8	0.4	0.04
Heptachlor epoxide	1024-57-3	0.2	0.02
Hexachlorobenzene	118-74-1	1	0.1
N-Hexane	110-54-3	600	120
Hydrogen sulfide	7783-06-4	30	6
Lead	- -	15	1.5
Lindane	58-89-9	0.2	0.02
Mercury	7439-97-6	2	0.2
Methanol	67-56-1	5,000	1,000
Methoxychlor	72-43-5	40	4
Methylene chloride	75-09-2	5	0.5
Methyl ethyl ketone (MEK)	79-93-3	460	90
Methyl isobutyl ketone (MIBK)	108-10-1	500	50
Methyl tert-butyl ether (MTBE)	1634-04-4	60	12
Metolachlor	51218-45-2	15	1.5
Metribuzin	21087-64-9	250	50
Monochlorobenzene	108-90-7	100	20
Naphthalene	91-20-3	40	8
Nickel	- -	100	20
Nitrate (as milligrams N per liter)	- -	10	2
Nitrate + Nitrite (as milligrams N per liter)	- -	10	2
Nitrite (as milligrams N per liter)	- -	1	0.2
N-Nitrosodiphenylamine	86-30-6	7	0.7
Pentachlorophenol (PCP)	87-86-5	1	0.1
Phenol (milligrams per liter)	108-95-2	6	1.2
Picloram	1918-02-1	500	100
Polychlorinated biphenyls (PCBs)[g]	1336-36-3	0.03	0.003
Prometon	1310-18-0	90	18
Pyrene	129-00-0	250	50
Pyridine	110-86-1	10	2
Selenium	- -	50	10
Silver	- -	50	10
Simazine	122-34-9	4	0.4
Styrene	100-42-5	100	10
1,1,1,2-Tetrachloroethane	630-20-6	70	7
1,1,2,2-Tetrachloroethane	79-34-5	0.2	0.002
Tetrachloroethylene	127-18-4	5	0.5

Table 24 (continued)

Substance	Chemical Abstract Service Registry Number[b]	Enforcement Standard (micrograms per liter, except as noted)	Preventive Action Limit (micrograms per liter, except as noted)[c]
Tetrahydrofuran	109-99-9	50	10
Thallium	- -	2	0.4
Toluene (milligrams per liter)	108-88-3	1	0.2
Toxaphene	8001-35-2	3	0.3
1,2,4-Trichlorobenzene	120-82-1	70	14
1,1,1-Trichloroethane	71-55-6	200	40
1,1,2-Trichloroethane	79-00-5	5	0.5
Trichloroethylene	79-01-6	5	0.5
2,4,5-Trichlorophenoxy-propionic acid (2,4,5-TP)	93-72-1	50	5
1,2,3-Trichloropropane	98-18-4	60	12
Trifluralin	1582-09-8	7.5	0.75
Trimethylbenzenes (1,2,4- and 1,2,5- combined)	- -[h]	480	96
Vanadium	- -	30	6
Vinyl chloride	75-01-4	0.2	0.02
Xylene (milligrams per liter)[i]	1330-20-7	10	1

[a]*As set forth in Section NR 140.10 of the* Wisconsin Administrative Code.

[b]*The Chemical Abstract Service registry numbers are unique numbers assigned to chemical substances.*

[c]*The preventive action limit is intended to inform the Wisconsin Department of Natural Resources of potential groundwater contamination problems, establish levels of contamination at which the WDNR is required to commence efforts to control contamination, and provide a basis for the design of management criteria in administrative rules.*

[d]*Total chlorinated atrazine residues includes parent compound and the following metabolites of health concern: 2-chloro-4-amino-6-isopropylamino-s-triazine (formerly deethylatrazine), 2-chloro-4-amino-6-ethylamino-s-triazine (formerly deisopropylatrazine), and 2-chloro-4,6-diamino-s-triazine (formerly diaminoatrazine).*

[e]*Total coliform bacteria may not be present in any 100 ml sample using either the membrane filter technique, the presence-absence coliform test, the minimal medium ONPG-MUG test or not present in any 10 ml portion of the 10-tube multiple tube fermentation technique.*

[f]*This is a combined chemical substance which includes cis 1,3-dichloropropene (CAS RN 10061-01-5) and trans 1,3-dichloropropene (CAS RN 10061-02-6).*

[g]*Polychlorinated biphenyls is a class of 209 compounds, each with its own Chemical Abstract Service registry number.*

[h]*This is a combined chemical substance which includes 1,2,4-trimethylbenzene (CAS RN 95-63-6) and 1,3,5-trimethylbenzene (CAS RN 108-67-8).*

[i]*Xylene includes meta-xylene (CAS RN 108-38-3), ortho-xylene (CAS RN 95-47-6), and para-xylene (CAS RN 106-42-3) combined. The preventative action limit has been set at a concentration that is intended to address taste and odor concerns associated with this substance.*

Source: Wisconsin Department of Natural Resources.

Table 25

GROUNDWATER QUALITY STANDARDS FOR SUBSTANCES OF PUBLIC WELFARE[a]

Substance	Enforcement Standard (milligrams per liter, except as noted)	Preventive Action Limit (milligrams per liter, except as noted)[b]
Chloride	250	125
Color (color units)	15	7.5
Foaming agents (methylene-blue active substances)	0.50	0.25
Iron	0.30	0.25
Manganese	0.050	0.025
Odor (threshold odor number)	3	1.5
Sulfate	250	125
Zinc	5	2.5

[a]*As set forth in Chapter NR 140.12 of the* Wisconsin Administrative Code.

[b]*The preventive action limit is intended to inform the Wisconsin Department of Natural Resources of potential groundwater contamination problems, establish levels of contamination at which the Wisconsin Department of Natural Resources is required to commence efforts to control contamination, and provide a basis for the design of management criteria in administrative rules.*

Source: Wisconsin Department of Natural Resources.