TECHNICAL REPORT NO. 65

MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

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[1] *Prior to March 2023, Sydney Weiss, U.S. EPA, served on the Technical Advisory Committee.*
[2] *Prior to December 2024, Steve Corsi, USGS, served on the Technical Advisory Committee.*
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INTRODUCTION 1

1.1 PURPOSE OF THIS REPORT

This Report documents the development of chloride loads from various sources throughout the Southeastern Wisconsin Region (Region) and presents the results of the chloride mass balance analysis performed by Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) staff for the Chloride Impact Study (Study) for Southeastern Wisconsin.[1] As documented in SEWRPC Technical Report No. 63 (TR-63), the concentrations of chloride in surface water and groundwater in the Region have shown increases over time.[2] This Report identifies sources of chloride to the environment within the Region and larger study area including: road salt and other chloride-based compounds applied for anti-icing and deicing of public and private roads, sidewalks, and parking lots; water softeners and other domestic wastewater sources that are conveyed to public wastewater treatment facilities or private onsite wastewater treatment systems; industrial wastewater from sources such as chemical manufacturing or food processing; livestock and large agricultural feedlots; agricultural fertilizers; and the atmospheric deposition of chloride.

This Report also documents the data, methods, and assumptions used to estimate the relative contribution of chloride from various sources within the Region and within the upstream contributing drainage areas for the stream monitoring sites employed for the Study. Continuous specific conductance data and discrete chloride samples were collected at stream monitoring sites as detailed in SEWRPC Technical Report No. 61 (TR-61).[3] These data were used to estimate chloride concentrations in the monitored streams using the regression models developed in SEWRPC Technical Report No. 64 (TR-64).[4] At select stream monitoring sites with reliable streamflow data, chloride mass loads were computed. This Report also presents the chloride mass balance analysis performed for these select sites, comparing the estimated chloride source inputs to surface water with the resulting chloride loads observed at the stream monitoring sites. Additionally, relative annual contributions from various chloride sources were estimated for each stream monitoring site and for the entire Region over the study period from October 2018 through October 2020.

1.2 RELATIONSHIP OF THIS REPORT TO THE CHLORIDE STUDY

This Technical Report presents some of the findings from the Commission's Chloride Impact Study.[5] This Study was initiated due to heightened public concern over the growing use of road salt and evidence of increasing chloride concentrations in surface water and groundwater within the Region. The findings of this Study are presented in a series of reports.

Major objectives of the Chloride Impact Study include:

1. Documenting historical and existing conditions and trends in chloride concentrations in surface and groundwater in the Southeastern Wisconsin Region

2. Evaluating the potential for increased amounts of chloride in the environment to cause impacts to surface water, groundwater, and the natural and built environment in the Region

3. Identifying the major sources of chloride to the environment in the Region

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[1] *Acronyms and abbreviations used in this Report are defined in Appendix A.*

[2] *SEWRPC Technical Report No. 63,* Chloride Conditions and Trends in Southeastern Wisconsin*, in preparation.*

[3] *SEWRPC Technical Report No. 61,* Field Monitoring and Data Collection for the Chloride Impact Study, *September 2023.*

[4] *SEWRPC Technical Report No. 64,* Regression Analysis of Specific Conductance and Chloride Concentrations*, May 2024.*

[5] *SEWRPC Planning Report No. 57,* A Chloride Impact Study for Southeastern Wisconsin, *in preparation.*

4. Investigating and defining the relationship between the introduction of chloride into the environment and the chloride content of surface and groundwater

5. Developing estimates of chloride loads introduced into the environment under existing conditions and forecasts of such loads under planned land use conditions

6. Evaluating the potential effects of long-term weather patterns on the major sources of chloride under planned land use conditions

7. Reviewing the state-of-the-art of technologies and best management practices affecting chloride inputs to the environment and developing performance and cost information for such practices and technologies

8. Exploring legal and policy options for addressing chloride contributions to the environment

9. Developing and evaluating alternative chloride management scenarios for minimizing impacts to the environment from chloride use while meeting public safety objectives

10. Present recommendations for the management of chloride and mitigation of impacts of chloride on the natural and built environment

The chloride mass balance analysis presented in this Report addresses Study Objectives 3 and 5, while utilizing the results from Study Objective 4 and the monitoring data collected for the Study. By quantifying the relative chloride contribution to the environment from various sources, the results presented in this Report support the prioritization of potential chloride management opportunities for Study Objectives 7, 9, and 10.

1.3 REPORT FORMAT AND ORGANIZATION

This Report is organized into four chapters. Following this Chapter, Chapter 2 presents the background information on the study area, along with the chloride sources and input data used to estimate chloride loads and develop the chloride mass balance analysis. In addition to defining chloride sources to the environment, this Chapter includes data related to developing in-stream chloride loads at monitoring sites.

Chapter 3 describes the chloride loading and mass balance analysis methodology employed for the Chloride Impact Study. The Chapter begins with a review of the mass balance analysis approach and describes the computation of chloride loads from each significant chloride source. Chapter 3 also presents the calculation of in-stream chloride loads, which required streamflow dataset development and chloride concentrations estimated from continuous specific conductance data.

Chapter 4 presents the results of the chloride loading and mass balance analysis. This Chapter examines the overall and relative chloride contribution by source within the Region. Chapter 4 also presents the results for a similar chloride source analysis performed for each of the stream monitoring sites. The chloride mass balance results were also evaluated at individual SEWRPC stream monitoring sites with reliable streamflow data, where the in-stream chloride load was compared to the chloride source load within each upstream drainage area. In addition to summarizing the results of the chloride loading and mass balance analyses, Chapter 4 examines those results in context with environmental factors and conditions.

CHLORIDE SOURCES AND DATA FOR CHLORIDE LOADING AND MASS BALANCE ANALYSIS 2

2.1 STUDY AREA OVERVIEW

The Southeastern Wisconsin Region (Region) covers approximately 2,690 square miles across seven counties (from north to south): Washington, Ozaukee, Waukesha, Milwaukee, Walworth, Racine, and Kenosha. The Region borders Lake Michigan to the east and encompasses roughly 5 percent of the total land area of Wisconsin. These seven counties are home to approximately 2.05 million people, accounting for about 35 percent of the population of the State. The Region is an economic hub of the State, spanning heavily urbanized metropolitan areas, highly productive agricultural lands, and high-quality natural lands. The residents and businesses of the Region rely on surface water and groundwater resources to provide a reliable source of domestic, municipal, and industrial water supply. These interconnected surface water and groundwater resources are also important to the economic development, recreational activity, and aesthetic quality of the Region. In response to growing public concern regarding the environmental impacts of chloride salts, particularly to the surface water and groundwater resources of the Region, the Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) developed and conducted the Regional Chloride Impact Study (Study).

Addressing water quality issues in surface water and groundwater resources often requires assessing conditions that go beyond regional and municipal boundaries. Contributing drainage areas upstream of a waterbody can have large impacts on downstream water quality conditions, regardless of political boundaries. Therefore, the study area for the Chloride Impact Study was expanded beyond the seven counties to include the areas outside the Region that drain into it, including adjacent portions of Dodge, Fond du Lac, Jefferson, and Sheboygan Counties. The full study area for the Chloride Impact Study encompasses approximately 2,982 square miles and is shown on Map 2.1. The map highlights the 12 major watersheds that are located within the study area, including the Des Plaines River, Fox River, Kinnickinnic River, Menomonee River, Milwaukee River, Oak Creek, Pike River, Rock River, Root River, Sauk Creek, and Sheboygan River watersheds, as well as the areas draining directly to Lake Michigan. The study area covers all or portions of 11 counties, 29 cities, 75 villages, and 73 townships, as presented in SEWRPC Technical Report No. 61 (TR-61).[6]

Land Use

The type, intensity, and spatial distribution of different land uses within a watershed is critical in determining where, how, and the extent to which a particular pollutant may impact the waterways of the Region. Since 1963, the Commission has regularly conducted definitive inventories of existing land use patterns within the seven-county Region. As part of the Chloride Impact Study, Commission staff assembled a uniform land use inventory representing existing conditions for the entire study area, including out-of-Region areas.[7] Areas considered "urban" under the Commission land use inventory include areas identified as residential; commercial; industrial; transportation, communication, and utility; governmental and institutional; intensive recreational uses; and unused urban lands. Areas considered "nonurban" under the land use inventory include agricultural lands, wetlands, woodlands, surface water, extractive and landfill sites, and unused rural lands. For the purpose of this Study, 16 major land use groupings were developed consisting of ten urban groups and six nonurban groups. The existing land use data for the study area, including the total acreage and percent of the study area represented by the 16 Study land use groups, is shown in Table 2.1. While over 70 percent of the existing land use in the study area is considered to be nonurban, large areas of highly urbanized development with a high density of roads and parking lots are prevalent throughout the central and eastern portions of the study area. The geographic distribution of the existing land use in the Region is presented in TR-61 on Map 2.5.[8]

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[6] *Refer to Map 2.3 and Table B.1 for a complete list of the civil divisions within the study area as presented in SEWRPC Technical Report No. 61,* Field Monitoring and Data Collection for the Chloride Impact Study, *September 2023.*

[7] *A detailed description of the assembly and integration of existing land use inventories for the study area is provided in SEWRPC Technical Report No. 61, 2023,* op. cit.

[8] *SEWRPC Technical Report No. 61, 2023,* op. cit.

Map 2.1
Major Watersheds Within the Study Area for the Regional Chloride Impact Study

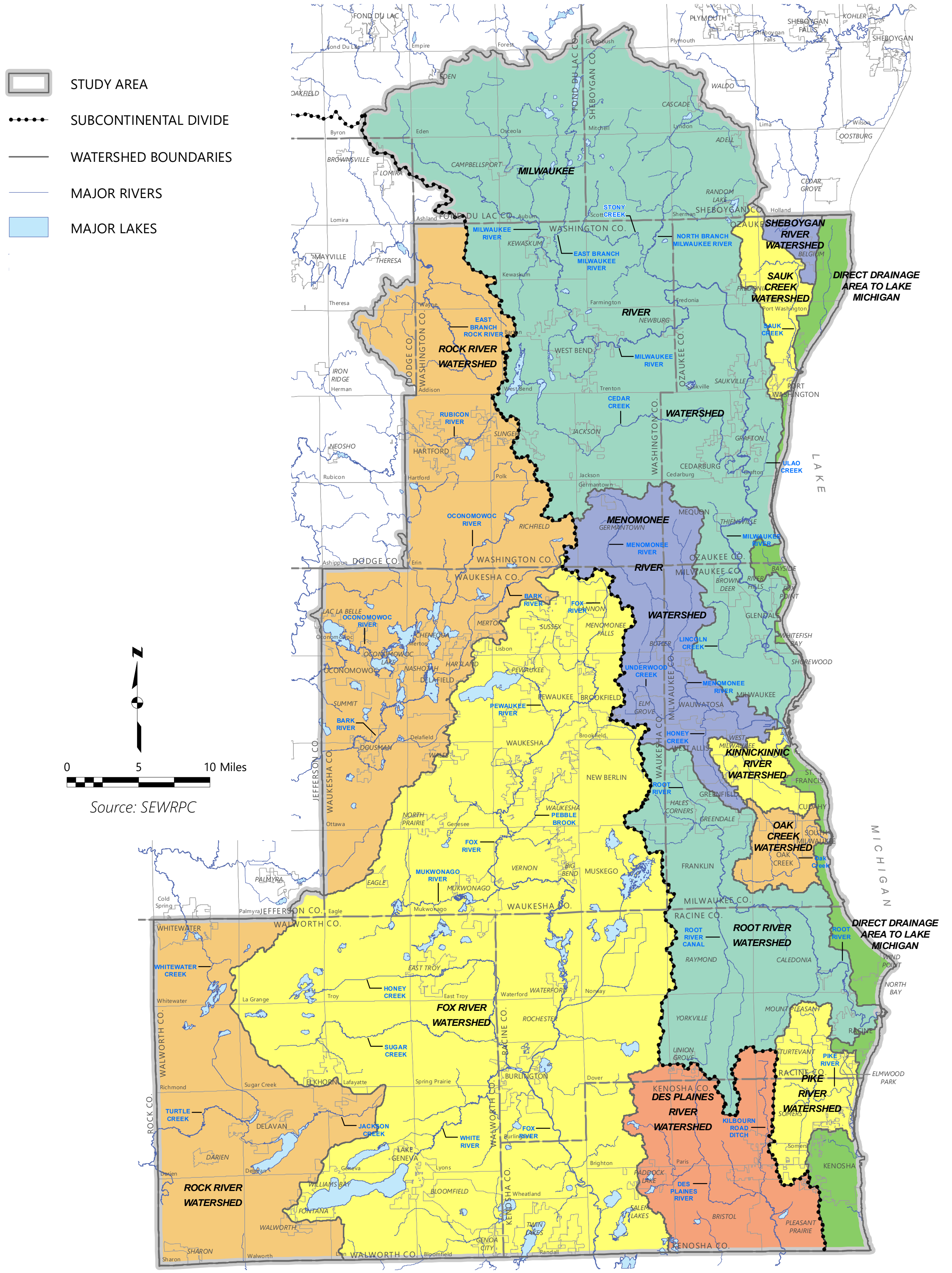


Table 2.1
Existing Land Use Within the Study Area

Land Use Group[a]	Acres	Percent of Study Area
Urban		
Lower-Density Residential	166,812	8.7
Medium-Density Residential	58,798	3.1
High-Density Residential	38,656	2.0
Commercial	11,897	0.6
Industrial	16,210	0.9
Government and Institutional	18,159	1.0
Roads and Parking Lots	153,929	8.1
Transportation, Communication, and Utilities	12,509	0.7
Recreational	35,135	1.8
Urban Unused Lands	35,104	1.8
Urban Subtotal	547,209	28.7
Nonurban		
Agricultural	784,063	41.1
Rural Unused Lands	114,237	6.0
Extractive and Landfills	12,151	0.6
Natural Lands		
Wetlands	236,918	12.4
Woodlands	157,083	8.2
Surface Water	56,451	3.0
Natural Lands Subtotal	450,452	23.6
Nonurban Subtotal	1,360,903	71.3
Total	1,908,112	--

[a] *See Table 2.3 in SEWRPC Technical Report No. 61 for the detailed land use categories that comprise each land use group.*

Source: SEWRPC

Chloride-Impaired Waterbodies

The State of Wisconsin has established two surface water quality criteria for chloride meant to protect aquatic organisms from toxic effects. Under the acute toxicity criterion, the maximum daily concentration of chloride is not to exceed 757 milligrams per liter (mg/l) more than once every three years. Under the chronic toxicity criterion, the four-day average of maximum daily chloride concentration is not to exceed 395 mg/l more than once every three years. Surface waterbodies that exceed either of these criteria are considered impaired for chloride under Section 303(d) of the Federal Clean Water Act. The Wisconsin Department of Natural Resources (WDNR) is required to submit a list of impaired waterbodies to the U.S. Environmental Protection Agency (USEPA) in even-numbered years. In 2022, 35 streams in southeastern Wisconsin were listed as impaired for chloride due to exceeding either the chronic or both the chronic and acute criteria, as listed in Table 2.2. Map 2.2 shows the locations of the chloride-impaired waterbodies in the Region. SEWRPC Technical Report No. 63 (TR-63) provides additional information related to chloride trends and conditions within the study area.[9]

Stream Monitoring Sites

Commission staff conducted water quality monitoring for the Study, collecting data at 41 stream sampling sites within the Region for the study period from October 2018 through October 2020. Map 2.3 shows the locations of the 41 stream monitoring sites installed for the Study, broken out by major watershed. Table 2.3 lists additional information for the 41 monitoring sites established for the Study. Appendix B presents maps with detailed land use and drainage area characteristics for each stream monitoring site. Several monitoring sites were located on the same stream, such that the upstream drainage areas of some monitoring sites were nested within the drainage areas of the sites located further downstream. The 15 stream monitoring sites with other Study monitoring sites nested within their drainage areas are provided in Table 2.4. Refer to TR-61 for detailed information related to the stream monitoring sites deployed for the Study, along with a description of the site selection process and data collection methods.[10]

[9] *SEWRPC Technical Report No. 63,* Chloride Conditions and Trends in Southeastern Wisconsin*, in preparation.*

[10] *SEWRPC Technical Report No. 61, 2023,* op. cit.

Table 2.2
Waterbodies Listed as Impaired Due to Chloride in Southeastern Wisconsin: 2022

Name	WBIC[a]	County	Extent (river mile)[b]	Impairment Acute Toxicity	Impairment Chronic Toxicity	Listing Date
Beaver Creek	20000	Milwaukee	0.00-2.65	--	X	2020
Brown Deer Creek	19700	Milwaukee	0.00-2.30	X	X	2018
Burnham Canal	3000042	Milwaukee	0.00-1.05	--	X	2018
Butler Ditch	18100	Waukesha	0.00-2.85	--	X	2020
Crestwood Creek	19450	Milwaukee	0.00-1.35	X	X	2020
Dousman Ditch	17100	Waukesha	0.00-2.50	X	X	2022
Fish Creek	44700	Ozaukee, Milwaukee	0.00-3.38	--	X	2018
Honey Creek	16300	Milwaukee	0.00-8.96	X	X	2018
Indian Creek	19600	Milwaukee	0.00-2.63	X	X	2018
Kilbourn Road Ditch	736900	Racine	0.0-14.3	--	X	2022
Kinnickinnic River (and Lyons Park Creek)	15100	Milwaukee	5.49-9.93	X	X	2018
Kinnickinnic River	15100	Milwaukee	3.16-5.49	X	X	2014
Kinnickinnic River	15100	Milwaukee	0.00-3.16	X	X	2022
Lilly Creek	18400	Waukesha	0.00-4.70	--	X	2016
Lincoln Creek	19400	Milwaukee	0.0-9.7	X	X	2014
Little Menomonee River	17600	Ozaukee, Milwaukee	0.0-9.0	X	X	2016
Meadowbrook Creek	772300	Waukesha	0.00-3.14	--	X	2018
Menomonee River	16000	Washington, Waukesha, Milwaukee	0.00-24.81	X	X	2018
Mitchell Field Drainage Ditch	14800	Milwaukee	0.0-2.3	X	X	2020
North Branch Oak Creek	14900	Milwaukee	0.0-5.7	X	X	2018
North Branch Pike River	1900	Racine, Kenosha	5.23-7.87	--	X	2018
Nor-X-Way Channel	18450	Ozaukee, Washington, Waukesha	0.0-4.9	--	X	2020
Noyes Creek	17700	Milwaukee	0.00-3.54	X	X	2020
Oak Creek	14500	Milwaukee	0.00-13.32	X	X	2014
Pewaukee River above Pewaukee Lake	771800	Waukesha	0.00-4.45	--	X	2020
Pike Creek	1200	Kenosha	0.00-3.69	X	X	2016
Pike River	1300	Kenosha	1.45-9.50	X	X	2016
Pike River	1300	Kenosha	0.00-1.45	--	X	2016
Root River	2900	Waukesha, Milwaukee	25.80-43.69	X	X	2014
Root River	2900	Milwaukee, Racine	5.82-20.48	--	X	2022
South 43rd Street Ditch	15900	Milwaukee	0.00-1.16	X	X	2022
Southbranch Creek	3000073	Milwaukee	0.00-2.36	X	X	2018
South Branch of Underwood Creek	16800	Waukesha, Milwaukee	0.00-1.11	X	X	2018
Ulao Creek	21200	Ozaukee	0.0-8.6	X	X	2016
Underwood Creek	16700	Waukesha, Milwaukee	0.00-8.54	X	X	2018
Unnamed Tributary to North Branch Pike River	2450	Racine	0.00-0.58	--	X	2016
Wilson Park Creek	15200	Milwaukee	0.0-3.5	X	X	2018
Zablocki Park Creek	5036633	Milwaukee	0.0-0.9	X	X	2022

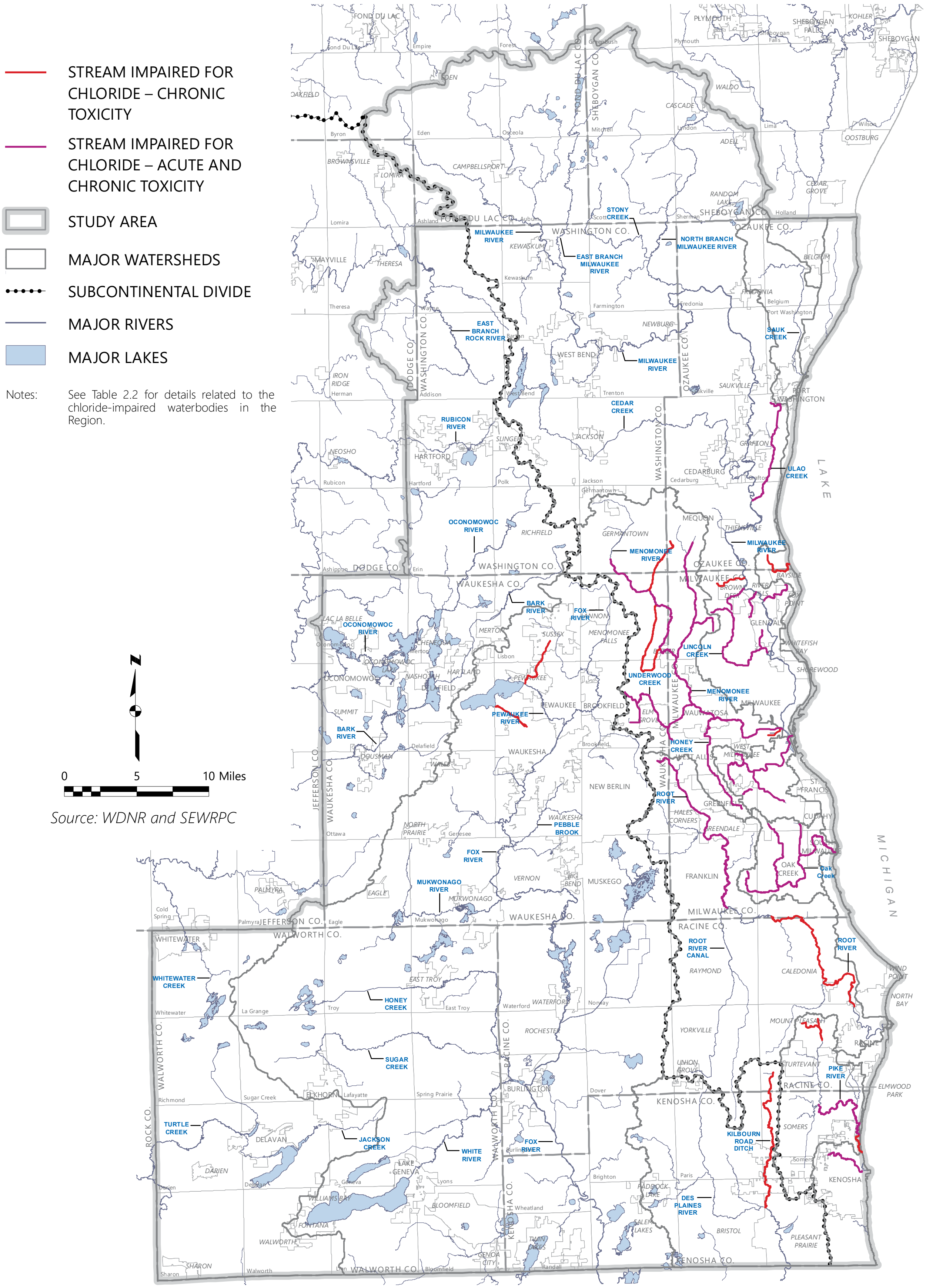
Note: See Map 2.2 for the locations of the chloride-impaired waterbodies in the Region.

[a] *The WBIC is a unique identification number for a waterbody assigned and used by the Wisconsin Department of Natural Resources.*

[b] *River mile is measured upstream from the mouth or downstream confluence.*

Source: WDNR

Map 2.2
Waterbodies Impaired for Chloride: 2022



Notes: See Table 2.2 for details related to the chloride-impaired waterbodies in the Region.

Source: WDNR and SEWRPC

Map 2.3
Stream Monitoring Sites for the Chloride Impact Study

MONITORING SITE

STUDY AREA

MAJOR WATERSHEDS

SUBCONTINENTAL DIVIDE

MAJOR RIVERS

MAJOR LAKES

Notes: See Table 2.3 for details related to the stream monitoring sites.

0 5 10 Miles

Source: SEWRPC

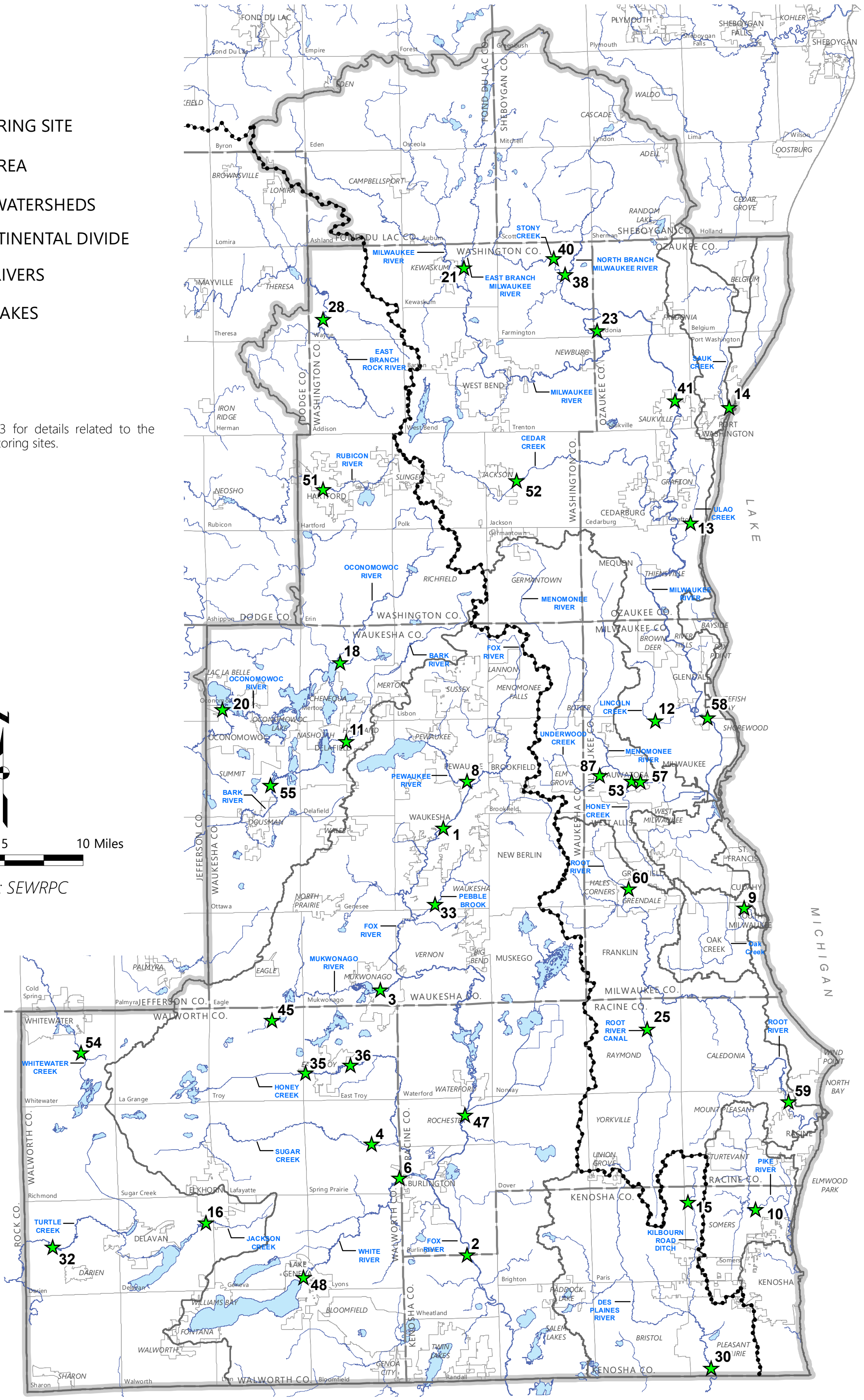


Table 2.3
Stream Monitoring Sites for the Chloride Impact Study

SEWRPC Site No.[a]	Site Name	Major Watershed	Site County	Counties Within Drainage Area[b]	Drainage Area Size (sq mi)	SWIMS Station ID	Nearest USGS Streamgage	Latitude	Longitude	Site Location
1[c]	Fox River at Waukesha	Fox River	Waukesha	Waukesha, Washington	126.3	683310	05543830	43.00501682	-88.24428955	Fox River about 100 feet downstream of Prairie Avenue near USGS Gage 05543830 at Waukesha (City of Waukesha)
2[c]	Fox River at New Munster	Fox River	Kenosha	Waukesha, Walworth, Racine, Kenosha, Jefferson, Milwaukee, Washington	807.1	523093	05545750	42.61102994	-88.22575534	Fox River about 30 feet downstream of CTH JB near USGS Gage 05545750 at New Munster (Town of Wheatland)
3[c]	Mukwonago River at Mukwonago	Fox River	Waukesha	Waukesha, Walworth, Jefferson	85.4	10032435	05544200	42.85698382	-88.32736057	Mukwonago River 35 feet downstream of STH 83 and 200 feet downstream of USGS Gage 05544200 at Mukwonago (Village of Mukwonago)
4	Sugar Creek	Fox River	Walworth	Walworth	60.5	10029083	--	42.71494642	-88.34238151	Sugar Creek about 60 feet upstream of Potter Road (Town of Spring Prairie)
6	White River near Burlington	Fox River	Walworth	Walworth, Racine, Kenosha	112.2	653104	--	42.68340253	-88.30797773	White River 40 feet downstream of CTH JS near Burlington (Town of Spring Prairie)
8	Pewaukee River	Fox River	Waukesha	Waukesha	38.1	10051685	--	43.04793066	-88.21308887	Pewaukee River at Steinhafels about 1,000 feet downstream of Busse Road (City of Pewaukee)
9[c]	Oak Creek	Oak Creek	Milwaukee	Milwaukee	25.8	413913	04087204	42.92486133	-87.86938351	Oak Creek 385 feet downstream of 15th Avenue and USGS Gage 04087204 at South Milwaukee (City of South Milwaukee)
10[c]	Pike River	Pike River	Kenosha	Kenosha, Racine	36.6	10034961	04087257	42.64700492	-87.86516338	Pike River at Petrifying Springs Park about 1,500 feet upstream of USGS Gage 04087257 (Village of Somers)
11[c]	Bark River Upstream	Rock River	Waukesha	Waukesha, Washington	35.0	683427	05426067	43.15954154	-88.36944299	Bark River about 100 feet downstream of STH 83 and about 3,950 feet upstream of USGS Gage 05426067 at Nagawicka Road (City of Delafield)
12[c]	Lincoln Creek	Milwaukee River	Milwaukee	Milwaukee	11.0	10047562	040869416	43.09927104	-87.97527082	Lincoln Creek about 400 feet downstream of 51st Blvd and about 2,500 feet upstream of USGS 040869416 Gage at Sherman Boulevard (City of Milwaukee)
13	Ulao Creek	Milwaukee River	Ozaukee	Ozaukee	9.2	10050932	--	43.28115708	-87.92473975	Ulao Creek about 40 feet downstream of CTH W (Town of Grafton)
14	Sauk Creek	Sauk Creek	Ozaukee	Ozaukee, Sheboygan	31.7	10030655	--	43.38648777	-87.87253643	Sauk Creek about 400 feet upstream of Wisconsin Street (City of Port Washington)
15	Kilbourn Road Ditch	Des Plaines River	Kenosha	Racine, Kenosha	8.5	10051686	--	42.65507120	-87.94899341	Kilbourn Road Ditch at CTH A (Village of Somers)
16[c]	Jackson Creek	Rock River	Walworth	Walworth	9.8	10051687	05431016	42.64536095	-88.55068624	Jackson Creek about 3,000 feet downstream of STH 67 and about 4,400 feet upstream of USGS Gage 05431016 at Mound Road (Town of Delavan)

Table continued on next page.

Table 2.3 (Continued)

SEWRPC Site No.[a]	Site Name	Major Watershed	Site County	Counties Within Drainage Area[b]	Drainage Area Size (sq mi)	SWIMS Station ID	Nearest USGS Streamgage	Latitude	Longitude	Site Location
18	Oconomowoc River Upstream	Rock River	Waukesha	Washington, Waukesha	41.3	683245	--	43.11796620	-88.51890233	Oconomowoc River about 325 feet upstream of STH 83 (Town of Merton)
20	Oconomowoc River Downstream	Rock River	Waukesha	Waukesha, Washington, Dodge, Jefferson	100.4	10051688	--	43.47604420	-88.38240756	Oconomowoc River near Lac La Belle Outlet about 75 feet downstream of STH 16 (City of Oconomowoc)
21	East Branch Milwaukee River	Milwaukee River	Washington	Sheboygan, Fond Du Lac, Washington	49.4	10051139	--	43.52109322	-88.20310120	East Branch Milwaukee River at STH 28 (Town of Kewaskum)
23	Milwaukee River Downstream of Newburg	Milwaukee River	Ozaukee	Fond Du Lac, Washington, Sheboygan, Ozaukee, Dodge	264.6	10051689	--	43.46025398	-88.03691368	Milwaukee River about 1,000 feet upstream of Hickory Drive (extended) and Washington/Ozaukee County line (Town of Fredonia)
25[c]	Root River Canal	Root River	Racine	Racine, Kenosha	58.8	10016596	04087233	42.81548800	-87.99495284	Root River Canal at USGS Gage 04087233 at 6 Mile Road (Village of Raymond)
28	East Branch Rock River	Rock River	Washington	Washington, Dodge	54.7	10032027	--	42.62553785	-88.74234642	East Branch Rock River about 80 feet downstream of CTH D (Town of Wayne)
30[c]	Des Plaines River	Des Plaines River	Kenosha	Kenosha, Racine	114.6	303054	05527800	42.50164176	-87.92539857	Des Plaines River at 122nd St (CTH ML) about 7,800 feet upstream of USGS Gage 05527800 at Russel Road, Illinois (Village of Pleasant Prairie)
32	Turtle Creek	Rock River	Walworth	Walworth	94.0	10051690	--	43.31952281	-88.38667623	Turtle Creek about 230 feet upstream of USH 14 (Town of Darien)
33	Pebble Brook	Fox River	Waukesha	Waukesha	16.0	10008183	--	42.93472331	-88.25683580	Pebble Brook about 300 feet upstream of CTH XX (Town of Waukesha)
35	Honey Creek Upstream of East Troy	Fox River	Walworth	Walworth	37.7	10032440	--	42.78177625	-88.42317446	Honey Creek about 800 feet downstream of Townline Road at Michael Fields Agricultural Institute (Town of East Troy)
36	Honey Creek Downstream of East Troy	Fox River	Walworth	Walworth	44.6	653244	--	42.78823546	-88.36653679	Honey Creek at Carver School Road (Town of East Troy)
38	North Branch Milwaukee River	Milwaukee River	Washington	Sheboygan, Ozaukee, Washington	105.8	10029089	--	43.51262786	-88.07534337	North Branch Milwaukee River about 25 feet downstream of CTH XX (Town of Farmington)
40	Stony Creek	Milwaukee River	Washington	Washington, Sheboygan, Fond Du Lac	17.8	673267	--	43.52741053	-88.08937392	Stony Creek at CTH X (Town of Farmington)
41	Milwaukee River near Saukville	Milwaukee River	Ozaukee	Fond Du Lac, Washington, Sheboygan, Ozaukee, Dodge	448.3	10051691	--	43.39366252	-87.94024145	Milwaukee River near Friendship Lane (extended) (Town of Saukville)
45	Mukwonago River at Nature Road	Fox River	Walworth	Walworth, Waukesha, Jefferson	24.4	10029287	--	42.83108888	-88.46375625	Mukwonago River about 150 feet downstream of Nature Road and upstream of Lulu Lake (Town of Troy)
47	Fox River at Rochester	Fox River	Racine	Waukesha, Racine, Walworth, Jefferson, Milwaukee, Washington	455.6	10032438	05544475[d]	42.74014301	-88.22477829	Fox River about 1,700 feet upstream of Rochester Dam near USGS Gage 05544475 at Rochester (Village of Rochester)

Table continued on next page.

Table 2.3 (Continued)

SEWRPC Site No.[a]	Site Name	Major Watershed	Site County	Counties Within Drainage Area[b]	Drainage Area Size (sq mi)	SWIMS Station ID	Nearest USGS Streamgage	Latitude	Longitude	Site Location
48	White River at Lake Geneva	Fox River	Walworth	Walworth	29.1	10051692	055451345	42.59328722	-88.43008313	White River about 1,430 feet downstream of Geneva Lake outlet and USGS Gage 055451345 (City of Lake Geneva)
51	Rubicon River	Rock River	Washington	Washington, Dodge	27.5	10051693	--	42.80382218	-88.70293308	Rubicon River at West Side Park about 250 feet upstream of Grant Street (City of Hartford)
52	Cedar Creek	Milwaukee River	Washington	Washington, Ozaukee	53.6	673048	--	43.32350934	-88.14256630	Cedar Creek about 150 feet upstream of STH 60 (Town of Jackson)
53[c]	Honey Creek at Wauwatosa	Menomonee River	Milwaukee	Milwaukee	10.7	10030407	04087119	43.04426929	-88.00683244	Honey Creek about 1,500 feet upstream of the confluence with the Menomonee River and about 600 feet upstream of USGS Gage 04087119 (City of Wauwatosa)
54	Whitewater Creek	Rock River	Walworth	Walworth	18.8	653291	--	43.04745799	-88.45981016	Whitewater Creek about 30 feet upstream of Millis Road (Town of Whitewater)
55	Bark River Downstream	Rock River	Waukesha	Waukesha, Washington	53.2	683424	--	43.15954154	-88.36944299	Bark River about 50 feet upstream of Genesee Lake Road (Village of Summit)
57[c]	Menomonee River at Wauwatosa	Menomonee River	Milwaukee	Milwaukee, Waukesha, Washington, Ozaukee	124.5	10012584	04087120	43.04348983	-87.99543034	Menomonee River near Jacobus Park and about 1,500 feet downstream of USGS Gage 04087120 at 70th Street (City of Wauwatosa)
58[c]	Milwaukee River at Estabrook Park	Milwaukee River	Milwaukee	Washington, Ozaukee, Fond Du Lac, Sheboygan, Milwaukee, Dodge	684.7	413640	04087000	43.10080823	-87.90949931	Milwaukee River at Estabrook Park about 2,100 feet downstream of Port Washington Road and 330 feet upstream of USGS Gage 04087000 (City of Milwaukee)
59[c]	Root River near Horlick Dam	Root River	Racine	Racine, Milwaukee, Waukesha, Kenosha	189.7	10044817	04087240	42.74522748	-87.82038887	Root River at Racine Country Club Golf Course Bridge and about 2,600 feet downstream USGS Gage 04087240 at STH 38 (Village of Mount Pleasant)
60	Root River at Grange Avenue	Root River	Milwaukee	Milwaukee, Waukesha	15.0	413716	04087214	42.94500273	-88.01399744	Root River near USGS Gage 04087214 (Village of Greendale)
87	Underwood Creek	Menomonee River	Milwaukee	Waukesha, Milwaukee	19.0	10031613	04087088	43.05008628	-88.04639671	Underwood Creek at Gravel Sholes Park about 870 feet downstream of STH 100 at USGS Gage 04087088 (City of Wauwatosa)

[a] *The SEWRPC site numbering is nonconsecutive, see Map 2.3 for the location of each stream monitoring site.*

[b] *Counties are listed in the order of largest proportion of the drainage area.*

[c] *Stream monitoring site included in the mass balance analysis.*

[d] *The USGS gage on the Fox River at Rochester only measures water level and does not measure streamflow discharge.*

Source: SEWRPC

Table 2.4
Stream Monitoring Sites with Drainage Areas Containing Additional Monitoring Sites Upstream

SEWRPC Site No.[a]	Site Name	Upstream Monitoring Sites Nested Within Drainage Area[b]
1	Fox River at Waukesha[c]	Site 8 (Pewaukee River)
2	Fox River at New Munster	Site 8 (Pewaukee River) Site 1 (Fox River at Waukesha) Site 33 (Pebble Brook) Site 45 (Mukwonago River at Nature Road) Site 3 (Mukwonago River at Mukwonago) Site 47 (Fox River at Rochester) Site 35 (Honey Creek Upstream of East Troy) Site 36 (Honey Creek Downstream of East Troy) Site 4 (Sugar Creek) Site 48 (White River at Lake Geneva) Site 6 (White River at Burlington)
3	Mukwonago River at Mukwonago[c]	Site 45 (Mukwonago River at Nature Road)
6	White River near Burlington[c]	Site 48 (White River at Lake Geneva)
20	Oconomowoc River Downstream	Site 18 (Oconomowoc River Upstream)
23	Milwaukee River Downstream of Newburg[c]	Site 21 (East Branch Milwaukee River)
30	Des Plaines River	Site 15 (Kilbourn Road Ditch)
32	Turtle Creek	Site 16 (Jackson Creek)
36	Honey Creek Downstream of East Troy[c]	Site 35 (Honey Creek Upstream of East Troy)
41	Milwaukee River near Saukville[c]	Site 21 (East Branch Milwaukee River) Site 23 (Milwaukee River Downstream of Newburg) Site 40 (Stony Creek) Site 38 (North Branch Milwaukee River)
47	Fox River at Rochester[c]	Site 8 (Pewaukee River) Site 1 (Fox River at Waukesha) Site 33 (Pebble Brook) Site 45 (Mukwonago River at Nature Road) Site 3 (Mukwonago River at Mukwonago)
55	Bark River Downstream	Site 11 (Bark River Upstream)
57	Menomonee River at Wauwatosa	Site 87 (Underwood Creek) Site 53 (Honey Creek at Wauwatosa)
58	Milwaukee River at Estabrook Park	Site 21 (East Branch Milwaukee River) Site 23 (Milwaukee River Downstream of Newburg) Site 40 (Stony Creek) Site 38 (North Branch Milwaukee River) Site 41 (Milwaukee River near Saukville) Site 52 (Cedar Creek) Site 13 (Ulao Creek) Site 12 (Lincoln Creek)
59	Root River near Horlick Dam	Site 60 (Root River at Grange Avenue) Site 25 (Root River Canal)

[a] *See Map 2.3 for the locations of the stream monitoring sites.*

[b] *The nested monitoring sites are listed in order from upstream to downstream.*

[c] *The monitoring site is also nested within the drainage area of a monitoring site located downstream.*

Source: SEWRPC

Continuous monitoring using in-stream sensors was conducted at stream monitoring sites to collect specific conductance, water temperature, and water depth over the course of the study period, including two full winter seasons. The continuous monitoring for specific conductance data was supplemented by regular surface water sample collection at the same locations to be analyzed for concentrations of chloride and some of the other constituent chemicals that comprise specific conductance. The data collected at stream monitoring sites is discussed in Section 2.3, and the evaluation of the water quality data collected during the study period is detailed in TR-63.[11]

[11] *SEWRPC Technical Report No. 63, in preparation,* op. cit.

Climate and Weather Conditions During the Study Period

Climate is a primary driver of the hydrologic cycle and can have a significant effect on chloride in the environment, as discussed in a separate technical report prepared for this Study.[12] The mid-continental location of the Southeastern Wisconsin Region gives the study area a typical continental climate, characterized primarily by a continuous progression of markedly different seasons and a large range in annual temperature. Low temperatures during winter are intensified by prevailing frigid northwesterly winds, while summer high temperatures are reinforced by the warm southwesterly winds common during that season.[13]

While the Region exhibits spatial variations in weather due primarily to its proximity to Lake Michigan, from a climate perspective the Southeastern Wisconsin Region is considered similar enough to be entirely encompassed by one of the nine climate divisions in Wisconsin. The U.S. Climate Divisional Dataset was developed by the National Oceanic and Atmospheric Administration (NOAA) to divide the contiguous United States into regional areas that have relatively uniform climate characteristics. The boundaries of Wisconsin Climate Division 9 match the seven-county Region in southeastern Wisconsin, and the climate data for Climate Division 9 were used to characterize the climatological conditions in the Region as presented in the following paragraphs.

NOAA's National Centers for Environmental Information (NCEI, formerly the National Climatic Data Center or NCDC) maintains one of the most comprehensive climate data archives in the world. The NCEI climate datasets provide the underlying data source for most of the information presented in this section. The national climate datasets for temperature and precipitation within Wisconsin Climate Division 9 extend back to 1895 and have been compiled from meteorological data collected at stations within the Region.[14] The NCEI does not provide similar long-term datasets for snowfall. Monthly snowfall data for the Region was obtained from the Wisconsin State Climatology Office, which maintains snowfall datasets for each climate division in Wisconsin from 1950 to present.[15]

U.S. Climate Normals are developed by NOAA's NCEI every 10 years and represent typical or average climatological conditions over a 30-year period. Climate normals are often used as a baseline for climate data comparisons, and departures from normal represent the difference between a specific meteorological observation and the 30-year average. The 30-year period is considered long enough to dampen the influence of short-term fluctuations and anomalies. The 1991-2020 climate normals for the Region are presented in Table 2.5 and represent the 30-year averages for temperature, precipitation, and snowfall on a monthly basis. The table also presents the 30-year average annual temperatures along with annual precipitation and snowfall totals.

Temperature

The average annual mean temperature in the Region is 47.1 degrees Fahrenheit (°F) based on the most recent climate normals (1991-2020). Throughout the year the normal average daily temperatures range from 20.7°F in January to 71.3°F in July (see Table 2.5). During the winter months, typically defined by meteorologists and climatologists as December, January, and February, the normal daily high temperatures range from 28.3°F to 33.5°F and the normal daily low temperatures range from 13.0°F to 19.2°F. Figure 2.1 presents the observed mean temperature for each month of the study period from October 2018 through October 2020 along with the monthly temperature normals representing the 30-year average monthly temperatures. For the study period, the mean monthly temperatures were near normal, with a slightly cooler than normal 2018-2019 winter season followed by a slightly warmer than normal 2019-2020 winter season. Chapter 2 of TR-63 compares temperatures during the study period with long-term temperature

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[12] *SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment, *April 2024.*

[13] *In meteorology and climatology, the seasons are defined based on the calendar with three-month durations as follows: Winter spans from December through February, Spring runs from March through May, Summer extends from June through August, and Autumn covers the period from September through November.*

[14] *NOAA National Centers for Environmental Information,* Climate Division Datasets (nClimDiv), *www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00005, accessed August 2024.*

[15] *Wisconsin State Climatology Office,* Wisconsin Climate Divisions: Divisional 12-Month Snowfall, *climatology.nelson.wisc.edu/wisconsin-climate-divisions/divisional-12-month-snowfall, accessed August 2024.*

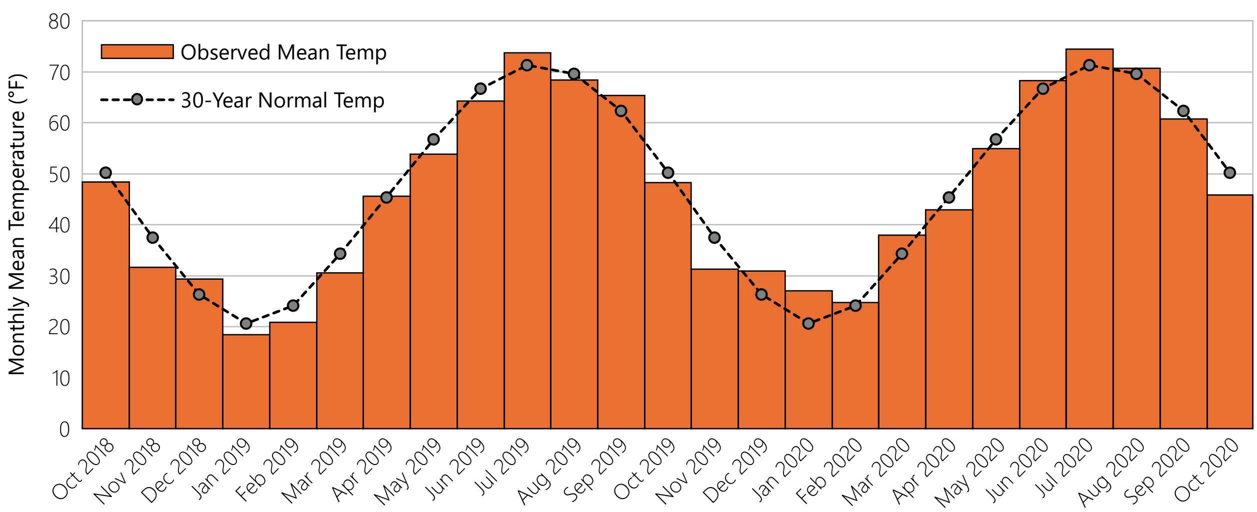
Table 2.5
30-Year Climate Normals for Southeastern Wisconsin: 1991-2020

Month	Mean Daily Temperature (°F)	Maximum Daily Temperature (°F)	Minimum Daily Temperature (°F)	Precipitation (inches)[a]	Snowfall (inches)
January	20.7	28.3	13.0	1.64	12.6
February	24.2	32.2	16.1	1.56	10.7
March	34.3	43.3	25.3	2.05	5.3
April	45.4	55.8	35.1	3.67	1.7
May	56.7	67.6	45.8	3.96	0.1
June	66.7	77.5	55.8	4.60	0.0
July	71.3	81.8	60.8	3.67	0.0
August	69.6	79.8	59.4	3.80	0.0
September	62.3	72.9	51.8	3.33	0.0
October	50.2	60.1	40.3	2.91	0.2
November	37.5	45.5	29.4	2.22	2.1
December	26.3	33.5	19.2	1.87	9.8
Annual Average/Total	47.1	56.5	37.7	35.28	42.3

[a] *Precipitation totals include the liquid water equivalent of all forms of liquid and frozen precipitation.*

Source: Wisconsin State Climatology Office and NOAA NCEI

Figure 2.1
Monthly Mean Temperatures for Southeastern Wisconsin: Study Period (October 2018-October 2020)



Source: Wisconsin State Climatology Office and NOAA NCEI

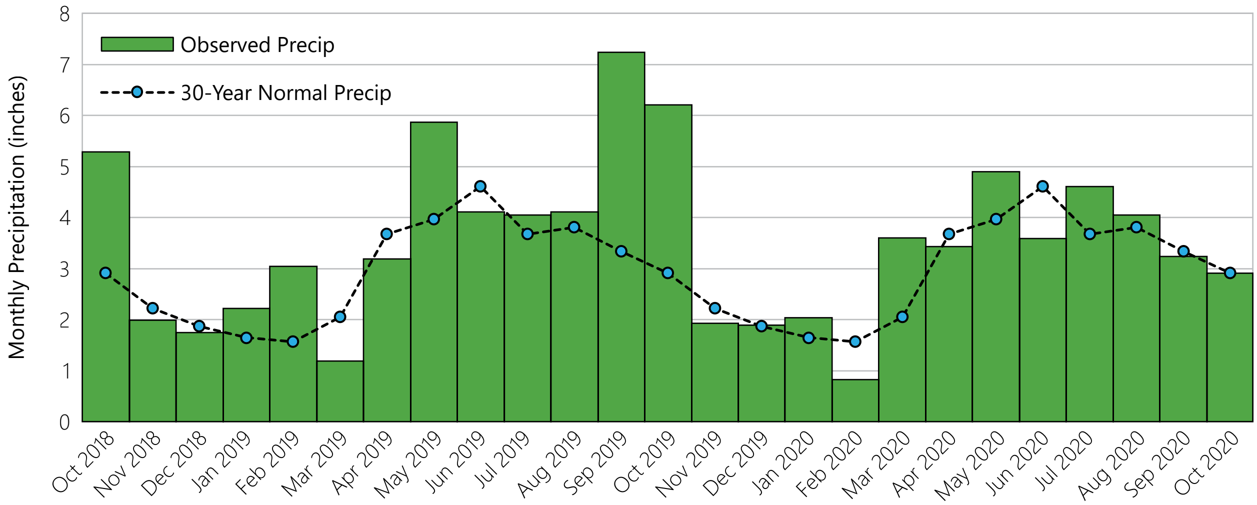
data dating back to 1895.[16] While the annual temperatures and winter temperatures during the study period were warmer than long term averages, the study period was not atypical when compared to temperatures observed since about 2000.

Precipitation

Precipitation within the Region takes the form of rain, sleet, hail, and snow. Climatological records for precipitation data represent the total depth of the liquid water equivalent for all forms of precipitation, liquid and frozen. The Region receives on average 35.3 inches of precipitation per year, and nearly three-quarters of this precipitation falls within the months of April through October. June is typically the wettest month of the year, and the driest periods occur during the winter months. Precipitation conditions varied widely over the course of the Chloride Impact Study, as shown in Figure 2.2, which compares the observed monthly precipitation totals during the study period with the monthly precipitation normals or 30-year monthly averages. Wetter than normal conditions at the beginning of the Study were punctuated by

[16] *SEWRPC Technical Report No. 63, in preparation,* op. cit.

Figure 2.2
Monthly Precipitation Totals for Southeastern Wisconsin: Study Period (October 2018 – October 2020)



Source: Wisconsin State Climatology Office and NOAA NCEI

monthly precipitation departures as large as 4 inches greater than normal and transitioned to more normal and drier than normal conditions by the end of the Study. Overall, 2018 and 2019 were much wetter than average. Based on climate division data for the period from 1895 to 2024, 2019 ranks as the wettest year ever recorded in southeastern Wisconsin and 2018 ranks as the second wettest year on record.[17]

Snowfall

Based on the 1991-2020 climate normals, the Region receives on average 42.3 inches of snow annually, with nearly 80 percent falling within the months spanning from December through February (see Table 2.5). The snowfall data is reported as the average of the actual snowfall depth measured at all available stations across the Region. Figure 2.3 presents the monthly snowfall totals for each winter season of the Chloride Study along with the normal snowfall totals. Considering the winter season snowfall totals overall, the 2018-2019 winter season snowfall totals were higher than normal, while the snowfall totals for the 2019-2020 winter season were near normal.

Relative Measures of Winter Severity

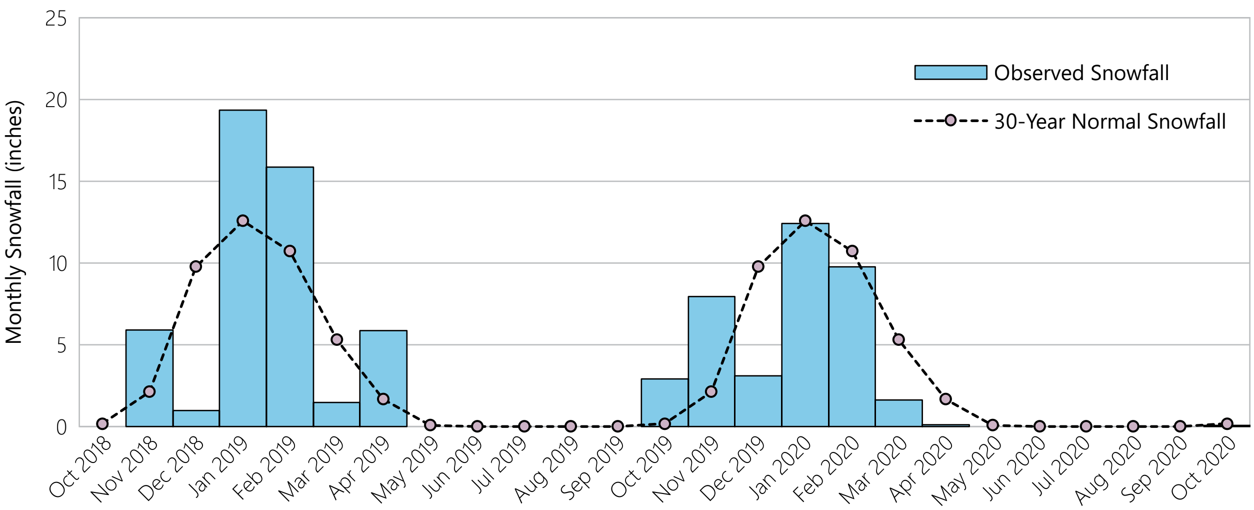
Several factors affect the amount of road salt applied to transportation networks during any given winter season. These factors include the extent of the transportation network, winter maintenance policies, public expectations, and the harshness or severity of the winter season. Weather conditions have a significant influence on the timing and quantity of salt applications and can vary widely from year to year. Across the United States, different methods and indices have been developed to represent the harshness of winter weather conditions, and the two relative measures of winter severity that were considered for the Study are described below. These measures of winter severity are intended to be used for comparing the relative severity of winter seasons to one another; hence, the absolute value is not as meaningful as a relative comparison with other winter seasons to provide historical context.

<u>WisDOT Winter Severity Index</u>

In 1995, the Wisconsin Department of Transportation (WisDOT) began developing a metric to compare severity of winter seasons. The Winter Severity Index (WSI) was developed to support winter road maintenance management using storm report data submitted by each County. This index is derived from several weather and transportation related criteria that are important to highway maintenance authorities including snow events, freezing rain events, snow amount, storm duration, and occurrence of incidents such as blowing and drifting snow, frost, and cleanup runs. The WisDOT WSI data were obtained from two sources for the

[17] *NOAA National Centers for Environmental Information,* Climate at a Glance: Divisional Rankings*, www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/divisional/rankings, accessed August 2024.*

Figure 2.3
Monthly Snowfall Totals for Southeastern Wisconsin: Study Period (October 2018 – October 2020)



Source: Wisconsin State Climatology Office and NOAA NCEI

Study. The end-of-season WSI values for the seven counties in the Southeastern Wisconsin Region from the 2001-2002 winter season through the 2022-2023 winter season were obtained from the winter storm report system end-of-season reports through the WisTransPortal system. This system is maintained by the Wisconsin Traffic Operations and Safety (TOPS) Laboratory, established at the University of Wisconsin-Madison in partnership with WisDOT.[18] Published WSI values from the 1992-1993 winter season to the 2000-2001 winter season were obtained from the Annual Winter Maintenance Report for the 2001-2002 winter season.[19] Additional information related to the WSI is available through the WisDOT Annual Winter Maintenance Reports.

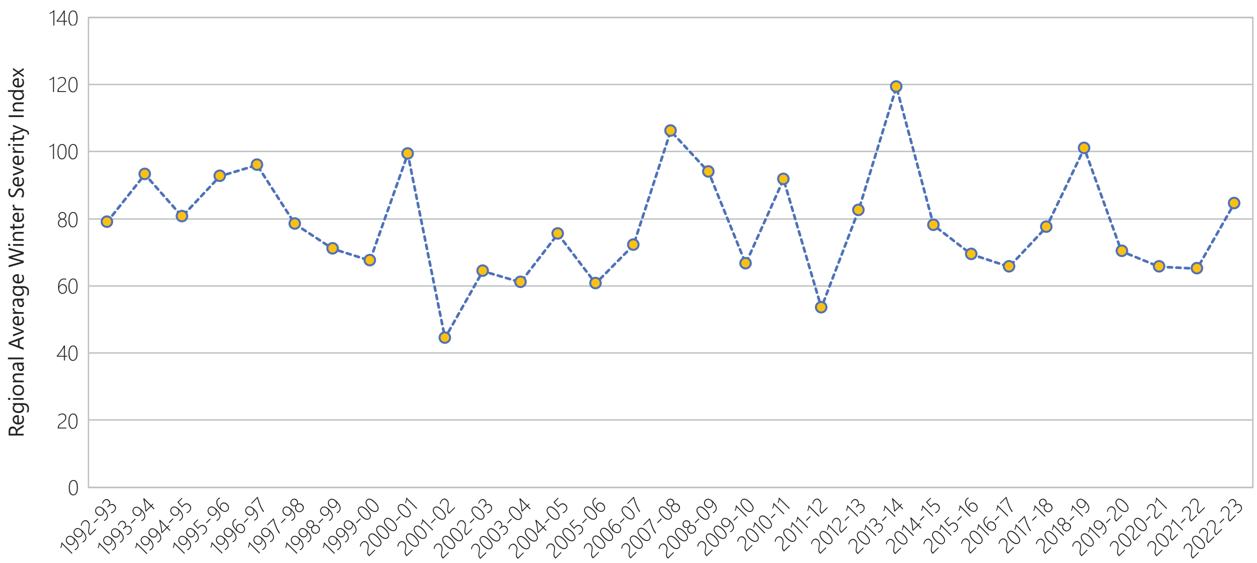
Figure 2.4 presents the average WSI for the Southeastern Wisconsin Region for the full period of record from 1992-1993 to 2022-2023. The WSI scale is unitless and the average WSI for the Region ranges from 44.4 for the 2001-2002 winter season to 119.3 for the 2013-2014 winter season. The regional average WSI was computed from the annual WSIs published for each County in the Region, with an adjustment factor applied to WSI values prior to the 2013-2014 winter season. The adjustment was necessary because the WSI equation has been modified slightly over the 30-year data record, and the baseline data used for comparison has evolved over time; however, a standard baseline for comparison was established for the 2013-2014 winter season and has been used consistently for each winter season since then.[20] The average WSI computed for the Region correlates well with the Regional snowfall data maintained by the Wisconsin State Climatology Office, as shown in Figure 2.5. The computed WSI also correlates well with historical WisDOT road salt usage in the Region. Figure 2.6 demonstrates how trends in the regional average WSI generally correspond to the quantity of road salt applied to State Highways and Interstates in the Region from the 2001-2002 winter season to 2022-2023.

[18] *University of Wisconsin-Madison Wisconsin Traffic Operations and Safety (TOPS) Laboratory,* WisTransPortal System, *www.transportal.cee.wisc.edu/storm-report, accessed July 2023.*

[19] *T.J. Martinelli,* Wisconsin Department of Transportation Annual Winter Maintenance Report: 2001-2002 Season, *July 2002.*

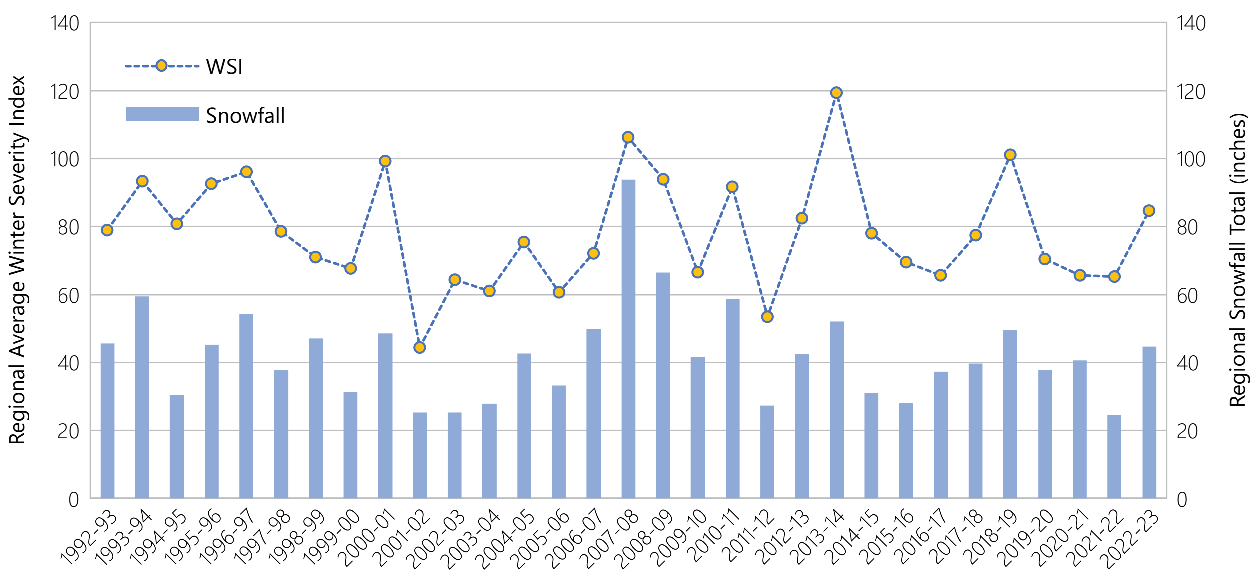
[20] *To account for the baseline data shift and to allow for relative comparisons over the entire period of the published WSI data record, an adjustment factor of 2.985 has been applied to WSI data prior to the 2013-2014 winter season based on discussions with WisDOT.*

Figure 2.4
WisDOT Winter Severity Index: Regional Average (1992-1993 to 2022-2023)



Source: WisDOT and SEWRPC

Figure 2.5
Regional Average WSI and Total Winter Season Snowfall: (1992-1993 to 2022-2023)



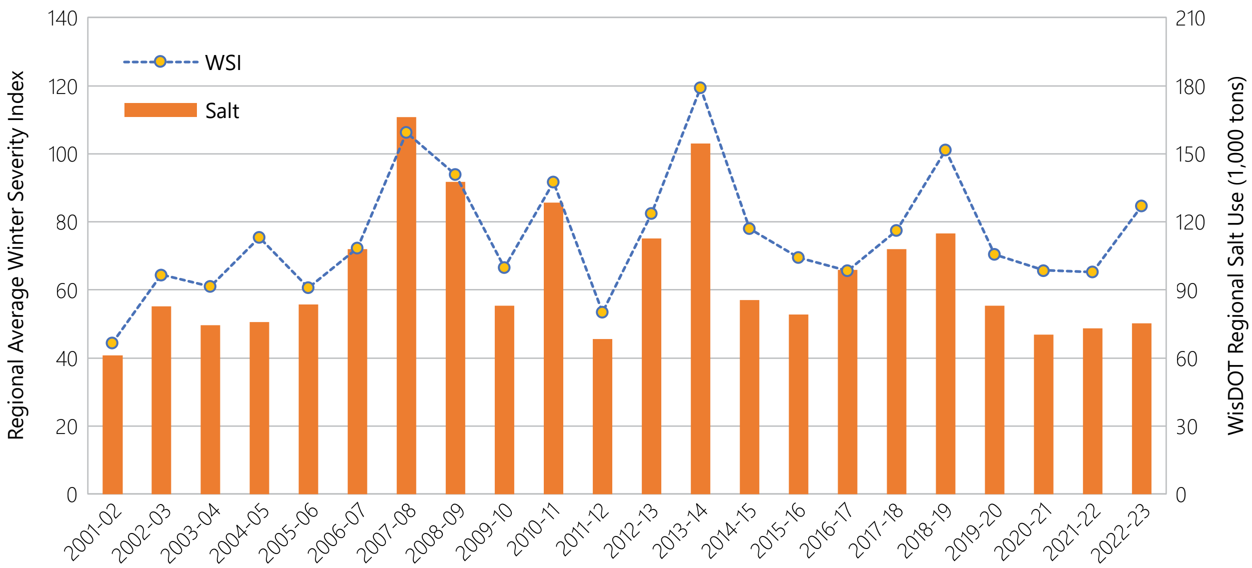
Source: Wisconsin State Climatology Office, WisDOT, and SEWPRC

MRCC Accumulated Winter Season Severity Index

The Midwestern Regional Climate Center (MRCC) at Purdue University developed the Accumulated Winter Season Severity Index (AWSSI) to describe the relative severity of winter seasons from year to year.[21] The AWSSI is an objective index computed using daily temperature, snowfall, and snow depth data collected at National Weather Service (NWS) weather stations. Additionally, the MRCC uses data collected at these stations to define the duration of each winter season in the record employing consistent, objective criteria to retrospectively establish the start and end dates each year. Milwaukee Mitchell International Airport (MMIA) is the only station in the Southeastern Wisconsin Region with AWSSI data, and the data for this

[21] *B.E. Mayes Boustead, S.D. Hilberg, M.D. Shulski, and K.G. Hubbard,* The Accumulated Winter Season Severity Index (AWSSI), *Journal of Applied Meteorology and Climatology, 54(8): 1693-1712, August 2015.*

Figure 2.6
Regional Average WSI and WisDOT Regional Road Salt Use: (2001-2002 to 2022-2023)



Source: WisDOT and SEWRPC

station were downloaded directly from the MRCC website.[22] Figure 2.7 shows the AWSSI for Milwaukee from the 1950-1951 winter season through 2022-2023. Similar to the WSI, the AWSSI scale is unitless and the values range from 337 for the 2011-2012 winter season to 1537 for the 1978-1979 winter season.

<u>Comparison of Winter Severity Indexes</u>

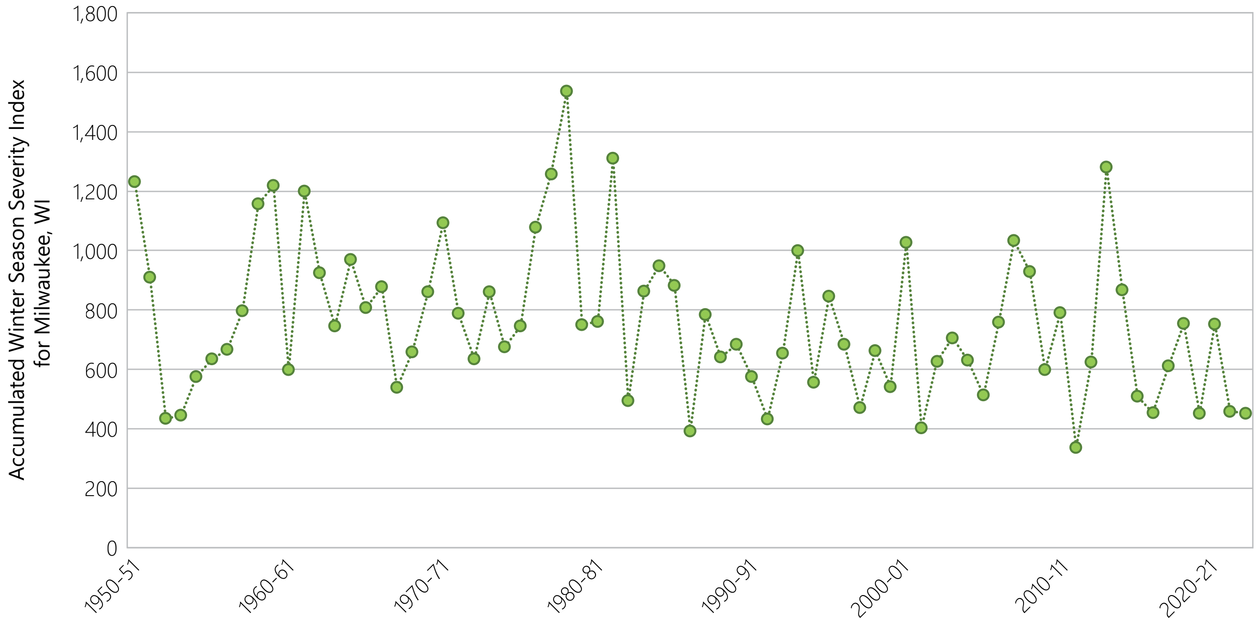
The two indices were evaluated and compared to one another for use in the Chloride Impact Study. For most purposes, the WisDOT WSI is the preferred relative measure of winter severity for the Study because it provides good coverage of the Region and is better correlated to winter road maintenance activities and road salt usage than the AWSSI. It should be noted that the AWSSI does not account for some winter weather conditions that can influence the application of road salt such as freezing rain, mixed precipitation, blowing or drifting snow, and frost. Additionally, the AWSSI considers only temperature and snowfall observed at one location in the Region. Despite these limitations, the AWSSI is an objective, data-driven metric that allows for comparisons of winter seasons from 1950 to present day.

While the WisDOT WSI was originally developed to facilitate winter road maintenance management, the index has some limitations. Changes to the WSI equation and the baseline comparison data over time may pose issues when comparing WSI values across the full 30-year data record. Additionally, the input data used to compute this index are subjective. Historically these data have been self-reported by the Counties, and the subjective nature of the data reporting may create inconsistencies between counties or from one year to another. In 2014, WisDOT started computing the WSI using data automatically collected and reported through the Maintenance Decision Support System (MDSS) instead of the storm report data submitted by the Counties. This change allowed for a more objective representation of winter weather conditions across the state while addressing some of the limitations of the earlier WSI data.

The AWSSI data trends generally compare well with WisDOT WSI trends, supporting the validity of the latter. Figure 2.8 shows the WisDOT WSI and the AWSSI from 1992-1993 to 2022-2023. While the index scales are different, the figure illustrates how the index trends generally correspond to each other. Overall, the WisDOT WSI is considered acceptable for comparing winter seasons and provides context for salt usage and chloride data over the last 30 years for the Study. Both the WSI and AWSSI indicate that the winters during the study period were fairly representative of past winters and not unusually severe when compared to the periods of record for each index.

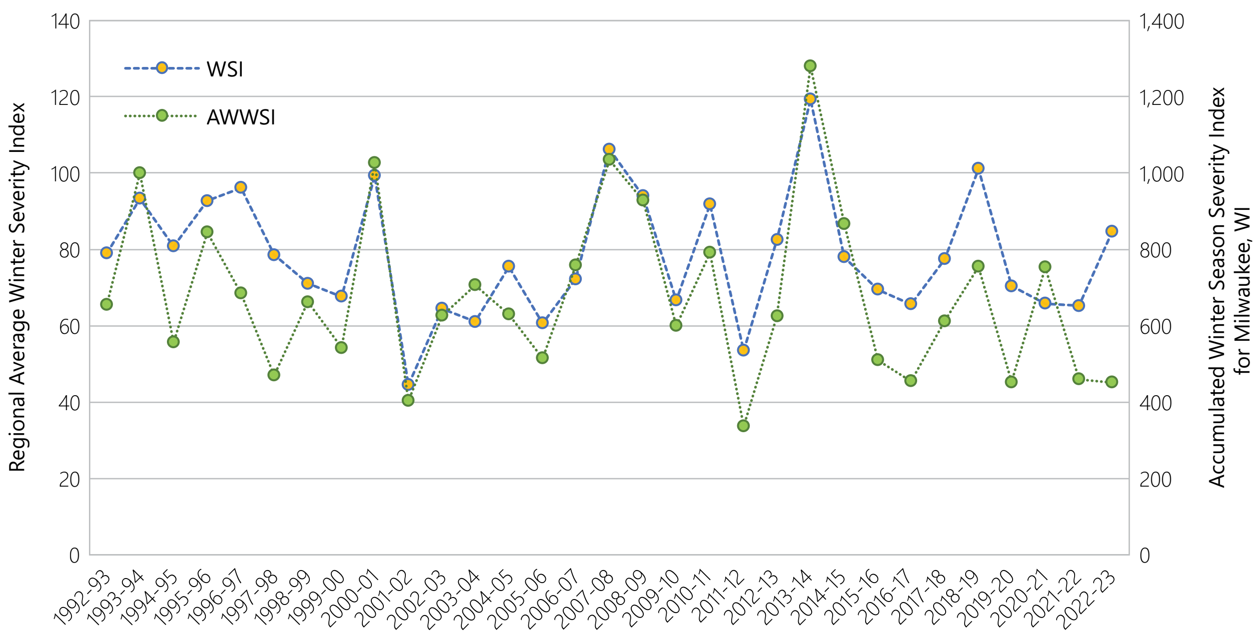
[22] *Midwestern Regional Climate Center*, Accumulated Winter Season Severity Index (AWSSI), *accessed February 2024 through www.mrcc.purdue.edu/research/awssi.*

Figure 2.7
MRCC Accumulated Winter Season Severity Index: Milwaukee (1950-1951 to 2022-2023)



Source: MRCC

Figure 2.8
Comparison of the Regional Average WSI and Milwaukee AWSSI (1992-1993 to 2022-2023)



Source: MRCC, WisDOT, and SEWRPC

2.2 CHLORIDE SOURCES AND INPUT DATA

There are many different sources of chloride in the Region. While some chloride sources occur naturally, a vast majority of chloride contributions to the environment are from anthropogenic sources. As discussed in TR-62, chloride salts are highly soluble, and chloride ions move with water through the natural environment. Also discussed in TR-62, chloride and chloride salts entering the environment can have a wide range of impacts including physical and chemical interactions with the natural environment; impacts on biological systems, infrastructure, and manmade systems; as well as positive and negative effects on human health and activities.[23] That same report presents a figure (see TR-62 Figure 2.4) showing the principal sources of chloride and detailed pathways through the environment. Chloride, a highly mobile pollutant, is transported by water through the hydrologic system of a watershed along a variety of pathways with a wide range of timescales. Figure 2.9 highlights major and minor sources of chloride in the Region and defines simplified transport pathways through the environment. A 2015 U.S. Geological Survey (USGS) report detailing methods for evaluating potential sources of chloride to the environment provided guidance along with a collection of references that were useful for the analysis.[24] The following paragraphs present the sources of chloride that were investigated for this Report and summarize the data obtained for each chloride source. Chapter 3 details the methodology and assumptions used to estimate chloride loads for many of these chloride sources.

Winter Maintenance Operations

Chemical compounds containing chloride are often used to manage snow and ice on paved surfaces such as roads, parking lots, and walkways. In general terms, salt and other deicing chemicals work by lowering the freezing point of water to prevent snow and ice from adhering to paved surfaces and to facilitate the removal of snow and ice through plowing or other mechanical removal methods. Sodium chloride (NaCl), also known as road salt, is the most common chemical used for winter maintenance and can be applied as solid rock salt or a liquid brine for use in prewetting, anti-icing, and deicing applications. The effectiveness of NaCl is reduced at temperatures below 15°F and other chemicals may be employed for deicing under these conditions, such as calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$). Alternative deicing materials are used less often in southeastern Wisconsin and may include proprietary chemical blends, organic deicers, and industrial byproducts such as cheese brine. Alternative deicers are discussed further in SEWRPC Technical Report No. 66 (TR-66), and this Report focuses primarily on chloride-based deicers such as NaCl, $CaCl_2$, and $MgCl_2$.[25]

Chloride-containing compounds used for winter road maintenance can travel through the environment via multiple pathways. Solid deicing salts applied to impervious surfaces may be subject to bouncing and scattering, spreading chloride beyond the intended target area. Deicing salts can be plowed onto adjacent roadside areas. Roadway traffic can further the spread of chloride through splash or spray onto nearby vegetation and lands. Deicing salts may dissolve in melting snow and ice and can be transported with runoff directly into surface waters. Chloride-laden runoff that flows onto pervious surfaces may infiltrate through underlying soils into groundwater. Salt residues on roadways and adjacent roadsides can be mobilized into the air through aerosolization, and these particulates can be transported by wind and settle on the ground or other surfaces.

Road salt is critical to public safety and traffic operations, providing significant benefits to the public by allowing access to roadways and vehicular travel during severe winter weather conditions or shortly thereafter. Chloride-based deicers also improve pedestrian safety by reducing the risk of injury that could result from the accumulation of snow and ice on walkways and parking lots. Public expectations and perception influence winter road maintenance practices for public road deicing, while the risk of slip and fall liability is a consideration that impacts private winter maintenance practices. These topics and other legal and policy considerations related to chloride management are discussed in SEWRPC Technical Report No. 67 (TR-67).[26]

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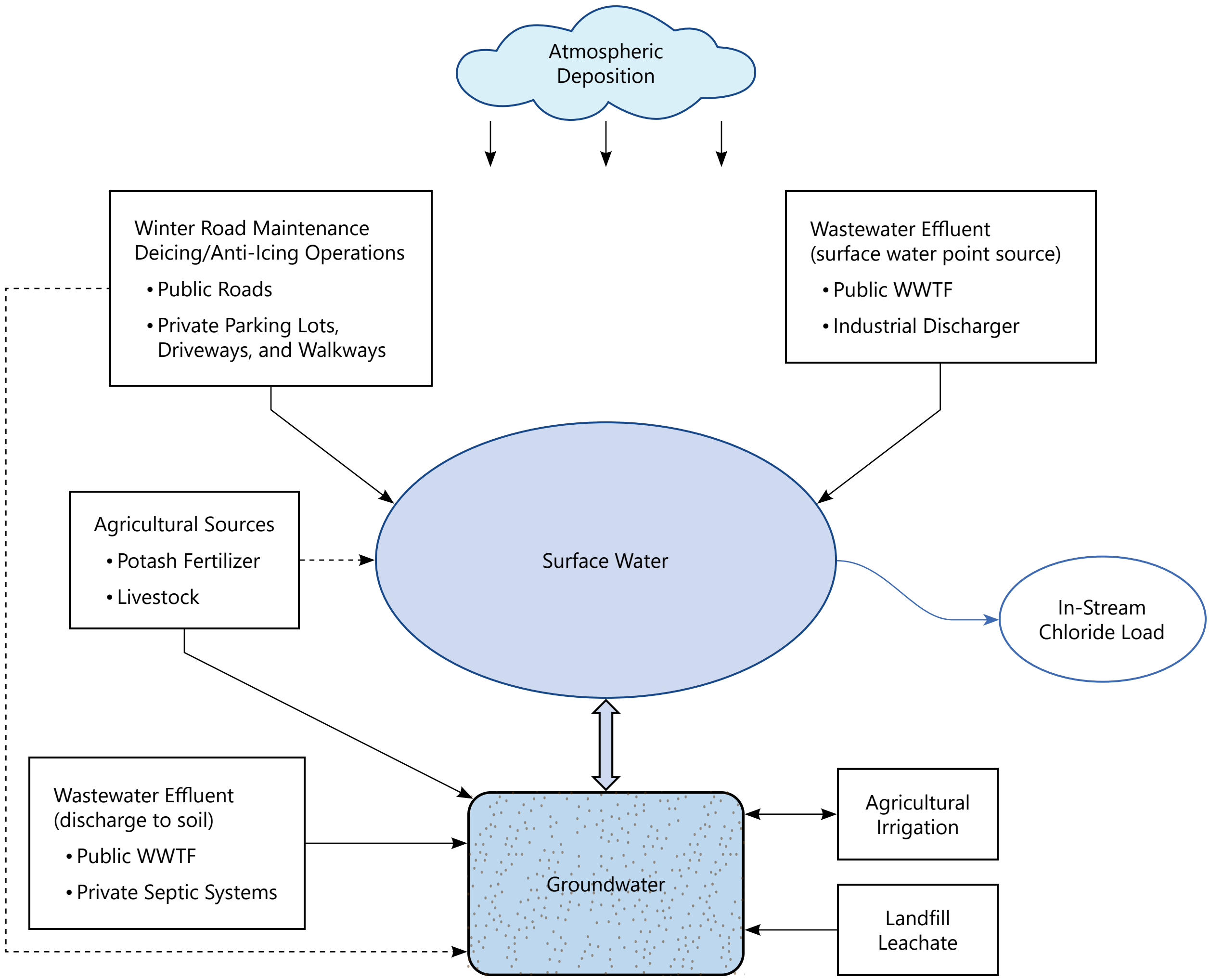
[23] *SEWRPC Technical Report No. 62, 2024,* op. cit.

[24] *G.E. Granato, L.A. DeSimone, J.R. Barbaro, and L. C. Jeznach,* Methods for Evaluating Potential Sources of Chloride in Surface Waters and Groundwaters of the Conterminous United States*, U.S. Geological Survey Open-File Report No. 2015-1080, 2015.*

[25] *SEWRPC Technical Report No. 66,* State of the Art for Chloride Management*, in preparation.*

[26] *SEWRPC Technical Report No. 67,* Legal and Policy Considerations for the Management of Chloride*, April 2024.*

Figure 2.9
Regional Chloride Sources and Simplified Transport Schematic



Note: Solid arrows define primary transport pathways and arrows with dashed lines define secondary transport pathways. For agricultural sources, the transport pathway to surface water may be considered primary for agricultural fields underlain by drain tiles.

Source: SEWRPC

Public Road Deicing and Anti-Icing

Public roadways in Wisconsin fall under various jurisdictions that designate the entities responsible for maintaining the roadways. There are three types of state and federal roadways in Wisconsin, Interstate Highways (IH), U.S. Highways (USH), and State Trunk Highways (STH). While the state and federal roadways are under WisDOT jurisdiction, winter road maintenance operations for these roadways are contracted out to the individual county highway departments. The Counties maintain separate stockpiles and accounting of deicing and anti-icing materials used on state and federal roads and regularly report winter maintenance activity data to WisDOT. Furthermore, each county highway department is responsible for maintaining the County Trunk Highway (CTH) network throughout the entire county.[27] Many of the communities within the Region are responsible for the winter maintenance of the local roads within their corporate limits. Some smaller communities may contract winter road maintenance work to another municipality, the County, or to a private entity.

[27] *In Wisconsin, County Trunk Highways are assigned a highway letter designation, whereas state and federal highways have numerical route designations.*

Winter Maintenance Material (Road Salt) Usage Data

Data for Road Salt and Deicing/Anti-Icing Materials Applied to State and Federal Roadways

Data related to the usage of various deicing and anti-icing materials used for winter maintenance on state and federal highways was obtained from WisDOT. The Counties perform winter maintenance operations on state and federal roadways and report data to WisDOT via weekly storm reports. The weekly storm reports provide information related to the dates, times and types of storms, deicing/anti-icing material usage, and snow depth, among other data relevant to winter maintenance operations. Weekly storm reports and winter season summaries for each county were obtained from the WisTransPortal database to determine the deicing/anti-icing material usage across the study area for each month within the study period.[28]

Data for Road Salt and Deicing/Anti-Icing Materials Applied to County and Local Roadways

Winter road maintenance data for county and local roadways was obtained primarily from two sources: annual reports generated to satisfy the WDNR municipal separate storm sewer system (MS4) permit requirements and data that was submitted directly to the Commission. MS4 permittees are required to implement stormwater runoff pollution reduction measures and best management practices. Communities that participate in the MS4 permit program are also required to submit an annual report to the WDNR detailing water quality-related information, including a section related to winter road maintenance operations.[29] The annual report data includes the monthly totals for road salt and other materials used for winter road maintenance activities, total lane miles maintained, and additional information related to equipment calibration and staff training. MS4 report data were available for many municipalities within the Region, along with six out of seven counties in the Region, plus two additional counties located within the greater study area.

Commission staff sent a letter requesting information on winter maintenance operations and deicing/anti-icing material usage to all communities in the Region, including communities that are not required to hold an MS4 permit and report winter maintenance data to WDNR. A small number of non-MS4 municipalities in the Region reported data separately to the Commission in response to the request letter, while a few MS4 communities provided supplemental data. Additionally, some towns in the Region contract with their County to provide winter maintenance operations. Map 2.4 shows the different sources of winter road maintenance data for county and local roadways in the study area, highlighting the communities with MS4 permits, the communities that have reported data separately to the Commission, and those that contract their winter road maintenance to the County. The winter road maintenance data that was reported separately were relatively limited and the data reported separately was combined with the MS4 data for analysis purposes.

Geospatial Data for Transportation Networks, Site Drainage Areas, and Civil Divisions

Regional transportation network data for federal, state, and county roadways within southeastern Wisconsin for the year 2020 was obtained from the transportation inventory data maintained by the Commission and presented on Map 2.5. The transportation network shapefile provided geospatial information as well as attribute data for the roadways related to the number of lanes and the lengths of roadway segments which facilitated the computation of lane miles throughout different areas of the Region.

For roadways within the portions of the study area located outside the Region, federal, state, and county highway mapping data were obtained from two sources: directly from the County by request or from GeoData@Wisconsin, an online geoportal maintained by the UW-Madison Geography Department's Robinson Map Library and the State Cartographer's Office.[30,31,32]

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[28] *University of Wisconsin-Madison Wisconsin Traffic Operations and Safety (TOPS) Laboratory, WisTransPortal System, www.transportal.cee.wisc.edu/storm-report, accessed July 2023.*

[29] *Wisconsin Department of Natural Resources,* Annual Report Under Municipal Separate Storm Sewer System (MS4) Permit, *Form 3400-224, revised 10/2018.*

[30] *Email correspondence between Dodge County staff (J. O'Neill) and Commission staff (M. Gosetti), October 5, 2020.*

[31] *Sheboygan County (2020),* Roads Sheboygan County, WI 2020, *geodata.wisc.edu/catalog/2CC6F51E-EA0E-4ABA-BA13-40B248CA631B, accessed June 2023.*

[32] *Fond du Lac County (2021),* Roads and ROW Fond du Lac County, WI 2021, *geodata.wisc.edu/catalog/0C80F62E-0F4B-44DF-8273-AAFAF669913A, accessed June 2023.*

Map 2.4
Communities Reporting Public Winter Road Maintenance Data Within the Study Area

LOCAL GOVERNMENT TYPE

CITY: WAUWATOSA

VILLAGE: *UNION GROVE*

TOWN: Addison

MS4 PERMIT REPORT DATA

DATA REPORTED SEPARATELY

MAINTAINED BY COUNTY

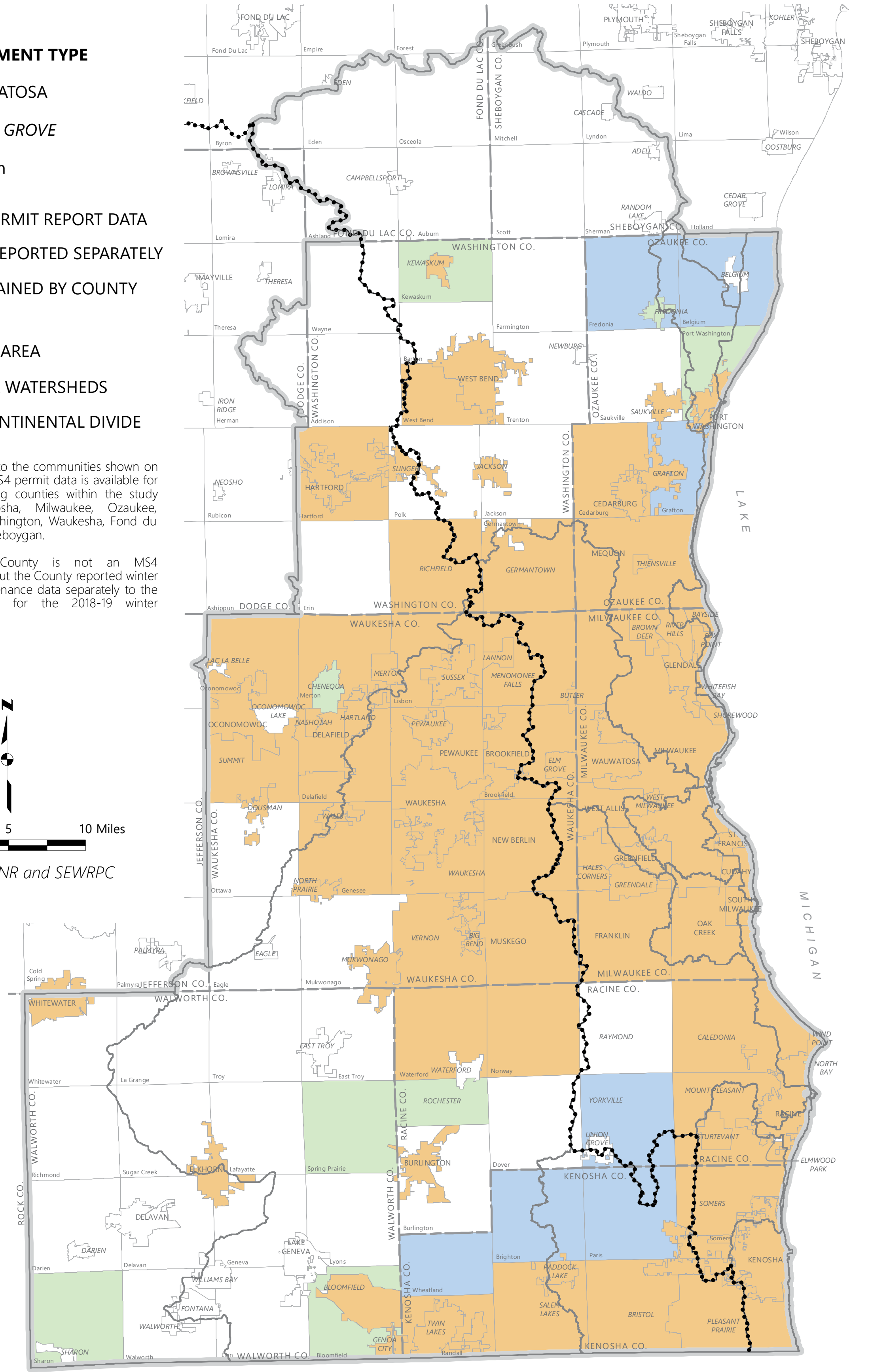
STUDY AREA

MAJOR WATERSHEDS

SUBCONTINENTAL DIVIDE

Notes: In addition to the communities shown on the map, MS4 permit data is available for the following counties within the study area: Kenosha, Milwaukee, Ozaukee, Racine, Washington, Waukesha, Fond du Lac, and Sheboygan.

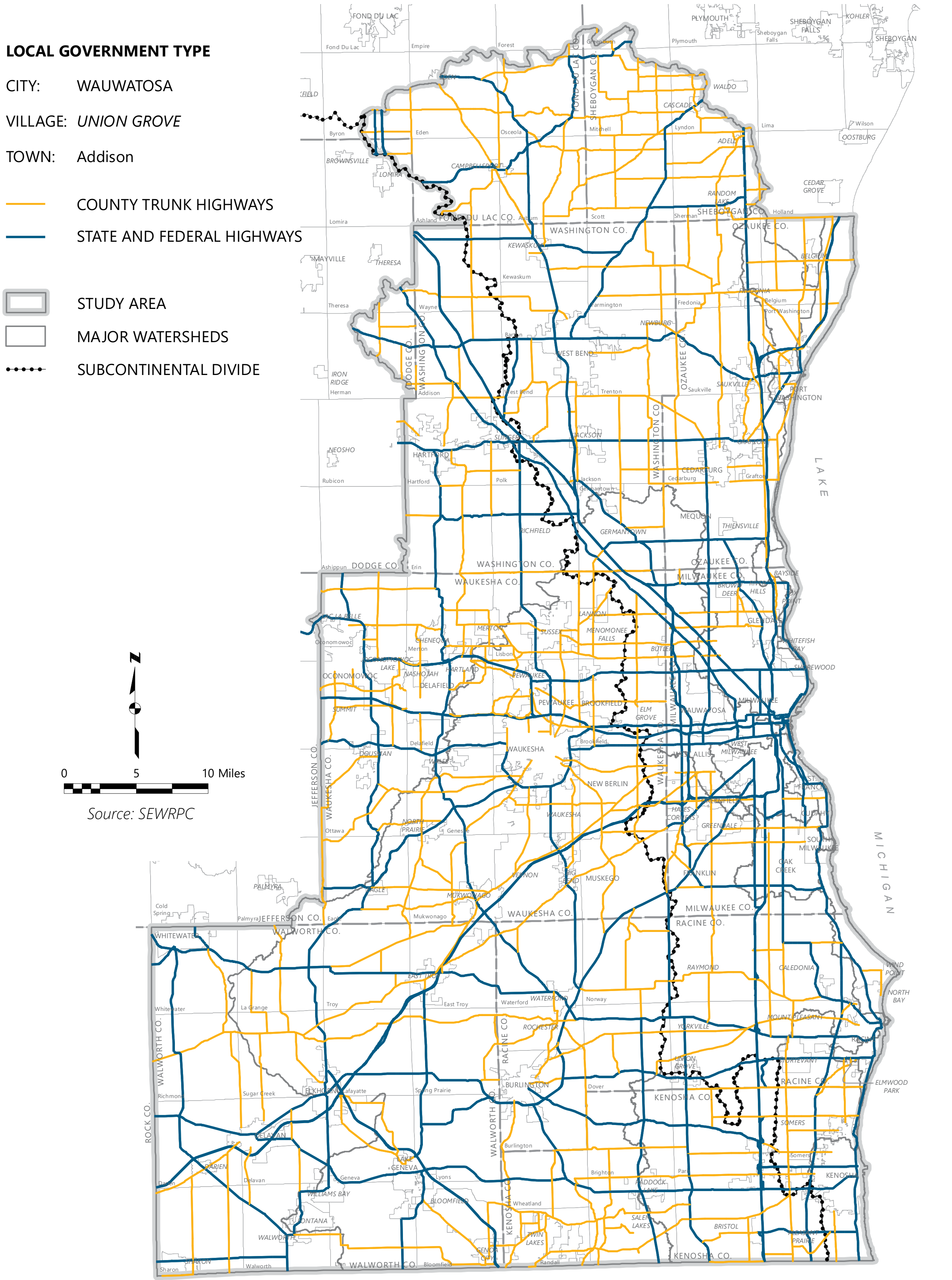
Walworth County is not an MS4 permittee, but the County reported winter road maintenance data separately to the Commission for the 2018-19 winter season.



0 5 10 Miles

Source: WDNR and SEWRPC

Map 2.5
County, State, and Federal Highways Within the Study Area: 2020



Source: SEWRPC

Additional geospatial datasets were used to geographically distribute the deicing/anti-icing material usage for analysis. For each monitoring site deployed for the Chloride Impact Study, the upstream contributing drainage area was delineated as presented in TR-61.[33] Civil division mapping defines the municipal boundaries for towns, villages, and cities throughout the Region and within the larger study area. The civil divisions within each monitoring site drainage area are shown on the individual monitoring site maps presented in Appendix B. The civil division mapping and municipal boundaries were used to geographically distribute the winter maintenance materials applied to local roadways, as discussed in Chapter 3.

Private Deicing and Anti-Icing

In addition to winter maintenance on public roadways, deicing and anti-icing materials can also be applied to sidewalks, walkways, driveways, and parking lots on private residential or commercial properties. Private owners of large commercial parking lots and walkways oftentimes utilize a private winter maintenance contractor. Residential winter maintenance may involve the application of deicing materials on private driveways and sidewalks. Previous studies have indicated that while residential salt usage is likely small, the salt applied to parking lots can be a significant source of chloride to the environment.[34,35] For the Chloride Impact Study, private salt usage was estimated for parking lots but not residential driveways and walkways.

Data for private salt usage was not readily available; however, a range of private salt application rates were compiled from previous studies through a literature review. A New Hampshire study estimated annual private salt application rates ranging from 4.8 to 6.4 tons per acre (0.22 to 0.29 pounds per square foot) per winter season.[36] A 2006 report on salt use prepared for the City of Madison included salt application data gathered from private contractors who perform winter maintenance on parking lots in the City. This study estimated that private salt applications rates for parking lots ranged from 0.14 to 0.30 tons per acre per application (6 to 14 pounds per 1,000 square feet per application), with 20 to 30 applications per winter season.[37] Wisconsin Salt Wise provided anecdotal data for parking lot salt application rates estimated by private contractors, indicating an industry standard of approximately 600 pounds per acre per application with a recommended smart salting rate of 200 pounds per acre per application.[38] Private parking lot salt application rates and related assumptions used in the analysis are presented in Chapter 3.

The SEWRPC existing land use dataset was used to identify off-street parking lot areas. The land use dataset identifies off-street parking areas with space to accommodate 10 or more vehicles, related to a wide array of land uses such as residential, commercial, transportation, and recreation. The computational methodology for estimating the chloride load resulting from winter maintenance activities for private parking lots in the Region is described in Chapter 3.

Salt Storage Areas

In Wisconsin, any public or private facility that stores more than 1,000 pounds of road salt or similar materials used for winter maintenance must be registered with WisDOT and must adhere to permitted storage practices and facility requirements.[39] Potential pathways for chlorides entering the environment from storage areas include material spillage and tracking, which leaves salt on surfaces that may be exposed to environmental elements such as precipitation. The resulting chloride-laden runoff can enter surface water or infiltrate through the soil into groundwater. Best management practices may reduce or eliminate chloride contributions to the environment from salt storage areas. Storage facilities should be on impervious surfaces and covered to protect against the elements, moisture, and contamination. Collection

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[33] *SEWRPC Technical Report No. 61, 2023,* op. cit.

[34] *K.W.F. Howard and J. Haynes, "Groundwater Contamination Due to Road-Deicing Chemicals: Salt-Balance Implication," Geoscience Canada, 20:1-8, 1993.*

[35] *Madison Wisconsin Salt Use Subcommittee,* Report of the Salt Use Subcommittee to the Commission on the Environment on Road Salt Use and Recommendations*, Madison, WI, December 11, 2006.*

[36] *D. Sassan and S. Kahl,* Salt Loading Due to Private Winter Maintenance Practices*, Beaver Brook/Policy Brook I-93 Chloride TMDL, Plymouth State University, June 30, 2007.*

[37] *Madison Wisconsin Salt Use Subcommittee 2006,* op. cit.

[38] *Email correspondence between Wisconsin Salt Wise staff (A. Madison) and Commission staff (L. Herrick), October 5, 2024.*

[39] *Wisconsin Administrative Code,* Trans 277: Highway Salt Storage Requirements*, March 2012.*

and containment systems capture runoff that has been potentially exposed to chloride and prevent it from leaving the facility. Any registered salt storage facility may not be located within 50 feet of any lake or stream. Additionally, these facilities must be located at least 250 feet from existing private wells and 1,200 feet from municipal wells. Salt storage and loading areas require regular and thorough cleaning and housekeeping practices to further safeguard against the release of chloride from these facilities. Similar practices should be applied to the cleaning, storage, and maintenance of vehicles and equipment used to transport and/or apply deicing materials. Following these best management practices would reduce or largely prevent chloride from entering the environment from salt storage facilities. When proper management, handling, and housekeeping practices are maintained, salt storage facilities would not be considered a significant source of chloride. Therefore, chloride contributions from salt storage facilities in the Region were not included in the analysis.

Wastewater

Wastewater can be described in general as either sewage or non-sewage, or it may be categorized according to the underlying anthropogenic source as domestic, industrial, or agricultural wastewater. This section addresses domestic and industrial sources of wastewater, while agricultural sources are described later in this Chapter. Throughout the Region, wastewater is generated from a variety of private and public sources including homes, commercial businesses, government institutions, agricultural operations, and industrial facilities. Wastewater from these sources typically undergo some level of treatment to improve water quality prior to being discharged into the environment. Domestic and industrial wastewater contains varying levels of chloride concentrations, and conventional treatment practices do not remove chloride from wastewater. Treated wastewater from the various sources follow different pathways into and through the environment, as discussed in TR-62 and in the following sections.[40]

Public Wastewater Treatment Facilities

Wastewater treatment facility (WWTF) effluent can be a significant point source for chloride pollution to the environment. Wastewater generated from a variety of sources is typically conveyed to public WWTFs through an underground sewer network or transported to the facility by licensed waste haulers. Following treatment at the facility, wastewater effluent is discharged to a nearby surface waterbody or to groundwater through infiltration ponds. Standard wastewater treatment technology does not remove chloride from water, so chloride present within the incoming wastewater passes through the facility and is discharged into the environment.

While public WWTFs typically do not generate chloride at the facility, there are many different sources of chloride in the wastewater received by WWTFs. The mass balance analysis considers WWTF effluent as a point source for chloride loading, however, this Study does not attempt to quantify the individual sources of chloride conveyed to each facility. WWTF effluent may contain chloride from water softening salt, domestic and sanitary waste (human excreta and household products), industrial wastewater, and wastewater from commercial operations such as laundromats, hotels, or car washes. On the water supply side, the raw water sources across the Region contain varying levels of background chloride concentrations, and additional chloride may be added to the water supply through chemicals used for disinfection or other drinking water treatment processes. Some WWTFs use a relatively small amount of chloride-containing chemical additives in their treatment process, for example ferric chloride or ferrous chloride are commonly used for phosphorus removal. Another potential source of chloride to WWTFs is road salt inflow and infiltration into the underground pipe network. For this Report all the sources of chloride that are conveyed to WWTFs were collectively represented by the total chloride in the WWTF effluent at the location where the WWTF discharges to the receiving waterbody.

The WDNR regulates wastewater treatment facilities under the Wisconsin Pollution Discharge Elimination System (WPDES), which permits these facilities to discharge municipal waste to surface water or groundwater. A majority of the permitted facilities in the Region are publicly owned municipal treatment plants. Map 2.6 shows the 49 public WWTFs within the study area that were in operation during the study period, along with the planned sanitary sewer service areas served by these treatment facilities. There are nine private facilities within the study area that serve manufactured home communities, institutional populations, or are limited to seasonal recreational usage. All public and private WWTFs within the study area are listed in Table 2.6.

[40] *SEWRPC Technical Report No. 62, 2024*, op. cit.

Map 2.6
Public Wastewater Treatment Facilities and Planned Sanitary Sewer Service Areas Within the Study Area

PUBLIC WASTEWATER TREATMENT FACILITY (DISCHARGES TO SURFACE WATER)

PUBLIC WASTEWATER TREATMENT FACILITY (DISCHARGES TO SOIL)

PLANNED SANITARY SEWER SERVICE AREA

STUDY AREA

MAJOR WATERSHEDS

SUBCONTINENTAL DIVIDE

MAJOR RIVERS

MAJOR LAKES

Notes: See Table 2.6 for details related to wastewater treatment facilities that were active during the study period.

The Delafield-Hartland WWTP discharges effluent to the Bark River at a point approximately four miles southwest of the facility.

The Whitewater WWTP serves areas within the Region but is located and discharges effluent outside of the study area.

The Belgium WWTP discharges effluent to a stream that flows out of the Region.

The Adell sanitary sewer service area sends wastewater to a WWTP outside of the study area.

0 5 10 Miles

Source: SEWRPC

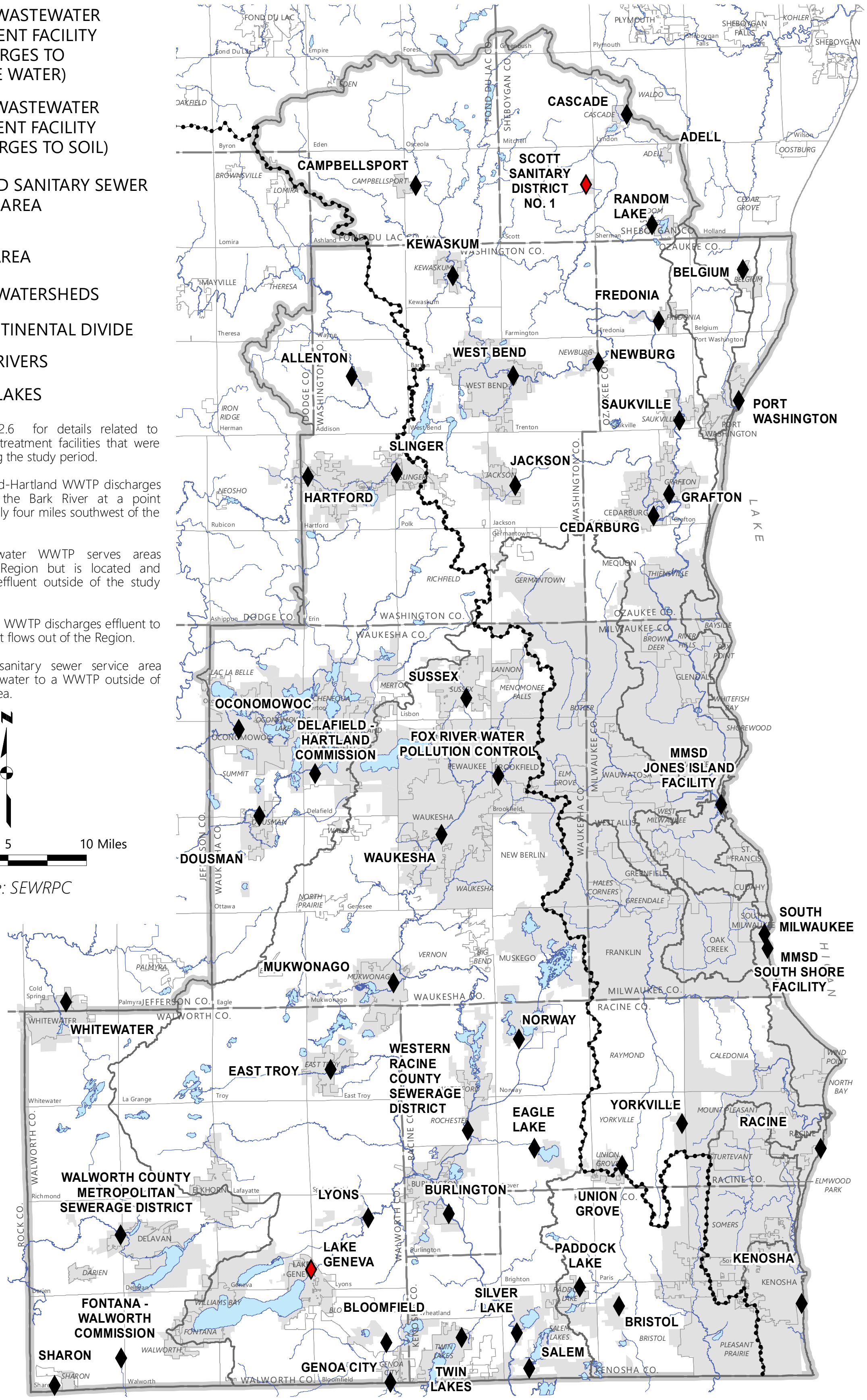

Table 2.6
Active Wastewater Treatment Facilities Within the Study Area: 2018-2020

Facility Name	Receiving Water	County	Ownership	Annual Average Design Flow (mgd)	SEWRPC Sites Downstream (site no.)
Des Plaines Watershed					
Brighton Dale Links Wastewater Treatment Plant	Unnamed wetland-marsh complex (Brighton Creek Watershed)	Kenosha	Private	0.01	30
Bristol Utility District No.1	Tributary to Des Plaines River	Kenosha	Public	0.87	30
Fonks Home Center Inc, Hickory Haven	Tributary to Des Plaines River	Kenosha	Private	0.03	30
MHC Rainbow Lake, LLC	Diffuse wetland draining to Mud Lake (Dutch Gap Canal Watershed)	Kenosha	Private	0.04	--
Paddock Lake Wastewater Treatment Facility	Tributary to Brighton Creek	Kenosha	Public	0.80	30
Direct Drainage Area Tributary to Lake Michigan					
Kenosha Wastewater Treatment Facility	Lake Michigan	Kenosha	Public	28.6	--
Milwaukee Metropolitan Sewerage District – Jones Island	Milwaukee River Outer Harbor	Milwaukee	Public	123	--
Milwaukee Metropolitan Sewerage District –South Shore	Lake Michigan	Milwaukee	Public	113	--
Port Washington Wastewater Treatment Plant	Lake Michigan	Ozaukee	Public	3.10	--
Racine Wastewater Utility	Lake Michigan	Racine	Public	36.0	--
South Milwaukee Wastewater Treatment Facility	Lake Michigan	Milwaukee	Public	6.00	--
Fox River Watershed					
Village of Bloomfield Utility Department	Tributary to East Branch Nippersink Creek	Walworth	Public	0.46	--
Burlington Water Pollution Control	Fox River	Racine	Public	3.50	2
Eagle Lake Sewer Utility District	Eagle Creek	Racine	Public	0.40	2
East Troy Wastewater Treatment Facility	Honey Creek	Walworth	Public	0.81	36, 2
Fox River Water Pollution Control Center	Fox River	Waukesha	Public	12.5	1, 47, 2
Genoa City Water Treatment Plant	North Branch Nippersink Creek	Walworth	Public	0.58	--
Grand Geneva Resort and Spa	Wetland adjacent to Como Creek	Fox River	Private	0.40	6, 2
Lake Geneva Wastewater Treatment Plant	Discharge to Soil/Groundwater	Walworth	Public	2.50	--
Lakeview Neurological Rehab Center - Midwest	Dover Ditch	Racine	Private	0.03	47, 2
Lyons Sanitary District No. 2	White River	Walworth	Public	0.21	6, 2
Mukwonago Wastewater Treatment Plant	Mukwonago River	Waukesha	Public	1.50	47, 2
Town of Norway Sanitary District No. 1 Wastewater Treatment Facility	Tributary to Wind Lake Drainage Canal	Racine	Public	1.60	47, 2
Salem Lakes – Salem Wastewater Treatment Plant[a]	Fox River	Kenosha	Public	2.13	--
Salem Lakes – Silver Lake Wastewater Treatment Plant[a]	Fox River	Kenosha	Public	0.47	--
Sussex Wastewater Treatment Facility	Spring Creek	Waukesha	Public	5.10	1, 47, 2
Twin Lakes Wastewater Treatment Facility	Tributary to Bassett Creek	Kenosha	Public	1.30	--
Waukesha Wastewater Treatment Facility[b]	Fox River	Waukesha	Public	14.0	47, 2

Table continued on next page.

Table 2.6 (Continued)

Facility Name	Receiving Water	County	Ownership	Annual Average Design Flow (mgd)	SEWRPC Sites Downstream (site no.)
	Fox River Watershed (continued)				
Western Racine County Sewerage District	Fox River	Racine	Public	2.50	2
Wheatland Estates MHC	Fox River	Kenosha	Private	0.06	--
	Milwaukee River Watershed				
Campbellsport Wastewater Treatment Facility	Milwaukee River	Fond du Lac	Public	0.47	23, 41, 58
Cascade Wastewater Treatment Facility	North Branch Milwaukee River	Sheboygan	Public	0.13	38, 41, 58
Cedarburg Wastewater Treatment Facility	Cedar Creek	Ozaukee	Public	2.75	58
Fredonia Municipal Sewer and Water Utility	Milwaukee River	Ozaukee	Public	0.60	41, 58
Grafton Water and Wastewater Utility	Milwaukee River	Ozaukee	Public	2.50	58
Jackson Wastewater Treatment Plant	Cedar Creek	Washington	Public	1.69	52, 58
Kettle Moraine Correctional Facility	Discharge to Soil/Groundwater	Sheboygan	Private	0.19	--
Kewaskum Wastewater Treatment Plant	Milwaukee River	Washington	Public	0.75	23, 41, 58
Long Lake Recreation Area Wastewater Treatment Facility	Discharge to Soil/Groundwater	Fond du Lac	Private	0.02	--
Village of Newburg Sanitary Sewer Treatment Facility	Milwaukee River	Washington	Public	0.12	23, 41, 58
Random Lake Sewage Treatment Plant	Silver Creek	Sheboygan	Public	0.45	38, 41, 58
Saukville Sewer Utility	Milwaukee River	Ozaukee	Public	1.61	58
Town of Scott Sanitary District No.1	Discharge to Soil/Groundwater	Sheboygan	Public	0.03	--
City of West Bend Sewage Treatment Facility	Milwaukee River	Washington	Public	9.00	23, 41, 58
	Rock River Watershed				
Allenton Sanitary District Wastewater Treatment Plant	East Branch Rock River	Washington	Public	0.35	28
Delafield – Hartland Water Pollution Control Commission	Bark River[c]	Waukesha	Public	3.23	--
Dousman Wastewater Treatment Facility	Bark River	Waukesha	Public	0.57	--
Fontana – Walworth Water Pollution Control Commission	Picasaw Creek	Walworth	Public	1.77	--
Hartford Water Pollution Control Facility	Rubicon River	Washington	Public	3.60	--
Oconomowoc Wastewater Treatment Plant	Oconomowoc River	Waukesha	Public	4.02	--
Sharon Wastewater Treatment Facility	Little Turtle Creek	Walworth	Public	0.26	--
Slinger Wastewater Treatment Facility	Tributary to the Rubicon River	Washington	Public	1.50	51
Walworth County Metropolitan Sewerage District	Turtle Creek	Walworth	Public	7.00	32
Whitewater Wastewater Treatment Facility	Whitewater Creek[d]	Walworth	Public	3.65	--
	Root River Watershed				
Fonks Home Center Inc, Harvest View Estates	East Branch Root River Canal	Racine	Private	0.10	25, 59
Union Grove Wastewater Treatment Plant	West Branch Root River Canal	Racine	Public	2.00	25, 59
Yorkville Sewer Utility District No. 1	Ives Grove Ditch (to Hoods Creek)	Racine	Public	0.15	59
	Sheboygan River Watershed				
Belgium Wastewater Treatment Facility	Belgian-Holland Ditch[d]	Ozaukee	Public	0.63	--

Table continued on next page.

Table 2.6 (Continued)

Note: See Map 2.6 for the locations of the public wastewater treatment facilities.

[a] *The Town of Salem and Village of Silver Lake merged to create the Village of Salem Lakes in 2017. There were two wastewater treatment facilities that originally served the two separate municipalities. In 2021 a project was completed that converted the Silver Lake Wastewater Treatment Plant to a lift station that now pumps wastewater to a sanitary sewer where it then flows by gravity to the Salem Wastewater Treatment Plant for treatment. The latter plant was expanded and currently operates as the only wastewater treatment facility for the Village of Salem Lakes.*

[b] *Following the transition of the water supply from groundwater to Lake Michigan in October 2023, effluent from the City of Waukesha facility is primarily discharged to the Root River in Milwaukee County in Franklin to satisfy the Great Lakes Basin return flow requirements. The Fox River outfall was the only discharge location during the study period and remains in operation as a secondary outfall after October 2023.*

[c] *Effluent from the Delafield-Hartland Water Pollution Control Commission treatment facility is pumped via force main and discharged into the Bark River at a point approximately four miles southwest of the facility.*

[d] *Flows out of the Southeastern Wisconsin Region.*

Source: WDNR and SEWRPC

The WDNR provided chloride sample and flow data for all WWTFs in the study area.[41] Public treatment facilities monitor and report daily flow data according to their individual permitting requirements. Many facilities report daily effluent flow data, while other facilities report only daily influent flow data. Some facilities are not required to monitor chloride if the effluent chloride concentrations are demonstrably below acceptable limits in the receiving waterbody. For WWTFs that are required to monitor chloride, the frequency of chloride sampling varies by facility, ranging from quarterly sampling to daily sampling. The flow data and chloride sample datasets were used to estimate the average monthly chloride load from WWTF effluent, as detailed in Chapter 3.

Additional waste generated from WWTF processes includes biosolids or sludge. These types of waste are typically stored onsite until the waste can be processed or hauled for disposal at a permitted facility. The waste may be land applied at permitted locations during specific times of the year, landfilled, or processed into commercial fertilizer products. Fields used for land spreading are rotated regularly and may receive sludge every three to five years based on discussions with WNDR.[42] WDNR permit requirements limit the total amount of land-applied chloride to 340 pounds per acre over a two year period. While biosolids and sludge generated at WWTFs were recognized as another source of chloride to the environment, the chloride load from these sources was not estimated for the analysis. This was due to a lack of chloride data and limited geospatial data for land spreading locations.

Private Onsite Wastewater Treatment Systems

Private onsite wastewater treatment systems collect domestic wastewater from households that are not connected to a public sanitary sewer system. Onsite wastewater treatment systems are typically used in rural areas, at households located outside of municipal sanitary sewer service areas. The domestic wastewater that is collected by onsite wastewater treatment systems is generated from typical household activities such as cooking, cleaning, bathing, laundry, sanitary-related, and dishwashing. Domestic wastewater contains chloride from various sources including water softening salt, household consumer products, and human excreta. Onsite wastewater treatment systems may be categorized based on their wastewater treatment and disposal methods into two general types, septic systems and holding tanks.

Septic systems collect wastewater in a septic tank, which allows solids to settle out before discharging effluent to a subsurface drain field where it infiltrates through the soil for further treatment and disposal. Depending on site conditions, septic systems may be designed as conventional gravity-fed systems or as mound systems which are built above-grade in places where groundwater is high or bedrock is shallow. Holding tanks may be installed where space is limited for a drain field or as a replacement for a failed septic system. Onsite wastewater treatment systems with holding tanks provide temporary storage of wastewater. Holding tanks are typically pumped several times per year and wastewater is transported by a permitted waste hauler. The waste may be transported to a permitted treatment facility, typically a public WWTF, or land spread.[43] Within the Region, holding tanks are not permitted for new residential construction and generally they are only allowed when there are no other feasible alternatives. Septic systems are recognized as a source of chloride to the environment with a potential to have an impact on water quality. The chloride load from septic systems was estimated for the Regional chloride budget; however, this source of chloride was not included in the individual site mass balance analyses, as discussed in Chapter 3.

The following data sources were used to determine the quantity and distribution of private onsite wastewater treatment systems throughout the Region. The SEWRPC Planning Report No. 55, *VISION 2050: A Regional Land Use and Transportation Plan for Southeastern Wisconsin* summarized the 2010 existing sewered and unsewered populations and households in the Region on a quarter-section scale based on 2010 census data.[44] The relatively coarse quarter-section scale allowed for an approximate geospatial distribution of 2010 population and household data and quantified how many were served by a public sanitary sewer system versus those that

[41] *Email correspondence between WDNR staff (B. Hartsook) and Commission staff (K. Hollister), March 24, 2021.*

[42] *Online meeting between WDNR staff (B. Hartsook and S. Warrner) and Commission staff (L. Herrick, J. Boxhorn, and K. Hollister), June 9, 2022.*

[43] *In southeastern Wisconsin an estimated 60 to 70 percent of septage waste is transported to a public WWTF for treatment and disposal, per discussion during an online meeting between WDNR staff and Commission staff June 9, 2020,* op. cit.

[44] *SEWRPC Planning Report No. 55,* VISION 2050, Volume III: Recommended Regional Land Use and Transportation Plan for Southeastern Wisconsin, Appendix O*, 2nd Edition, June 2020.*

utilize an onsite wastewater system. The quarter-section data were geographically assigned to watersheds and subwatersheds and combined as needed to estimate the sewered and unsewered population and households for individual monitoring site drainage areas and the major watersheds in the Study. For areas outside of the Region but within the study area, the population and households were determined using census block data from the 2010 census; households located within the corporate limits of a village were assumed to be served by the public sanitary sewer system and the other households were assumed to be unsewered.

Since conventional treatment and onsite wastewater treatment systems do not remove chloride from wastewater, the total chloride in domestic wastewater that enters an onsite wastewater treatment system will pass through the system and be discharged into the environment. Several studies have provided a wide range of estimates for the concentration of chloride in the wastewater discharged from private septic systems.[45] Chloride samples collected from septic system effluent for an Illinois study indicated concentrations ranging from 21 to 5,260 mg/l, with a mean chloride concentration of 334 mg/l and a median concentration of 91 mg/l.[46]

The following data were used to estimate the potential chloride loading from different domestic chloride sources to onsite wastewater treatment systems. As mentioned in TR-62, one study estimated that human excretion contributed approximately 9,000 milligrams (mg) of chloride per person per day, with consumer household products contributing an additional 25,000 mg per person per day.[47] Water softener salt usage can be highly variable and is dependent on several factors including the source water hardness, the household water usage, along with the water softener type, age, and efficiency. Wisconsin Salt Wise recommends servicing or replacing residential water softeners that use more than one 40 pound bag of salt per month.[48] The upper limit of water softener salt usage considered for the Study was 480 pounds of salt per household per year, corresponding to one 40 pound bag of water softener salt per month. The assumptions used to estimate residential water softener salt usage and the methodology used evaluate the potential contribution of chloride from private septic systems serving the unsewered households and population in the Region are discussed further in Chapter 3.

Industrial Wastewater Dischargers

Southeastern Wisconsin is home to a wide array of industries and water is a foundational component for many different industrial processes. Industrial facilities that are permitted to discharge wastewater to surface water and groundwater may contribute chloride in the environment. Chloride and chloride salt brines are used in a variety of industrial operations and manufacturing processes. Chloride can be an industrial product ingredient, as is common in food processing operations such as meat packing, vegetable canning, and dairy processing. Chloride can also be an industrial waste by-product, commonly resulting from chemical manufacturing as well as metal smelting and refining processes. Additionally, some industrial processes require conditioning of the raw supply water to improve water quality prior to use and wastewater streams from water softening systems can also contain high levels of chloride. Some of the industrial facilities included in this analysis were chemical manufacturers, water/wastewater equipment manufacturers, metal forges, and food processing facilities such as meat processing plants, vegetable canning, and dairy operations.

Industrial facilities that discharge wastewater to surface water and groundwater in the State are regulated by the WDNR under the WPDES program. Industrial facilities that are permitted to discharge wastewater are subject to the water quality monitoring requirements set forth in their individual facility permit. Some industrial facilities are required to monitor chloride in wastewater effluent, while other facilities with high chloride concentrations in their effluent send wastewater to municipal wastewater treatment facilities. The industrial permittees located within the study area that were required to monitor chloride during the 25-month study period were included in the analysis. The list of facilities was developed in conjunction with WDNR staff and there were 12 industrial facilities that met these criteria, including facilities operating within

[45] *Granato et al. 2015,* op. cit.

[46] *S.V. Panno, K.C. Hackley, H.H. Hwang, S.E. Greenberg, I.G. Krapac, S. Landberger, and D.J. O'Kelly, "Characterization and Identification of NaCl Sources in Ground Water," Ground Water, 44(2): 176–187, 2006.*

[47] *V.R. Kelly, G.M. Lovett, K.C. Weathers, S.E.G. Findlay, D.L. Strayer, D.J. Burns, and G.E. Likens, "Long-Term Sodium Chloride Retention in a Rural Watershed—Legacy Effects of Road Salt on Streamwater Concentration," Environmental Science & Technology, 42:410-415, 2008.*

[48] *Wisconsin Salt Wise, Water Softeners, wisaltwise.com/Take-Action/Home-Water-Softeners, accessed December 2024.*

the food processing, chemical manufacturing, and metal manufacturing industries. Table 2.7 presents a list of the facilities within the study area that were considered in the analysis. These facilities are identified by the type of industry served and are shown on Map 2.7. The WDNR provided effluent water quality data for each of the 12 facilities.[49] The WDNR data included effluent chloride concentrations and flow rates, which were used to estimate the monthly chloride mass load for each industrial facility that discharged to surface waters within the study area. Details related to the chloride load computations for permitted industrial wastewater dischargers are presented in Chapter 3.

Agricultural Sources of Chloride

Wisconsin has a rich agricultural history, earning the nickname "America's Dairyland" in 1940 when the Wisconsin Legislature adopted the slogan for use on state license plates.[50] While agriculture has played a significant role in Wisconsin's economy, it has a smaller footprint in southeastern Wisconsin compared to other parts of the state. Nonetheless, chloride can be released into the environment through various agricultural products and practices used in the Region, including synthetic fertilizers, livestock feed, manure, and irrigation water.

The primary environmental pathway for agricultural chlorides is through soils, as discussed in TR-62, and chloride can travel through subsurface soils into surface water or groundwater.[51] It should be noted that subsurface drain tile networks have been installed under some of the agricultural fields in the Region to promote the drainage of soils. Runoff collected by drain tiles typically discharges directly to surface water ditches or streams. Agricultural fields with underlying drain tiles transport more water to surface water resources at much faster rates than those without drain tiles. Drain tiles divert water that would naturally percolate through the soil into the groundwater.

The primary agricultural sources of chloride to the environment within the Region and wider study area are summarized in the following sections.

Agricultural Fertilizer

While chloride deficiency is effectively non-existent in Wisconsin soils underlying agricultural fields, chloride is commonly combined with potassium and applied to Wisconsin cropland as "potash" fertilizer. Potash is a catch-all term describing a range of potassium-containing fertilizers including potassium chloride (KCl) which is also called muriate of potash, potassium sulfate (K_2SO_4), potassium-magnesium sulfate (K_2SO_4-$MgSO_4$), potassium thiosulfate ($K_2S_2O_3$), and potassium nitrate (KNO_3). Of these potash forms, KCl is the most commonly applied fertilizer since it is the most economical to produce, the least costly to purchase, and has the highest concentration of potassium within the compound. Several references estimate that about 95 percent of potash used in the United States is applied as muriate of potash, or KCl.[52,53] Potash fertilizer usage is typically reported as an equivalent mass of K_2O, which can be converted to chloride using stoichiometry as discussed in Chapter 3.

Potash fertilizer applications primarily add potassium and chloride to the soil to satisfy plant nutrient requirements in areas where the native soil potassium levels are low. Nutrient requirements vary by crop and higher levels of potassium are generally required for fruiting and flowering plants, as well as potatoes.[54] Potassium is a macronutrient for plants, while chloride is a micronutrient. Therefore, when applied together as KCl much more of the potassium is utilized by the plant than the chloride, leaving excess chloride ions in the soil. KCl readily dissolves in water, and the potassium ions are either taken up by the plant or remain bound to soil particles, while the excess chloride ions move with water through the environment. The general sources of data used to estimate the chloride load from potash fertilizer are presented below, while analysis details and assumptions are addressed in Chapter 3.

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[49] *Email correspondence between WDNR staff (B. Hartsook) and Commission staff (K. Hollister), February 26, 2024.*

[50] *Wisconsin State Historical Society, wisconsinhistory.org/Records/Article/CS2908, accessed May 2025.*

[51] *SEWRPC Technical Report No. 62, 2024,* op. cit*.*

[52] *D.L. Armstrong, and K.P. Griffin, "Production and Use of Potassium,"* Better Crops with Plant Food*, 82(3):6-8, 1998.*

[53] *S.M. Jasinski, D.A. Kramer, J.A. Ober, and J.P. Searls,* Fertilizers—Sustaining Global Food Supplies*, U.S. Geological Survey Fact Sheet No. 99-155, 1999.*

[54] *C.A.M. Laboski and J.B. Peters,* Nutrient Allocation Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin (A2809)*, University of Wisconsin-Extension, 2012.*

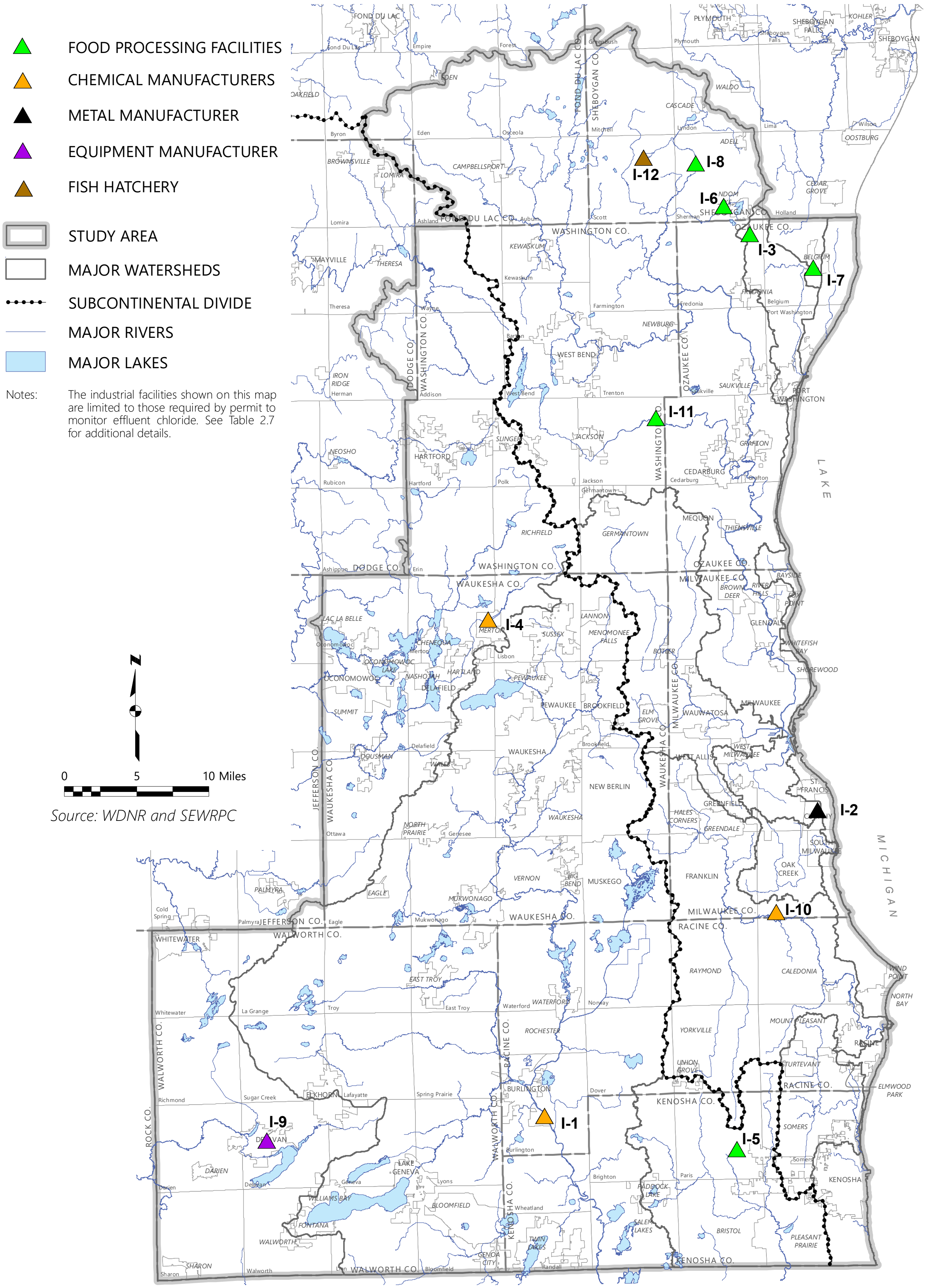
Table 2.7
Industrial Wastewater Dischargers Within the Study Area that Monitor Chloride

Facility ID	Industrial Facility Type	Receiving Water	Major Watershed	Civil Division	County	SEWRPC Sites Downstream (site no.)
I-1	Chemical Manufacturer	Fox River	Fox River	Burlington	Racine	2
I-2	Metal Manufacturer/Forge	Edgerton Ditch & Lake Michigan Direct	Lake Michigan	Cudahy	Milwaukee	--
I-3	Food Processing	Tributary to Sauk Creek	Sauk Creek	Belgium	Ozaukee	14
I-4	Chemical Manufacturer	Bark River	Rock River	Merton	Waukesha	11, 55
I-5	Food Processing	Unnamed Tributary to Root River (Des Plaines Watershed)	Des Plaines	Town of Paris	Kenosha	30
I-6	Food Processing	Silver Creek to North Branch Milwaukee River	Milwaukee River	Random Lake	Sheboygan	38, 41, 58
I-7	Food Processing	Unnamed tributary to Belgium-Holland Drainage Ditch then to Onion River	Sheboygan River	Belgium	Ozaukee	--
I-8	Food Processing	North Branch Milwaukee River	Milwaukee River	Adell	Sheboygan	38, 41, 58
I-9	Manufacturer	Roadside swale tributary to Swan Creek (Turtle Creek Watershed)	Rock River	Delavan	Walworth	32
I-10	Manufacturer	Tributary to Root River	Root River	Oak Creek	Milwaukee	59
I-11	Food Processing	Cedar Creek	Milwaukee River	West Bend	Washington	58
I-12	Fish Hatchery	Unnamed tributary to Melius Creek to North Branch Milwaukee River	Milwaukee River	Adell	Sheboygan	38, 41, 58

Note: See Map 2.7 for the industrial facility locations.

Source: WDNR and SEWRPC

Map 2.7
Industrial Wastewater Dischargers with Chloride Monitoring Within the Study Area



Geospatial crop data was obtained through the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) CropScape Cropland Data Layer (CDL) program to characterize the type and location of crops grown during the study period.[55] The CDL program produces a georeferenced raster land cover dataset that provides annual crop-specific information for each growing season or year. These data are collected using satellite imagery and "extensive agricultural ground reference data."[56] Annual cropland datasets were obtained from the CropScape CDL website.

Information on fertilizer use was obtained from the NASS Agricultural Chemical Use Program, which surveys U.S. farmers to collect data on the chemicals applied on-farm through fertilizers and pest management practices.[57] Survey data in the top-producing states for a particular crop are summarized in agricultural chemical use reports. The reports include average annual fertilizer application rates along with the percentage of acres fertilized for specific crops grown in the surveyed states. For Wisconsin, the agricultural chemical use data were limited to barley, corn, and soybeans.

For Wisconsin crops that receive potash fertilizer but are not surveyed as part of the NASS Agricultural Chemical Use Program, the fertilizer application rate guidelines presented in Table 7.4 of the Nutrient Allocation Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin were used.[58] That document provides recommended potash application rates for different crops based on potassium soil conditions and target crop yield goals. Potassium soil conditions were estimated using available soil testing data summarized by county for all agricultural field samples analyzed in Wisconsin.[59,60] The potassium soil testing data were interpreted and assigned a test level based on the guidelines set forth in Table 4 of the Optimum Soil Test Levels for Wisconsin publication.[61] Actual crop yield data was used to inform target crop yield goals and fertilizer applications as discussed in Chapter 3.[62]

Livestock Feeding Operations and Manure Spreading

Chloride is prevalent in livestock feed, typically supplemented to satisfy nutritional requirements and maintain livestock health. Most of the chloride consumed by livestock enters the environment through manure. Livestock manure is typically stored until it can be applied to permitted agricultural fields. Manure can contain varying chloride concentrations, depending on the type of livestock, differences in feed, or whether the manure is in solid or liquid form. Chloride testing of manure is not as common as testing manure for other nutrients, and chloride data were not only sparsely available but also broadly variable across references. Several studies provide data that can be used to estimate chloride content in manure for different types of animals, with chloride concentrations ranging from 400 mg/l for horse manure to 1,650 mg/l for dairy cow manure.[63,64] The specific data and references used in the livestock manure chloride analysis are discussed in Chapter 3.

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[55] *USDA National Agricultural Statistics Service,* Cropland Data Layer: USDA NASS*, USDA NASS Marketing and Information Services Office, Washington, D.C., nassgeodata.gmu.edu/CropScape, accessed December 2022.*

[56] *USDA National Agricultural Statistics Service,* "Cropland Data Layer – FAQs," *nass.usda.gov/Research_and_Science/Cropland/sarsfaqs2.php, accessed December 2022.*

[57] *USDA National Agricultural Statistics Service,* Agricultural Chemical Use Program, *nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use, accessed December 2022.*

[58] *C.A.M. Laboski and J.B. Peters 2012,* op. cit.

[59] *University of Wisconsin-Madison College of Agricultural and Life Sciences,* Soil Test K: 2005-2009, *uwlab.webhosting.cals.wisc.edu/wp-content/uploads/sites/17/2016/06/K_05-09.pdf, accessed December 2022.*

[60] *Wisconsin Department of Agriculture, Trade and Consumer Protection,* DATCP Soil Summaries: 2010-2014 and 2015-2019, *uwlab.soils.wisc.edu/soil-samples/datcp-soil-summary, accessed May 2025.*

[61] *K.A. Kelling, L.G. Bundy, S.M. Combs, and J.B. Peters,* Optimum Soil Test Levels for Wisconsin (A3030), *University of Wisconsin-Extension R-11-99-2M-100, 1999.*

[62] *United States Department of Agriculture National Agricultural Statistics Service in cooperation with the Wisconsin Department of Agriculture, Trade and Consumer Protection,* Wisconsin 2022 Agricultural Statistics, *September 2022.*

[63] *S.V. Panno, K.C. Hackley, H.H. Hwang, S.E. Greenberg, I.G. Krapac, S. Landberger, and D.J. O'Kelly,* Database for the Characterization and Identification of NaCl Sources in Natural Waters of Illinois*, Illinois State Geological Survey Open File Series 2005-1, 2005.*

[64] *J.P. Zublena, J.C. Barker, and D.P. Wessen,* Soil Facts: Dairy Manure as a Fertilizer Source*, North Carolina State University Agricultural Extension Service Publication AG-439-28 WQWM-122, 2012.*

The USDA Census of Agriculture is published every five years and provides livestock inventories for every county in Wisconsin.[65] The Census of Agriculture includes approximate headcounts for many different categories of livestock including various types of cattle, cows, and calves; goats; hogs and pigs; horses and ponies; sheep and lambs; along with various types of chickens, turkeys, and other poultry. While this dataset does not have a detailed geospatial component finer than county-level, it was used to estimate the total amount of livestock in the Region. Table 2.8 provides the livestock inventories by county from the 2017 Census of Agriculture, representing the total number or head of livestock in the Region as of December 31, 2017.

In Wisconsin, a livestock operation with 1,000 animal units (AU) or more is defined as a concentrated animal feeding operation (CAFO).[66,67] Under state and federal law, CAFOs must have a WDNR-issued WPDES permit to protect surface water and groundwater from excessive runoff and animal waste. Consequently, CAFOs are more stringently monitored and regulated than smaller livestock operations. CAFOs are required to have a minimum 180-day manure storage capacity to provide adequate manure storage throughout the winter season and prevent manure spreading on frozen or snow-covered ground. The CAFOs located within the Region and larger study area are listed in Table 2.9. The WDNR provided CAFO locations as shown on Map 2.8.[68] The map identifies the main farm site where livestock are housed and does not show the locations of any satellite facilities or agricultural fields used for spreading manure generated by the CAFO. The facilities and fields associated with CAFO operations are typically located relatively close to the main farm site or within a reasonable hauling distance. With proper storage and housekeeping practices at the main farm site, there should be a minimal amount of chloride entering the environment at that location compared to the fields used for spreading manure. CAFO data including the type and number of animals, AU calculation worksheets, spreading reports, and other operational information were obtained from CAFO permit program documents downloaded from the WDNR website.[69] Information and methods used to estimate the chloride load generated by the livestock at each CAFO in the study area are discussed in Chapter 3.

Irrigation

Irrigation practices supplement soil moisture from groundwater or surface water sources to meet water requirements for crops and other vegetation, or to increase crop yields and improve crop quality. Irrigation practices vary year to year, and are influenced by weather conditions, crop type, and farming practices. In general, agricultural irrigation is not a widespread practice within the Region. The USGS estimated that in 2015 approximately 12,200 acres, equivalent to approximately two percent of the agricultural land in the Region, were irrigated in the seven counties in southeastern Wisconsin, with an average application of 9.5 million gallons per day (mgd).[70] On irrigated lands, background chloride in the irrigation water is transferred to the soil and most is not taken up by plants. Chapter 3 provides computational details related to the estimated total annual chloride load resulting from irrigation within the Region.

Other Sources of Chloride

The following sections describe minor sources of chloride, most of which have not been analyzed in detail for the Chloride Impact Study.

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[65] *United States Department of Agriculture, National Agricultural Statistics Service,* 2017 U.S. Census of Agriculture: Wisconsin State and County Data, *Volume 1, Geographic Area Series, Part 49, April 2019.*

[66] *Animal units (AU) are a standard unit of measure that allows for the comparison between different animal types and sizes by converting the number of animals to a common mass equivalent. One AU is equal to the normalized mass of 1,000 pounds of live animal(s).*

[67] *Wisconsin Administrative Code, NR 243: Animal Feeding Operations, relates an AU to the impact of one beef steer or cow. Therefore, 1,000 beef cattle are equivalent to 1,000 AU, and other livestock animals have differing ratios. For example, the following numbers of animals are equivalent to 1000 AU: 500 horses, 715 dairy cows, 5,000 calves, and 10,000 sheep.*

[68] *Email correspondence between WDNR staff (B. Benninghoff) and Commission staff (L. Herrick), March 24, 2021.*

[69] *Wisconsin Department of Natural Resources,* Water Permit Applications, *dnr.wisconsin.gov/permits/water, accessed November 2024.*

[70] *U.S. Geological Survey,* USGS Water Use Data for Wisconsin: 1985-2015, *waterdata.usgs.gov/wi/nwis/wu, accessed April 2025.*

Table 2.8
County Livestock Inventories by Head: 2017 U.S. Census of Agriculture

Type of Livestock	Kenosha	Milwaukee	Ozaukee	Racine	Walworth	Washington	Waukesha	Region
Chickens (broilers)	796	(D)	(D)	2,747	458	636	261	4,898
Cattle and Calves[a]	9,805	(D)	26,421	10,079	38,419	45,180	7,765	137,669
Beef Cows	987	(D)	431	1,515	2,325	1,218	1,024	7,500
Milk Cows	3,520	(D)	9,163	3,209	14,786	15,290	1,627	47,595
Other Cattle	5,298	(D)	16,827	5,355	21,308	28,672	5,114	82,574
Goats	108	86	965	603	1,952	53	131	3,898
Hogs and Pigs	546	6	145	1,951	13,329	165	(D)	16,142
Horses and Ponies	1,589	(D)	384	865	1,482	799	1,640	6,759
Chickens (layers)	4,527	554	(D)	3,288	3,191	(D)	2,566	14,126
Pullets	94	(D)	(D)	909	400	148	122	1.673
Sheep and Lambs	513	(D)	186	905	2,568	532	1,041	5,745
Turkeys	184	(D)	--	224	95	72	79	654

Note: (D) indicates that data was withheld to avoid disclosing data for individual operations.

[a] *The Cattle and Calves inventory is broken into three subgroups: Beef Cows, Milk Cows and Other Cattle. The Other Cattle subgroup includes heifers that had not calved, steers, calves, and bulls.*

Source: USDA NASS

Table 2.9
Concentrated Animal Feeding Operations Located Within the Study Area: 2020

Farm Name	County	Major Watershed	Animal Type	2019 Animal Units[a]	Within SEWRPC Site Drainage Areas[b] (site no.)
Melichar Broad Acres	Ozaukee	Milwaukee River	Dairy	2,484	41, 58
Opitz Dairy Farm	Ozaukee	Milwaukee River	Dairy	1,369	41, 58
Paulus Dairy	Ozaukee	Milwaukee River	Dairy	2,426	41, 58
Maple Leaf Farms Downy Duck Farm	Racine	Milwaukee River	Ducks	847	47, 2
S&R Egg Farms LaGrange	Walworth	Rock River	Layers[c]	14,921	45, 3, 47, 2
Katzman Farms	Walworth	Fox River	Dairy	2,442	2
Merry Water Farms	Walworth	Fox River	Dairy	2,667	--
Snudden Farms, LLC	Walworth	Fox River	Dairy	4,975	--
Beck Dairy Farm, LLC	Washington	Milwaukee River	Dairy	2,080	23, 41, 58
Golden E Dairy, LLC	Washington	Milwaukee River	Dairy	3,855	41, 58
Kettle Moraine Egg Ranch, LLC	Washington	Rock River	Layers[c]	1,433	40, 41, 58
Sunset Farms, Inc	Washington	Milwaukee River	Dairy	2,865	28
T. Volm Farms/Iron Ridge Dairy	Washington	Fox River	Dairy	1,349	23, 41, 58
S&R Egg Farms Genesee	Waukesha	Rock River	Layers[c]	1,951	47, 2
Second Look Holsteins, LLC	Fond Du Lac	Milwaukee River	Dairy	1,654	23, 41, 58
Hickory Lawn Dairy Farm	Sheboygan	Milwaukee River	Dairy	1,545	38, 41, 58
Rockland Dairy, Inc	Sheboygan	Milwaukee River	Dairy	3,258	38, 41, 58

Note: See Map 2.8 for the locations of each CAFO.

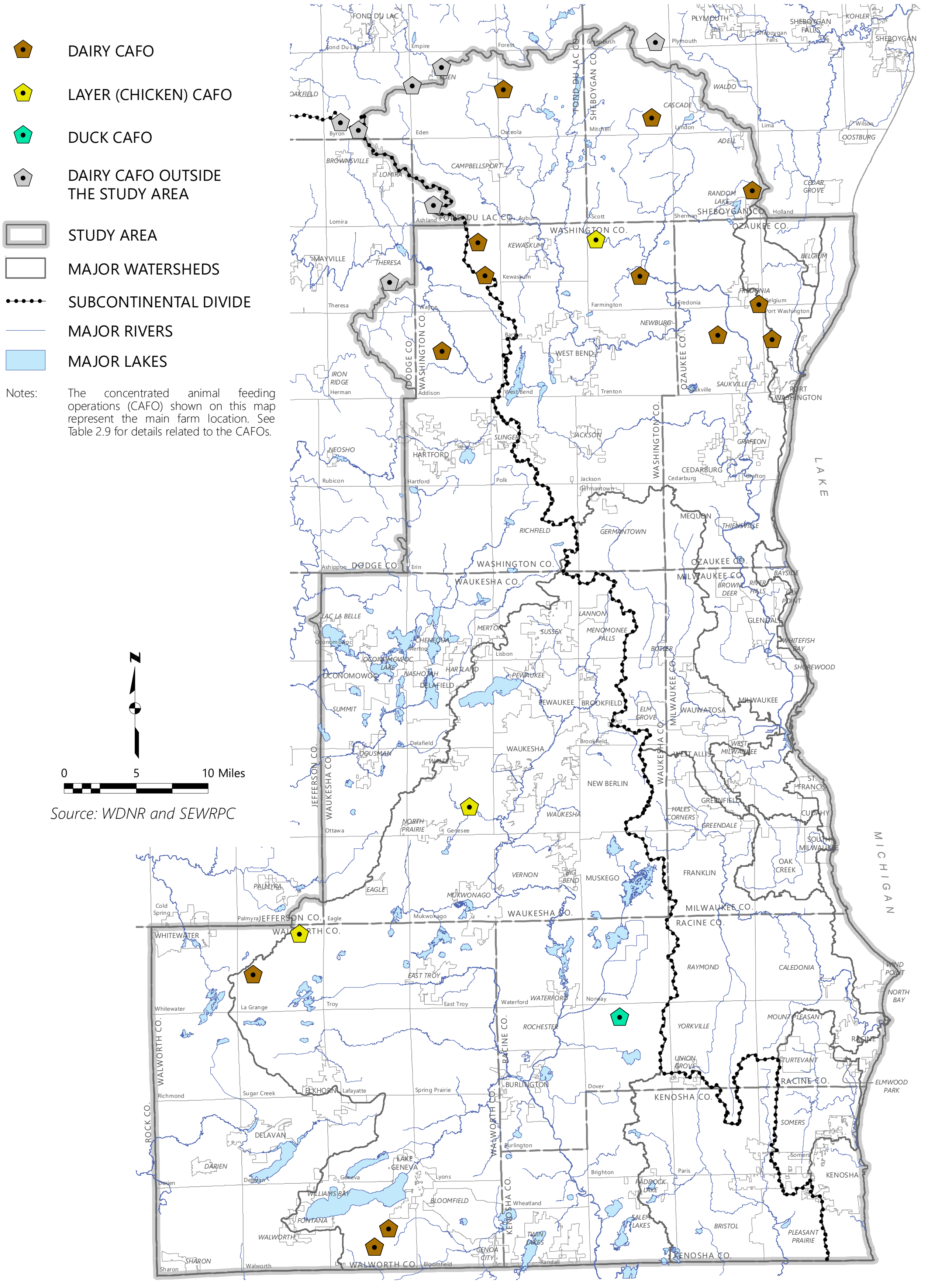
[a] *Animal units are a standard unit of measure used to compare different animal types and sizes converted to a common unit equivalent, and the values in the table represent the total animal units computed for the 2019 CAFO permit documents.*

[b] *The CAFO main farm that houses livestock is located within the upstream contributing drainage area of the SEWRPC monitoring site identified by site number. If no site number is listed, the CAFO is not located upstream of a stream monitoring site.*

[c] *Layers refers to chickens that are raised to produce eggs.*

Source: WDNR and SEWRPC

Map 2.8
Concentrated Animal Feeding Operations Within and Surrounding the Study Area: 2020



Atmospheric Deposition

Atmospheric deposition is a natural process by which ions or particles in the atmosphere fall to the ground through either wet or dry deposition. Much of the chloride in the atmosphere comes from the oceans as marine aerosols, mobilized to the atmosphere through processes like wave action and sea spray.[71] Atmospheric chloride is also generated from anthropogenic sources such as emissions from fossil fuel combustion or large-scale incineration, which can release hydrochloric acid (HCl) and other compounds to the atmosphere.[72] The highest levels of chloride deposition are observed along the coasts, while chloride concentrations in atmospheric deposition are relatively low within the interior of the continental United States.[73] Wet deposition occurs through precipitation sources including rain, snow, ice and fog, which carry dissolved chloride from the atmosphere to the ground. During dry deposition, chloride particles in dust, gases, or aerosols settle directly on the Earth's surface. In southeastern Wisconsin a majority of the total atmospheric deposition of chloride falls in the form of wet deposition. Wetter years with higher than normal precipitation are correlated with greater quantities of chloride atmospheric deposition compared to drier years.

The interagency National Atmospheric Deposition Program (NADP), led by the USGS, has been monitoring precipitation chemistry and atmospheric deposition across the United States since 1978. The NADP produces maps and gridded geospatial data for concentrations and annual rates of wet, dry, and total deposition of major ions. The total chloride deposition rate maps and gridded raster data for the study area were obtained from the NADP website.[74] These data were used to compute the total chloride load from atmospheric deposition, as presented in Chapter 3.

Natural Weathering of Rock and Soil Minerals

Chemical weathering is a natural process that breaks down rock and soil minerals, releasing ions that can contribute chloride to groundwater and surface water. Natural sources include the dissolution of chloride-bearing rock, such as halite, when exposed to water or acidic solutions. These are minor sources of chloride to the environment in southeastern Wisconsin because chloride is a minor component of the bedrock underlying the Region. As such, natural weathering was not evaluated as a source of chloride for this analysis.

Dust Suppression

Chloride compounds such as calcium chloride and magnesium chloride are commonly used to control dust on unpaved road surfaces.[75] Dust suppression is not a widely used practice in southeastern Wisconsin, primarily because there are very few unpaved roads in the Region. Dust suppression is typically required during construction operations as part of an overall erosion control plan. Due to the relatively small and temporary nature of dust suppression usage in the Region, this chloride source was not evaluated for the Study analysis.

Landfill Leachate

There are different types of landfills that accept various types of waste such as solid municipal waste, industrial waste, or hazardous waste. Within southeastern Wisconsin there are six municipal solid waste landfills currently in operation and two additional landfills that are used to dispose of coal combustion residuals (CCR). Landfill leachate is the liquid generated from the waste itself or when precipitation infiltrates through the waste buried in a landfill. Modern landfills are designed with highly impermeable liners and leachate collection systems to prevent leachate from seeping out of the landfill into the surrounding soils. Over time, however, landfill liners may deteriorate or fail and allow leachate to permeate through to the soils surrounding the landfill. A landfill leachate plume could migrate through the soil, eventually

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[71] *T.E. Graedel, and W.C. Keene;* "The Budget and Cycle of Earth's Natural Chlorine," *Pure & Applied Chemistry, 68(9): 1,689-1,697, 1996.*

[72] *J.D. Haskins, L. Jaegle, and J.A. Thornton,* "Significant Decrease in Wet Deposition of Anthropogenic Chloride Across the Eastern United States, 1998-2018," *Geophysical Research Letters, 47: e2020GL090195, doi 10.1029/2020GL090195, 2020.*

[73] *J.H. Feth,* Chloride in Natural Continental Water--A Review, *U.S. Geological Survey Water-Supply Paper No. 2176, 1981, and J.W. Munger and S.J. Einsenreich,* Continental-scale Variations in Precipitation Chemistry, *Environmental Science and Technology, 17(1), 32A-42A, 1983, as cited in Granato et al. 2015,* op. cit.

[74] *National Atmospheric Deposition Program, 2021.* Total Deposition Maps*, version 2021.01. nadp.slh.wisc.edu/committees/tdep, accessed October 2022.*

[75] *Wisconsin Transportation Information Center,* Wisconsin Transportation Bulletin No. 13: Dust Control on Unpaved Roads, *January 1997.*

contaminating groundwater or surface water resources. While landfills are recognized as a potential source of chloride to the environment if leachate is not properly contained, this chloride source was not evaluated in detail for this analysis due to the limited amount of data available.

2.3 IN-STREAM CHLORIDE LOAD DATA

To estimate the amount of chloride that is carried by a stream over time, the mass load of chloride within a stream is computed using reliable streamflow discharge data and chloride concentration data. The following sections present the data that were used to estimate in-stream chloride loads at stream monitoring sites deployed for the Chloride Impact Study.

Streamflow Discharge

The USGS maintains several stream gage stations within the Region as part of the greater USGS national streamgaging network (NSN). While the stream gage stations are primarily operated and maintained by the USGS, they are funded in partnership with one or more federal, state, and local agencies or organizations.[76] These stations continuously monitor streamflow throughout the year by measuring stream water levels and computing streamflow discharge from those measurements using a rating curve. Rating curves are developed for individual stream gage stations to provide a relationship between water levels and streamflow discharge and are periodically refined over time. In 2018, there were 34 continuous recording stream gaging stations within the study area. The 14 stations located near Study monitoring sites that were used for the mass balance analysis are shown on Map 2.9.[77] Additionally, Table 2.10 presents details related to the USGS stream gage stations used in the analysis. Streamflow discharge data for each of the 14 USGS stream gage stations were downloaded from the individual gage station webpages through the USGS Water Data for the Nation website for the entire study period.[78]

Commission staff investigated the feasibility of developing streamflow datasets for the stream monitoring sites that were not located near USGS stations. Staff considered using streamflow data collected in the field by the Commission as well as several different agencies and organizations, paired with water depth measurements recorded by the in-stream monitoring equipment. Some Study monitoring sites had enough data to establish a relationship between the depth of water measured above the in-stream sensor and the estimated streamflow; however, the range of flow measurements was relatively limited, covering only a wadable range of water levels. Additionally, the water depth data collected by the in-stream sensors at the Study monitoring sites was determined to not be reliable enough to use for flow estimates, as the depth sensor was subject to malfunction. Furthermore, because the in-stream sensors were not secured in position on the stream bed, they could be moved during high flow events or by human intervention, and occasionally the sensors were found buried in the streambed substrate. These challenging conditions limited the development of a reliable streamflow record at ungaged stream monitoring sites; hence in-stream chloride loads were computed only for the Study stream monitoring sites located near USGS stream gage stations.

Stream Water Quality Monitoring Data

The continuous and discrete water quality data collected at stream monitoring sites for the Chloride Impact Study are briefly described in the following sections. TR-61 provides a detailed description of the data collection equipment and methods, along with data management and post-processing procedures.

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[76] *USGS National Streamgaging Network website: www.usgs.gov/mission-areas/water-resources/science/usgs-national-streamgaging-network, accessed May 2025.*

[77] *The total includes the USGS stream gage on the Des Plaines River at Russell, Illinois, located just outside of the study area.*

[78] *U.S. Geological Survey, National Water Information System (NWIS) data available on the World Wide Web (USGS Water Data for the Nation), 2016, waterdata.usgs.gov/nwis, accessed April 2022.*

Map 2.9
Locations of U.S. Geological Survey Stream Gage Stations used in the Mass Balance Analysis: 2018

CONTINUOUS STREAM GAGE STATIONS

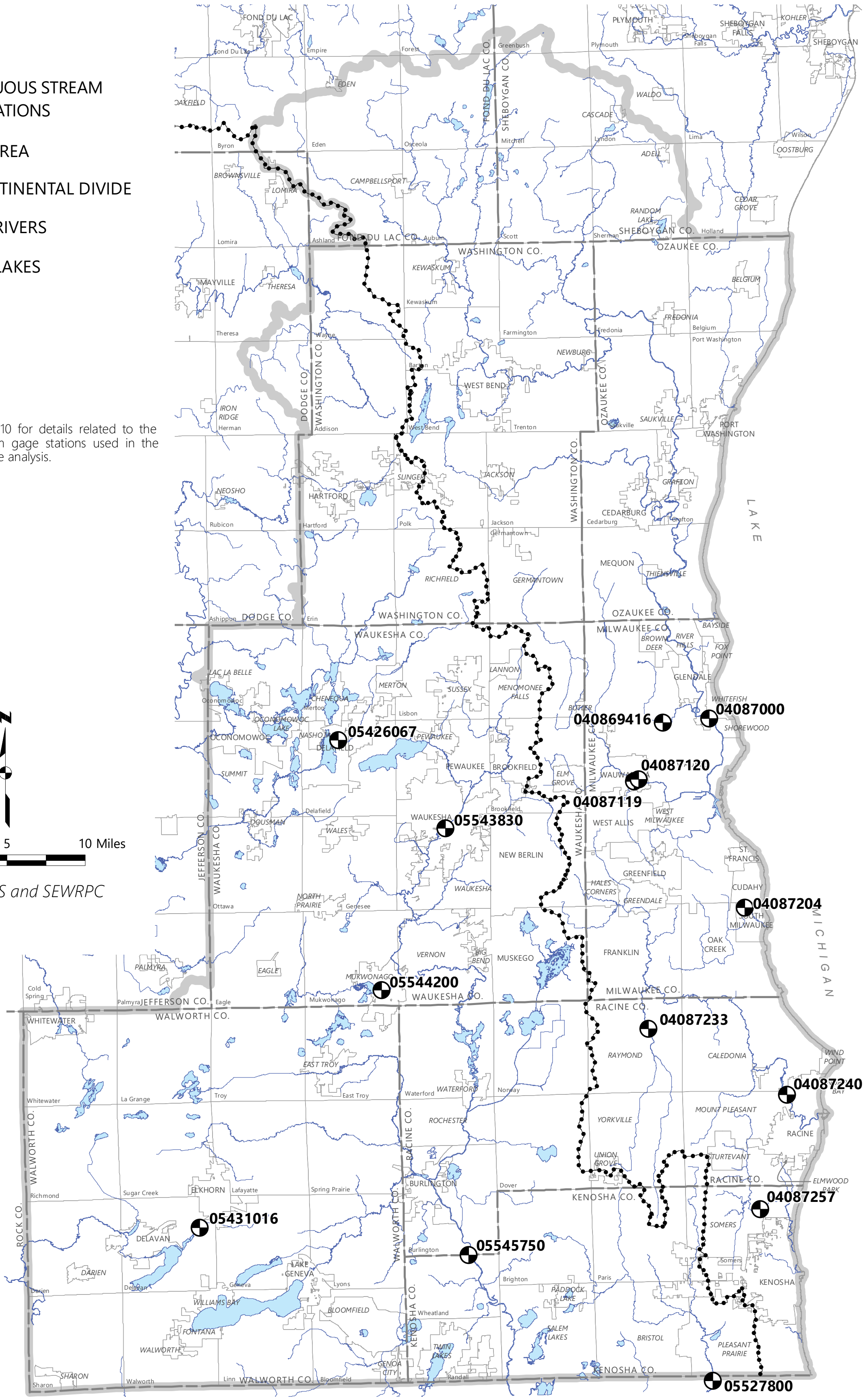
STUDY AREA

SUBCONTINENTAL DIVIDE

MAJOR RIVERS

MAJOR LAKES

Notes: See Table 2.10 for details related to the USGS stream gage stations used in the mass balance analysis.



0 5 10 Miles

Source: USGS and SEWRPC

Table 2.10
USGS Stream Gage Stations Located near Stream Monitoring Sites for the Mass Balance Analysis

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Streamflow Data Interval (minutes)	Period of Record	Nearby Stream Monitoring Site[a]
05543830	Fox River at Waukesha, WI	126	15	1986 - present	1
05545750	Fox River at New Munster, WI	811	15	1993 - present	2
05544200	Mukwonago River at Mukwonago, WI	74.1	15	1986 - present	3
04087204	Oak Creek at South Milwaukee, WI	25	15	1986 - present	9
04087257	Pike River near Racine, WI	38.5	15	1986 - present	10
05426067	Bark River at Nagawicka Road at Delafield, WI	35.9	15	2002 - present	11
040869416	Lincoln Creek at Sherman Blvd at Milwaukee, WI	13.48	5	2003 - present	12
05431016	Jackson Creek at Mound Rd near Elkhorn, WI	16.8	5	1993 - present	16
04087233	Root River Canal near Franklin, WI	57	15	1986 - present	25
05527800	Des Plaines River at Russell, IL	123	15	1986 - present	30
04087119	Honey Creek at Wauwatosa, WI	10.3	5	2004 - present	53
04087120	Menomonee River at Wauwatosa, WI	123	15	1986 - present	57
04087000	Milwaukee River at Milwaukee, WI	696	15	1986 - present	58
04087240	Root River at Racine, WI	190	15	1986 - present	59

Note: See Map 2.9 for the locations of each stream gage station.

[a] *Stream monitoring sites are listed by site number, refer to Table 2.3 for additional monitoring site information.*

Source: USGS and SEWRPC

Continuous Data Collection

Continuous water quality data were collected at 41 stream monitoring sites using in-stream sensors deployed for the 25-month study period from October 2018 through October 2020.[79] The in-stream sensors collected data at 5-minute intervals, including water temperature, specific conductance, and the depth of water above the sensor. This analysis focuses primarily on the specific conductance dataset as previous studies have demonstrated that specific conductance is a good predictor of chloride once a reliable relationship is established between the two constituents.[80] The monitoring period was extended into 2021 at several sites to enable collection of paired specific-conductance-chloride samples during winter storm and spring snowmelt events to better define the regression models.

Discrete Water Quality Sampling

Regular chloride samples were collected monthly during the 25-month study period at each stream monitoring site to measure chloride concentrations, among other water quality constituents. Targeted event sampling was employed at some sites to collect water samples during winter storms and snowmelt events in order to capture paired data during periods of high specific conductance and represent the full range of chloride concentrations and specific conductance levels observed throughout the study period.

Chloride-Specific Conductance Regression Relationship

SEWRPC Technical Report No. 64 (TR-64) presents the development of the Study regression relationship between chloride and specific conductance.[81] The regression equations that were developed based on paired specific conductance and chloride data collected for the Chloride Impact Study were used to convert the 5-minute continuous specific conductance data observed at stream monitoring sites to chloride concentrations. The piecewise regression model was used to estimate chloride concentrations for the 14 stream monitoring sites included in the mass balance analysis. Chapter 3 describes how these estimated chloride concentrations were used to calculate in-stream chloride loads.

[79] *Additional monitoring sites were installed over the course of the Study and the water quality data collected at these sites cover a shorter period of record.*

[80] *Howard and Haynes 1993,* op. cit.

[81] *SEWRPC Technical Report No. 64,* Regression Analysis of Specific Conductance and Chloride Concentrations*, May 2024.*

CHLORIDE LOADING AND MASS BALANCE ANALYSIS METHODOLOGY 3

3.1 INTRODUCTION

This Chapter outlines the methodologies for the chloride loading calculations and mass balance analysis, along with the assumptions underlying these methods, that were employed for the Chloride Impact Study (Study) for the Southeastern Wisconsin Region (Region). Chloride source loads and in-stream chloride loads were computed for the 25-month study period from October 2018 through October 2020, using the data presented in Chapter 2 and the methodologies described in Sections 3.2 and 3.3, respectively. Chloride source loads were computed for the entire Region and for each stream monitoring site, utilizing similar methodologies applied over different geographical areas. Regional source loads were used to develop a Regional chloride budget to estimate the average annual chloride contribution from the sources presented in Section 3.2. Monitoring site chloride source loads and in-stream chloride loads were compared at a subset of Study monitoring sites using the chloride mass balance approach described in the next section.

Chloride Mass Balance Approach

The Study mass balance analysis approach for individual stream monitoring sites used a simplified model based on conservation of mass principles to demonstrate the movement of chloride through the environment. The law of conservation of mass dictates that the mass of chloride entering a system should be equal to the mass of chloride leaving a system. Since chloride is a highly mobile pollutant in water, watershed boundaries naturally define the mass balance "system" with a focus on surface water.[82] Figure 3.1 presents a simplified schematic of the chloride mass balance system for a stream monitoring site. This figure shows the sources of chloride analyzed for the mass balance and the input data used to compute chloride loads. It was assumed that chloride contributions within the drainage area upstream of a monitoring site would be transported along with water to the watershed outlet (i.e. stream monitoring site) and out of the system. The mass balance model used the following equation to compare chloride source inputs with the in-stream chloride output at individual stream monitoring sites; the terms of the equation are defined below.

$$\Sigma \textit{ Chloride Inputs} - \textit{Chloride Output} = \Delta \textit{ Chloride Retained in the System}$$

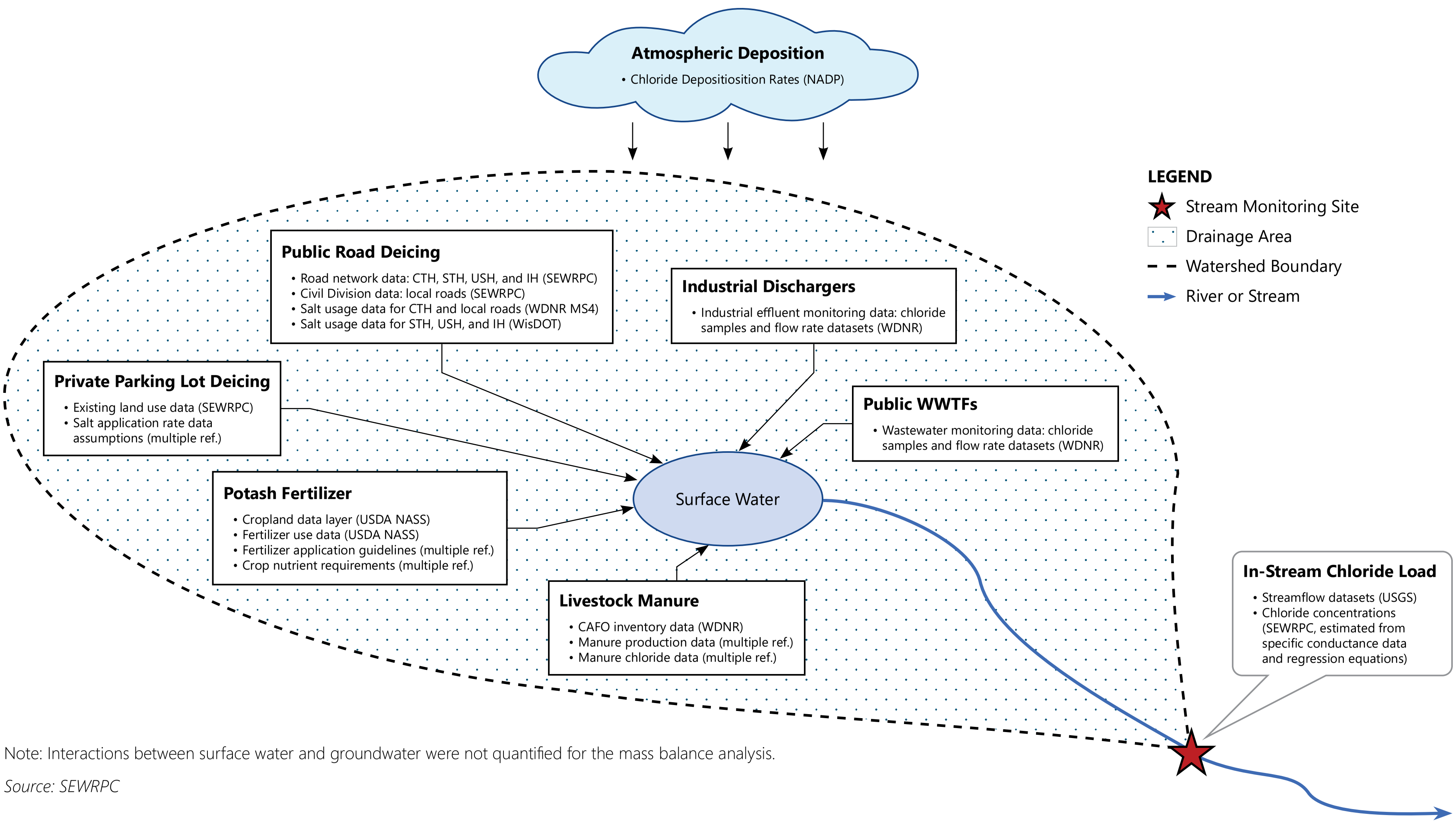
- **Σ Chloride Inputs:** The sum of chloride inputs term in the equation represents the total amount of chloride applied within the system and encompasses a variety of chloride sources that are shown in Figure 3.1. The chloride mass load from various sources of chloride within the monitoring site upstream drainage area were estimated on a monthly basis over the study period from October 2018 through October 2020.[83] Chloride point source loading was computed from the best-available monitoring data. In general, the chloride mass load for point sources is estimated by multiplying the chloride concentration in water by the discharge or flow rate. Chloride from nonpoint sources was included in the analysis for datasets with detailed geospatial data readily available and for chloride sources that were likely to be transported to the stream within the relative timeline of the study period. For nonpoint sources, the mass load of chloride is estimated by multiplying a chloride application rate by the area over which the chloride is applied. The general equations used to estimate chloride mass loads may also include unit conversion factors or scaling factors.

- **Chloride Output:** The chloride output term in the equation is the amount of chloride exported from the system, represented by the estimated in-stream chloride load that was computed for the stream monitoring sites for the study period from October 2018 through October 2020. Similar to the computation for point source inputs, the in-stream chloride mass load is estimated by

[82] *The chloride mass balance analysis focused primarily on surface water systems, and interactions between surface water and groundwater systems were not quantified.*

[83] *The amount of chloride entering the environment over a specific time period is referred to as the chloride mass load or chloride load.*

Figure 3.1
Chloride Mass Balance Schematic for Stream Monitoring Sites



Note: Interactions between surface water and groundwater were not quantified for the mass balance analysis.

Source: SEWRPC

multiplying the chloride concentration in the stream by the streamflow discharge. Only those Study monitoring sites that were located near U.S. Geological Survey (USGS) stream gage stations with reliable streamflow data were used in the mass balance analysis.

- **Δ Chloride Retained in the System:** The change in the amount of chloride retained within the watershed is equal to the difference between the sum of chloride inputs minus the chloride output. When the sum of chloride inputs is greater than the in-stream load at the monitoring site, the excess chloride may be considered as being stored or retained within the watershed. However, chloride retention within a watershed is transient and represents chloride moving slowly with water through the underlying soils. Over long periods of time, chloride within soils and groundwater could be gradually released into surface waters or could be exported out of the system into deeper groundwater aquifers.

Chloride transport was not explicitly modeled, but timing considerations were recognized as having an influence on transport processes as well as the results of the mass balance analyses. The chloride pathways with the shortest travel times are typically associated with runoff to surface waters in response to precipitation or snowmelt events. Surface water transport through a watershed is influenced by a variety of factors and flow path characteristics such as length, slope, and land cover. Even for the largest drainage areas considered for the Study, the time it takes for a drop of water to travel from the most remote point in the watershed to the outlet is on the order of days.

In contrast, subsurface pathways and travel times can be significantly longer. Figure 3.2 illustrates idealized groundwater flow systems under steady state conditions, following subsurface flow paths from where water enters the system in groundwater recharge areas to discharge areas where groundwater leaves the system and flows into surface water bodies. The figure is discussed in further detail in the Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) Technical Report No. 62 (TR-62), and shows that the time it takes groundwater to move from a recharge area to a discharge area may range from a few days to thousands of years, depending on subsurface geology and aquifer system characteristics.[84] Chloride sources that are expected to infiltrate into groundwater aquifers were not included in the mass balance analysis; however, some of those sources were evaluated on a Regional basis to develop a Regional chloride budget.

Chloride source loads were computed for all 41 stream monitoring sites, but only the sites with reliable streamflow data that could be used to develop in-stream chloride loads were included in the mass balance analysis. Map 3.1 shows the 14 stream monitoring sites evaluated in the mass balance analysis, along with the contributing drainage areas. Figure 3.3 presents land use percentage breakouts for these 14 sites. The figure shows the proportion of the upstream drainage area for each site dedicated to broader land use categories including rural and natural areas, agriculture, and urban land uses with a separate breakout for roads and parking lots. Detailed land use maps and additional drainage area characteristics are provided for each stream monitoring site in Appendix B.

The following sections describe the methodologies and assumptions used to estimate chloride source loads and in-stream chloride loads.

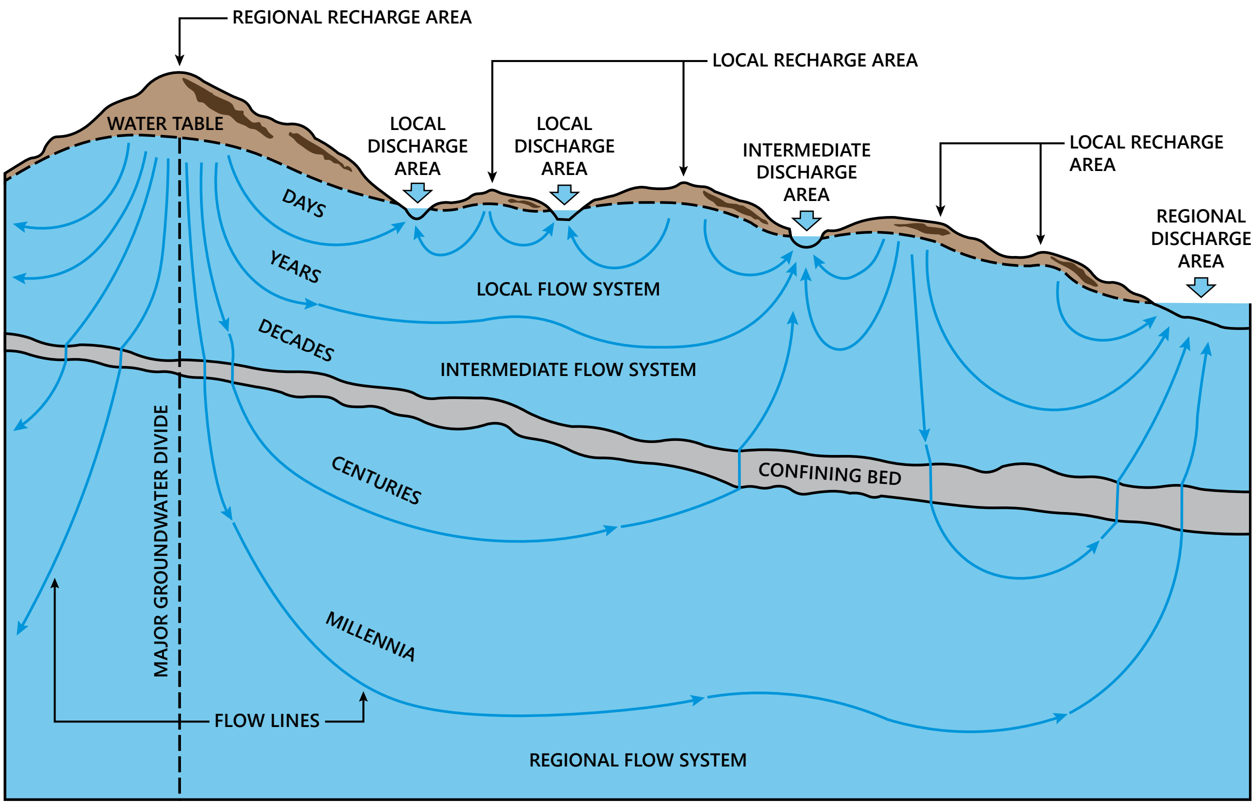
3.2 CHLORIDE SOURCE LOADING COMPUTATIONS

Chloride source loads for the Study were computed for point and nonpoint sources with reliable datasets from which a chloride mass load could be estimated. The sources of chloride evaluated for the Regional chloride budget include atmospheric deposition, winter maintenance operations such as deicing salts applied to public roads and private parking lots, wastewater from public treatment facilities and residential septic systems, industrial wastewater discharge, potash fertilizer, livestock, and agricultural irrigation.[85] This evaluation captured many, but not all, of the sources of chloride within Southeastern Wisconsin. The total chloride source load within individual stream monitoring site drainage areas were computed for chloride sources that had datasets with geospatial distribution information. These chloride sources, shown in

[84] *SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment, *April 2024.*

[85] *Of the chloride sources listed in Chapter 2, natural weathering, dust suppression, and landfill leachate were not analyzed for this Study.*

Figure 3.2
Idealized Groundwater Flow Systems Under Steady State Conditions



Note: Drain tiles are not shown in the figure above, but can influence subsurface flow systems in agricultural areas. Drain tiles provide a conduit for transporting water through subsurface soils above the water table directly to surface waters with travel times on the order of hours to days.

Source: Modified from A. Zaporozec in SEWRPC Technical Report No. 37, Groundwater Resources of Southeastern Wisconsin, *2002*

Figure 3.1, include the sources listed above with the exception of residential septic systems and irrigation. The methodology and assumptions used to estimate chloride source loads for the entire Region and for individual stream monitoring sites are discussed in the following sections.

Atmospheric Deposition

Atmospheric deposition is the only natural source of chloride that was evaluated in the analysis. The total chloride atmospheric deposition gridded geospatial raster data for years 2018 to 2020 were obtained from the National Atmospheric Deposition Program (NADP) as described in Chapter 2. The source raster data cover the entire continental United States, with a 4 kilometer (km) by 4 km raster grid size and deposition rates reported in kilograms per hectare (kg/ha).[86] The geospatial coordinate system used in the source dataset was converted to match the spatial reference of the Study geographic information system (GIS) datasets. The gridded raster dataset was overlain onto southeastern Wisconsin and clipped to the study area to include the upstream extend of the Milwaukee River watershed north of the Region. Figure 3.4 presents the total annual chloride deposition rates for the Region from 2018 through 2020.

Statistical data were extracted from the total chloride deposition gridded raster data for each county and each stream monitoring site drainage area for each year between 2000 and 2020. The statistical data included minimum, maximum, mean, and median total chloride deposition in kg/ha. During the study period, the mean chloride deposition rates ranged from approximately 0.75 to 1.0 kg/ha (0.67 to 0.89 pounds per acre) for the seven counties in southeastern Wisconsin. Using the mean chloride deposition rate applied over the corresponding area of deposition, the total chloride loads were calculated for each county in the Region and for the individual monitoring site drainage areas. The average annual chloride load from atmospheric

[86] *1 kg/ha = 0.89 pounds per acre (lb/ac).*

Map 3.1
Stream Monitoring Sites and Upstream Drainage Areas used for the Chloride Mass Balance Analysis

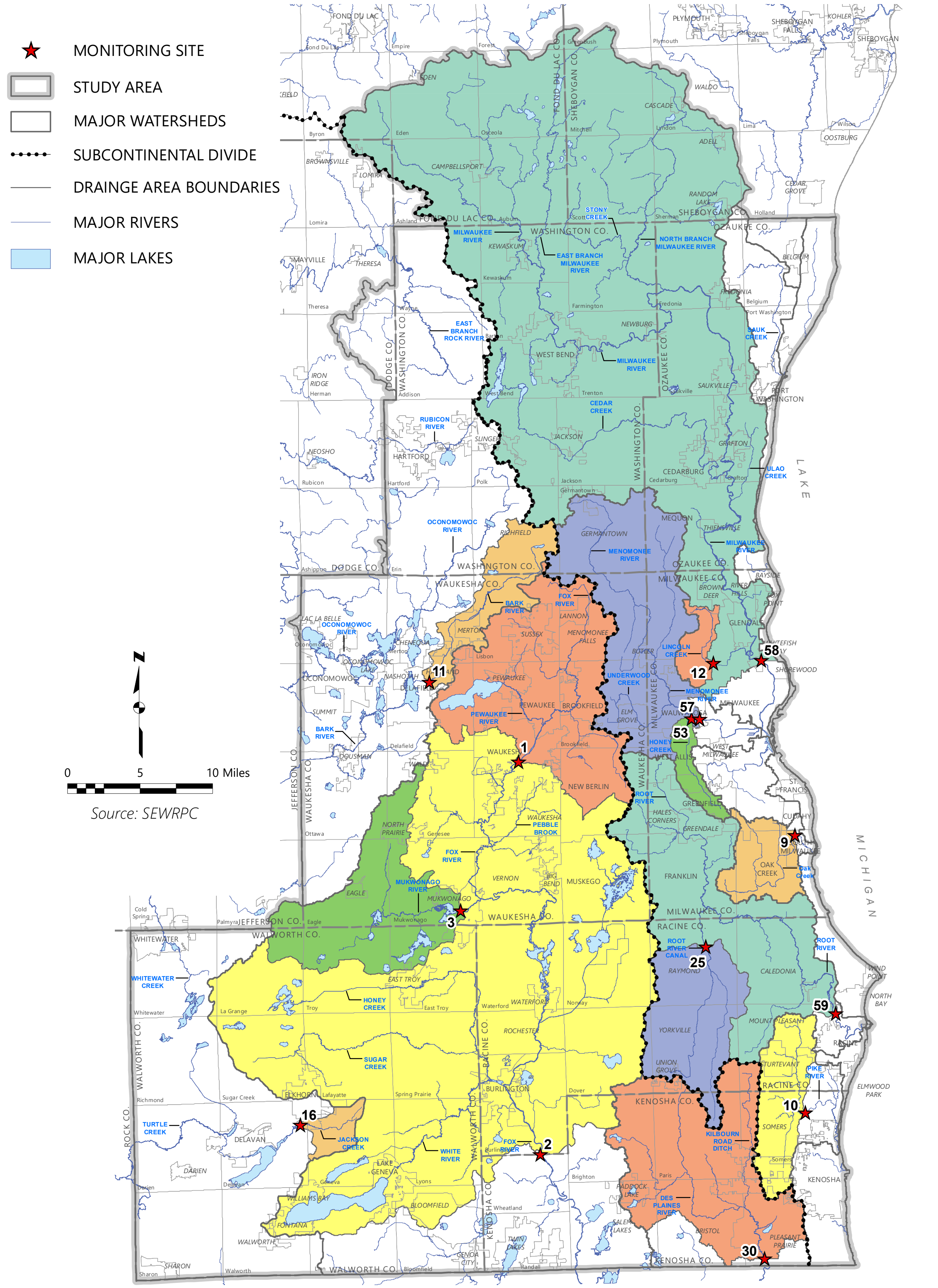
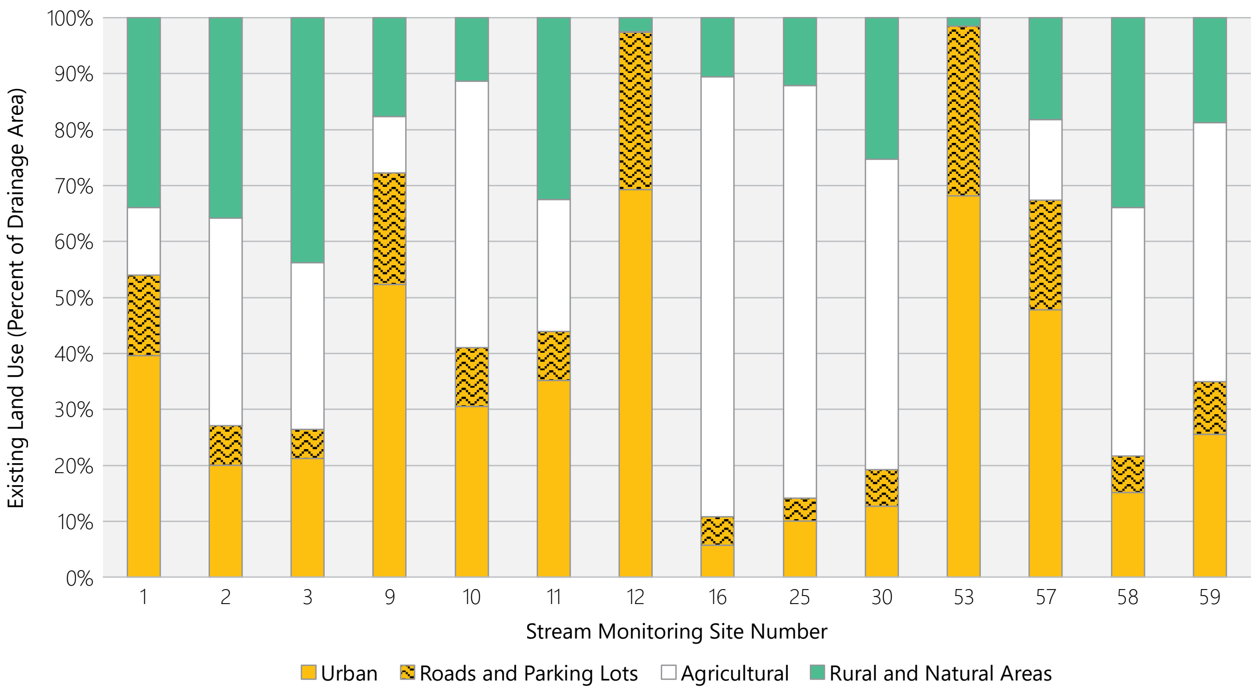


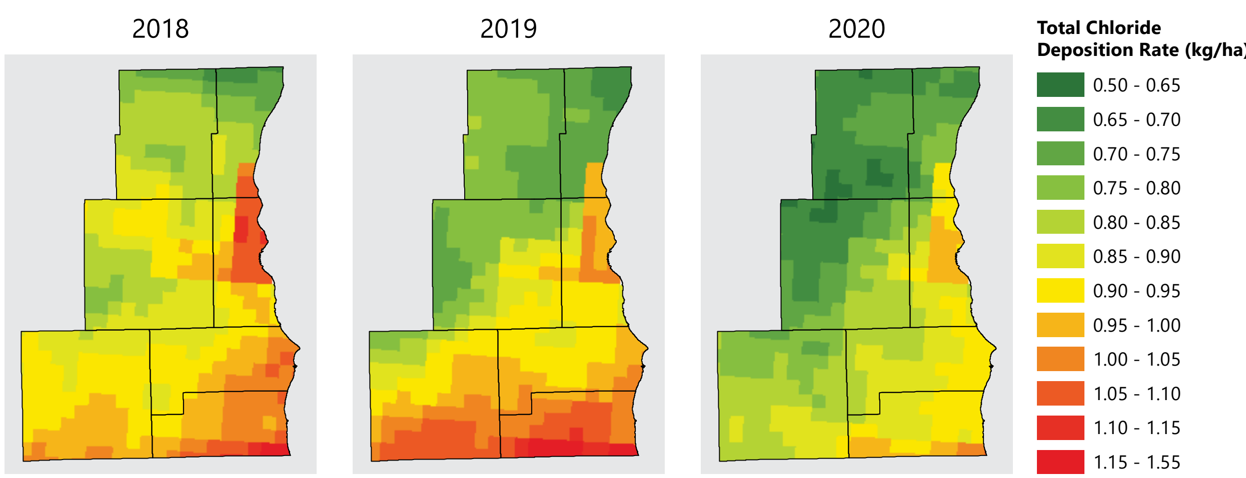
Figure 3.3
Existing Generalized Land Use Percentages for Monitoring Sites in the Mass Balance Analysis



Note: Refer to Table 2.3 for the site drainage area size and other stream monitoring site details. Urban land use includes residential, commercial, industrial, government and institutional, and other urban land uses, while roads and parking lots are represented separately. Rural and natural areas include wetlands, woodlands, surface water, unused rural lands, and extractive lands, while agricultural lands are represented separately.

Source: SEWRPC

Figure 3.4
Atmospheric Deposition of Chloride: Total Deposition Rates for the Region 2018-2020



Source: NADP and SEWPRC

deposition in the Region was approximately 660 tons per year during the study period from 2018 to 2020. The total annual chloride loading from atmospheric deposition for each County and the entire Region during the study period is shown in Table 3.1.

Atmospheric deposition of chloride is a natural source of chloride, and while some of the sources of chloride to the atmosphere are anthropogenic, humans have no control over how much chloride falls to the ground through atmospheric deposition. As the only natural source in the analysis, it is one of the smallest sources considered and makes up a small portion of the average annual contribution of chloride in the Region. As such, it can be considered a baseline for chloride loading, and the results of the subsequent chloride loading analyses for other sources of chloride can be normalized or expressed in terms of the equivalent amount of chloride resulting from atmospheric deposition over the Region. The annual average chloride from atmospheric deposition for the study period from 2018 to 2020 is the same as the 10-year average from 2011 to 2020, and this relative stability over the recent decade is another characteristic that makes atmospheric deposition a suitable baseline comparison for various sources of chloride during the study period.

Winter Maintenance Operations

Chloride used for winter road maintenance operations is typically reported on a winter seasonal basis rather than an annual basis. While the winter season includes months that straddle more than one calendar year, the winter season totals may be referred to herein as the annual totals.[87] The methodology to geographically distribute road salt and other deicing/anti-icing material usage varies by road type and data source, utilizing the best available data as described in the following sections. These analyses assume that road salt and deicing materials are applied evenly throughout a particular jurisdictional area, without consideration of the level of service that may be assigned to different roadways. For example, the total amount of road salt applied to County roadways during a particular month was assumed to be distributed equally on all of the County highway lane miles within that county. While it is recognized that not all roads are treated equally under practical winter maintenance applications, and some areas such as hills and bridge decks may require targeted and repeated applications during a single storm event, data reporting did not supply this level of detail. Therefore, the uniform application assumption was deemed acceptable for this Regional-scale study.

State and Federal Highways and Interstates: WisDOT Chloride Load

The Wisconsin Department of Transportation (WisDOT) relies on the Counties to provide winter road maintenance on state and federal highways and interstates. Each County regularly reports the amount of road salt and other deicing material usage and application data to WisDOT throughout each winter season, typically covering the period from October through April of the following year. Data for each county in the study area were obtained from the WisDOT storm reports and tabulated into monthly totals for the 2018-19, 2019-20, and 2020-21 winter seasons.

The quantities of different materials used for deicing and anti-icing operations were converted to an equivalent chloride mass using deicing chemical property data provided by the Federal Highway Administration (FHWA).[88] Sodium chloride (NaCl) is slightly more than 60 percent chloride by mass, and that ratio was used to estimate the amount of chloride in rock salt. The ratio is slightly conservative as it does not account for salt impurities, which occur naturally in mined salt; rock salt has been estimated to contain 1 to 5 percent impurities depending on where it was mined.[89] Liquid salt brine used for pre-wetting and deicing/anti-icing was assumed to be an optimized 23.3 percent NaCl in solution. Similarly, the calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) liquids used for deicing and pre-wetting were assumed to be approximately

[87] *The study period from October 2018 through October 2020 covered two full winter seasons and the first month of a third winter season. In some cases, the chloride load results presented for public winter road maintenance utilized data from all three winter seasons, as noted in the text.*

[88] *S.A. Ketcham, L.D. Minsk, R.R. Blackburn, and E.J. Fleege,* Manual of Practice for An Effective Anti-Icing Program, Appendix A: Selected Chemicals and Their Properties*, U.S. Department of Transportation, Federal Highway Administration Report Number: FHWA-RD-95-202, June 1996.*

[89] *Cargill, "What is Rock Salt?", cargill.com/what-is-rock-salt, accessed May 2025.*

30 percent and 22 percent in solution, respectively.[90] The only reported proprietary deicer applied to state and federal highways during the study period was Beet Heet, which is a liquid product comprised of several carbohydrate sugars and chloride compounds.[91] Beet Heet was assumed to be approximately 30 percent chloride based on limited ingredient lists and bounding ranges provided by the manufacturer.

The total chloride mass load from deicing was summed for each County for every month of the study period. The average annual chloride mass load applied to state and federal highways in the Region during the study period was 51,300 tons per winter season, approximately 78 times the average annual amount of chloride in the Region from atmospheric deposition.[92] Figure 3.5 shows the monthly chloride loads resulting from deicing and anti-icing activities for the state and federal highways located within the Region over three winter seasons.

Table 3.1
Annual Chloride Loads from Atmospheric Deposition: 2018-2020

County	2018 (tons)	2019 (tons)	2020 (tons)
Kenosha	80.7	85.0	72.8
Milwaukee	68.8	65.1	62.5
Ozaukee	54.0	49.9	49.5
Racine	92.7	92.2	84.7
Walworth	152.8	159.0	134.9
Washington	100.7	94.4	84.5
Waukesha	144.2	135.7	123.1
Region	693.9	681.2	612.0

Source: NADP and SEWRPC

To estimate the total amount of WisDOT winter road maintenance materials applied to state and federal roadways within each monitoring site drainage area, the portions of the drainage area within the Region and outside of the Region were computed separately by county using a lane mile ratio approach, as presented in the following general equation.

$$S_{DA} = \Sigma\,(S_{X1} * LMR_{X1} + S_{X2} * LMR_{X2} + \ldots + S_{Xn} * LMR_{Xn})$$

Where:

S_{DA} = WisDOT deicing salt applied within a monitoring site drainage area
S_{Xi} = total amount of WisDOT deicing salt applied within a given County X
LMR_{Xi} = site-specific WisDOT lane mile ratio for County X = (LM_{DAX} / LM_X), where:
LM_{DAX} = state and federal highway lane miles in the site drainage area within County X
LM_X = total state and federal highway lane miles in County X

Within the Region, the Regional transportation network map was geospatially intersected with the site drainage areas using GIS to determine the total lane miles of state and federal roadways within each drainage area by county. The total state and federal highway lane miles within each County were obtained from the Regional transportation network attribute data. For each county in a specific monitoring site drainage area, a WisDOT lane mile ratio was computed by dividing the state and federal roadway lane miles within the drainage area by the total state and federal roadway lane miles within that county. The site-specific WisDOT lane mile ratio computed for each county was then applied to the deicing and anti-icing material usage data to determine the amount spread within each drainage area by each county. The county totals were summed to estimate the total monthly chloride mass load contributed by the usage of winter maintenance materials on state and federal roadways within the portions of the monitoring site drainage areas located within the Region.

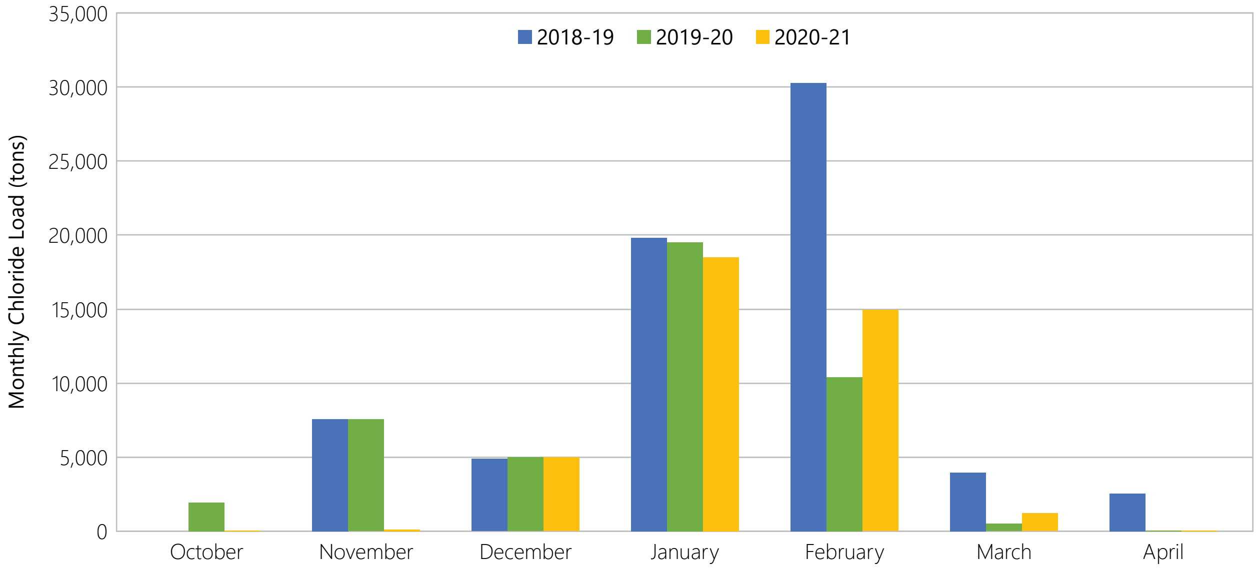
A similar approach was taken for the state and federal roadways located in the portions of site drainage areas outside of the Region but still within the boundaries of the study area. The total state and federal lane miles within each drainage area were computed from available roadway mapping data in GIS. A lane mile ratio was computed for each county in the drainage area by dividing the lane miles within the drainage area

[90] *The assumed concentrations in solution were chosen near the "eutectic" point for each chemical, which is defined as the concentration that results in the lowest temperature at which a solution can exist while remaining completely liquid. (i.e. optimized concentrations for winter road maintenance because the resulting liquid solution would have the lowest effective working temperature).*

[91] *K-Tech Specialty Coating, Inc., "Beet Heet Booklet," ktechcoatings.com/sites/default/files/file-table/2020-07/BEET%20 HEET%20Booklet%207-27-20.pdf, accessed November 2021.*

[92] *The average annual chloride load for the study period was calculated as an average of the total chloride loads computed for the 2018-19, 2019-20, and 2020-21 winter seasons. While only a portion of the third winter season was part of the study period, the annual average chloride load for the Region was computed using the full three winter seasons to represent average conditions during the study period.*

Figure 3.5
Total Monthly Chloride Loads from Deicing State and Federal Highways in Southeastern Wisconsin



Source: WisDOT and SEWRPC

by the total state and federal lane miles in the county reported with the WisDOT storm report data. The lane mile ratio was applied to the total WisDOT road salt and other deicing material usage for each County to estimate the total quantity of deicing and anti-icing materials applied to state and federal highways within the site drainage area for the counties located outside the Region. The chloride loads for the portions of the drainage areas outside the Region were combined with the Regional chloride loads to estimate the total monthly chloride mass load contributed by the usage of winter maintenance materials on Regional state and federal roadways within each monitoring site drainage area. The total WisDOT chloride load from road salt and deicing materials applied to state and federal highways within the drainage area of each stream monitoring site is presented in Chapter 4.

County Highways and Local Roads: MS4 Chloride Load and Deicing Data Reported Separately

The chloride mass loads computed for county and local roadways included a combination of data from municipal separate storm sewer system (MS4) permittees and data reported separately to the Commission. MS4 annual report data for winter road management includes the total quantities of materials used each month throughout the winter season covering the six-month period from October through March of the following year. The materials that were reported on the MS4 permit forms were limited to those available within the form drop-down menu, with the earliest versions of the form specifying only the use of solids and liquids in general. The MS4 form used during the study period included an expanded but still largely general list of deicing and anti-icing materials. Solid materials included on the permit form were rock salt, sand, and a salt/sand mixture. The sand/salt mixture was assumed to be 5 percent salt by weight based on typical practices in Wisconsin, with salt considered to be approximately 60 percent chloride by mass.[93] Liquid materials included on the permit form were salt brine, beet juice, and general categories for pre-wetting compounds and chem-melt. During the study period, liquid salt brine represented approximately 90 percent of the liquids reportedly used for winter road maintenance by MS4 permittees in the Region. Therefore, salt brine was the only liquid included in the loading analysis and was assumed to have a 23.3 percent chloride concentration in solution.

The MS4 report data were obtained from the Wisconsin Department of Natural Resources (WDNR), and the winter maintenance material usage totals were converted to chloride content and summed to estimate the total chloride mass load for the entire Region and for each county. Additional local roadway and community salt usage data that was submitted directly to the Commission was combined with the MS4 report data

[93] *Sand-salt mixtures with more than 5 percent salt content are considered the same as salt from a regulatory perspective and are subject to the same storage and handling requirements as salt per Wisconsin Administrative Code, Trans 277.*

and incorporated into the analysis. Map 2.4 shows where winter maintenance data were available within the study area. Some portions of the study area were not well represented for local road deicing, and the dataset may underestimate the chloride load in those areas. Furthermore, the data reported separately to the Commission was typically limited to the 2018-19 winter season, the first winter of the study period. The average annual chloride mass load from winter maintenance operations on county highways and local roadways in the Region during the study period was 135,140 tons per winter season, approximately 204 times the average annual chloride load in the Region from atmospheric deposition.[94] The monthly chloride loads resulting from deicing and anti-icing activities for the MS4 communities located within the Region over the three winter seasons are presented in Figure 3.6.

The total amount of deicing and anti-icing materials applied to County Trunk Highways within each monitoring site drainage area was estimated using a GIS procedure similar to the analysis performed for the state and federal highways. The Regional transportation network dataset was geospatially intersected with the site drainage areas using GIS to determine the total lane miles of County Trunk Highways (CTH) in each County within each drainage area. A County lane mile ratio was computed for every county in a specific drainage area by dividing the County roadway lane miles within the drainage area by the total CTH lane miles in the County. Similarly, for the portions of any drainage area located outside of the Region, a lane mile ratio was computed for each county outside the Region and applied to the MS4 county data. The chloride loads for each drainage area were estimated by multiplying the lane mile ratio computed for each county by the total monthly usage for each county, and combining Regional chloride loads with chloride loads estimated for areas outside of the Region as necessary.

A different approach was taken for local roads that are maintained by municipalities and communities in the Region, focused on an areal proportioning methodology that assumes a relatively equal distribution of local roadways and winter road maintenance throughout the community. This approach was necessary due to a lack of detailed lane mile data available for local roadway mapping at a Regional scale. This simplification was considered acceptable at a Regional scale considering the relatively dense distribution of local roads within a municipality compared to the sparser distribution of county, state, and federal highways within the Region. The Commission civil divisions mapping layer was intersected with the monitoring site drainage areas in GIS to determine the areal extent of the communities located within each monitoring site drainage area. For municipalities that straddle drainage area boundaries, the portion of the municipality within the drainage area was divided by the total area of the municipality to compute an areal proportion ratio. The areal proportion ratio was applied to the total reported salt, sand/salt mixture, or salt brine used by the municipality each month, and then converted to a chloride mass load based on the chloride content of the material. Large lakes such as Pewaukee Lake and Geneva Lake were manually removed from consideration in the areal proportioning analysis because they would not receive direct salt applications. Additionally, the analysis was performed only for communities located within the Region as there was no MS4 salt usage data available for municipalities outside the Region.

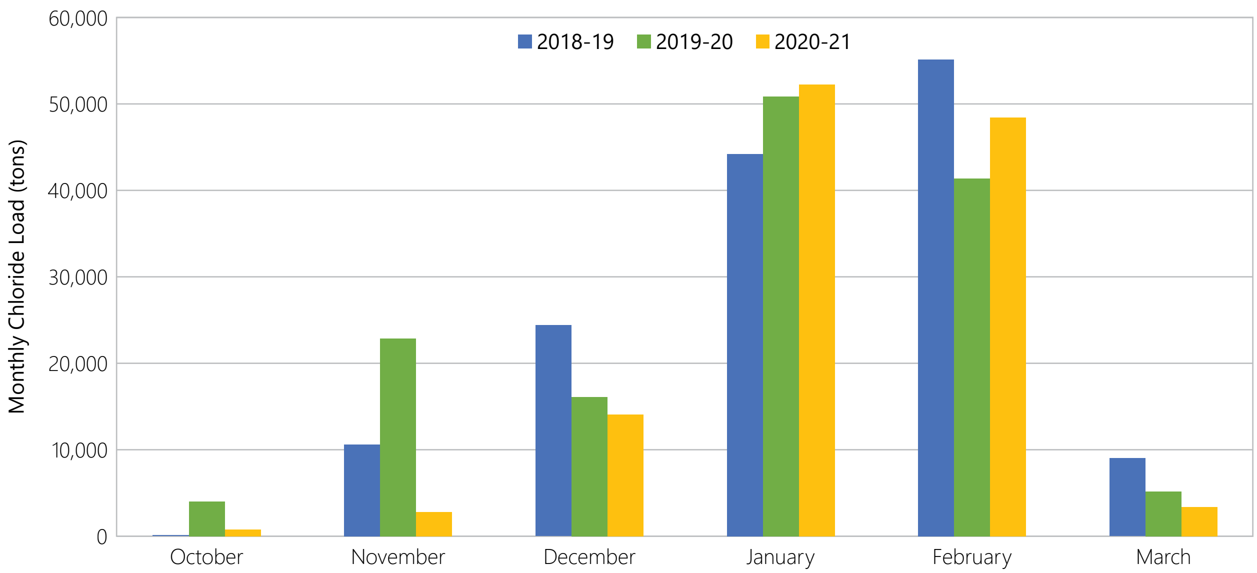
The total chloride mass load for all the municipalities and counties within a drainage area were summed to estimate the total monthly deicing chloride load for each drainage area. The total chloride load from road salt and deicing materials applied to local and county roads within each monitoring site is presented in Chapter 4.

Private Winter Maintenance: Parking Lot Chloride Load

Unlike public road winter maintenance, material usage data were not available for private deicing and anti-icing operations. These operations would include winter maintenance for parking lots, sidewalks, and driveways. For private winter maintenance, the Study analysis focused on deicing of parking lots. Geospatial land use data with detailed land use codes for the existing 2015 land use dataset were examined in GIS to identify all the individual designated parking lot areas within the Region. The off-street parking areas in the existing land use dataset total over 25,500 acres and include parking related to residential, commercial, industrial, transportation, government and institutional, and recreational land uses. It is not practical

[94] The average annual chloride load for the study period was calculated as an average of the rock salt, salt brine, and sand/salt mixture usage totals computed for the 2018-19, 2019-20, and 2020-21 winter seasons. While only a portion of the third winter season was part of the study period, the annual average chloride load for the Region was computed using the full three winter seasons to represent average conditions during the study period.

Figure 3.6
Total Monthly Chloride Loads from Deicing for MS4 Communities in Southeastern Wisconsin



Note: Data reported separately for communities without MS4 permits were not included in the totals above. Also, approximately 99 percent of the chloride comes from rock salt, the rest is from salt brine and a sand/salt mixture.

Source: WDNR and SEWRPC

to assume that every square foot of parking lot in the Region would receive the same level of winter maintenance and salt treatment. Some parking lots may not be in use year-round, and furthermore, many parking lots utilize a portion of the parking surface area for snow storage during winter. To account for this, a reduction factor may be applied for the parking lot area that would receive road salt and these salt application rate assumptions are discussed in the next paragraph.

While actual salt application rates vary based on pavement temperature and weather conditions, data from a literature review and previous studies were taken into consideration to estimate a salt application rate for parking lots. Rock salt was the only deicing material considered in the chloride loading analysis for private parking lots. Salt brine was not estimated because of the relatively low chloride content and smaller contribution to the overall chloride load. The industry standard salt application rate for parking lots was examined as a starting point. As described in Chapter 2, the industry standard for parking lots was estimated at approximately 600 pounds of salt per acre per application or storm event. There were approximately 25 storms per winter season on average from 2018-19 through 2020-21 based on the WisDOT winter storm reports for counties in the study area, which was equivalent to the average applications considered in a 2006 study for the City of Madison.[95] Assuming the industry standard salt application was applied to parking lots 25 times per winter season yields an annual rate of 0.34 pounds per square foot. It was further assumed that 75 percent of the parking lot acreage in the Region would receive salt and that reduction factor was applied to the salt application rate, resulting in an approximate annual rate of 0.26 pounds per square foot per winter season.[96] Therefore, the estimated annual salt application rate assumed for the Study analysis was 0.25 pounds per square foot of parking lot per winter season.[97] Similarly, if the average application rate for parking lots from the City of Madison study is annualized based on 25 events per winter season, the resulting average annual salt application rate for parking lots would be 0.25 pounds per square foot per winter season, further supporting the assumed application rate used in this analysis.

[95] *Madison Wisconsin Salt Use Subcommittee 2006,* op. cit.

[96] *The Madison study considered an 80 percent reduction factor for parking lots, as cited in Madison Wisconsin Salt Use Subcommittee 2006,* op. cit.

[97] *This value is also in line with the average of the annual application rates reported in Sasson and Kahl 2007,* op. cit.

The total annual chloride load estimated for private parking lot salting in the Region is approximately 84,430 tons per winter season on average, equivalent to approximately 128 times the average annual amount of chloride the Region received through atmospheric deposition during the study period. This analysis does not include the study areas outside of the Region because the detailed land use dataset with parking areas delineated does not extend beyond the Regional boundaries. However, since it is the best available data, the Regional detailed land use dataset was used for the individual site load analysis described in the following paragraph. It should be noted that the total parking lot area and the subsequent chloride load from private parking lot salt applications may be underestimated for monitoring sites with drainage areas extending outside the Region (Sites 21, 23, 28, 38, 40, 41, and 58). This was considered acceptable for the analysis because the areas outside of the Region in the upper Milwaukee River watershed are dominated by largely rural and natural lands, with fewer parking lots than in areas with more urban land uses.

To estimate the total acres of parking lots in each monitoring site drainage area, the Regional existing land use dataset was intersected with the monitoring site drainage areas using GIS. The estimated annual salt application rate of 0.25 pounds per square foot was applied to the total parking lot area within each drainage area to determine the total amount of salt applied per winter season. To better estimate the monthly parking lot deicing during the study period, the monthly distribution of the WisDOT salt usage data for each monitoring site was applied to the total amount of salt used on parking lots per winter season to estimate the monthly private parking lot salt usage. The results of the mass balance analysis and chloride load analysis for monitoring site drainage areas are presented in Chapter 4.

Wastewater Treatment Facility Effluent Chloride Load

The average monthly chloride load discharged to surface waters of the Region through wastewater treatment facility (WWTF) effluent was estimated for facilities in the study area using chloride sample data and flow data collected by each facility to satisfy WDNR permit requirements. Daily WWTF effluent flow data was used to compute the average monthly flow for the chloride loading computations. When effluent flow data was not available, influent flow was used and assumed to be the equivalent to the effluent flow. This assumption does not account for any water that could be lost or gained throughout the treatment process but was considered acceptable based on conversations with the WDNR.

Many, but not all, WWTFs in the Region are required by permit to monitor chloride in their wastewater effluent discharged to the environment. When possible, average monthly effluent chloride concentrations were computed directly from chloride samples collected each month during the study period. For WWTFs that did not have chloride data for every month of the study period, average monthly chloride concentrations were estimated using the best available data. For example, monthly average chloride concentrations were computed for some facilities using chloride sample data collected outside the study period. For facilities that are not required to regularly monitor for chloride, chloride sample data were limited to the few chloride samples submitted to the WDNR with the facility permit application to provide evidence of compliance with water quality standards.

The six public WWTFs that discharge effluent directly to Lake Michigan are not required by permit to monitor chloride. These facilities serve some of the largest cities in the Region, including Milwaukee, Racine and Kenosha. Since these facilities serve approximately two-thirds of the population within the Southeastern Wisconsin Region, a separate chloride load was computed for the facilities that discharge directly to Lake Michigan. The wastewater received by these WWTFs would likely have a lower concentration of salt from residential water softeners since most of the population served are on Lake Michigan water supply. However, the large WWTF facilities that discharge directly to Lake Michigan also serve many significant industrial and commercial users, which have the potential to generate wastewater with high levels of chloride. While regular chloride monitoring is not required for these six WWTFs, each facility must submit supplemental chloride sample data to the WDNR as part of the Wisconsin Pollutant Discharge Elimination System (WPDES) permit renewal process. Most of these chloride samples were collected between 2015 and 2024 and were considered acceptably representative of chloride concentrations during the study period. An average chloride concentration was computed for each facility based on supplemental chloride sample data submitted to the WDNR with WPDES permit application documents. The average chloride concentrations were multiplied by the flow rate data for these facilities to determine a monthly chloride mass load for each facility during the study period. Table 3.2 summarizes details related to the chloride and flow data used in the analysis.

Table 3.2
Study Period Data and Chloride Loads for Public Wastewater Treatment Facilities Within the Study Area

Facility Name	Daily Flow Monitoring Location	Study Period Average Flow (mgd)	Chloride Monitoring Samples Collected during Study Period	Study Period Average Chloride Concentration (mg/l)	Study Period Months without Chloride Data	Study Period Chloride Load (tons)[a]
Des Plaines Watershed						
Bristol Utility District No.1	Effluent	0.57	15	217	10	426
Paddock Lake Wastewater Treatment Facility	Effluent	0.53	100	332	0	548
Direct Drainage Area Tributary to Lake Michigan						
Kenosha Wastewater Treatment Facility	Influent	28.2	0	173[b]	25	15,287
Milwaukee Metropolitan Sewerage District – Jones Island	Effluent	122.8	0	255[b]	25	98,352
Milwaukee Metropolitan Sewerage District –South Shore	Effluent	102.6	0	278[b]	25	89,901
Port Washington Wastewater Treatment Plant	Effluent	1.72	0	437[b]	25	2,355
Racine Wastewater Utility	Effluent	26.06	0	169[b]	25	13,766
South Milwaukee Wastewater Treatment Facility	Effluent	4.61	0	262[b]	25	3,799
Fox River Watershed						
Village of Bloomfield Utility Department	Effluent	0.39	100	283	0	343
Burlington Water Pollution Control	Effluent	3.53	0	352[c]	25	3,919
Eagle Lake Sewer Utility District	Influent	0.39	78	259	4	325
East Troy Wastewater Treatment Facility	Influent	0.43	100	436	0	596
Fox River Water Pollution Control Center	Effluent	10.4	100	492	0	15,987
Genoa City Water Treatment Plant	Effluent	0.40	3	250	22	370
Lake Geneva Wastewater Treatment Plant	Influent	1.51	25	269	0	1,277
Lyons Sanitary District No. 2	Influent	0.10	12	434	15	135
Mukwonago Wastewater Treatment Plant	Influent	1.09	0	443[d]	25	1,524
Town of Norway Sanitary District No. 1 Wastewater Treatment Facility	Effluent	1.14	102	421	0	1,451
Salem Lakes – Salem Wastewater Treatment Plant[e]	Effluent	1.58	36	386	16	2,165
Salem Lakes – Silver Lake Wastewater Treatment Plant[e]	Influent	0.34	13	443	13	478
Sussex Wastewater Treatment Facility	Effluent	2.40	100	423	0	3,146
Twin Lakes Wastewater Treatment Facility	Effluent	1.02	328	408	0	1,304
Waukesha Wastewater Treatment Facility	Effluent	10.6	100	532	0	17,530
Western Racine County Sewerage District	Effluent	1.22	43	366	14	1,657

Table continued on next page.

Table 3.2 (Continued)

Facility Name	Daily Flow Monitoring Location	Study Period Average Flow (mgd)	Chloride Monitoring Samples Collected during Study Period	Study Period Average Chloride Concentration (mg/l)	Study Period Months without Chloride Data	Study Period Chloride Load (tons)[a]
Milwaukee River Watershed						
Campbellsport Wastewater Treatment Facility	Effluent	0.25	100	393	0	308
Cascade Wastewater Treatment Facility	Effluent	0.09	9	1,089	16	326
Cedarburg Wastewater Treatment Facility	Influent	2.27	100	388	0	2,752
Fredonia Municipal Sewer and Water Utility	Effluent	0.25	11	434	15	367
Grafton Water and Wastewater Utility	Influent	1.73	64	434	9	2,384
Jackson Wastewater Treatment Plant	Effluent	1.22	25	377	0	1,449
Kewaskum Wastewater Treatment Plant	Effluent	0.54	108	484	0	821
Village of Newburg Sanitary Sewer Treatment Facility	Influent	0.12	0	716[f]	25	325
Random Lake Sewage Treatment Plant	Effluent	0.37	100	281	0	320
Saukville Sewer Utility	Effluent	1.25	48	584	13	2,451
Town of Scott Sanitary District No.1[g]	--	--	0	--	25	--
City of West Bend Sewage Treatment Facility	Influent	5.06	270	542	0	8,671
Rock River Watershed						
Allenton Sanitary District Wastewater Treatment Plant	Effluent	0.13	48	435	13	175
Delafield – Hartland Water Pollution Control Commission	Effluent	2.04	100	533	0	3,435
Dousman Wastewater Treatment Facility	Effluent	0.52	0	273[h]	25	456
Fontana – Walworth Water Pollution Control Commission	Effluent	1.40	112	409	0	1,786
Hartford Water Pollution Control Facility	Influent	2.30	100	460	0	3,288
Oconomowoc Wastewater Treatment Plant	Influent	2.86	100	444	0	3,988
Sharon Wastewater Treatment Facility	Effluent	0.33	0	258[i]	25	265
Slinger Wastewater Treatment Facility	Effluent	0.88	756	537	0	3,146
Walworth County Metropolitan Sewerage District	Influent	5.38	9	292	16	5,205
Whitewater Wastewater Treatment Facility	Effluent	1.71	10	221	15	1,254
Root River Watershed						
Union Grove Wastewater Treatment Plant	Effluent	1.27	102	339	0	1,319
Yorkville Sewer Utility District No. 1	Effluent	0.08	100	577	0	147
Sheboygan River Watershed						
Belgium Wastewater Treatment Facility	Effluent	0.32	8	244	17	244

Table continued on next page.

Table 3.2 (Continued)

Note: See Map 2.6 for the public wastewater treatment facility locations.

[a] *The chloride load for the study period was computed using monthly data and summed over the study period; the average flow and chloride concentration data presented in the table were not directly used in the analysis.*

[b] *Average chloride concentrations for facilities discharging directly to Lake Michigan were computed based on supplemental chloride sample data submitted to the WDNR with permit application documents. The South Milwaukee facility did not have any available chloride data, and the average chloride concentration was computed from the average of the other five WWTFs discharging directly to Lake Michigan.*

[c] *The Burlington facility was not required to monitor chloride during the study period, and the average chloride concentration was computed based on 42 samples collected between 2000 and 2023.*

[d] *The Mukwonago facility was not required to monitor chloride during the study period, and the average chloride concentration was computed based on 16 samples collected between 2008 and 2019.*

[e] *The Town of Salem and Village of Silver Lake merged to create the Village of Salem Lakes in 2017. At the time of water quality monitoring site selection and throughout a portion of the water quality data collection period for the Chloride Impact Study, the Village of Salem Lakes was served by two wastewater treatment facilities that originally served the two separate municipalities. In 2021 a project was completed that converted the Silver Lake Wastewater Treatment Plant to a lift station that now pumps wastewater to a sanitary sewer where it then flows by gravity to the Salem Wastewater Treatment Plant for treatment. The latter plant was expanded and currently operates as the only wastewater treatment facility for the Village of Salem Lakes.*

[f] *The Newburg facility was not required to monitor chloride during the study period, and the average chloride concentration was computed based on 4 samples collected in 2022.*

[g] *The Town of Scott facility discharges to soil, and there were no flow or chloride data available.*

[h] *The Dousman facility was not required to monitor chloride during the study period, and the average chloride concentration was computed based on 46 samples collected between 2000 and 2021.*

[i] *The Sharon facility was not required to monitor chloride during the study period, and the average chloride concentration was computed based on 192 samples collected between 1999 and 2018.*

Source: WDNR and SEWRPC

The average annual chloride load from public WWTFs that discharge into streams and rivers in the study area was approximately 46,280 tons per year during the study period, equivalent to about 70 times the average annual amount of chloride from atmospheric deposition across the Region. The average annual chloride load from public WWTF effluent discharged directly to Lake Michigan during the study period was estimated to be 107,260 tons per year, which is approximately 2.3 times the amount of chloride discharged to streams from the other public WWTFs in the study area and 162 times the average annual amount of chloride from atmospheric deposition across the Region. To estimate the chloride load from WWTF effluent for individual monitoring sites, the chloride load for each facility located in the upstream drainage area of the monitoring site were summed. Table 3.3 identifies the WWTFs that were located within the contributing drainage area and discharge treated wastewater effluent upstream of each stream monitoring site. The results of the chloride loading analysis for public WWTF effluent for the entire study area and upstream of individual stream monitoring sites are presented in Chapter 4.

Private Onsite Wastewater Treatment (Septic) Systems

As detailed in Chapter 2, the existing sewered and unsewered populations and households in the Region were based on 2010 census data. In 2010 there were approximately 81,909 unsewered households in the Region with an estimated population of 222,942. This equates to approximately 10 percent of the Regional population which were not served by a public sanitary sewer system. The 2010 unsewered household and population data was further broken out to estimate the percentage of septic systems versus holding tanks. Data provided by Walworth, Washington, and Waukesha County indicated that less than five percent of the unsewered households use holding tanks in those counties combined.[98] The unsewered households in those counties represent about 75 percent of the unsewered households in the Region as a whole. Conservatively, it was assumed that all of the unsewered households are on septic systems, neglecting the small percentage that have holding tanks. While some areas have locally higher concentrations of holding tanks, such as residential properties adjacent to some of the Regional lakes, in general the Counties prohibit holding tanks for new residential construction. This assumption provides a conservative yet reasonable representation of private septic systems across the Region.

The following data was used to estimate the potential chloride loading from different domestic sources of chloride. However, this Study did not explicitly include background chloride concentrations in the water supply. The chloride from domestic waste sources such as human excreta and household products was estimated from literature values as a combined 34,000 milligrams (mg) of chloride per person per day, which is approximately equivalent to 27.3 pounds of chloride per person per year.[99] The chloride mass load for the Region was estimated by multiplying the Regional unsewered population by the per capita chloride estimates, resulting in 3,043 tons of chloride per year across the Region.

The Study analysis assumed that the unsewered households in the Region use groundwater supply and also utilize a conventional salt-based water softener for all indoor residential water usage. Chapter 2 discusses how water softener salt usage is dependent on several factors and considers an upper limit of 480 pounds per household per year. For the septic system chloride load analysis, an average water softener salt usage of 420 pounds per household per year was assumed for the unsewered households in the Region, which is equivalent to 35 pounds per household per month. When applied to the total unsewered households in the Region, the total mass of chloride from water softener salt was approximately 10,435 tons per year.

[98] *Email correspondence between Walworth County staff (R. Dorgay) and Commission staff (L. Herrick), July 18, 2025; Email correspondence between Washington County staff (M. Zawicki) and Commission staff (L. Herrick), July 2, 2025; Email correspondence between Waukesha County staff (S. Behm) and Commission staff (L. Herrick), July 3, 2025.*

[99] *V.R. Kelly, G.M. Lovett, K.C. Weathers, S.E.G. Findlay, D.L. Strayer, D.J. Burns, and G.E. Likens, "Long-Term Sodium Chloride Retention in a Rural Watershed—Legacy Effects of Road Salt on Streamwater Concentration," Environmental Science & Technology, 42:410-415, 2008.*

Table 3.3
Stream Monitoring Sites that Receive Streamflow Containing Treated Wastewater Effluent

SEWRPC Site No.[a]	Site Name	Wastewater Facility Discharging Effluent to Surface Water[b]
1	Fox River at Waukesha	Sussex Wastewater Treatment Facility Fox River Water Pollution Control Center
2	Fox River at New Munster	Sussex Wastewater Treatment Facility Fox River Water Pollution Control Center Waukesha Wastewater Treatment Facility Mukwonago Wastewater Treatment Plant Town of Norway Sanitary District No. 1 Wastewater Treatment Facility Western Racine County Sewerage District Eagle Lake Sewer Utility District East Troy Wastewater Treatment Facility Lyons Sanitary District No. 2 Burlington Water Pollution Control
6	White River near Burlington	Lyons Sanitary District No. 2
23	Milwaukee River Downstream of Newburg	Campbellsport Wastewater Treatment Facility Kewaskum Wastewater Treatment Plant City of West Bend Sewage Treatment Facility Village of Newburg Sanitary Sewer Treatment Facility
25	Root River Canal	Union Grove Wastewater Treatment Plant
28	East Branch Rock River	Allenton Sanitary District Wastewater Treatment Plant
30	Des Plaines River	Paddock Lake Wastewater Treatment Facility Bristol Utility District No. 1
32	Turtle Creek	Walworth County Metropolitan Sewerage District
36	Honey Creek Downstream of East Troy	East Troy Wastewater Treatment Facility
38	North Branch Milwaukee River	Cascade Wastewater Treatment Facility Random Lake Sewage Treatment Plant
41	Milwaukee River near Saukville	Campbellsport Wastewater Treatment Facility Kewaskum Wastewater Treatment Plant City of West Bend Sewage Treatment Facility Village of Newburg Sanitary Sewer Treatment Facility Cascade Wastewater Treatment Facility Random Lake Sewage Treatment Plant Fredonia Municipal Sewer and Water Utility
47	Fox River at Rochester	Sussex Wastewater Treatment Facility Fox River Water Pollution Control Center Waukesha Wastewater Treatment Facility Mukwonago Wastewater Treatment Plant Town of Norway Sanitary District No. 1 Wastewater Treatment Facility
51	Rubicon River	Slinger Wastewater Treatment Facility
52	Cedar Creek	Jackson Wastewater Treatment Plant
58	Milwaukee River at Estabrook Park	Campbellsport Wastewater Treatment Facility Kewaskum Wastewater Treatment Plant City of West Bend Sewage Treatment Facility Village of Newburg Sanitary Sewer Treatment Facility Cascade Wastewater Treatment Facility Random Lake Sewage Treatment Plant Fredonia Municipal Sewer and Water Utility Saukville Sewer Utility Grafton Water and Wastewater Utility Jackson Wastewater Treatment Plant Cedarburg Wastewater Treatment Facility
59	Root River near Horlick Dam	Union Grove Wastewater Treatment Plant Yorkville Sewer Utility District No.1

[a] *See Map 2.3 for the locations of the stream monitoring sites.*

[b] *See Map 2.6 for the locations of the public wastewater treatment facilities and Appendix B for wastewater treatment facility locations within the stream monitoring site drainage areas.*

Source: WDNR and SEWRPC

The 420 pounds per household per year annual water softener salt usage assumption was checked using an alternate methodology from a Minnesota study, which estimated water softener salt usage based on per capita water usage, water hardness to be removed, and water softener efficiency using the following equation.[100]

$$\left(\frac{Hardness\ removed\ in\ grains\ per\ gallon\ (gpg) * Per\ capita\ water\ usage\ in\ gallons\ (gal) * Population\ using\ water\ softeners}{Average\ water\ softener\ efficiency\ in\ grains\ per\ lb\ NaCl}\right)$$

= Water softener salt usage in pounds (lb NaCl)

The 2015 USGS domestic water use data for each County in the Region were used to estimate per capita water use; the Regional average of 57.8 gallons per day (gpd) per capita was rounded up to 60 gpd for use in the equation.[101] The average Regional hardness of the assumed groundwater supply was estimated using shallow sand and gravel aquifer hardness data from a 1981 USGS study.[102] The average of the mean hardness for the Region was 359 milligrams per liter (mg/l).[103] Similar to the Minnesota study, it was conservatively assumed that water is softened to zero grains per gallon (gpg), for a total hardness removed of 21 gpg.[104] The Minnesota study assumed water softener efficiencies of 2,000 and 4,000 grains per pound of salt for timer and demand-based water softeners, respectively. An average water softener efficiency of 3,000 grains per pound of salt was assumed for this analysis. Using the above parameters along with the total unsewered population in the Region results in an estimated 10,364 tons of chloride per year from water softener salt usage. This calculated chloride load is less than one percent different than the chloride load computed using the assumed 420 pounds of water softener salt per household per year; the similar results provide further support for the assumed water softener salt usage per household.

The estimated chloride from domestic waste sources were added to the chloride estimates for water softener salt usage to determine the Regional chloride load from private septic systems. Based on the estimates of chloride loading for the unsewered households and population in the Region, the total chloride load estimated for private septic systems in the Region is approximately 13,480 tons per year, which is equivalent to approximately 20 times the average annual amount of chloride the Region receives through atmospheric deposition. The chloride load from private septic systems was not estimated for individual monitoring site drainage areas for the mass balance analysis because this source is designed to discharge wastewater to subsurface soils for treatment and ultimately to groundwater. While there may be subsurface pathways that transport the treated wastewater to a surface waterbody over longer periods of time, it is not possible to determine the timing nor the amount of chloride from septic systems that end up in streams versus the deeper groundwater aquifer. Thus, chloride contributions from septic systems were included in the Regional chloride budget but were not calculated for individual monitoring sites or included in the mass balance analysis.

Industrial Wastewater Effluent Chloride Load

While there are hundreds of industrial operations located within the Region, this Study focused on those facilities that were permitted to discharge wastewater to surface waters and were also required by permit to monitor chloride in the wastewater effluent. The locations of these facilities are shown on Map 2.7. The WDNR provided water quality monitoring data for each facility that included chloride concentrations and flow rates. The flow rate data available for each facility ranged from daily measurements to monthly observations. The frequency of effluent chloride sampling was monthly at best; however, most of the industrial wastewater permittees had a more sporadic sampling frequency that varied by facility. Table 3.4 summarizes details related to the flow rate and chloride dataset available for each facility during the study

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[100] *A. Overbo, S. Heger, and J. Gulliver, "Evaluation of Chloride Contributions for Major Point and Nonpoint Sources in a Northern U.S. State," Science of the Total Environment, 764: 144179, doi: 10.1016/j.scitotenv2020.144179, 2021.*

[101] *U.S. Geological Survey,* USGS Water Use Data for Wisconsin: 1985-2015, *waterdata.usgs.gov/wi/nwis/wu, accessed June 2025.*

[102] *P.A. Kammerer, Jr.,* Ground-Water-Quality Atlas of Wisconsin, *United States Geological Survey Information Circular 39, 1981.*

[103] *The mean hardness value is in line with the shallow well data from the WDNR Groundwater Retrieval Network (GRN) and data from the University of Wisconsin Stevens Point well database. Additionally, GRN hardness samples collected over the last 50 years show no discernable trend over time, hence the relatively stable nature of the data supports use of the 1981 USGS report to represent shallow groundwater conditions during the study period.*

[104] *Hardness may be measured in grains per gallon (gpg) or an equivalent concentration of calcium carbonate ($CaCO_3$) in mg/l, and one gpg is equivalent to 17.1 mg/l.*

Table 3.4
Study Period Data and Chloride Loads for Industrial Wastewater Dischargers Within the Study Area

Facility ID	Industrial Facility Type	Flow Monitoring Frequency	Study Period Months Missing Flow Data	Chloride Samples Collected During the Study Period	Study Period Months Missing Chloride Data	Estimated Average Chloride Concentration (mg/l)	Study Period Chloride Load (tons)	SEWRPC Sites Downstream (site no.)
I-1	Chemical Manufacturer	Daily	1	24	1	155	44.0	2
I-2	Metal Manufacturer/Forge	Monthly	0	22	3	224	7.1	--
I-3	Food Processing	Daily	0	0	25[a]	2.8	0.7	14
I-4	Chemical Manufacturer[b]	Daily	25	0	25[a]	1.3	0.4	11, 55
I-5	Food Processing	Daily	0	0	25[a]	217	39.2	30
I-6	Food Processing	Daily	0	0	25[a]	34.8	0.6	38, 41, 58
I-7	Food Processing	Daily	0	86	0	88	23.0	--
I-8	Food Processing	Daily	0	25	0	176	563.3	38, 41, 58
I-9	Manufacturer	Daily	1	22	3	205	255.8	32
I-10	Manufacturer	Daily	7	5	20	477	75.5	59
I-11	Food Processing	Daily	0	89	3	443	271.3	58
I-12	Fish Hatchery	Monthly	0	4	21	19.9	44.5	38, 41, 58

Note: See Map 2.7 for the locations of each industrial facility.

[a] *Average chloride concentration was estimated using chloride samples collected outside of the 25-month study period.*

[b] *Monitoring data for this facility was collected from November 2020 through December 2023.*

Source: WDNR and SEWRPC

period. Of the 12 industrial wastewater dischargers considered in this analysis, the table shows that two facilities had chloride data for every month of the 25-month study period, four were missing data for 3 months or less, and six facilities were missing data for 20 months or more, including four facilities had no chloride sample data collected during study period. An average monthly chloride load was estimated for each month of the study period, either using chloride sample data or when sample data were not available, estimated chloride concentrations were developed using chloride data collected outside of the October 2018 to October 2020 study period. The average monthly chloride concentration and flow data were multiplied to estimate the monthly chloride mass load for each industrial facility. The total chloride loads computed for each industrial facility over the 25-month study period are presented in Table 3.4.

The resulting average annual chloride load estimated for industrial wastewater point source discharge in the study area was 640 tons per year, which is slightly less than but on the order of the average annual amount of chloride contributed to the Region through atmospheric deposition. It is important to reiterate that these industrial discharge chloride loads do not represent the full extent of chloride contributed to the environment by industrial facilities, but only those that discharge directly to surface water and are required to provide chloride monitoring data to the WDNR. These estimates do not include chloride from industrial wastewater discharge sent to municipal wastewater treatment facilities or disposed of through land spreading. The results of the chloride loading analysis for industrial wastewater effluent for the entire study area and upstream of individual stream monitoring sites are presented in Chapter 4.

Agricultural Sources of Chloride

Agricultural sources of chloride that were analyzed for the Study include agricultural fertilizers, livestock operations, and irrigation.

Chloride Load from Agricultural Fertilizer

While the types of crops planted and fertilizing practices can vary year to year, the first step in determining how much chloride was applied to the Region through agricultural fertilizers during the study period was to determine which crops were grown between 2018 and 2020. The cropland raster data were downloaded from the Cropscape website, and ArcMap was used to convert the spatial raster data into shapefiles and reproject the data into the proper coordinate system.[105] The annual cropland datasets were geospatially intersected with County and stream monitoring site drainage area shapefiles to estimate the total acreage of different crops grown each year throughout the Region. Based on this geo-spatial analysis, selected crops grown within the Region are summarized in Table 3.5. Of the crops grown most prevalently in the Region, corn, soybeans, and alfalfa utilize the greatest amount of potassium. Potatoes, barley, and winter wheat require potassium as well, but these crops are grown in much smaller quantities within the Region. As such, the only crops that were considered for the potash fertilizer chloride loading analysis were corn, soybeans, and alfalfa. Table 3.6 summarizes the total acreage of these three crops within each County for the 2018 through 2020 growing seasons. Additionally, pastureland is rarely fertilized aside from incidental manure applications during livestock grazing and was not considered in the analysis. This assumption is supported by Table 40 of the 2017 Census of Agriculture, which shows that the acres of pastureland that are fertilized are a fraction of a percent of the total cropland acres in the Region that are fertilized.[106]

After determining the types of crops that are grown within the study area, the amount of potash fertilizer applied to relevant crops was estimated. The U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) agricultural chemical use reports for corn and soybeans were used to estimate potash usage on these crops in Wisconsin.[107,108] The statewide 2018 data for corn indicates that approximately 79 percent of the acres planted with corn received potash with an average application rate of 76 pounds per acre per year. Similar information was obtained from the 2020 soybean data showing

[105] *USDA National Agricultural Statistics Service,* Cropland Data Layer: USDA NASS, *USDA NASS Marketing and Information Services Office, Washington, D.C., nassgeodata.gmu.edu/CropScape, accessed December 2022.*

[106] *USDA National Agricultural Statistics Service 2017.* op. cit.

[107] *USDA National Agricultural Statistics Service,* Agricultural Chemical Use Program, 2018 Agricultural Chemical Use Survey: Corn, *nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use, accessed December 2022.*

[108] *USDA National Agricultural Statistics Service,* Agricultural Chemical Use Program, 2020 Agricultural Chemical Use Survey: Soybeans, *nass.usda.gov/Surveys/Guide_to_NASS_Surveys/Chemical_Use, accessed December 2022.*

that approximately 77 percent of the acres planted with soybeans received potash with an average application rate of 92 pounds per acre per year. These rates were applied to the cropland acres planted each year with corn and soybeans, respectively, to estimate the amount of potash applied to those crops annually during the study period.

Table 3.5
Selected Crops Grown Within the Region: Cropscape Datasets 2018-2020

Type of Crop	2018 (acres)	2019 (acres)	2020 (acres)
Corn	270,184	210,740	278,215
Soybeans	180,390	149,829	170,664
Pasture/Grasslands	159,507	128,005	123,459
Alfalfa	69,803	82,958	90,378
Winter Wheat	31,440	24,893	17,378
Barley	68	62	193
Potatoes	28	15	54

Source: USDA NASS

The amount of potash fertilizers applied annually to alfalfa fields within the study area was estimated using the fertilizer application rate guidelines presented in Table 7.4 of the Nutrient Allocation Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin, along with assumptions for soil conditions and target crop yields.[109] Potassium soil conditions were estimated using the results from soil testing data for all farmer field samples analyzed between 2005 and 2019 to estimate a mean potassium soil concentration for each County. Overall, the soils in the Region range between optimum levels and high levels for potassium, with a majority falling within the optimum range.[110] The crop yield data for alfalfa in the state of Wisconsin compiled by the USDA NASS was 2.35 tons per acre in 2018, 2.4 tons per acre in 2019, and 3.2 tons per acre in 2020. The target crop yield goal range was set to the next higher yield category. Based on the fertilizer application guidelines for alfalfa, considering optimum potassium soil conditions and a target crop yield of 3.6 to 4.5 tons per acre, the recommended potash application rate of 240 pounds per acre per year was used to estimate the total potash applied to alfalfa during the study period.

As mentioned in Chapter 2, potassium chloride (KCl) is the most prevalent form of potash fertilizer used in the United States. Regardless of what form of potash is applied, it is often reported as a mass of potassium oxide (K_2O), which was converted to an equivalent amount of KCl required to deliver an equal mass of potassium to the soil. Using chemical stoichiometry, the mass quantity of K_2O was multiplied by 1.583 to determine the mass of KCl with an equivalent amount of potassium. Since KCl is 47.6 percent chloride by weight, the mass quantity of KCl was multiplied by 0.476 to get mass quantity of chloride. The resulting ratio of K_2O to KCl is approximately 0.754, which is aligned with literature values ranging from 0.76 to 0.78.[111] These chloride load estimates are conservative, representing the maximum amount of chloride applied as potash, assuming all potash is applied as KCl. This is a reasonable assumption as historical fertilizer usage data compiled by the USDA show that approximately 90 percent of the potash applied in the United States between 1960 and 2015 is applied as KCl.[112,113] Other references have estimated this value could be as high as 95 percent as discussed in Chapter 2. However, it is likely that the amount of chloride applied may be smaller, because potash can be applied as KCl or a variety of other compound forms. These estimates also do not account for any crop uptake of chloride, which is an appropriate assumption for the types of crops considered in the analysis, considering that chloride is a micronutrient and is applied in much larger amounts than is utilized by plants.

The timing of fertilizer applications across the Region is complex and varies by crop, by location, and by year. Fertilizer application timing guidelines for row crops like corn or soybeans recommend fertilizer applications either in spring or in fall, or split applications based on different considerations including crop type and toxicity risk, as well as weather and soil conditions. In southeastern Wisconsin, potash is typically applied to alfalfa fields several times during the growing season following each cutting, with the first cutting typically in June and the last cutting in the fall.[114] For the mass balance analysis the monthly

[109] *C.A.M. Laboski and J.B. Peters 2012,* op. cit.

[110] *K.A. Kelling, L.G. Bundy, S.M. Combs, and J.B. Peters 1999,* op. cit.

[111] *Granato et al. 2015,* op. cit.

[112] *USDA Economic Research Service,* Fertilizer Use and Price: Table 5. U.S. consumption of selected phosphate and potash fertilizers, *October 30, 2019 Version, ers.usda.gov/data-products/fertilizer-use-and-price, accessed June 2022.*

[113] *This percentage was estimated by averaging the annual total for U.S. consumption of KCl compared with the average of annual usage for other single nutrient forms of potash presented in Table 5 of the above reference.*

[114] *Email correspondence between Walworth County staff (B. Smetana), WDNR staff (S. Haydin) and Commission staff (L. Herrick), April 15, 2019.*

Table 3.6
County Crop Inventories by Acre: Cropscape Datasets 2018-2020

Type of Crop	Kenosha (acres)	Milwaukee (acres)	Ozaukee (acres)	Racine (acres)	Walworth (acres)	Washington (acres)	Waukesha (acres)	Region (acres)
2018 Growing Season								
Corn	35,260	2,061	19,616	41,344	108,053	36,023	27,827	270,184
Soybeans	26,220	2,910	13,602	37,389	57,475	24,759	18,035	180,390
Alfalfa	5,601	446	12,078	6,685	18,350	18,345	8,298	69,803
2019 Growing Season								
Corn	19,778	580	18,916	20,575	96,826	34,757	19,308	210,740
Soybeans	21,033	1,640	11,468	29,642	46,919	23,486	15,642	149,830
Alfalfa	6,800	907	13,890	7,899	20,177	22,721	10,565	82,959
2020 Growing Season								
Corn	31,701	2,436	22,929	40,731	112,623	40,234	27,560	278,214
Soybeans	27,112	2,638	12,184	34,838	53,763	22,701	17,425	170,661
Alfalfa	6,719	847	16,739	7,954	21,281	26,303	10,534	90,377

Source: USDA NASS

chloride load from fertilizer was estimated by distributing the total annual load equally across the warmer season months from April to October. This assumption was considered reasonable given the temporal uncertainty in the dataset and variability of fertilizer application timing, and the relatively long chloride transport times through soil. It is likely that chloride from fertilizer applications slowly move through the soil over the growing season, year after year.

The average annual chloride load from agricultural fertilizer applied to the Region during the study period was approximately 17,510 tons per year. This average was computed for three growing seasons over the period from 2018 to 2020 and is equivalent to approximately 26 times the average annual amount of chloride from atmospheric deposition over the Region during the study period. The total annual chloride load from potash by crop type for each County in the Region is presented in Figure 3.7. Additional results and details for chloride loading from agricultural fertilizer are discussed in Chapter 4.

Chloride Load from Livestock Operations

Livestock operations contribute chloride to the environment predominantly through animal waste (manure). Two sources of livestock manure data were utilized for the Study. Countywide livestock inventories were used to estimate chloride loads for the Region, and CAFO data were used to estimate chloride loads for individual monitoring sites as detailed in the following sections.

Total Regional Chloride Load from Livestock Manure

The total Regional chloride load from livestock manure was computed using the livestock inventory data from the 2017 Census of Agriculture paired with chloride concentration data for various types of manures as discussed in Chapter 2. Of the livestock listed in Table 2.8, chloride loading estimates were made for all animals except goats, due to a lack of chloride data available for goat manure. This was considered acceptable based on the relatively small Regional goat inventory. The computations for the Regional livestock chloride load estimates are detailed in the following paragraphs.

A 2003 American Society of Agricultural Engineers (ASAE) standard provides manure characteristics for different types of livestock as well as the typical live animal mass per animal.[115] The chloride content for manure generated by dairy cattle, swine, sheep and layers (chicken) is reported in pounds of chloride per 1,000 pounds of live animal mass (equivalent to one animal unit (AU) per day. To determine the chloride generated daily by these livestock populations, the total number of animals were multiplied by the typical live animal mass converted to animal units and the chloride content using the data shown in Table 3.7. For the purposes of estimating a Regional chloride load from livestock, the chloride content for layers was applied to the other types of chickens represented in the inventory under the broilers and pullets categories.

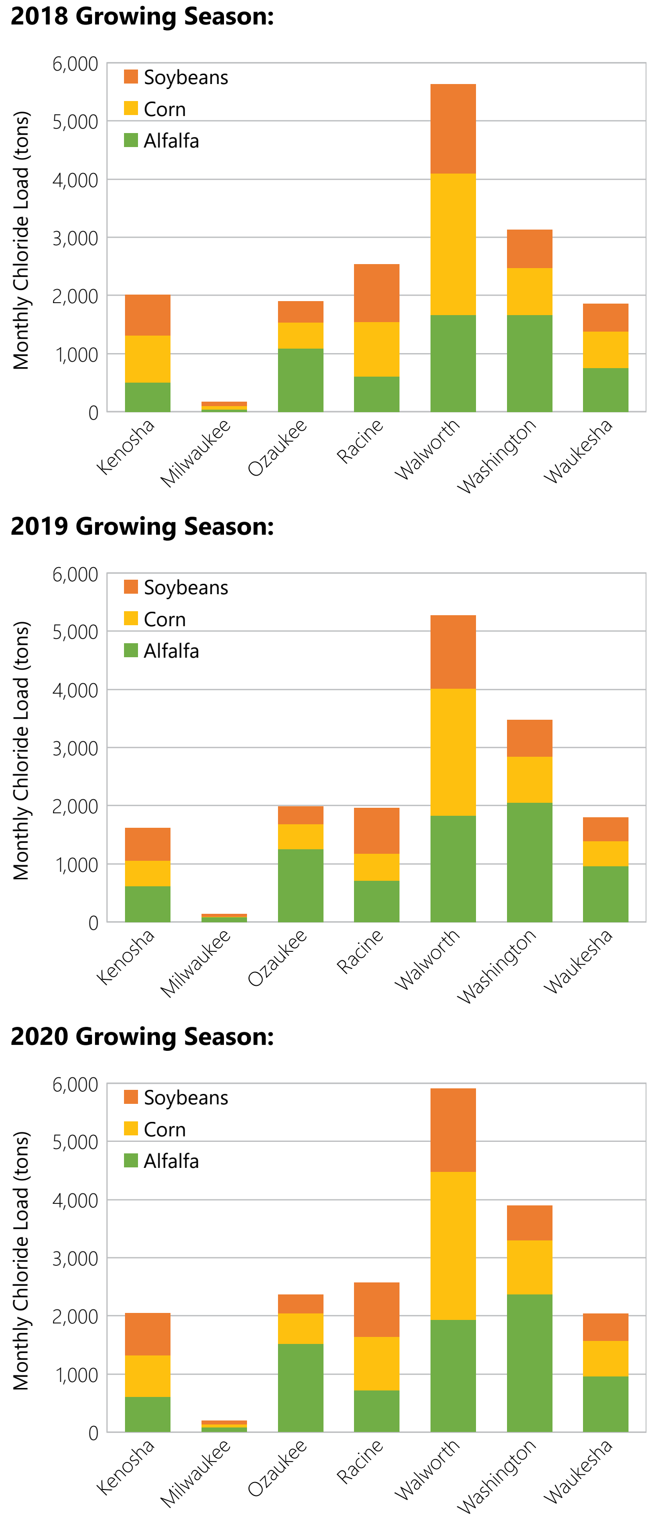
[115] *American Society of Agricultural Engineers,* Manure Production and Characteristics, *Standard ASAE D384.1 FEB03, St. Joseph, MI, 2003.*

A different approach was taken to determine the chloride load from livestock manure for horses, beef cows, and turkeys. The daily manure production per animal was obtained from the USDA/Natural Resources Conservation Service (NRCS) 2016 technical note and multiplied by the total number of animals to estimate total waste generated daily.[116] Chloride concentration data for different types of animal manure were obtained from various sources as shown in Table 3.7. These estimated chloride concentrations were applied to the total waste generated by the livestock populations to estimate the total chloride mass load.

The 2017 livestock inventory for the Region includes a breakout of the cattle and calves category into three subgroups: dairy cows, beef cows and other cattle. The "other cattle" subgroup is defined as heifers that had not calved, steers, bulls, and calves. The "other cattle" subgroup made up approximately 60 percent of the total Regional inventory of cattle and calves in 2017, so it was important to include an estimate of the potential chloride load generated from such a large proportion of livestock in the Region. The distribution of cattle and calves documented for each dairy concentrated animal feeding operation (CAFO) in the Region was used to estimate the type and size of livestock represented by the "other cattle" subgroup. While CAFOs are addressed in detail in the next section, livestock inventories were obtained from the CAFO AU calculation worksheets to develop a distribution of dairy CAFO livestock in the Region by animal type and size.[117] The dairy CAFO livestock distribution was applied to the "other cattle" subgroup to estimate the number of steers, calves, and heifers of various sizes. The chloride load for heifers and calves was calculated by applying the chloride content for dairy cows to the total AU represented by heifers and calves. For steers, the chloride load was computed using the same methodology and data that was used for beef cows.

The annual chloride load from livestock manure estimated for the Region was 3,440 tons per year, with over 95 percent of the chloride load generated by cattle, cows, and calves. The annual chloride load from livestock manure was approximately five times the average annual amount of chloride from atmospheric deposition over the Region during the study period. Figure 3.8 presents the annual chloride load from livestock manure for the seven Counties in the Region. The countywide

Figure 3.7
Annual Estimated Chloride Load from Potash Fertilizer by County and Crop: 2018-2020



Source: USDA NASS and SEWRPC

[116] *United States Department of Agriculture, Natural Resources Conservation Service,* Nutrient Management (590): Wisconsin Conservation Planning Technical Note 1, *February 2016.*

[117] *Wisconsin Department of Natural Resources,* Animal Unit Calculation Worksheet*, Form 3400-025A, revised March 2012.*

Table 3.7
Livestock Manure Characteristics and Data used to Estimate Chloride Loads

Type of Livestock	Daily Chloride Production in Livestock Manure[a] (lb/AU/day)	Typical Live Animal Mass[a] (lb)	Daily Manure Production[b] Solid (lb/day)	Daily Manure Production[b] Liquid (gal/day)	Manure Chloride Concentrations Solid[c] (lb/ton)	Manure Chloride Concentrations Liquid[d] (mg/l)
Dairy Cattle	0.13	--	--	--	--	--
Milking and Dry Cows	--	1,400	--	--	--	--
Heifers (800-1200 lbs)	--	1,100[e]	--	--	--	--
Heifers (400-800 lbs)	--	600[e]	--	--	--	--
Calves (under 400 lbs)	--	200[e]	--	--	--	--
Swine	0.26	135	--	--	--	--
Sheep	0.089	60	--	--	--	--
Layers (chickens)	0.56	4	--	--	--	--
Broilers and Pullets	--	2	--	--	--	--
Beef Cattle	--	--	63	--	4.34	--
Turkeys	--	--	0.9	--	2.7	--
Horses	--	--	--	5.98	--	400

[a] *The daily manure chloride production and typical live animal mass data were obtained from ASAE (2003), except as noted in the table. One animal unit (AU) is equivalent to 1,000 pounds of live animal mass.*

[b] *The daily manure production for various livestock was obtained from USDA/NRCS (2016).*

[c] *Manure chloride concentrations for beef were obtained from Wilson (2018) and turkeys from Sherwood (1989), as cited in Overbo et al. (2021).*

[d] *Manure chloride concentrations for horses were obtained from Panno et al. (2005).*

[e] *Typical live animal mass was estimated using the AU equivalent factors provided in the WDNR Form 3400-025A AU Calculation Worksheets.*

Source: SEWRPC

inventories used to estimate the chloride load for the Region could not be used to estimate the chloride load for individual monitoring sites due to a lack of detailed geospatial data. Instead, manure generated from livestock that are housed on CAFO farms was used to estimate the livestock chloride load for monitoring sites as described in the next section.

Chloride Load from CAFOs within the Study Area

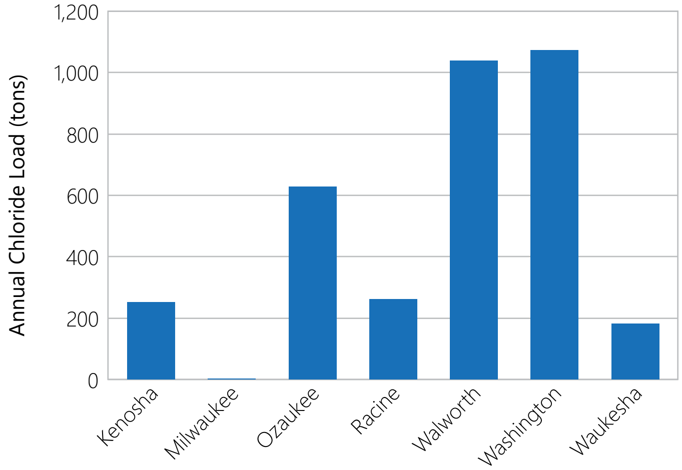
The livestock animals housed at CAFO farms are a subset of the total livestock population within the Region and larger study area. The estimated chloride load from CAFOs located within the study area was computed for use in the mass balance analysis for individual stream monitoring sites. During the study period, a majority of the CAFOs in the study area were dairy operations, along with three "layer" (chicken) CAFOs and one duck CAFO (see Map 2.8). According to the CAFO permit documents, the CAFO operations with layers did not land-spread any chicken manure. All chicken manure generated on the farms was composted and sold as consumer fertilizer off-farm; therefore, the layer CAFOs were not included in the Study analysis. Similarly, the duck CAFO was not included in the chloride loading analysis since the process wash water generated on-farm was sent to a permitted municipal WWTF. While the duck operation was permitted to spread up to 5,000 tons of manure per year, a chloride load was not estimated due to a lack of chloride content data.[118] Hence, the only CAFOs for which a chloride load was estimated for individual monitoring sites were dairy operations, using the methodology described in the following paragraphs.

The animal counts for each dairy CAFO farm from the years 2018 through 2020 were obtained from the AU calculation worksheets downloaded from the WDNR e-permitting website referenced in Chapter 2. The AU calculation worksheets are updated annually and submitted to the WDNR to satisfy CAFO permit requirements. The annual chloride load produced by each CAFO was estimated from the animal counts, along with daily chloride production numbers and manure chloride concentrations from literature. The methodology was similar to the approach used to estimate the Regional chloride load from the County

[118] *Data reported with permit documents show that approximately 1,500 to 2,000 tons of bedding was spread annually during the study period.*

livestock inventories, only with more detailed input data. The AU for milk cows, heifers, and calves were computed and summed, and the dairy manure chloride content from ASAE 2003 was applied to determine the chloride load. The chloride load for steers was computed using the data for beef cows as explained in the previous section and was added the dairy chloride load to estimate the total annual chloride load generated at each dairy CAFO for every year during the study period.

Figure 3.8
Annual Chloride Load Estimated for Livestock Manure Spreading by County: 2017



Source: USDA NASS and SEWRPC

The average annual chloride load estimated for all dairy CAFO operations in the Region was approximately 617 tons and 772 tons for CAFOs within the wider study area (see Map 2.8). Additionally, the chloride load was estimated for stream monitoring sites by summing the chloride load from each CAFO located within the upstream drainage area of individual stream monitoring sites. The entirety of the chloride load from livestock manure was assumed to be land spread within the drainage area in which the main farm site is located; however, there is a chance that some of the manure from the CAFO could be spread in an area outside of the drainage area. Similarly, there are CAFO operations located near but outside of the boundary of the study area that may land spread manure on fields within the study area, but these were not included in the analysis.

The timing of this chloride source was harder to estimate. The spreading logs that were submitted to the WDNR as part of the required permit reporting indicated that the timing of land spreading was variable from year to year and farm to farm. Wisconsin enforces regulations to limit land spreading practices in order to protect water quality; consequently, land spreading is typically performed when conditions are favorable and as needed to free-up additional manure storage on the farm. Because a temporal component is required for the individual site mass balance analyses, it was assumed that the majority of CAFO land spreading occurred during the growing season when the ground is not frozen, thus the annual load was distributed evenly across the months from April to November. Results for the CAFO chloride loading analysis for each monitoring site are presented in Chapter 4.

Irrigation Chloride Load

Based on USGS estimates for 2015, water used for irrigation within the seven counties in southeastern Wisconsin was approximately 9.5 million gallons per day (mgd). The study estimates that 95 percent of the water used for irrigation was pumped from groundwater. Data presented in SEWRPC Technical Report No. 63 (TR-63) related to chloride conditions and trends in groundwater were used to estimate the chloride concentration of irrigation water used in the Region.[119] Considering recent conditions covering the period from 2013 to 2022, the mean chloride concentration in shallow groundwater within the Region was 96.7 mg/l. By multiplying the total water used for irrigation by the average chloride concentration in shallow groundwater, the resulting annual chloride load estimated for the Region was 1,400 tons per year, which is equivalent to approximately twice the average annual amount of chloride resulting from atmospheric deposition over the Region during the study period. An annual chloride load is estimated for this source based on USGS data, but there is no geospatial or temporary component to the dataset, so this source is not included in the individual site mass balance analyses presented in Chapter 4.

[119] *SEWRPC Technical Report No. 63,* Chloride Conditions and Trends in Southeastern Wisconsin*, in preparation.*

3.3 IN-STREAM CHLORIDE LOAD COMPUTATIONS

In-stream pollutant loads estimate the mass quantity of a pollutant carried by a waterbody over a specific period of time. The in-stream chloride mass load for a specific period of time was calculated using the following general equation:

$$\textit{In-Stream Chloride Mass Load} = C * Q * \Delta t * k$$

Where:

C = chloride concentration expressed in terms of mass per volume, typically mg/l
Q = flow rate expressed in terms of volume per time, typically cubic feet per second (cfs)
Δt = computational time interval
K = unit conversion factor

The in-stream chloride loads calculated for each time interval using the above equation can be summed to estimate the total chloride load carried by a stream over various time periods. Monthly in-stream chloride loads were developed for the 14 stream monitoring sites located near USGS stream gage stations (see Map 3.1) using the methodology described in the following sections.

Streamflow Discharge

The 14 USGS stream gage stations used for the analysis provided reliable streamflow discharge data, reported at 5-minute or 15-minute intervals depending on the station. Streamflow datasets with variable time intervals were formatted into 15-minute intervals for the entire study period record. At times during winter some stream gages were affected by ice, interrupting continuous data collection at the station. During these ice-affected periods, the USGS provides estimated streamflow data and typically reports the estimated data on a 3-hour interval. Commission staff examined the USGS streamflow datasets to identify periods of missing data. Shorter durations of missing data were filled in using linear interpolation, which was deemed acceptable over short time periods. Most of the missing flow data that was filled-in covered periods of less than 30 minutes. Linear interpolation was also used to fill-in the gaps between the 3-hour estimated streamflow data. Extended periods of missing streamflow data that were longer than 3 hours were not adjusted.

Previous studies have shown that chloride levels in streams are highly dependent on streamflow discharge.[120] Sensitivity testing for the chloride loading analysis confirmed that in-stream chloride loading results are highly sensitive to discharge, particularly in streams with a wide range of discharges and rapid changes in streamflow. Additionally, the sensitivity testing evaluated various chloride load computation intervals ranging from 15-minute to monthly data averaging intervals. The total monthly chloride load was compared for each computation interval and results indicated that smaller computational intervals provided more accurate estimates of chloride loads in streams. The smaller computation interval better represented variations in discharge and in-stream chloride concentrations that were not captured when data were averaged over longer intervals. Chloride load differences were greater for “flashier” sites with greater variability in streamflow discharge and observed specific conductance. Typically, the monthly chloride load computed using the average monthly discharge and average chloride concentration was much higher than the monthly chloride load computed from the sum of the daily, hourly, or sub-hourly averaged parameters. This is partially because averages tend to skew upward with outliers, resulting in overestimates. While it was noted that the smaller computation intervals were more sensitive to missing data, ultimately the 15-minute computational interval was chosen to estimate in-stream chloride loads.

In most cases, the Study stream monitoring site was close to the USGS stream gage station, and the upstream contributing drainage areas were similar enough to use the streamflow discharge dataset directly. One exception was Site 16 Jackson Creek, which was located nearly a mile upstream of the USGS stream gage station. The predominantly rural 9.8 square mile upstream drainage area for Site 16 is approximately 58 percent of the upstream contributing drainage area to the Jackson Creek USGS stream gage. The portion of the drainage upstream of the USGS that is outside of the Site 16 drainage area includes the southern half

[120] *S.R. Corsi, L.A. De Cicco, M.A. Lutz, and R.M. Hirsch, “River Chloride Trends in Snow-Affected Urban Watersheds: Increasing Concentrations Outpace Urban Growth Rate and Are Common Among All Seasons,” Science of the Total Environment, 508:488-497, 2015.*

of the City of Elkhorn and has more developed urban land use. Since the difference in drainage areas is less than 50 percent, the stream gage data transfer methodology recommended in the *Wisconsin Administrative Code*, Chapter NR 116 was used to determine the proportion of streamflow at the gage to be applied to Site 16.[121] Based on the drainage area ratio and regional coefficient provided for Southeastern Wisconsin, the streamflow data at the gage was reduced by a factor of 0.71 to estimate the streamflow at Site 16.

In-Stream Chloride Concentrations

As discussed in Chapter 2, the specific conductance data collected for the Study was used to estimate in-stream chloride concentrations at 14 stream monitoring sites. The 5-minute specific conductance data was averaged over 15-minute intervals and then converted to estimated chloride concentrations using the piecewise regression equations. This created the 15-minute estimated chloride dataset used to compute in-stream chloride loads. The development of the regression relationship between chloride and specific conductance is detailed in SEWRPC Technical Report No. 64 (TR-64).[122]

There are many factors that can influence in-stream chloride concentration estimates, such as the performance of the in-stream sensor and the quality of the specific conductance data collected during the study period. Sensor fouling was observed at several monitoring sites during the study and resulted in dampened or lower specific conductance readings. In some cases the specific conductance data were adjusted, and in rare cases, the specific conductance data were deemed too severely dampened to apply the adjustment. The periods of dampened specific conductance data translate to underestimated chloride concentrations and lower monthly in-stream chloride loads. Monitoring site maintenance procedures along with specific conductance data post-processing and adjustment procedures are discussed in further detail SEWRPC Technical Report No. 61 (TR-61).[123]

The performance of the piecewise regression for individual monitoring sites varied during the study period, and overestimates or underestimates of chloride concentrations would have a carry-over effect on the in-stream chloride load estimates. The regression performance was evaluated for the mass balance monitoring sites by comparing the in-stream chloride concentration estimated using the regression equations with the chloride concentration from water quality samples collected during the study period. Details related to in-stream chloride concentrations for the 14 monitoring sites and their impact on the results of the chloride mass balance evaluation are discussed in Chapter 4.

In-Stream Chloride Loads

The 15-minute datasets for streamflow discharge and estimated chloride concentration were used in the equation presented at the beginning of Section 3.3 to determine the total mass of chloride for each of the 14 monitoring sites. The total chloride mass load for each month of the study period was computed by summing the chloride mass load for each 15-minute interval over the entire month. The chloride load calculated during months for which some of the streamflow data or estimated chloride data were missing resulted in an underestimated monthly chloride load.

Most of the stream monitoring sites were deployed for the full 25-month study period; however, a few additional sites were installed during the course of the Study. Site 57 Menomonee River at Wauwatosa and Site 58 Milwaukee River at Estabrook Park were installed in late November 2019, and hence the period of record for the analysis at these two sites spans 11 months from December 2019 through October 2020. Site 59 Root River near Horlick Dam is unique because the dataset is the composite of two separate sites located in close proximity to each other. The first monitoring site deployed in this area of the Root River was located in a heavily frequented public space, subject to human interference and often experienced equipment issues. In late November 2019, a second monitoring site was installed approximately 300 feet upstream on the Root River in a more secluded area. The in-stream chloride loads computed for the study period at Site 59 utilized data from the first site location from October 2018 through November 2019 and data collected from the second location was utilized from December 2019 through October 2020. The results of the in-stream chloride loading calculations and the mass balance analysis are presented in Chapter 4.

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[121] *D. Conger,* Techniques for Estimating Magnitude and Frequency of Floods for Wisconsin Streams*, USGS Water-Resources Investigations, Open-File Report 80-1214, March 1981.*

[122] *SEWRPC Technical Report No. 64,* Regression Analysis of Specific Conductance and Chloride Concentrations*, May 2024.*

[123] *SEWRPC Technical Report No. 61,* Field Monitoring and Data Collection for the Chloride Impact Study, *September 2023.*

CHLORIDE LOADING AND MASS BALANCE ANALYSIS RESULTS 4

4.1 INTRODUCTION

This Chapter presents the chloride source loads estimated for the Southeastern Wisconsin Region (Region) and at each stream monitoring site, along with the results of the chloride mass balance analyses performed at select stream monitoring sites for the Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) Chloride Impact Study (Study). These analyses utilized the data sources presented in Chapter 2 along with the calculation methodologies and assumptions described in Chapter 3 to produce the results detailed in the following sections.

4.2 REGIONAL CHLORIDE SOURCE LOADS: REGIONAL CHLORIDE BUDGET

The Regional chloride budget quantifies the annual chloride contributions from a variety of point and nonpoint sources throughout the Region. The average annual chloride load was estimated for sources in the Region during the 25-month study period from October 2018 through October 2020, and the results of the Regional chloride budget are presented in Figure 4.1. The total average annual chloride load to the environment from the eight Regional sources considered in the analysis was approximately 461,540 tons per year, as shown in Table 4.1. The table groups the chloride sources evaluated for the Regional chloride budget into four general categories: natural sources represent atmospheric deposition; winter maintenance (deicing salt) sources include public and private deicing activities; wastewater sources include treated effluent discharged from public wastewater treatment facilities (WWTFs), industrial facilities, and residential septic systems; and agricultural sources represent potash fertilizer, livestock waste, and irrigation.[124] Evaluating the general chloride source categories, winter maintenance had the highest chloride contribution at approximately 59 percent, followed by wastewater at about 36 percent, agricultural sources at 5 percent, and natural sources of chloride had the lowest estimated contribution at slightly more than 0.1 percent.

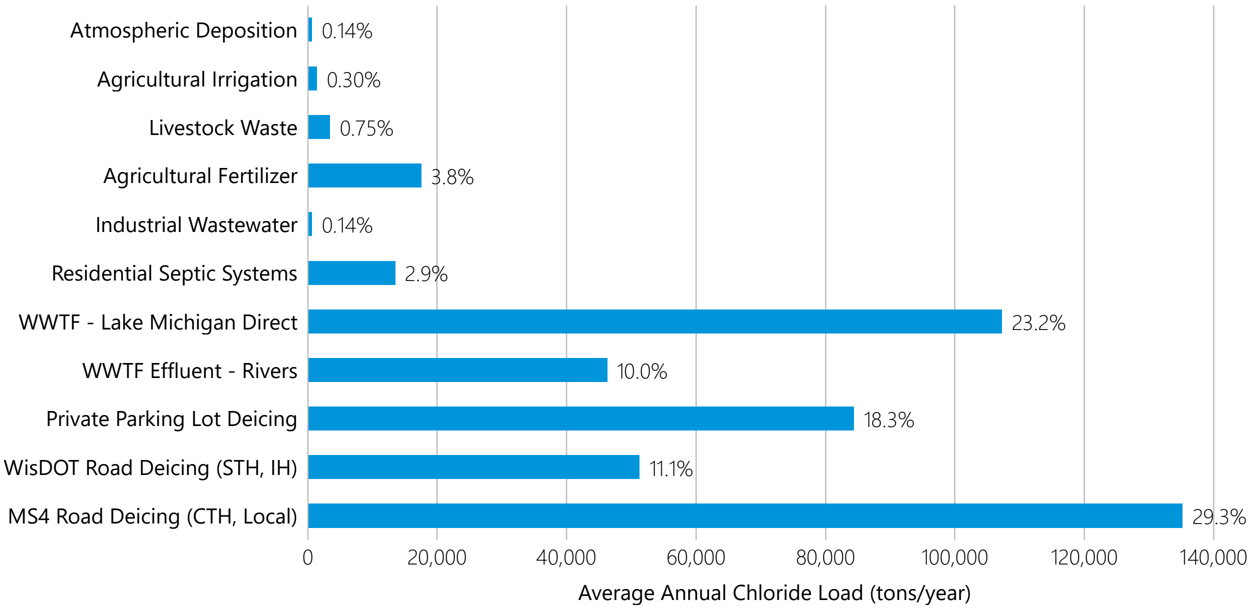
Winter Maintenance Operations

As the largest source of chloride in the Regional chloride budget, public and private winter maintenance operations had a combined annual average chloride load of approximately 270,870 tons per year, accounting for about 59 percent of the annual chloride budget. The deicing activities on local and county roadways contributed approximately 50 percent of the total chloride estimated for winter road maintenance. The dataset used to compute the chloride load for local and county winter road maintenance did not include data for all the municipalities in the Region, likely underestimating the total amount of chloride-based materials applied to local and county roadways during the study period. The next highest source of chloride for winter maintenance activities in the Region was estimated for salt applied to private parking lots, accounting for slightly more than 30 percent of the winter maintenance total. Due to a lack of available data related to deicing and anti-icing activities on private property, the estimated amount of chloride applied to parking lots in the Region was based on several assumptions discussed in Chapter 3. Deicing and anti-icing activities on state and federal roadways contributed the remaining 20 percent of the total annual chloride load for winter maintenance activities in the Region. The WisDOT dataset for state and federal highway deicing was the most complete and reliable of all the winter road maintenance (deicing salt) sources considered in the Study.

The total chloride load from deicing and anti-icing activities on public roadways in the Region showed a decreasing trend through the three winter seasons examined for the Study. This trend was generally consistent with the Winter Severity Index (WSI) trend over the same period, which indicated that the 201819 winter season was the most severe of the study period. During the study period, a majority of the estimated chloride load from deicing and anti-icing activities on public roadways in the Region came from solid rock salt applications (approximately 96 to 99 percent each year). While over 2 million gallons of liquid salt brine

[124] *The term deicing salt is used in this Chapter as a catch-all or shorthand phrase encompassing a variety of chloride-based compounds that are used to manage snow and ice on impervious surfaces for winter maintenance operations.*

Figure 4.1
Regional Chloride Budget: Average Annual Chloride Source Loads for Southeastern Wisconsin



Note: Average annual chloride source loads were computed for the study period as described in Chapter 3.

Source: SEWRPC

Table 4.1
Regional Chloride Budget: Estimated Average Annual Chloride Contributions

Chloride Source	General Source Category	Annual Average Chloride Load (tons/year)[a]	Percent of Total Chloride Load (percent)
MS4 deicing salt applied to local and county roadways	Winter maintenance	135,140	29.3
WisDOT deicing salt applied to state and federal roadways	Winter maintenance	51,300	11.1
Private parking lot deicing salt	Winter maintenance	84,430	18.3
WWTF effluent discharged to rivers and streams	Wastewater	46,280	10.0
WWTF effluent discharged directly to Lake Michigan	Wastewater	107,260	23.2
Private residential septic systems	Wastewater	13,480	2.92
Industrial wastewater effluent	Wastewater	640	0.14
Agricultural potash fertilizer	Agricultural	17,510	3.79
Livestock manure	Agricultural	3,440	0.75
Agricultural irrigation	Agricultural	1,400	0.30
Atmospheric deposition	Natural	660	0.14
	Total	461,540	100[b]

[a] *The average annual chloride mass load computed for each source of chloride during the study period was rounded to the nearest 10 tons.*

[b] *The rounded percentages in the table add up to slightly less than 100 percent.*

Source: SEWRPC

were applied to public roads in the Region during each winter season of the study period, the chloride content in liquid brines is much lower than the chloride content in rock salt, and thus the chloride load from salt brine comprised only a small proportion of the total winter maintenance chloride load. In general, the use of salt brine for winter maintenance operations reduced the amount of chloride contributed to the environment compared to rock salt.

Wastewater

The next largest source of chloride in the Region during the study period was from wastewater, with a combined total annual average chloride load of approximately 167,660 tons per year, accounting for about 36 percent of the annual chloride budget. Wastewater sources estimated for the Regional chloride budget include public WWTFs, industrial wastewater, and residential septic systems. The wastewater effluent discharged by public WWTFs may contain chloride from a variety of sources, such as: water softening salt, domestic and sanitary waste, industrial wastewater, wastewater from commercial operations, road salt inflow and infiltration, background chloride concentrations in the water supply source, and chloride-based chemicals used to treat drinking water or wastewater. Public WWTFs serving southeastern Wisconsin were responsible for over 91 percent of the combined wastewater chloride load, with annual average loads of approximately 107,260 tons of chloride per year discharged directly into Lake Michigan and approximately 46,280 tons of chloride per year discharged into rivers and streams in the study area. For public WWTFs that discharge to inland rivers and streams, approximately 23 percent of the chloride is discharged into streams within the Great Lakes basin, ultimately ending up in Lake Michigan, while the remaining 77 percent is discharged into streams west of the subcontinental divide, subsequently transported downstream toward the Mississippi River and eventually the Gulf of Mexico. The total annual chloride load to Lake Michigan from public WWTF effluent was estimated to be 117,900 tons.

Most of the public WWTFs included in the study had daily flow data, but the effluent chloride sample datasets were more variable and less complete. The six WWTFs that discharge directly to Lake Michigan were not required to regularly sample effluent for chloride, therefore the estimated chloride concentrations used in the loading analysis were based on a small set of samples collected to satisfy permit renewal requirements. This permit sample dataset may not reflect the actual variation of WWTF effluent chloride during the study period.

Industrial wastewater effluent discharged directly to surface waters in the study area contributed an average annual chloride load of approximately 640 tons, the smallest amount of chloride computed in the wastewater category and for all chloride sources in the Regional chloride budget. Over two-thirds of the chloride from industrial wastewater in the study area is discharged from food processing facilities. The estimated industrial wastewater chloride loads do not represent the full extent of chloride contributed to the environment by industrial facilities, only the permitted facilities that discharge directly to surface water and were required to monitor chloride through effluent sampling were included in the analysis.

The remaining estimated chloride load from wastewater was computed for private onsite residential septic systems, contributing an annual average chloride load of approximately 13,480 tons. The estimated amount of chloride from residential septic systems in the Region was based on several assumptions described in Chapter 3.

Agricultural Sources

Agricultural sources of chloride contributed a combined average annual chloride load of approximately 22,350 tons per year, accounting for approximately 5 percent of the total annual chloride load estimated for the Regional chloride budget. Agricultural sources estimated for the Regional chloride budget include potash fertilizer, livestock manure, and agricultural irrigation. Potash fertilizer contributed over 78 percent of the agricultural chloride load, followed by livestock manure at nearly 16 percent, and irrigation made up the remaining 6 percent of chloride from agricultural sources. The datasets for agricultural sources were not as strong as some of the other chloride source datasets, and several assumptions were used to estimate each of the agricultural sources of chloride as discussed in Chapter 3. While the Regional chloride budget showed that the total annual chloride load contributed by agricultural sources was substantially lower than some of the other chloride sources, the relatively small agricultural sources may have more significant impacts on a local scale.

Atmospheric Deposition

Atmospheric deposition was the only natural source of chloride evaluated for the Study and had the smallest estimated chloride contribution of all the general chloride source categories in the Regional chloride budget. The average annual amount of chloride that was distributed across the Region through wet and dry deposition was estimated at approximately 660 tons per year, accounting for about 0.1 percent of the annual chloride budget.

Chapter 3 explains how the atmospheric deposition of chloride can be used as a baseline for comparing other sources of chloride to the environment, expressing those other sources of chloride in terms of the equivalent annual amount of chloride resulting from atmospheric deposition over the Region. Applying this concept to the general source categories in the Regional chloride budget indicates that the amount of chloride from winter maintenance activities was approximately 410 times the amount of chloride from atmospheric deposition. The total chloride loads from wastewater sources and from agricultural sources were approximately 254 times and 34 times, respectively, the chloride load from the atmospheric deposition over the Region.

Regional Chloride Budget Compared with the Minnesota Statewide Chloride Budget

A similar study and chloride budget was developed for the entire state of Minnesota.[125] The Minnesota study covered over 79,600 square miles, an area much larger than Southeastern Wisconsin with vastly different land use and demographic characteristics. For example, the population density of the Region is over 10 times the population density of the State of Minnesota. Despite these differences, both studies identified road salt used for winter maintenance operations as the predominant source of chloride to the environment. The next two largest chloride sources identified by the Minnesota statewide chloride budget were potash fertilizer and WWTF effluent. The Regional chloride budget also had those two sources in the top three chloride contributors, but the chloride load computed from WWTF effluent was higher than the chloride load from potash fertilizers. Despite the differences between the study area scale, land use, and some of the calculation methodologies and assumptions, the top three chloride sources to the environment were consistent between the Southeastern Wisconsin Regional chloride budget and the Minnesota statewide chloride budget.

4.3 CHLORIDE SOURCE LOADS FOR STREAM MONITORING SITES

Chloride loads were estimated for sources within each stream monitoring site drainage area for every month of the study period from October 2018 through October 2020. The chloride sources evaluated include atmospheric deposition, winter maintenance operations such as deicing salts applied to public roads and private parking lots, wastewater from public treatment facilities, industrial wastewater discharge, potash fertilizer, and livestock manure from concentrated animal feeding operations (CAFO). These monitoring site source loads were also used in the mass balance analysis discussed in the next section. Table 4.2 summarizes the chloride source loads estimated for each stream monitoring site for the full 25-month study period. The total chloride source load is normalized by drainage area and reported in tons per square mile. The table presents the relative chloride contribution from each chloride source as a percentage of the total chloride source load. When evaluating chloride loads on the basis of total tons, the monitoring sites with the largest loads are typically the sites with the largest drainage areas; however, normalizing chloride loads by drainage area allows for direct comparisons between monitoring sites. Some of the stream monitoring sites were not in operation for the entire study period, but the chloride source loads were computed for the entire 25-month study period for all sites regardless of the monitoring site Study deployment dates.

As shown in Table 4.2, different combinations of chloride source loads were computed for the individual monitoring sites. The chloride source loads computed for every monitoring site in the Study included atmospheric deposition, public and private winter maintenance operations, and potash fertilizer. Chloride source loads for WWTFs, industrial wastewater, and CAFOs were calculated only for the monitoring sites where these facilities were contributing chloride within the site drainage area. The highest total chloride source load was 971.9 tons per square mile computed for Site 12 Lincoln Creek. Site 21 East Branch Milwaukee River had the lowest total chloride source load at 22.9 tons per square mile. For Site 12, deicing salt used for winter maintenance was the dominant chloride source load, while the chloride source loads for Site 21 were split between winter maintenance and potash fertilizer.

The total chloride source loads estimated for all 41 stream monitoring sites during the study period are presented in Figure 4.2. The sites are ranked from lowest to highest chloride source load across four separate bar charts with varying y-axis ranges. The total chloride source loads shown on the bar charts represent the four general chloride source categories for each monitoring site. As a companion to the figure, Table 4.3 presents the estimated chloride source loads by general source category for each monitoring site, and the sites are ranked in order from the highest to lowest total chloride load for the study period. These results are further discussed in the following sections.

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[125] *A. Overbo, S. Heger, and J. Gulliver, "Evaluation of Chloride Contributions for Major Point and Nonpoint Sources in a Northern U.S. State," Science of the Total Environment, 764: 144179, doi: 10.1016/j.scitotenv2020.144179, 2021.*

Table 4.2
Chloride Source Loads Estimated for Stream Monitoring Sites: October 2018 – October 2020

Site No.	Drainage Area (sq mi)	Sources of Chloride (percent)[a]								Total Chloride Source Load (tons/sq mi)
		Natural	Winter Maintenance			Wastewater		Agricultural		
		Atm Dep	WisDOT	MS4	Pkg Lot	WWTF	Ind WW	Potash	CAFO	
1	126.3	0.1	8.1	34.7	29.3	27.1	--	0.7	--	558.9
2	807.1	0.2	12.9	35.8	20.1	25.4	<0.1	5.5	0.1	225.6
3	85.4	0.7	19.8	45.0	20.6	--	--	13.9	--[b]	73.1
4	60.5	0.5	23.6	45.3	12.9	--	--	17.7	--	118.3
6	112.2	0.7	41.2	16.0	24.4	1.4	--	16.3	--	86.3
8	38.1	0.1	16.5	50.1	32.1	--	--	1.2	--	367.5
9	25.8	0.1	25.1	41.9	32.6	--	--	0.3	--	649.8
10	36.6	0.1	10.3	56.0	30.9	--	--	2.7	--	457.5
11	35.0	0.2	7.5	64.6	23.9	--	<0.1	3.8	--	200.8
12	11.0	0.1	19.3	53.0	27.6	--	--	<0.1	--	971.9
13	9.2	0.1	23.4	37.0	35.2	--	--	4.3	--	298.2
14	31.7	0.3	16.0	39.4	10.5	--	<0.1	33.8	--	117.3
15	8.5	0.2	40.1	50.7	2.4	--	--	6.6	--	286.3
16	9.8	0.4	19.8	40.9	20.9	--	--	18.0	--	144.9
18	41.3	0.5	15.1	59.3	11.0	--	--	14.1	--	87.0
20	100.4	0.4	21.6	52.5	16.3	--	--	9.2	--	112.7
21	49.4	1.8	25.5	4.4	16.3	--	--	52.0	--	22.9
23	264.6	0.3	11.2	31.4	13.9	27.5	--	15.0	0.7	139.4
25	58.8	0.3	12.4	58.0	5.6	12.3	--	11.4	--	181.5
28	54.7	0.5	37.1	8.3	6.8	3.8	--	40.3	3.2	83.5
30	114.6	0.2	17.9	57.4	16.2	2.7	0.1	5.5	--	314.0
32	94.0	0.3	16.5	22.7	16.8	29.9	1.5	12.3	--	185.5
33	16.0	0.2	17.0	56.6	23.9	--	--	2.3	--	251.9
35	37.7	0.6	33.0	37.7	2.8	--	--	25.9	--	83.7
36	44.6	0.4	31.7	28.9	11.8	11.0	--	16.2	--	121.8
38	105.8	0.5	9.8	36.9	3.6	7.2	6.8	32.5	2.7	84.6
40	17.8	0.8	31.5	16.2	4.6	--	--	46.9	--[b]	53.6
41	448.3	0.4	11.6	31.7	11.3	21.5	1.2	20.3	2.0	115.5
45	24.4	1.5	35.0	7.0	10.2	--	--	46.3	--[b]	32.4
47	455.6	0.2	10.1	35.7	22.3	28.8	--	2.9	--[b]	301.7
48	29.1	0.9	41.7	1.0	45.6	--	--	10.8	--	65.7
51	27.5	0.2	19.2	29.1	21.5	22.0	--	8.0	--	247.5
52	53.6	0.3	32.4	24.0	19.6	15.2	--	8.5	--	178.3
53	10.7	0.1	19.1	49.9	30.9	--	--	<0.1	--	909.1
54	18.8	1.0	7.0	51.3	5.4	--	--	35.3	--	47.3
55	53.2	0.2	11.1	60.1	25.6	--	<0.1	3.0	--	223.2
57	124.5	0.1	19.0	43.8	36.4	--	--	0.7	--	599.7
58	684.7	0.2	14.6	36.9	20.7	15.8	0.7	10.3	0.8	186.7
59	189.7	0.2	17.5	53.1	22.0	2.7	0.2	4.3	--	288.5
60	15.0	0.1	20.9	46.5	32.5	--	--	<0.1	--	796.9
87	19.0	0.1	25.0	34.9	40.0	--	--	<0.1	--	759.2

Note: Some of these monitoring sites (57, 58, 60, 87) were not in operation for the entire study period; however, the chloride source loads were computed for the entire 25-month study period for all sites regardless of the monitoring site deployment date. The data presented in the table have been rounded to the nearest tenth. Refer to Table 2.3 for monitoring site details.

[a] *The data in the table represents each source of chloride that was evaluated for individual stream monitoring sites, expressed as a percentage of the total chloride mass load computed for each monitoring site over the study period.*

[b] *There are CAFOs in the upstream drainage area, but there was no chloride load computed for the facilities because the waste from those facilities was not applied to the land during the study period for reasons discussed in the text.*

Source: SEWRPC

Figure 4.2
General Chloride Source Loads Estimated for Stream Monitoring Sites: October 2018-October 2020

Note: The x-axes display the stream monitoring site number, with sites ranked from the lowest to the highest chloride source loads. The y-axes display the chloride source loads in tons per square mile and the y-axis range varies for each plot. See Table 4.3 for additional information related to the stream monitoring sites and estimated chloride source loads.

Source: SEWRPC

Table 4.3
General Chloride Source Loads Estimated for Stream Monitoring Sites Ranked Highest to Lowest: October 2018 – October 2020

Site No.	Site Name	Drainage Area (sq mi)	General Sources of Chloride (tons/sq mi)				Total Chloride Source Load (tons/sq mi)[a]
			Natural	Winter Maintenance	Wastewater	Agricultural	
12	Lincoln Creek[a]	11.0	0.5	971.0	--	0.4	971.9
53	Honey Creek at Wauwatosa[a]	10.7	0.6	908.3	--	0.2	909.1
60	Root River at Grange Avenue[a]	15.0	0.6	796.1	--	0.2	796.9
87	Underwood Creek[a,b]	19.0	0.5	758.4	--	0.3	759.2
9	Oak Creek[a,b]	25.8	0.6	647.5	--	1.8	649.8
57	Menomonee River at Wauwatosa[a,b]	124.5	0.5	594.7	--	4.4	599.7
1	Fox River at Waukesha[b]	126.3	0.5	403.0	151.5	4.0	558.9
10	Pike River[a,b]	36.6	0.6	444.4	--	12.5	457.5
8	Pewaukee River[b]	38.1	0.5	362.5	--	4.5	367.5
30	Des Plaines River[b]	114.6	0.6	287.4	8.9	17.2	314.0
47	Fox River at Rochester[b]	455.6	0.5	205.6	87.0	8.7	301.7
13	Ulao Creek[a]	9.2	0.5	285.0	--	12.8	298.2
59	Root River near Horlick Dam[b]	189.7	0.5	267.5	8.1	12.4	288.5
15	Kilbourn Road Ditch[a]	8.5	0.6	266.9	--	18.8	286.3
33	Pebble Brook	16.0	0.5	245.6	--	5.8	251.9
51	Rubicon River	27.5	0.4	172.9	54.4	19.7	247.5
2	Fox River at New Munster[b]	807.1	0.5	155.1	57.4	12.6	225.6
55	Bark River Downstream	53.2	0.4	216.0	--	6.7	223.2
11	Bark River Upstream	35.0	0.4	192.7	--	7.7	200.8
58	Milwaukee River at Estabrook Park[b]	684.7	0.4	134.8	30.7	20.7	186.7
32	Turtle Creek	94.0	0.5	104.0	58.1	22.8	185.5
25	Root River Canal	58.8	0.5	137.8	22.4	20.8	181.5
52	Cedar Creek	53.6	0.4	135.7	27.0	15.2	178.3
16	Jackson Creek	9.8	0.6	118.3	--	26.1	144.9
23	Milwaukee River Downstream of Newburg	264.6	0.4	78.8	38.3	21.9	139.4
36	Honey Creek Downstream of East Troy	44.6	0.5	88.1	13.4	19.8	121.8
4	Sugar Creek	60.5	0.5	96.8	--	21.0	118.3
14	Sauk Creek	31.7	0.4	77.3	--	39.6	117.3
41	Milwaukee River near Saukville	448.3	0.4	63.2	26.2	25.7	115.5
20	Oconomowoc River Downstream	100.4	0.4	101.9	--	10.3	112.7
18	Oconomowoc River Upstream	41.3	0.4	74.3	--	12.2	87.0
6	White River near Burlington	112.2	0.6	70.4	1.2	14.1	86.3
38	North Branch Milwaukee River	105.8	0.4	42.5	11.9	29.8	84.6
35	Honey Creek Upstream of East Troy	37.7	0.5	61.5	--	21.6	83.7
28	East Branch Rock River	54.7	0.4	43.6	3.2	36.3	83.5
3	Mukwonago River at Mukwonago	85.4	0.5	62.4	--	10.1	73.1
48	White River at Lake Geneva	29.1	0.6	58.0	--	7.1	65.7
40	Stony Creek	17.8	0.4	28.0	--	25.2	53.6
54	Whitewater Creek	18.8	0.5	30.1	--	16.7	47.3
45	Mukwonago River at Nature Road	24.4	0.5	16.9	--	15.0	32.4
21	East Branch Milwaukee River	49.4	0.4	10.5	--	11.9	22.9

Note: Chloride source loads were computed for the full 25-month study period for all monitoring sites and are rounded to the nearest tenth. Due to rounding, the total chloride source loads may be slightly different than the sum of the chloride loads computed for each source.

[a] *The stream monitoring site was located on a chloride-impaired stream segment.*

[b] *The stream monitoring site had one or more chloride-impaired waterbodies located upstream within the site drainage area.*

Source: SEWRPC

Winter Maintenance Operations

Similar to the results from the Regional chloride budget, the chloride load from winter maintenance operations or deicing salt contributed the highest amount of chloride at every stream monitoring site, except for one (Site 21 East Branch Milwaukee River) as discussed later in this section. The monitoring sites with the highest chloride loads from deicing salts are the same sites with the highest total chloride source loads and include Site 12 Lincoln Creek (971.0 tons per square mile), Site 53 Honey Creek at Wauwatosa (908.3 tons per square mile), and Site 60 Root River at Grange Avenue (796.1 tons per square mile). For the six monitoring sites with the highest total chloride source loads during the study period, Table 4.3 shows that deicing salts accounted for over 99 percent of the chloride source load. These six sites (Site 12 Lincoln Creek, Site 53 Honey Creek at Wauwatosa, Site 60 Root River at Grange Avenue, Site 87 Underwood Creek, Site 9 Oak Creek, and Site 57 Menomonee River at Wauwatosa) were all located in highly urbanized areas. Of the 15 monitoring sites with the highest chloride source loads, deicing salt contributed over 90 percent of the chloride source load at all but two monitoring sites: Site 1 Fox River at Waukesha and Site 47 Fox River at Rochester. While Site 1 and Site 47 received a significant amount of chloride from deicing salt (72.1 percent and 68.1 percent, respectively), the next highest chloride source contributions at these two sites were from WWTF effluent (27.1 percent and 28.8 percent, respectively).

Wastewater

There were 16 stream monitoring sites that had active public WWTFs discharging treated effluent within their upstream drainage areas during the study period, as shown in Table 3.3. Several stream monitoring sites had only one public WWTF located upstream, while Site 58 Milwaukee River at Estabrook Park had the most WWTFs upstream with 11 active facilities, followed by Site 2 Fox River at New Munster with 10 WWTFs located upstream. The monitoring sites with the largest chloride loads from WWTF effluent calculated over the full 25-month study period were Site 2 Fox River at New Munster (46,269 tons), Site 47 Fox River at Rochester (39,638 tons), and Site 58 Milwaukee River at Estabrook Park (20,175 tons).[126] The monitoring sites with the lowest chloride loads from WWTF effluent over the study period were Site 6 White River near Burlington (135 tons), Site 28 East Branch Rock River (175 tons), and Site 36 Honey Creek Downstream of East Troy (596 tons). Evaluating the WWTF chloride load normalized by drainage area, the monitoring sites with the highest chloride loads from WWTF effluent over the full 25-month study period were on the Fox River and included Site 1 Fox River at Waukesha, with a total load of 151.5 tons per square mile, followed by Site 47 Fox River at Rochester and Site 2 Fox River at New Munster with 87.0 and 57.3 tons per square mile, respectively.

The results of the Regional chloride budget shown in Table 4.1 indicated that public WWTF effluent was the second highest source of chloride in the Region during the study period. The computed chloride contribution from WWTF effluent maintained a similar rank among chloride sources for individual stream monitoring sites and did not exceed 30 percent of the total chloride load at any Study site over the full study period as shown in Table 4.2. The chloride contribution from WWTF effluent at individual sites ranged from 1.4 percent at Site 6 White River near Burlington to 29.9 percent at Site 32 Turtle Creek (both sites had only one facility located upstream). The relationship between chloride from WWTF effluent and in-stream chloride is examined in the mass balance results discussion later in this Chapter.

The results of the Regional chloride budget presented in Table 4.1 showed that chloride contributions from industrial wastewater dischargers was the smallest source of chloride in the Region during the study period, slightly less than the chloride load from atmospheric deposition. During the study period there were 10 stream monitoring sites with at least one industrial facility located upstream that monitored chloride in its surface water discharge. Of those 10 monitoring sites, the sites with smallest estimated chloride loads from industrial wastewater over the full study period were on the Bark River (Site 11 Bark River Upstream and Site 55 Bark River Downstream both had 0.36 tons) and the largest estimated industrial wastewater chloride load was at Site 58 Milwaukee River at Estabrook Park (880 tons). Similar to the Regional chloride budget, chloride from industrial wastewater discharged to surface waters made up a small portion of the total chloride source load at individual stream monitoring sites. Table 4.2 shows that of the monitoring sites with at least one industrial facility discharging wastewater upstream, the chloride load from industrial wastewater was less than 1 or 2 percent at all sites except one. The lone exception was at Site 38 North Branch Milwaukee River, where the chloride load from three industrial wastewater dischargers located

[126] *Refer to Table 3.2 for the chloride loads computed for public WWTFs during the study period.*

upstream was nearly 7 percent of the total chloride source load for the site. While the industrial wastewater contribution at Site 38 is still relatively low, it demonstrates how relatively minor sources of chloride can have a more significant impact locally.

Agricultural Sources

The monitoring sites with the lowest estimated total chloride source loads were also the sites that had the highest proportion of agricultural source loads. The two agricultural sources of chloride for which loads were estimated for individual monitoring sites were potash fertilizer and livestock manure from CAFOs. Table 4.2 shows that the chloride load from potash fertilizer made up over 90 percent of the total chloride load from agricultural sources at all monitoring sites. The sites with the highest total chloride load from potash fertilizer were the sites with the largest drainage areas and the greatest amount of land devoted to agriculture and cropland (Site 58 Milwaukee River at Estabrook Park, Site 41 Milwaukee River near Saukville, and Site 2 Fox River at New Munster). The monitoring sites with the highest normalized potash fertilizer chloride loads were Site 14 Sauk Creek (39.6 tons per square mile), Site 28 East Branch Rock River (33.6 tons per square mile), and Site 38 North Branch Milwaukee River (27.5 tons per square mile).

While the results of the Regional chloride budget indicated that agricultural sources were a moderately significant source of chloride during the study period, Table 4.1 shows that the contribution of chloride from livestock manure was very low. The same holds true for the individual monitoring sites and the chloride load from livestock manure generated at CAFOs. There were six Study monitoring sites with at least one CAFO located within the drainage area upstream of the site. The lowest total chloride load from CAFOs at individual monitored sites was 126 tons at Site 2 Fox River at New Munster where approximately 0.1 percent of the total chloride source loads was from CAFOs as shown in Table 4.2. The highest total chloride load from CAFOs estimated for individual monitored sites was 1,023 tons over the 25-month study period and occurred at two sites: Site 41 Milwaukee River near Saukville and Site 58 Milwaukee River at Estabrook Park where the chloride loads from CAFOs were 2.0 and 0.8 percent of the total chloride source loads, respectively.

Site 21 East Branch Milwaukee River, where potash fertilizer made up 52 percent of the total chloride source load estimated for the study period, was the only monitoring site in the Study for which deicing salts used for winter maintenance were not the largest estimated source of chloride. The drainage area upstream of Site 21 is over 55 percent natural lands, which is the highest proportion of natural lands of all the stream monitoring sites in the Study.[127] Site 21 ranks the lowest of all stream monitoring sites in percent urban lands and percent roads and parking lots in the upstream drainage area (6.0 percent and 2.6 percent, respectively). With nearly 37 percent agricultural land, Site 21 ranks 24 out of 41 for the Study monitoring sites in that land use category and ranks 26 out of 41 for the total chloride load from potash fertilizer normalized by drainage area. While potash fertilizer was the largest source of chloride estimated for Site 21 during the study period, its higher percentage was more likely due to the absence of other chloride sources in the predominantly natural watershed. The relationships between land use and monitoring site chloride source loads are examined in greater detail later in this Chapter.

Atmospheric Deposition

The chloride atmospheric deposition rates were relatively stable across the Region during the study period, and Table 4.3 shows that the total chloride load from atmospheric deposition at stream monitoring sites over the 25-month study period ranged from 0.4 to 0.6 tons per square mile. In terms of total chloride load, the monitoring site with the largest drainage area, Site 2 Fox River at New Munster, had the highest amount of chloride from atmospheric deposition (414 tons). In contrast, the monitoring sites with the smallest drainage areas received approximately 4 to 5 tons of chloride from atmospheric deposition during the study period. As one of the smallest chloride sources in the Regional chloride budget, chloride from atmospheric deposition similarly made up a small percentage of the total chloride source load at individual stream monitoring sites. The chloride load from atmospheric deposition over the monitoring site drainage areas made up 1 percent or less of the total chloride source load at most stream monitoring sites, as shown in Table 4.2. The atmospheric deposition of chloride accounted for more than 1 percent at only two sites: Site 21 East Branch Milwaukee River (1.8 percent) and Site 45 Mukwonago River at Nature Road (1.5 percent). The drainage areas upstream of these two sites have large proportions of natural lands. The atmospheric deposition of chloride made up a slightly higher proportion of the estimated total chloride source load at these two sites, which can be attributed to the absence of other chloride sources in the largely natural watershed upstream.

[127] *Site rankings for different land use categories are presented in Table 4.4 and discussed in the following section.*

Chloride Source Load Correlations and Relationships

This section investigates potential relationships or associations between the normalized total chloride source loads for the Study monitoring sites versus land use, waterbodies designated as impaired for chloride, and estimated in-stream chloride concentrations. The total chloride source loads presented in this section are normalized by drainage area to allow for direct comparison between monitoring sites, as described in the previous section. Spearman's rank correlation coefficient (Spearman's ρ) was used to assess potential associations. Spearman's ρ is a unitless coefficient that indicates the relative strength and monotonic direction of the relationship between two variables.[128] Spearman's ρ provides insight into potential associations and correlations but does not provide evidence of causation between two variables.

Land Use

Land use can have a significant influence on the water quality of a stream or lake. Land use can also dictate the types of chloride sources that are present within a watershed. Winter deicing and anti-icing activities are a major source of chloride in the Region, particularly in areas with more urban land use, whereas treated wastewater effluent and agricultural fertilizers may have a greater impact in more rural areas. Table 4.4 summarizes the normalized total chloride source load and relative ranking for each monitoring site along with various land use category breakouts and their related rankings among all sites.[129] The land use category breakouts include percent urban lands, roads and parking lots, agricultural lands, and natural lands.[130] These ranked datasets were used to evaluate correlations between the total chloride source load and the land use categories, and the resulting Spearman's ρ for each category is shown at the bottom of the table. Figure 4.3 illustrates the relationships between the total chloride source load estimated for each monitoring site and the four land use categories listed in Table 4.4. These plots include linear regressions that provide insight into the strength of the relationship between the two variables.[131]

The total estimated chloride source loads (in tons per square mile) for the stream monitoring sites exhibited a very strong positive correlation with both urban land use (ρ = 0.806, R^2 = 0.8845) and the percent of roads and parking lots in the drainage area (ρ = 0.885, R^2 = 0.9408). These relationships reflect the importance of impervious surfaces, along with deicing and anti-icing activities, as major drivers of chloride pollution. The total chloride source loads for each site show a strong negative correlation with natural lands (ρ = -0.690, R^2 = 0.4618) and a moderate negative correlation with agricultural lands (ρ = 0.502, R^2 = 0.4612). The graphs in Figure 4.3 show that the relationships between chloride source loads and natural lands and agricultural lands exhibited greater variability than the relationships between chloride source loads and urban land use and roads and parking lots. The higher variability likely reflects differences in the other types of land use present within each drainage area. The decreasing relationship between agricultural land use and total chloride source loads suggests that the use of potash fertilizers does not have as large an influence on chloride pollution in southeastern Wisconsin as the use of deicing salts for winter maintenance, which is also reflected in the results of the Regional chloride budget.

Chloride-Impaired Waterbodies

Associations between the total chloride source loads and chloride-impaired waterbodies in the study area were also investigated for monitoring sites that were located on a chloride-impaired waterbody or had a chloride-impaired body within the monitoring site drainage area. During the study period, there were nine monitoring sites that were located on a chloride-impaired stream segment as identified in Table 4.3, with

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[128] *Spearman's rank correlation coefficient values range from -1 to +1, where +1 indicates a perfect positive correlation for which both variables increase or decrease together, and -1 indicates a perfect negative correlation for which one variable increases while the other variable decreases. Spearman's rank correlation coefficient can be interpreted using the following ranges: 0 to 0.2 = negligible to very weak correlation; 0.2 to 0.4 = weak correlation; 0.4 to 0.6 = moderate correlation; 0.6 to 0.8 = strong correlation; 0.8 to 1.0 = very strong correlation.*

[129] *Site rankings for each category range from 1 to 41, with 1 representing the highest value and 41 representing the lowest value in each category.*

[130] *The natural lands category includes woodlands, wetlands, and open water.*

[131] *For regression models, R-squared (R^2) values measure the percentage of the variance in the dependent variable that can be attributed to or explained by the independent variable, or in other words, how well the model fits the observed data. R-squared values range from 0 to 1, where 1 indicates a perfect fit and higher values generally represent a stronger relationship between the variables.*

Table 4.4
Total Chloride Source Loads Estimated for the Study Period and Drainage Area Characteristics Ranked for each Stream Monitoring Site

Site	Total Chloride Source Load		Drainage Area Size		Urban Lands		Roads and Parking Lots		Natural Lands		Agricultural Lands	
No.[a]	(tons/sq mi)	(rank)	(sq mi)	(rank)	(percent)	(rank)	(percent)	(rank)	(percent)	(rank)	(percent)	(rank)
1	558.9	7	126.3	7	54.0	7	14.4	7	24.2	20	12.1	35
2	225.6	17	807.1	1	27.1	17	7.0	18	28.0	15	37.1	23
3	73.1	36	85.4	14	26.4	18	5.2	27	33.5	8	29.7	27
4	118.3	27	60.5	15	13.1	29	4.7	30	23.1	24	57.5	9
6	86.3	32	112.2	10	20.6	24	5.7	24	33.2	10	38.4	22
8	367.5	9	38.1	23	52.7	8	13.7	8	28.6	13	11.3	36
9	649.8	5	25.8	30	72.3	5	19.9	5	13.1	33	10.1	37
10	457.5	8	36.6	25	41.1	12	10.5	10	5.4	39	47.6	15
11	200.8	19	35.0	26	43.9	9	8.8	14	22.2	25	23.5	30
12	971.9	1	11.0	37	97.4	2	28.1	2	2.4	40	0.1	40
13	298.2	12	9.2	40	32.5	15	12.5	9	19.6	27	29.6	28
14	117.3	28	31.7	27	11.5	34	4.6	31	8.7	36	76.7	2
15	286.3	14	8.5	41	12.3	31	6.6	20	13.8	30	71.3	4
16	144.9	24	9.8	39	10.9	36	5.1	28	6.7	38	78.6	1
18	87.0	31	41.3	22	22.3	22	4.5	32	33.3	9	36.8	25
20	112.7	30	100.4	12	26.4	19	5.9	23	35.9	5	30.7	26
21	22.9	41	49.4	20	6.0	41	2.6	41	55.6	1	36.9	24
23	139.4	25	264.6	5	12.9	30	4.5	33	34.2	7	48.9	14
25	181.5	22	58.8	16	14.2	28	4.1	34	9.3	35	73.7	3
28	83.5	35	54.7	17	10.6	37	5.7	25	19.8	26	65.2	5
30	314.0	10	114.6	9	19.2	25	6.5	22	17.4	29	55.5	10
32	185.5	21	94.0	13	16.2	26	5.5	26	19.3	28	59.5	7
33	251.9	15	16.0	35	41.9	11	9.5	11	30.1	12	18.6	32
35	83.7	34	37.7	24	10.4	38	3.4	36	24.2	21	59.4	8
36	121.8	26	44.6	21	15.3	27	5.1	29	23.9	22	54.2	11
38	84.6	33	105.8	11	7.4	40	3.1	40	27.2	18	62.9	6
40	53.6	38	17.8	34	8.2	39	3.3	38	34.7	6	51.0	13
41	115.5	29	448.3	4	11.7	33	4.1	35	31.2	11	52.7	12
45	32.4	40	24.4	31	11.7	32	3.1	39	38.8	3	41.7	21
47	301.7	11	455.6	3	35.6	13	8.7	15	28.4	14	27.6	29
48	65.7	37	29.1	28	31.8	16	6.7	19	46.8	2	14.6	33
51	247.5	16	27.5	29	25.8	20	7.2	17	26.8	19	42.6	20
52	178.3	23	53.6	18	23.3	21	8.0	16	23.2	23	43.4	19
53	909.1	2	10.7	38	98.5	1	30.4	1	1.5	41	0.0	41

Table continued on next page.

Table 4.4 (Continued)

Site	Total Chloride Source Load		Drainage Area Size		Urban Lands		Roads and Parking Lots		Natural Lands		Agricultural Lands	
No.[a]	(tons/sq mi)	(rank)	(sq mi)	(rank)	(percent)	(rank)	(percent)	(rank)	(percent)	(rank)	(percent)	(rank)
54	47.3	39	18.8	33	11.2	35	3.4	37	38.5	4	45.5	17
55	223.2	18	53.2	19	43.3	10	9.3	13	27.3	17	19.7	31
57	599.7	6	124.5	8	67.3	6	19.5	6	13.5	32	14.4	34
58	186.7	20	684.7	2	21.7	23	6.6	21	27.8	16	44.4	18
59	288.5	13	189.7	6	35.0	14	9.4	12	13.6	31	46.3	16
60	796.9	3	15.0	36	91.9	3	26.4	3	7.5	37	0.3	39
87	759.2	4	19.0	32	88.4	4	25.5	4	10.6	34	0.5	38
Spearman's rank correlation coefficient[b]			ρ = -0.120		ρ = 0.806		ρ = 0.885		ρ = -0.690		ρ = -0.502	

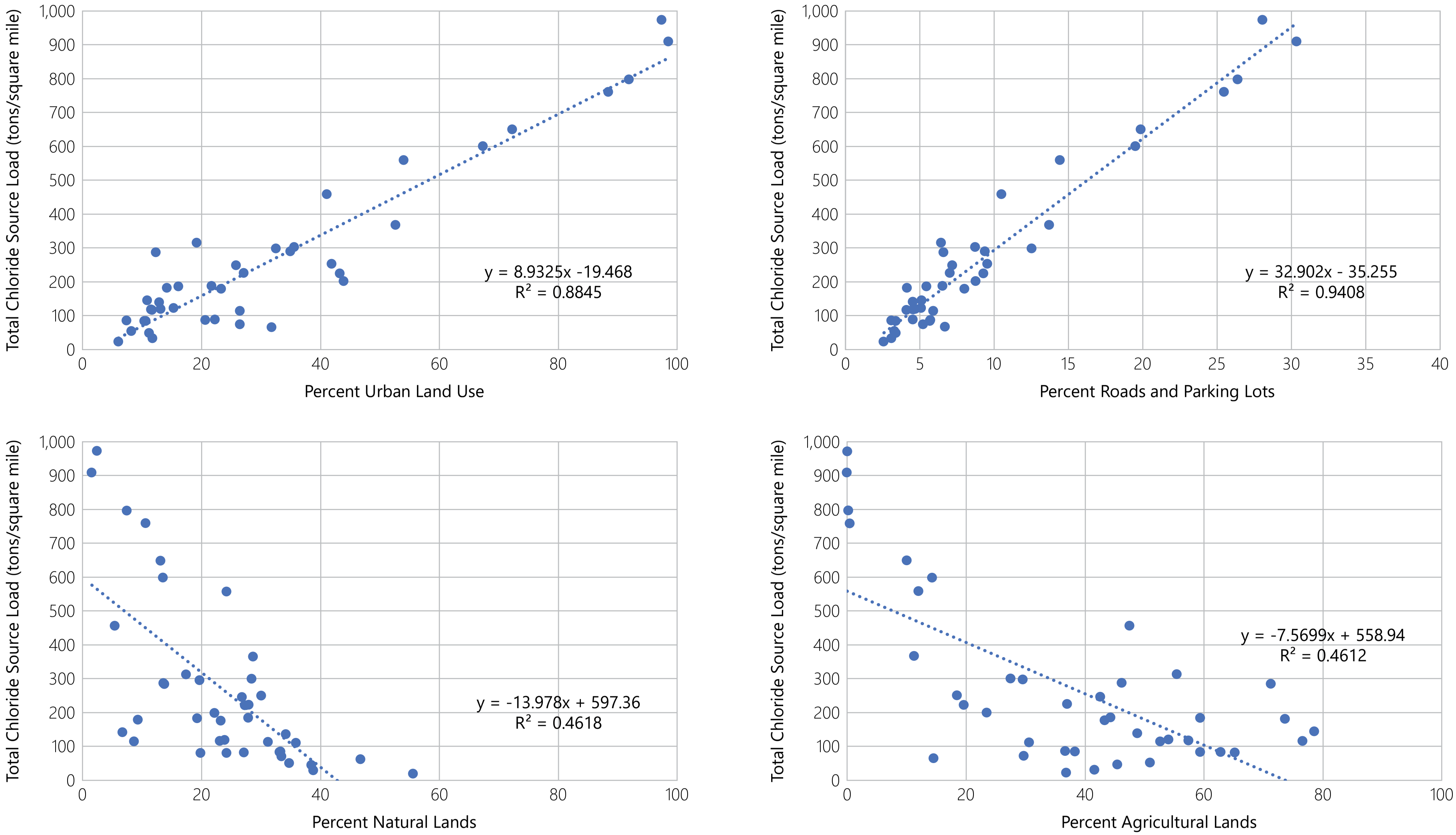
Note: Land use category breakout percentages represent the percentage of the specific land use category within the upstream drainage area for each site, along with how that percentage ranks among all of the monitoring sites.

[a] *The SEWRPC site numbering is nonconsecutive, refer to Map 2.3 for the locations of each stream monitoring site and Table 2.3 for monitoring site details.*

[b] *The Spearman correlation coefficient was computed to evaluate the relationships between the total chloride source loads in tons per square mile and each of the percent land use categories as well as drainage area size.*

Source: SEWRPC

Figure 4.3
Relationships Between Drainage Area Land Use and Estimated Chloride Source Loads for Stream Monitoring Sites over the Study Period



Source: SEWRPC

total chloride source loads ranging from 286.3 to 971.9 tons per square mile. The table shows that the six monitoring sites with the highest total chloride source loads, all of which were greater than or equal to 600 tons per square mile (Site 12 Lincoln Creek, Site 53 Honey Creek at Wauwatosa, Site 60 Root River at Grange Avenue, Site 87 Underwood Creek, Site 9 Oak Creek, and Site 57 Menomonee River at Wauwatosa), were located on stream segments that are impaired for chloride. The nine monitoring sites located on chloride-impaired stream segments were among the 14 stream monitoring sites with the highest total chloride source loads shown in Table 4.3, and the remaining five sites had chloride-impaired waterbodies within their upstream drainage areas. A closer examination of those five monitoring sites revealed that one site (Site 59 Root River near Horlick Dam) was located a few hundred feet downstream of a chloride-impaired stream segment; one (Site 8 Pewaukee River) was located on a stream that was previously listed as impaired for chloride in 2018 but was delisted in 2020; two sites (Site 1 Fox River at Waukesha and Site 30 Des Plaines River) were on stream segments not listed but recommended for potential chloride impairment listing in SEWRPC Technical Report No. 63 (TR-63); and one site (Site 47 Fox River at Rochester) had two of the other monitoring sites (Site 1 and Site 8) nested within its upstream drainage area as shown in Table 2.4.[132] Furthermore, the 16 Study monitoring sites with chloride-impaired waterbodies located in their upstream contributing drainage areas were among the top 20 sites with the highest total chloride source loads in Table 4.3. It was not possible to quantify a correlation coefficient for chloride impairments; however, it is evident that the stream monitoring sites that were either located on a chloride-impaired waterbody or had chloride impairments upstream within the site drainage area also had the highest estimated total chloride source loads for the study period.

Estimated In-Stream Chloride Concentration

Commission staff also examined the relationship between the total chloride source loads and the in-stream chloride concentrations for Study monitoring sites estimated using the regression equations develop for the Study as described in SEWRPC Technical Report No. 64 (TR-64).[133] The estimated chloride concentration statistics used in the comparison included the mean, median and maximum chloride concentrations for each monitoring site. These statistics were calculated for the 25-month study period except for the four monitoring sites that were installed during the project and utilized an extended period of record stretching into 2021.[134] The strongest correlation was observed between chloride source loads and the mean estimated chloride concentration for each monitoring site, with a computed Spearman's ρ of 0.943. The Spearman's correlation coefficients comparing the total chloride source loads with the median and maximum estimated chloride concentrations for each site were also very strong, 0.898 and 0.917, respectively. Figure 4.4 illustrates the relationship between the estimated mean chloride concentration and the total chloride source load computed for each monitoring site. A linear regression performed for these two variables also indicated a strong correlation with a R^2 of 0.8934. These strong correlations highlight how in-stream chloride concentrations rise with the increasing amount of chloride applied within the upstream drainage area from a variety of sources. The relationships between chloride sources and in-stream chloride loads are further examined using the results of the chloride mass balance analysis discussed in the next section.

4.4 CHLORIDE MASS BALANCE ANALYSIS RESULTS

In addition to estimating the major chloride source loads for each stream monitoring site, a detailed mass balance analysis was performed for the 14 stream monitoring sites located near U.S. Geological Survey (USGS) stream gage stations. These sites were selected for the analysis due to the availability of reliable streamflow discharge data that was used to estimate in-stream chloride loads. The mass balance analysis compared in-stream chloride loads with the chloride source loads generated in the upstream drainage area for each monitoring site during the study period spanning from October 2018 through October 2020. The chloride loads were estimated on a monthly basis for the mass balance analysis, and these loads are evaluated over various time periods, from monthly to seasonally to the full 25-month study period.

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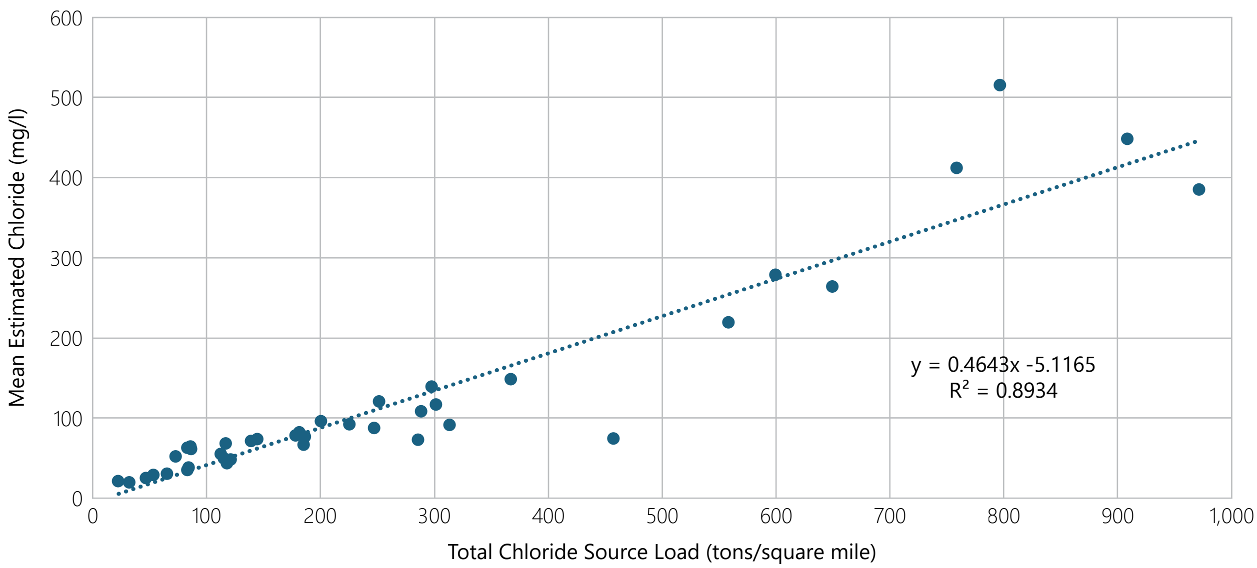
[132] *SEWRPC Technical Report No. 63,* Chloride Conditions and Trends in Southeastern Wisconsin*, in preparation*.

[133] *SEWRPC Technical Report No. 64,* Regression Analysis of Specific Conductance and Chloride Concentrations*, May 2024*.

[134] *Site 57 Menomonee River at Wauwatosa, Site 58 Milwaukee River at Estabrook Park, Site 60 Root River at Grange Avenue, and Site 87 Underwood Creek were installed during the course of the Study. Also, Site 55 Bark River Downstream was not included in the comparison because a regression relationship for estimated chloride concentrations from specific conductance could not be developed for that monitoring site.*

Figure 4.4
Chloride Source Loads Versus Mean Estimated Chloride Concentrations for each Monitoring Site



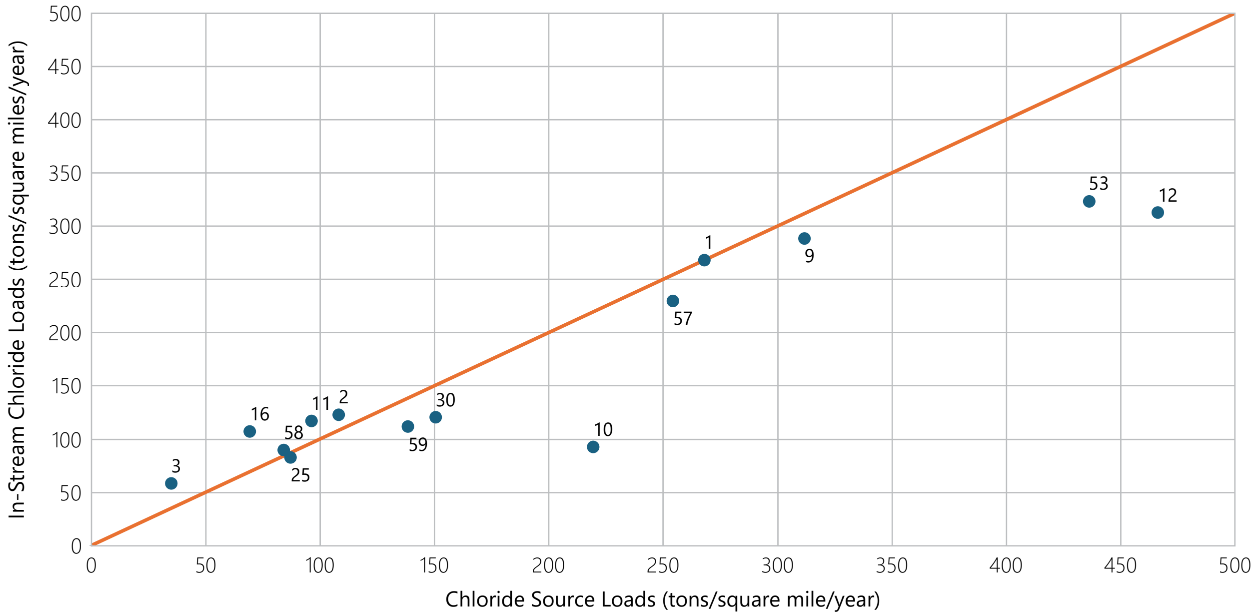
Note: Mean chloride concentrations were estimated for the study period using the regression equations developed in TR-64.

Source: SEWRPC

Figure 4.5 compares the total chloride source loads and in-stream chloride loads (in tons per square mile per year) for each monitoring site over the entire study period. The orange line represents the line of parity where chloride source loads on the x-axis and in-stream chloride loads on the y-axis are equal, indicating a perfect match or balance between the computed chloride source loads and the estimated in-stream loads. The sites that are plotted below this line had higher chloride source loads during the study period, and the sites plotted above the line had higher estimated in-stream chloride loads during the study period. The plotted datapoints are labeled with the Study monitoring site number, and the farther away a site is plotted from the line of parity, the larger the difference between the chloride source loads and in-stream chloride loads. Significant differences between the chloride source loads and in-stream chloride loads were observed at Site 10 Pike River, Site 12 Lincoln Creek, and Site 3 Mukwonago River at Mukwonago. The sites with the smallest differences between the chloride source loads and the in-stream chloride loads were Site 1 Fox River at Waukesha, Site 58 Milwaukee River at Estabrook Park, and Site 25 Root River Canal. The mass balance results for each site are presented in Table 4.5 and include the total computed chloride source loads and estimated in-stream chloride loads in tons over the full study period, along with the percent difference between the two. The monitoring sites presented in Table 4.5 are arranged in order by the chloride load percent difference, from the site with the highest excess chloride source load (positive percent difference) to the site with the highest excess in-stream chloride load (negative percent difference). Detailed results for the 14 stream monitoring sites considered in the mass balance analysis are presented in Appendix C.

Appendix C presents one-page summaries of the mass balance results for each stream monitoring site. The site summaries are organized by ascending site number, and each monitoring site summary page is assigned a figure number ranging from Figure C.1 to Figure C.14, as listed in Table 4.5. Each mass balance site summary page shows three different figures labeled (a) through (c). Figure (a) presents the total computed chloride source loads and estimated in-stream chloride loads for every month of the study period from October 2018 through October 2020. Figure (b) shows a similar monthly comparison that reflects the difference between chloride source loads and in-stream chloride loads each month; the yellow bars (positive differences) indicate an excess of chloride source load while the blue bars (negative differences) represent excess in-stream chloride loads. The third figure, Figure (c), compares chloride source loads and in-stream chloride loads on a seasonal basis, using the 3-month meteorological definition of the seasons. The estimated chloride loads on this figure are represented in tons per month to account for the different number of study period months across the four seasons. Additional information presented for each stream monitoring site in Appendix C includes the overall mass balance for the study period, excess chloride load balances between winter and non-winter months, along with flow-weighted chloride concentrations, which are discussed later in this Chapter.

Figure 4.5
Comparison of Chloride Source Loads with In-Stream Chloride Loads During the Study Period



Note: The chloride source loads and in-stream chloride loads were computed for the study period, annualized, and normalized by drainage area. The orange line on the plot represents the line of parity, for which the x- and y-values are equal.

Source: SEWRPC

Table 4.5
Chloride Mass Balance for Stream Monitoring Sites During the Study Period

Site No.	Site Name	Appendix C Figure No.[a]	Drainage Area (sq mi)	Study Period Months	In-Stream Chloride Load (tons)	Chloride Source Load (tons)	Chloride Load Percent Difference[b]
10	Pike River	C.5	36.6	25	7,030	16,751	138.3
12	Lincoln Creek	C.7	11.0	25	7,167	10,713	49.5
53	Honey Creek at Wauwatosa	C.11	10.7	25	7,213	9,763	35.3
30	Des Plaines River	C.10	114.6	25	28,636	35,983	25.7
59	Root River near Horlick Dam	C.14	189.7	25	44,111	54,744	24.1
57	Menomonee River at Wauwatosa	C.12	124.5	11	26,174	29,035	10.9
9	Oak Creek	C.4	25.8	25	15,476	16,765	8.3
25	Root River Canal	C.9	58.8	25	10,067	10,681	6.1
1	Fox River at Waukesha	C.1	126.3	25	70,440	70,587	0.2
58	Milwaukee River at Estabrook Park	C.13	684.7	11	55,937	52,859	-5.5
2	Fox River at New Munster	C.2	807.1	25	205,865	182,076	-11.6
11	Bark River Upstream	C.6	35.0	25	8,483	7,026	-17.2
16	Jackson Creek	C.8	9.8	25	2,181	1,423	-34.7
3	Mukwonago River at Mukwonago	C.3	85.4	25	10,269	6,238	-39.3

[a] *Appendix C presents additional mass balance results organized by stream monitoring site under the figure numbers presented in the table.*

[b] *Percent differences are based on the in-stream chloride load (percent difference = (source – in-stream) / in-stream) and the results presented in the table are positive when source loads are greater than in-stream loads and negative when in-stream loads are greater than source loads.*

Source: SEWRPC

The mass balance results for individual stream monitoring sites showed very large differences between computed chloride source loads and estimated in-stream chloride loads month to month as presented in Appendix C Figure (a). However, the difference between source loads and in-stream loads was lower when evaluated over the entire 25-month study period. Of the 14 monitoring sites included in the mass balance analysis, Site 1 Fox River at Waukesha had the best match between the computed chloride source loads and estimated in-stream loads over the 25-month study period. While Appendix C Figure C.1 shows that the differences between chloride source loads and in-stream loads at that site were very large on a monthly basis (ranging from -231 percent to 77 percent) the overall difference for the full study period was 0.2 percent. The site with the largest percent difference between computed chloride source loads and estimated in-stream chloride loads was Site 10 Pike River, with an overall difference of 138 percent during the study period.

Table 4.5 shows that there were six monitoring sites that had an overall difference between chloride source loads and in-stream loads within 12 percent for the full study period, and nine monitoring sites were within 30 percent. All but two of the monitoring sites evaluated for the mass balance analysis had an overall difference between chloride source loads and in-stream loads within 40 percent over the full study period. The six monitoring sites with the best or most-closely matching chloride mass balances (within 12 percent at Site 1, Site 58, Site 25, Site 9, Site 57, and Site 2) were all located on streams designated as fourth-order to sixth-order streams, and the five monitoring sites with the largest chloride mass balance differences (over 30 percent at Site 10, Site 12, Site 3, Site 53, and Site 16) were located on streams designated as second-order to fourth-order streams.[135] While stream order does not reflect the actual size of a stream, this relationship appears to suggest that the chloride mass balance analysis yielded better results on higher order streams, which typically have larger drainage areas than lower order streams. More significantly, however, this relationship demonstrates how monitoring sites with smaller drainage areas are more sensitive than sites with larger drainage areas to the factors influencing the chloride mass balance results, discussed in the next section.

Of the five monitoring sites that had chloride mass balance differences greater than 30 percent, three sites (Site 10, Site 12, and Site 53) had computed chloride source loads greater than estimated in-stream chloride loads and the other two sites (Site 3 and Site 16) had estimated in-stream chloride loads greater than chloride source loads. Site 12 and Site 53 are ranked the highest for percent urban land use and percent roads and parking lots of all 14 monitoring sites in the mass balance analysis, while Site 3 and Site 16 rank among the lowest sites in these land use categories. In general, the mass balance results indicated that monitoring sites with chloride source loads significantly greater than in-stream chloride loads over the study period tended to have more highly urbanized drainage areas, while the sites that had in-stream chloride loads greater than chloride source loads had upstream drainage areas with more nonurban land uses. However, there are many factors that may contribute to the differences observed between the computed chloride source loads and estimated in-stream chloride loads, as discussed in the next section.

Potential Factors Influencing the Chloride Mass Balance Results

The differences observed over the study period between the computed chloride source loads and estimated in-stream chloride loads could be attributed to a variety of factors depending on the stream monitoring site. As with any analysis, the results were only as good as the input data. Both the chloride source loads and in-stream chloride loads estimated for each site may be affected by issues with the underlying datasets. In other cases, drainage area characteristics may influence the way chloride moves through the environment and could affect the chloride loads estimated for a stream monitoring site. These factors are described in the following sections.

[135] *The Strahler stream order designation is a simplified method of classifying stream segments based on the number of tributaries upstream. A first-order stream is a headwater stream with no tributaries, a second-order stream is formed downstream of the confluence of two first-order streams, and this hierarchical system of joining lower order streams continues up to a sixth-order stream, which is the highest designation. Higher order streams are generally larger and convey more water than lower order streams. The stream order designations for the Study monitoring sites are presented in Table 2.11 of SEWRPC Technical Report No. 61, Field Monitoring and Data Collection for the Chloride Impact Study, September 2023.*

Input Dataset Issues that Could Affect In-Stream Chloride Load Estimates

Estimated in-stream chloride loads may be affected by the quality of the streamflow discharge dataset as well as the continuous specific conductance data collected at five-minute intervals for the Study. The specific conductance data were converted to estimated chloride concentrations that were used to calculate in-stream chloride loads. Periods of missing data in either dataset may lead to underestimated in-stream chloride loads. Data gaps within the USGS streamflow datasets were typically limited to 24 hours or less. Longer periods of missing streamflow data, due to ice effects, were filled in by the USGS using estimated streamflow data. The estimated streamflow data may not represent actual streamflow conditions during those periods, contributing to uncertainty in the in-stream chloride load estimates.

Overall, missing specific conductance data that resulted from issues with the in-stream monitoring equipment, had a greater impact on the in-stream chloride loads estimated for the mass balance analysis. Of the nine stream monitoring sites for which the total chloride source load was greater than the total in-stream chloride load for the study period, six sites had at least one month with a significant amount of specific conductance data missing. For example, during spring 2020 the specific conductance dataset for Site 30 Des Plaines River was missing approximately 30 percent of the data in February, 16 percent in March, and 25 percent in April. Another example was at Site 25 Root River Canal, where nearly 85 percent of the specific conductance data was missing in September 2020 and nearly 25 percent was missing in October 2020. The total monthly in-stream chloride loads for each site were calculated by summing the estimated loads computed over 15-minute intervals, however, a chloride load could not be generated for periods of missing specific conductance data. The impact of missing input data resulted in reduced or underestimated in-stream chloride loads at these sites.

Another issue with the specific conductance data collected for the Study that could influence the estimated in-stream chloride loads was fouling of the in-stream sensor. Sensor fouling was observed at some stream monitoring sites and caused dampened or lower specific conductance readings. In some cases, Commission staff adjusted portions of the specific conductance dataset that were dampened, but in extreme cases the data were considered too dampened to adjust. For example, the specific conductance dataset for Site 9 Oak Creek had two such periods of severe dampening: from October 1 through October 24, 2018 and from May 19 to June 17, 2020. Additionally, the in-stream continuous specific conductance sensors were factory-calibrated and could not be calibrated by the user. Most of the monitoring sites had lower in-stream specific conductance observations when compared to the specific conductance readings taken monthly with a separate handheld sonde that was regularly calibrated before use.[136] For example, the 25 monthly handheld sonde specific conductance field measurements collected during the study period at Site 10 Pike River were over 21 percent higher on average than the simultaneous specific conductance measurements recorded by the in-stream sensor. Periods of dampened specific conductance data translate directly to lower estimated chloride concentrations and reduced monthly in-stream chloride loads.

Regression Equation Performance and Potential Impacts on In-Stream Chloride Load Estimates

The estimated in-stream chloride loads could also be influenced by the performance of the Study regression equations at each stream monitoring site. The piecewise regression equations used to estimate chloride from specific conductance data collected at the 14 mass balance sites may systematically underestimate or overestimate chloride at a particular monitoring site, which would have a similar effect on the estimated in-stream chloride load. To evaluate the regression equation performance at individual stream monitoring sites, estimated chloride concentrations were compared with chloride samples collected during the study period using the plots presented in Appendix C of TR-63.[137] The regression equations tended to underestimate chloride concentrations at the four monitoring sites for which the estimated in-stream chloride load was less than the estimated chloride source load by at least 25 percent over the study period (Site 10 Pike River, Site 12 Lincoln Creek, Site 53 Honey Creek at Wauwatosa, and Site 30 Des Plaines River). At Site 10 Pike River, for example, the chloride concentrations were underestimated by approximately 30 percent on average when compared to the corresponding chloride sample data. The opposite was observed at Site 3 Mukwonago River at Mukwonago, where the chloride concentrations estimated using the regression equations were on average 23 percent greater than the measured chloride concentrations from the water

[136] *For additional information related to data collection, monitoring site equipment and maintenance procedures, and specific conductance data post-processing and adjustment procedures, refer to SEWRPC Technical Report No. 61, 2023,* op. cit.

[137] *SEWRPC Technical Report No. 63, in preparation,* op. cit.

quality samples collected at that site. Systematic or consistent overestimates or underestimates of chloride concentrations by the piecewise regression equations would have a carry-over effect on the estimated in-stream chloride loads.

Uncertainties with Input Data and Methodologies that Could Affect Chloride Source Load Estimates

The chloride source loads estimated for stream monitoring sites could be affected by uncertainties in input data or methodologies used to estimate the source loads. The estimated chloride source loads were affected by the availability and quality of the input datasets used to compute those loads. Missing data or the omission of chloride sources in the monitoring site drainage area would underestimate the total chloride source load for that site. For example, winter deicing salt usage data was not available for all local municipalities in the study area. This is particularly true within the upstream drainage areas of Site 3 Mukwonago River at Mukwonago and Site 16 Jackson Creek, where local road salt data was available for only one municipality within each upstream drainage area. As a result, the chloride source load from public road deicing at those sites did not capture data from all municipalities in their drainage areas and was most likely underestimated, The missing chloride source data contributed to the chloride load differences, and the calculated in-stream chloride loads were much greater than the chloride source loads at those monitoring sites. Another example that contributed to chloride source load uncertainties was the use of estimated chloride concentrations to compute point source loads for the study period months for which chloride monitoring data was not available. Additionally, some of the assumptions and simplifications used in the computation of chloride source loads may not accurately represent those sources. Examples of this include the areal proportioning of local road salting and the assumption that road salt would be distributed equally across all roadways within a particular jurisdiction or assumptions related to fertilizer application rates. These assumptions and simplifications were considered acceptable for the Regional analysis but may not reflect how some of the chloride sources were applied within smaller site drainage areas.

Chloride Transport Pathways that Could Affect the Chloride Mass Balance in a Watershed

At some Study monitoring sites, the way that chloride is transported through the environment may be responsible for some of the differences observed between the computed chloride source loads and the estimated in-stream chloride loads. It is possible that some of the chloride applied within a site drainage area may not be measured or accounted for at the stream monitoring site. Complex flow interactions between surface water and groundwater may explain some of the chloride mass balance differences. Two examples are at Site 10 Pike River and Site 59 Root River near Horlick Dam, where the chloride source loads computed for the study period were much greater than the estimated in-stream chloride loads. Both of these monitoring sites were located on streams within the eastern portion of the Region near Lake Michigan. The general direction of shallow groundwater flow, based on the hydraulic gradient established by the water table elevations, within both site drainage areas is easterly toward the lake.[138] Based on the configuration of the two upstream drainage areas, it would possible that chloride entering the environment within each of these watersheds could be transported through groundwater or subsurface pathways directly to Lake Michigan without being measured at the stream monitoring site.

There are other pathways, mechanisms, and timing considerations that could explain why chloride retained within surficial soils and groundwater aquifers may not have been accounted for at a stream monitoring site. Chloride moving through soils in urbanized areas may be lost to inflow and infiltration into underground pipe networks, transporting the chloride to public WWTFs. Furthermore, if the WWTF discharge outfall is not located upstream of the monitoring site, the chloride lost to inflow and infiltration would not be accounted for at the stream monitoring site. Chloride may also be exported out of a watershed or mass balance system through other means, such as aerosolization or a variety of subsurface transport pathways. Chloride may be transported through soils or underground drainage networks to a location downstream of the monitoring site or outside of the watershed entirely. For monitoring sites where the estimated in-stream chloride loads were greater than the computed chloride sources loads for the full study period, "legacy" chloride may be responsible for the excess in-stream chloride load. The term legacy chloride is used to describe chloride from earlier applications that is retained within surficial soil layers and slowly released into the surface water network. This phenomenon is discussed further in the next section.

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

Additional Chloride Relationships and Influencing Factors

Various factors such as land use, streamflow discharge, and seasonal patterns can influence chloride conditions in a stream as well as the chloride source loads and in-stream chloride loads estimated for the mass balance analysis, as described in the following sections.

Seasonal Patterns

Seasonality can have a significant influence on chloride contributions to the environment due to climate and weather conditions and human activities during different times of the year. Examples include road deicing and anti-icing during winter months and potash fertilizer usage during the growing season, depending on crop requirements and soil conditions. The Figure (c) graphs shown in Appendix C for each monitoring site present a seasonal comparison of the total chloride source loads and in-stream chloride loads for the full study period. The chloride loads and mass balances for each monitoring site followed similar patterns throughout the study period. Seasonal patterns reveal that source loads were much greater than in-stream loads during winter months at all monitoring sites, with a difference of approximately 175 percent on average. During the spring and summer months, in-stream chloride loads exceeded chloride source loads by approximately 75 percent on average across all sites. The chloride load balance during the fall months exhibited more variability. During fall, the estimated in-stream chloride loads exceeded the computed chloride source loads at most monitoring sites by approximately 26 percent on average. However, some of the sites with more urban development in the upstream drainage area had chloride source loads greater than in-stream loads during fall (Site 9 Oak Creek and Site 12 Lincoln Creek) or showed a more even balance between the chloride loads for those months (Site 53 Honey Creek at Wauwatosa).

Examining the seasonal patterns for the in-stream chloride loads reveals that the highest estimated in-stream chloride loads occurred during spring at most of the stream monitoring sites. However, for the monitoring sites with the highest percentages of urban land use, the estimated in-stream chloride loads were the largest during the winter months compared to the other seasons. The monitoring sites that exhibited the highest in-stream chloride loads during winter were Site 9 Oak Creek, Site 12 Lincoln Creek, Site 53 Honey Creek at Wauwatosa, and Site 57 Menomonee River at Wauwatosa.

The seasonal pattern for chloride source loads was the same for all the stream monitoring sites that were deployed for the entire 25-month study period, with the highest estimated source loads in winter, followed by fall, then spring, and the lowest estimated source loads were observed during the summer months. The timing of the individual chloride source contributions was well documented on a monthly basis for public road salt and WWTF effluent, but for this analysis the timing was assumed for the other sources of chloride. The seasonal patterns shown on the graphs in Appendix C Figure (c) for each monitoring site illustrate the importance of deicing salt as a major source of chloride to the environment.

The graphs shown in Appendix C Figure (b) for each stream monitoring site present the monthly differences between the estimated in-stream chloride loads and the calculated chloride source loads. A similar pattern emerges across all of the monitoring sites, showing excess chloride source loads during the winter followed by excess in-stream chloride loads during the subsequent non-winter months. Other studies have noted this phenomenon, suggesting that chloride applied to roadways during the winter season may be stored or retained in surficial soil layers and potentially in shallow groundwater, with slow release to surface water during the subsequent seasons.[139,140,141] The mass balance results for each monitoring site presented in Appendix C include an accounting of the winter season excess chloride source loads and the excess in-stream chloride loads over the following non-winter months throughout the study period. At some monitoring sites, the excess chloride source loads estimated for the 2018-19 winter season were largely accounted for by the excess in-stream loads over the subsequent or following non-winter months in 2019. At Site 9 Oak Creek, for example, the excess in-stream chloride load from March 2019 through October

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[139] *N. Perera, B. Gharabaghi, P. Noehammer, and B. Kilgour, "Road Salt Application in Highland Creek Watershed, Toronto, Ontario – Chloride Mass Balance,"* Water Quality Research Journal*, 45(4): 451-461, 2010.*

[140] *D.W. Kincaid and S.E.G. Findlay, "Sources of Elevated Chloride in Local Streams: Groundwater and Soils as Potential Reservoirs,"* Water, Air, and Soil Pollution*, 203: 335-342, 2009.*

[141] *C.J. Oswald, G. Gibberson, E. Nicholls, C. Wellen, and S. Oni, "Spatial Distribution and Extent of Urban Land Cover Control Watershed-scale Chloride Retention,"* Science of the Total Environment*, 652: 278-288, 2019.*

2019 (3,971 tons) accounted for 99.8 percent of the excess chloride source estimated for the previous winter from November 2018 through February 2019 (3,979 tons). Three other monitoring sites exhibited similar chloride load results between November 2018 and October 2019: Site 30 Des Plaines River, Site 2 Fox River at New Munster, and Site 1 Fox River at Waukesha all had excess in-stream chloride loads that accounted for greater than 95 percent of the excess chloride source loads from the previous winter season. Appendix C shows that the difference between the excess chloride loads at those same monitoring sites were not as balanced over the second year of the Study when compared to the first year. For example, at Site 9 Oak Creek the excess in-stream chloride load from March 2020 through October 2020 (2,493 tons) accounted for 63.5 percent of the excess chloride source load estimated for the previous winter from November 2019 through February 2020 (3,928 tons).

It is important to note that 2018 and 2019 had particularly high annual precipitation totals, and rank as the top two wettest years on record for the Region as discussed in Chapter 2. It is likely that the excess rainfall and soil moisture would help flush chloride through shallow soil layers. The total precipitation between November 2018 and October 2019 was 45 inches, which is ranked the wettest November to October period on record in the Region dating back to 1894, whereas the total precipitation between November 2019 and October 2020 was 37 inches and ranked as the 27th wettest November to October period on record.[142] The mass balance results presented in Appendix C demonstrate that the balance of the seasonal chloride load excesses for many of the Study monitoring sites was generally better for the first winter and subsequent non-winter months than for the second winter, which appears to be correlated with higher precipitation totals over the relatively short 25-month study period.

Land Use

Correlations between the total chloride source loads and various land use categories were performed for every stream monitoring site as presented in Section 4.3. A similar analysis was conducted for the 14 mass balance sites to evaluate the relationships between the estimated in-stream chloride loads and land use characteristics. This in-stream chloride load analysis yielded similar results. As with the chloride source loads, the in-stream chloride loads estimated for the 14 stream monitoring sites exhibited a very strong positive correlation with both urban land use (ρ = 0.802, R^2 = 0.8326) and the percent of roads and parking lots in the upstream drainage area (ρ = 0.837, R^2 = 0.8701). These relationships reiterate the importance of deicing salt as a major source of chloride, especially in urban areas where impervious surfaces are more prevalent. Impervious surfaces are often treated with chloride-based compounds during the winter season, and these surfaces also generate greater runoff volumes. These combined factors result in greater amounts of chloride entering surface waters with increasing impervious land cover. The estimated total in-stream chloride loads for each site show a weak negative correlation with natural lands (ρ = -0.376, R^2 = 0.1965) and a strong negative correlation with agricultural lands (ρ = -0.763, R^2 = 0.6463). These relationships suggest that potash fertilizer is a less significant source of chloride at monitoring sites in the Region.

Streamflow Discharge and Flow-Weighted Mean Chloride Concentrations

Chapter 3 of TR-63 explored the relationship between streamflow discharge and in-stream chloride, and examined in-stream chloride dynamics along with the response to various types of meteorological events.[143] In general, an inverse relationship was observed between streamflow discharge and chloride concentrations, by which high streamflow tended to lower in-stream chloride concentrations through dilution while low-flow conditions were associated with elevated chloride concentrations. Additionally, during winter and early spring chloride-laden runoff can cause short-term chloride concentration spikes in streams and rivers, as the “first flush” of pollutants carries excess chloride that had accumulated on surfaces and within the watershed throughout the winter season.

To account for the influence of streamflow discharge rates on chloride concentrations, in-stream chloride conditions were further evaluated using flow-weighted mean chloride concentrations (FWMCC). The FWMCC provide a more accurate representation of the chloride conditions in a stream from a pollutant load perspective. The FWMCC were computed for each monitoring site by dividing the total mass of chloride by the total volume of streamflow discharge over a specific period of time. For this evaluation, the FWMCC

[142] *NOAA National Centers for Environmental Information, Climate at a Glance: Divisional Rankings, www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/divisional/rankings, accessed August 2025.*

[143] *SEWRPC Technical Report No. 63, in preparation,* op. cit.

were computed for the full study period as well as for each month of the study period. Table 4.6 presents the FWMCC for each monitoring site over the entire study period as well as the monthly minimum and maximum FWMCC. The monitoring sites with the highest overall FWMCC for the study period were Site 53 Honey Creek at Wauwatosa, Site 12 Lincoln Creek, and Site 1 Fox River at Waukesha. The monitoring sites with the lowest overall FWMCC for the study period were Site 16 Jackson Creek, Site 25 Root River Canal, Site 3 Mukwonago River at Mukwonago, and Site 10 Pike River.

In addition to the overall study period and monthly FWMCC, the daily FWMCC were computed for Site 1 Fox River at Waukesha over the study period, as presented in Figure 4.6. The grey dots on this figure represent the daily FWMCC plotted against the mean daily streamflow discharge and illustrate the inverse relationship between chloride concentrations and streamflow discharge, as represented by the dashed trendline in red. This plot also shows outliers that don't follow the typical inverse relationship between chloride concentrations and streamflow discharge. These outliers, plotted above the rest of the datapoints, occurred when both chloride concentrations and streamflow rates were high. This typically was observed during the months of February and March when runoff and snowmelt can carry large amounts of chloride from the deicing and anti-icing activities throughout the winter months. The monthly FWMCC for Site 1 are represented by the blue dots plotted on the figure and ranged from 90.1 mg/l to 403.8 mg/l over the study period. The monthly data exhibited less variability than the daily data but followed the typical inverse relationship between chloride concentrations and streamflow discharge. The lone exception was an outlier in February 2019, which was also the maximum monthly FWMCC at that site for the study period. These outliers highlight how the months of February and March are critical for in-stream chloride conditions and potential chloride toxicity impacts to organisms. The impacts of chloride are discussed in detail in SEWRPC Technical Report No. 62 (TR-62).[144]

The monitoring sites with the largest monthly maximum FWMCC also had the largest range of monthly FWMCC and included Site 53, Site 12, Site 9, Site 57 and Site 1. Furthermore, these five monitoring sites had the highest percentages of urban land use and the lowest percentages of agricultural land use of all 14 sites considered in the chloride mass balance analysis. Site 12, Site 53 and Site 9 were also located on the most-flashy streams considered for the analysis, exhibiting large and rapid fluctuations in streamflow following a meteorological event. Of the 14 sites considered in the mass balance analysis, Site 3 Mukwonago River at Mukwonago had the smallest range of monthly FWMCC, from 42.3 mg/l to 57.8 mg/l. Site 3 is located less than 1,000 feet downstream of the dam that releases water from Lower Phantom Lake. The relatively steady nature of the monthly FWMCC and the estimated in-stream chloride loads at Site 3 demonstrate the buffering effect of the upstream lake on chloride concentrations in the water flowing out of the lake. The influence of lakes on in-stream chloride concentrations has been observed in other studies and are discussed further in a separate technical report.[145,146]

Wastewater Treatment Facility Effluent

WWTF effluent can influence chloride concentrations in surface water, especially when streamflow discharge is low, as described in detail in TR-63 Chapter 3.[147] During drought or low flow conditions, the effluent discharged by treatment facilities can make up a substantial portion of the flow in the stream. Additionally, TR-63 demonstrated the influence of WWTF effluent by comparing chloride concentrations at monitoring sites located upstream and downstream of a small public WWTF plant. The influence of upstream WWTF effluent on the amount of in-stream chloride is further examined at the six mass balance monitoring sites with WWTFs located upstream (Site 1, Site 2, Site 25, Site 30, Site 58, and Site 59). The total in-stream chloride load was compared with the WWTF effluent chloride load for each month of the study period to estimate the proportion of chloride in the stream that originated from the upstream WWTFs. This evaluation assumed that all flow and chloride discharged from the WWTF was conveyed downstream to the monitoring site, neglecting interactions with groundwater. Figure 4.7 shows the total percent of in-stream chloride by month for the study period that is attributed to the WWTF effluent chloride load for each of the six mass balance monitoring sites with WWTFs located upstream.

[144] *SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment, *April 2024.*

[145] *L.A. Rock and H.A. Dugan, "Lakes Protect Downstream Riverine Habitats from Chloride Toxicity,"* Limnology and Oceanography*, 68:1,216-1,231, 2023.*

[146] *SEWRPC Technical Report No. 64, 2024,* op. cit.

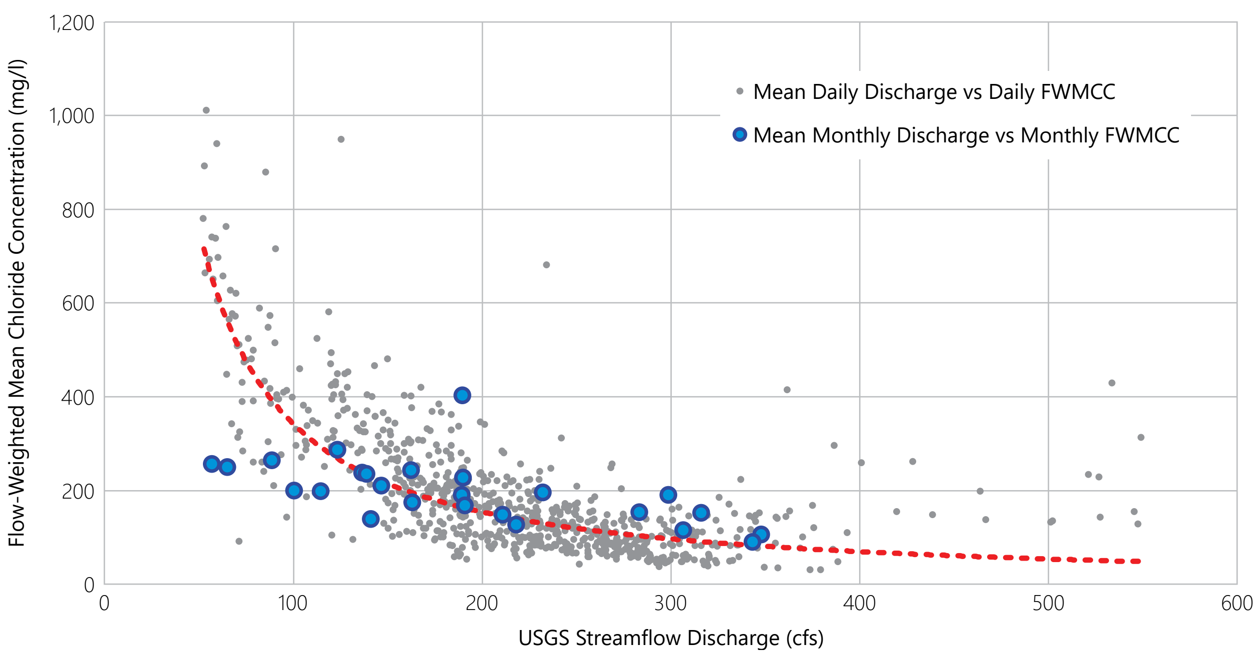
[147] *SEWRPC Technical Report No. 63, in preparation,* op. cit.

Table 4.6
Flow-Weighted Mean Chloride Concentrations for Stream Monitoring Sites: Study Period

Site No.	Site Name	Study Period FWMCC (mg/l)	Maximum Monthly FWMCC (mg/l)	Minimum Monthly FWMCC (mg/l)
1	Fox River at Waukesha	180.1	403.8	90.1
2	Fox River at New Munster	80.3	166.2	50.0
3	Mukwonago River at Mukwonago	50.5	57.8	42.3
9	Oak Creek	158.3	584.0	23.7
10	Pike River	51.5	113.9	20.9
11	Bark River Upstream	90.9	125.2	62.8
12	Lincoln Creek	196.3	1,035.5	25.0
16	Jackson Creek	49.5	125.3	24.3
25	Root River Canal	50.1	121.4	10.6
30	Des Plaines River	63.4	139.0	32.3
53	Honey Creek at Wauwatosa	221.6	1,232.5	52.9
57	Menomonee River at Wauwatosa	161.4	549.9	45.2
58	Milwaukee River at Estabrook Park	65.0	96.3	49.5
59	Root River near Horlick Dam	70.0	193.8	27.0

Source: SEWRPC

Figure 4.6
Flow-Weighted Mean Chloride Concentrations Versus USGS Streamflow Discharge: Daily and Monthly Comparisons for Site 1 Fox River at Waukesha



Note: The red dashed trendline is based on the daily dataset and does not include the monthly data.

Source: USGS and SEWRPC

Site 1 Fox River at Waukesha is considered the most critical monitoring site from a WWTF perspective, with the largest percentage of in-stream chloride load from WWTF effluent chloride load on average. Over the 25-month study period, the proportion of monthly in-stream chloride from WWTFs at Site 1 ranged from approximately 16 percent to 52 percent, and the chloride load from WWTF effluent made up slightly less than 30 percent on average of the in-stream chloride load. When the percent of in-stream chloride from WWTFs was compared to the average monthly USGS streamflow for all six sites over the study period, the highest proportions of in-stream chloride from WWTFs corresponded to periods of low streamflow. In general, the highest proportions of chloride from WWTFs occurred during the summer months, peaking in August at most sites as shown in Figure 4.7.

4.5 CONCLUSIONS

A summary of the conclusions and key findings from the evaluation of chloride source loads and in-stream chloride loads estimated for the study period as well as the chloride mass balance analysis are provided below:

- The Regional chloride budget results indicated that winter maintenance activities were the largest source of chloride to the environment during the study period. Chloride source loads were computed for deicing operations on public roadways, encompassing nearly 70 percent of the total chloride load from winter maintenance activities, as well as private parking lot deicing which accounted for slightly more than 30 percent of the total chloride load.

- The second largest source of chloride in the Regional chloride budget was wastewater effluent, which included chloride loads computed for wastewater treatment facilities, private residential septic systems, and industrial wastewater.

- The chloride source loads computed for all 41 stream monitoring sites in the Study indicated very strong positive correlations with the percent urban land use as well as percent roads and parking lots in the site drainage area.

- The chloride source load calculation results demonstrate that the use of liquids for winter road maintenance, either through pre-wetting or direct liquid application, had lower chloride contributions by volume than solid rock salt applications.

- Even relatively minor sources of chloride can have a significant effect on a local scale.

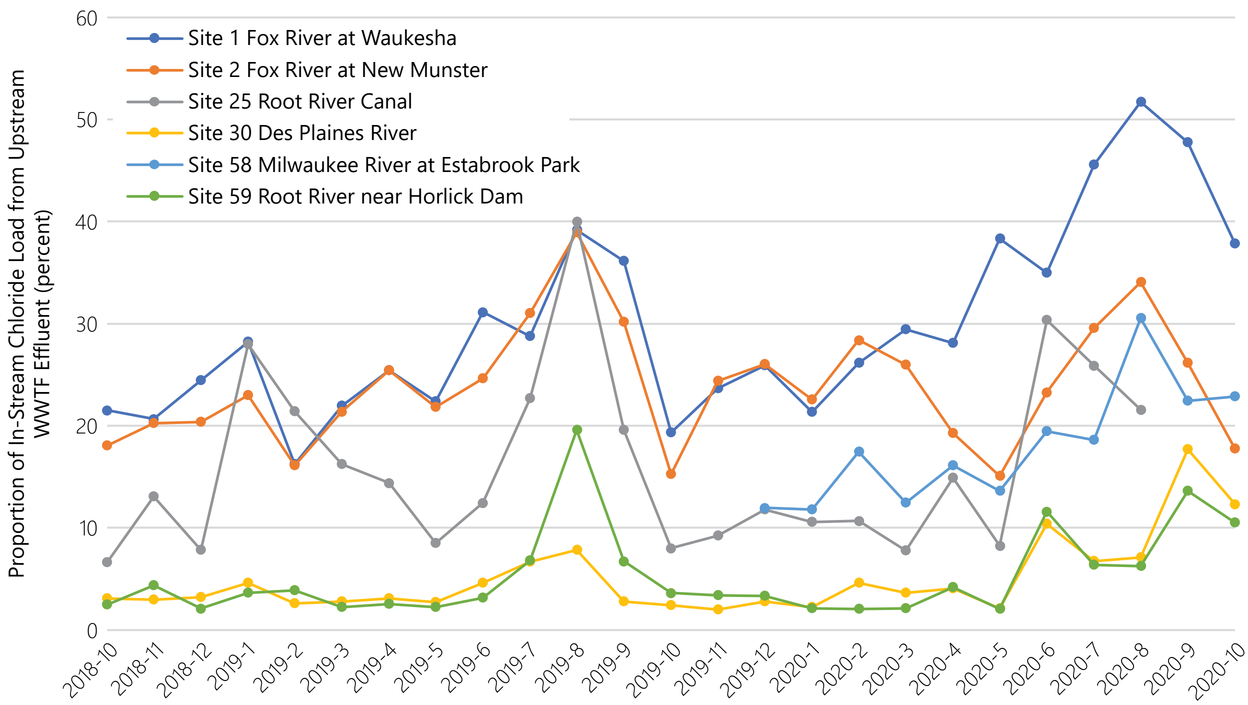
- Overall, the computed chloride source loads and estimated in-stream chloride loads matched well for the 14 stream monitoring sites evaluated for the chloride mass balance. There were six monitoring sites that had an overall difference between chloride source loads and in-stream chloride loads within 12 percent over the full study period. There were nine monitoring sites where the chloride source loads and in-stream chloride loads were within 30 percent, and only one site had chloride mass balance results greater than 50 percent.

- The highest estimated in-stream chloride loads occurred during spring at most of the stream monitoring sites, except for the sites with the highest percentage of urban land use, where the highest estimated in-stream chloride loads were observed during the winter months.

- A comparison of excess chloride sources loads during the winter months with the excess in-stream chloride loads during the subsequent non-winter months suggests that chloride from winter maintenance applications may be retained within a watershed, moving slowly through the surficial soil layers until they are released into the surface water network long after they were introduced into the environment.

- For the mass balance analysis, the monitoring sites that had excess chloride source loads that were significantly larger than the in-stream chloride loads over the study period tended to have more highly urbanized drainage areas. The sites that had excess in-stream chloride loads that were greater than the chloride source loads had upstream drainage areas with higher proportions of nonurban land uses.

Figure 4.7
Proportion of the In-Stream Chloride Load from Upstream WWTF Effluent During the Study Period



Note: The figure includes the six stream monitoring sites in the mass balance analysis that were located downstream of public wastewater treatment facilities. The period of record for Site 58 runs from December 2019 to October 2020. The Site 25 dataset excludes September and October 2020 due to missing specific conductance data that affected the estimated in-stream chloride loads for those months.

Source: SEWRPC

- Monitoring sites with smaller drainage areas are more sensitive to the factors influencing the chloride mass balance results than sites with larger drainage areas.

- Streamflow and in-stream chloride concentrations typically exhibited an inverse relationship, as increased streamflow generally reduces in-stream chloride concentrations through dilution. However, outliers for which chloride concentration and streamflow increased together were observed at some sites during February and March, suggesting that those months are critical time for elevated in-stream chloride concentrations and chloride impacts.

- Land use has a significant influence on chloride in the environment, and monitoring sites with more urbanized drainage areas had the highest chloride source loads computed for the study period. The sites with the highest percentage of urban land use also exhibited the highest flow-weighted mean chloride concentrations along with the largest range of variability in chloride concentrations.

- WWTF effluent has a greater impact on in-stream chloride conditions during dry conditions or low-flow periods.

- One of the more significant unknowns in the chloride mass balance analysis was the interaction between groundwater and surface water. While chloride may be lost to groundwater, groundwater-fed baseflow could also be a source of chloride to streams during low flow conditions; however, these interactions were not quantified for this analysis.

- Additional chloride monitoring data collection would help reduce uncertainties related to the point source loads that were computed using estimated chloride concentrations.

APPENDICES

ACRONYMS AND ABBREVIATIONS

APPENDIX A

°F	Degrees Fahrenheit
ρ	Spearman's rank correlation coefficient

A

ASAE	American Society of Agricultural Engineers
AU	Animal unit (1,000 pounds of live animal mass)
AWSSI	Accumulated Winter Season Severity Index

C

$CaCl_2$	Calcium chloride
$CaCO_3$	Calcium carbonate
CAFO	Concentrated animal feeding operation
CCR	Coal combustion residual
CDL	Cropland Data Layer
cfs	Cubic feet per second
Commission	Southeastern Wisconsin Regional Planning Commission
CTH	County Trunk Highway

F

FHWA	Federal Highway Administration
FWMCC	Flow-weighted mean chloride concentration

G

GIS	Geographic information system
gpd	Gallons per day
gpg	Grains per gallon
GRN	WDNR Groundwater Retrieval Network

H

HCl	Hydrochloric acid

I

IH	Interstate Highway

K

K_2O	Potassium oxide
$K_2S_2O_3$	Potassium thiosulfate
$K_2SO_4^-$	Potassium sulfate
$K_2SO_4^-MgSO_4$	Potassium-magnesium sulfate
KCl	Potassium chloride
kg/ha	Kilograms per hectare
km	Kilometer
KNO_3	Potassium nitrate

L

lb	Pounds
lb/ac	Pounds per acre

M

MDSS	Maintenance Decision Support System
mg	Milligrams
mg/l	Milligrams per liter
$MgCl_2$	Magnesium chloride
mgd	Million gallons per day
MMIA	Milwaukee Mitchell International Airport
MRCC	Midwestern Regional Climate Center
MS4	Municipal separate storm sewer system

N

NaCl	Sodium chloride
NADP	National Atmospheric Deposition Program
NASS	National Agricultural Statistics Service
NCDC	National Climatic Data Center
NCEI	National Centers for Environmental Information
NOAA	National Oceanic and Atmospheric Administration
NR	Natural Resources
NRCS	Natural Resources Conservation Service
NSN	National streamgaging network
NWIS	USGS National Water Information System
NWS	National Weather Service

R

R^2	Coefficient of determination (R-squared)
Region	Southeastern Wisconsin Region

S

SEWRPC	Southeastern Wisconsin Regional Planning Commission
STH	State Trunk Highway
Study	Chloride Impact Study

T

TOPS	Wisconsin Traffic Operations and Safety Laboratory
TR	Technical Report

U

USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
USH	U.S. Highway

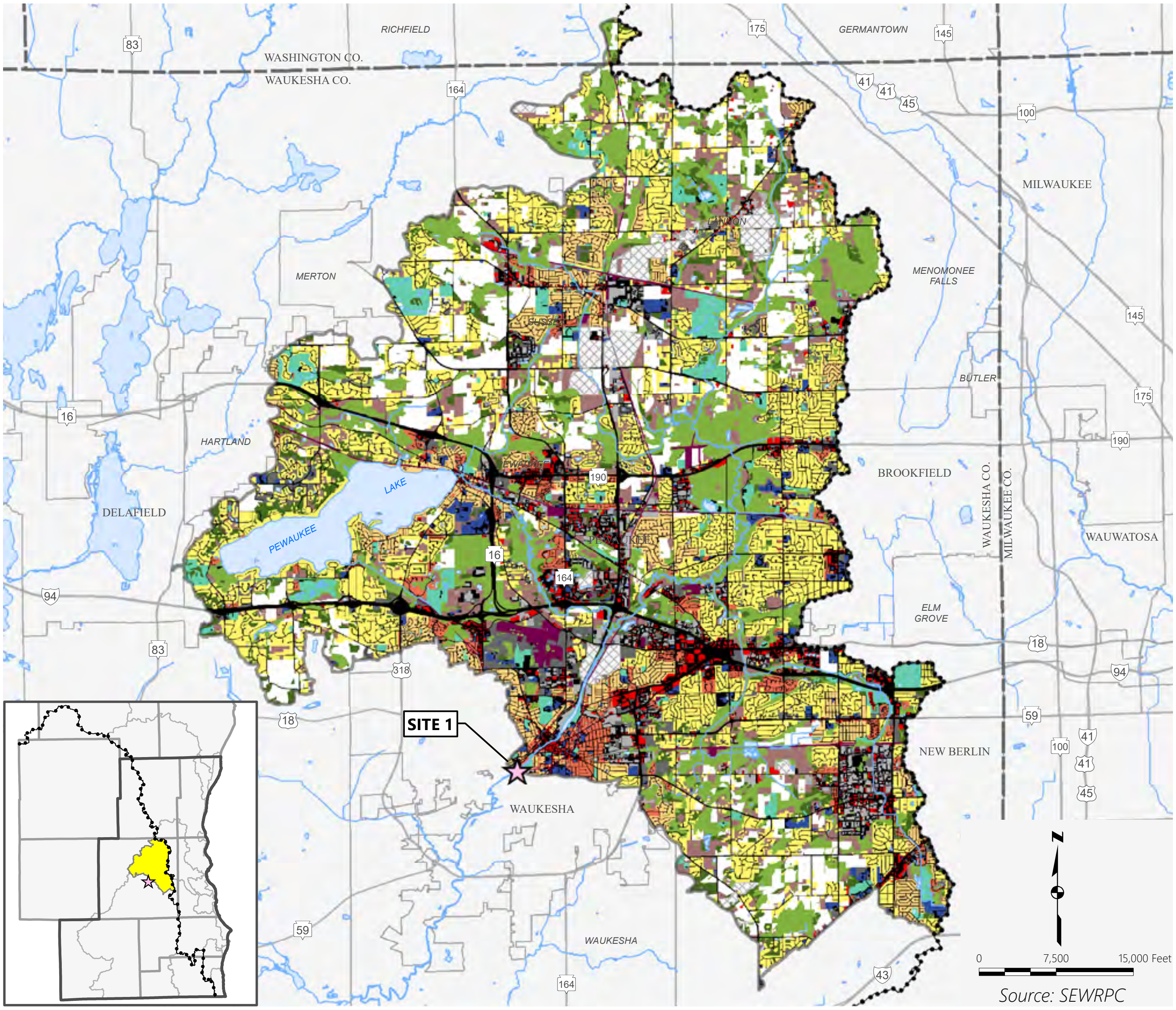
W

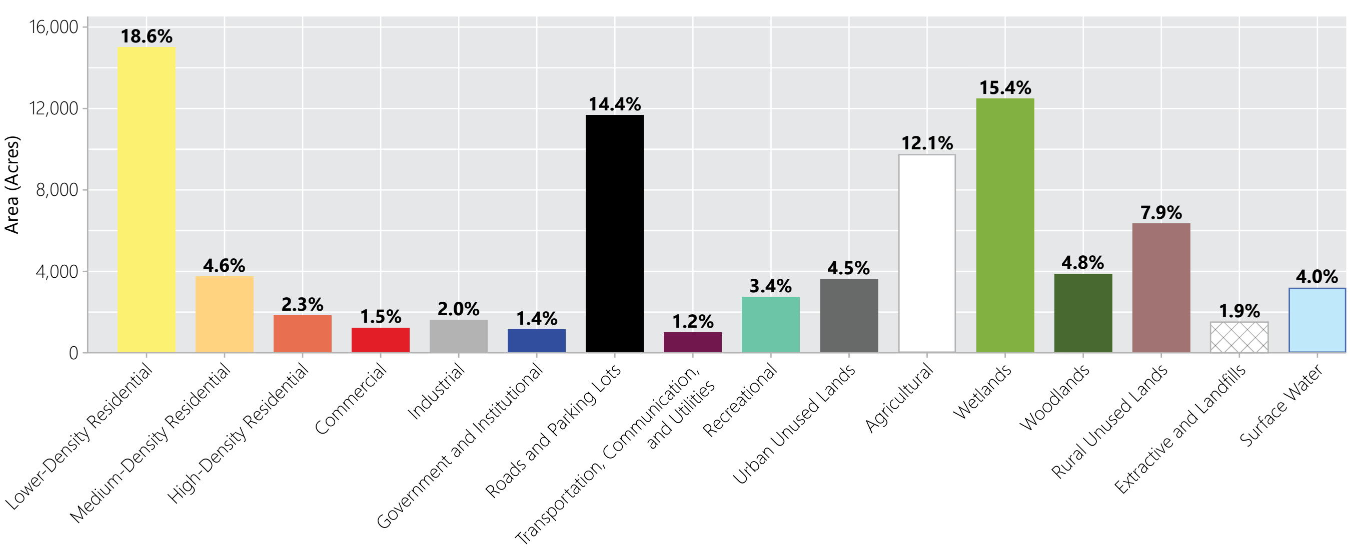
WBIC	WDNR Water Body Identification Code
WDNR	Wisconsin Department of Natural Resources
WICCI	Wisconsin Initiative on Climate Change Impacts
WisDOT	Wisconsin Department of Transportation
WPDES	Wisconsin Pollutant Discharge Elimination System
WSI	Winter Severity Index
WWTF	Wastewater treatment facility

APPENDIX B

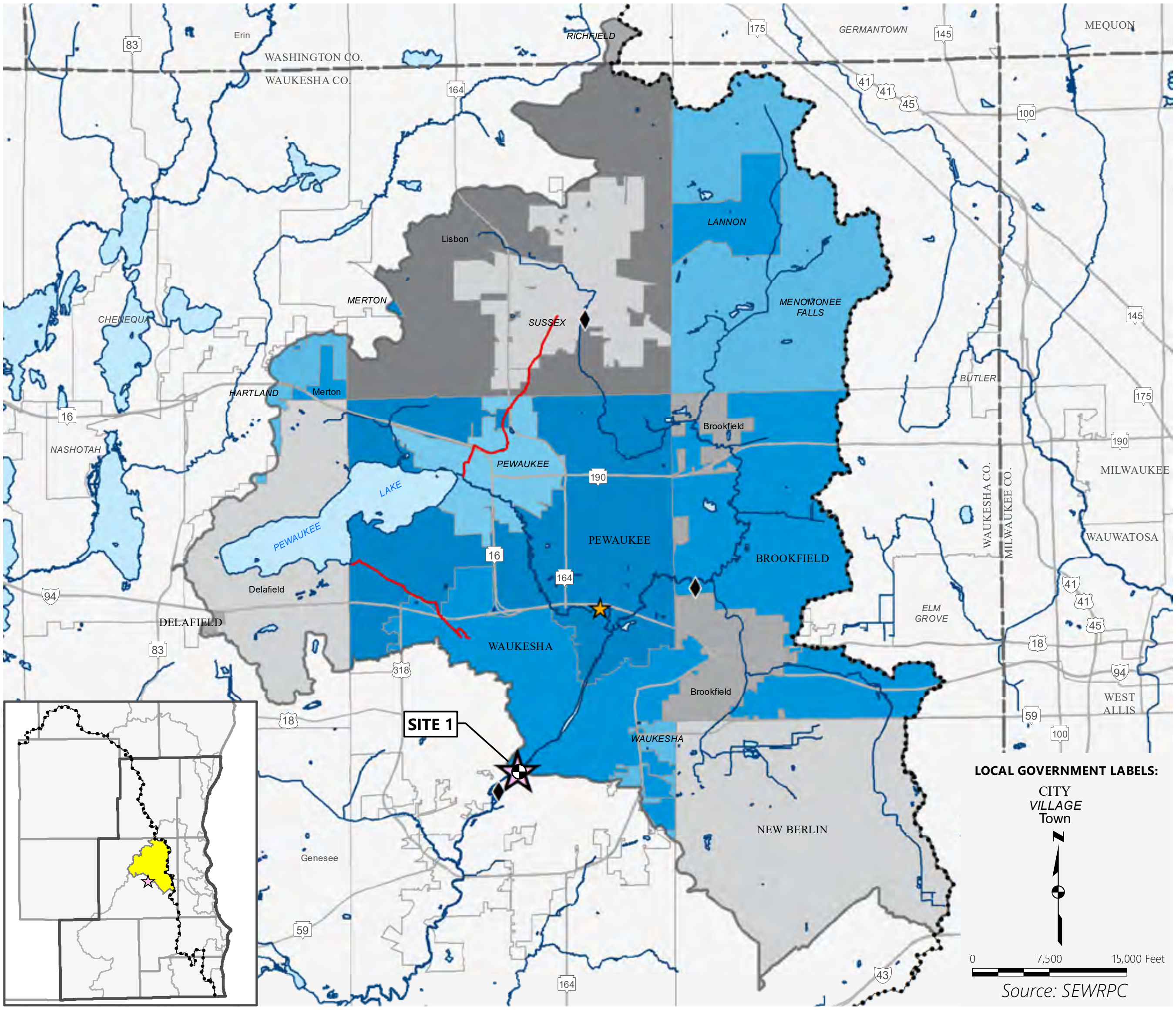
DRAINAGE AREA CHARACTERISTICS FOR STREAM MONITORING SITES

Map B.1
Site 1: Fox River at Waukesha Drainage Area – Existing Land Use





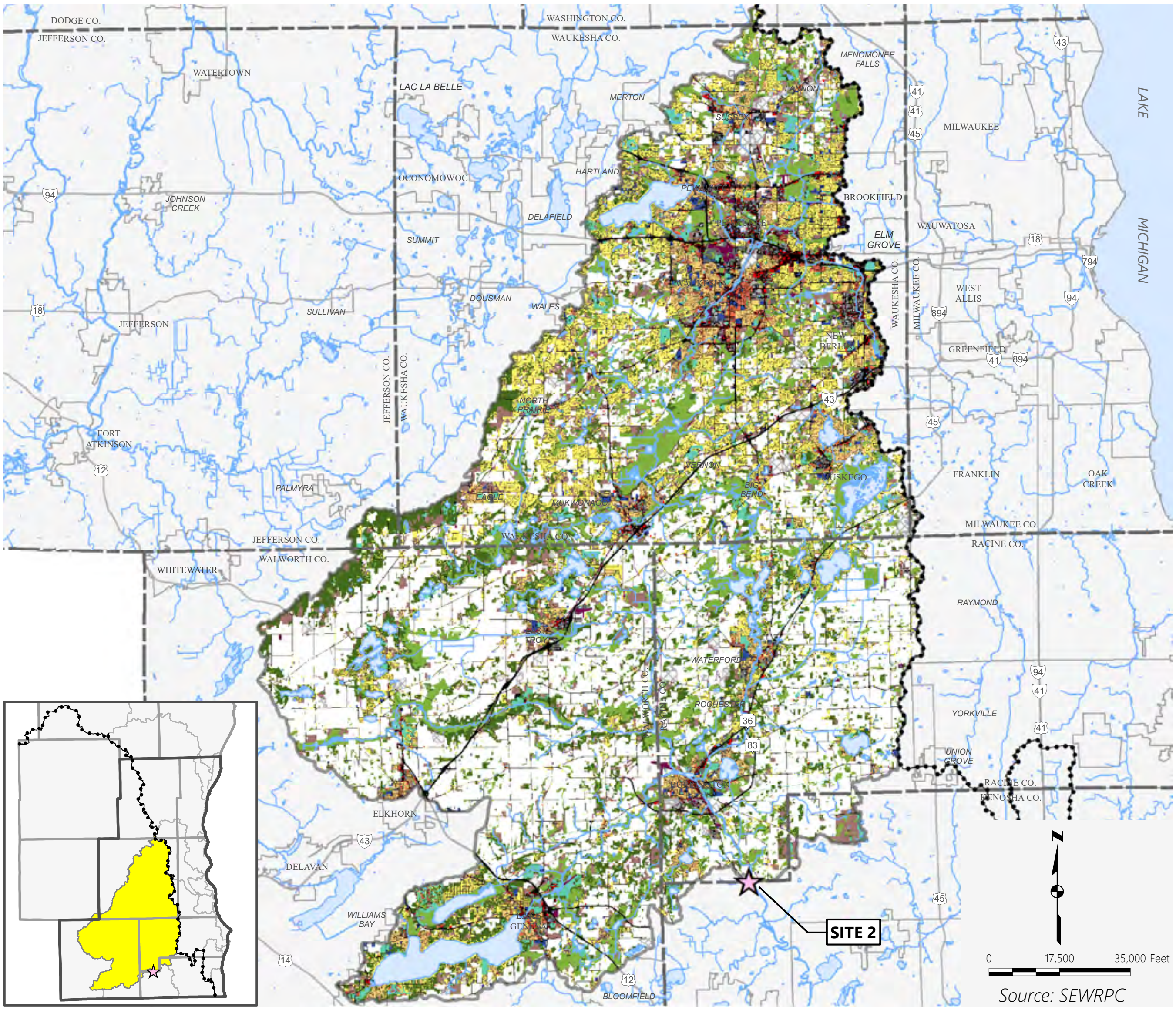
Map B.2
Site 1: Fox River at Waukesha Drainage Area – Features

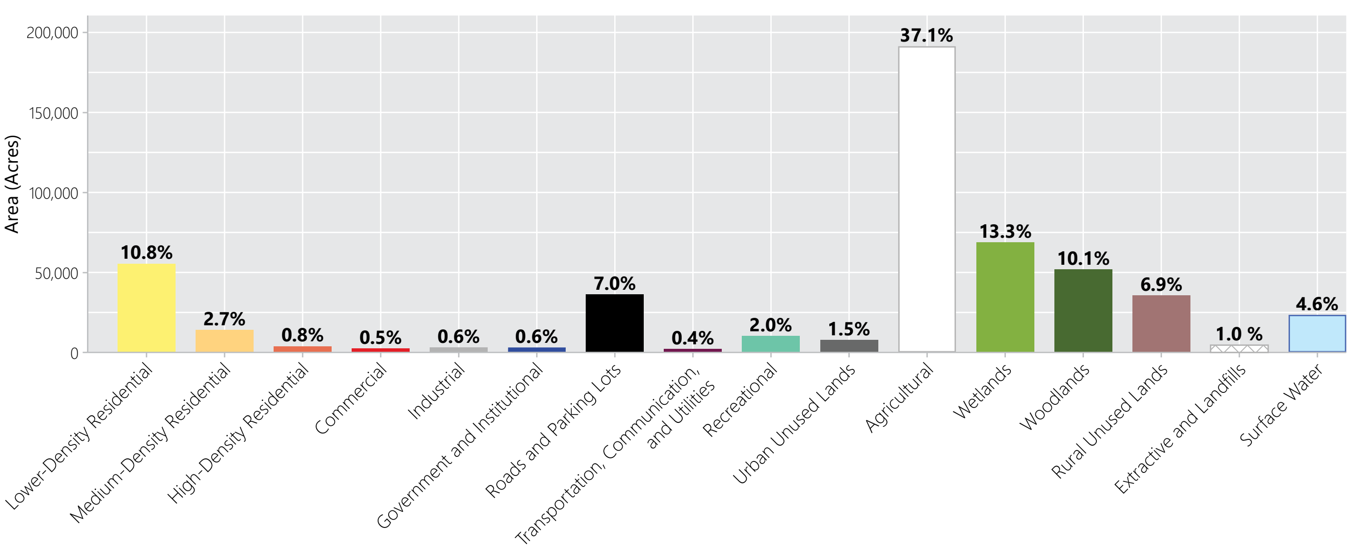


Facts at a Glance

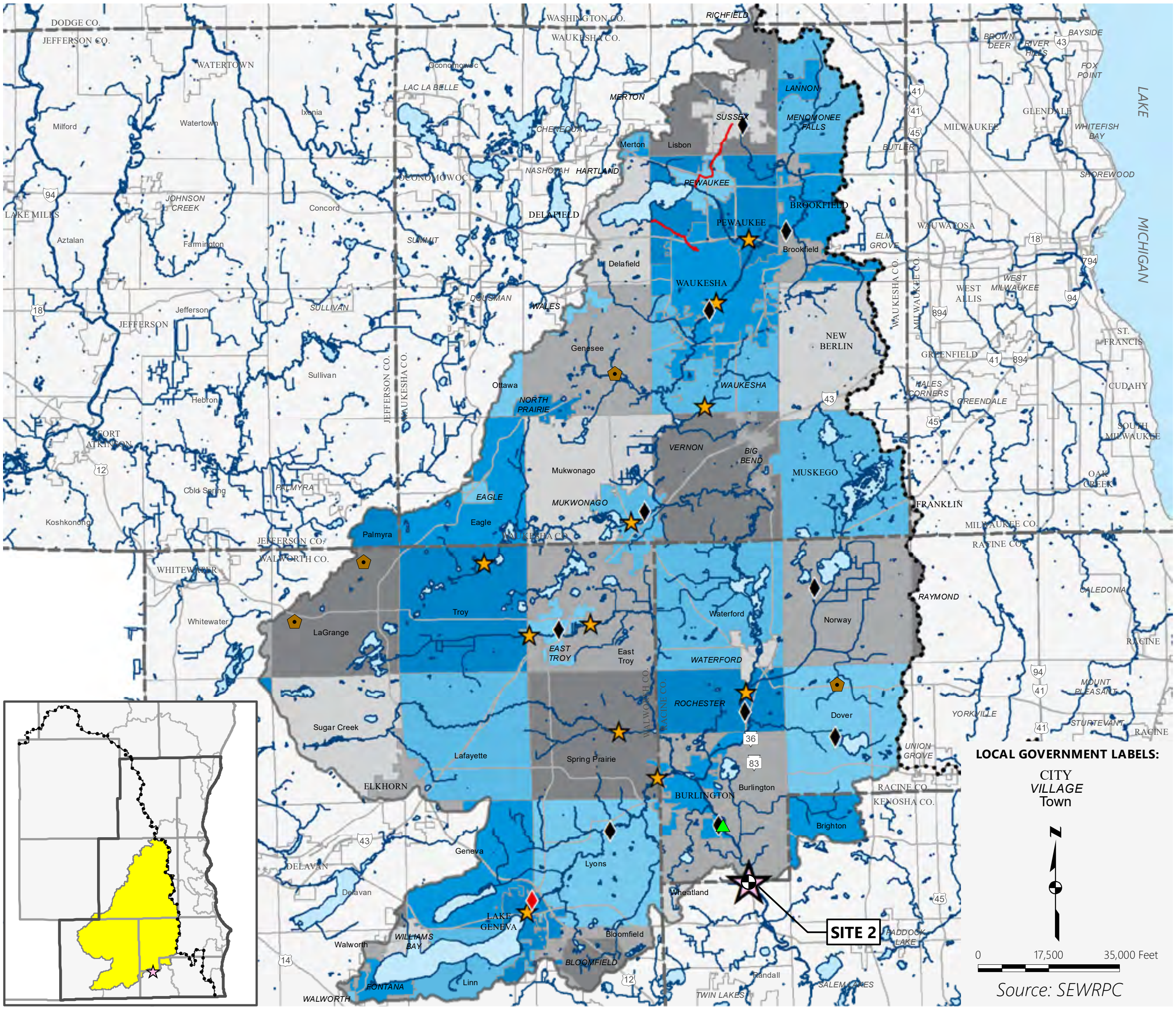
- **Drainage Area Size:** 126 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 54.0%; Rural – 46.0%
- **Roads and Parking Lots (% of drainage area):** 14.4
- **Estimated Population (2010):** 120,800
- **Estimated Households (2010):** 49,480 (91% served by public sanitary sewer)
- **Nearest USGS Streamgage (◉):** Fox River at Waukesha (05543830)
- **Other Monitoring Sites Within this Drainage Area (☆):** Site 8
- **Upstream Wastewater Treatment Facilities (♦):** 2
- **Chloride-Impaired Waters:** (—) Chronic Toxicity Impairment
- **Water Supply Source**: Groundwater and Lake Michigan (City of Waukesha converted to Lake Michigan supply in October 2023)

Map B.3
Site 2: Fox River at New Munster Drainage Area – Existing Land Use





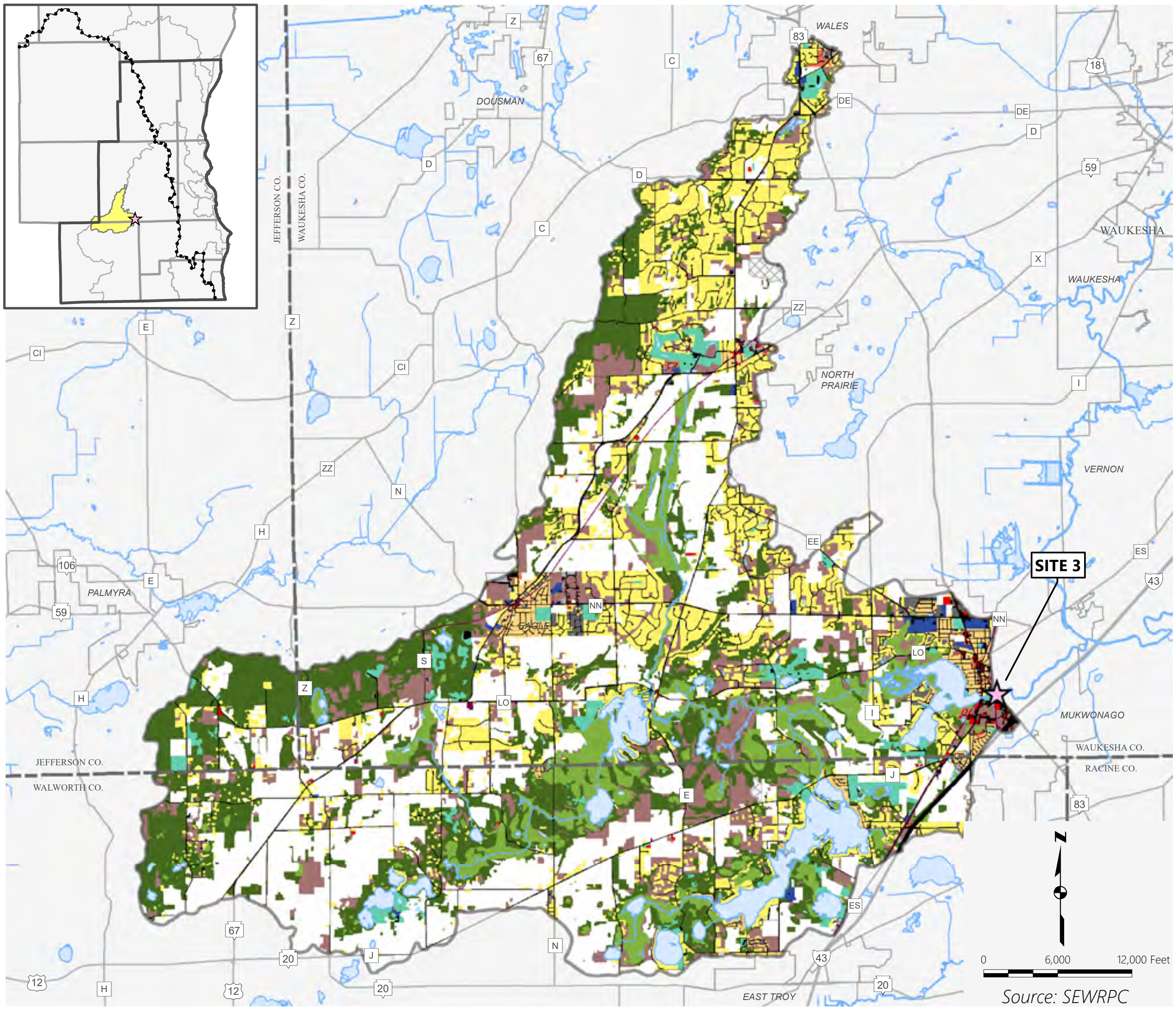
Map B.4
Site 2: Fox River at New Munster Drainage Area – Features

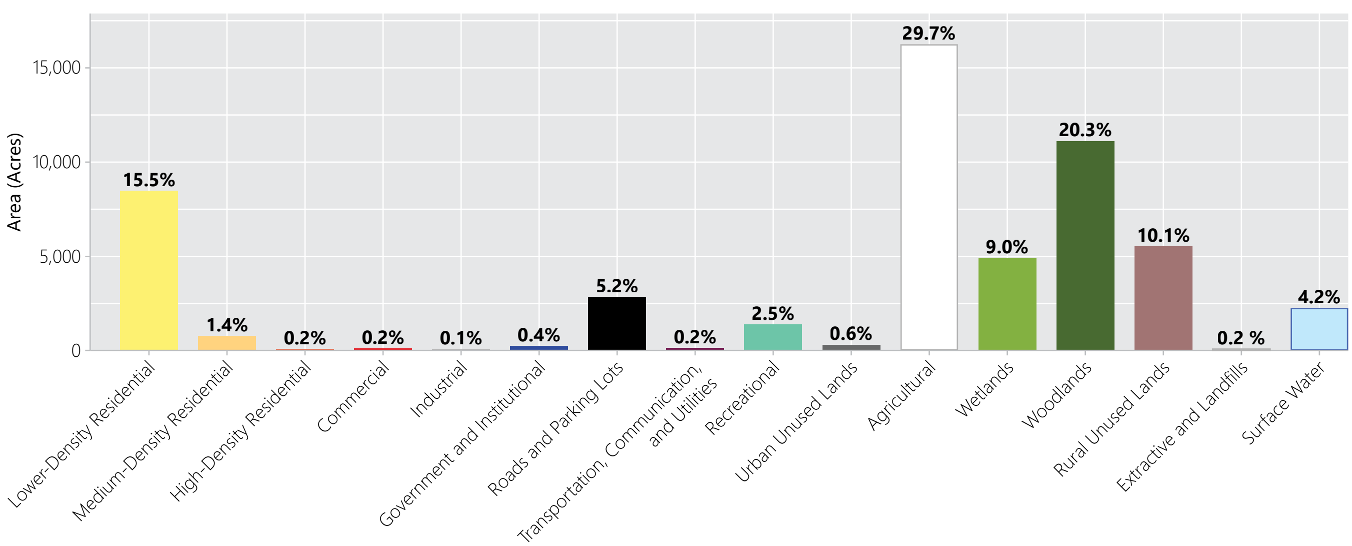


Facts at a Glance

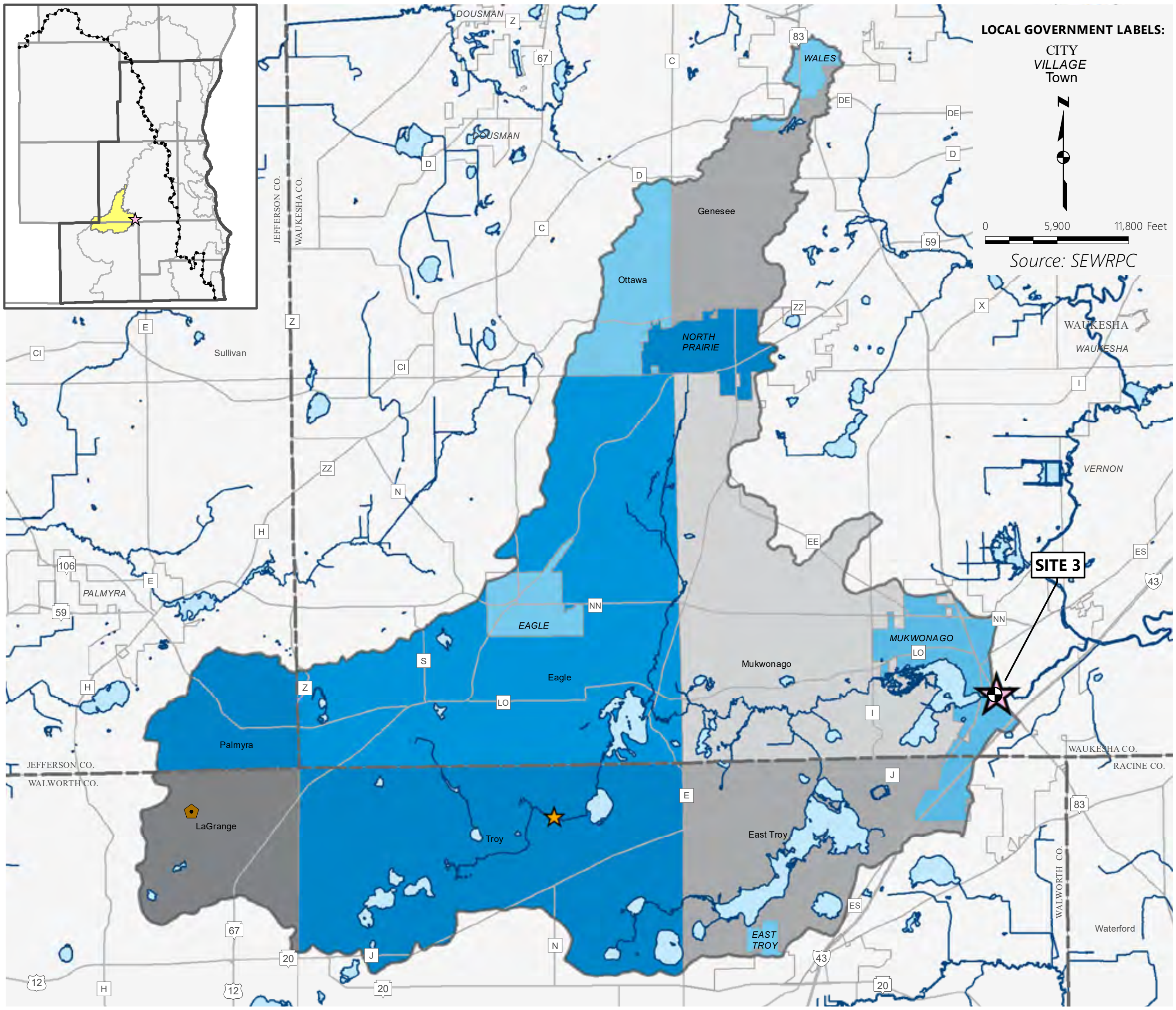
- **Drainage Area Size:** 807 square miles
- **Major Watershed:** Fox River
- **Land Use:** 27.1%; Rural – 72.9%
- **Roads and Parking Lots (% of drainage area):** 7.0
- **Estimated Population (2010):** 332,920
- **Estimated Households (2010):** 130,580 (76% served by public sanitary sewer)
- **Nearest USGS Streamgage (◐):** Fox River at New Munster (05545750)
- **Other Monitoring Sites Within this Drainage Area (☆):** Site 8, Site 1, Site 33, Site 45, Site 3, Site 35, Site 36, Site 47, Site 4, Site 48, and Site 6
- **Upstream Wastewater Treatment Facilities (♦):** 10
  WWTF discharge to soil (♦): 1
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Concentrated Animal Feeding Operations (⬟):** 4
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
- **Water Supply Source:** Groundwater and Lake Michigan (City of Waukesha converted to Lake Michigan supply in October 2023)

Map B.5
Site 3: Muwonago River at Mukwonago Drainage Area – Existing Land Use





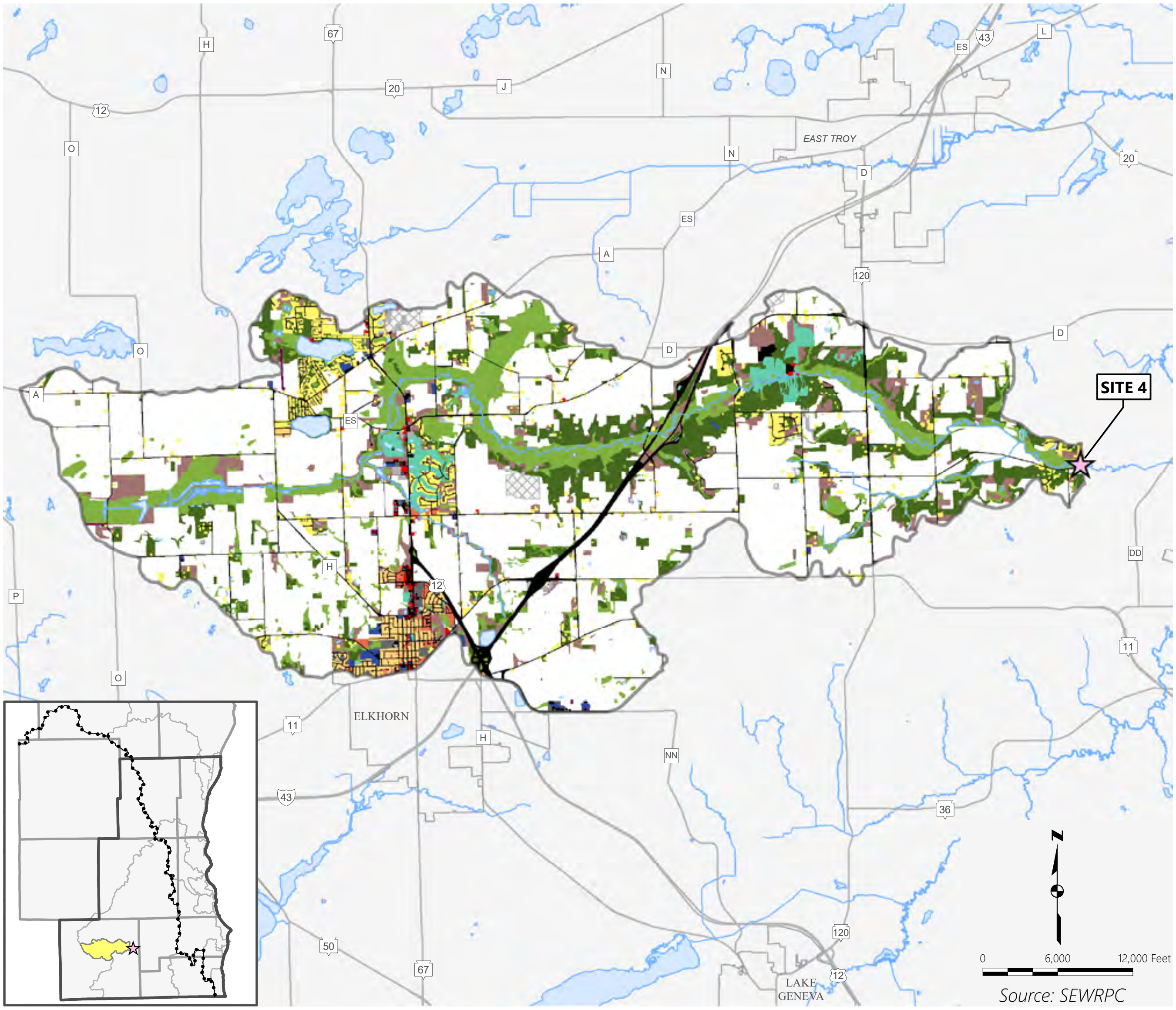
Map B.6
Site 3: Muwonago River at Mukwonago Drainage Area – Features



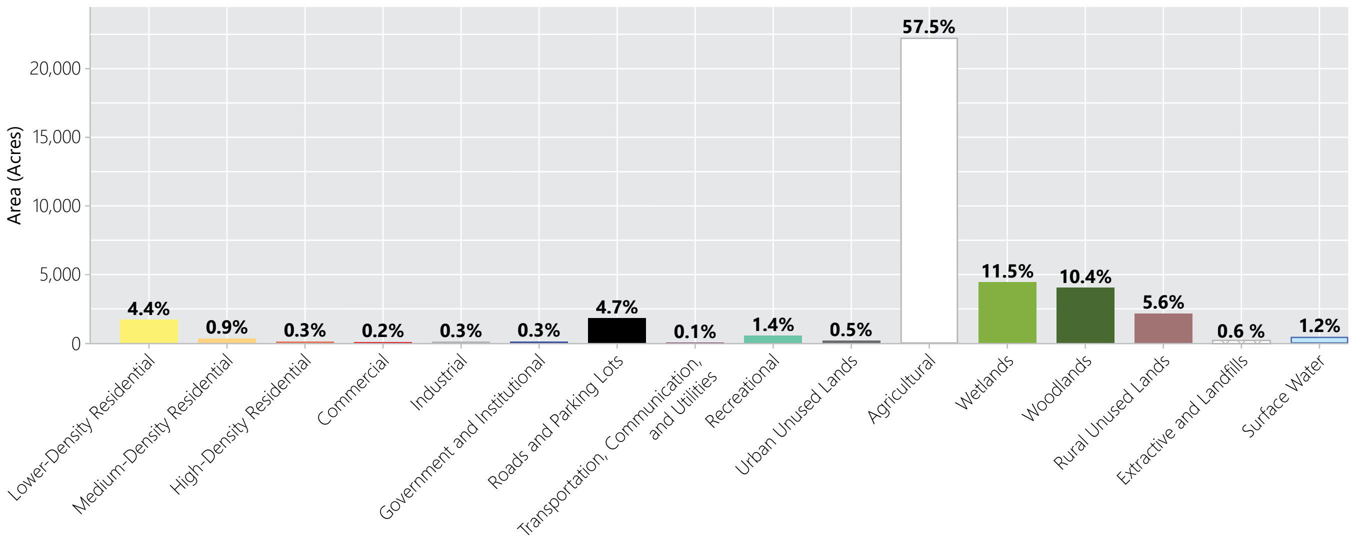
Facts at a Glance

- **Drainage Area Size:** 85 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 26.4%; Rural – 73.6%
- **Roads and Parking Lots (% of drainage area):** 5.2
- **Estimated Population (2010):** 20,670
- **Estimated Households (2010):** 7,610 (22% served by public sanitary sewer)
- **Nearest USGS Streamgage (◐):** Mukwonago River at Mukwonago (05544200)
- **Other Monitoring Sites Within this Drainage Area (☆):** Site 45
- **Concentrated Animal Feeding Operations (⬟):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

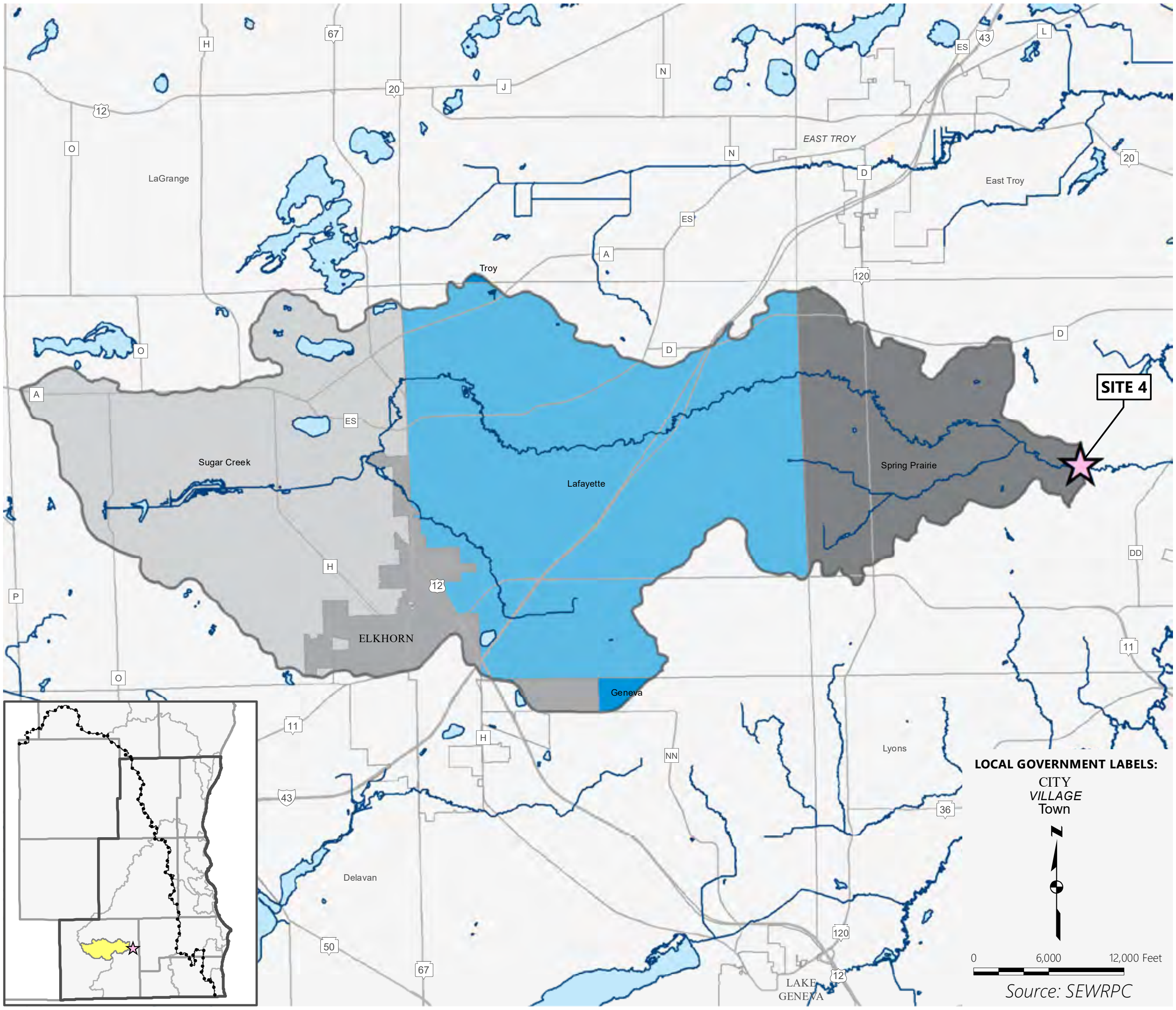
Map B.7
Site 4: Sugar Creek Drainage Area – Existing Land Use



Source: SEWRPC



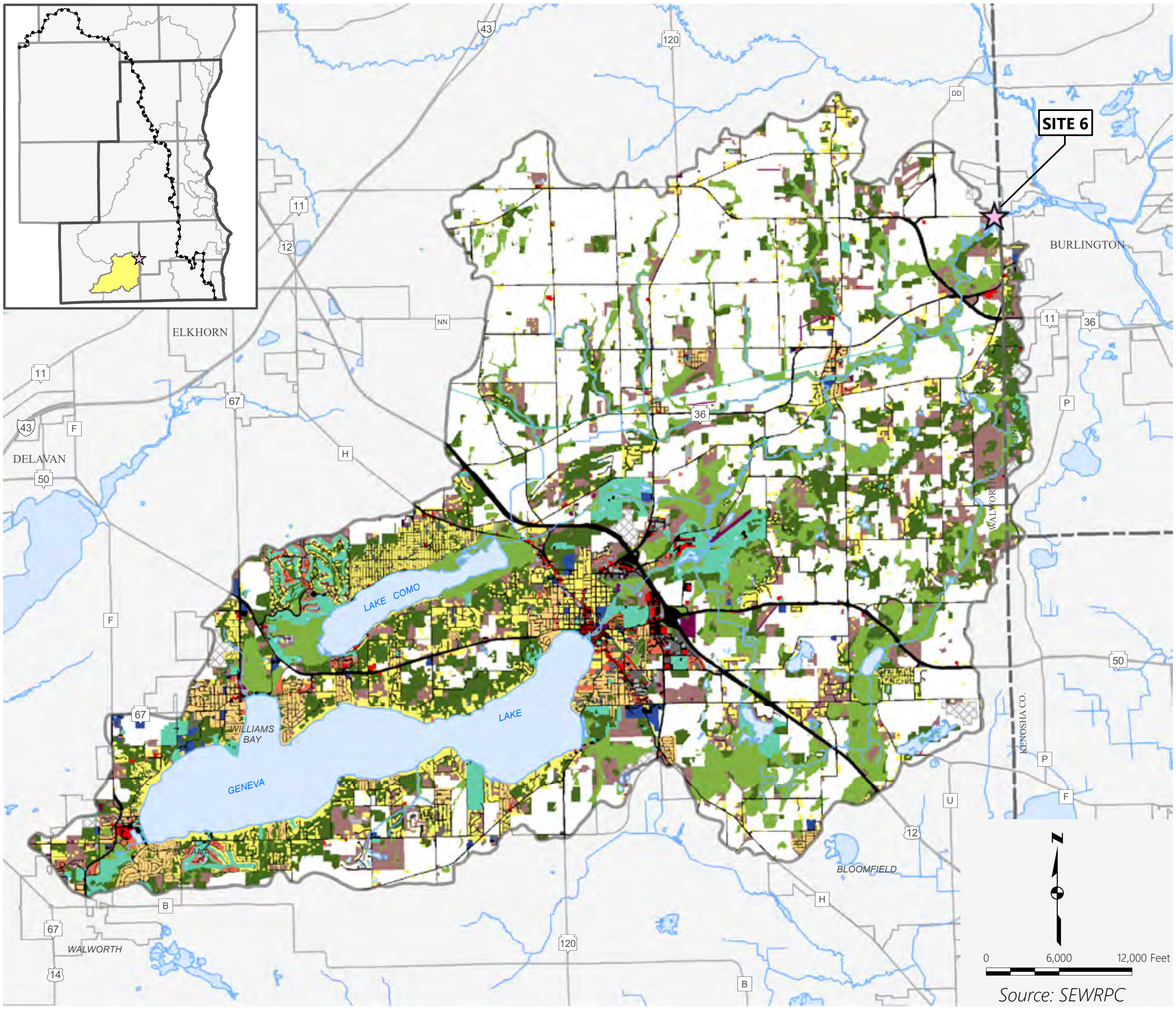
Map B.8
Site 4: Sugar Creek Drainage Area – Features



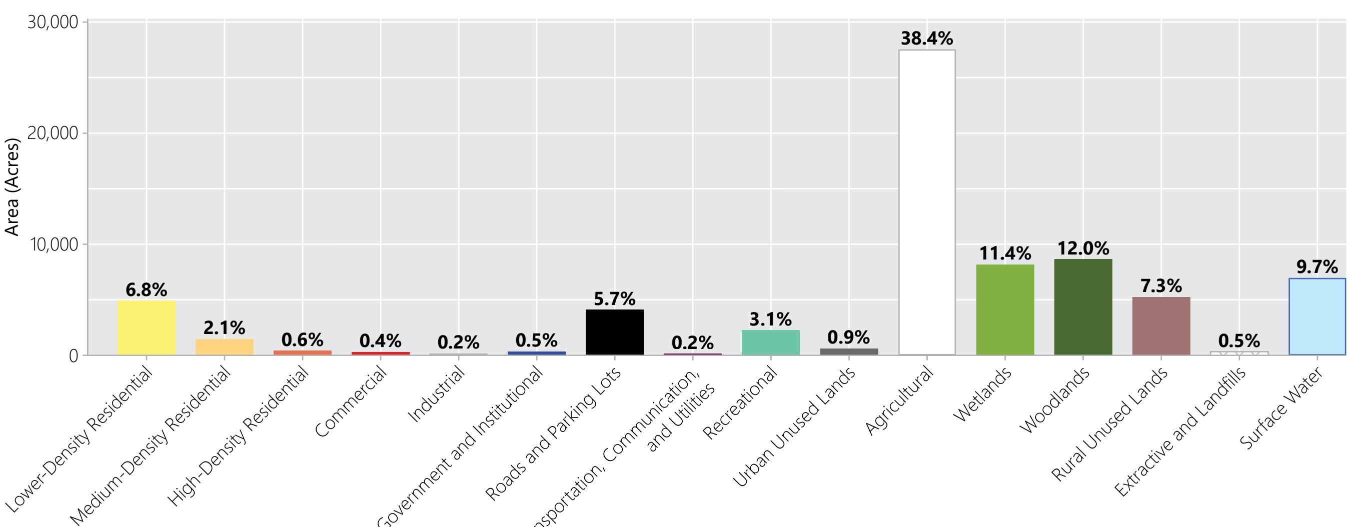
Facts at a Glance

- **Drainage Area Size:** 60 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 13.1%; Rural – 86.9%
- **Roads and Parking Lots (% of drainage area):** 4.7
- **Estimated Population (2010):** 10,970
- **Estimated Households (2010):** 4,070 (54% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

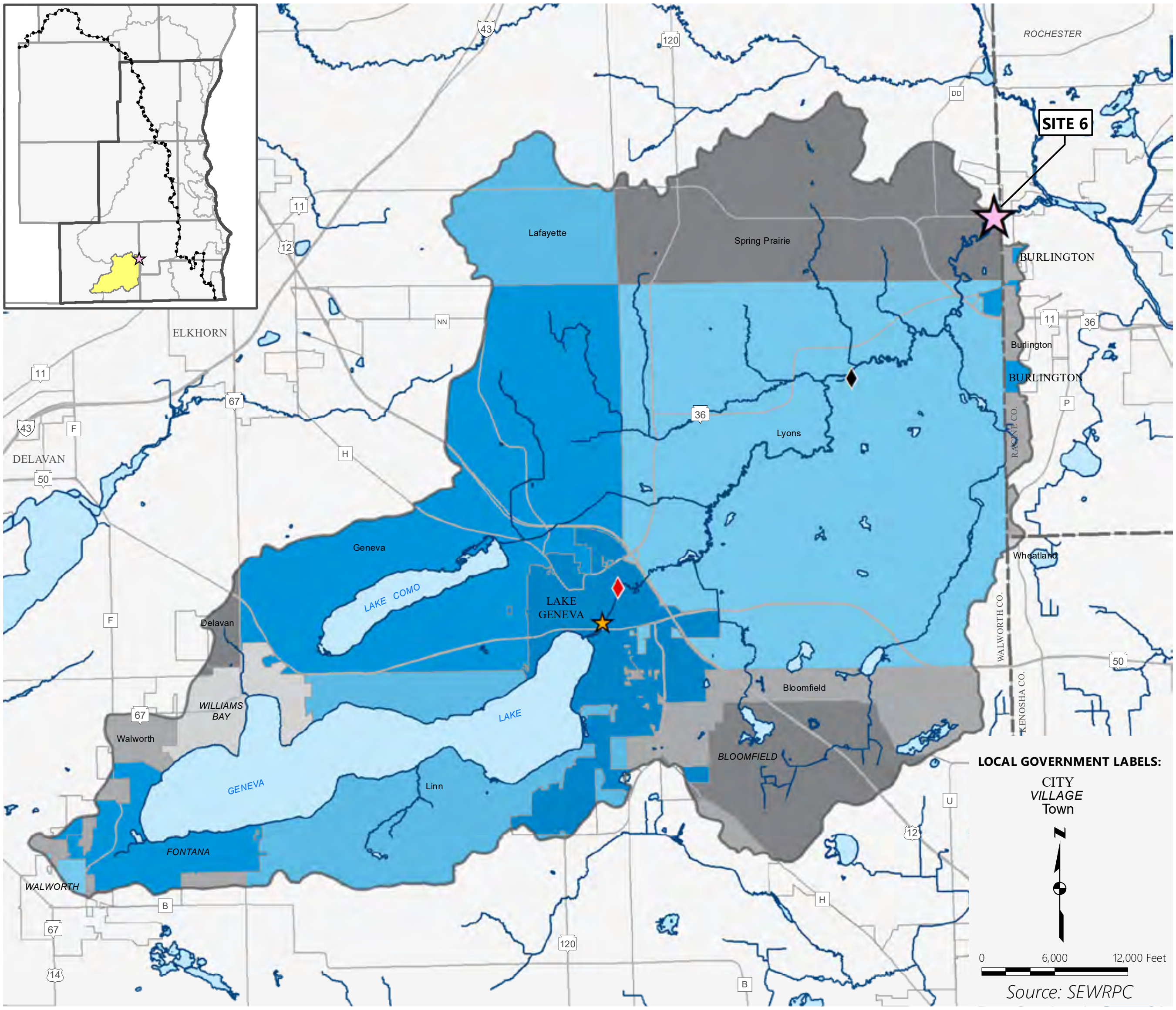
Map B.9
Site 6: White River near Burlington Drainage Area – Existing Land Use



Source: SEWRPC



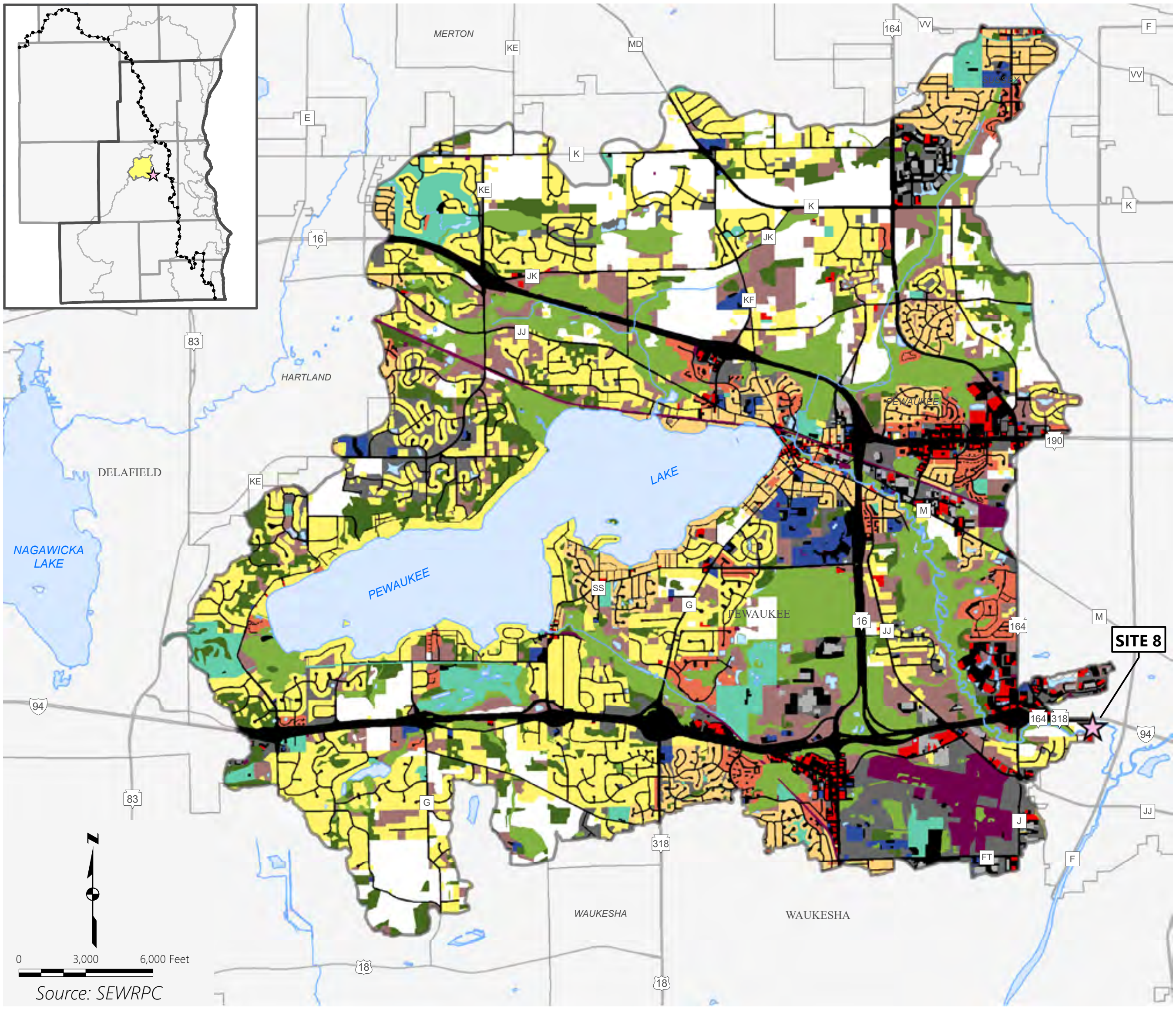
Map B.10
Site 6: White River near Burlington Drainage Area – Features

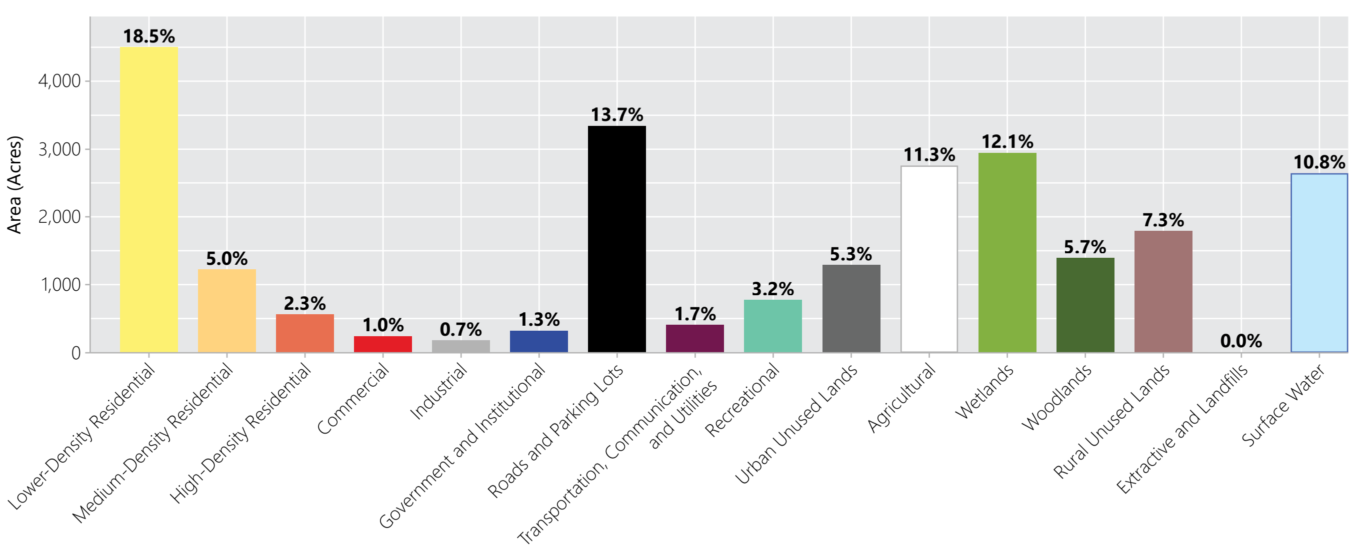


Facts at a Glance

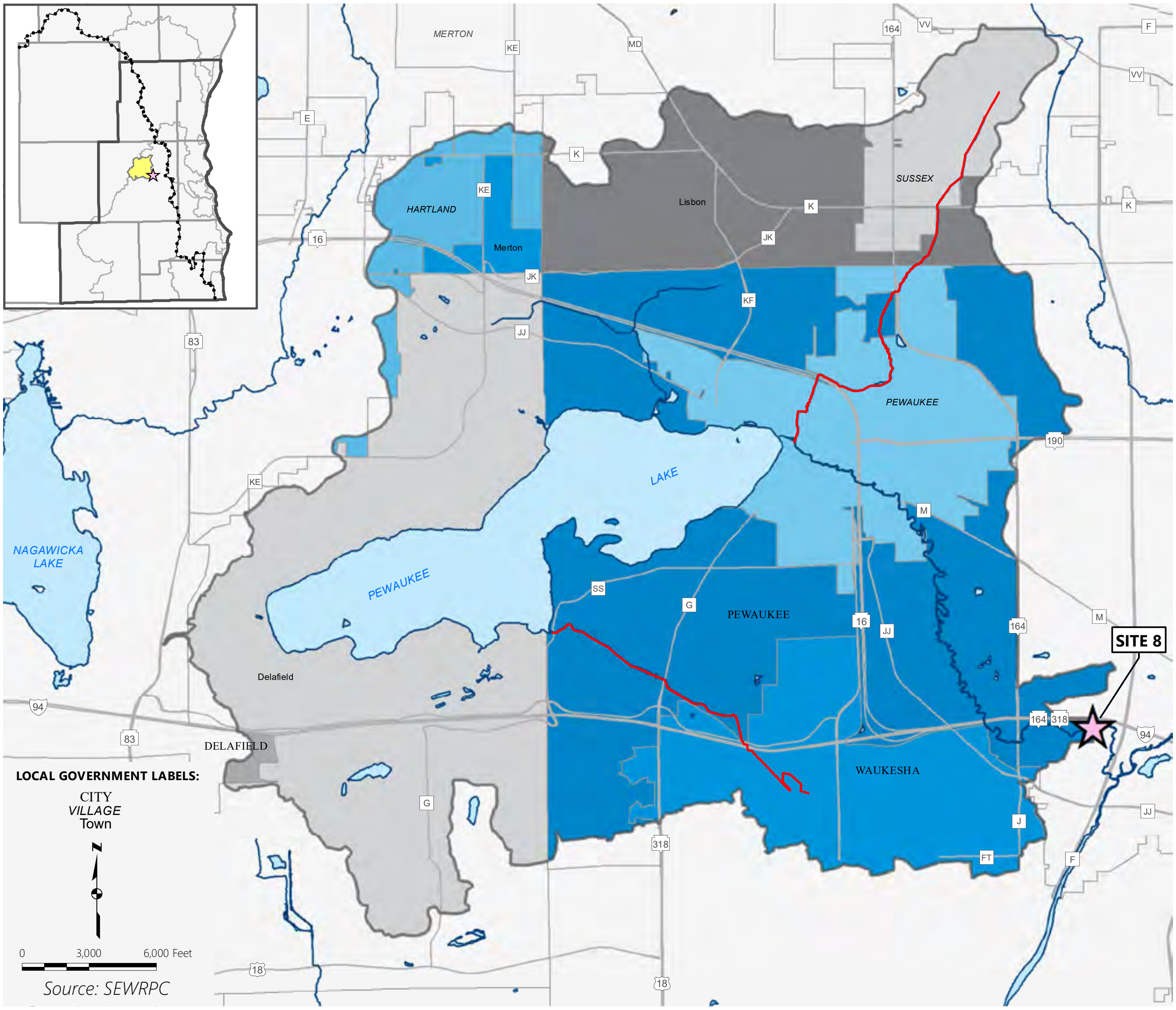
- **Drainage Area Size:** 112 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 20.6%; Rural – 79.4%
- **Roads and Parking Lots (% of drainage area):** 5.7
- **Estimated Population (2010):** 25,010
- **Estimated Households (2010):** 10,370 (73% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 48
- **Upstream Wastewater Treatment Facilities (♦):** 1
  WWTF discharge to soil (♦): 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.11
Site 8: Pewaukee River Drainage Area – Existing Land Use





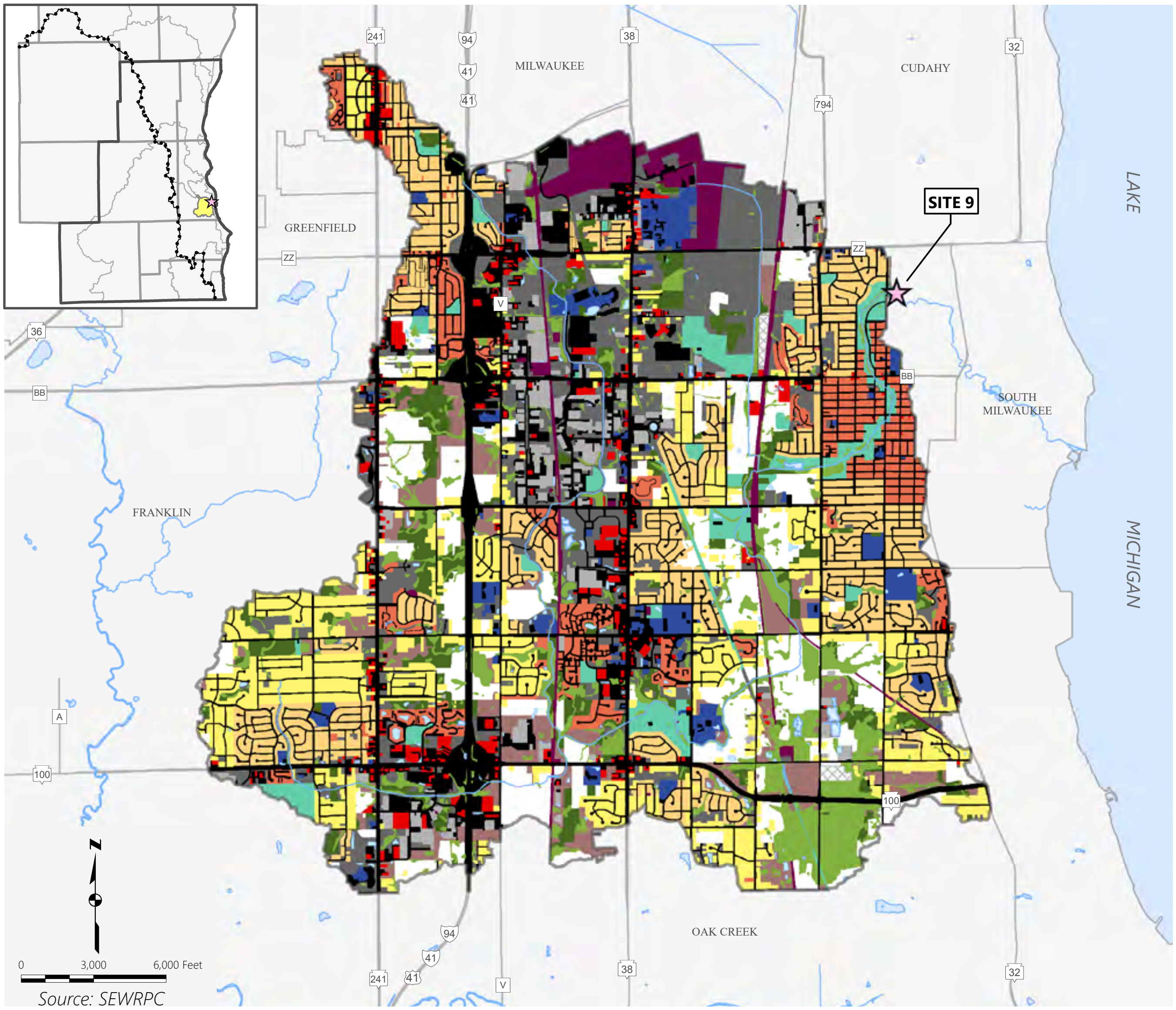
Map B.12
Site 8: Pewaukee River Drainage Area – Features



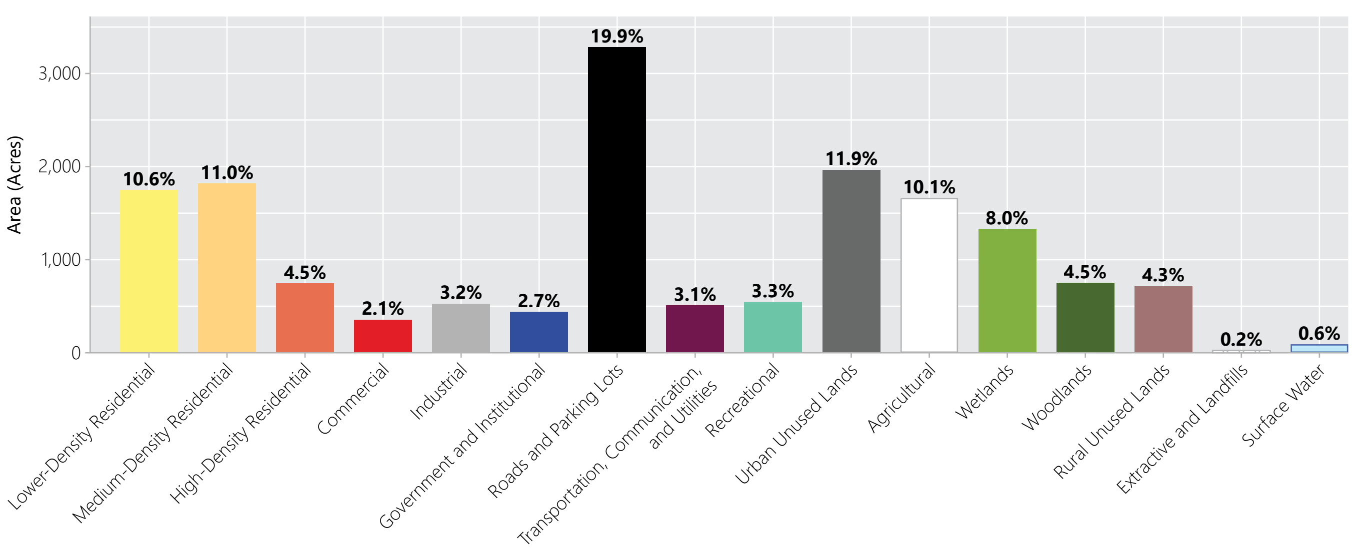
Facts at a Glance

- **Drainage Area Size:** 38 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 52.7%; Rural – 47.3%
- **Roads and Parking Lots (% of drainage area):** 13.7
- **Estimated Population (2010):** 32,830
- **Estimated Households (2010):** 13,340 (89% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** (—) Chronic Toxicity Impairment
- **Water Supply Source:** Groundwater and Lake Michigan (City of Waukesha converted to Lake Michigan supply in October 2023)

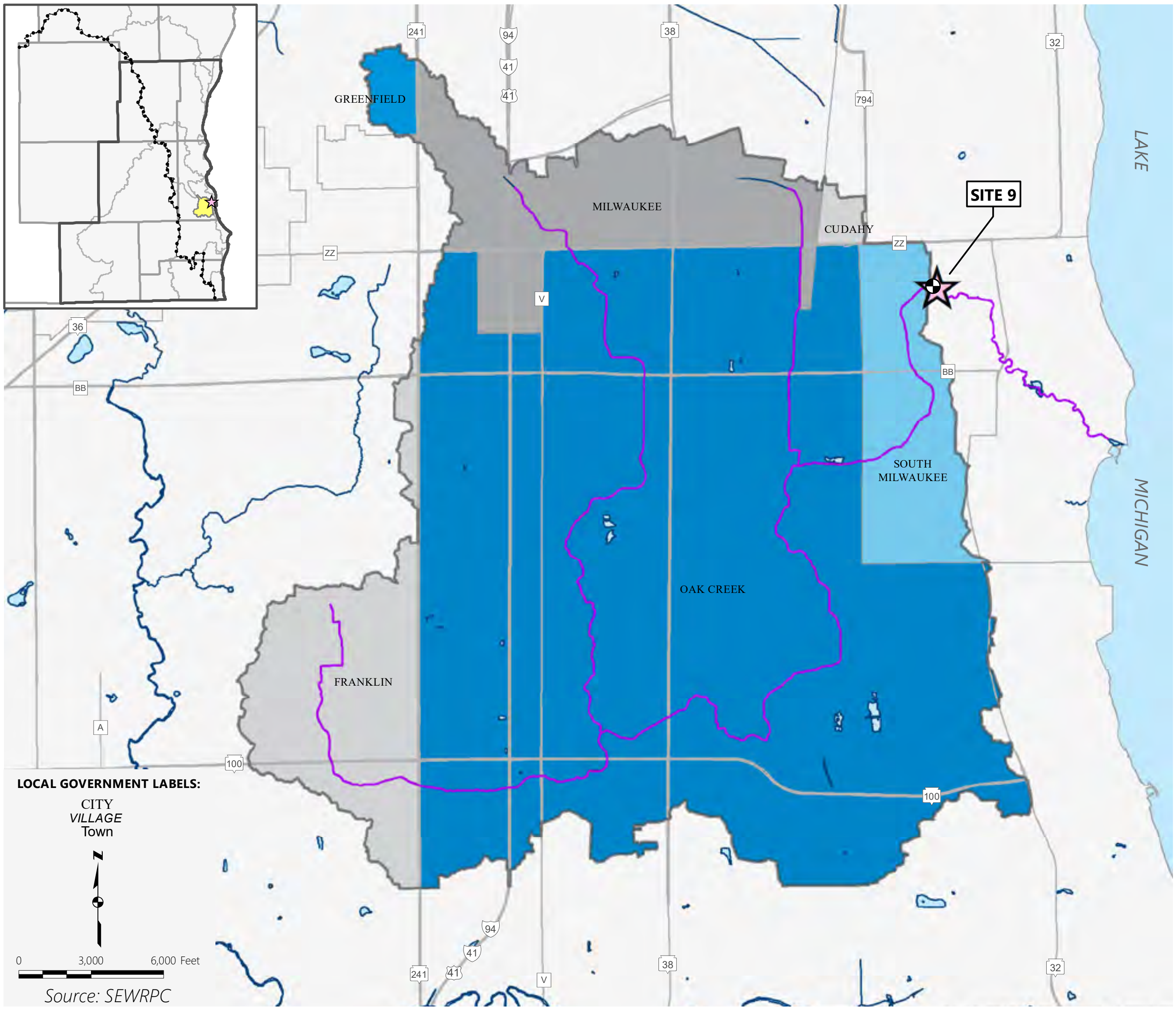
Map B.13
Site 9: Oak Creek Drainage Area – Existing Land Use



Source: SEWRPC



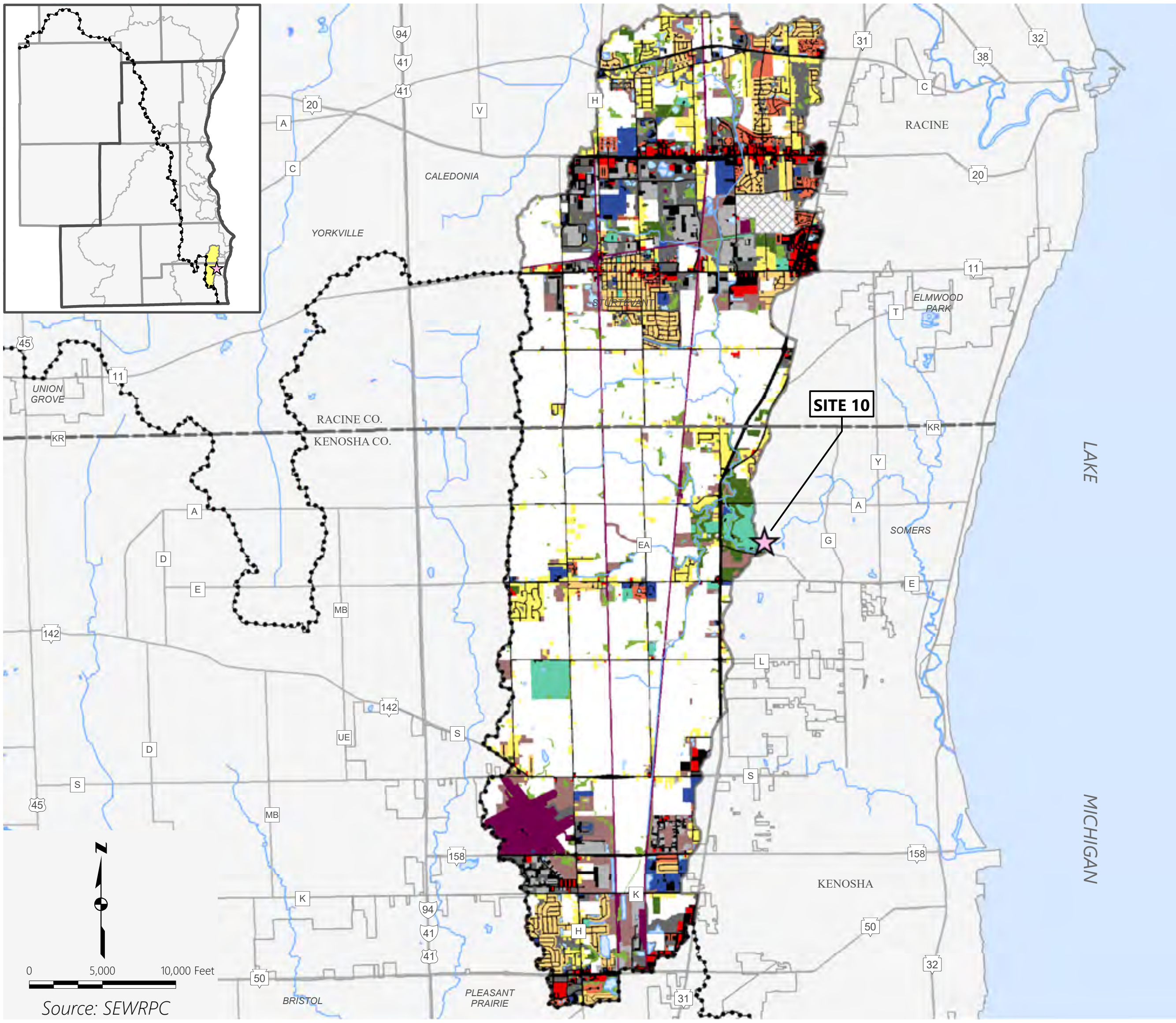
Map B.14
Site 9: Oak Creek Drainage Area – Features

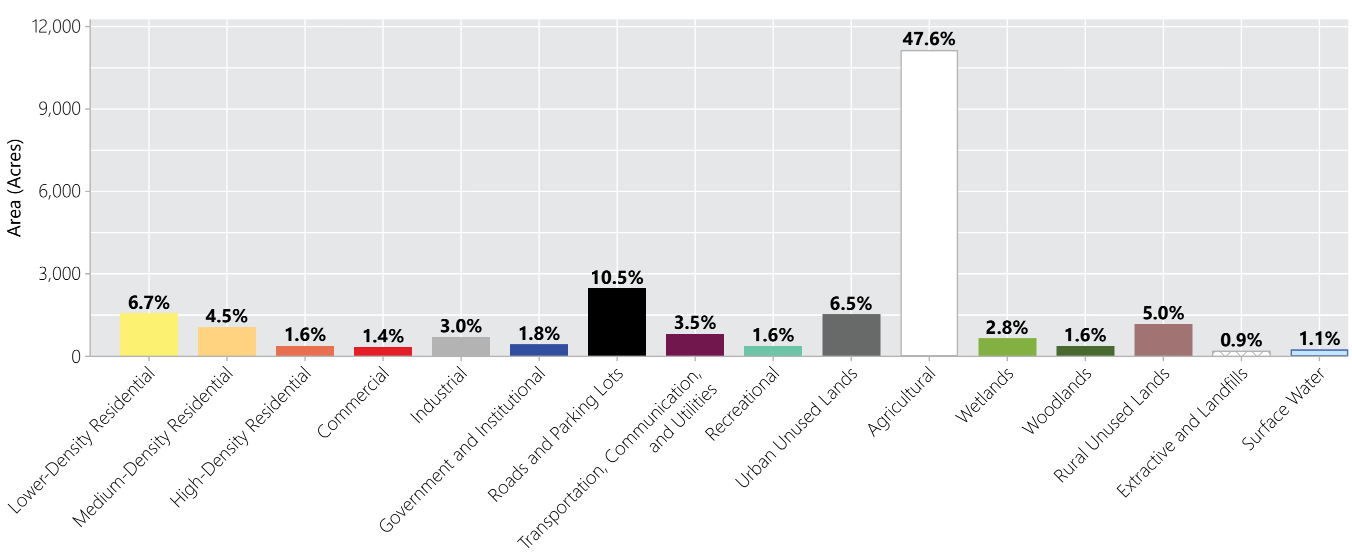


Facts at a Glance

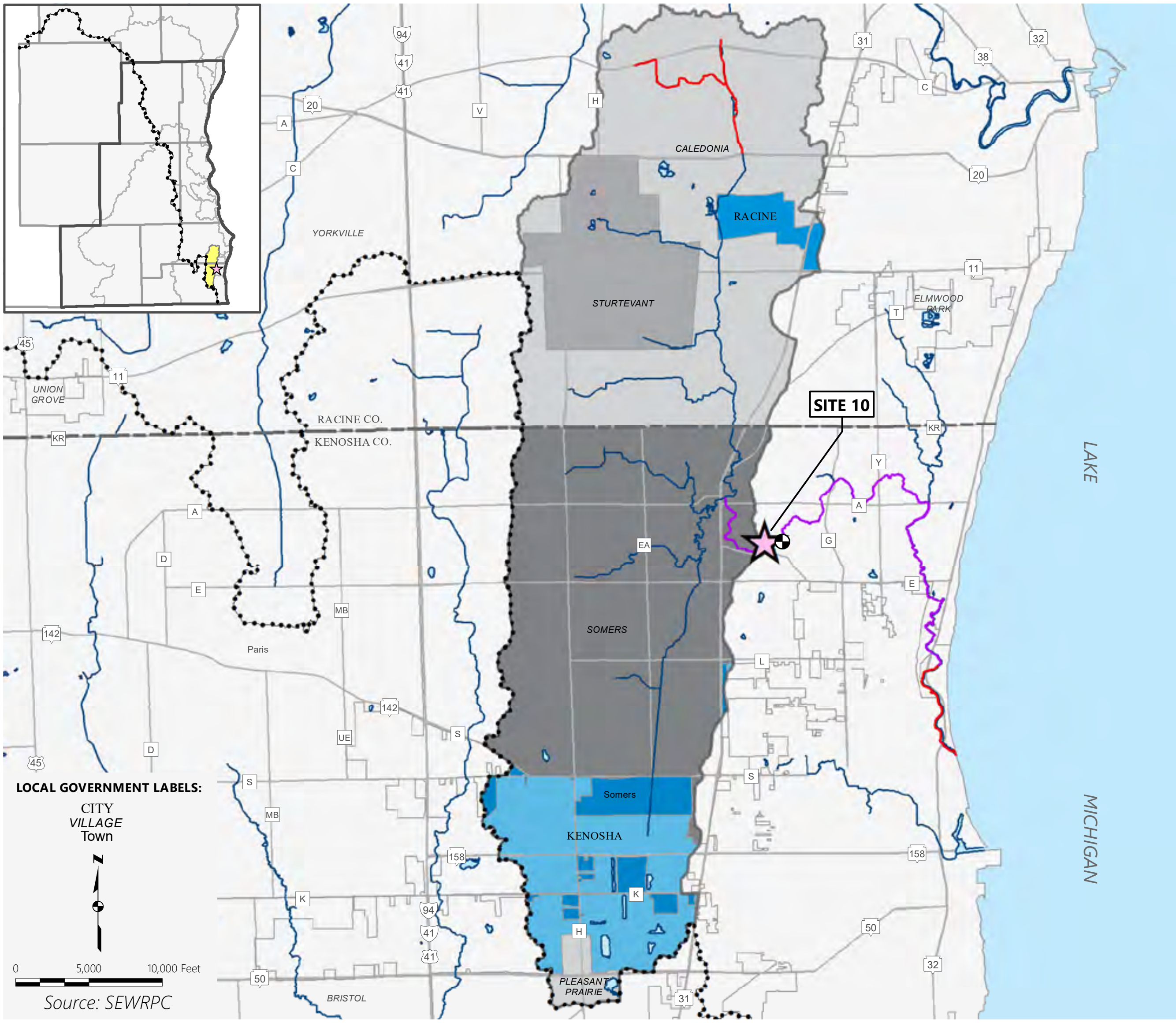
- **Drainage Area Size:** 26 square miles
- **Major Watershed:** Oak Creek
- **Land Use:** Urban – 72.3%; Rural – 27.7%
- **Roads and Parking Lots (% of drainage area):** 19.9
- **Estimated Population (2010):** 47,130
- **Estimated Households (2010):** 19,840 (100% served by public sanitary sewer)
- **Nearest USGS Streamgage (◉):** Oak Creek at South Milwaukee (04087204)
- **Chloride-Impaired Waters:** (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan

Map B.15
Site 10: Pike River Drainage Area – Existing Land Use





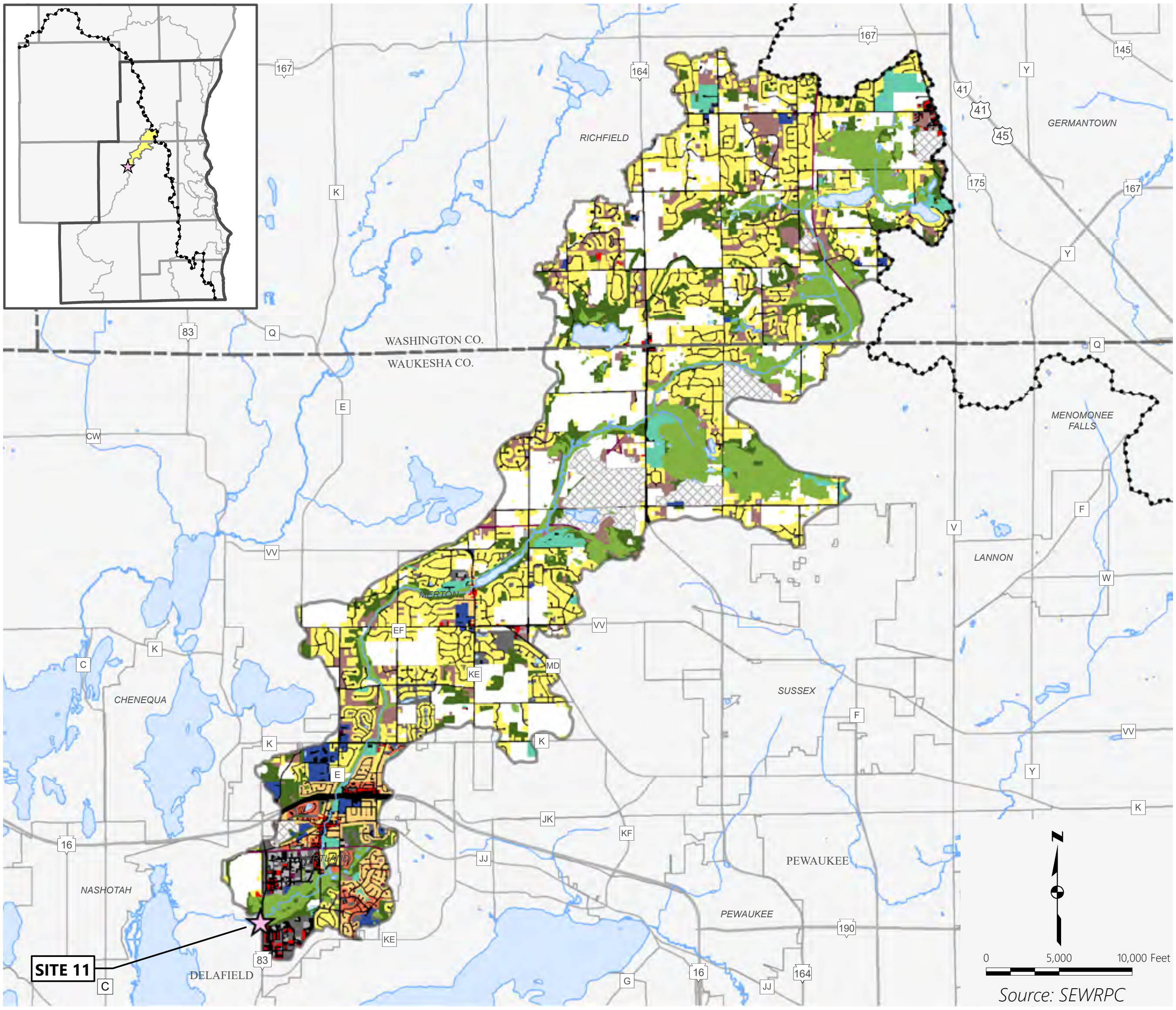
Map B.16
Site 10: Pike River Drainage Area – Features

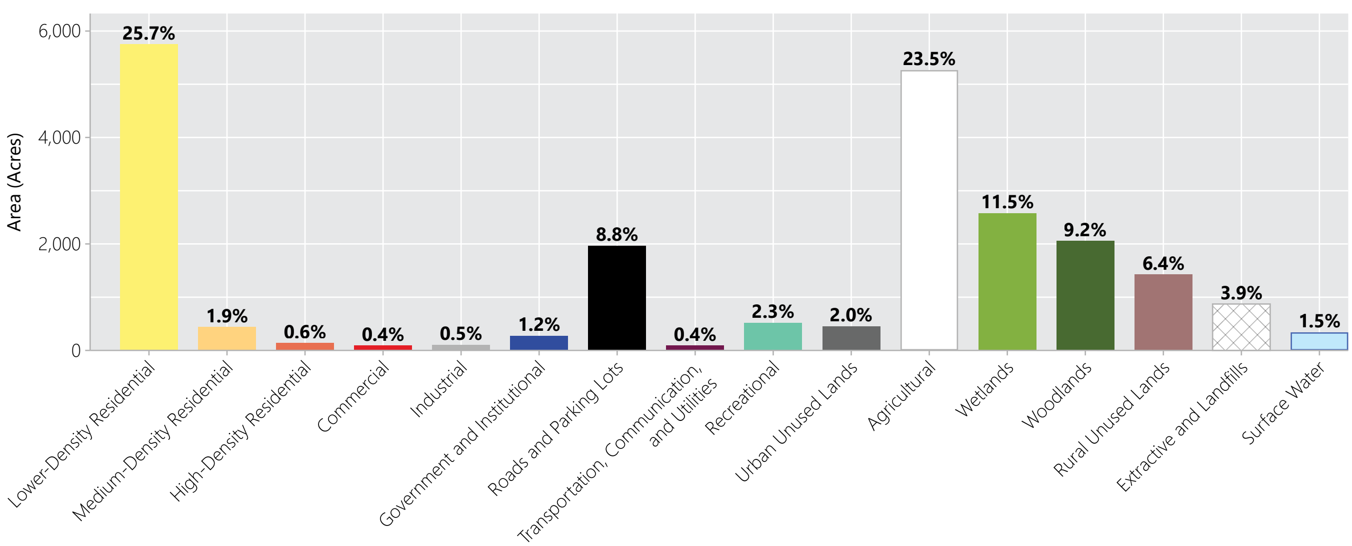


Facts at a Glance

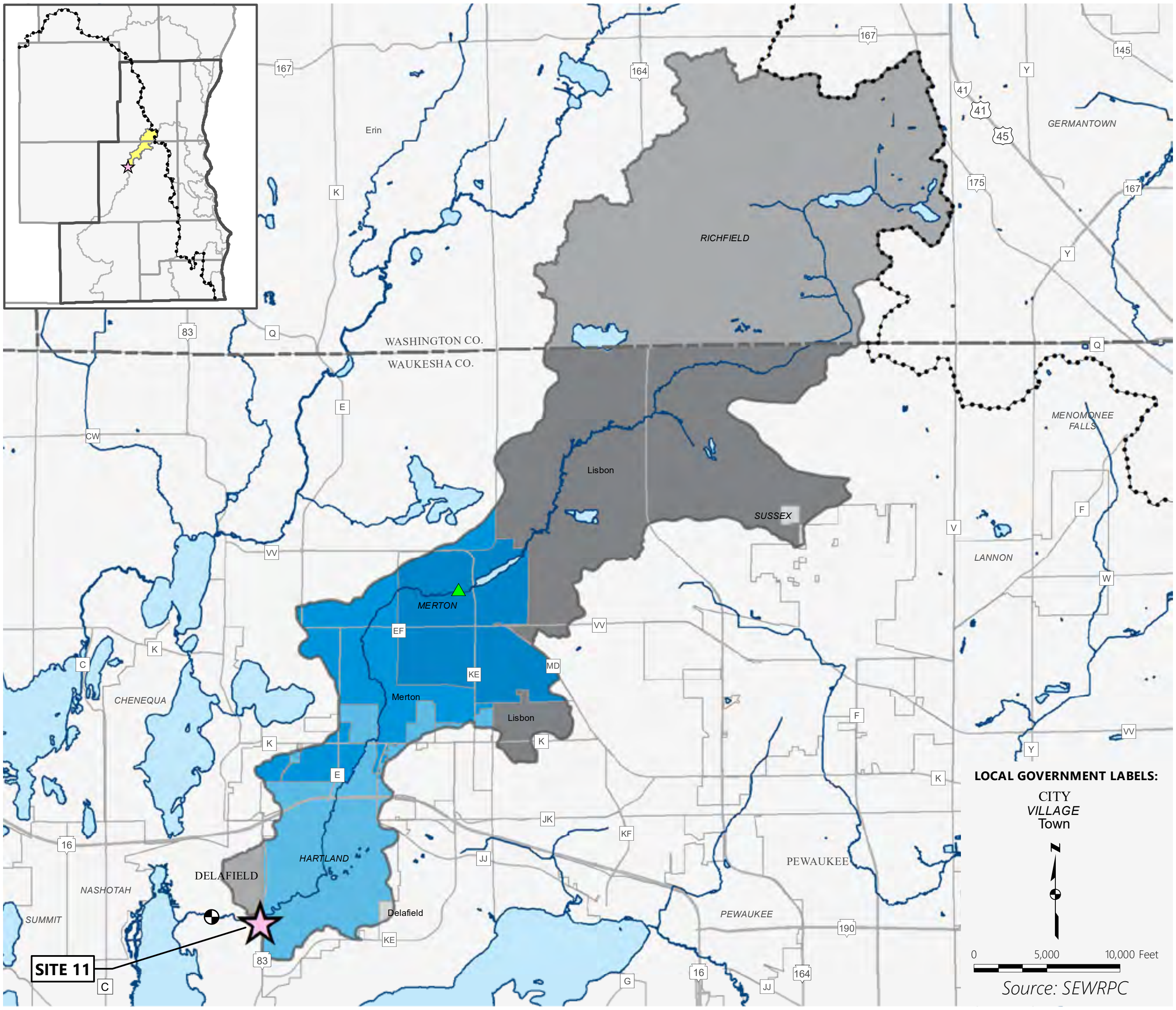
- **Drainage Area Size:** 37 square miles
- **Major Watershed:** Pike River
- **Land Use:** Urban – 41.1%; Rural – 58.9%
- **Roads and Parking Lots (% of drainage area):** 10.5
- **Estimated Population (2010):** 25,790
- **Estimated Households (2010):** 9,930 (96% served by public sanitary sewer)
- **Nearest USGS Streamgage (⊕):** Pike River near Racine (04087257)
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
  (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan

Map B.17
Site 11: Bark River Upstream Drainage Area – Existing Land Use





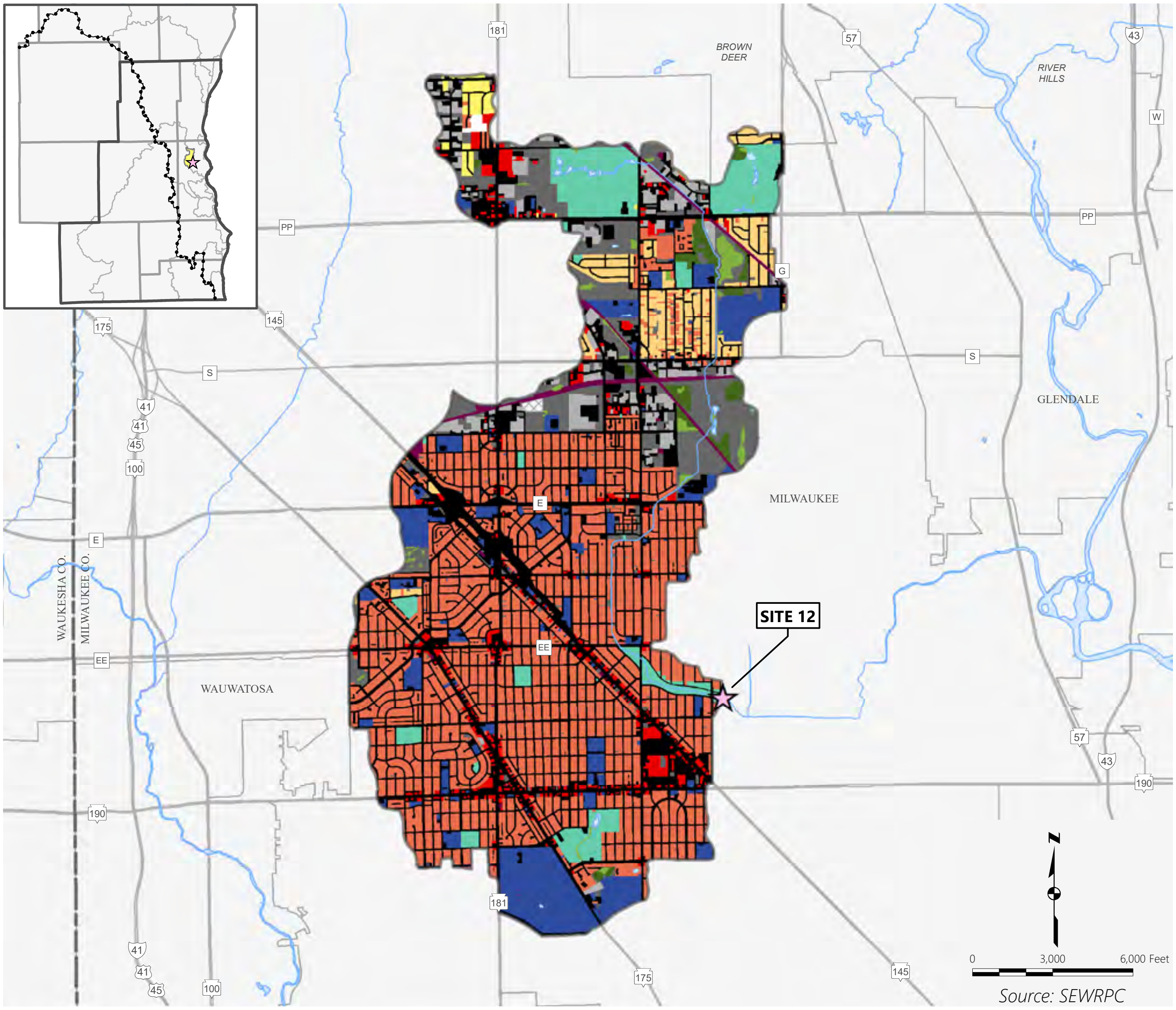
Map B.18
Site 11: Bark River Upstream Drainage Area – Features

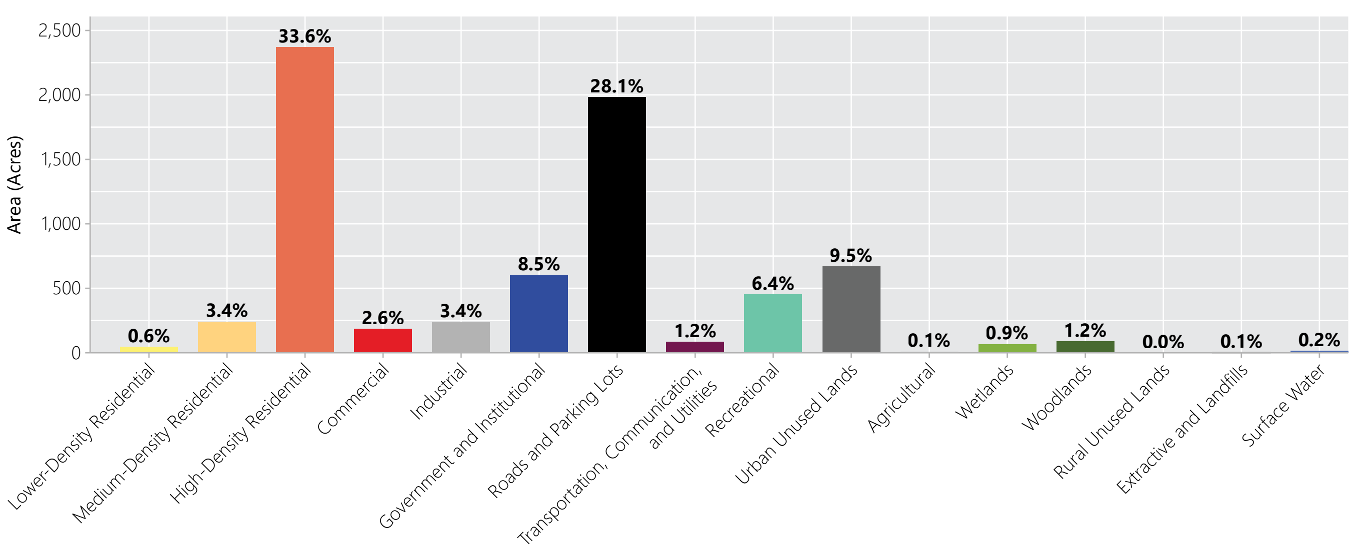


Facts at a Glance

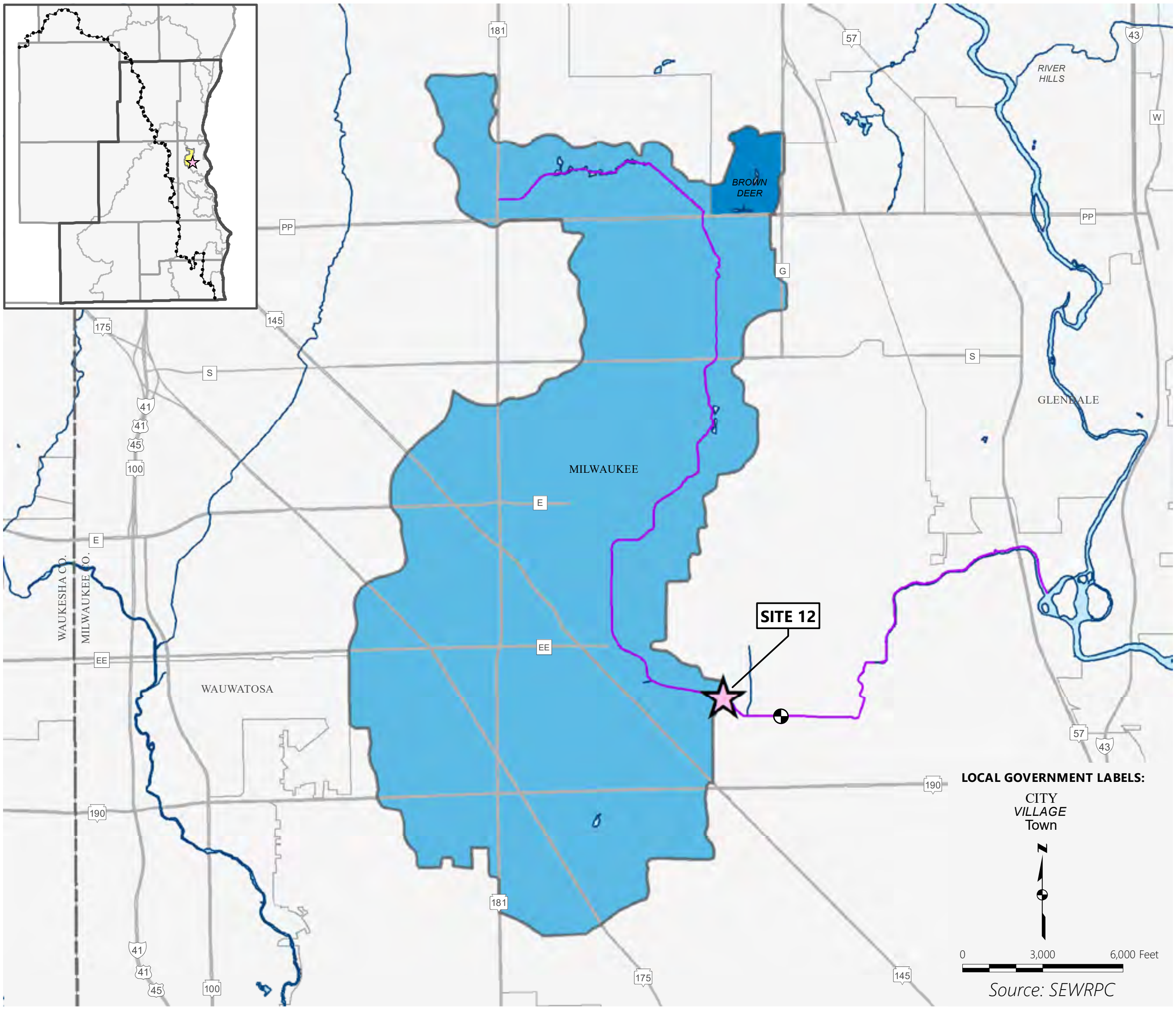
- **Drainage Area Size:** 35 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 43.9%; Rural – 56.1%
- **Roads and Parking Lots (% of drainage area):** 8.8
- **Estimated Population (2010):** 19,970
- **Estimated Households (2010):** 7,330 (41% served by public sanitary sewer)
- **Nearest USGS Streamgage (◒):** Bark River at Nagawicka Road (05426067)
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.19
Site 12: Lincoln Creek Drainage Area – Existing Land Use





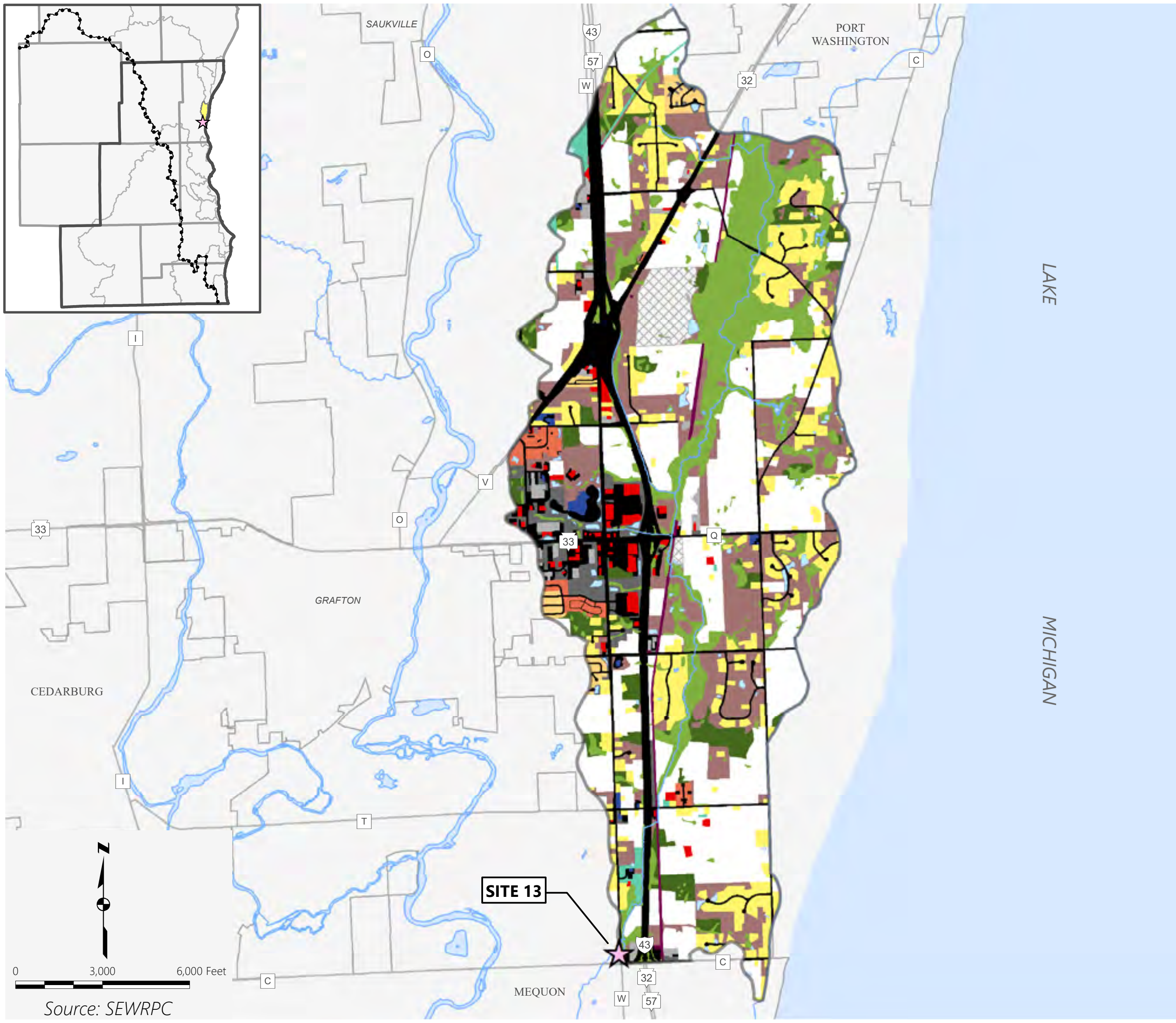
Map B.20
Site 12: Lincoln Creek Drainage Area – Features

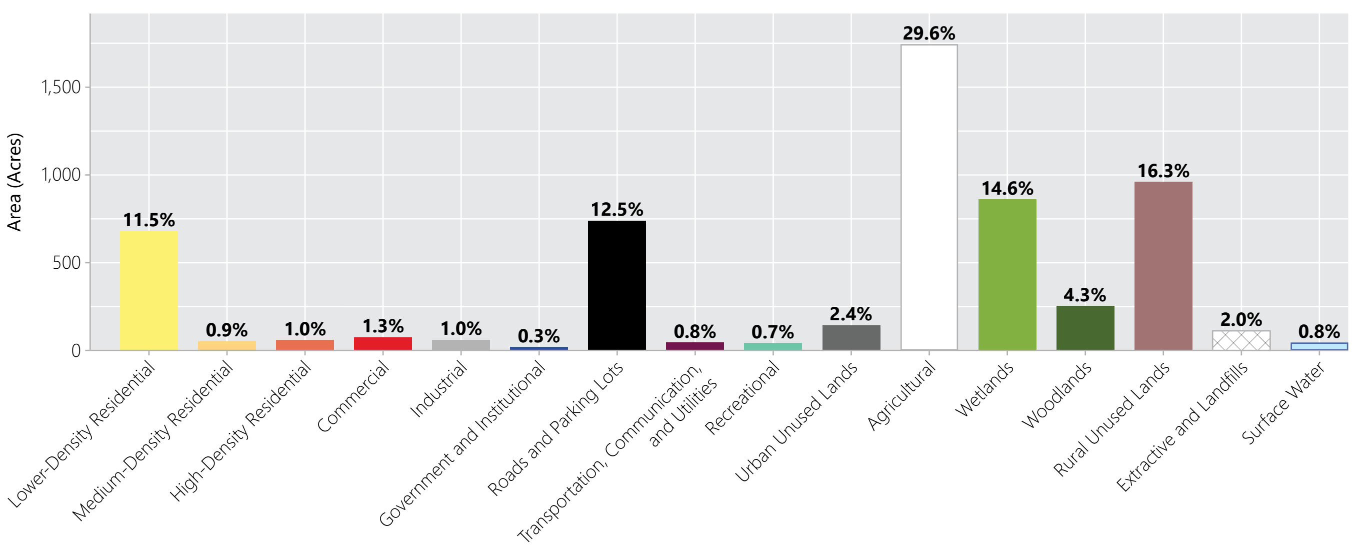


Facts at a Glance

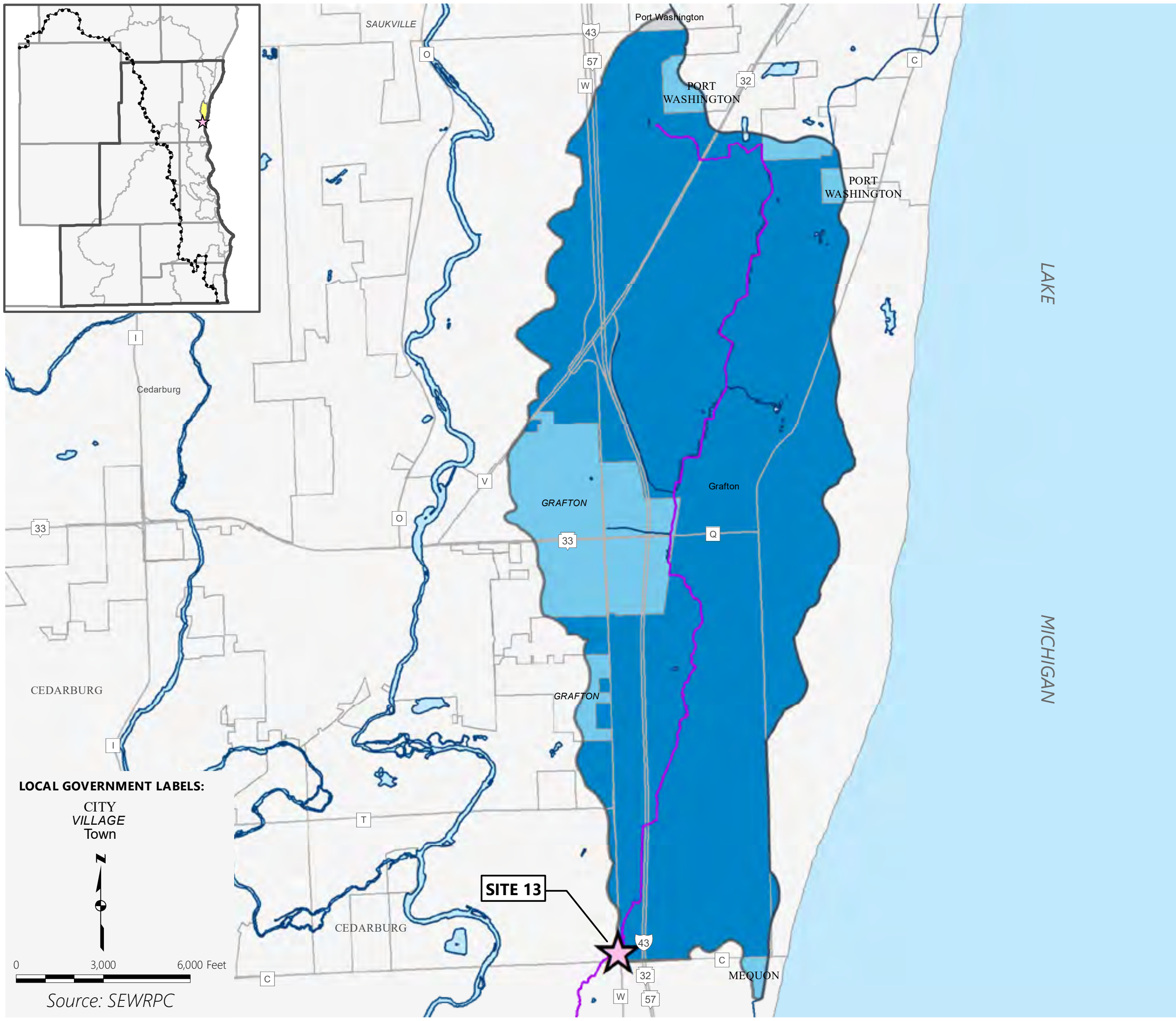
- **Drainage Area Size:** 11 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 97.4%; Rural – 2.6%
- **Roads and Parking Lots (% of drainage area):** 28.1
- **Estimated Population (2010):** 60,500
- **Estimated Households (2010):** 22,210 (100% served by public sanitary sewer)
- **Nearest USGS Streamgage (◐):** Lincoln Creek at Sherman Boulevard (040869416)
- **Chloride-Impaired Waters:** (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan

Map B.21
Site 13: Ulao Creek Drainage Area – Existing Land Use





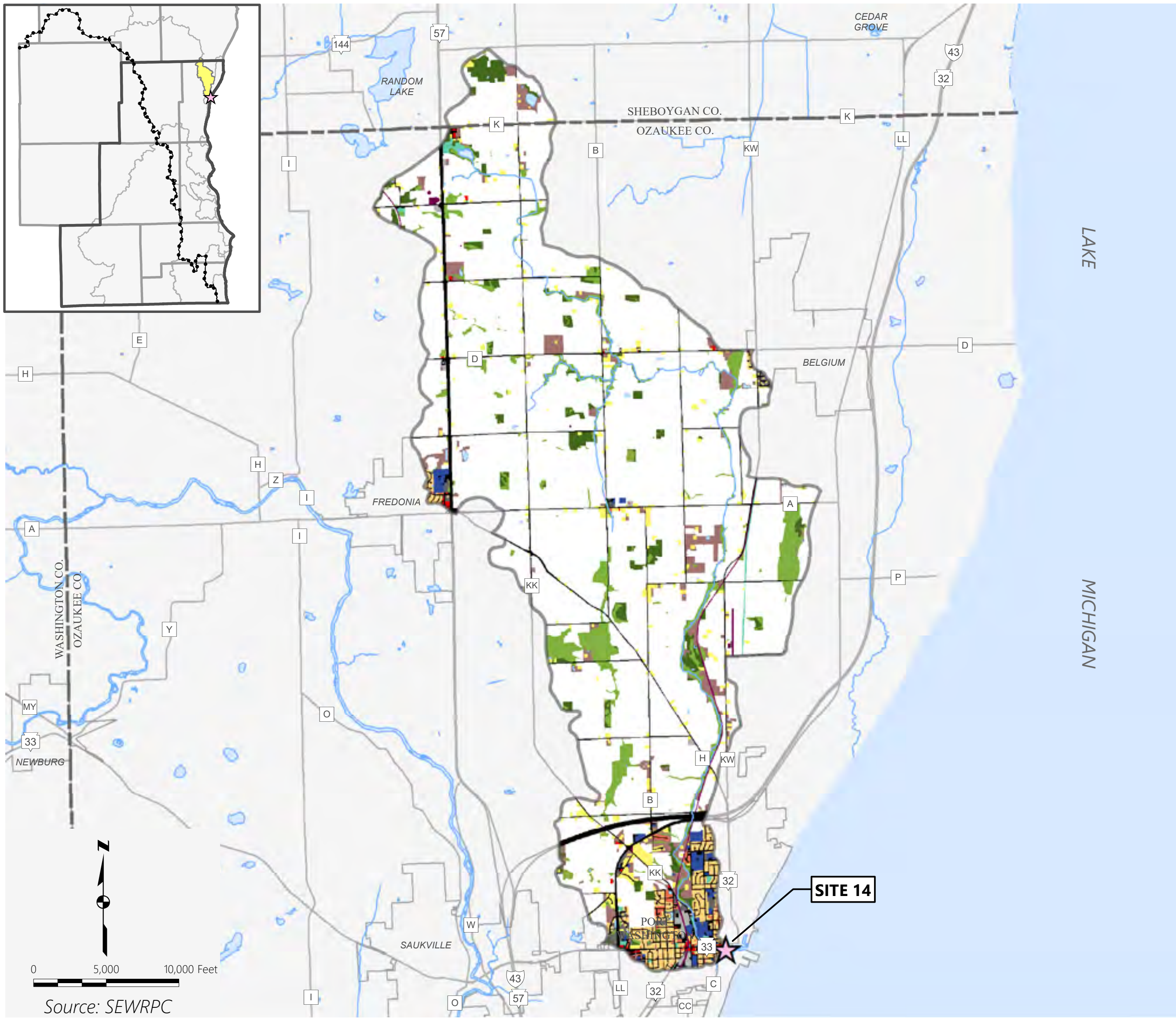
Map B.22
Site 13: Ulao Creek Drainage Area – Features



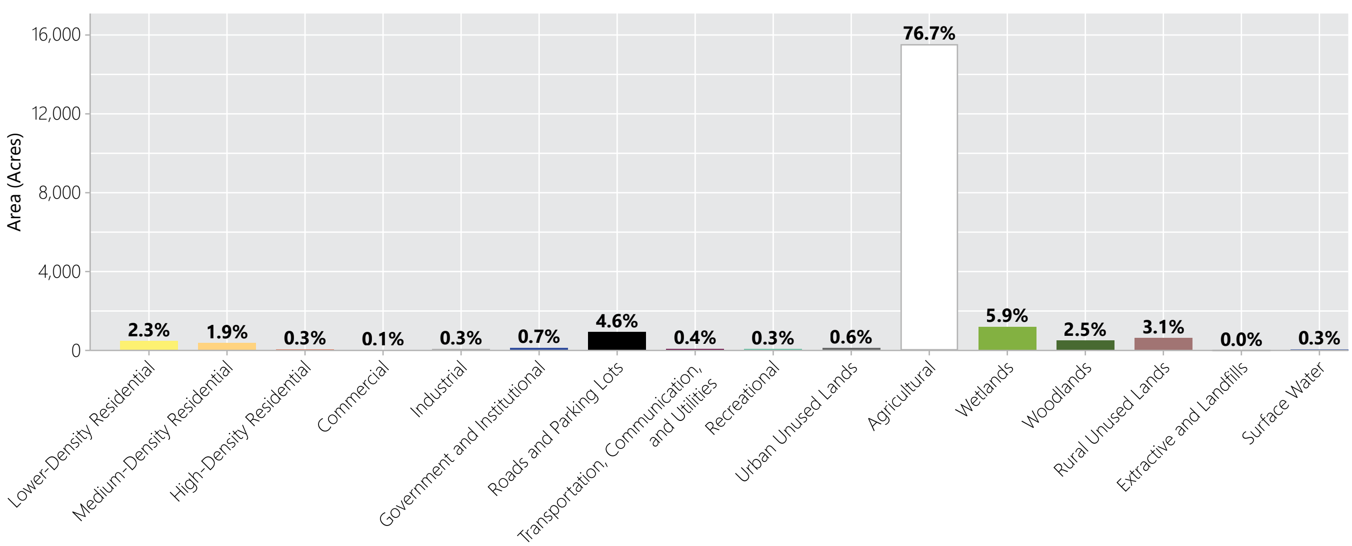
Facts at a Glance

- **Drainage Area Size:** 9 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 32.5%; Rural – 67.5%
- **Roads and Parking Lots (% of drainage area):** 12.5
- **Estimated Population (2010):** 2,130
- **Estimated Households (2010):** 920 (47% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan

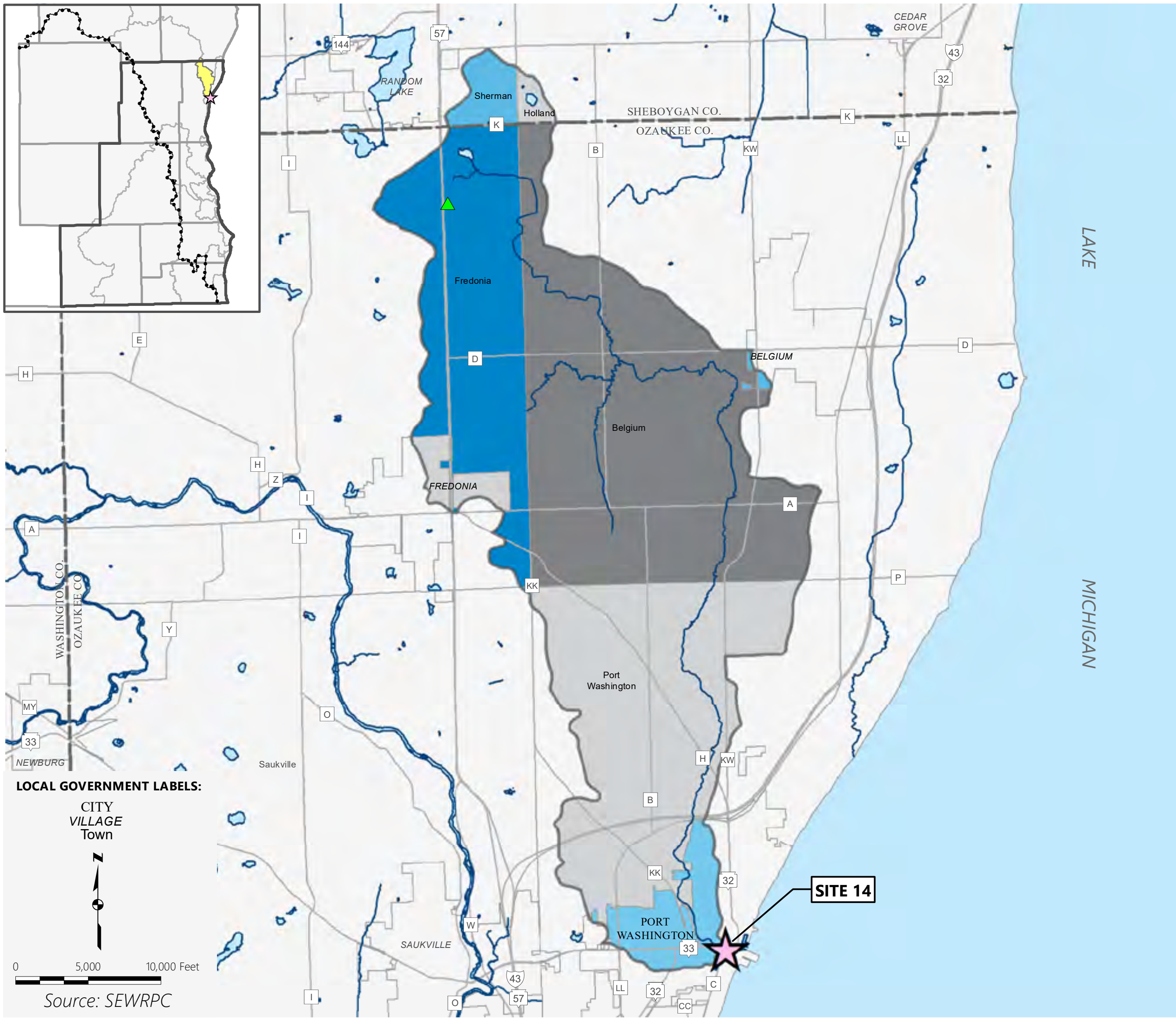
Map B.23
Site 14: Sauk Creek Drainage Area – Existing Land Use



Source: SEWRPC



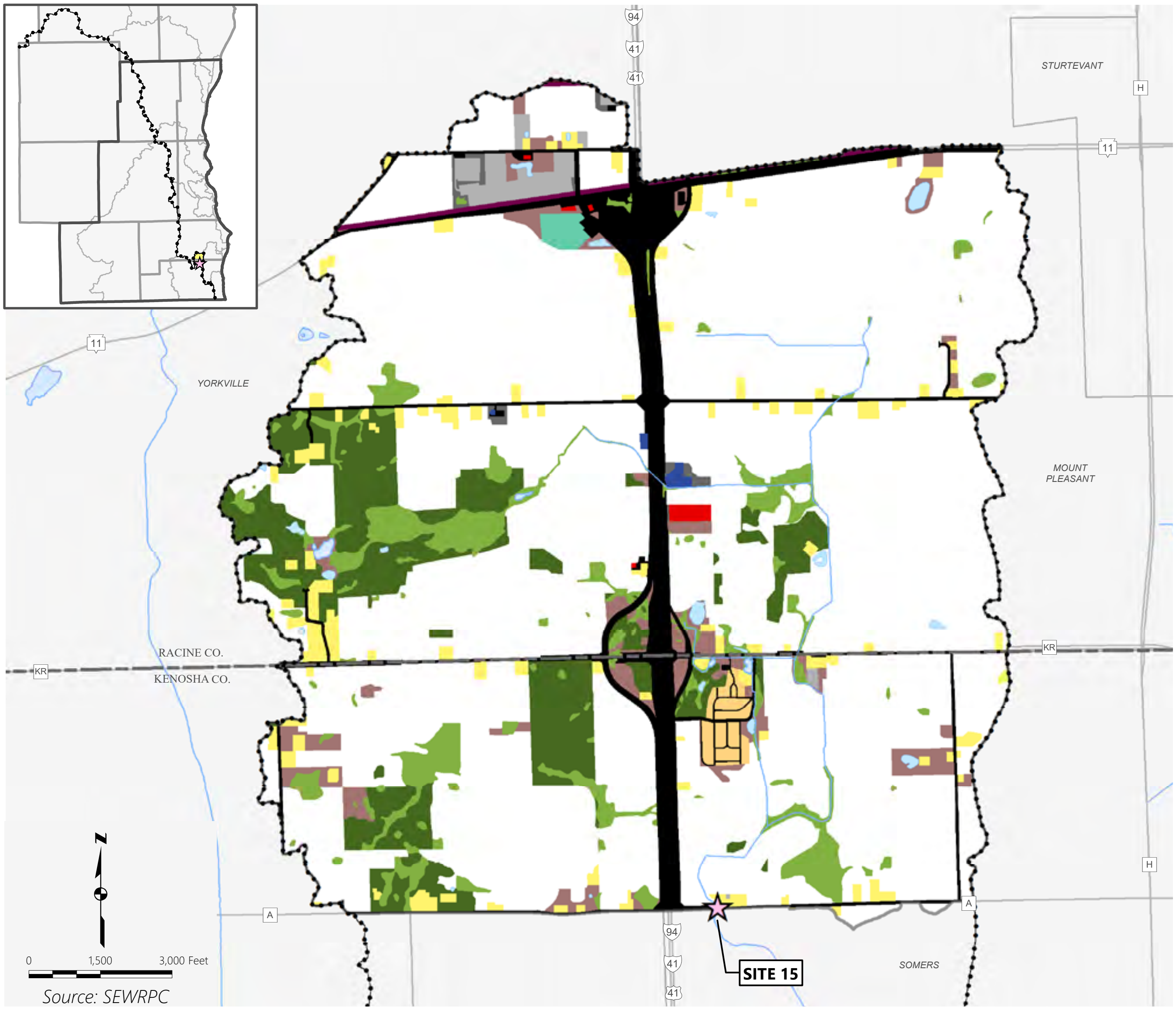
Map B.24
Site 14: Sauk Creek Drainage Area – Features

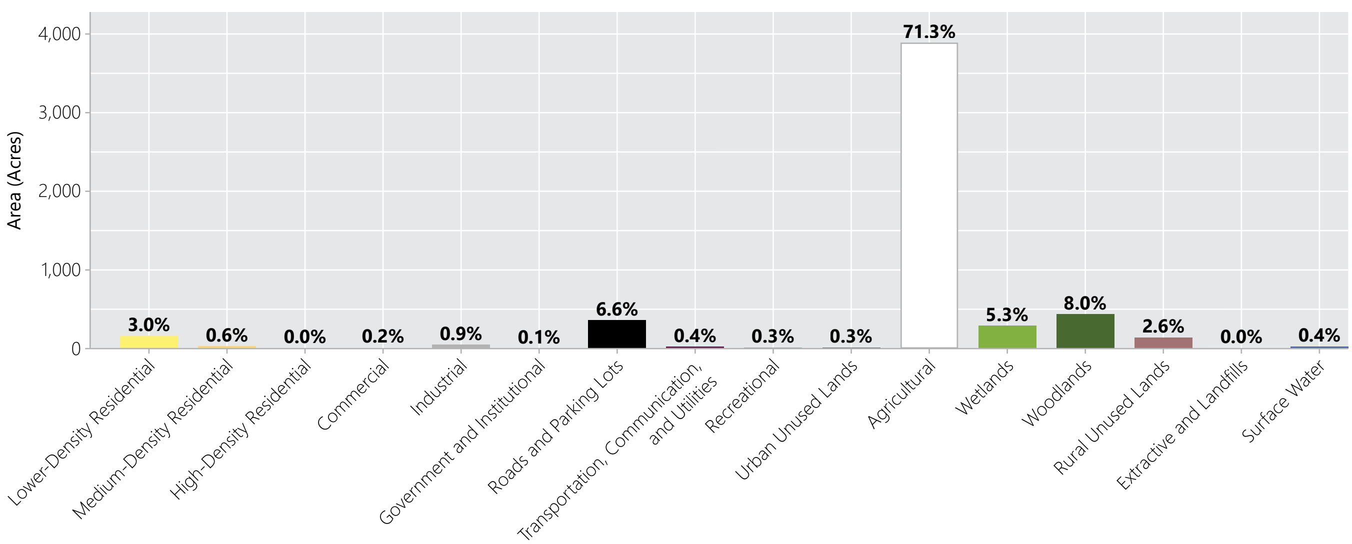


Facts at a Glance

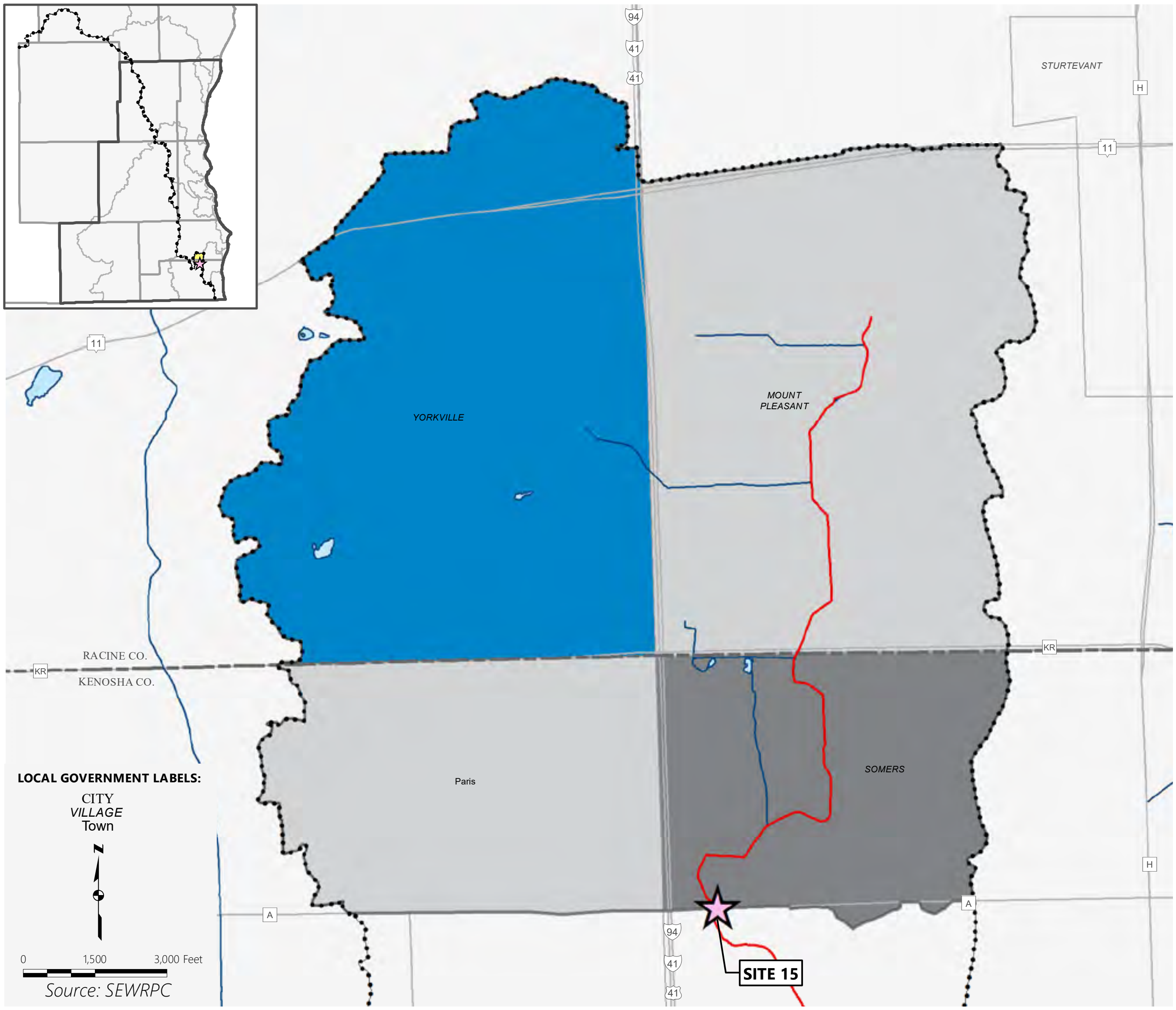
- **Drainage Area Size:** 32 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 11.5%; Rural – 88.5%
- **Roads and Parking Lots (% of drainage area):** 4.6
- **Estimated Population (2010):** 6,700
- **Estimated Households (2010):** 2,730 (84% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Lake Michigan and Groundwater

Map B.25
Site 15: Kilbourn Road Ditch Drainage Area – Existing Land Use





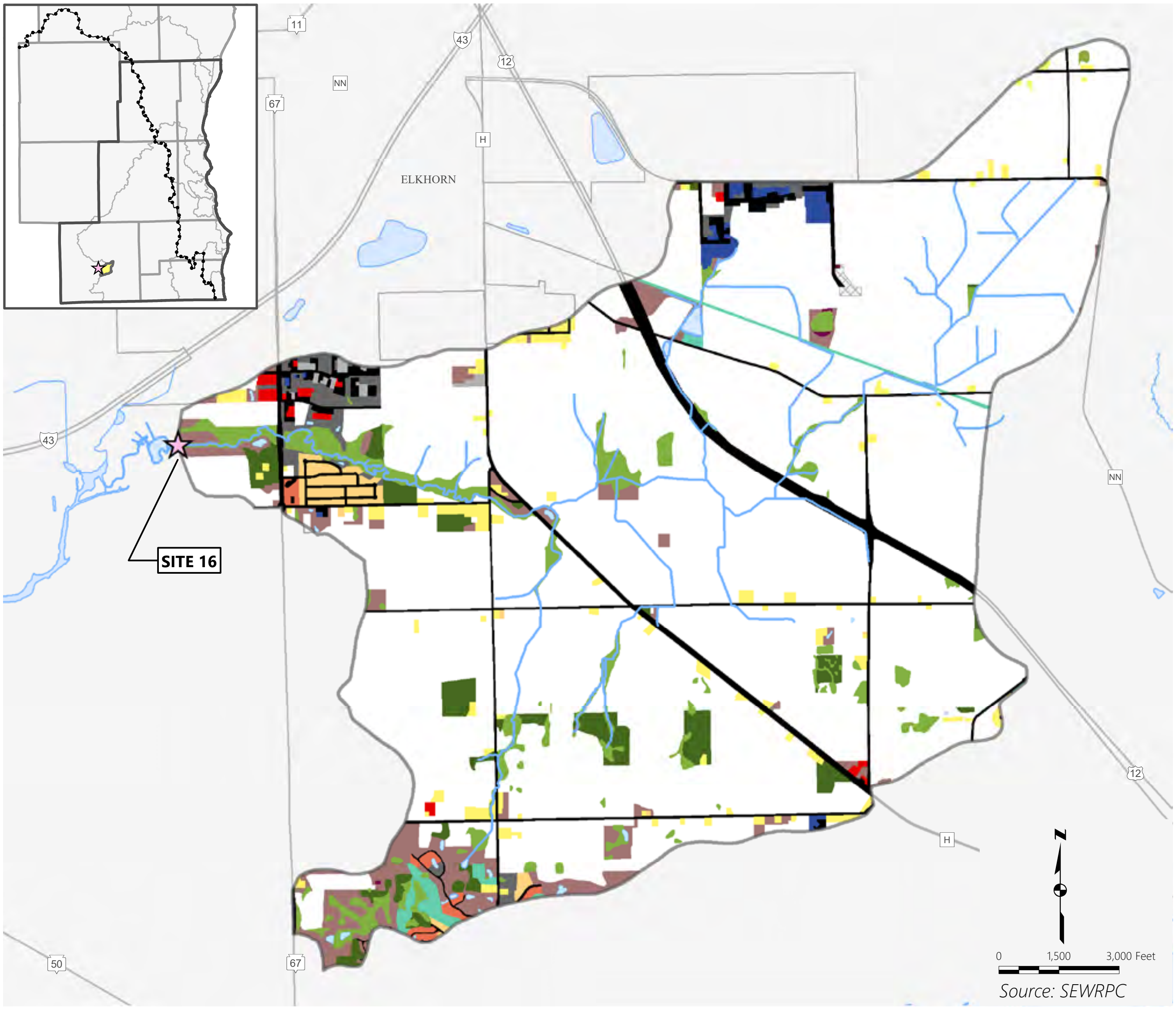
Map B.26
Site 15: Kilbourn Road Ditch Drainage Area – Features

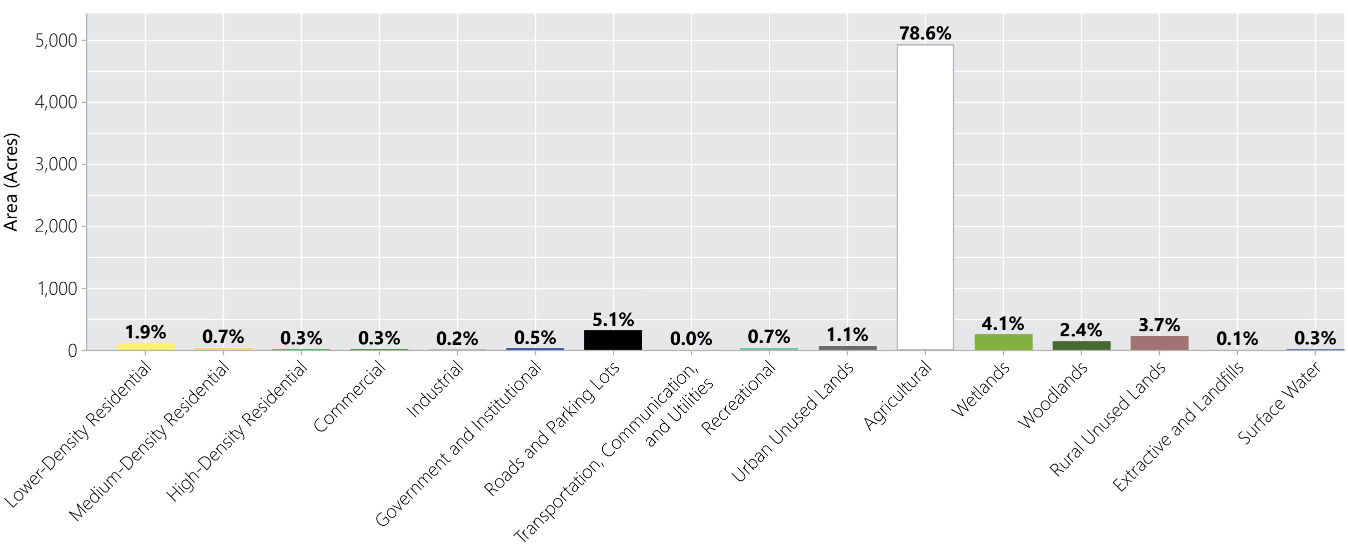


Facts at a Glance

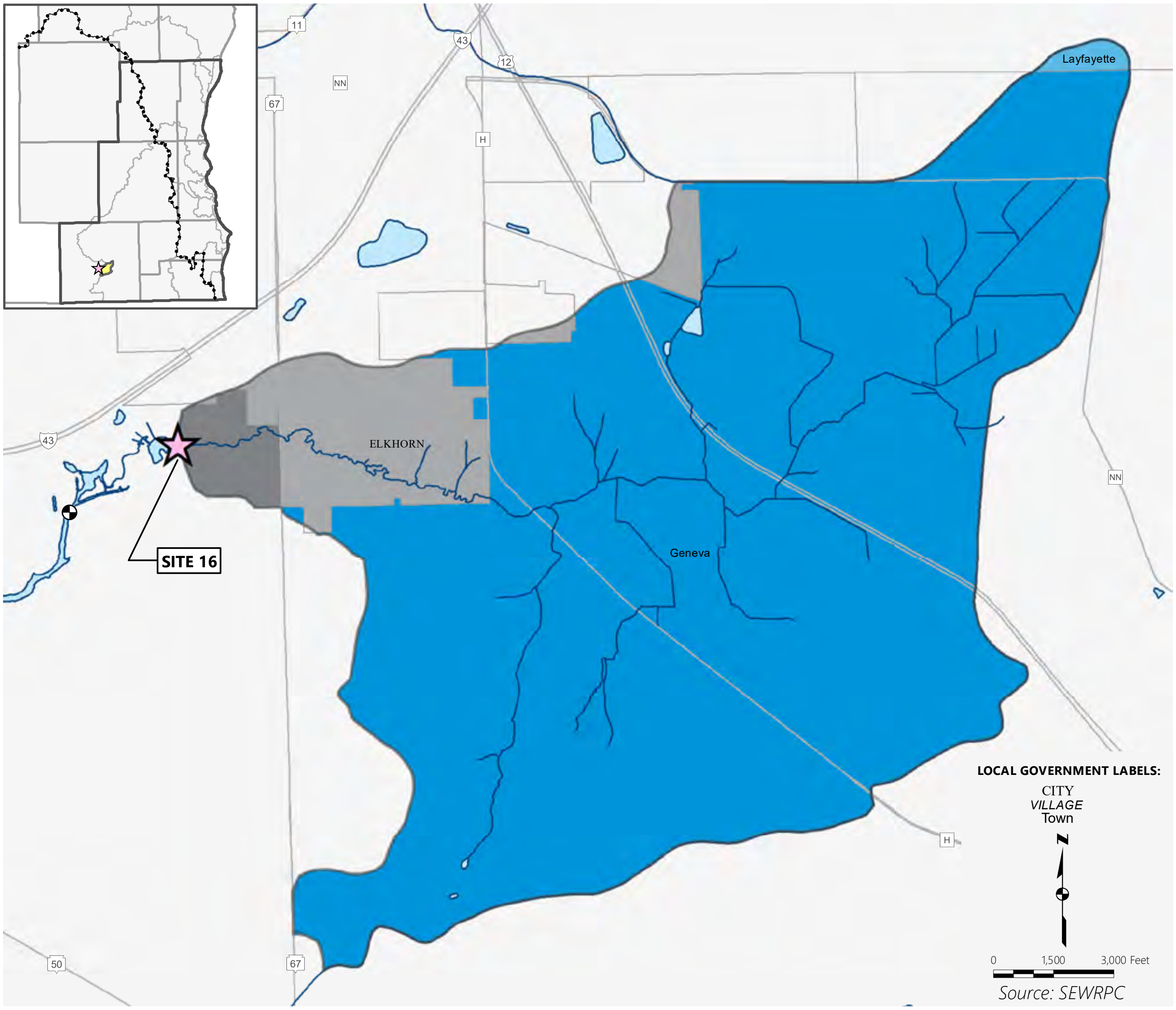
- **Drainage Area Size:** 9 square miles
- **Major Watershed:** Des Plaines River
- **Land Use:** Urban – 12.3%; Rural – 87.7%
- **Roads and Parking Lots (% of drainage area):** 6.6
- **Estimated Population (2010):** 570
- **Estimated Households (2010):** 290 (0% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** (—) Chronic Toxicity Impairment
- **Water Supply Source:** Lake Michigan and Groundwater

Map B.27
Site 16: Jackson Creek Drainage Area – Existing Land Use





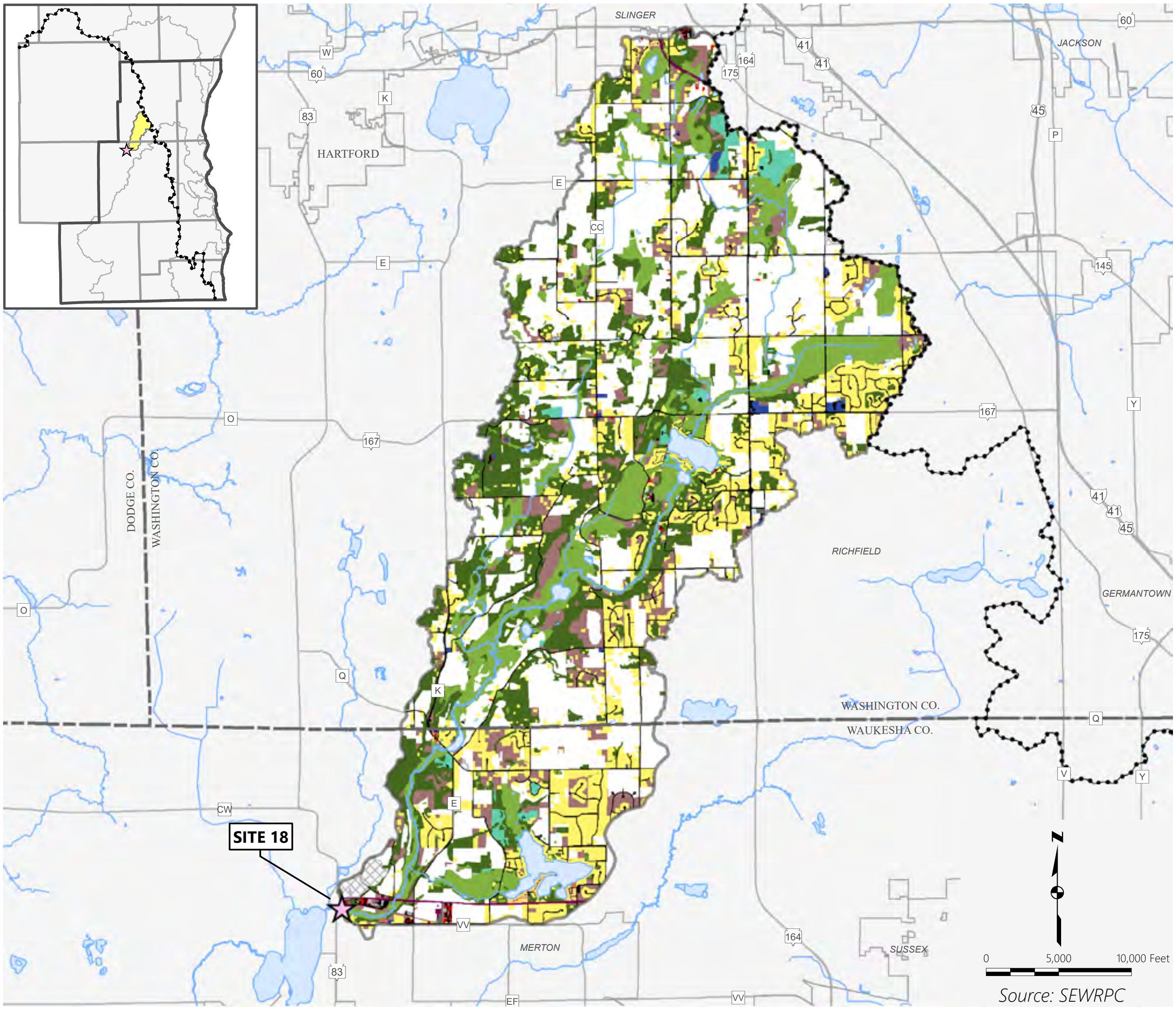
Map B.28
Site 16: Jackson Creek Drainage Area – Features

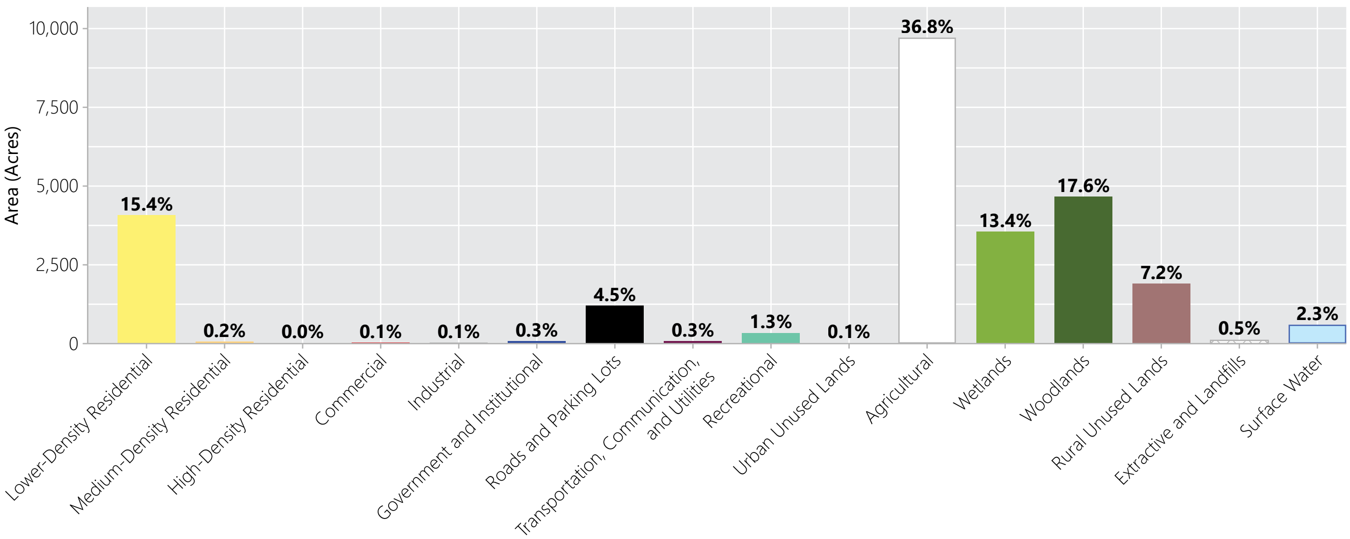


Facts at a Glance

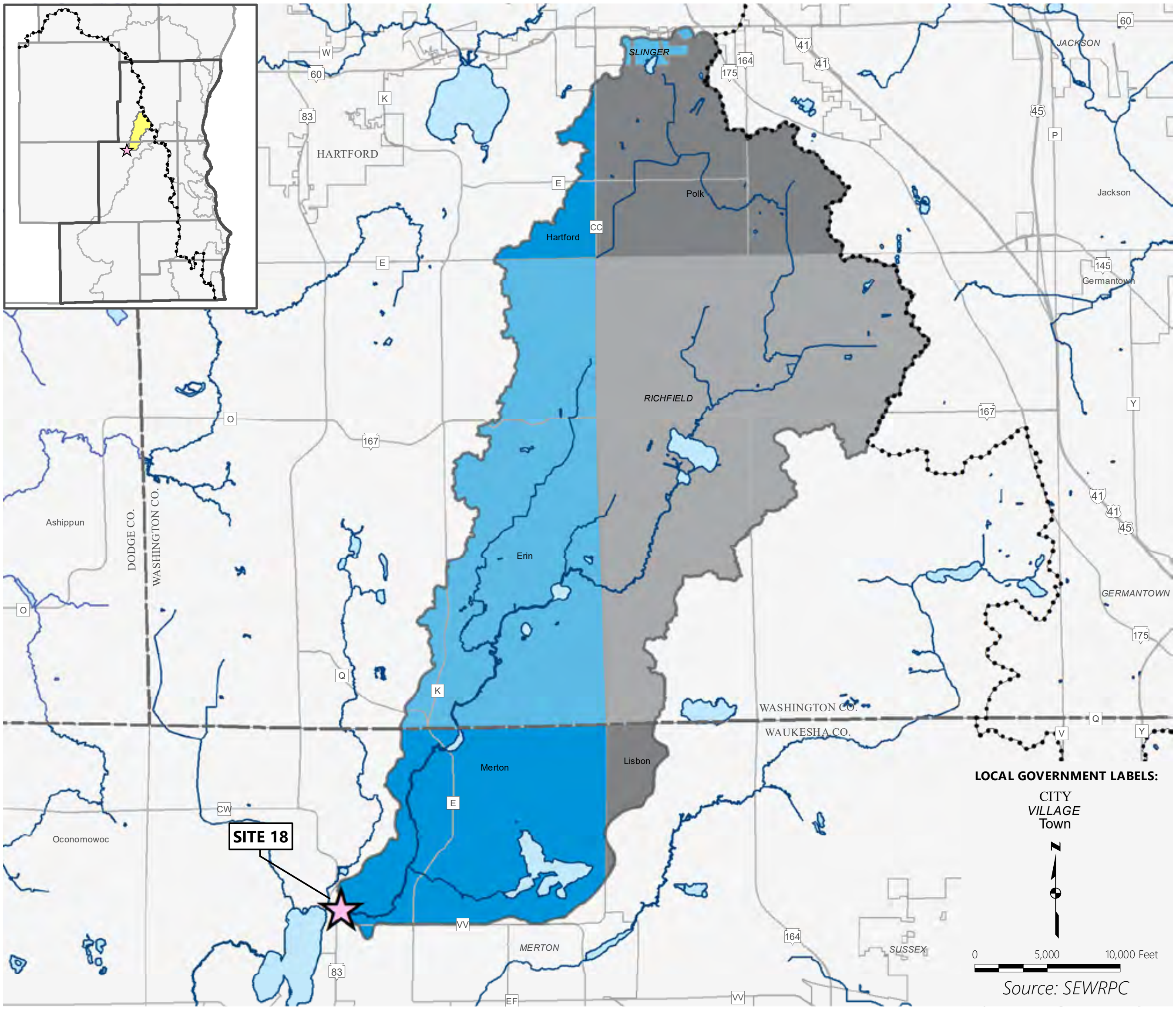
- **Drainage Area Size:** 10 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 10.9%; Rural – 89.1%
- **Roads and Parking Lots (% of drainage area):** 5.1
- **Estimated Population (2010):** 820
- **Estimated Households (2010):** 330 (73% served by public sanitary sewer)
- **Nearest USGS Streamgage (◉):** Jackson Creek at Mound Road (05431016)
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.29
Site 18: Oconomowoc River Upstream Drainage Area – Existing Land Use





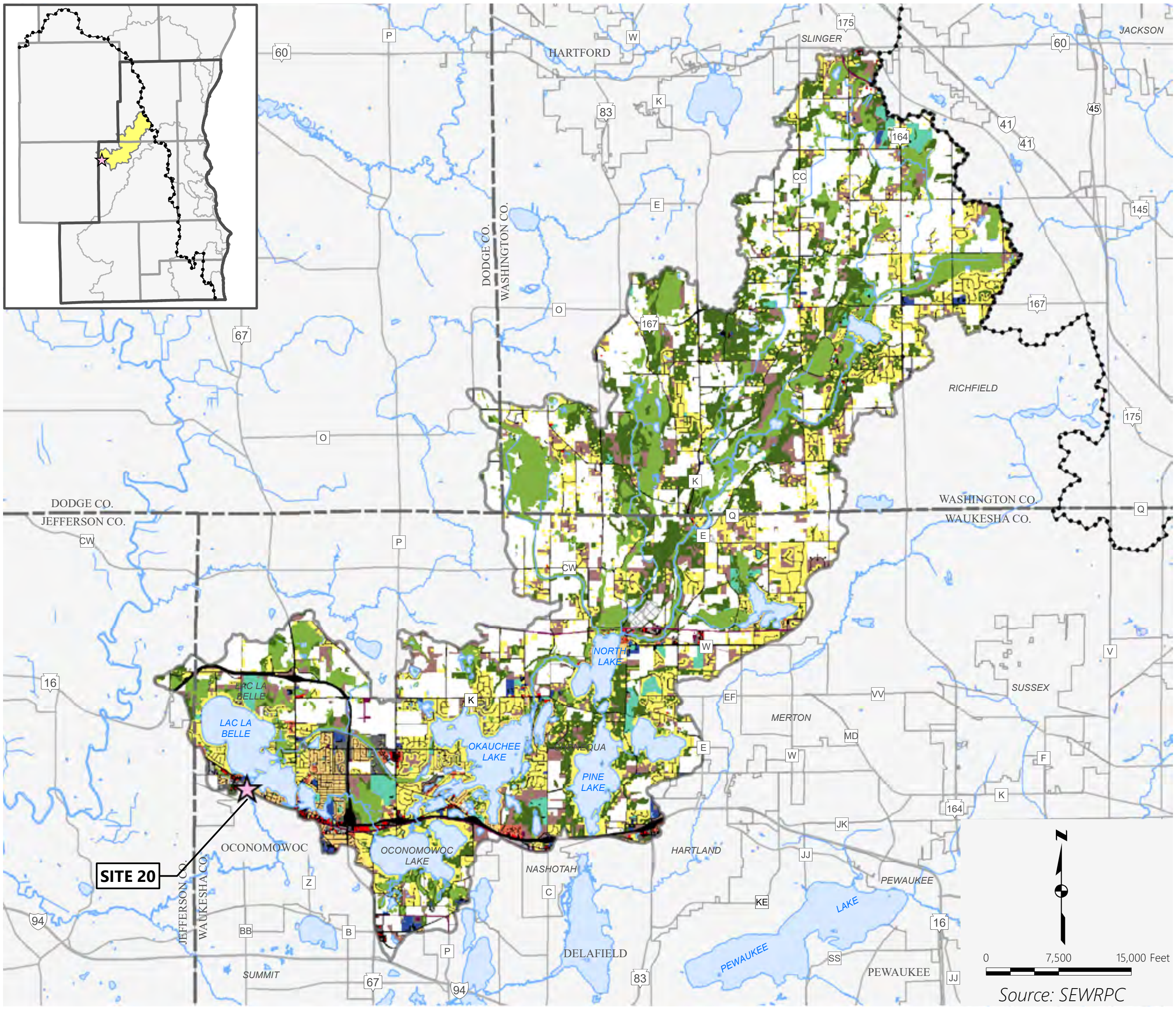
Map B.30
Site 18: Oconomowoc River Upstream Drainage Area – Features

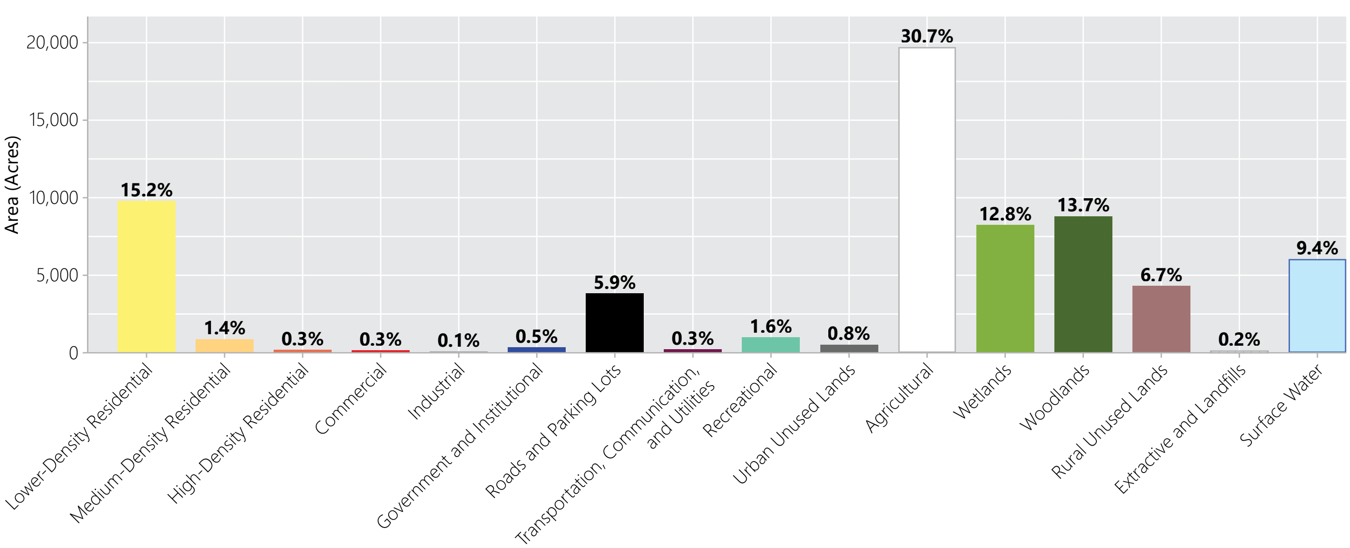


Facts at a Glance

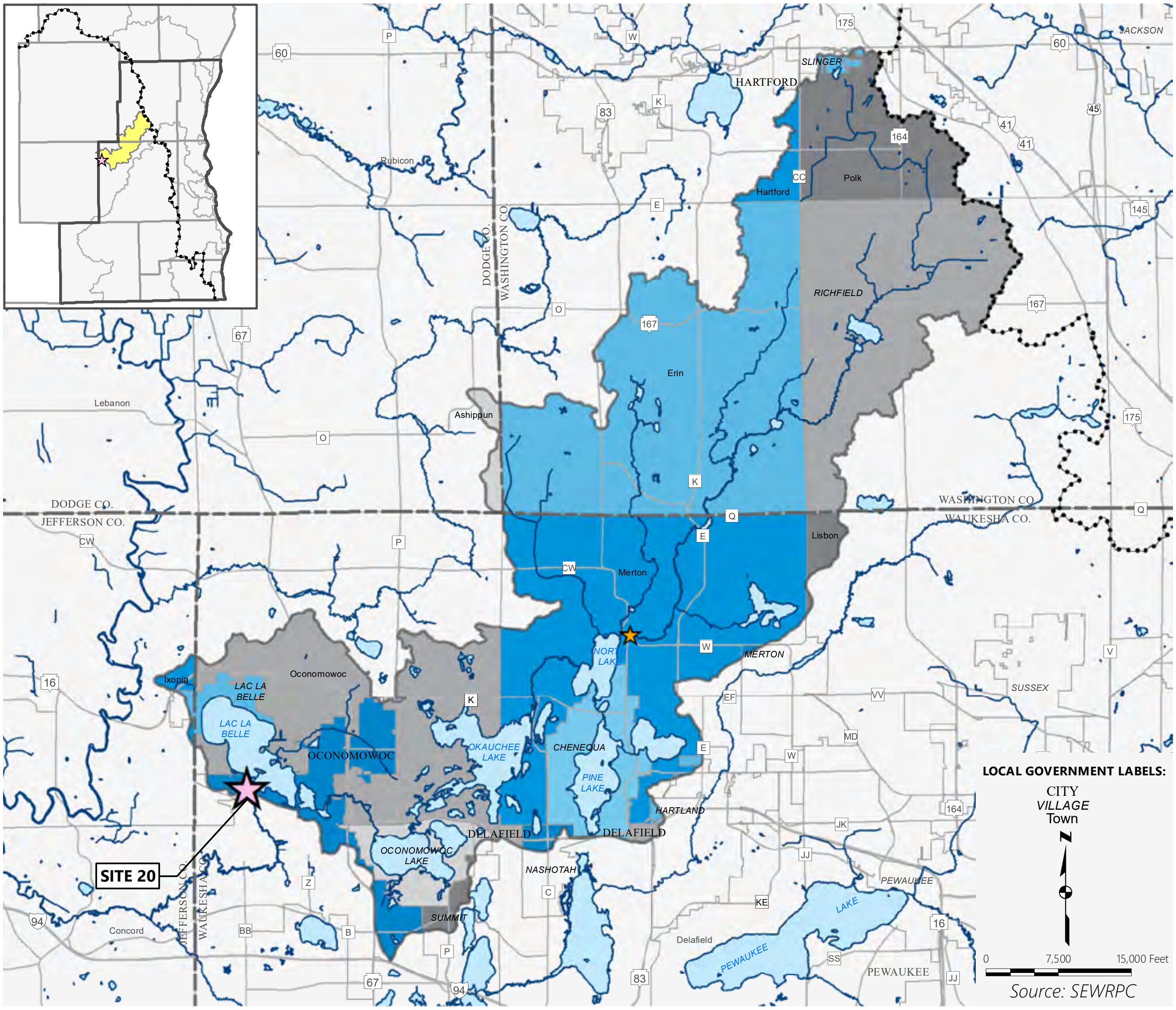
- **Drainage Area Size:** 41 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 22.3%; Rural – 77.7%
- **Roads and Parking Lots (% of drainage area):** 4.5
- **Estimated Population (2010):** 7,980
- **Estimated Households (2010):** 2,900 (6% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.31
Site 20: Oconomowoc River Downstream Drainage Area – Existing Land Use





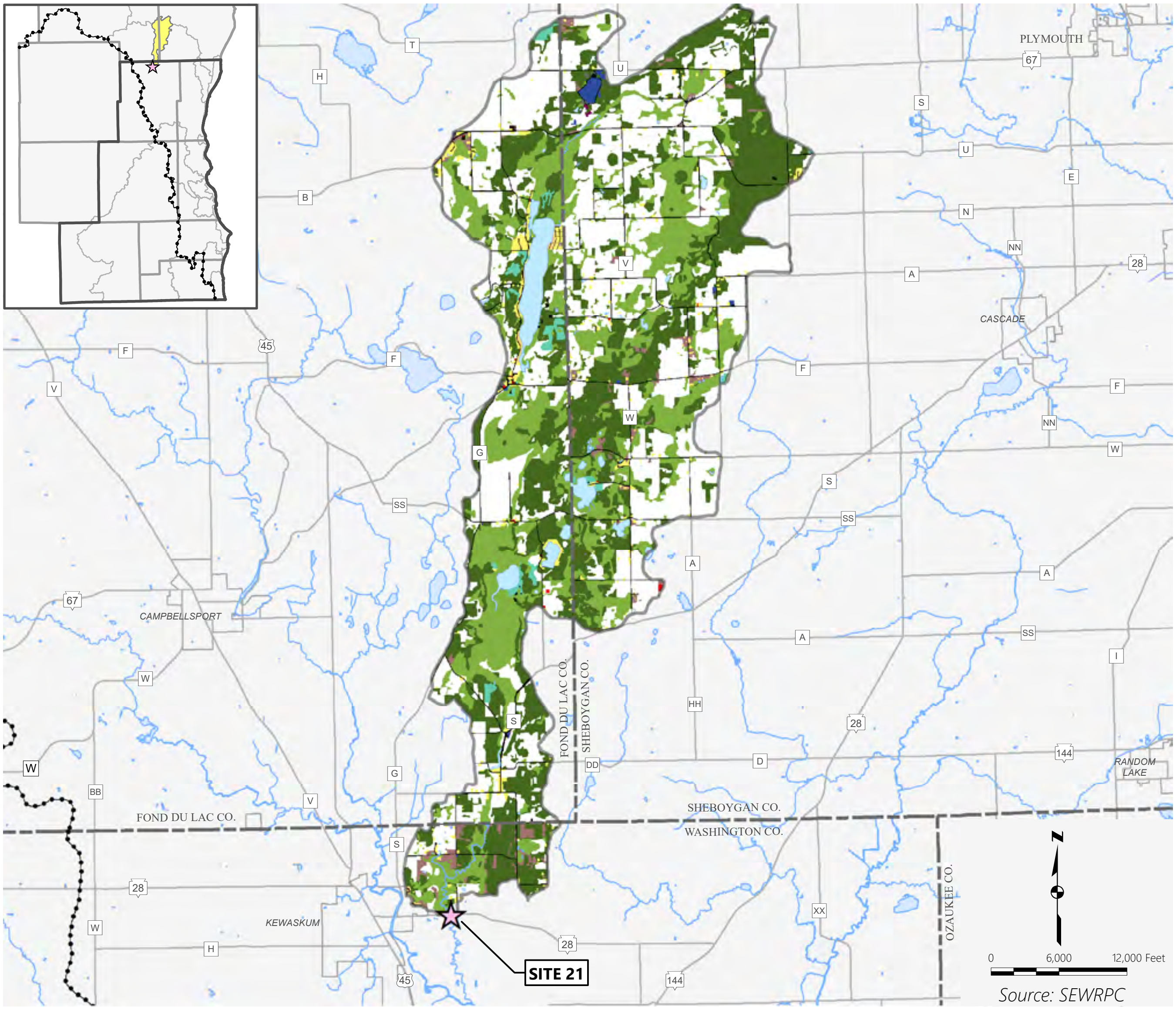
Map B.32
Site 20: Oconomowoc River Downstream Drainage Area – Features

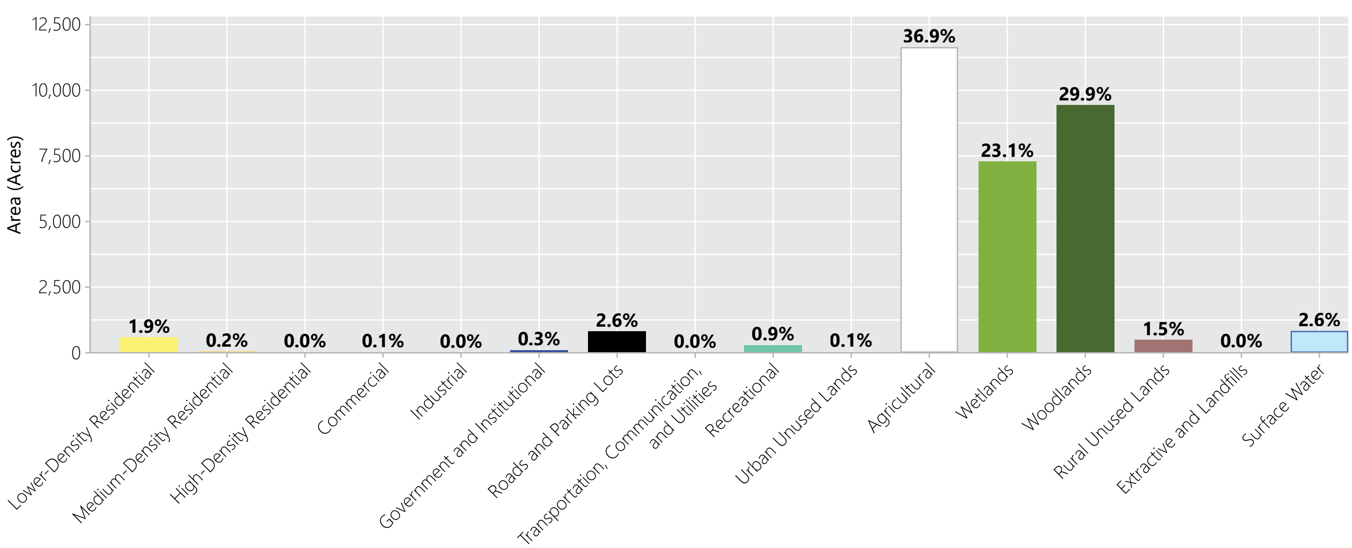


Facts at a Glance

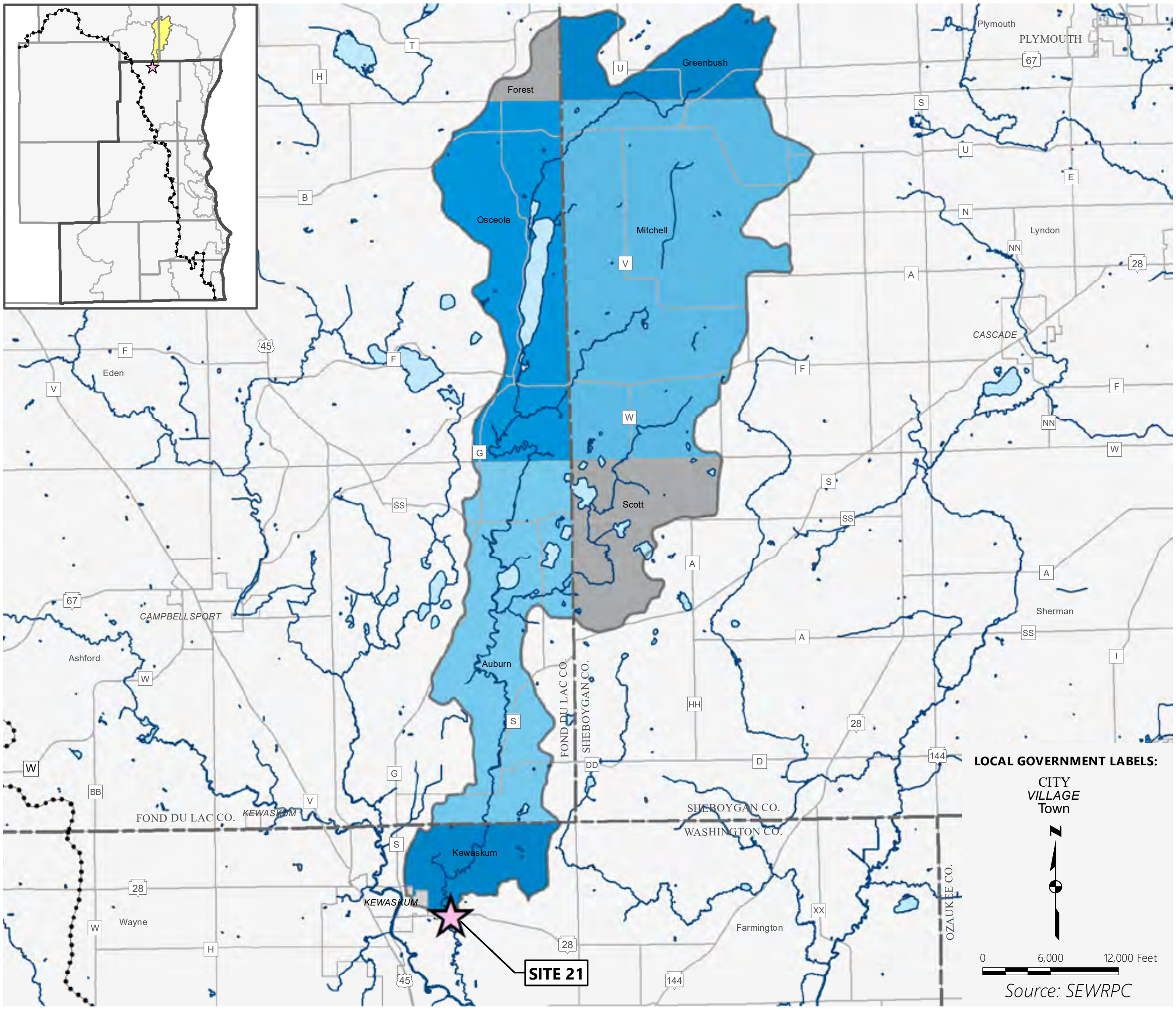
- **Drainage Area Size:** 100 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 26.4%; Rural – 73.6%
- **Roads and Parking Lots (% of drainage area):** 5.9
- **Estimated Population (2010):** 29,290
- **Estimated Households (2010):** 11,340 (44% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 18
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.33
Site 21: East Branch Milwaukee River Drainage Area – Existing Land Use





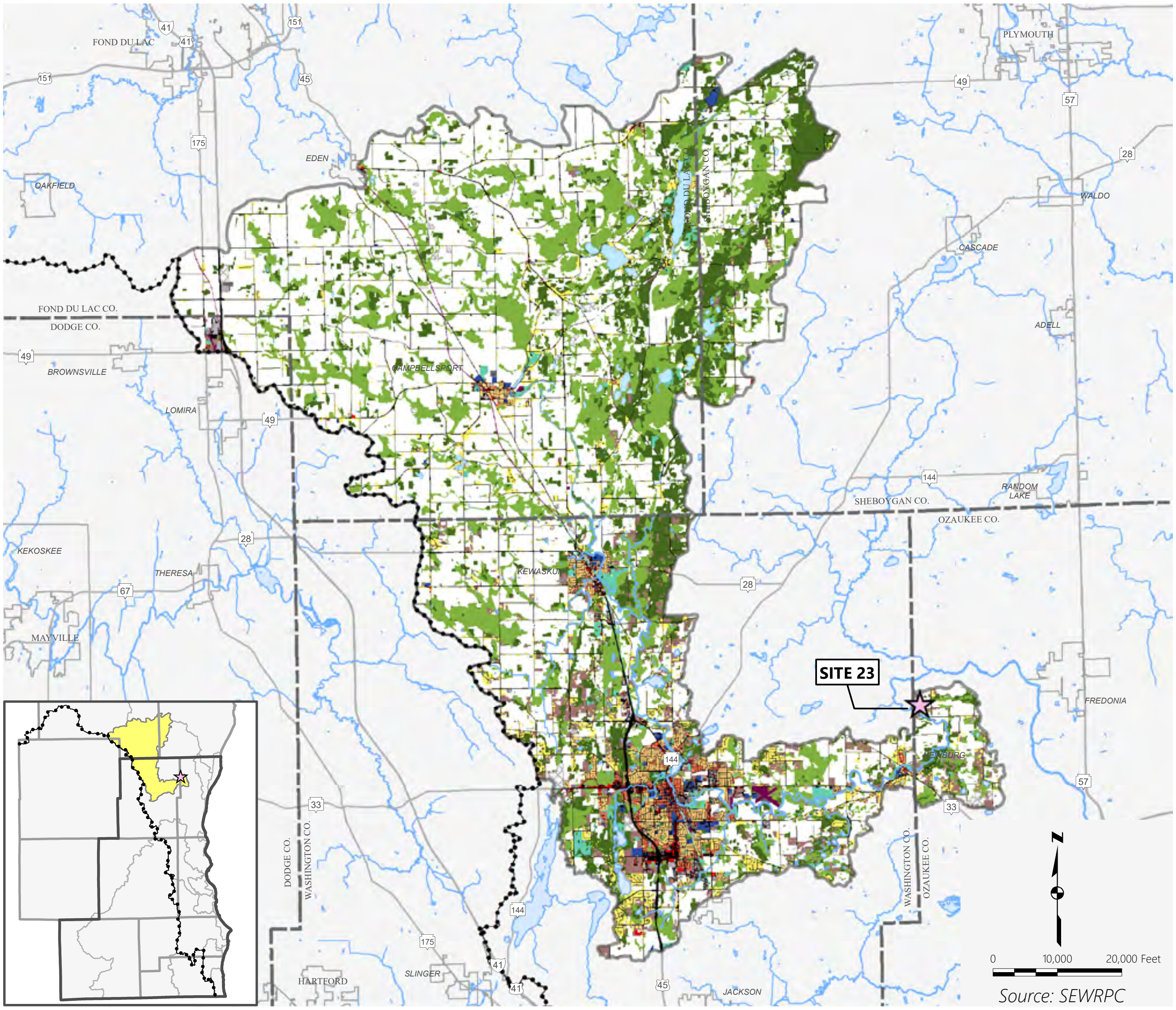
Map B.34
Site 21: East Branch Milwaukee River Drainage Area – Features

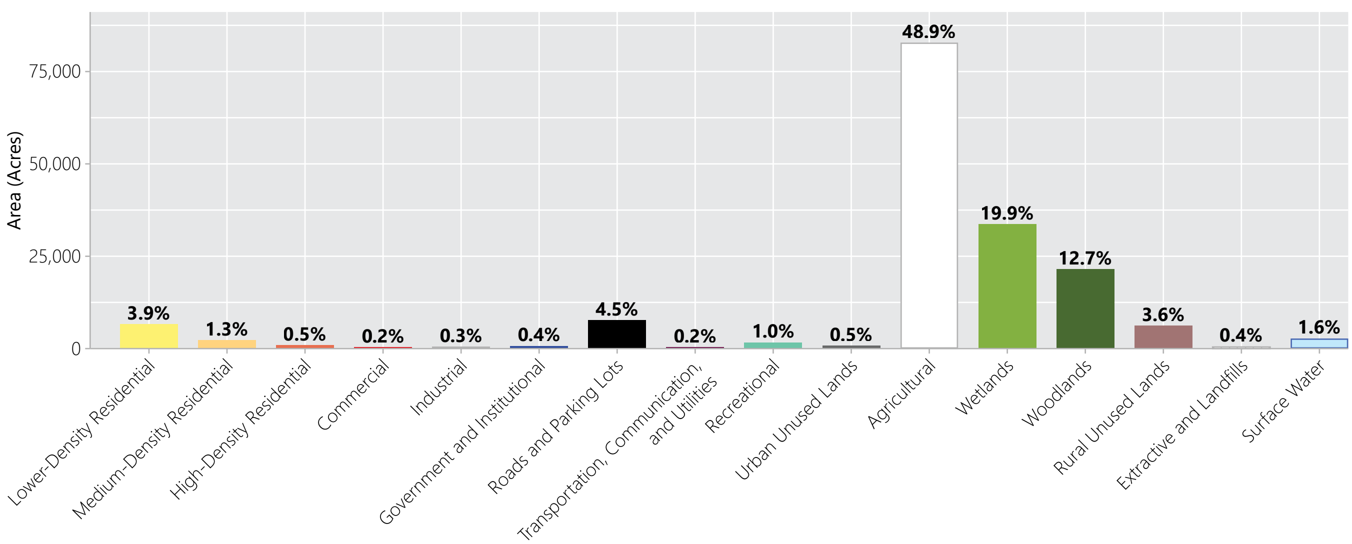


Facts at a Glance

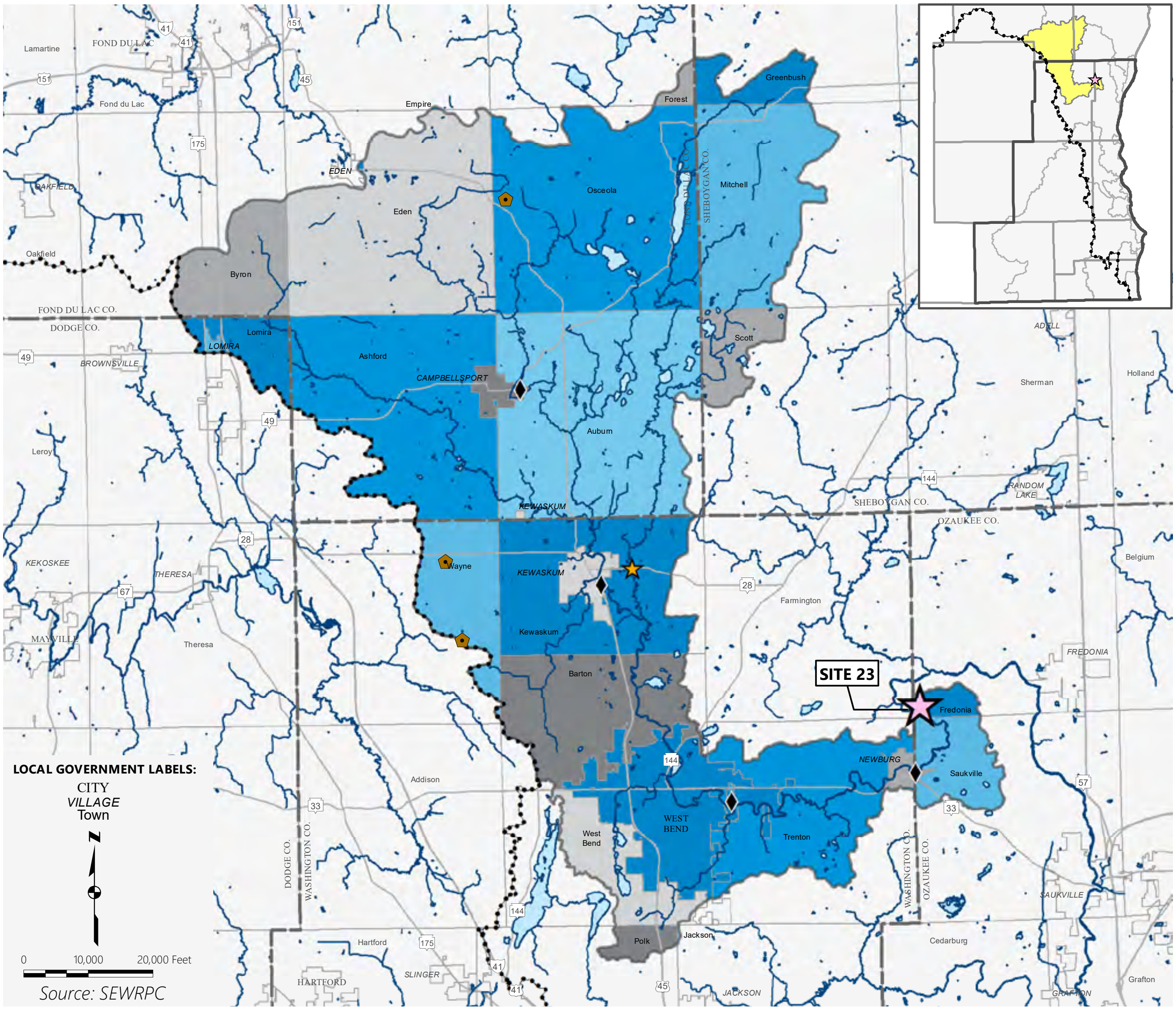
- **Drainage Area Size:** 49 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 6.0%; Rural – 94.0%
- **Roads and Parking Lots (% of drainage area):** 2.6
- **Estimated Population (2010):** 2,790
- **Estimated Households (2010):** 670 (0% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.35
Site 23: Milwaukee River Downstream of Newburg Drainage Area – Existing Land Use





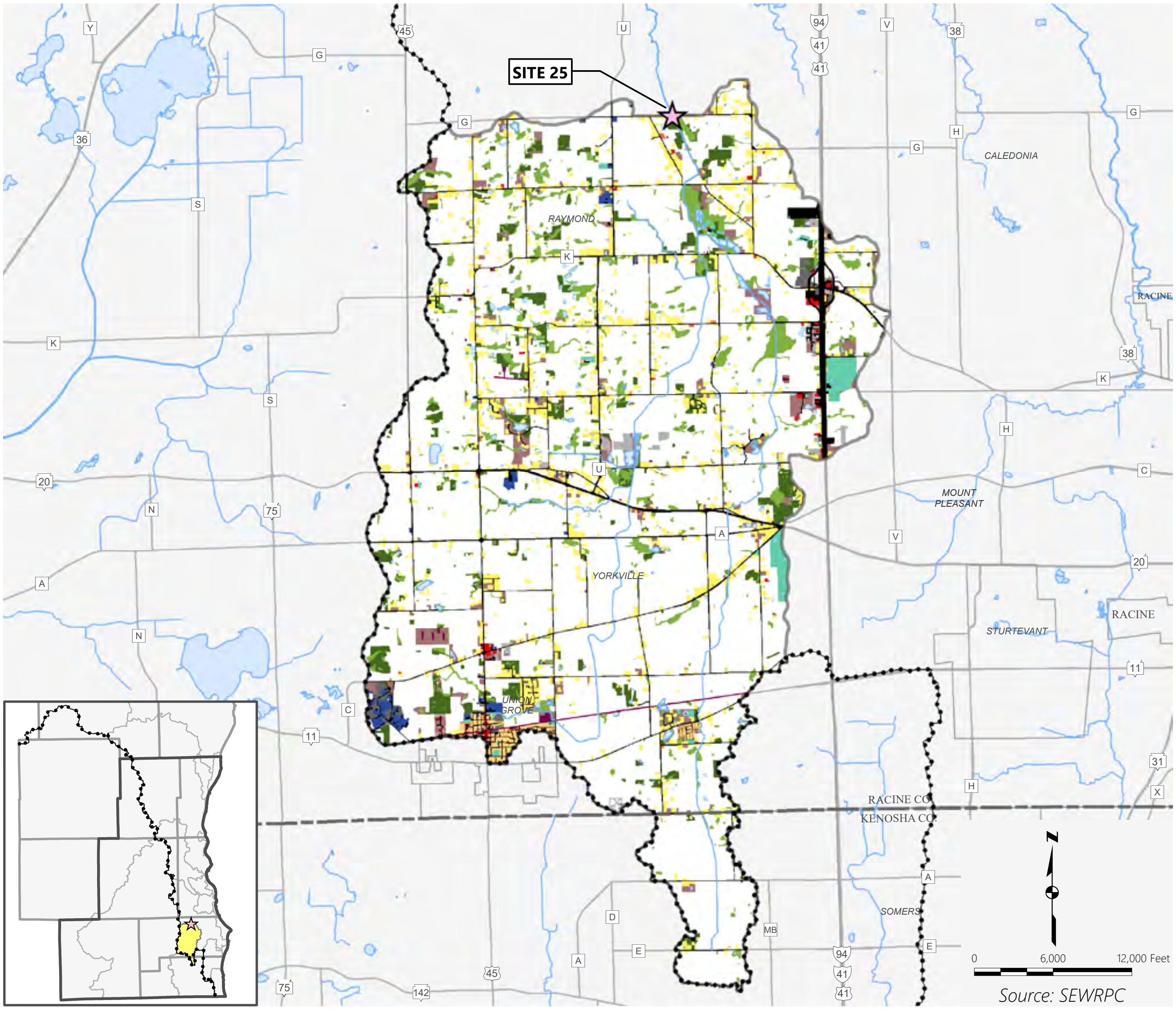
Map B.36
Site 23: Milwaukee River Downstream of Newburg Drainage Area – Features

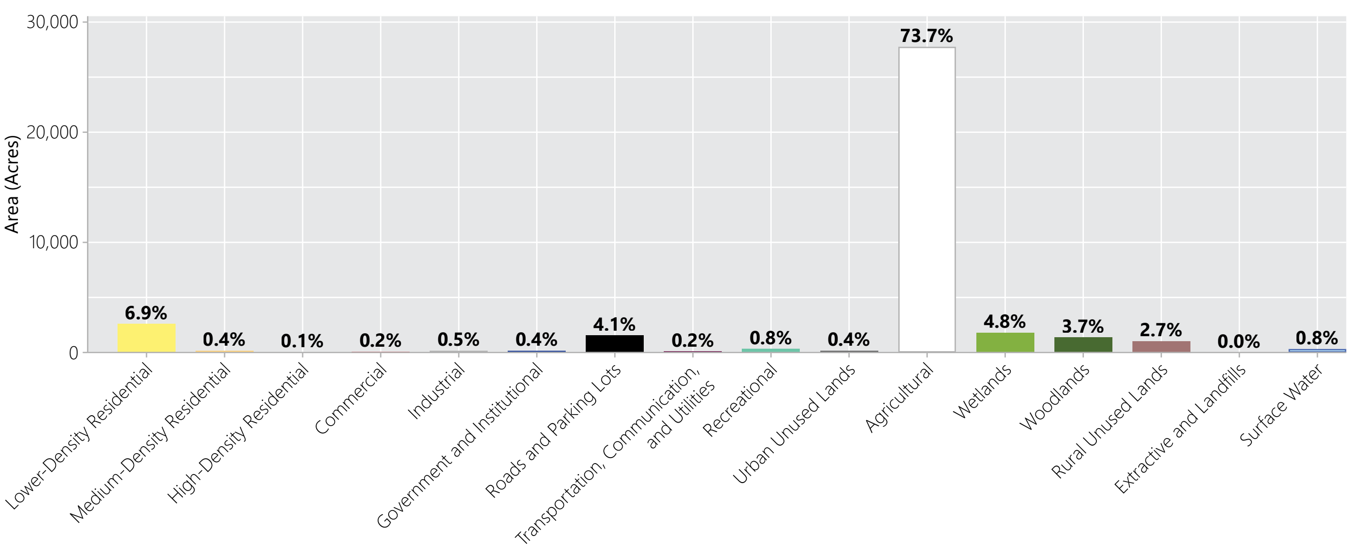


Facts at a Glance

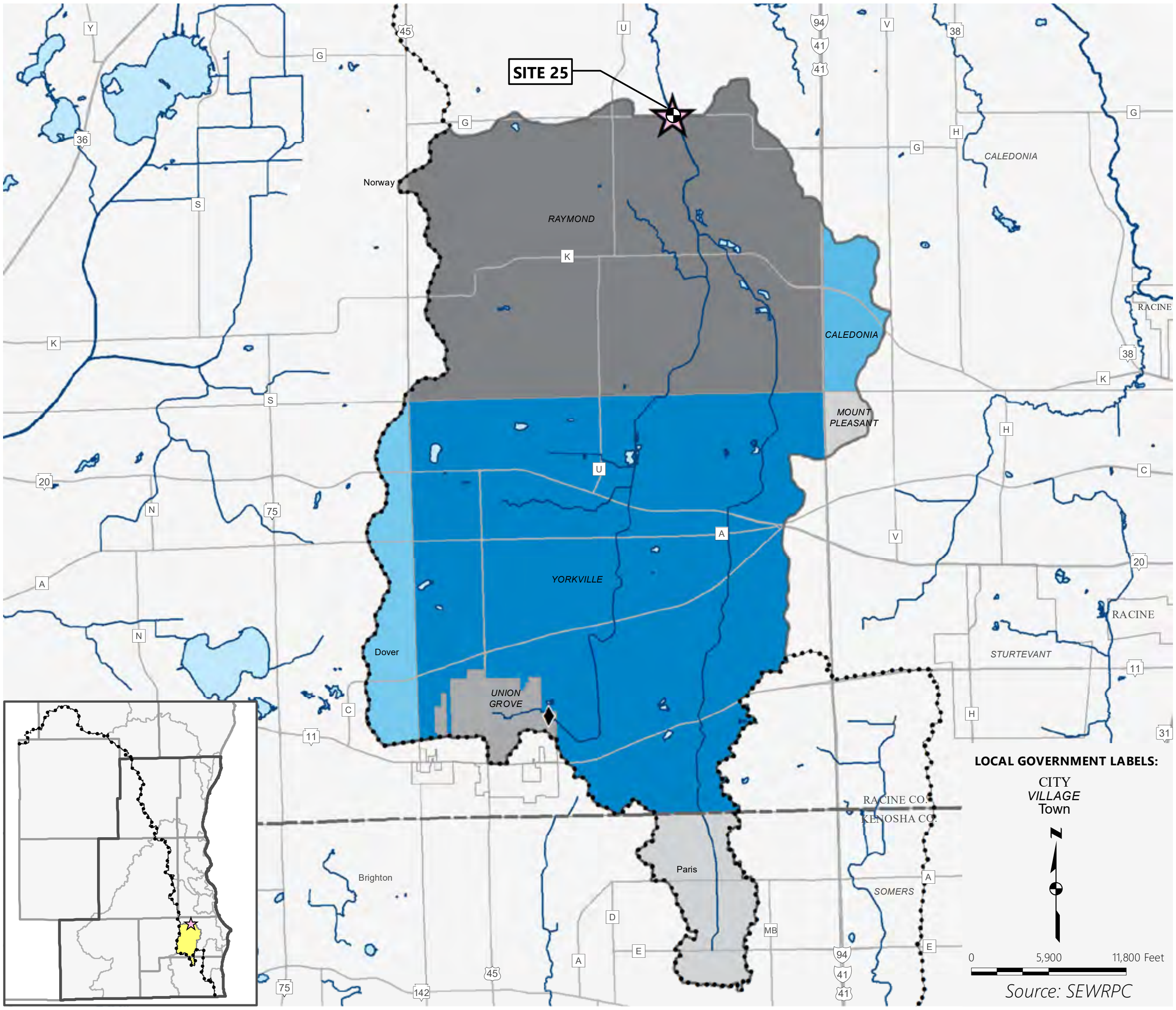
- **Drainage Area Size:** 265 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 12.9%; Rural – 87.1%
- **Roads and Parking Lots (% of drainage area):** 4.5
- **Estimated Population (2010):** 56,690
- **Estimated Households (2010):** 22,120 (73% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 21
- **Upstream Wastewater Treatment Facilities (♦):** 4
- **Concentrated Animal Feeding Operations (⬟):** 3
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.37
Site 25: Root River Canal Drainage Area – Existing Land Use





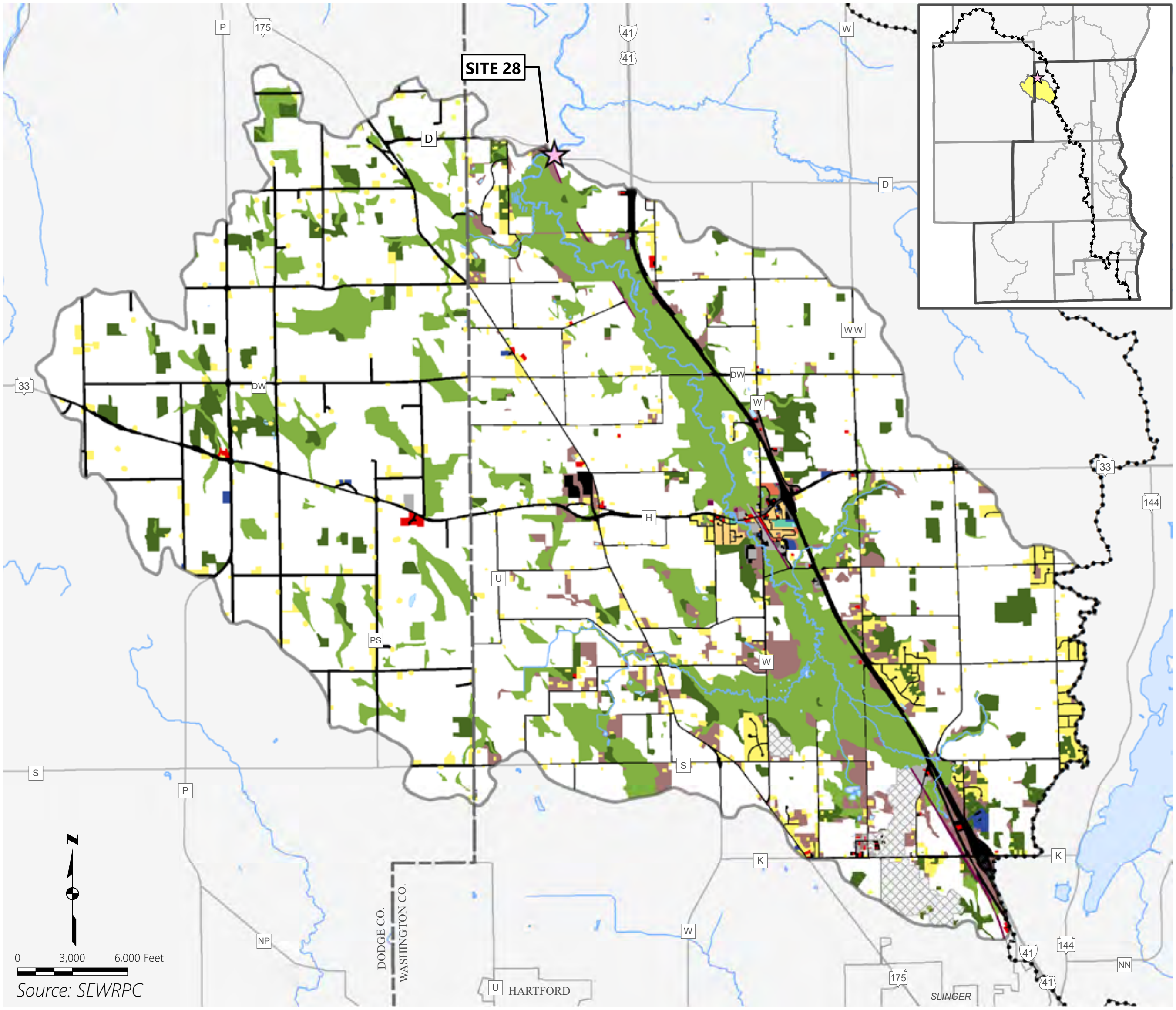
Map B.38
Site 25: Root River Canal Drainage Area – Features

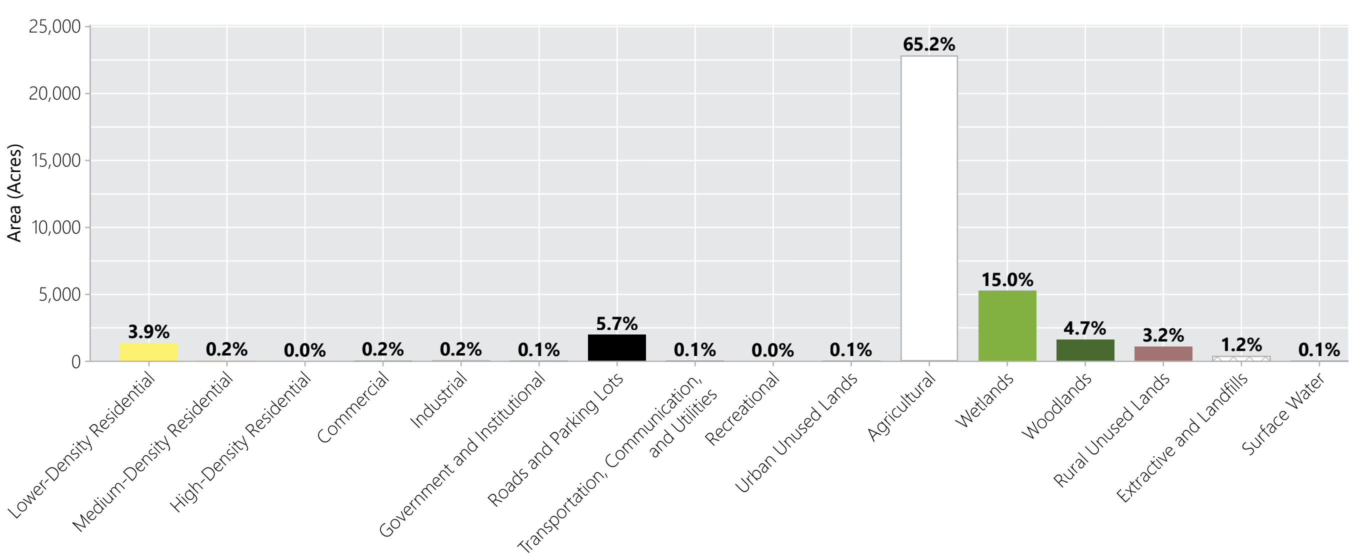


Facts at a Glance

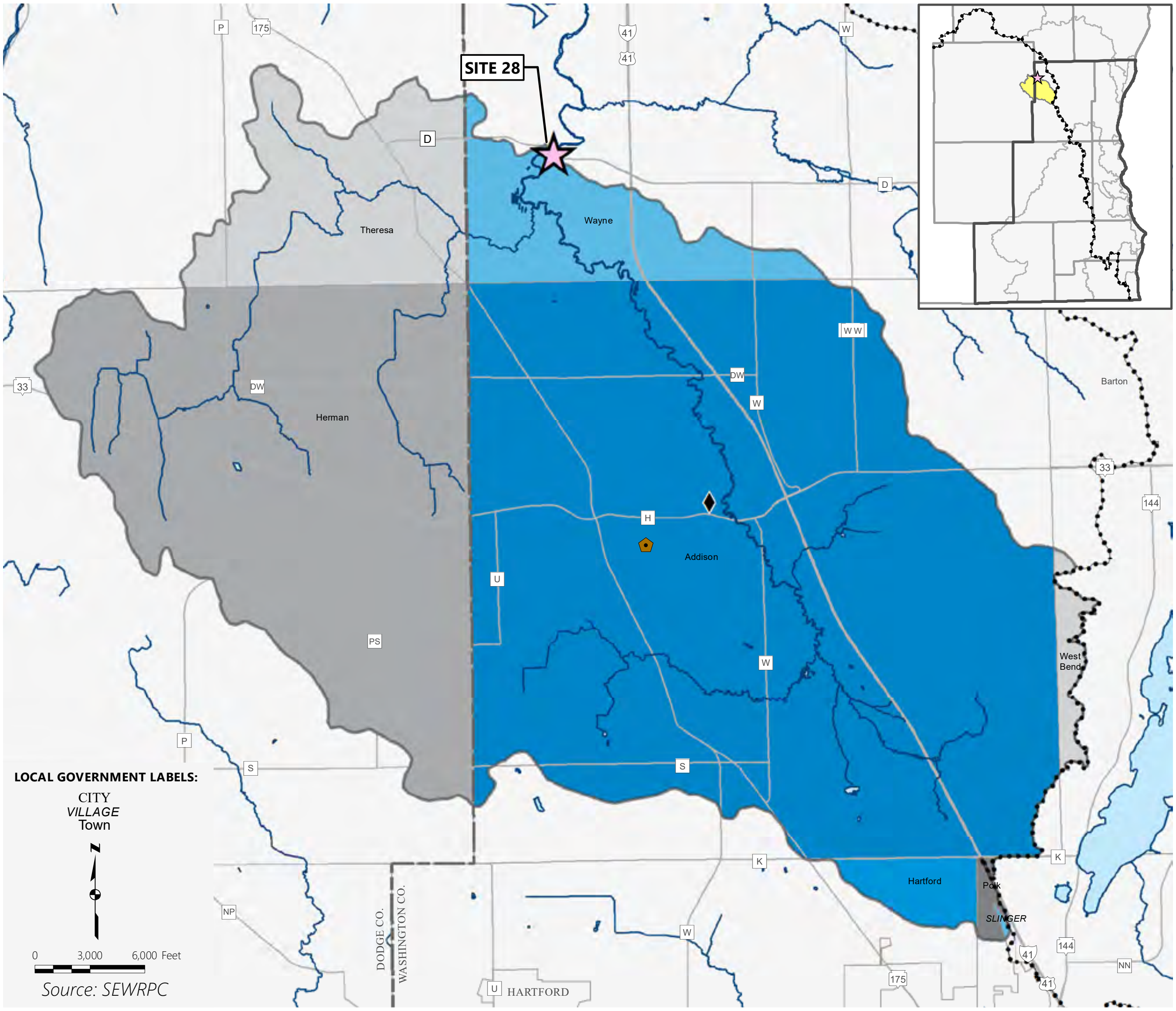
- **Drainage Area Size:** 59 square miles
- **Major Watershed:** Root River
- **Land Use:** Urban – 14.2%; Rural – 85.8%
- **Roads and Parking Lots (% of drainage area):** 4.1
- **Estimated Population (2010):** 8,080
- **Estimated Households (2010):** 2,880 (33% served by public sanitary sewer)
- **Nearest USGS Streamgage (⊕):** Root River Canal near Franklin (04087233)
- **Upstream Wastewater Treatment Facilities (♦):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.39
Site 28: East Branch Rock River Drainage Area – Existing Land Use





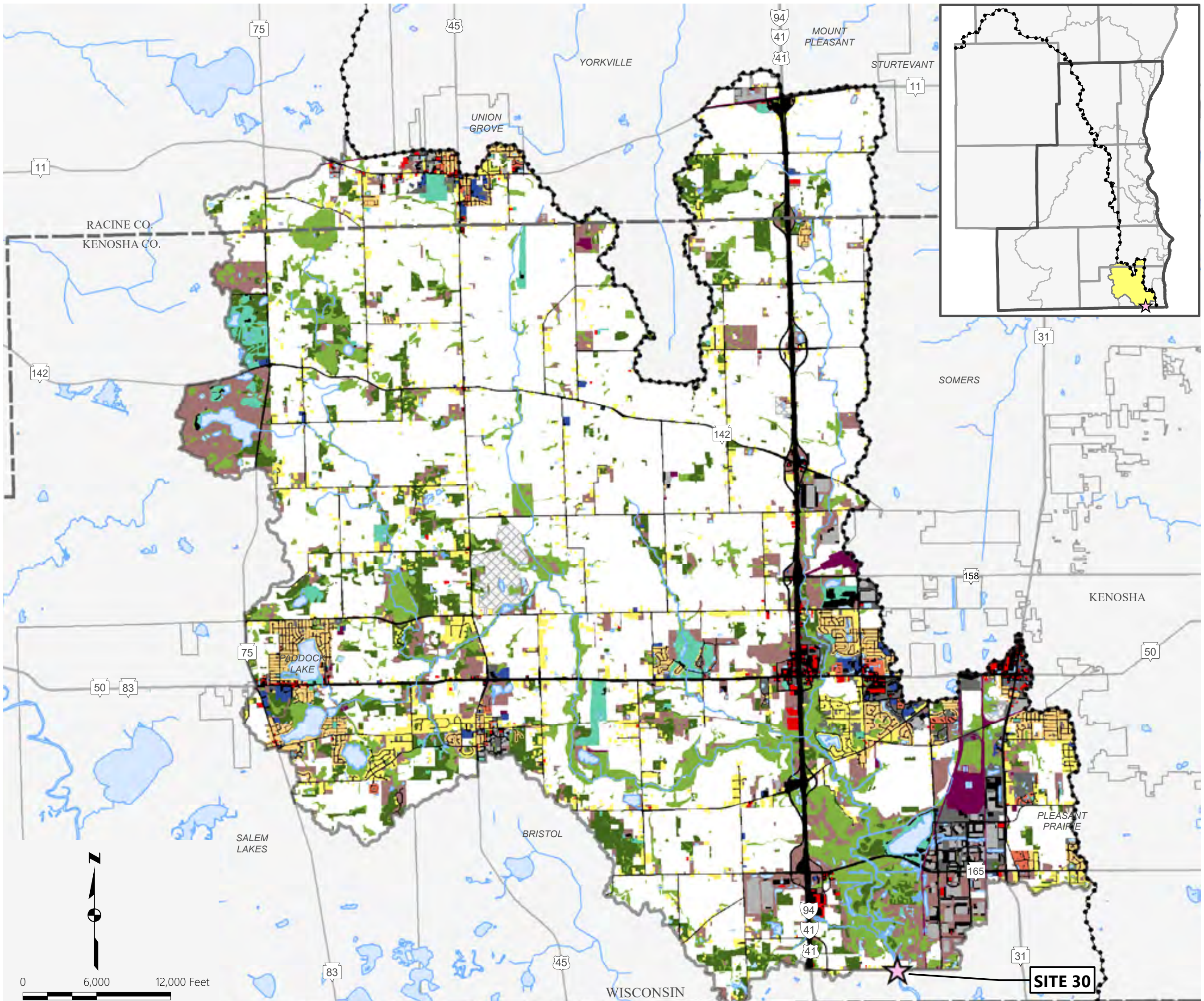
Map B.40
Site 28: East Branch Rock River Drainage Area – Features



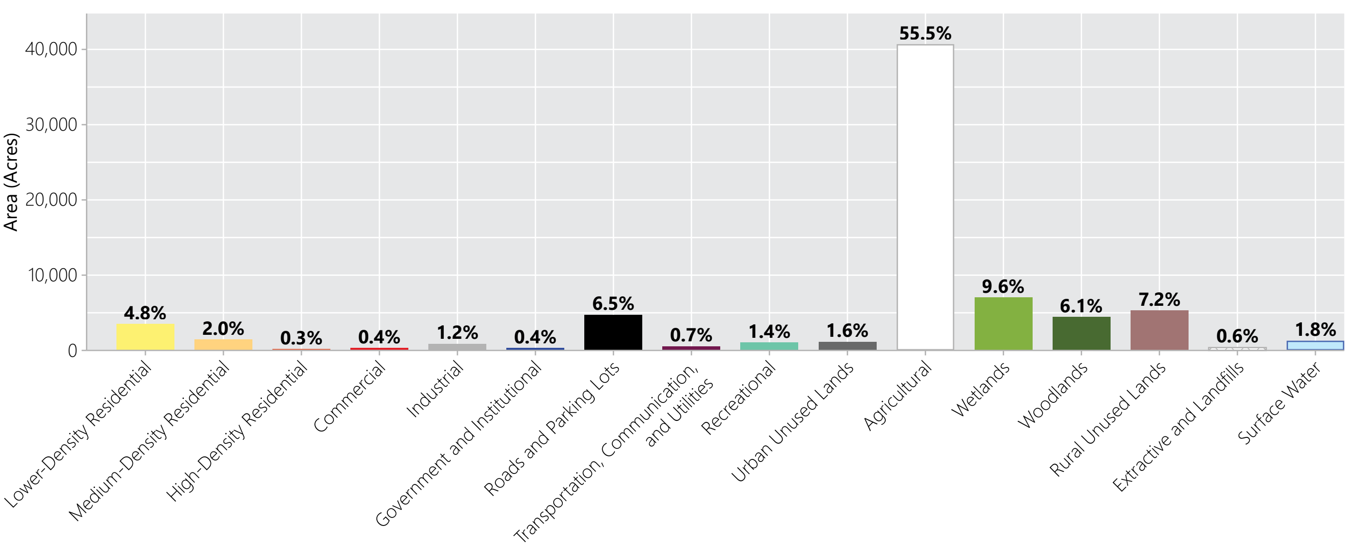
Facts at a Glance

- **Drainage Area Size:** 55 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 10.6%; Rural – 89.4%
- **Roads and Parking Lots (% of drainage area):** 5.7
- **Estimated Population (2010):** 4,310
- **Estimated Households (2010):** 1,610 (21% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Upstream Wastewater Treatment Facilities (♦):** 1
- **Concentrated Animal Feeding Operations (⬟):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

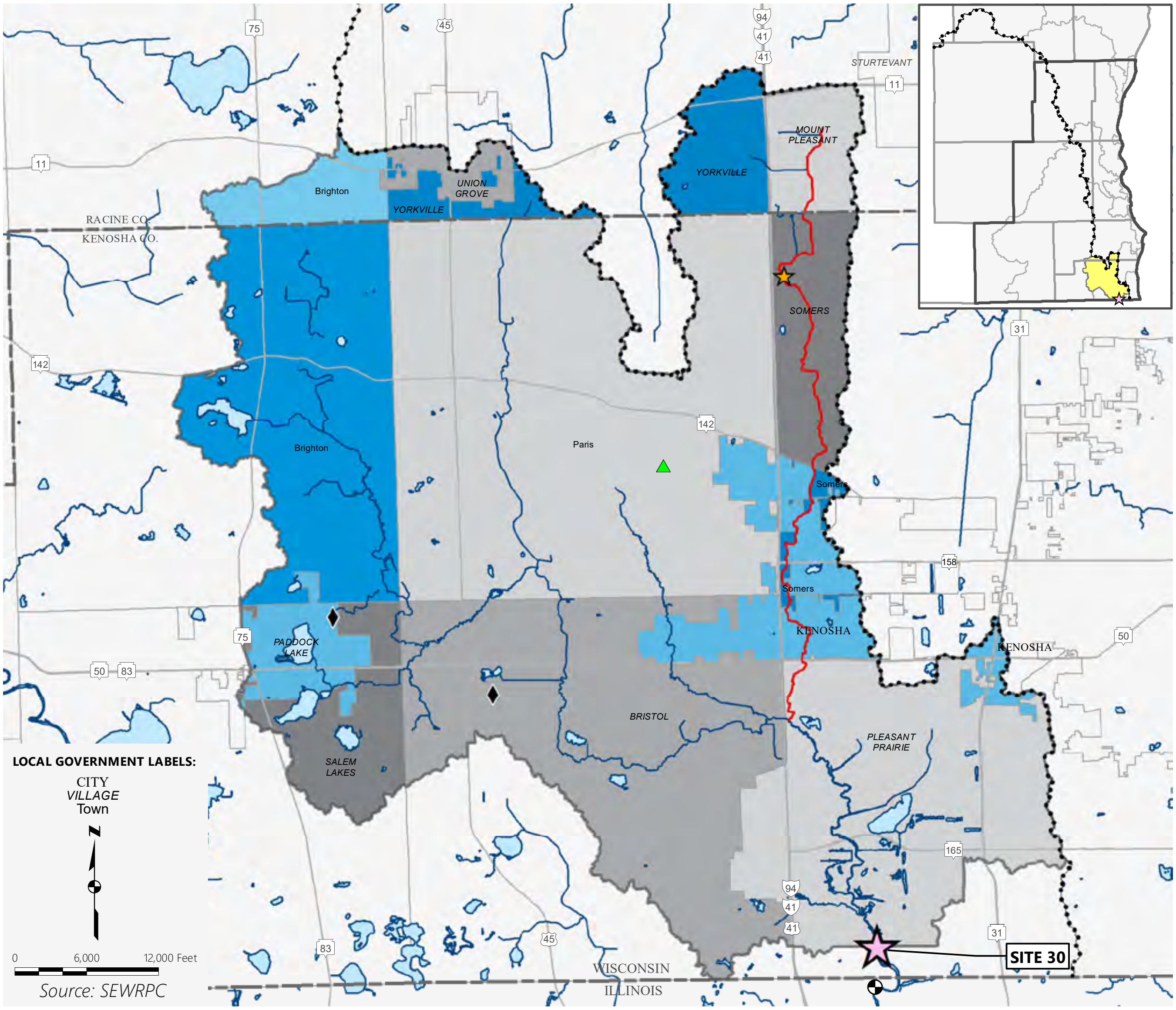
Map B.41
Site 30: Des Plaines River Drainage Area – Existing Land Use



Source: SEWRPC



Map B.42
Site 30: Des Plaines River Drainage Area – Features

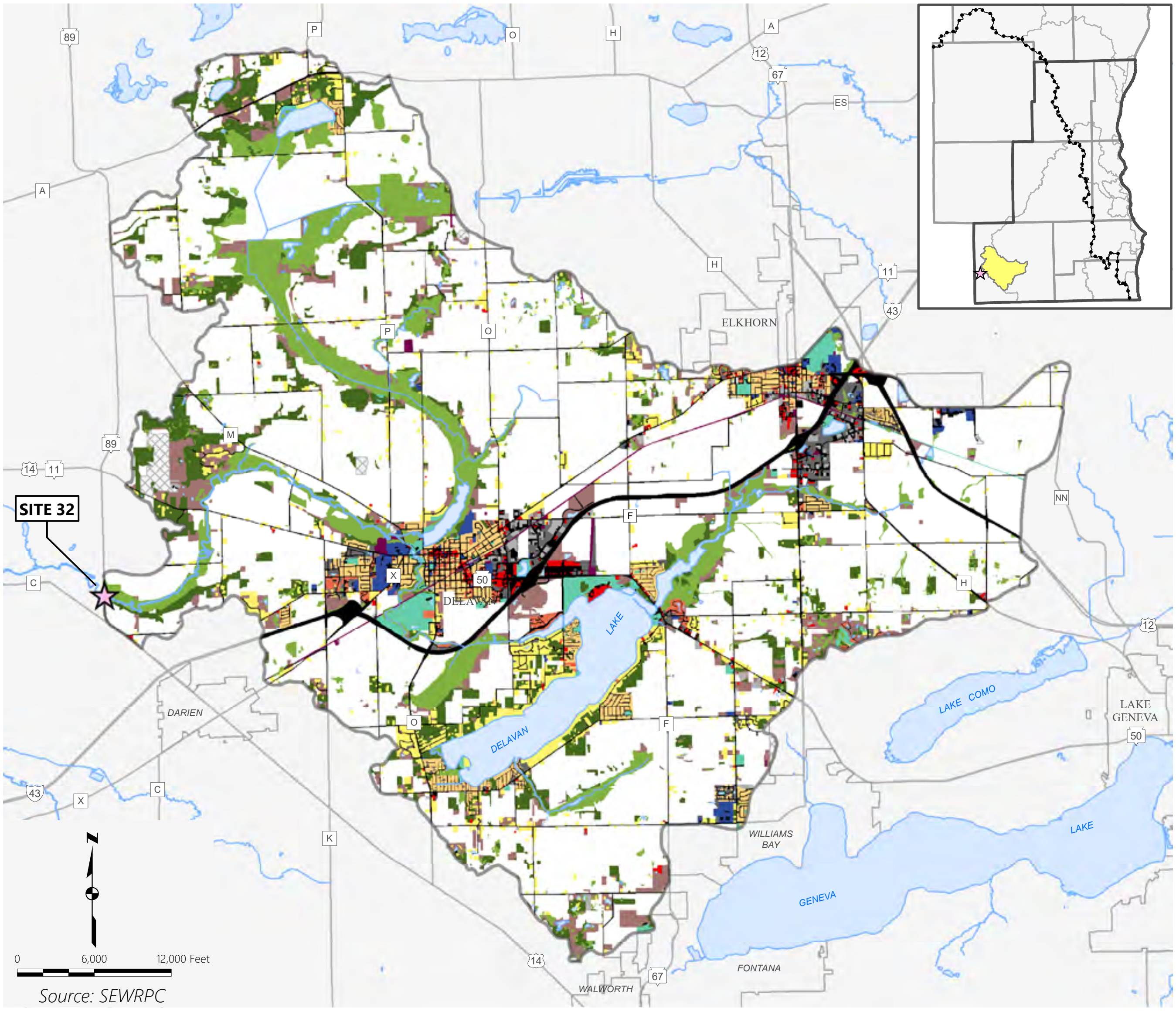


Source: SEWRPC

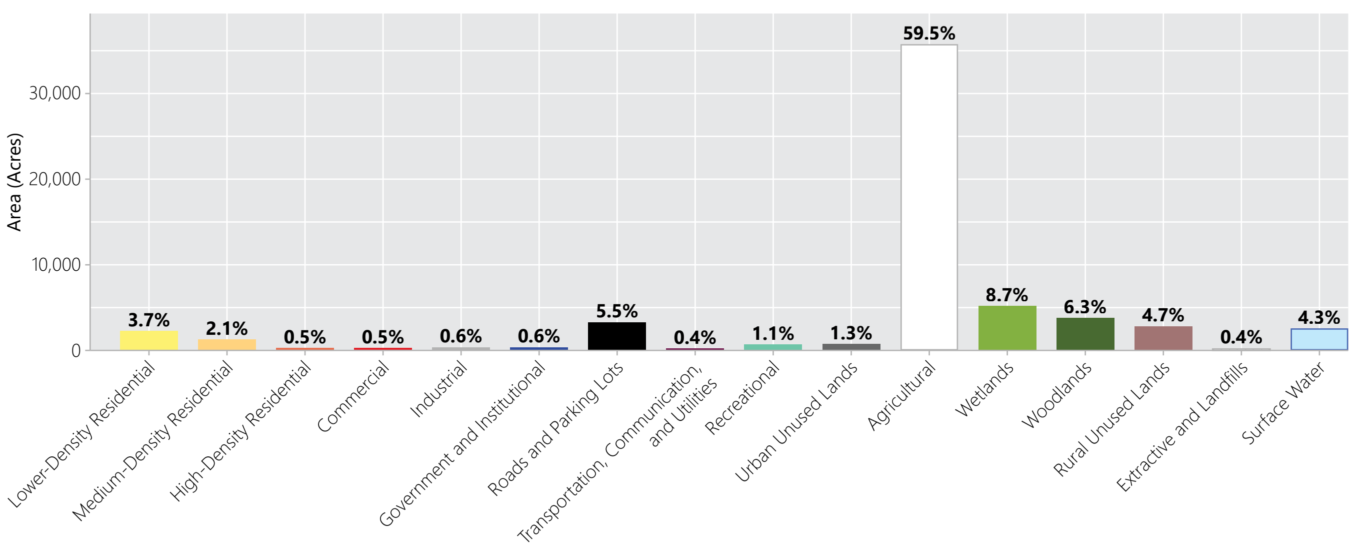
Facts at a Glance

- **Drainage Area Size:** 115 square miles
- **Major Watershed:** Des Plaines River
- **Land Use:** Urban – 19.2%; Rural – 80.8%
- **Roads and Parking Lots (% of drainage area):** 6.5
- **Estimated Population (2010):** 27,850
- **Estimated Households (2010):** 10,170 (80% served by public sanitary sewer)
- **Nearest USGS Streamgage (◉):** Des Plaines River at Russell, IL (05527800)
- **Other Monitoring Sites Within this Drainage Area (★):** Site 15
- **Upstream Wastewater Treatment Facilities (♦):** 2
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
- **Water Supply Source:** Lake Michigan and Groundwater

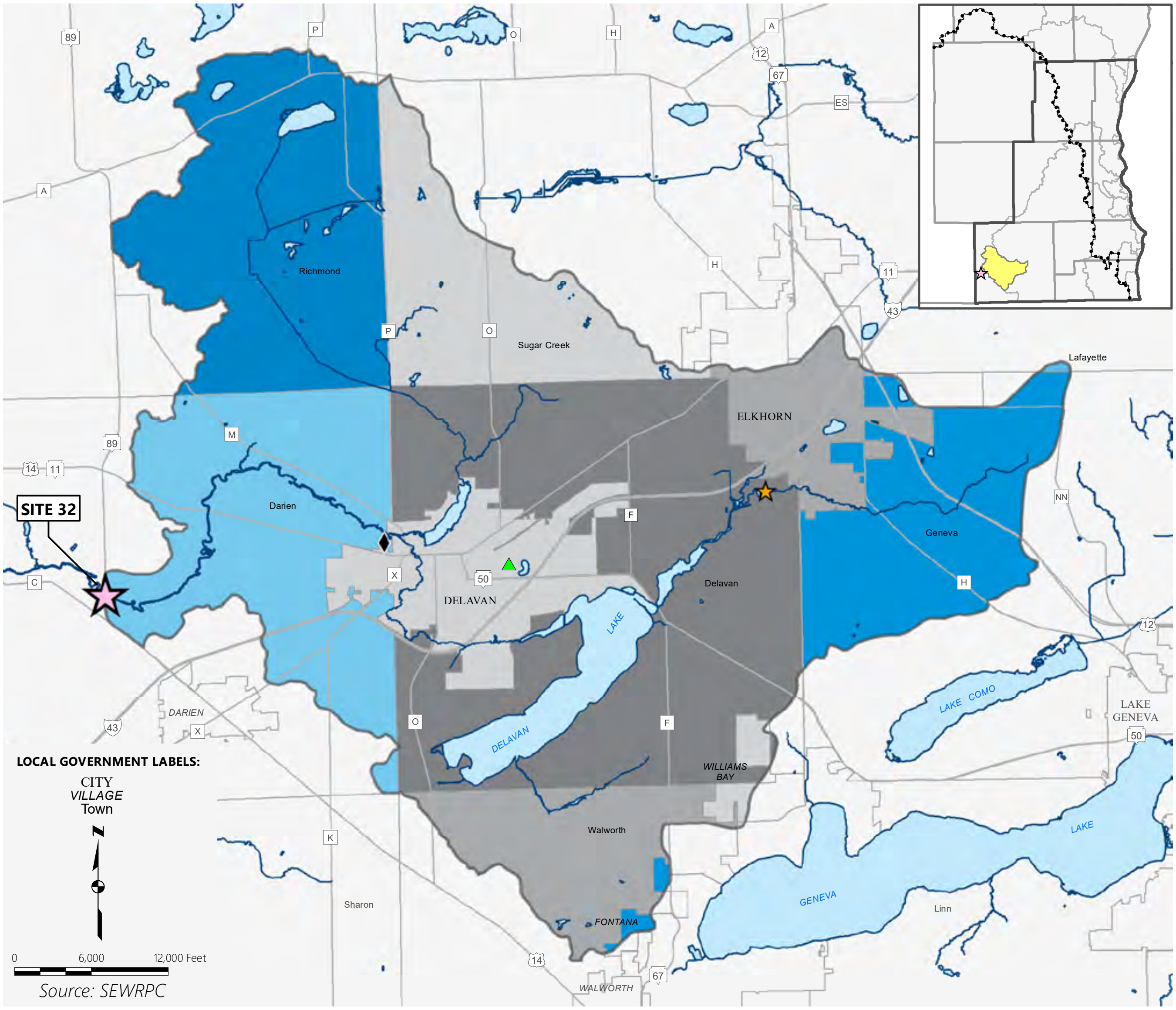
Map B.43
Site 32: Turtle Creek Drainage Area – Existing Land Use



Source: SEWRPC



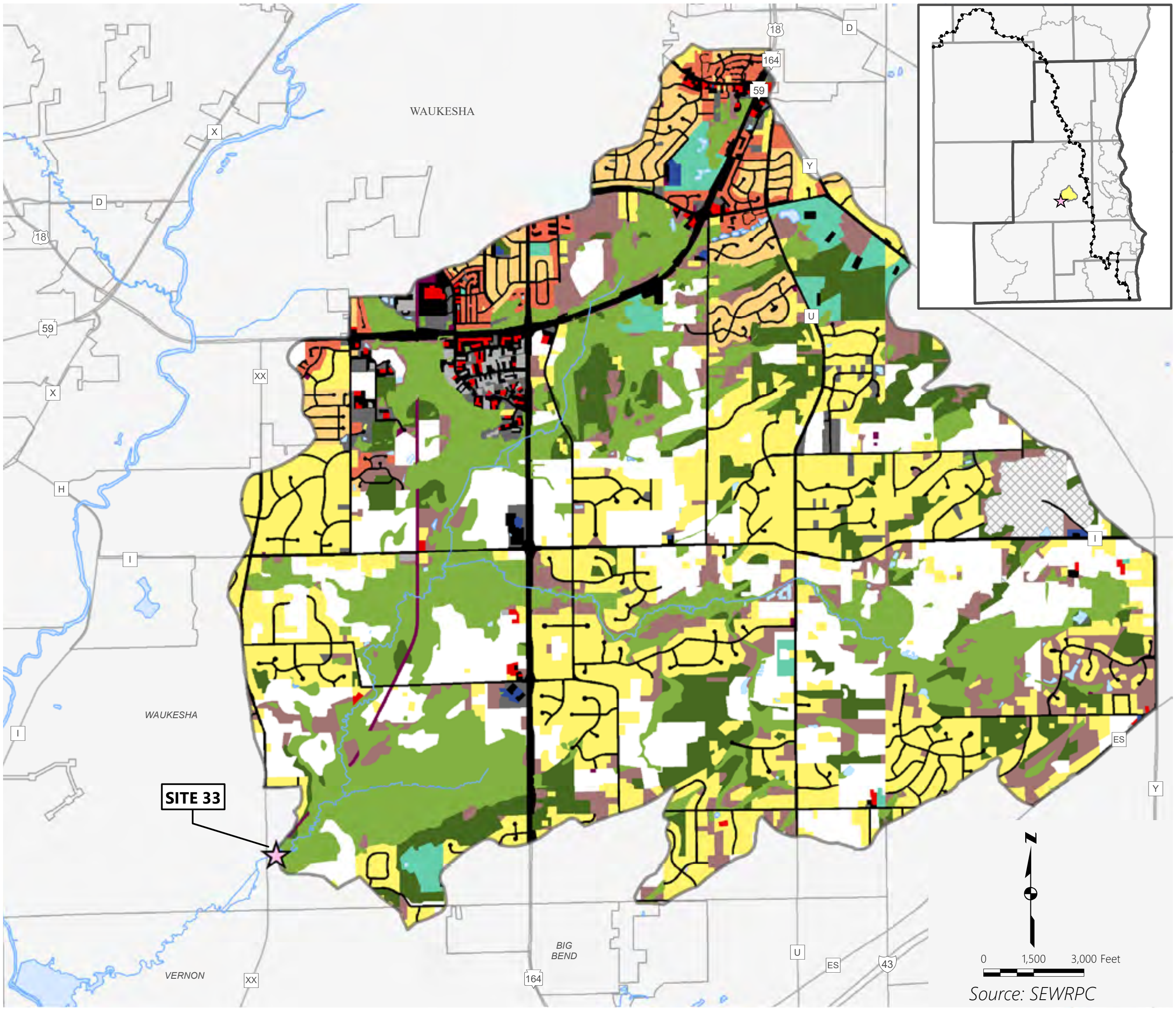
Map B.44
Site 32: Turtle Creek Drainage Area – Features

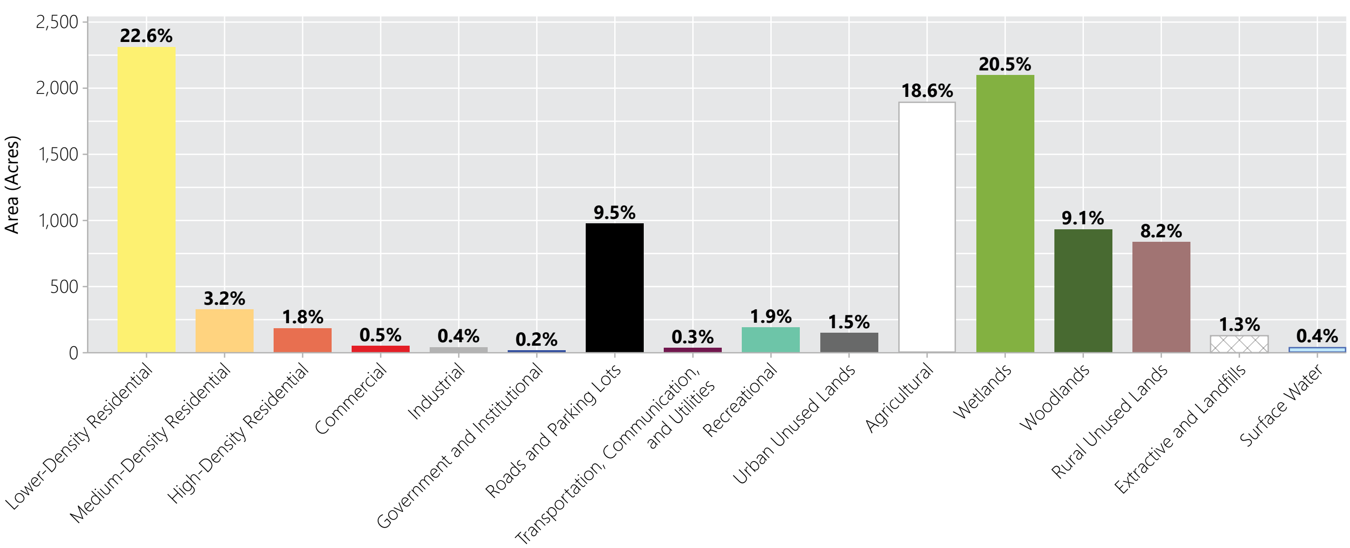


Facts at a Glance

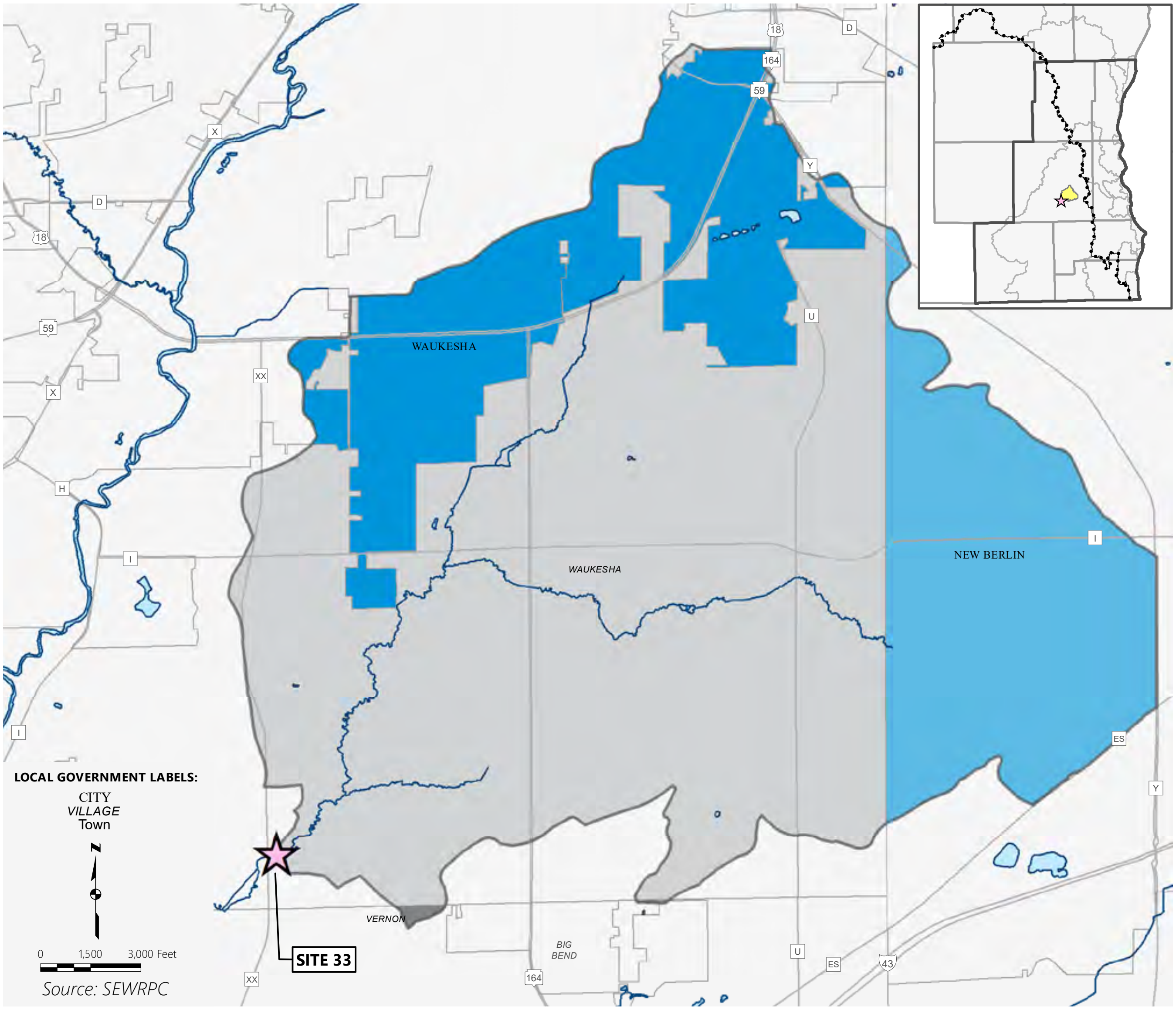
- **Drainage Area Size:** 94 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 16.2%; Rural – 83.8%
- **Roads and Parking Lots (% of drainage area):** 5.5
- **Estimated Population (2010):** 20,720
- **Estimated Households (2010):** 8,020 (84% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 16
- **Upstream Wastewater Treatment Facilities (♦):** 1
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.45
Site 33: Pebble Brook Drainage Area – Existing Land Use





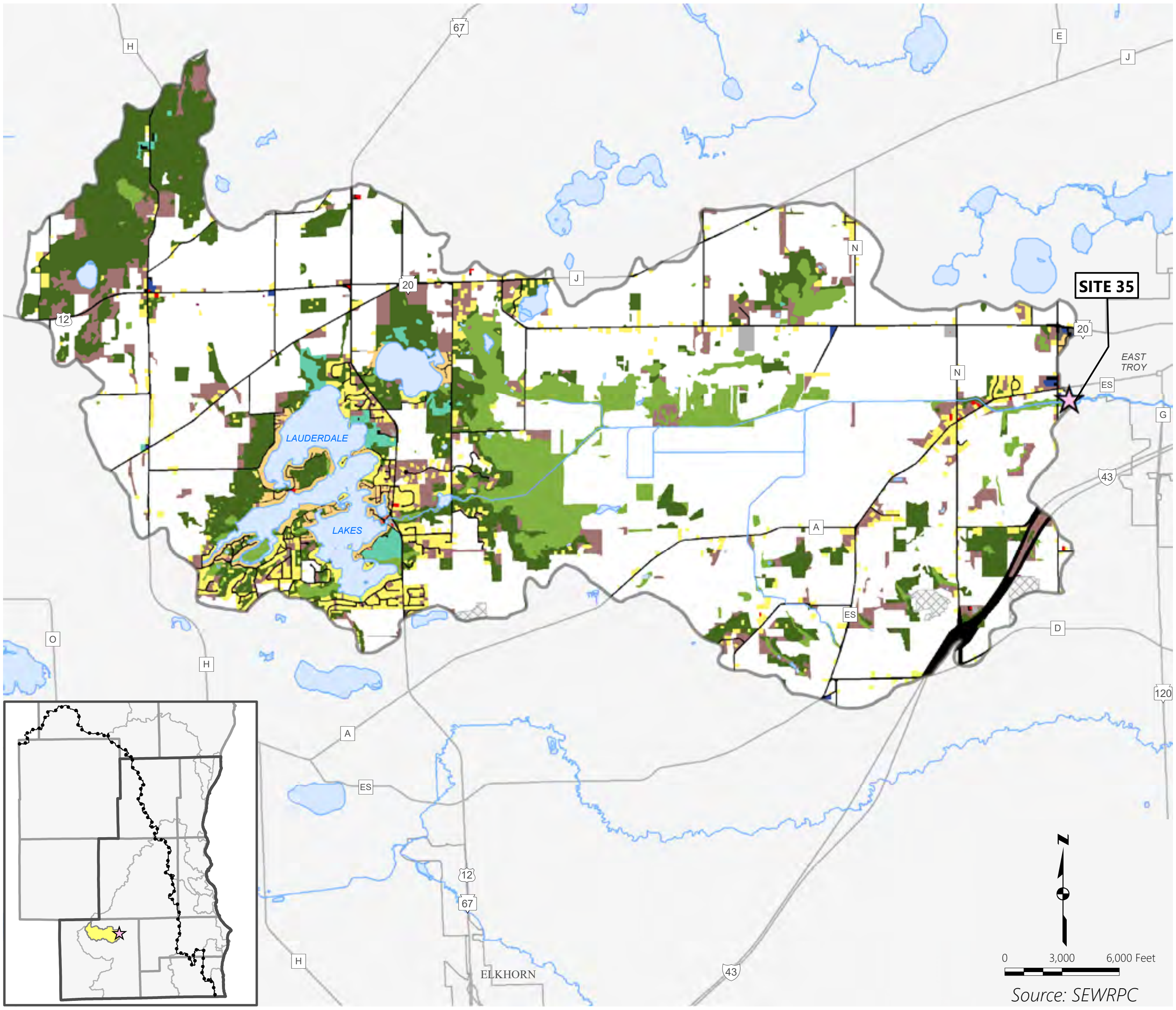
Map B.46
Site 33: Pebble Brook Drainage Area – Features

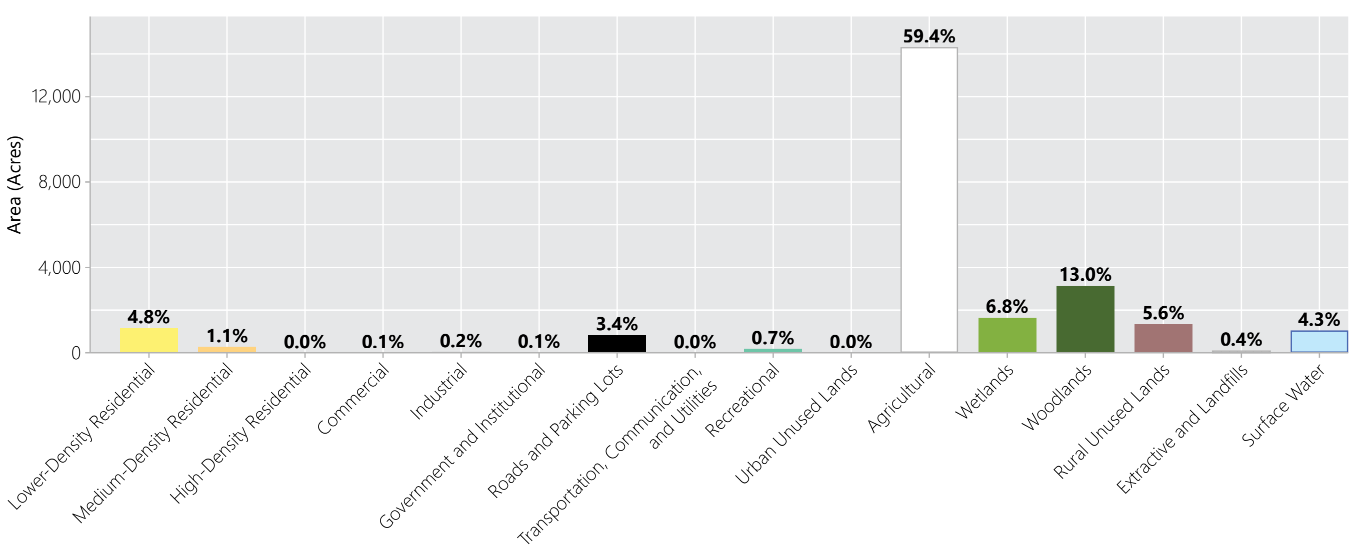


Facts at a Glance

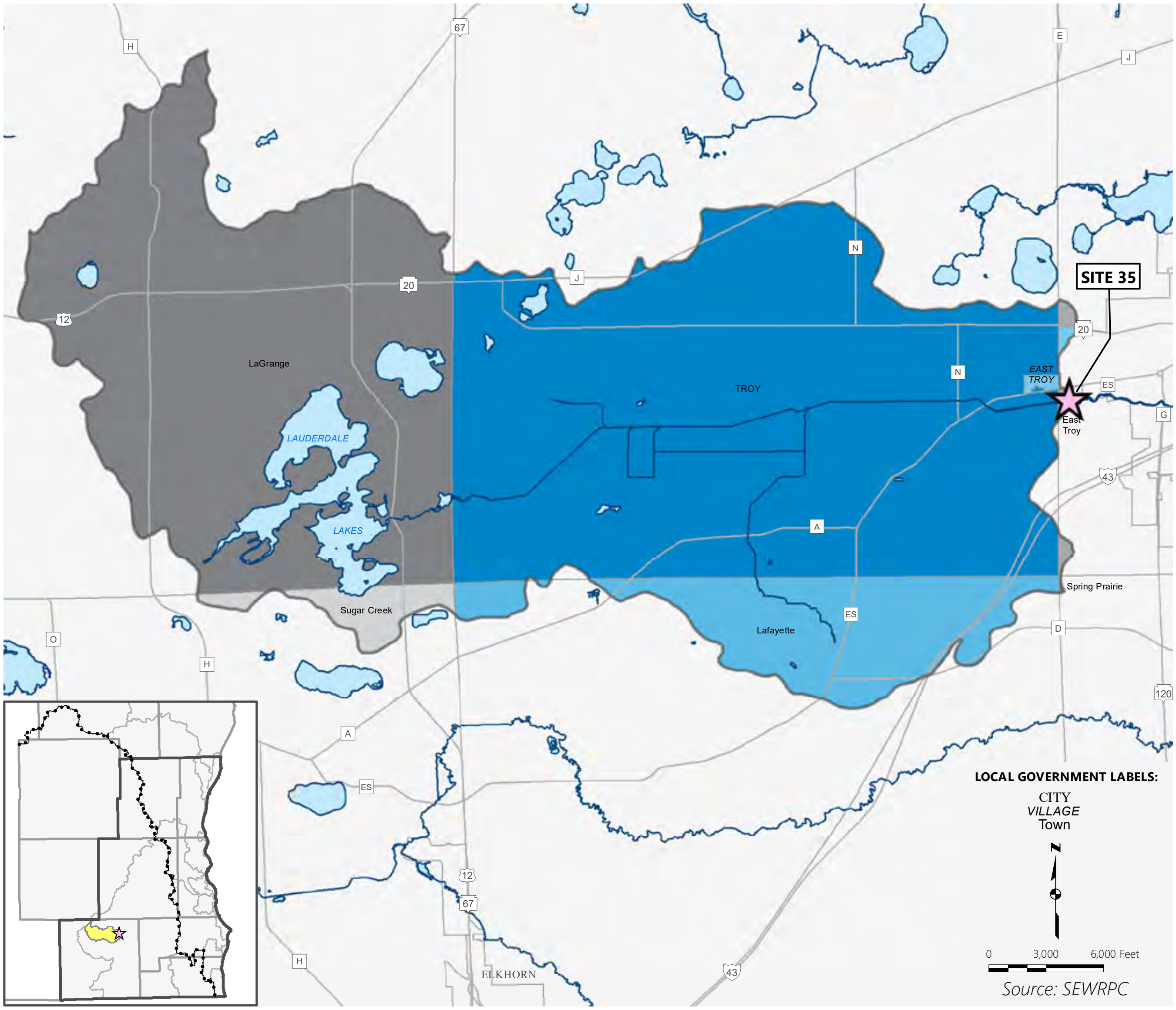
- **Drainage Area Size:** 16 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 41.9%; Rural – 58.1%
- **Roads and Parking Lots (% of drainage area):** 9.5
- **Estimated Population (2010):** 13,420
- **Estimated Households (2010):** 5,170 (67% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater and Lake Michigan (City of Waukesha converted to Lake Michigan supply in October 2023)

Map B.47
Site 35: Honey Creek Upstream of East Troy Drainage Area – Existing Land Use





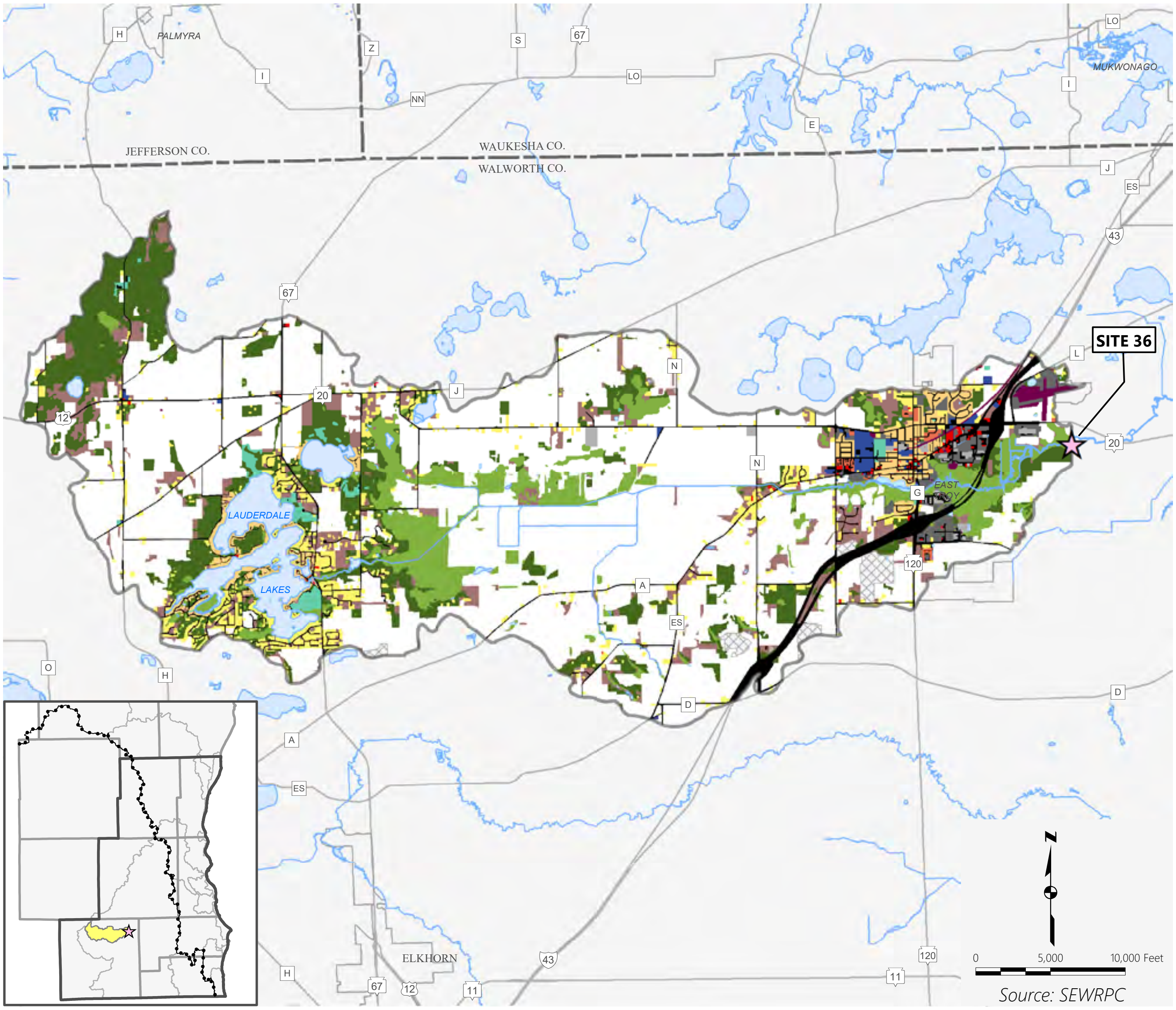
Map B.48
Site 35: Honey Creek Upstream of East Troy Drainage Area – Features

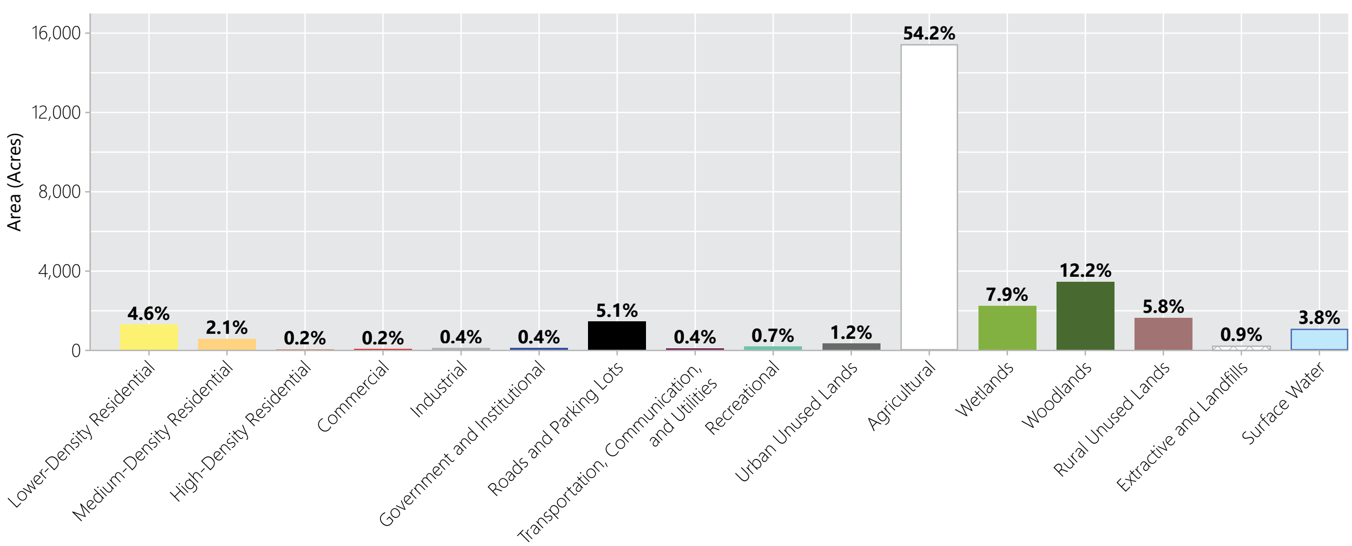


Facts at a Glance

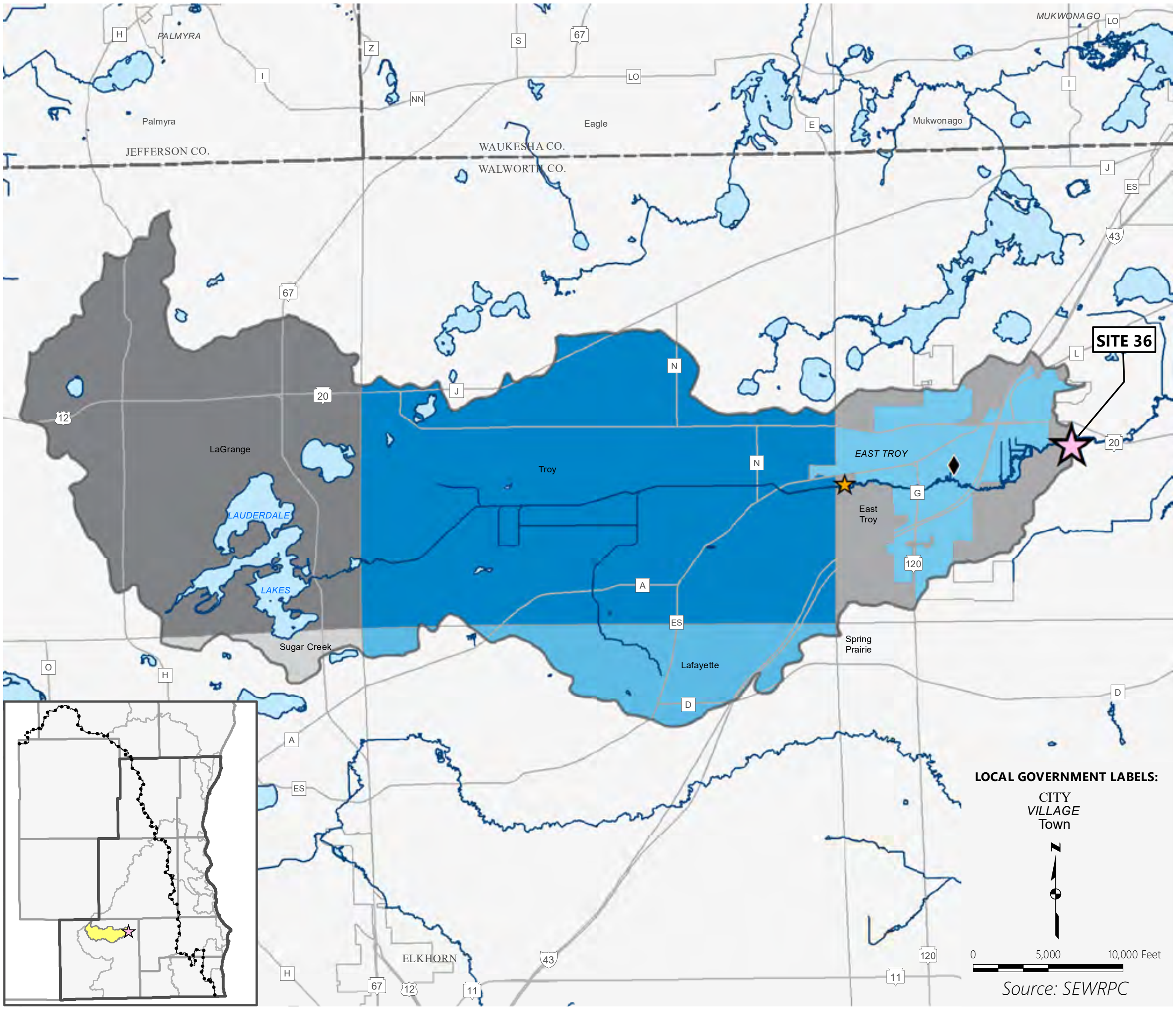
- **Drainage Area Size:** 38 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 10.4%; Rural – 89.6%
- **Roads and Parking Lots (% of drainage area):** 3.4
- **Estimated Population (2010):** 2,910
- **Estimated Households (2010):** 1,140 (0% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.49
Site 36: Honey Creek Downstream of East Troy Drainage Area – Existing Land Use





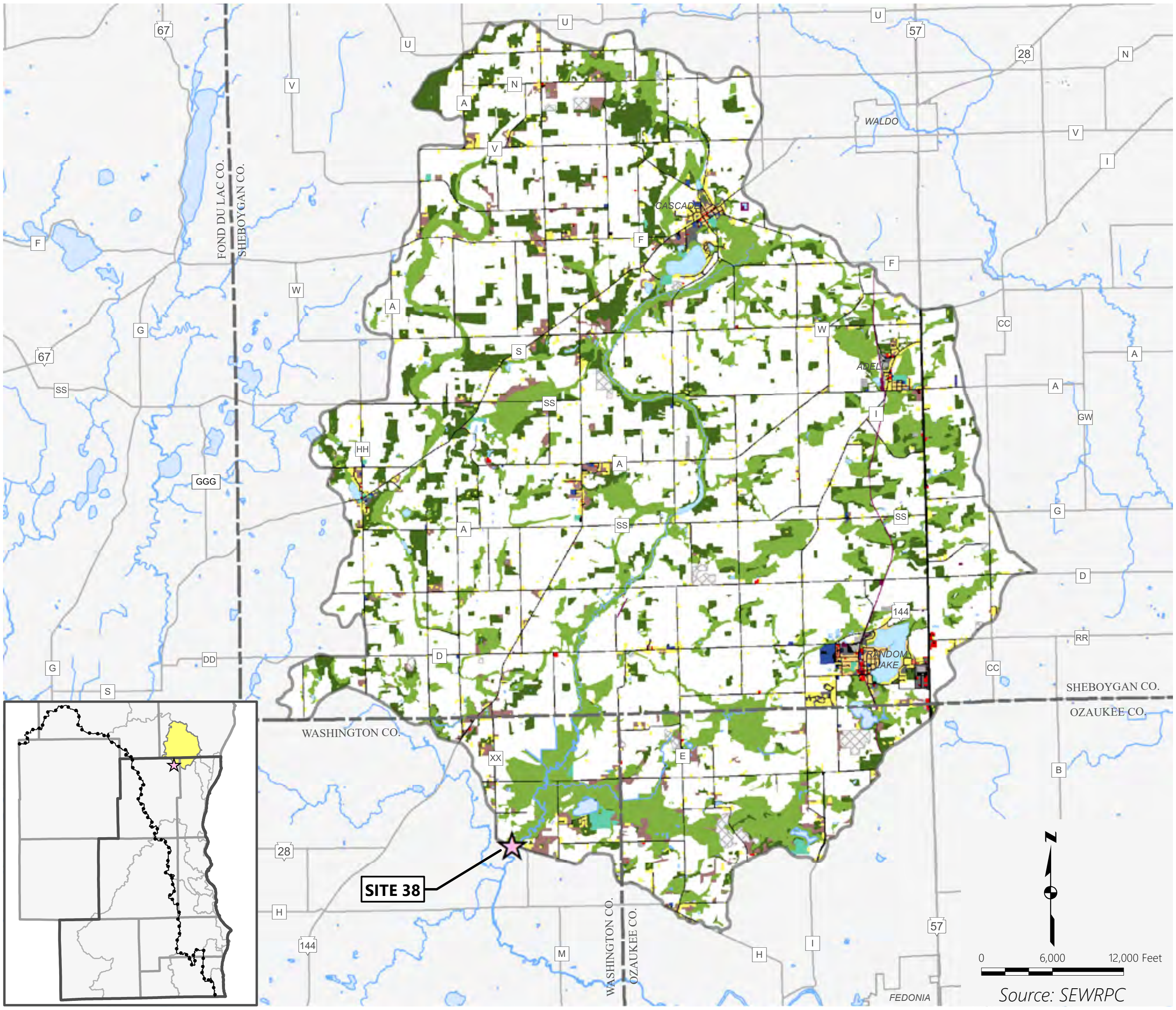
Map B.50
Site 36: Honey Creek Downstream of East Troy Drainage Area – Features

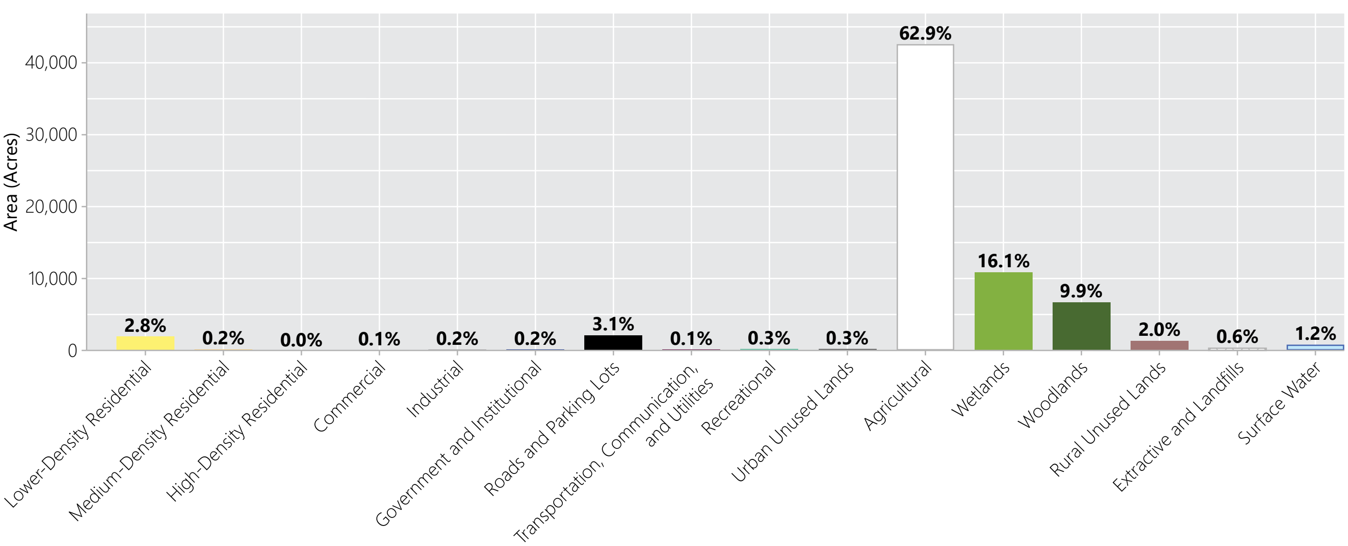


Facts at a Glance

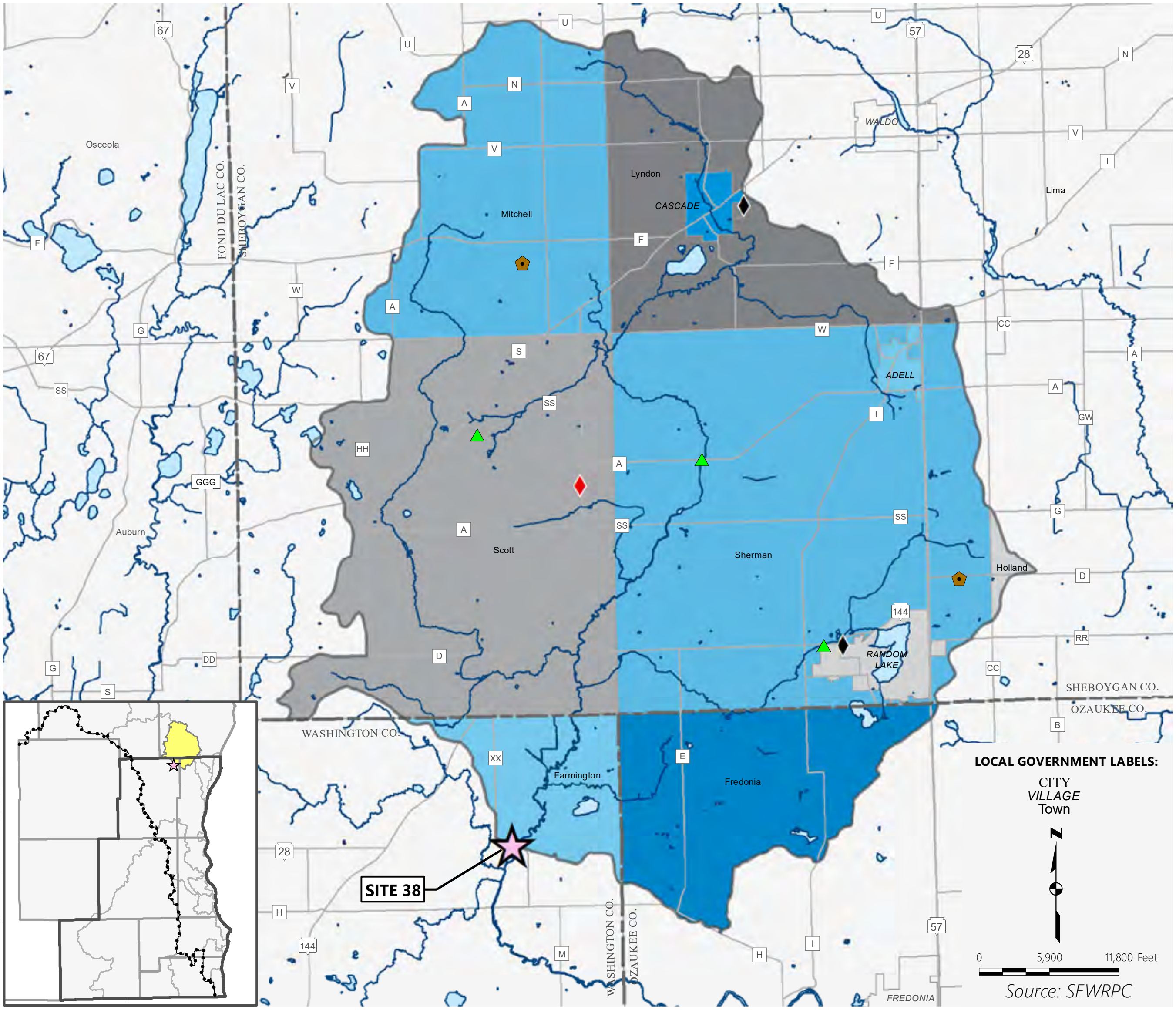
- **Drainage Area Size:** 45 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 15.3%; Rural – 84.7%
- **Roads and Parking Lots (% of drainage area):** 5.1
- **Estimated Population (2010):** 7,490
- **Estimated Households (2010):** 2,980 (60% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 35
- **Upstream Wastewater Treatment Facilities (♦):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.51
Site 38: North Branch Milwaukee River Drainage Area – Existing Land Use





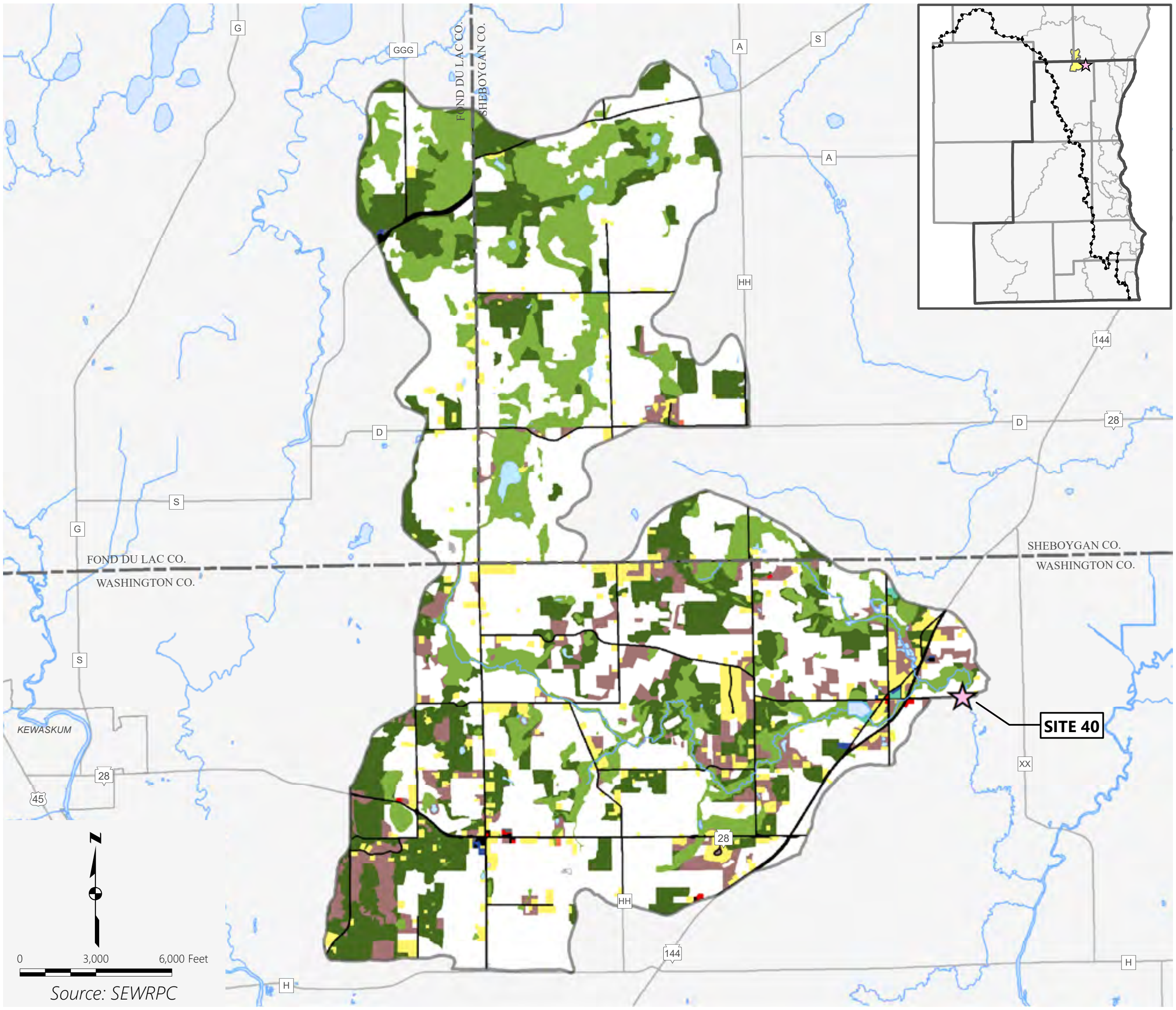
Map B.52
Site 38: North Branch Milwaukee River Drainage Area – Features



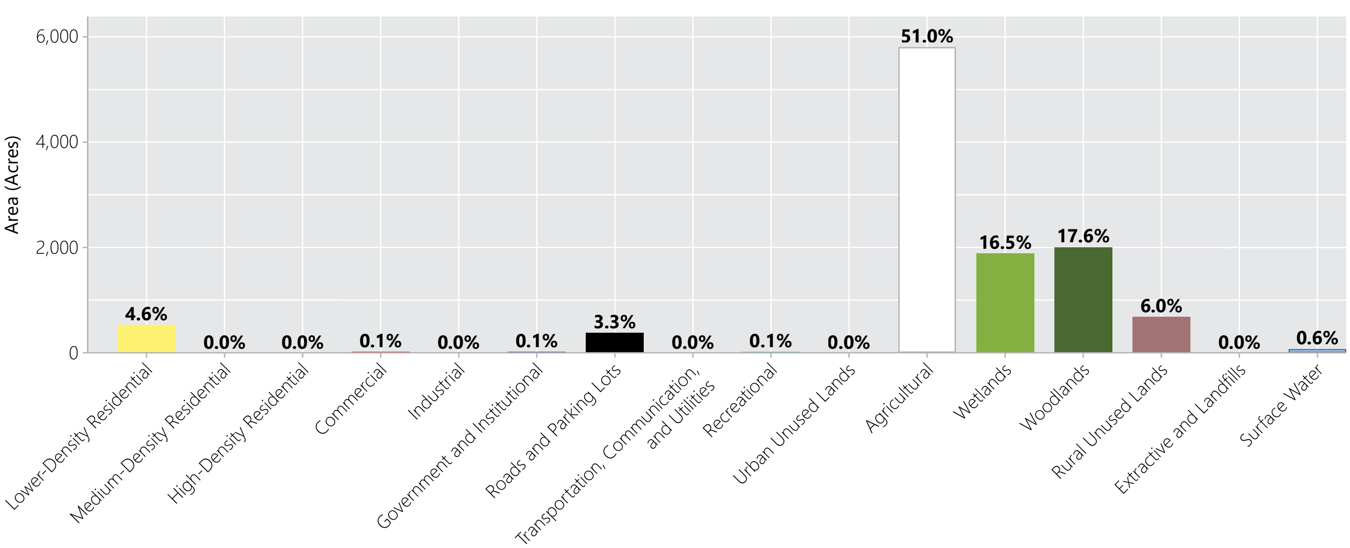
Facts at a Glance

- **Drainage Area Size:** 106 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 7.4%; Rural – 92.6%
- **Roads and Parking Lots (% of drainage area):** 3.1
- **Estimated Population (2010):** 7,910
- **Estimated Households (2010):** 3,080 (37% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Upstream Wastewater Treatment Facilities (♦):** 2
  WWTF discharge to soil (♦): 1
- **Upstream Industrial Wastewater Dischargers (▲):** 3
- **Concentrated Animal Feeding Operations (⬟):** 2
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

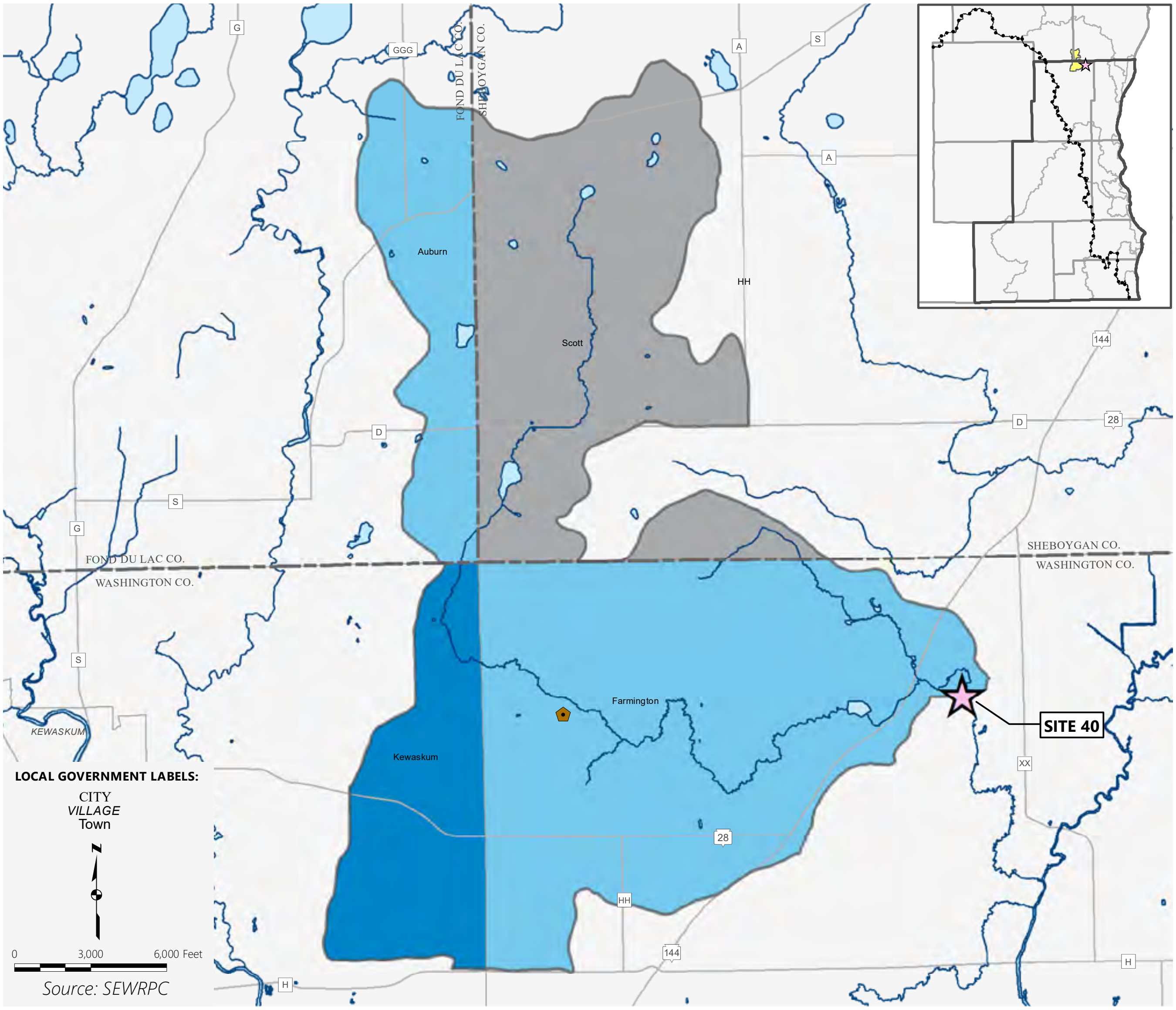
Map B.53
Site 40: Stony Creek Drainage Area – Existing Land Use



Source: SEWRPC



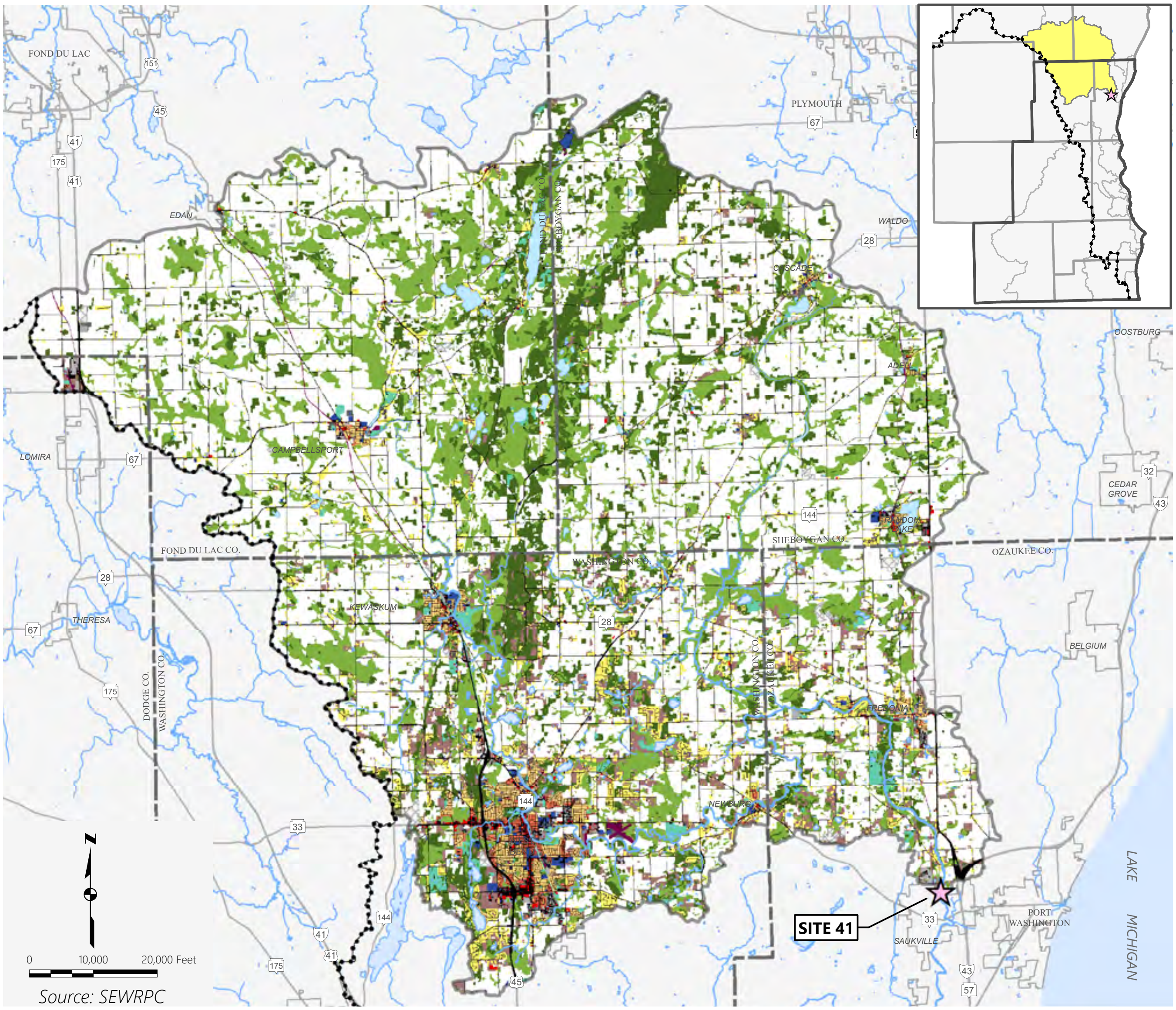
Map B.54
Site 40: Stony Creek Drainage Area – Features

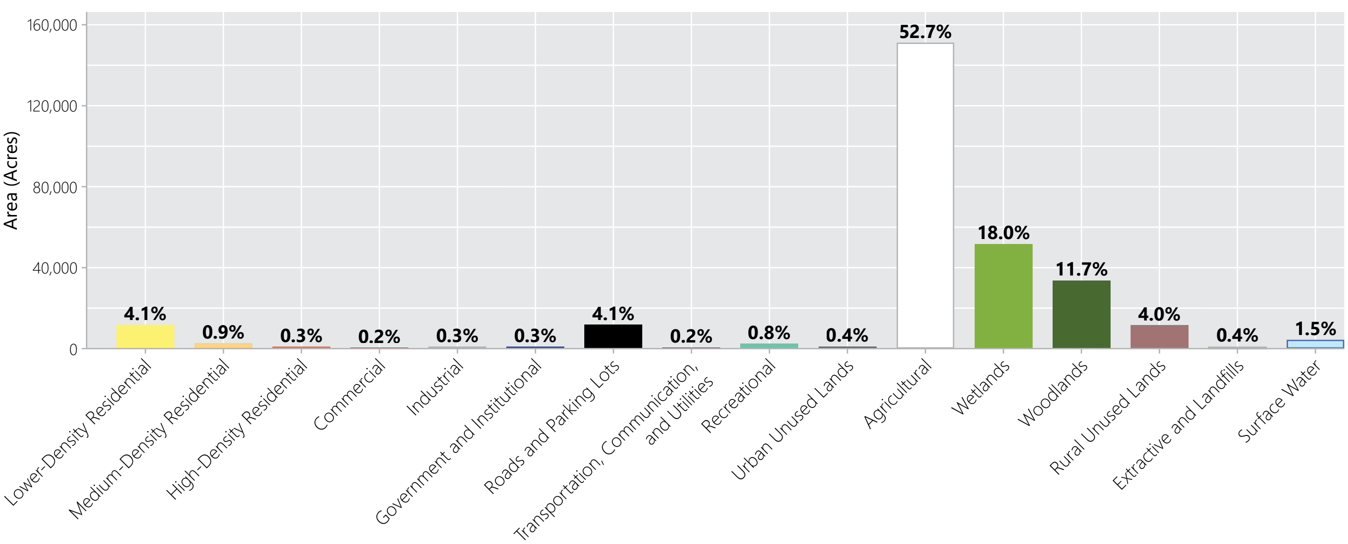


Facts at a Glance

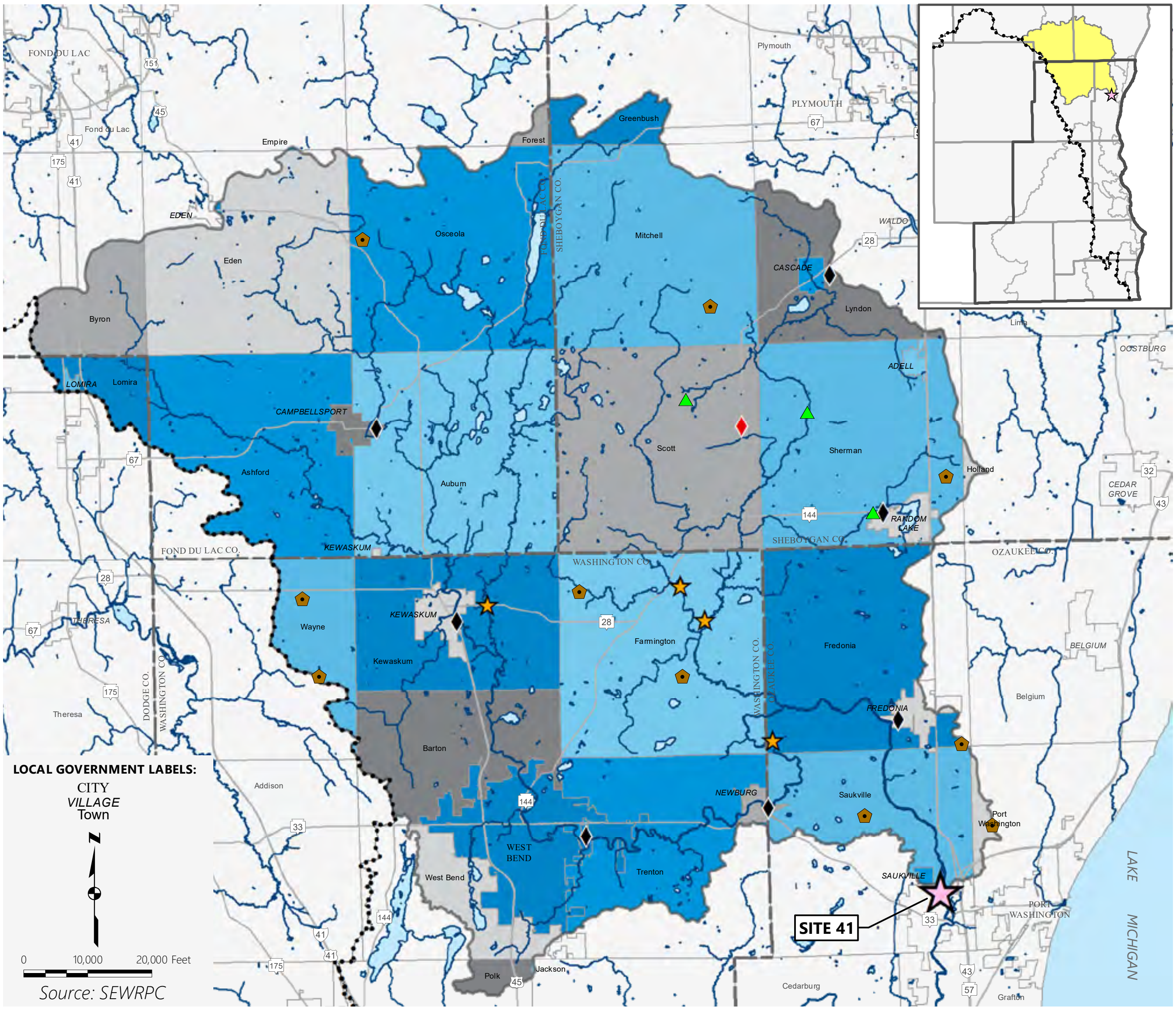
- **Drainage Area Size:** 18 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 8.3%; Rural – 91.7%
- **Roads and Parking Lots (% of drainage area):** 3.3
- **Estimated Population (2010):** 1,280
- **Estimated Households (2010):** 480 (0% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Concentrated Animal Feeding Operations (⬟):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.55
Site 41: Milwaukee River near Saukville Drainage Area – Existing Land Use





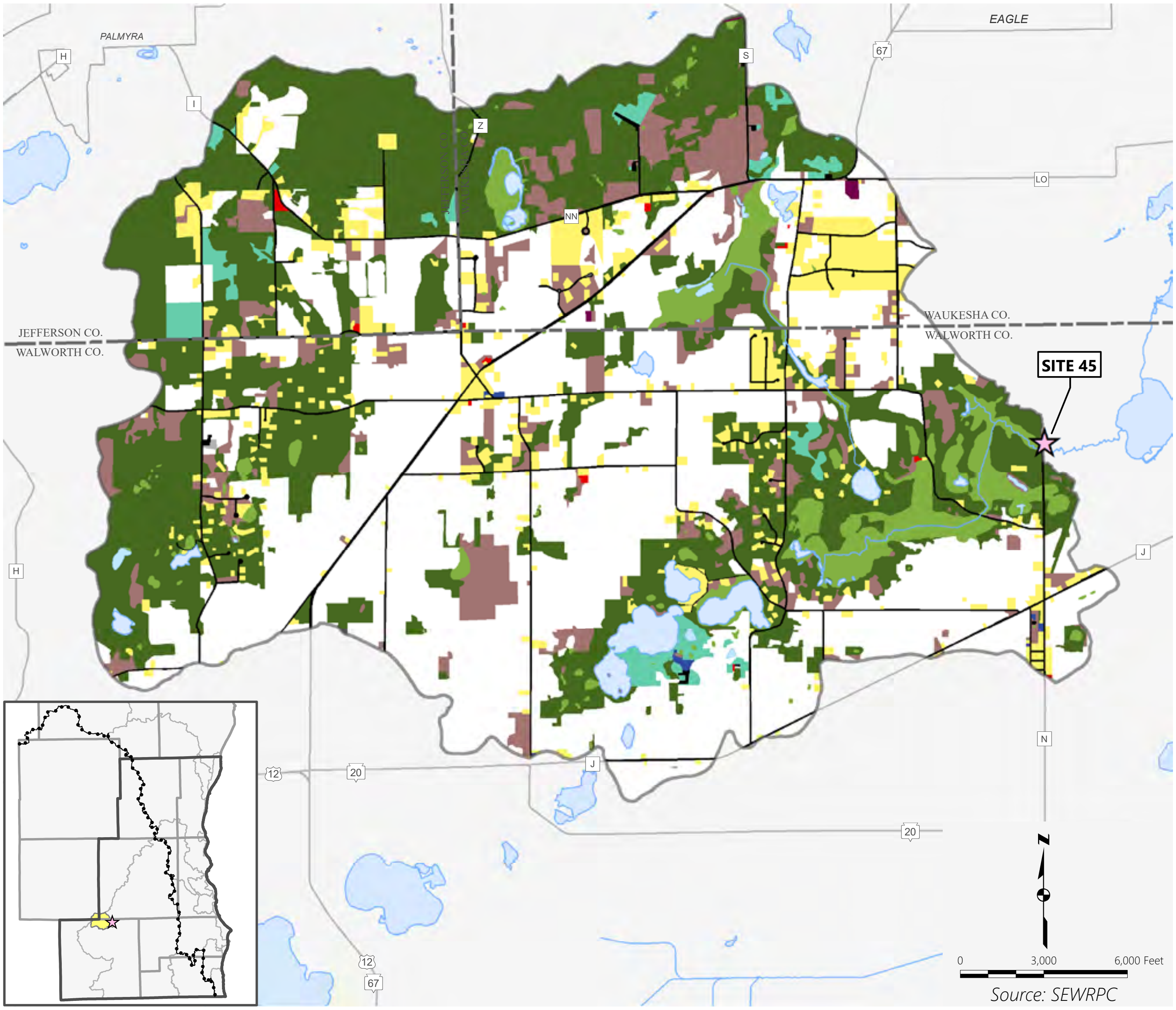
Map B.56
Site 41: Milwaukee River near Saukville Drainage Area – Features

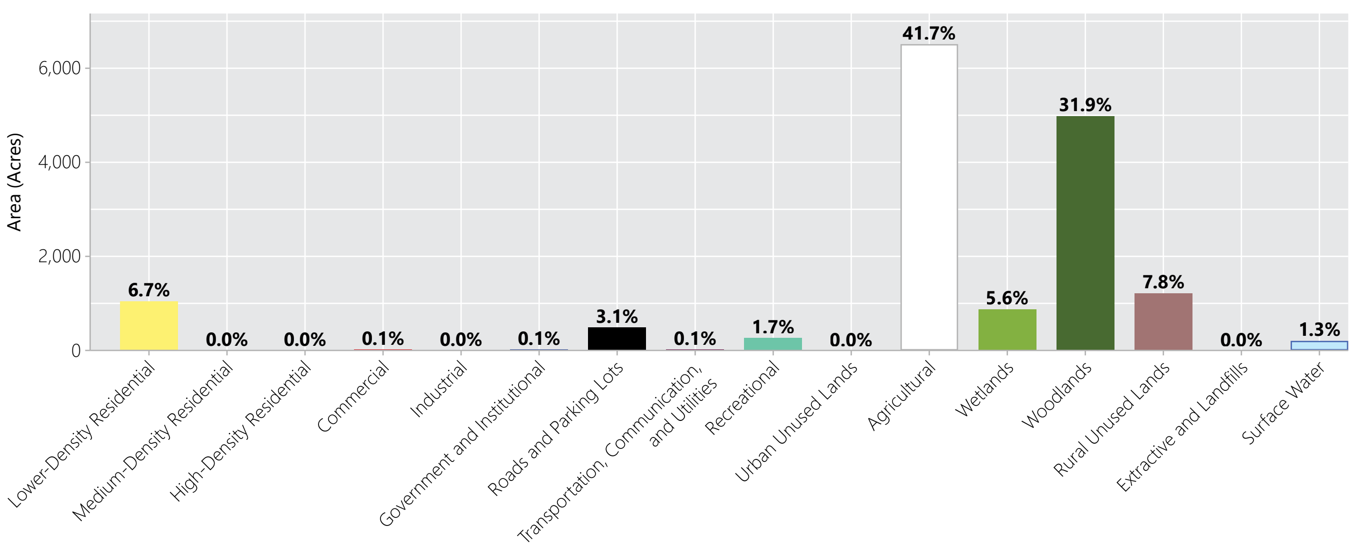


Facts at a Glance

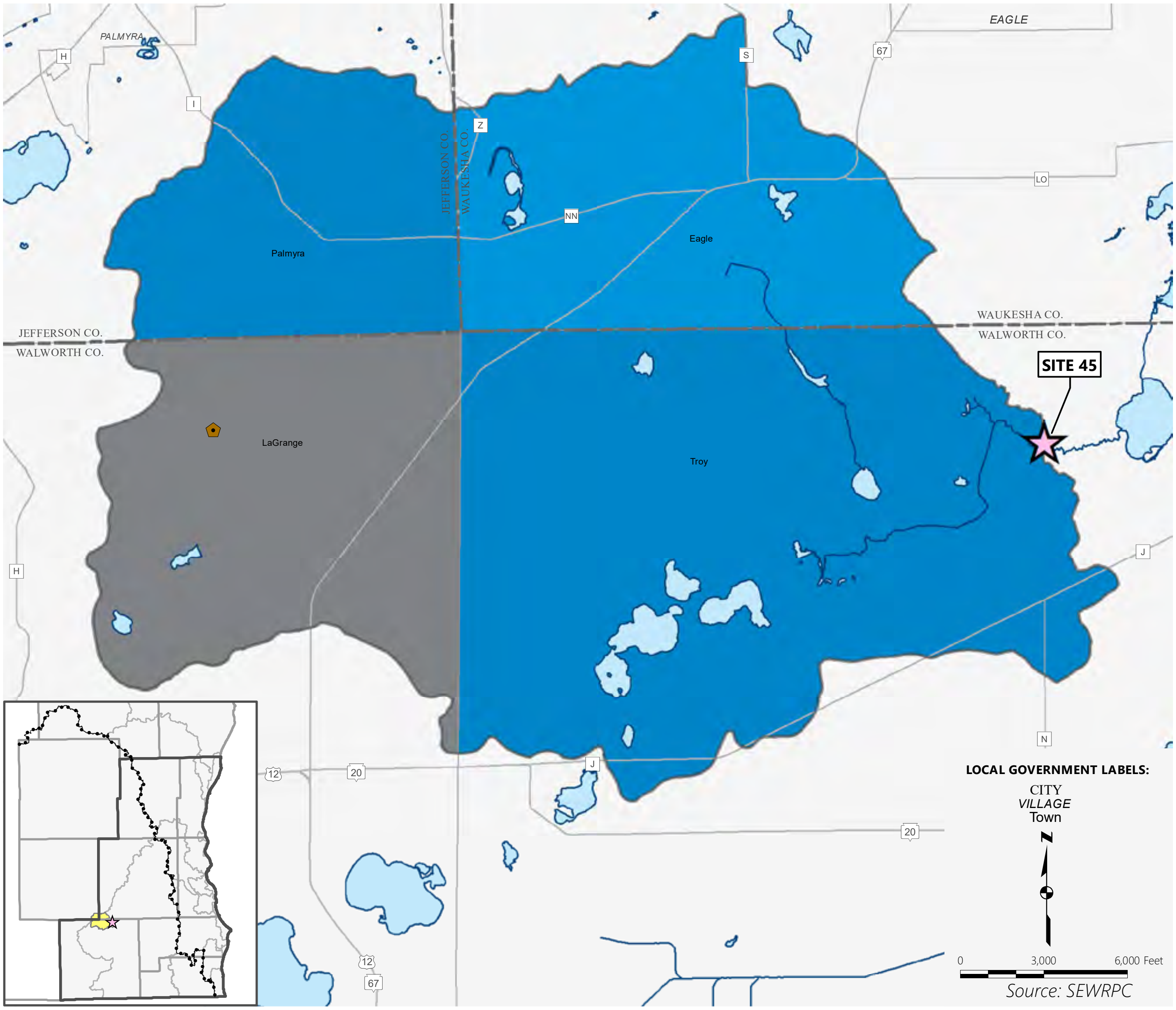
- **Drainage Area Size:** 448 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 11.7%; Rural – 88.3%
- **Roads and Parking Lots (% of drainage area):** 4.1
- **Estimated Population (2010):** 74,210
- **Estimated Households (2010):** 28,800 (63% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 40, Site 38, Site 23, and Site 21
- **Upstream Wastewater Treatment Facilities (♦):** 7
  WWTF discharge to soil (♦): 1
- **Upstream Industrial Wastewater Dischargers (▲):** 3
- **Concentrated Animal Feeding Operations (⬟):** 10
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.57
Site 45: Mukwonago River at Nature Road Drainage Area – Existing Land Use





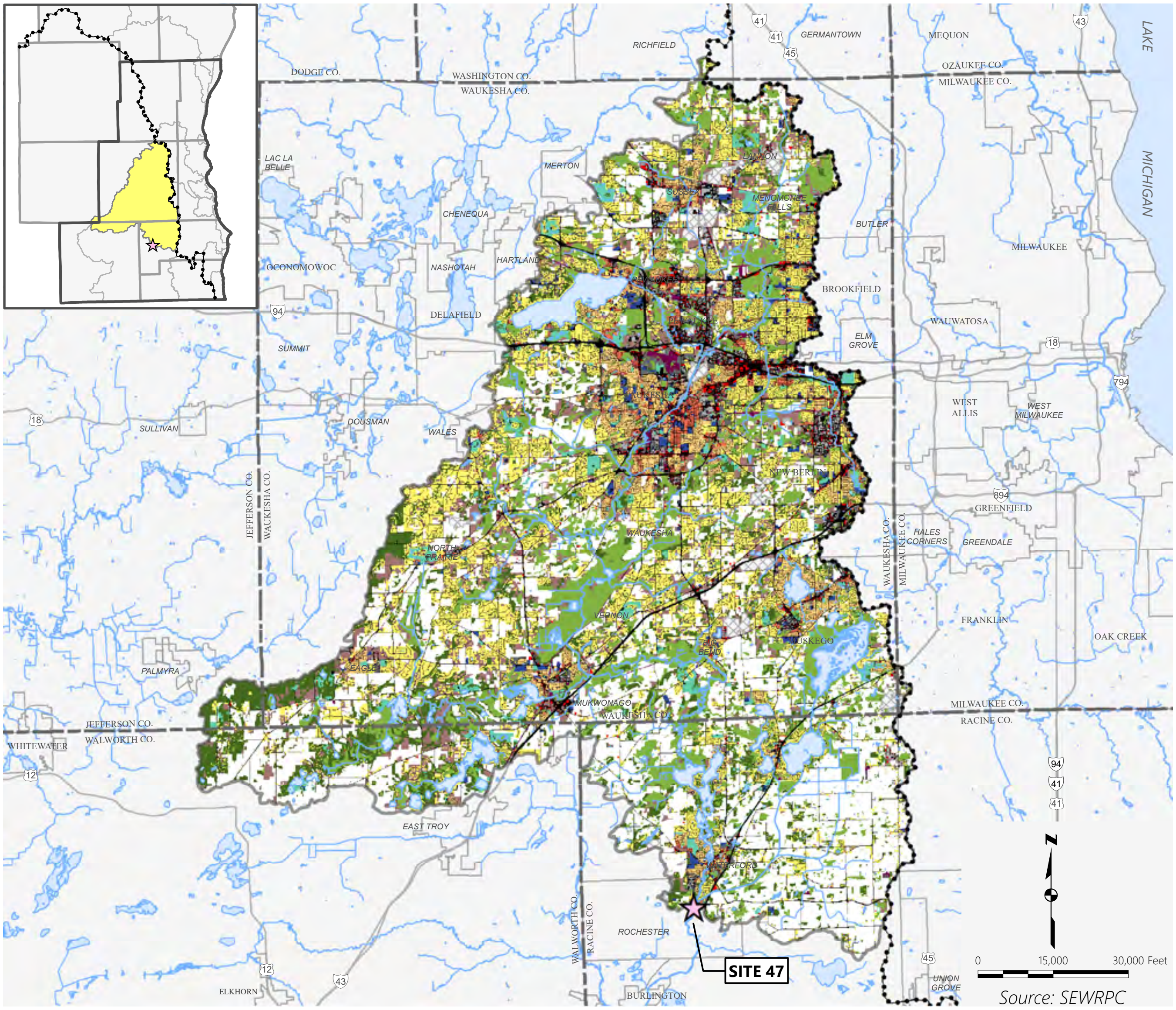
Map B.58
Site 45: Mukwonago River at Nature Road Drainage Area – Features

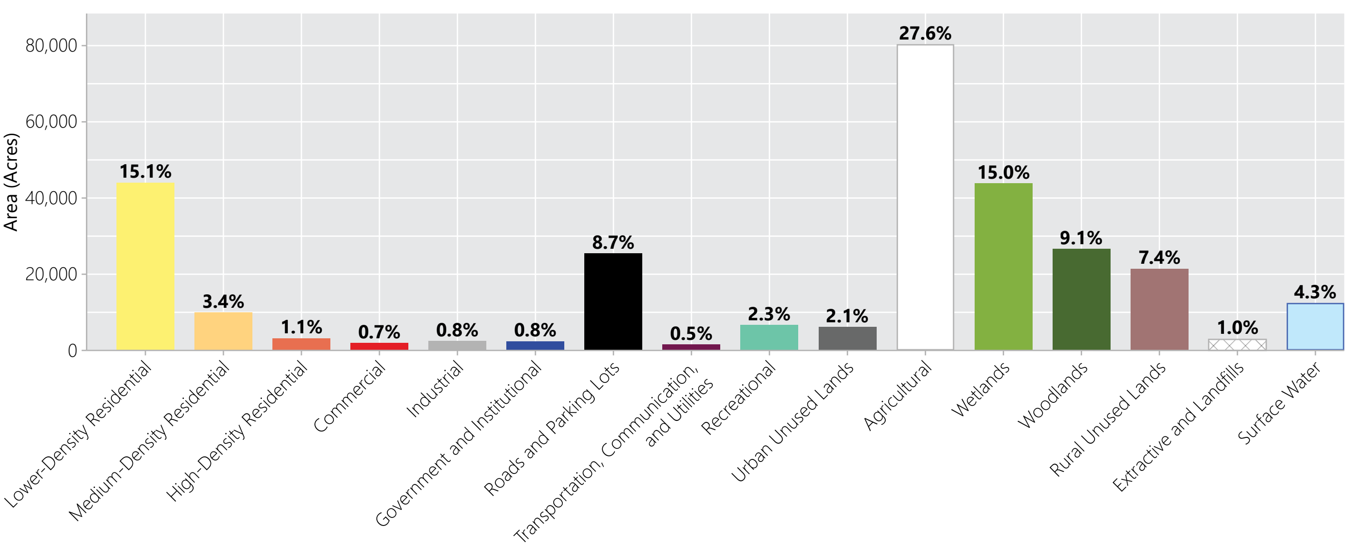


Facts at a Glance

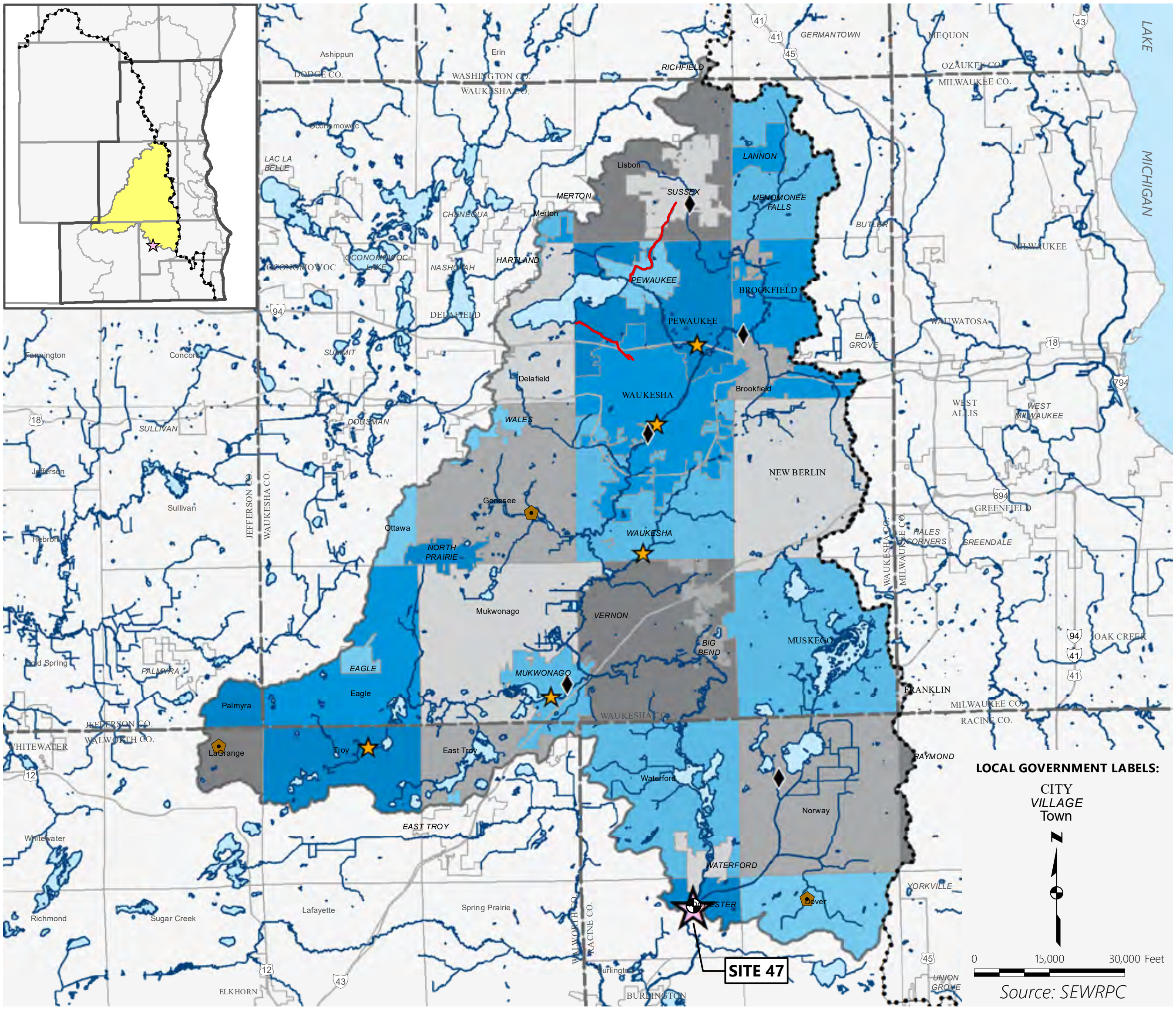
- **Drainage Area Size:** 24 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 11.8%; Rural – 88.2%
- **Roads and Parking Lots (% of drainage area):** 3.1
- **Estimated Population (2010):** 2,290
- **Estimated Households (2010):** 900 (28% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Concentrated Animal Feeding Operations (⬟):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.59
Site 47: Fox River at Rochester Drainage Area – Existing Land Use





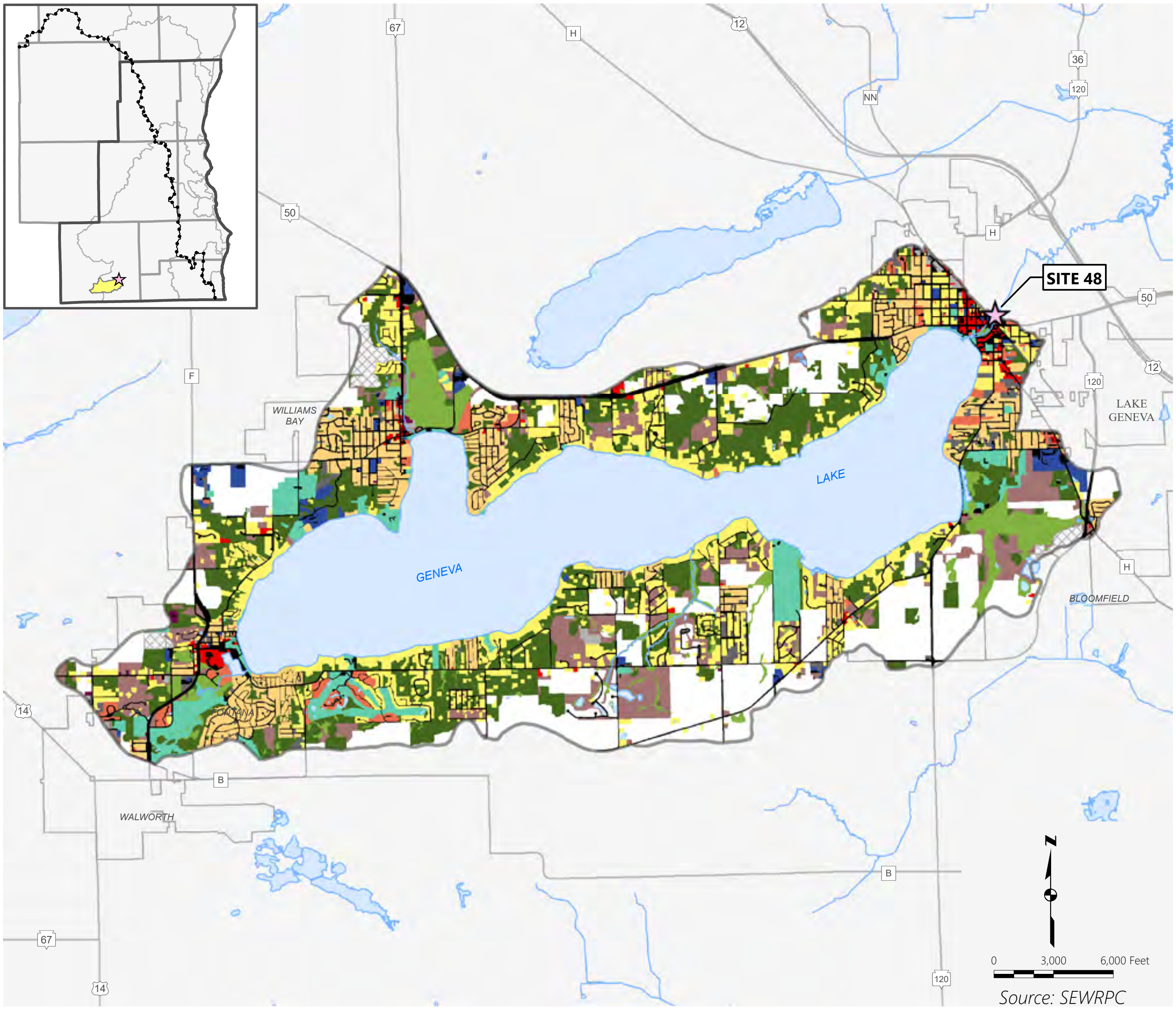
Map B.60
Site 47: Fox River at Rochester Drainage Area – Features

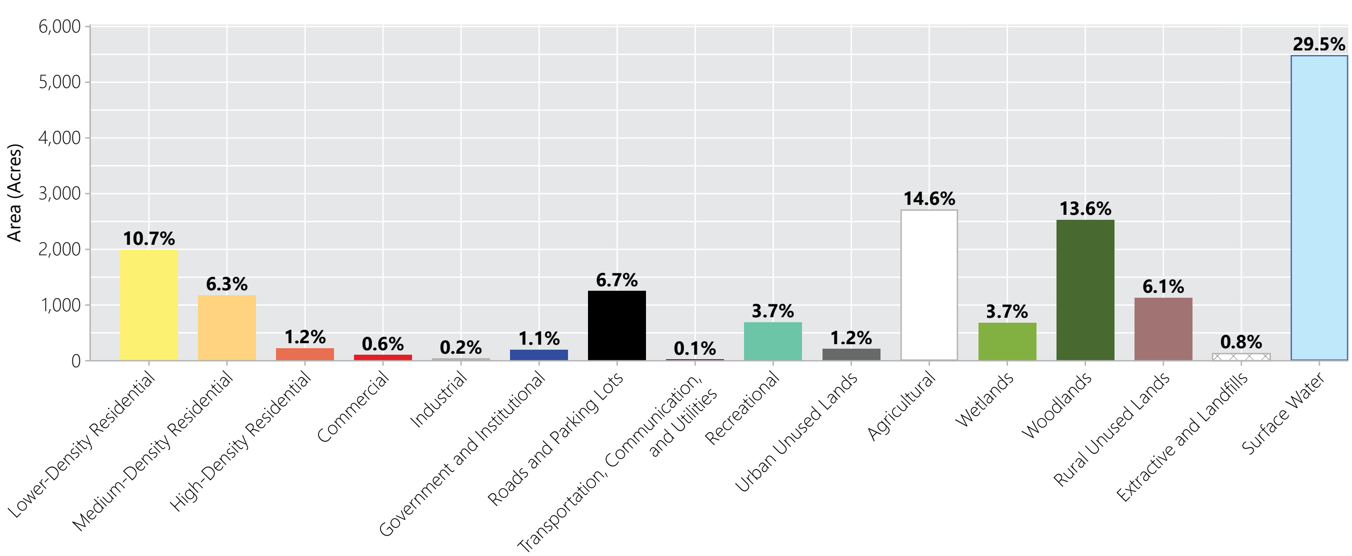


Facts at a Glance

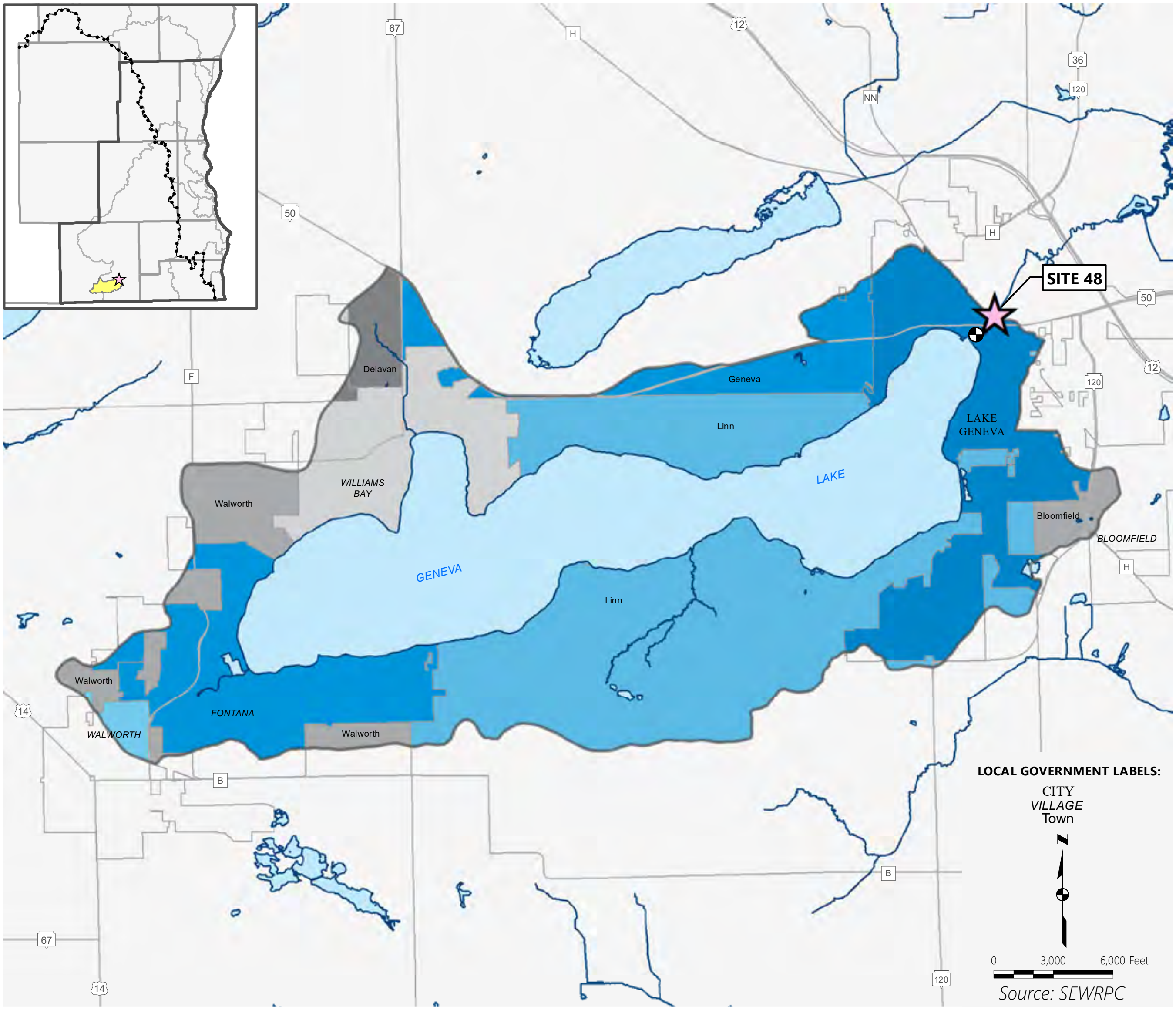
- **Drainage Area Size:** 456 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 35.6%; Rural – 64.4%
- **Roads and Parking Lots (% of drainage area):** 8.7
- **Estimated Population (2010):** 263,270
- **Estimated Households (2010):** 103,030 (78% served by public sanitary sewer)
- **Nearest USGS Streamgage (◈):** Fox River at Rochester (05544475) – Stage gage only, no discharge
- **Other Monitoring Sites Within this Drainage Area (☆):** Site 8, Site 1, Site 33, Site 45, and Site 3
- **Upstream Wastewater Treatment Facilities (♦):** 5
- **Concentrated Animal Feeding Operations (⬟):** 3
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
- **Water Supply Source:** Groundwater and Lake Michigan (City of Waukesha converted from groundwater to Lake Michigan supply in October 2023)

Map B.61
Site 48: White River at Lake Geneva Drainage Area – Existing Land Use





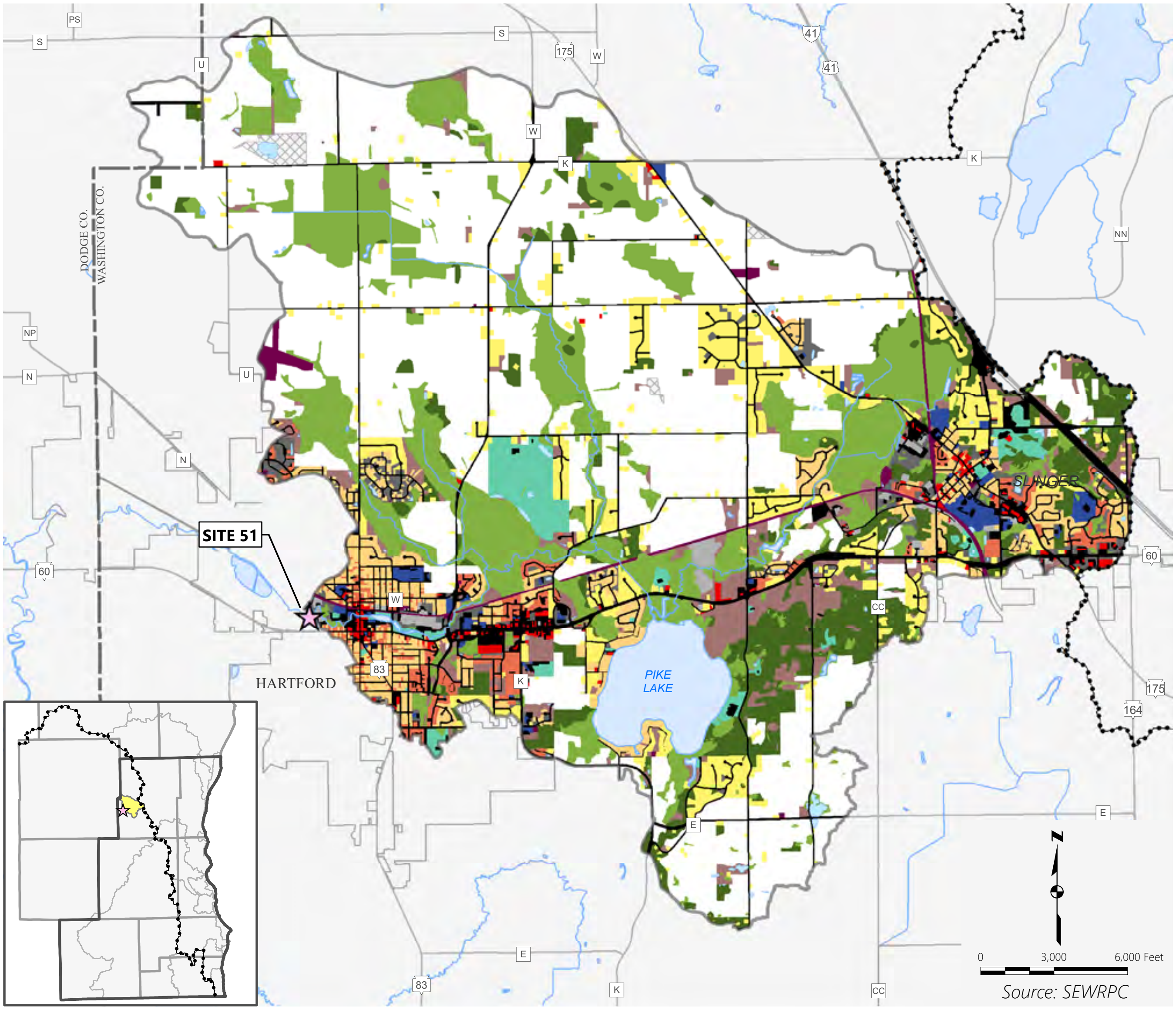
Map B.62
Site 48: White River at Lake Geneva Drainage Area – Features

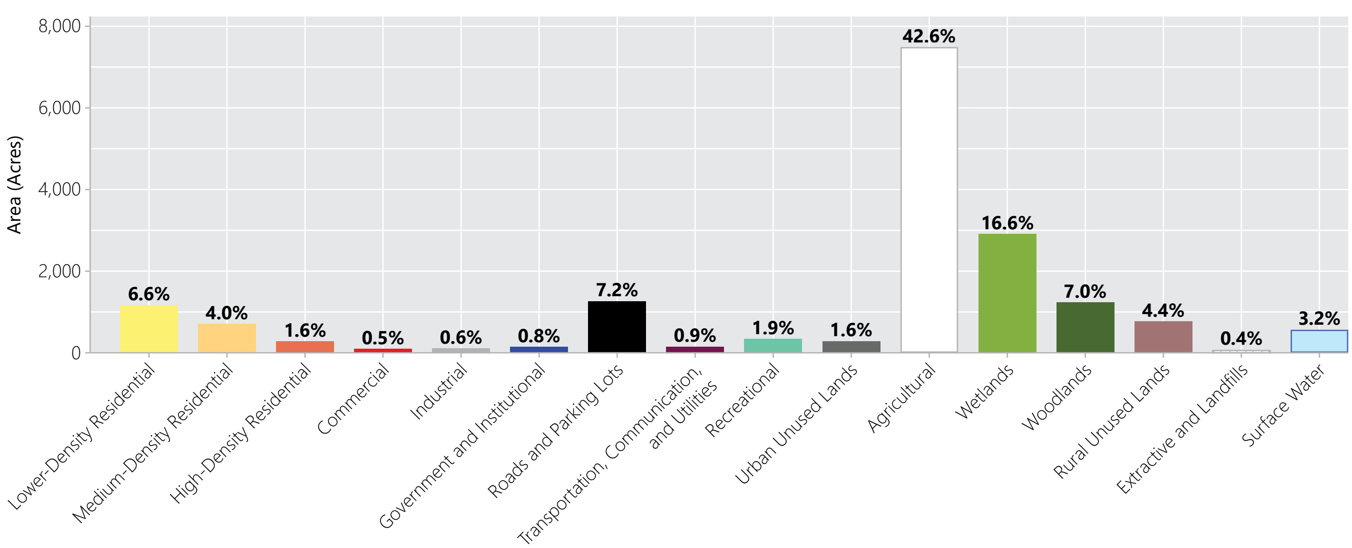


Facts at a Glance

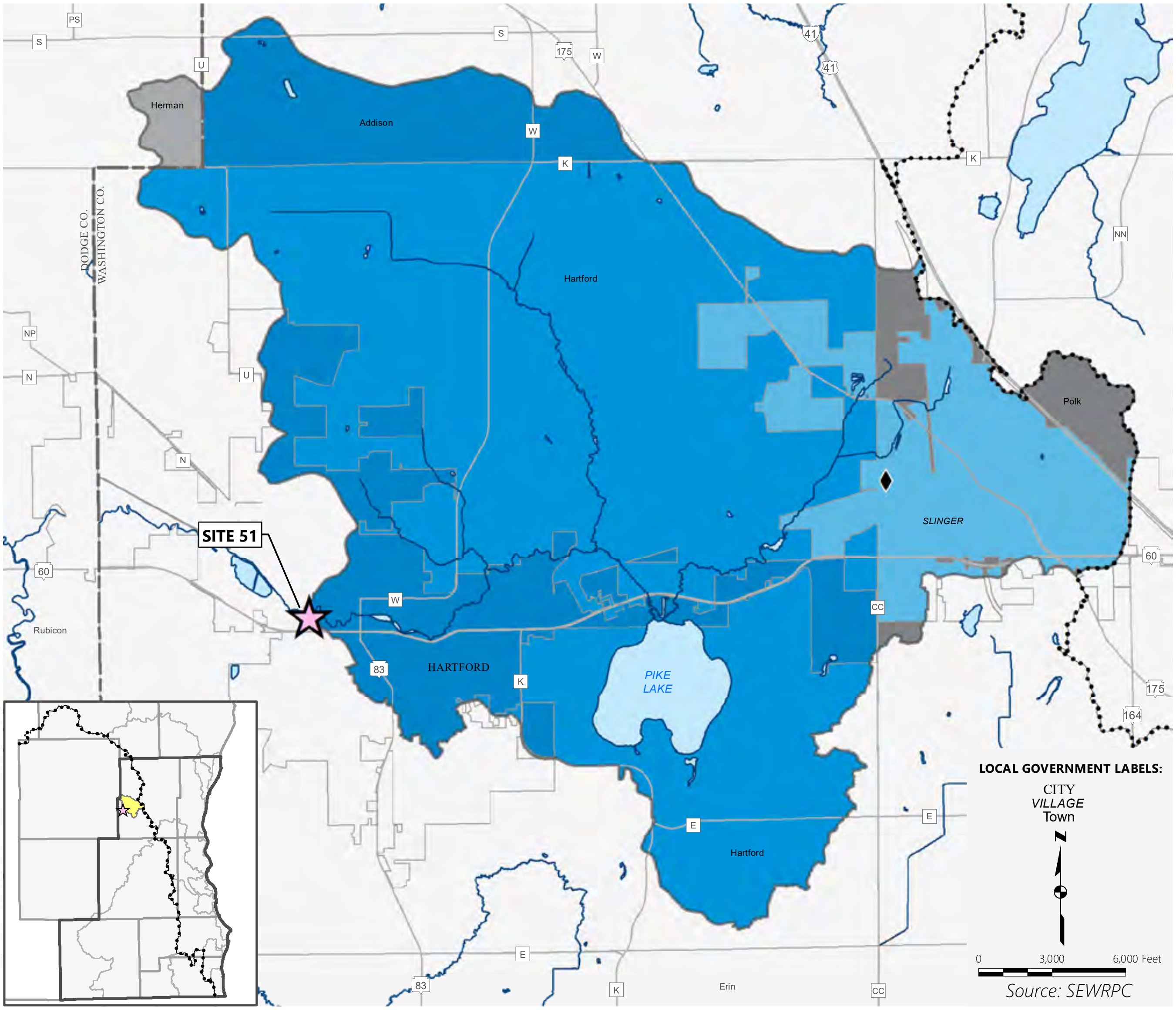
- **Drainage Area Size:** 29 square miles
- **Major Watershed:** Fox River
- **Land Use:** Urban – 31.8%; Rural – 68.2%
- **Roads and Parking Lots (% of drainage area):** 6.7
- **Estimated Population (2010):** 9,910
- **Estimated Households (2010):** 4,280 (79% served by public sanitary sewer)
- **Nearest USGS Streamgage (⊕):** White River at Center Street (055451345)
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.63
Site 51: Rubicon River Drainage Area – Existing Land Use





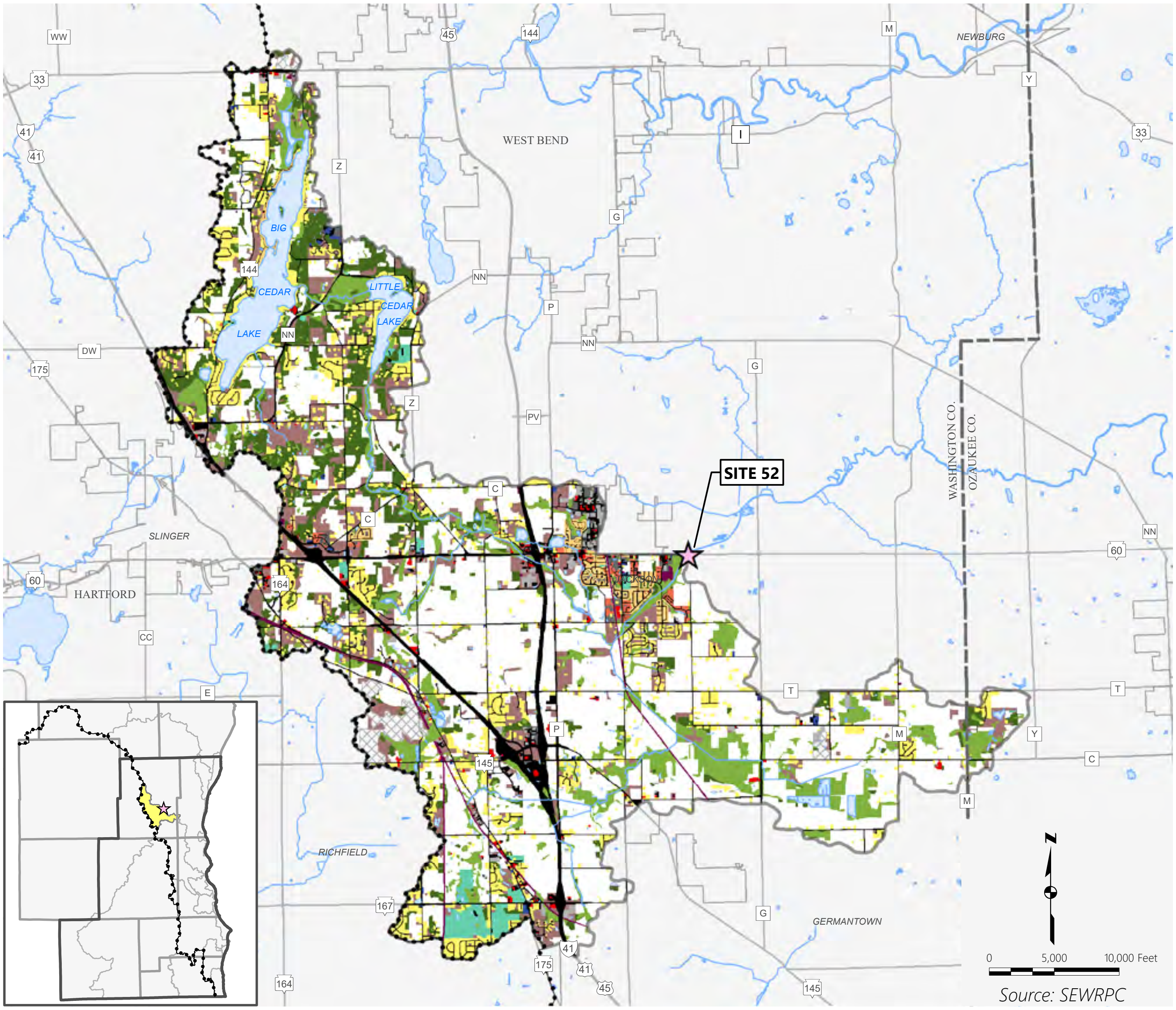
Map B.64
Site 51: Rubicon River Drainage Area – Features

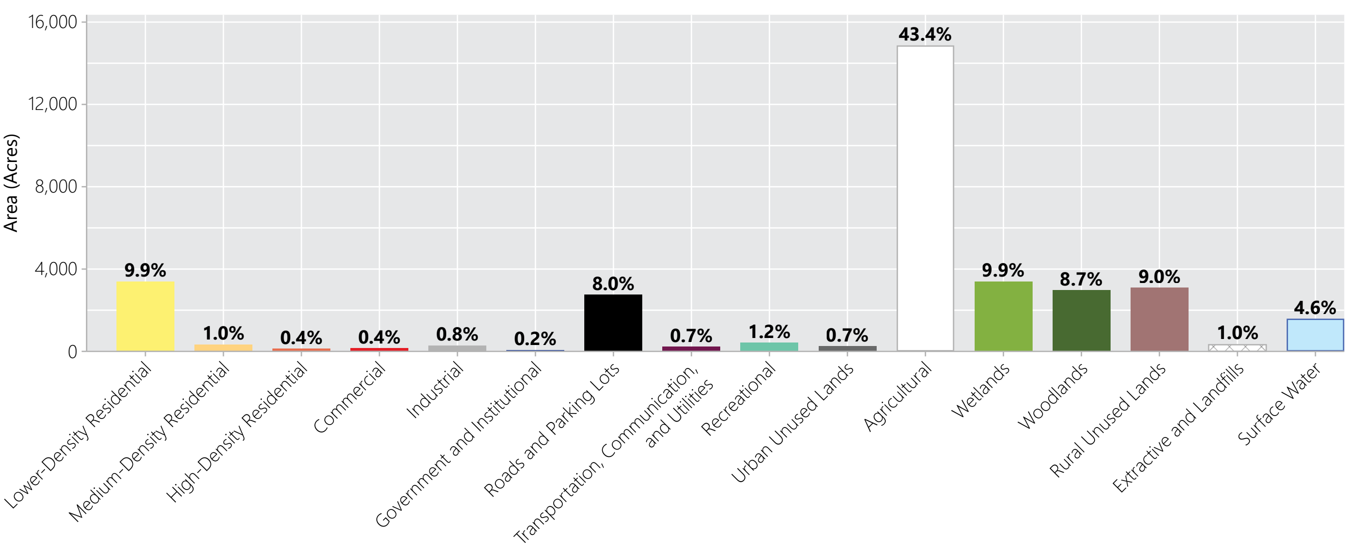


Facts at a Glance

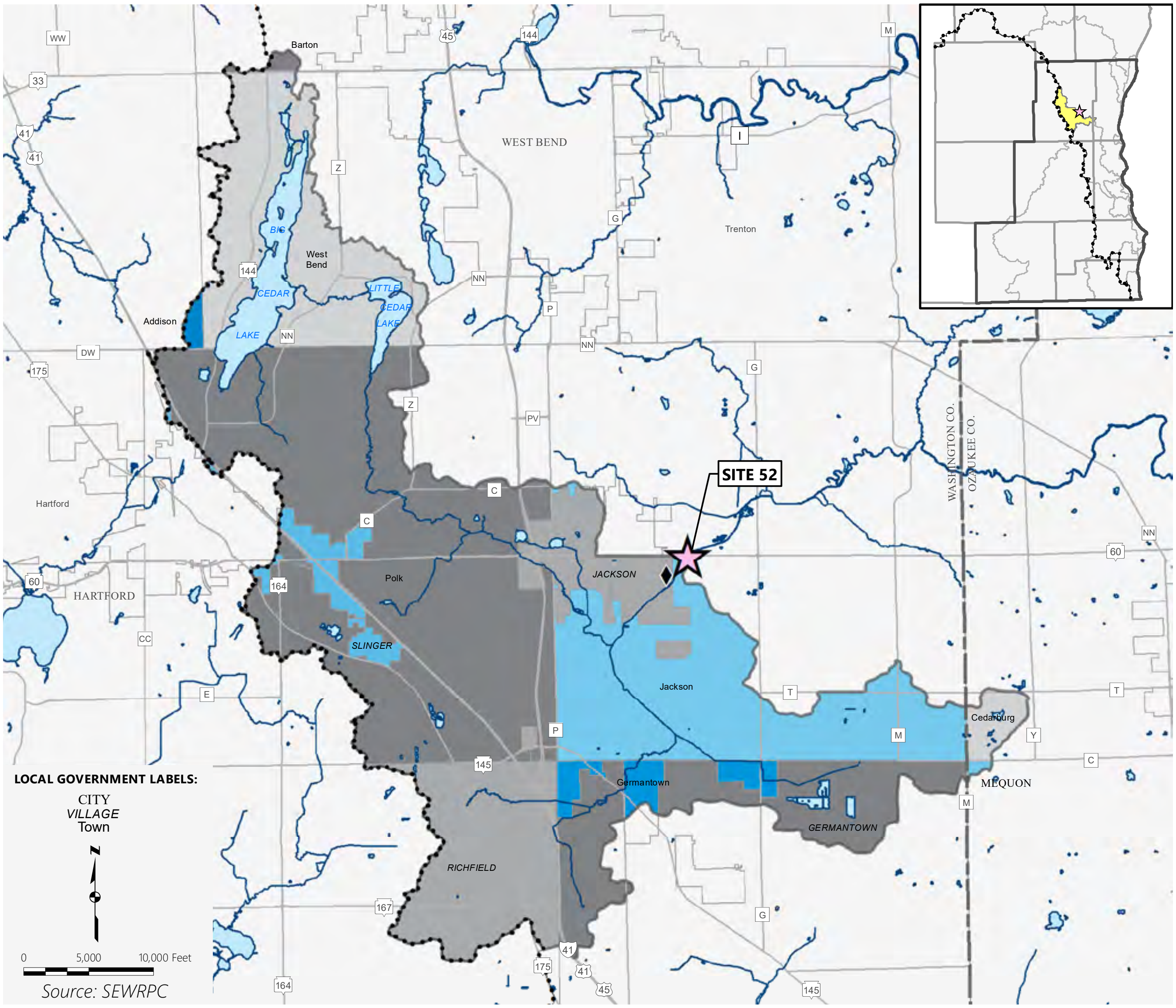
- **Drainage Area Size:** 27 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 25.8%; Rural – 74.2%
- **Roads and Parking Lots (% of drainage area):** 7.2
- **Estimated Population (2010):** 14,160
- **Estimated Households (2010):** 5,830 (89% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Upstream Wastewater Treatment Facilities (♦):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.65
Site 52: Cedar Creek Drainage Area – Existing Land Use





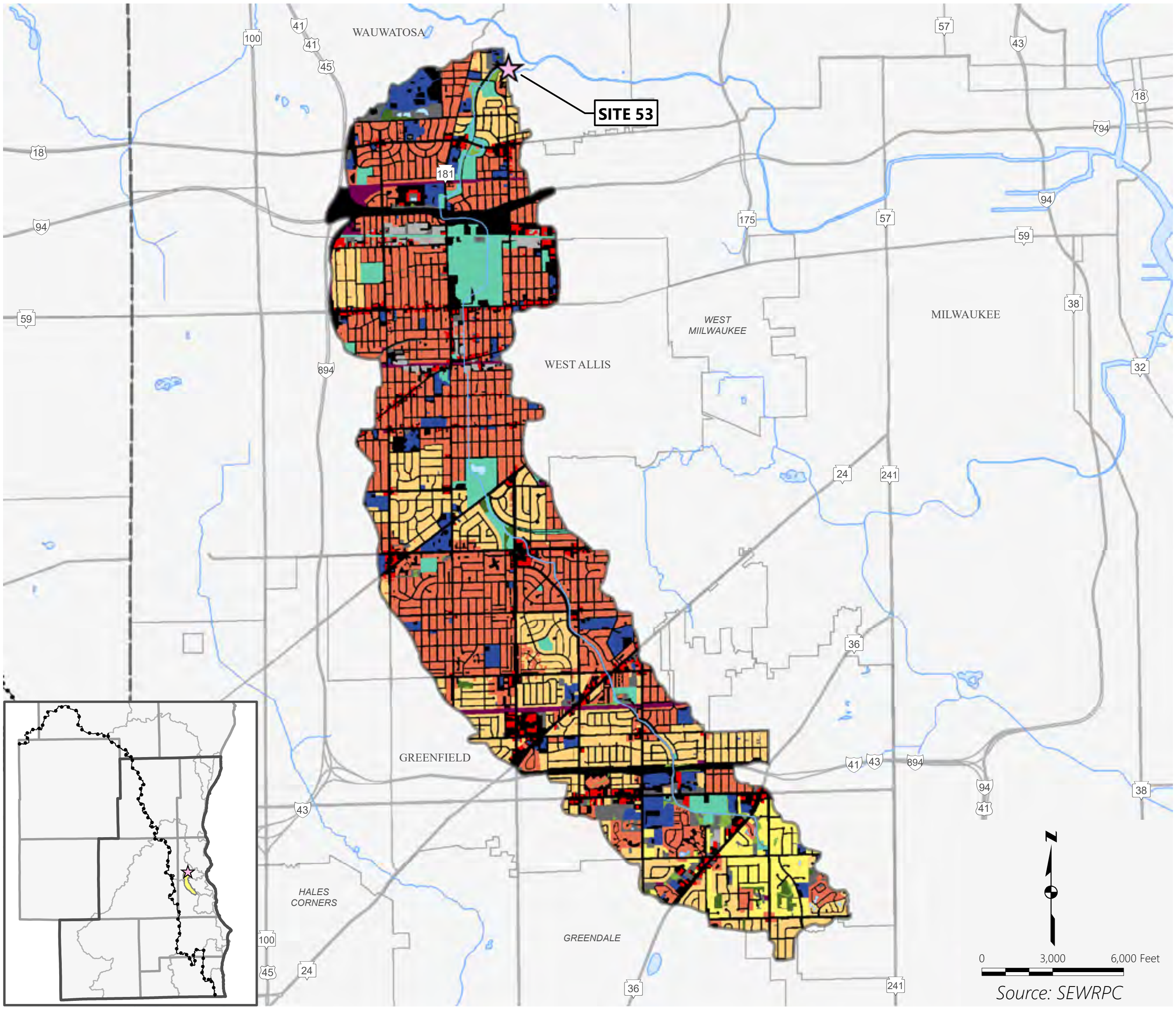
Map B.66
Site 52: Cedar Creek Drainage Area – Features

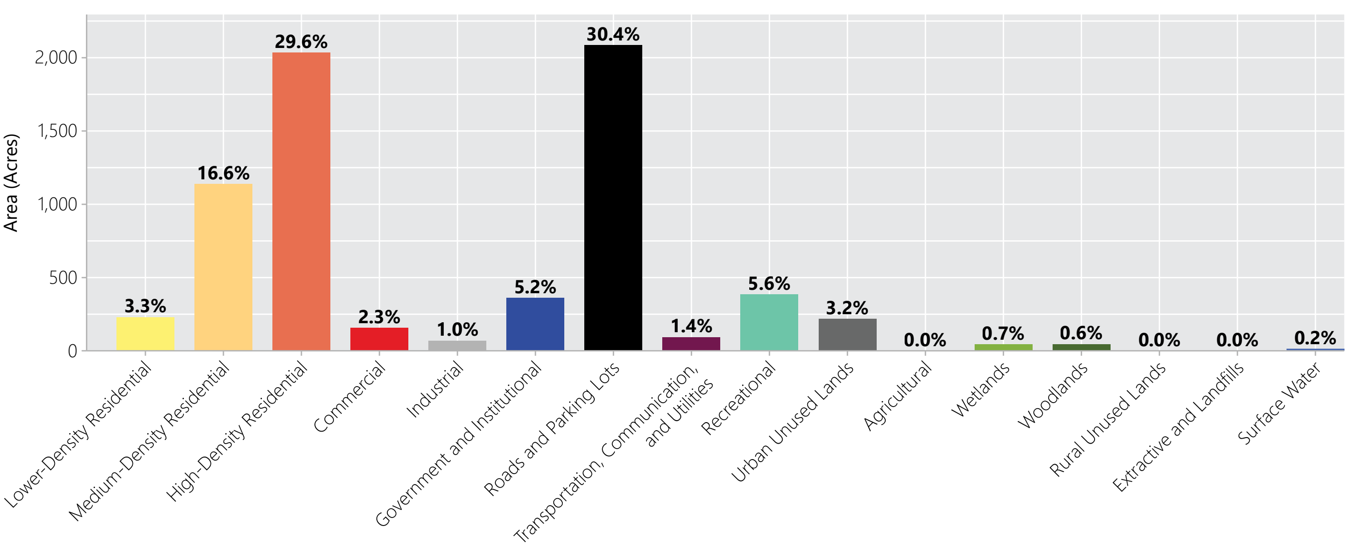


Facts at a Glance

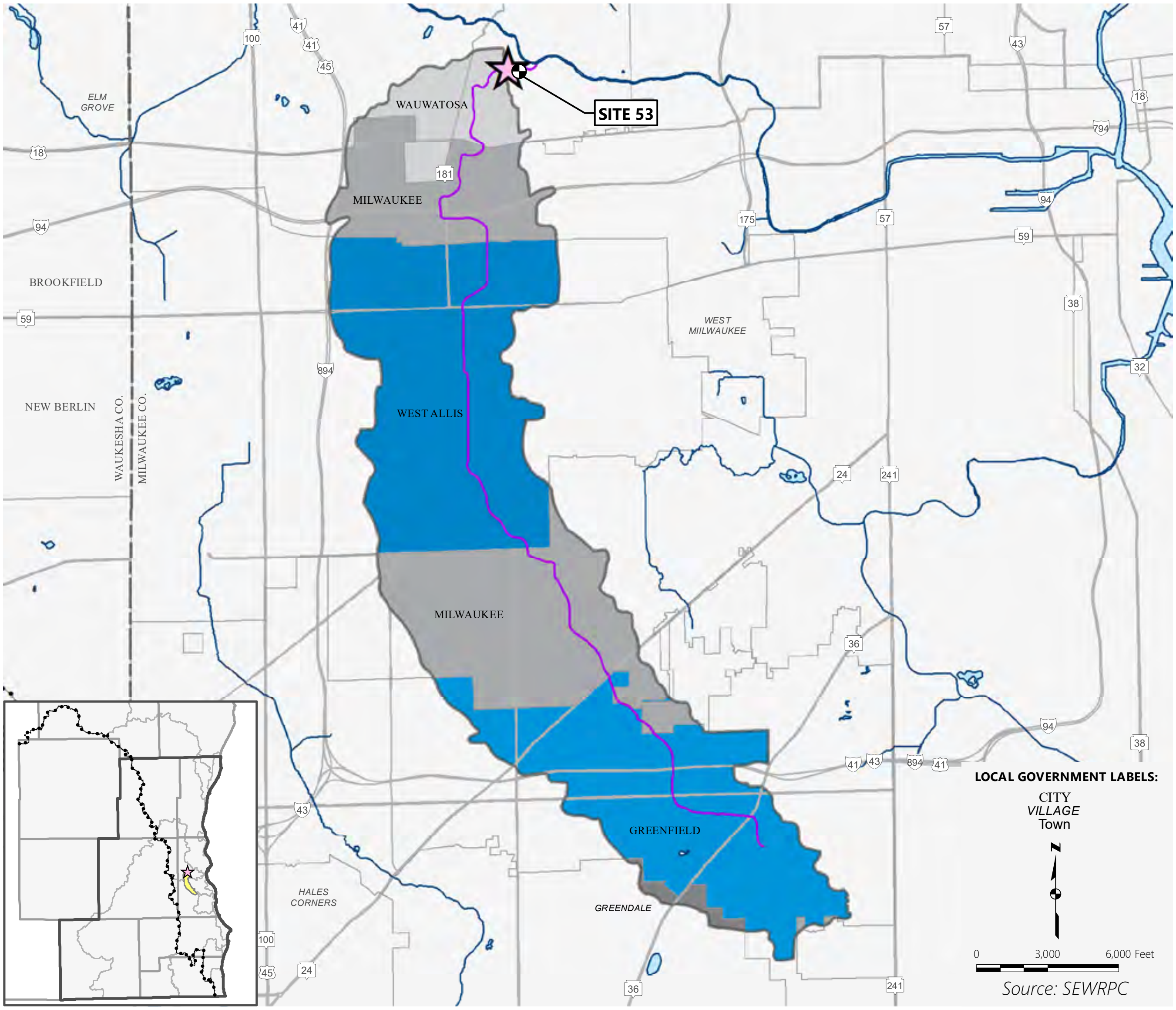
- **Drainage Area Size:** 54 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 23.3%; Rural – 76.7%
- **Roads and Parking Lots (% of drainage area):** 8.0
- **Estimated Population (2010):** 13,460
- **Estimated Households (2010):** 5,380 (47% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Upstream Wastewater Treatment Facilities (♦):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.67
Site 53: Honey Creek at Wauwatosa Drainage Area – Existing Land Use





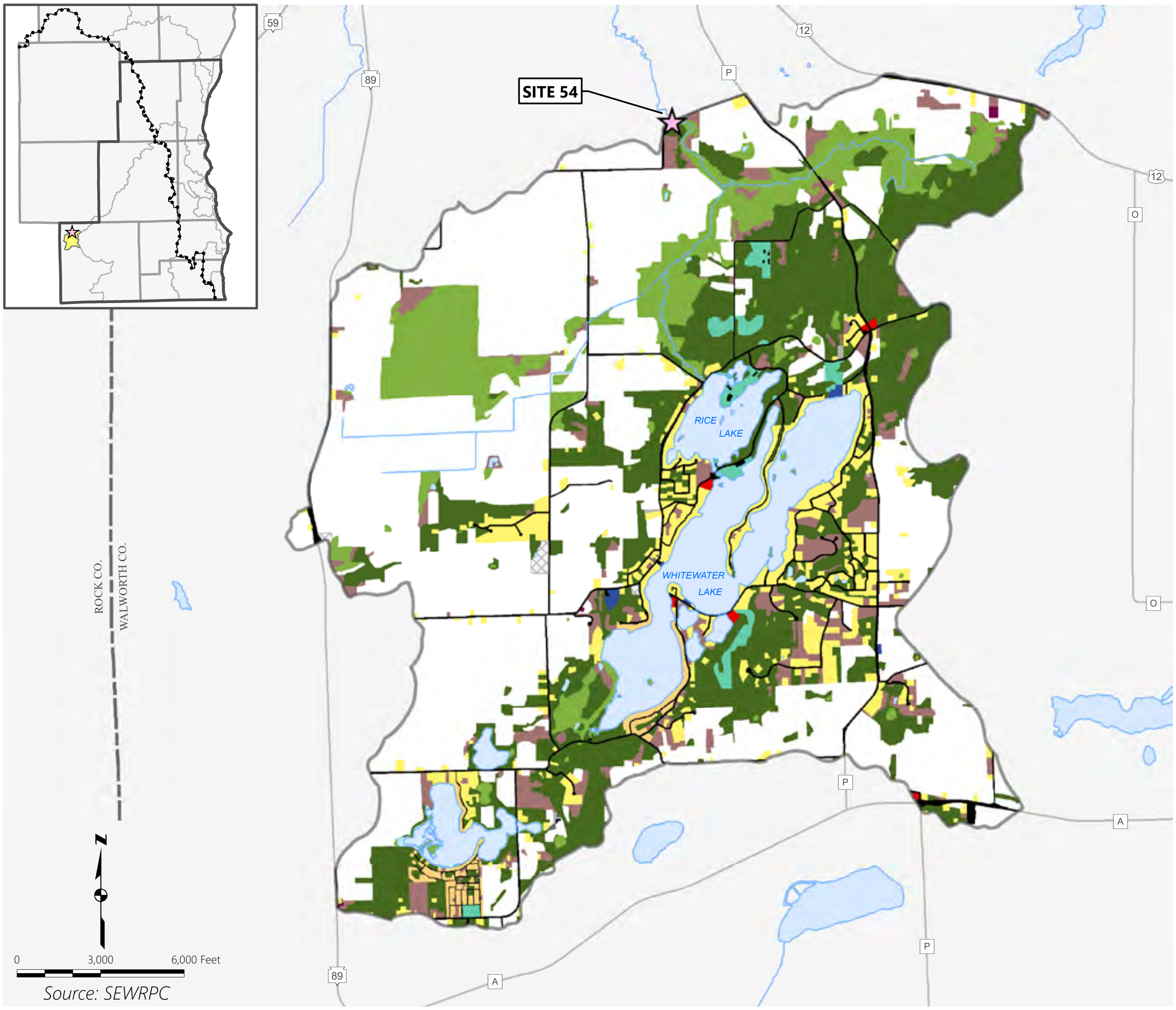
Map B.68
Site 53: Honey Creek at Wauwatosa Drainage Area – Features

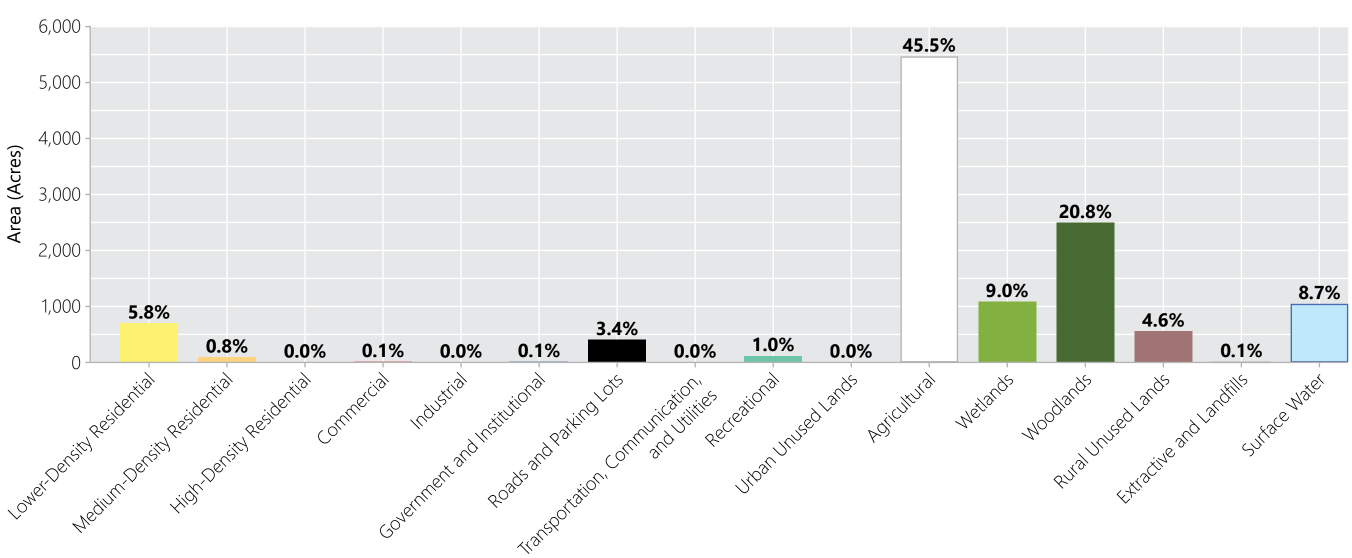


Facts at a Glance

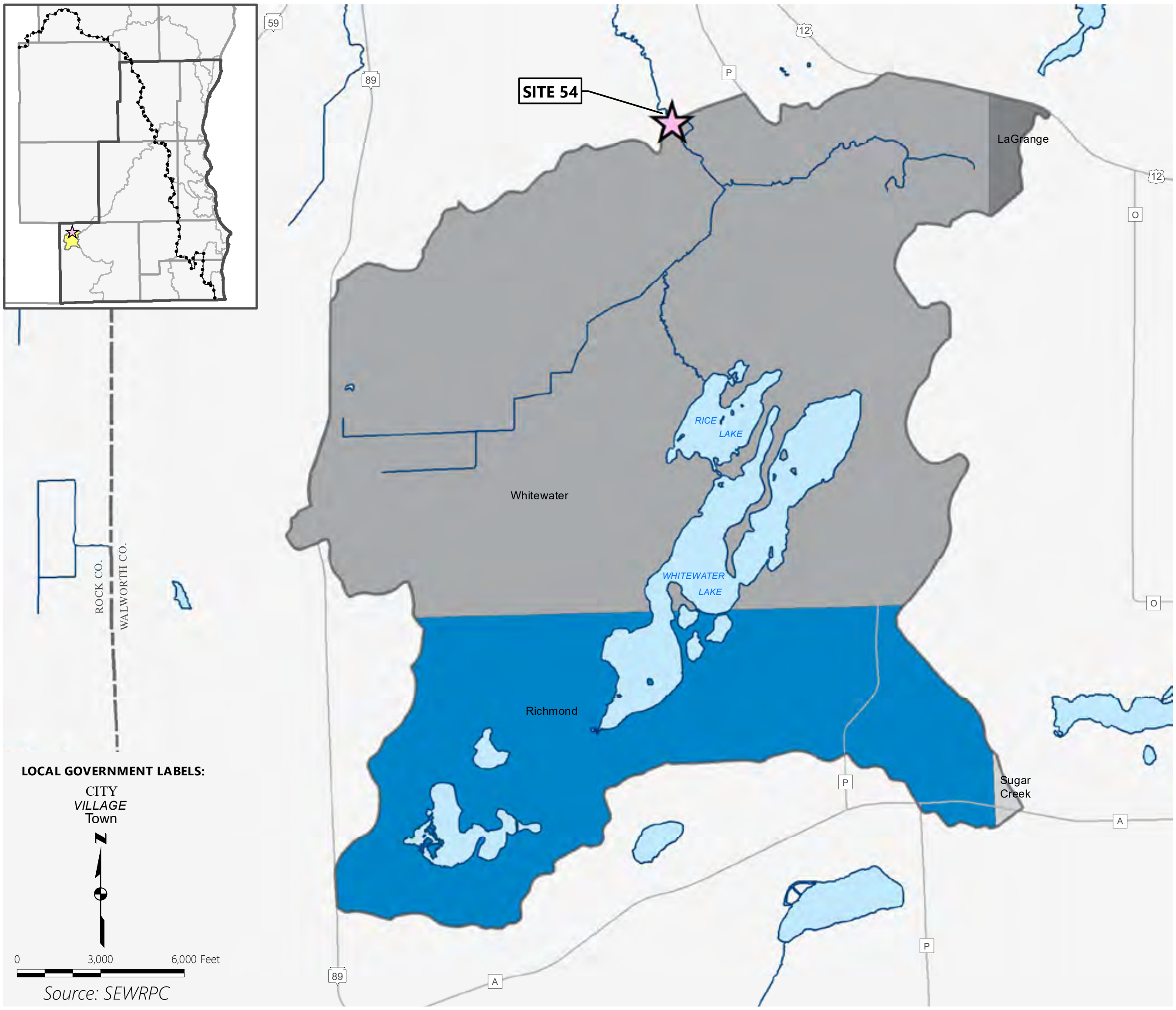
- **Drainage Area Size:** 11 square miles
- **Major Watershed:** Menomonee River
- **Land Use:** Urban – 98.5%; Rural – 1.5%
- **Roads and Parking Lots (% of drainage area):** 30.4
- **Estimated Population (2010):** 59,170
- **Estimated Households (2010):** 26,680 (100% served by public sanitary sewer)
- **Nearest USGS Streamgage (◉):** Honey Creek at Wauwatosa (04087119)
- **Chloride-Impaired Waters:**
  (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan

Map B.69
Site 54: Whitewater Creek Drainage Area – Existing Land Use





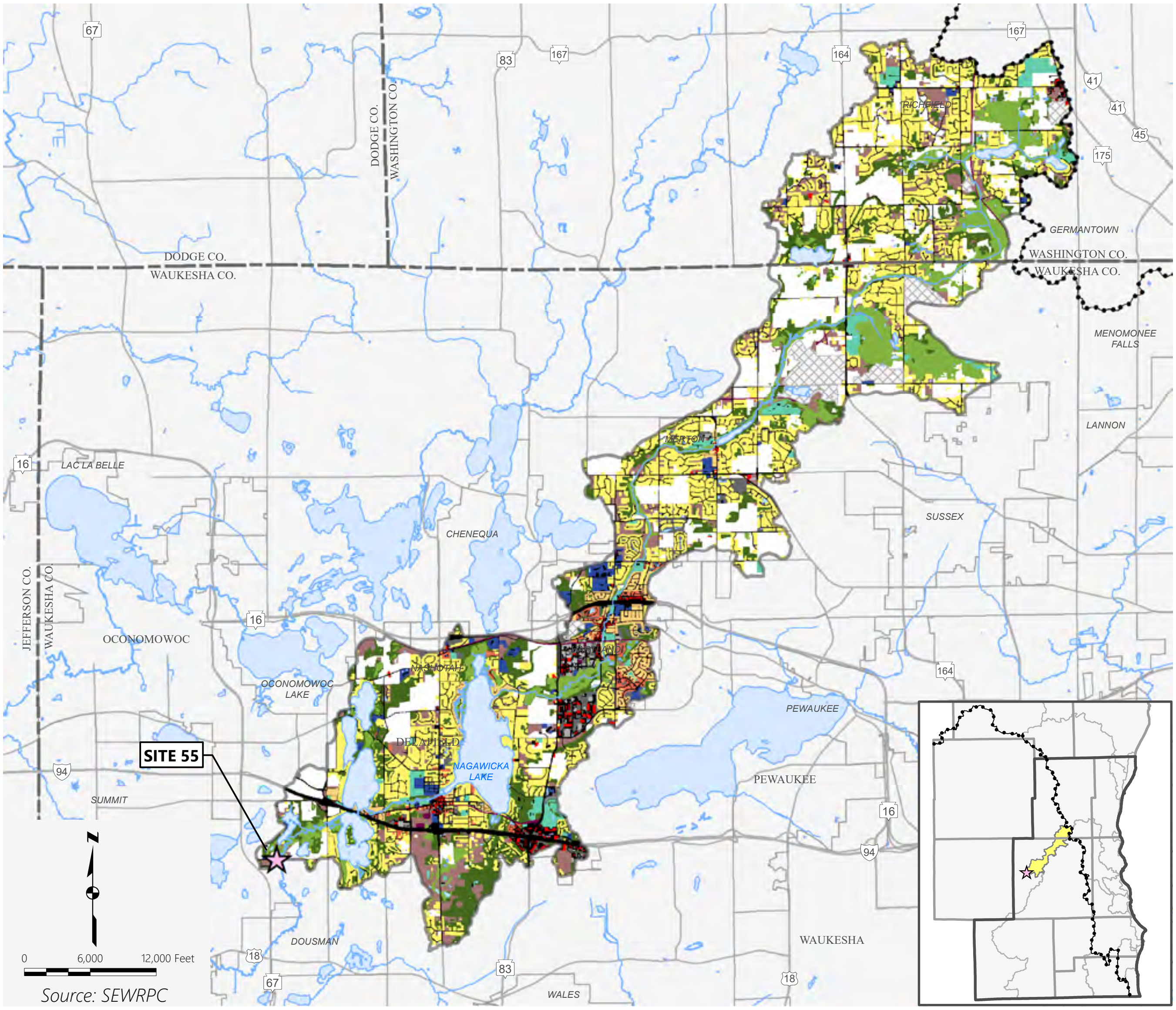
Map B.70
Site 54: Whitewater Creek Drainage Area – Features

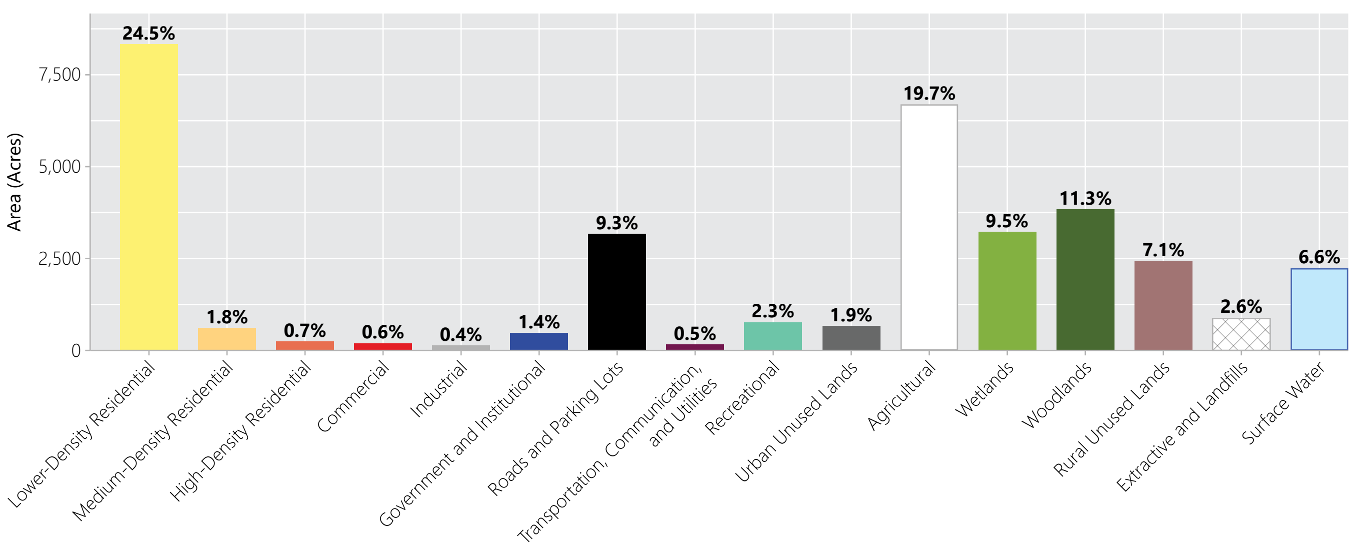


Facts at a Glance

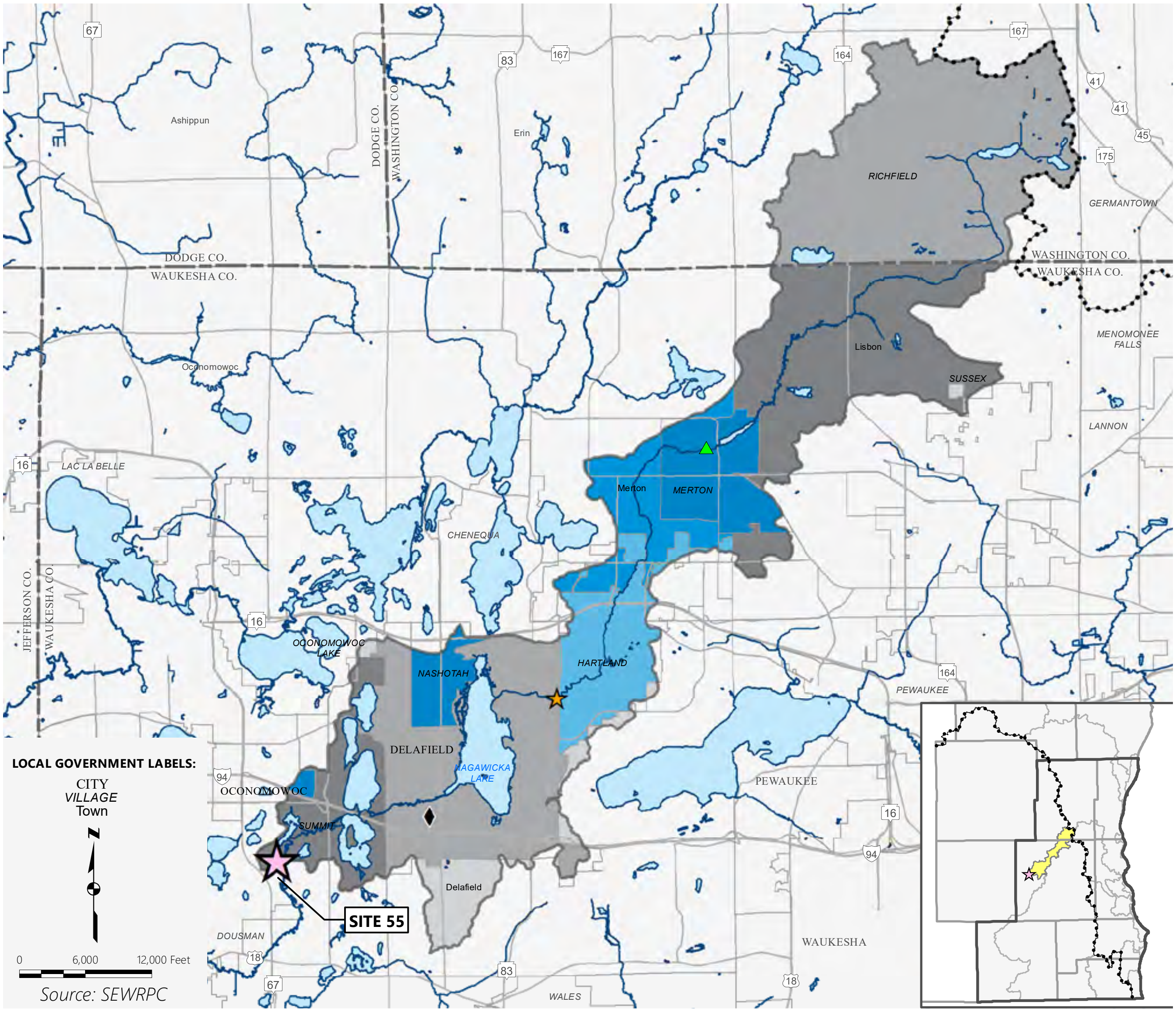
- **Drainage Area Size:** 19 square miles
- **Major Watershed:** Rock River
- **Land Use:** Urban – 11.2%; Rural – 88.8%
- **Roads and Parking Lots (% of drainage area):** 3.4
- **Estimated Population (2010):** 1,640
- **Estimated Households (2010):** 670 (0% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.71
Site 55: Bark River Downstream Drainage Area – Existing Land Use





Map B.72
Site 55: Bark River Downstream Drainage Area – Features

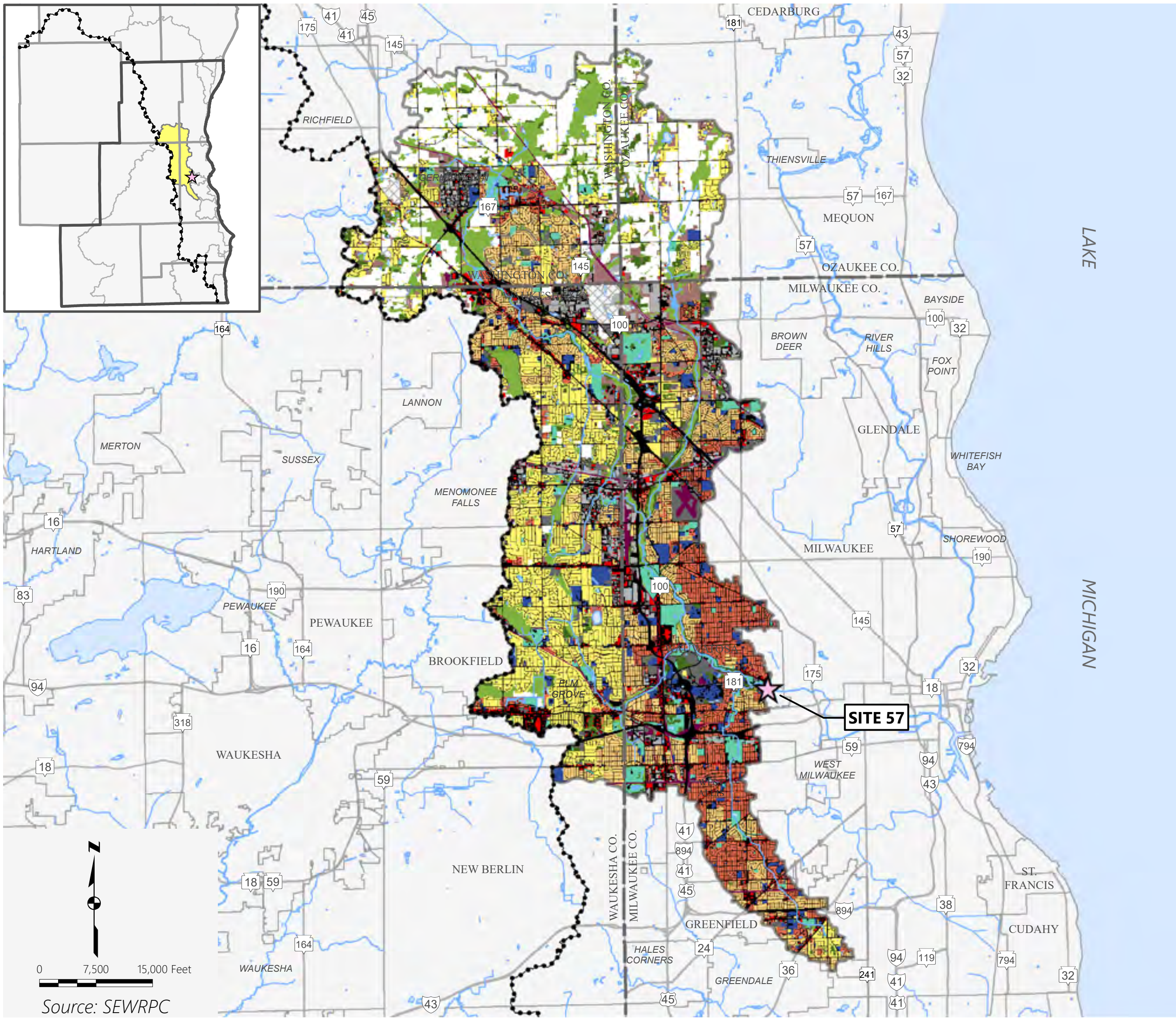


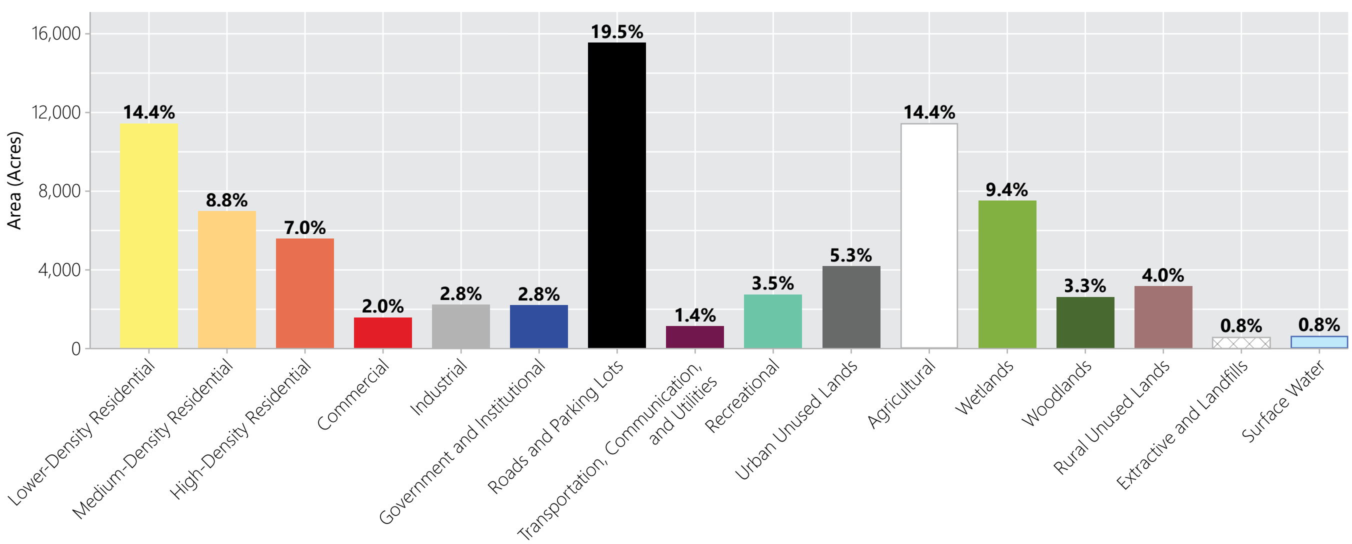
Source: SEWRPC

Facts at a Glance

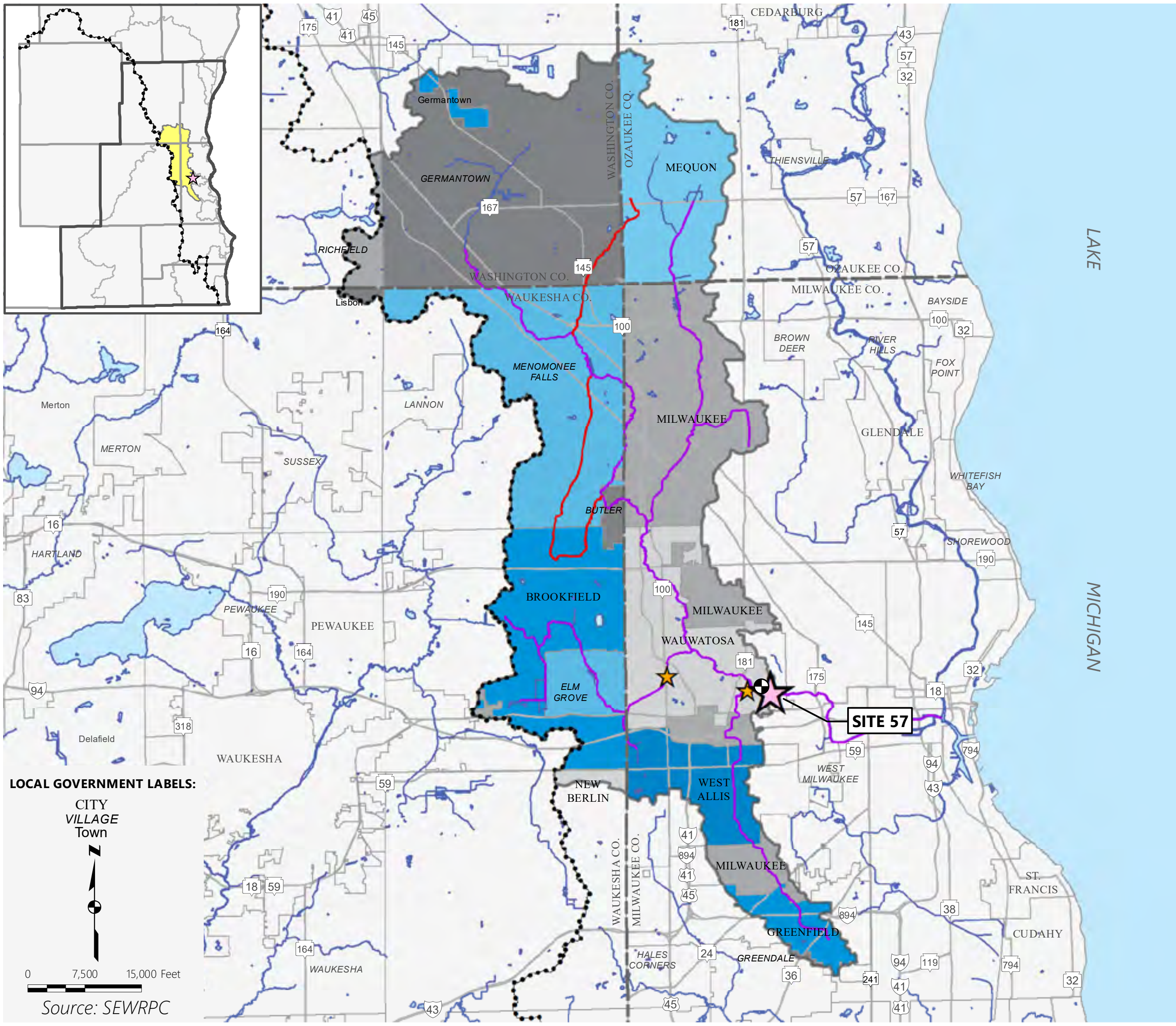
- **Drainage Area Size:** 53 square miles
- **Major Watershed:** Rock River
- **Land Use:**Urban – 43.3%; Rural – 56.7%
- **Roads and Parking Lots (% of drainage area):** 9.3
- **Estimated Population (2010):** 29,490
- **Estimated Households (2010):** 10,860 (52% served by public sanitary sewer)
- **Nearest USGS Streamgage:** None
- **Other Monitoring Sites Within this Drainage Area (★):** Site 11
- **Upstream Wastewater Treatment Facilities (♦):** 1 (effluent from this facility is pumped and discharged downstream of Site 55)
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Chloride-Impaired Waters:** None
- **Water Supply Source:** Groundwater

Map B.73
Site 57: Menomonee River at Wauwatosa Drainage Area – Existing Land Use





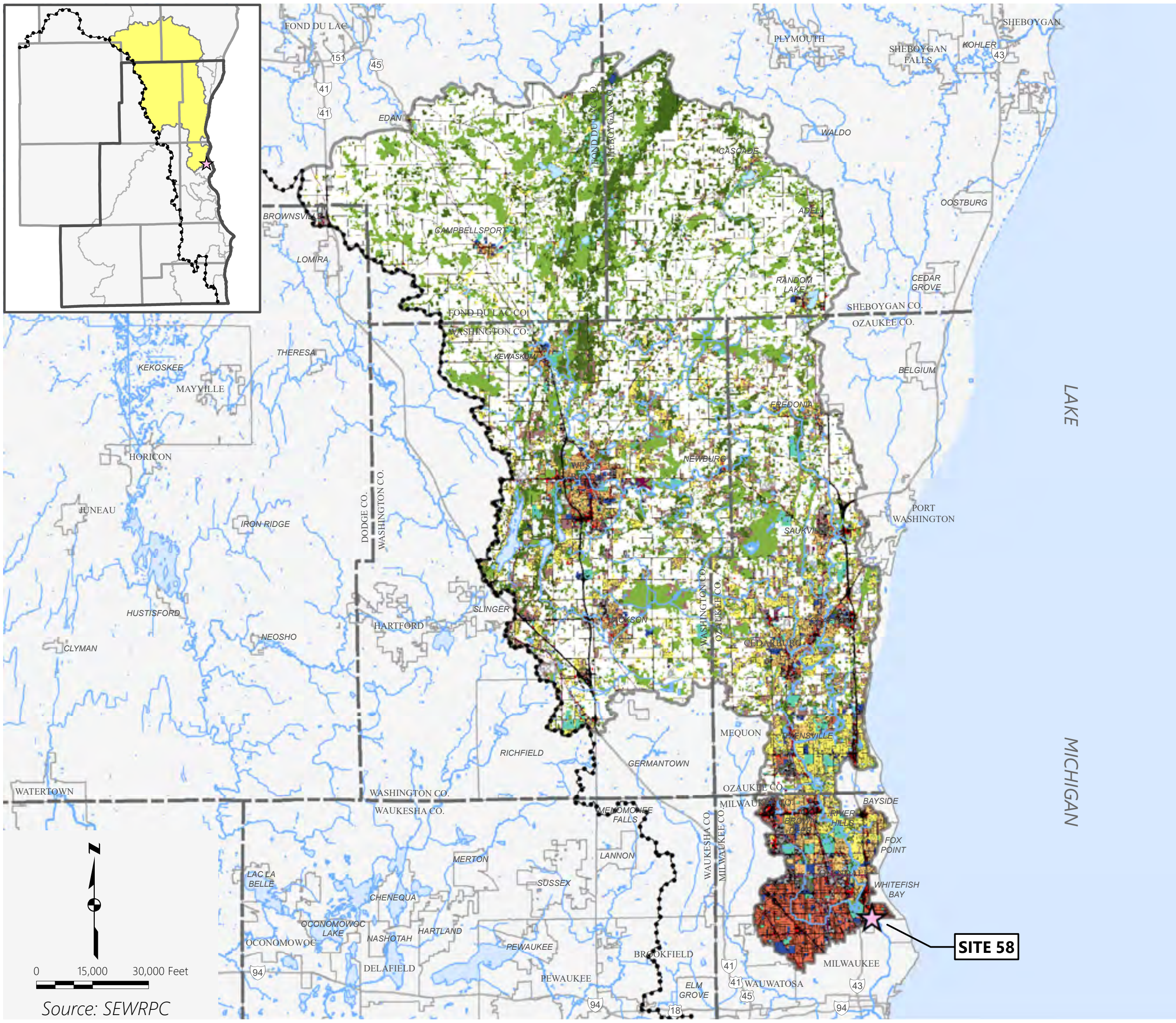
Map B.74
Site 57: Menomonee River at Wauwatosa Drainage Area – Features

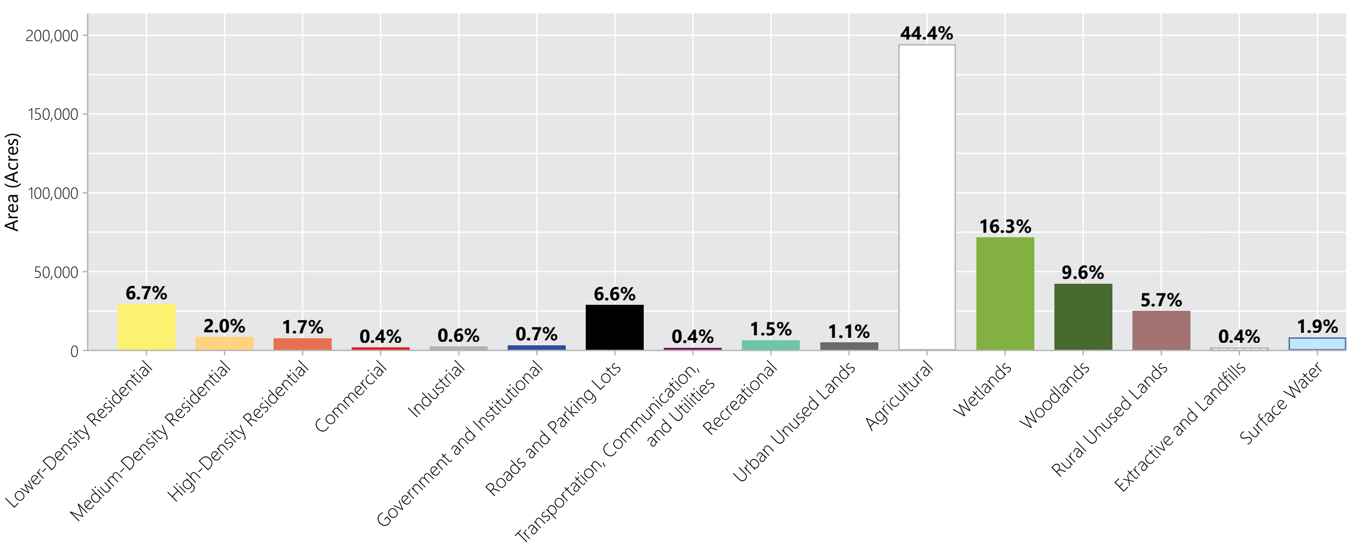


Facts at a Glance

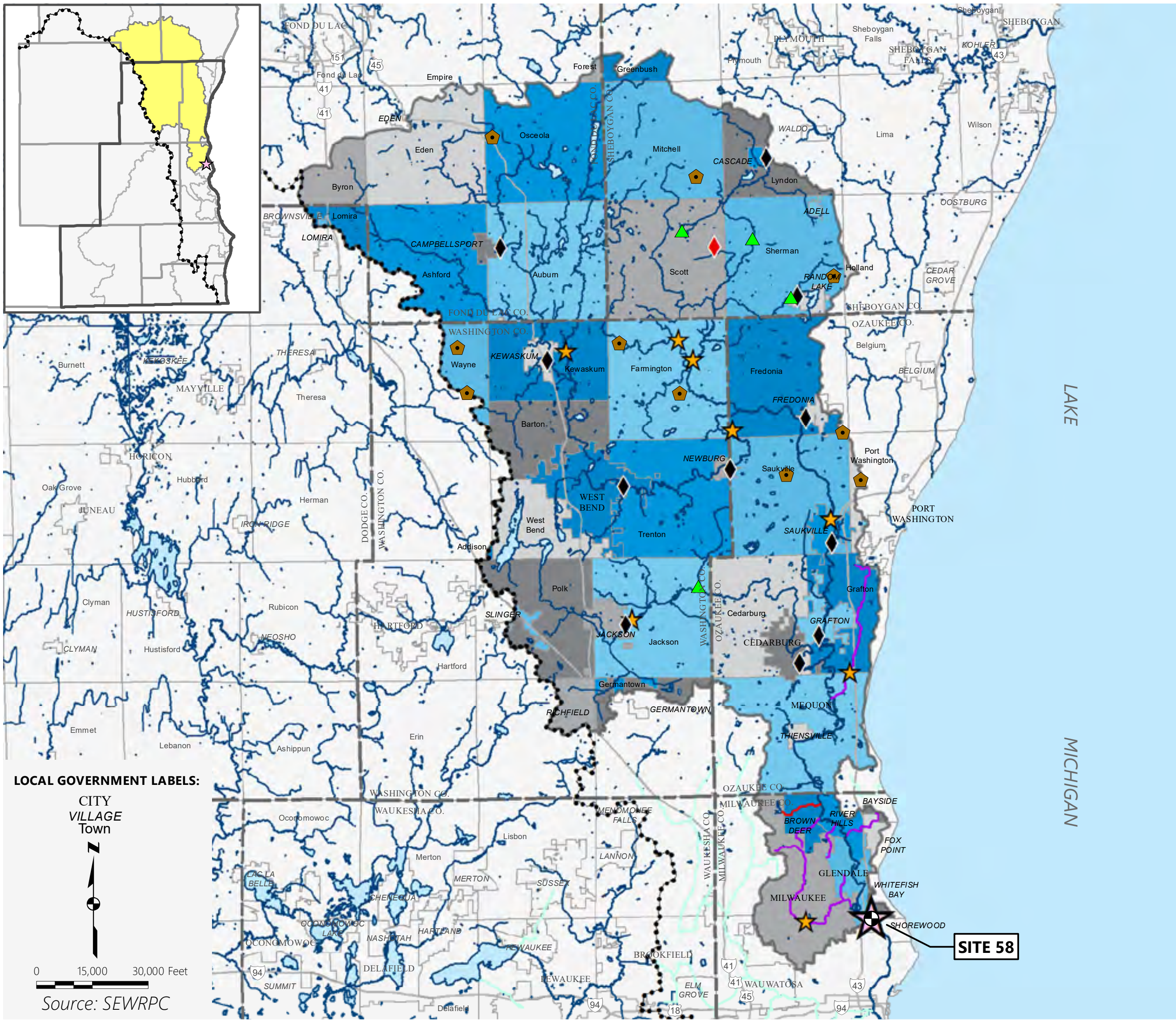
- **Drainage Area Size:** 124 square miles
- **Major Watershed:** Menomonee River
- **Land Use:** Urban – 67.3%; Rural – 32.7%
- **Roads and Parking Lots (% of drainage area):** 19.5
- **Estimated Population (2010):** 239,730
- **Estimated Households (2010):** 99,950 (98% served by public sanitary sewer)
- **Nearest USGS Streamgage (◐):** Menomonee River at Wauwatosa (04087120)
- **Other Monitoring Sites Within this Drainage Area (★):** Site 53 and Site 87
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
  (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan and Groundwater

Map B.75
Site 58: Milwaukee River at Estabrook Park Drainage Area – Existing Land Use





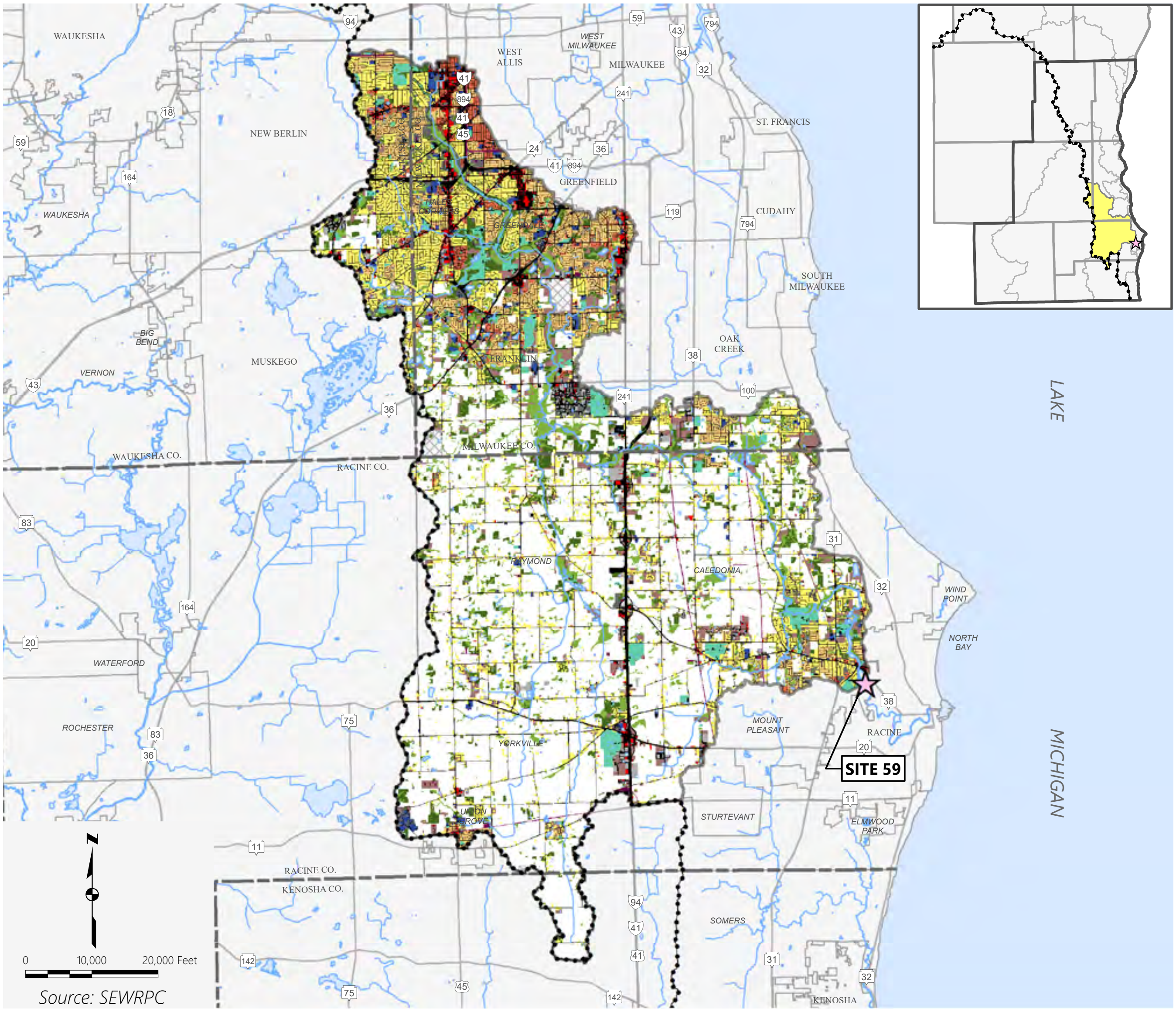
Map B.76
Site 58: Milwaukee River at Estabrook Park Drainage Area – Features



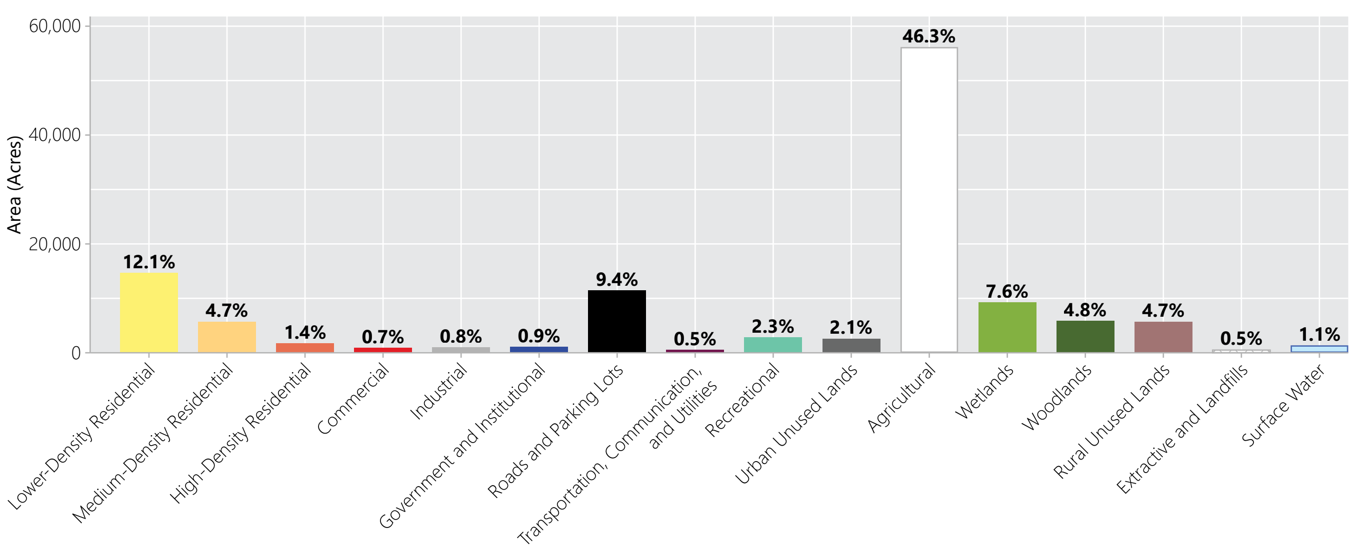
Facts at a Glance

- **Drainage Area Size:** 685 square miles
- **Major Watershed:** Milwaukee River
- **Land Use:** Urban – 21.7%; Rural – 78.3%
- **Roads and Parking Lots (% of drainage area):** 6.6
- **Estimated Population (2010):** 336,700
- **Estimated Households (2010):** 132,100 (86% served by public sanitary sewer)
- **Nearest USGS Streamgage (⊕):** Milwaukee River at Milwaukee (04087000)
- **Other Monitoring Sites Within this Drainage Area (★):** Site 21, Site 23, Site 40, Site 38, Site 41, Site 52, Site 13, and Site 12
- **Upstream Wastewater Treatment Facilities (♦):** 11
  WWTF discharge to soil (♦): 1
- **Upstream Industrial Wastewater Dischargers (▲):** 4
- **Concentrated Animal Feeding Operations (⬟):** 10
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
  (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan and Groundwater

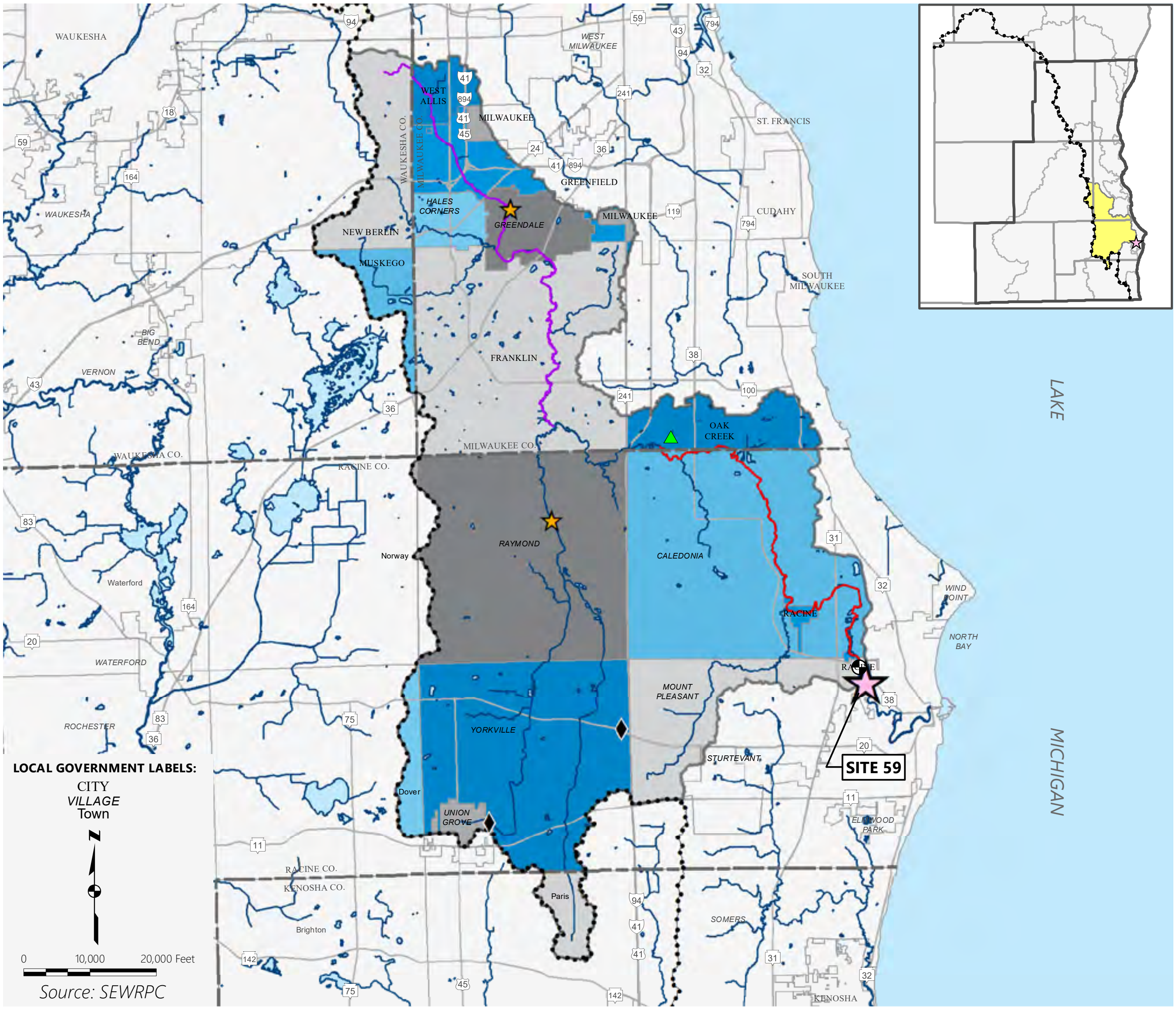
Map B.77
Site 59: Root River near Horlick Dam Drainage Area – Existing Land Use



Source: SEWRPC



Map B.78
Site 59: Root River near Horlick Dam Drainage Area – Features

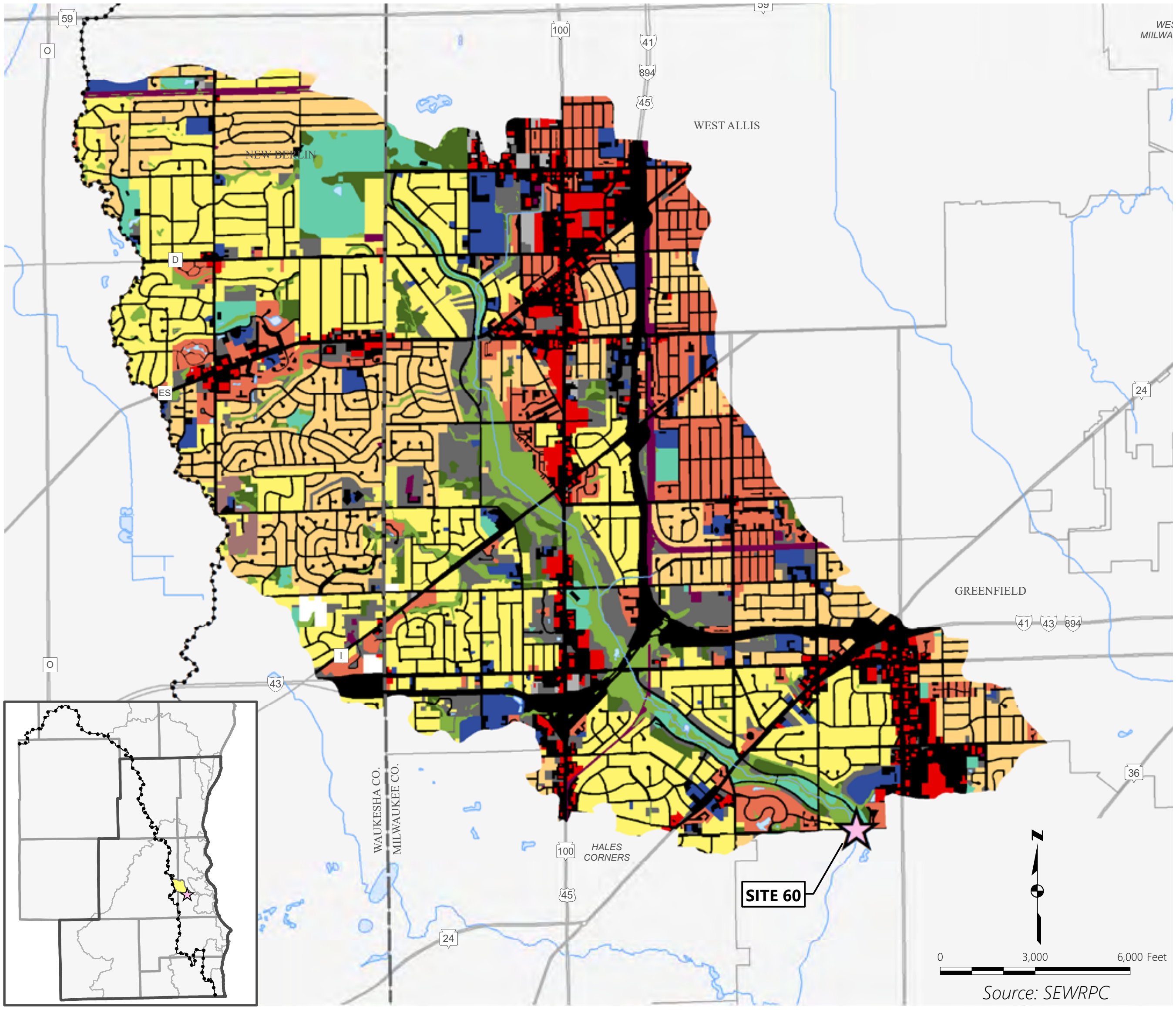


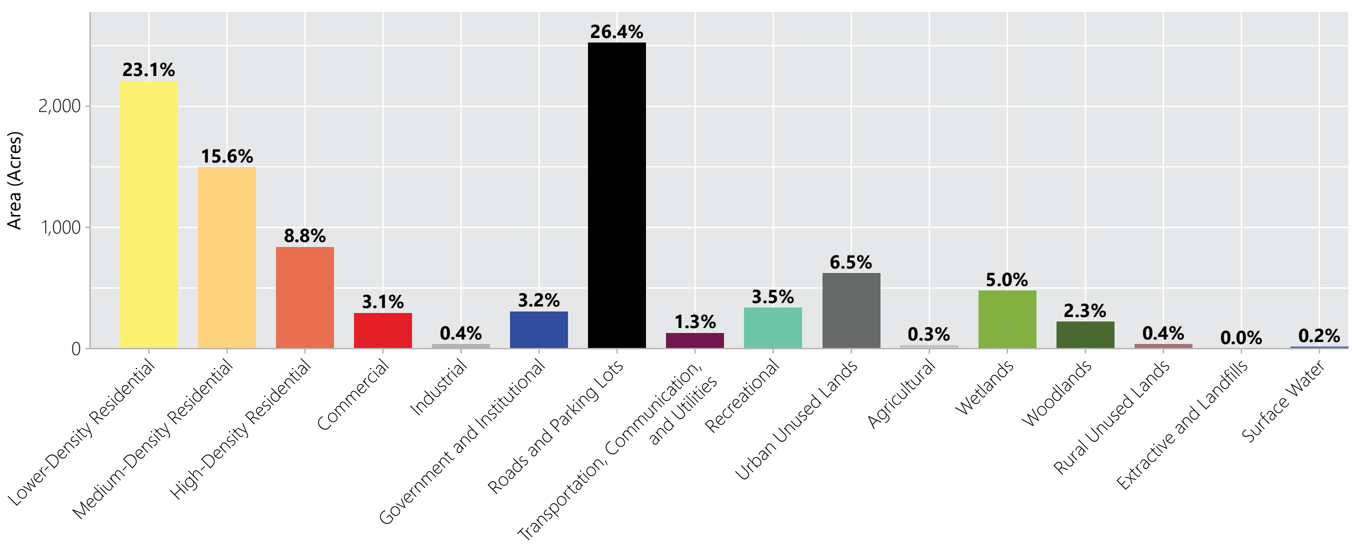
Facts at a Glance

- **Drainage Area Size:** 190 square miles
- **Major Watershed:** Root River
- **Land Use:** Urban – 35.0%; Rural – 65.0%
- **Roads and Parking Lots (% of drainage area):** 9.4
- **Estimated Population (2010):** 141,920
- **Estimated Households (2010):** 57,370 (93% served by public sanitary sewer)
- **Nearest USGS Streamgage (◔):** Root River at Racine (04087240)
- **Other Monitoring Sites Within this Drainage Area (★):** Site 60 and Site 25
- **Upstream Wastewater Treatment Facilities (♦):** 2
- **Upstream Industrial Wastewater Dischargers (▲):** 1
- **Chloride-Impaired Waters:**
  (—) Chronic Toxicity Impairment
  (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan and Groundwater

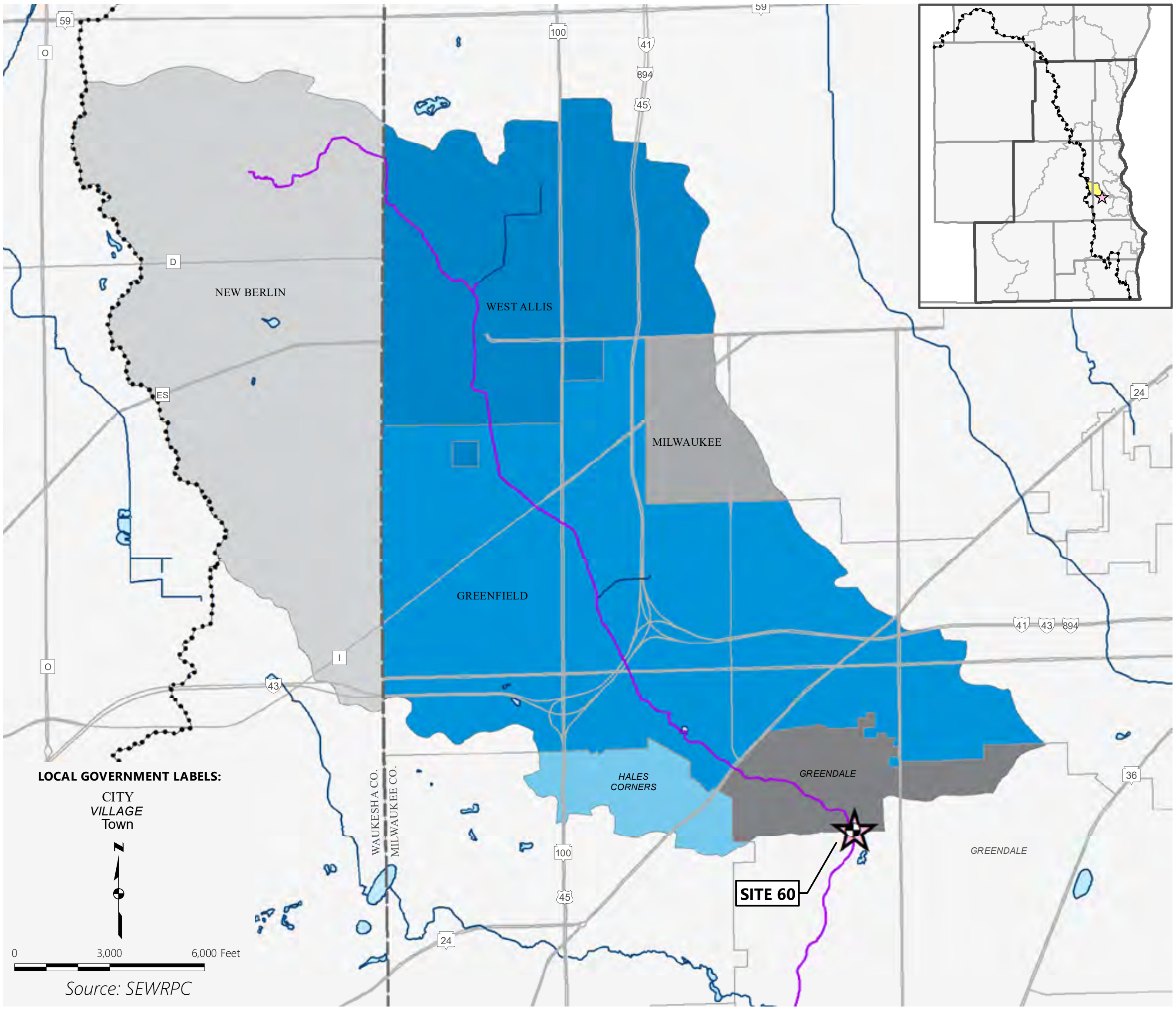
Map B.79

Site 60: Root River at Grange Avenue Drainage Area – Existing Land Use





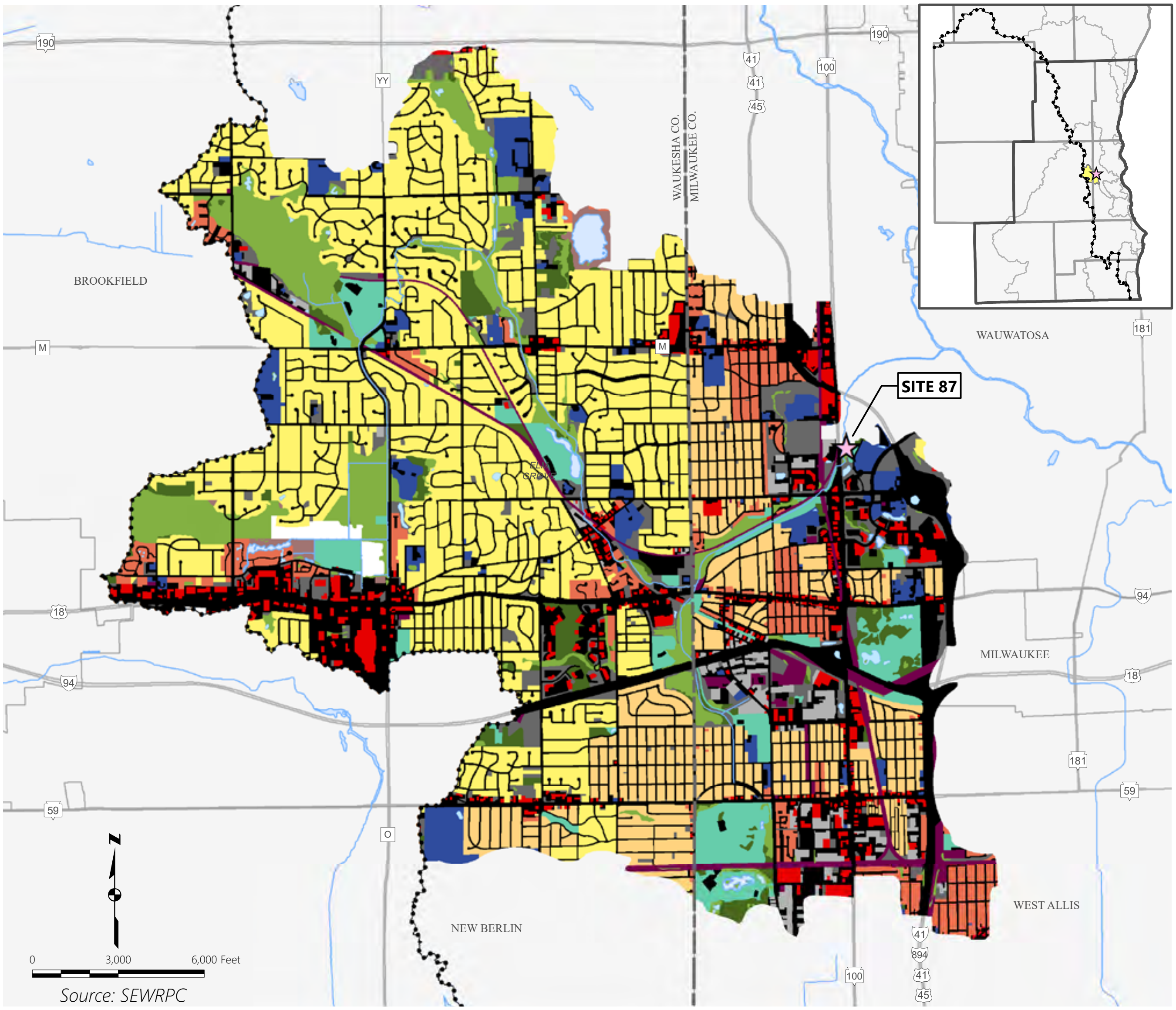
Map B.80
Site 60: Root River at Grange Avenue Drainage Area – Features

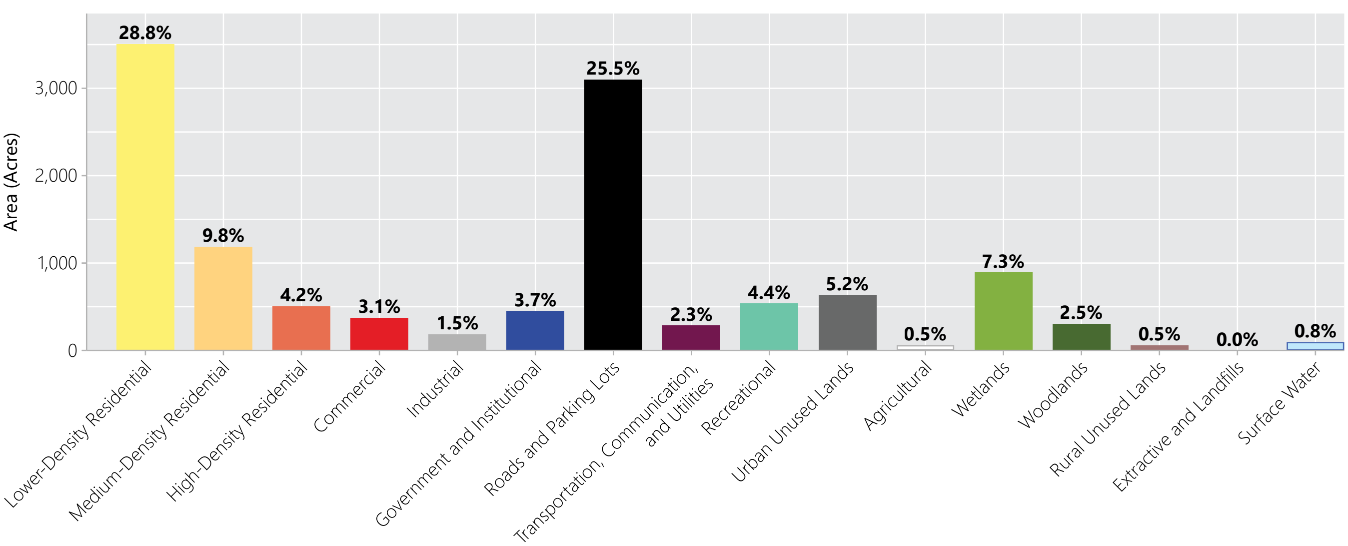


Facts at a Glance

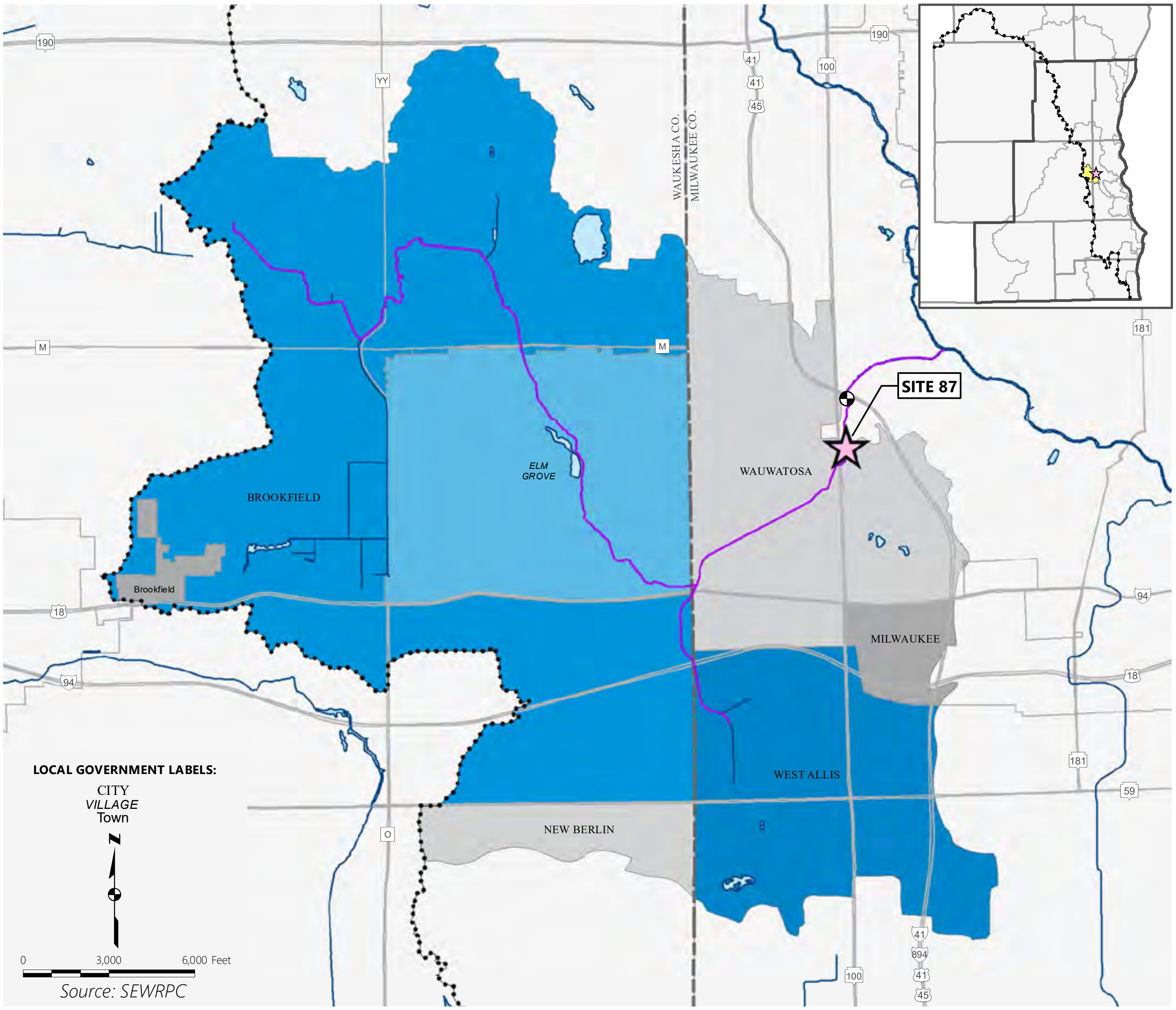
- **Drainage Area Size:** 15 square miles
- **Major Watershed:** Root River
- **Land Use:** Urban – 91.9%; Rural – 8.1%
- **Roads and Parking Lots (% of drainage area):** 26.4
- **Estimated Population (2010):** 43,470
- **Estimated Households (2010):** 19,530 (100% served by public sanitary sewer)
- **Nearest USGS Streamgage (◉):** Root River at Grange Avenue (04087214)
- **Chloride-Impaired Waters:** (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan

Map B.81
Site 87: Underwood Creek Drainage Area – Existing Land Use





Map B.82
Site 87: Underwood Creek Drainage Area – Features



Facts at a Glance

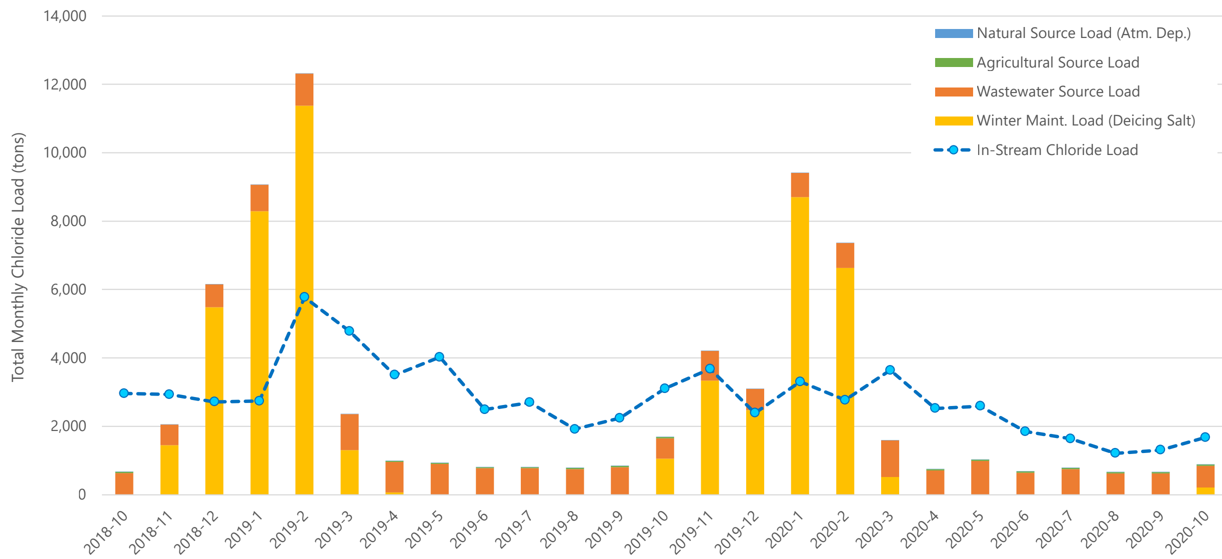
- **Drainage Area Size:** 19 square miles
- **Major Watershed:** Menomonee River
- **Land Use:** Urban – 88.4%; Rural – 11.6%
- **Roads and Parking Lots (% of drainage area):** 25.5
- **Estimated Population (2010):** 34,500
- **Estimated Households (2010):** 14,850 (100% served by public sanitary sewer)
- **Nearest USGS Streamgage (⊕):** Underwood Creek at Wauwatosa (04087088)
- **Chloride-Impaired Waters:** (—) Chronic and Acute Toxicity Impairment
- **Water Supply Source:** Lake Michigan and Groundwater

CHLORIDE MASS BALANCE ANALYSIS RESULTS FOR STREAM MONITORING SITES

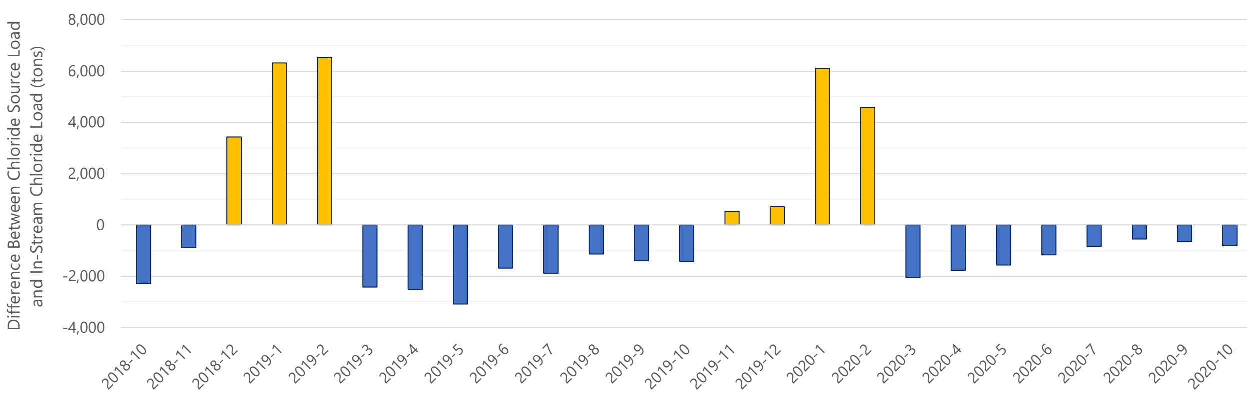
APPENDIX C

Figure C.1
Chloride Loads and Mass Balance Analysis Results at Site 1 Fox River at Waukesha

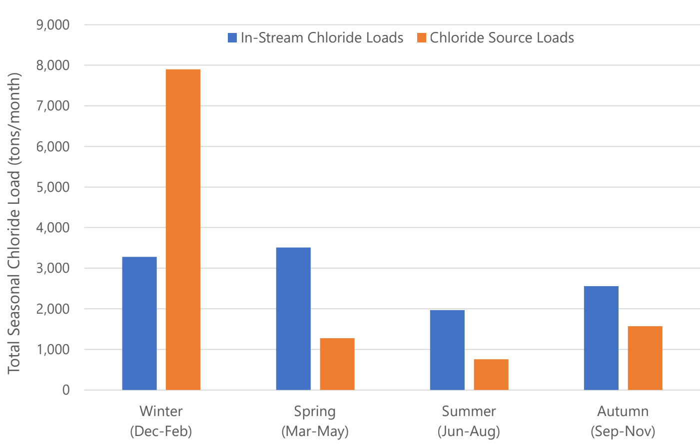
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 1

Chloride mass balance over the study period

- **0.21%** (sources > in-stream)

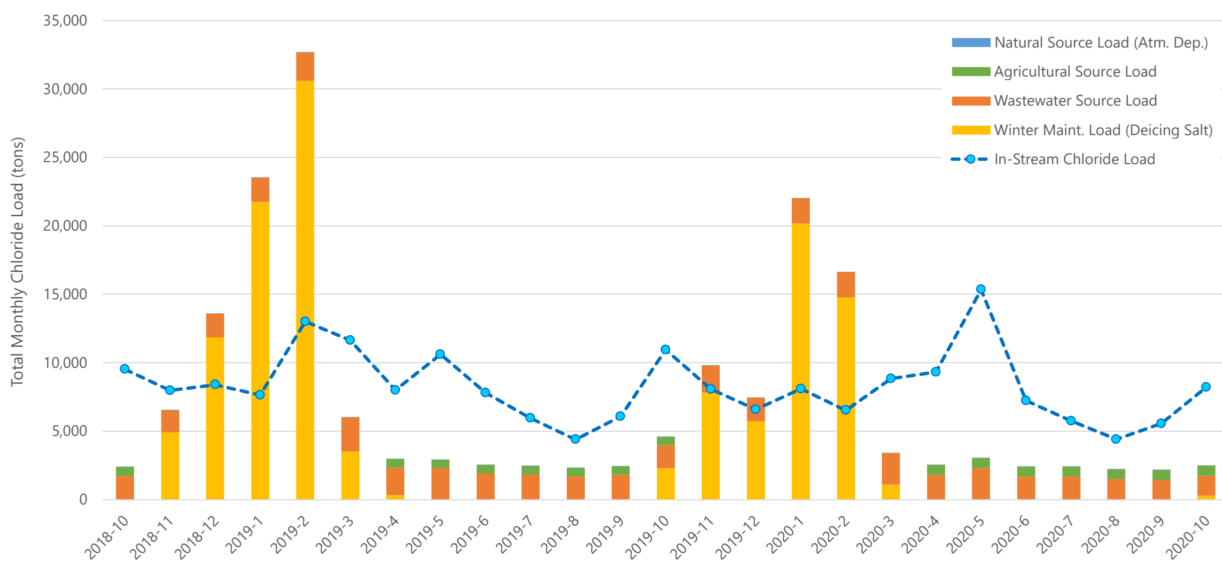
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **95.3%**
- Winter 2019-2020 = **78.6%**

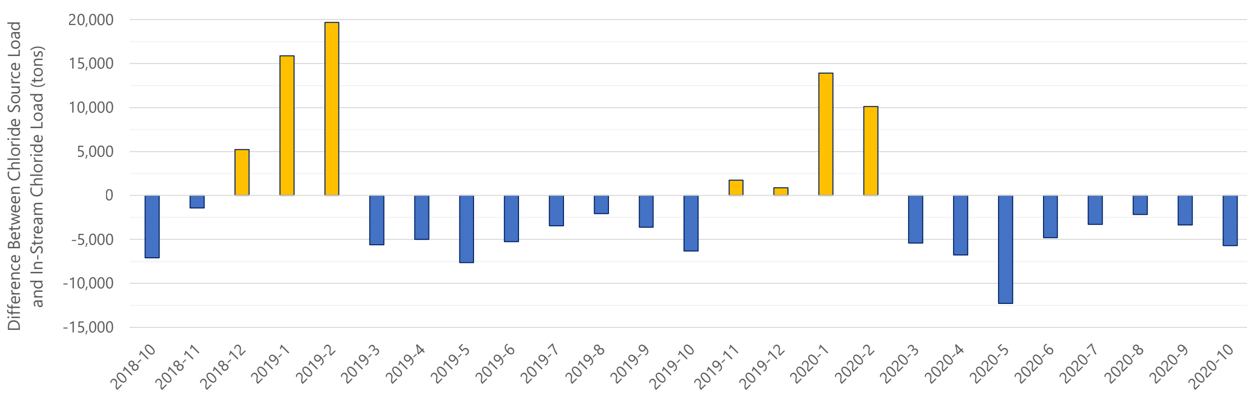
Source: SEWRPC

Figure C.2
Chloride Loads and Mass Balance Analysis Results at Site 2 Fox River at New Munster

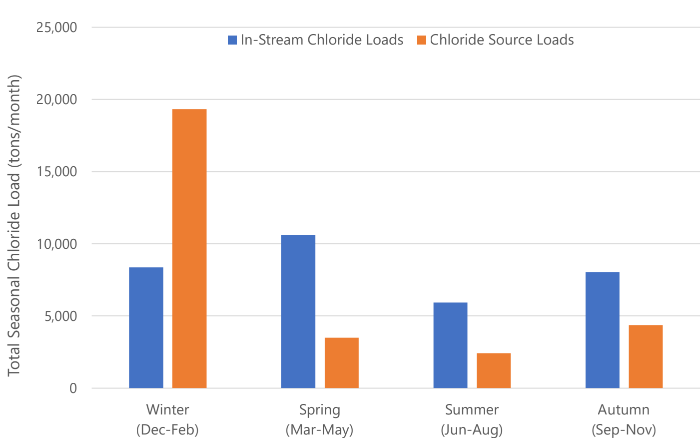
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 2

Chloride mass balance over the study period

- **-11.6%** (in-stream > sources)

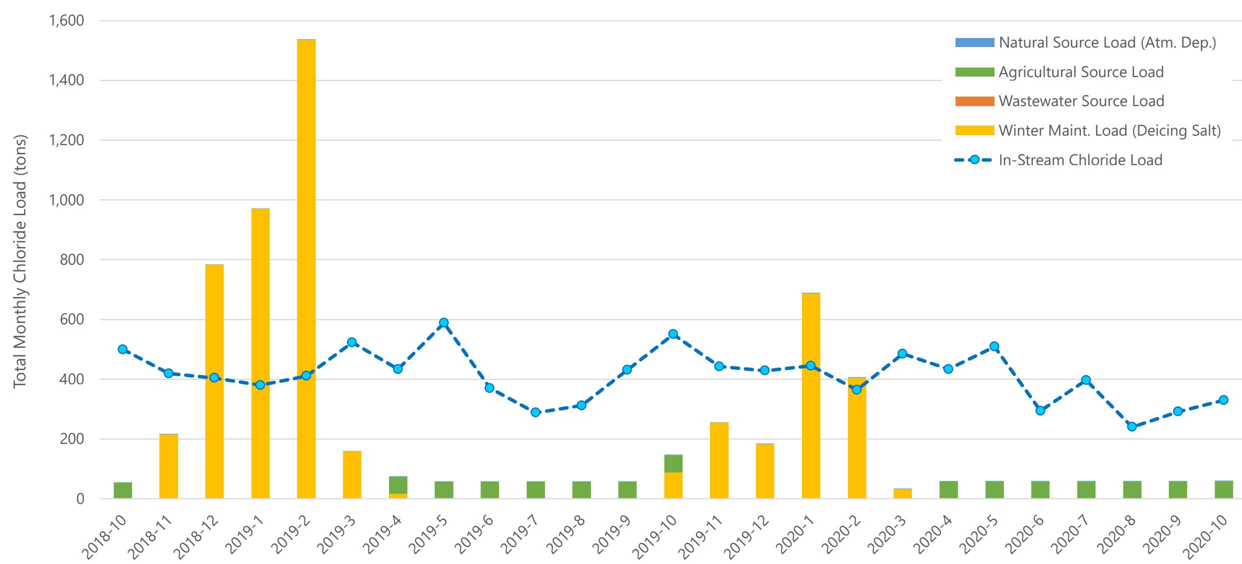
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **95.5%**
- Winter 2019-2020 = **164.2%**

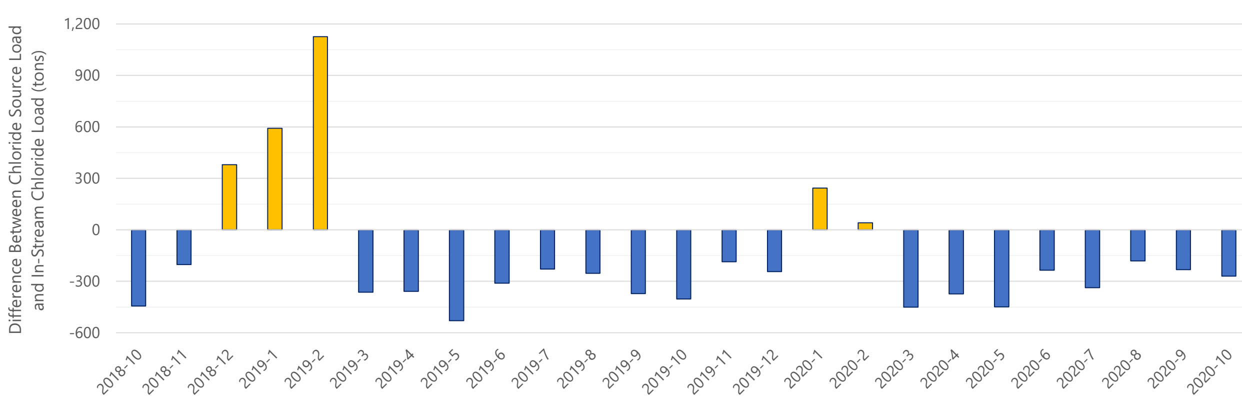
Source: SEWRPC

Figure C.3
Chloride Loads and Mass Balance Analysis Results at Site 3 Mukwonago River at Mukwonago

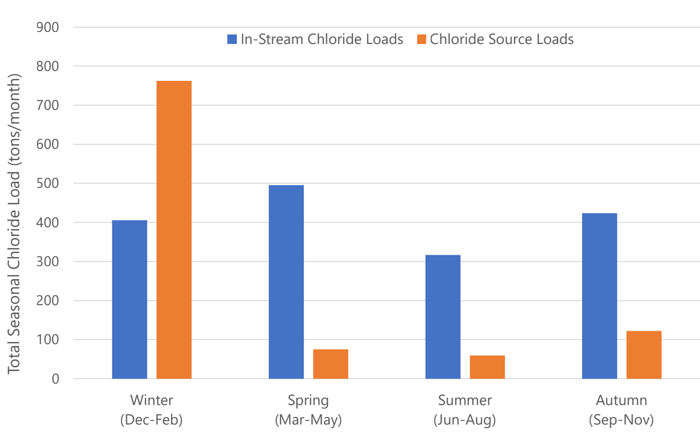
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 3

Chloride mass balance over the study period

- **-39.3%** (in-stream > sources)

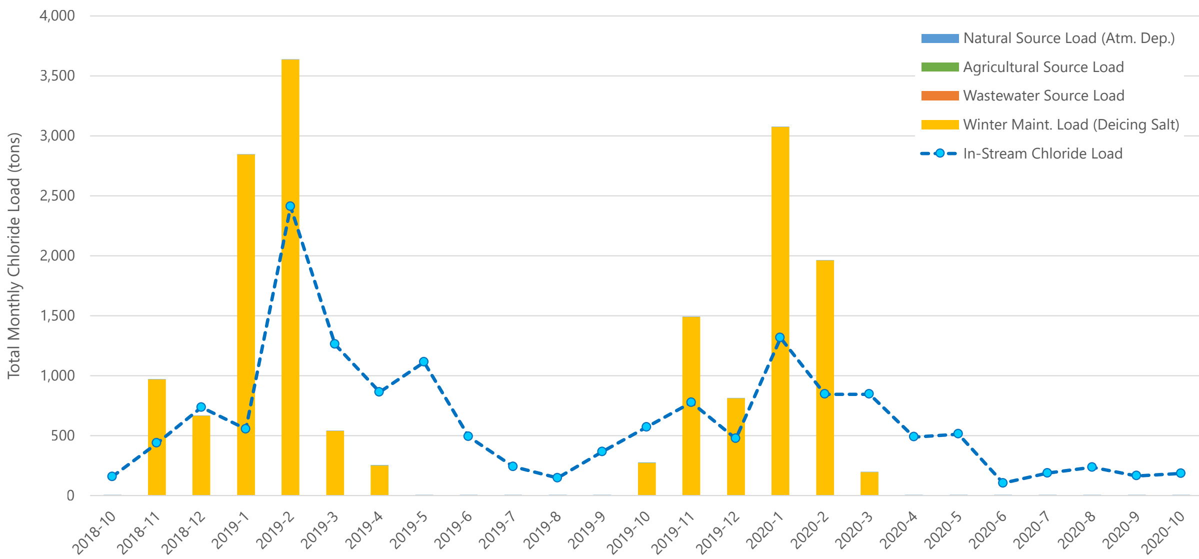
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **154.5%**
- Winter 2019-2020 = **882.1%**

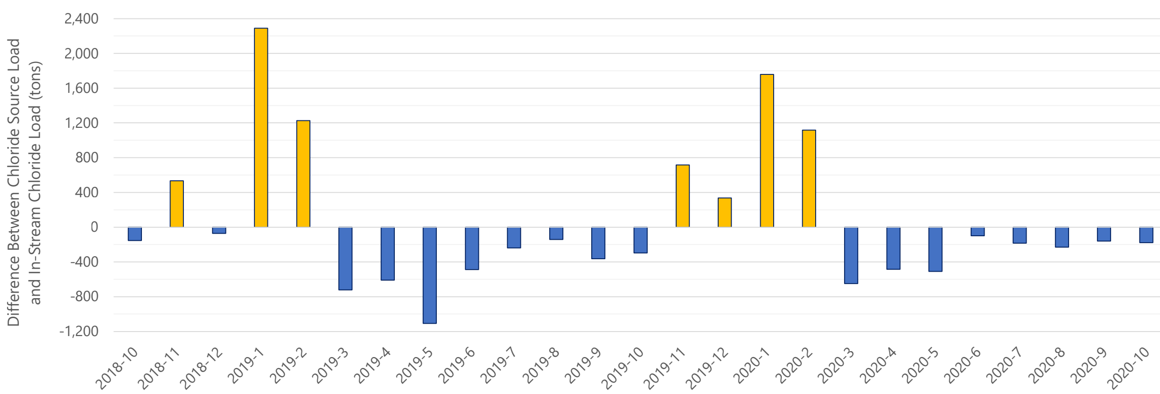
Source: SEWRPC

Figure C.4
Chloride Loads and Mass Balance Analysis Results at Site 9 Oak Creek

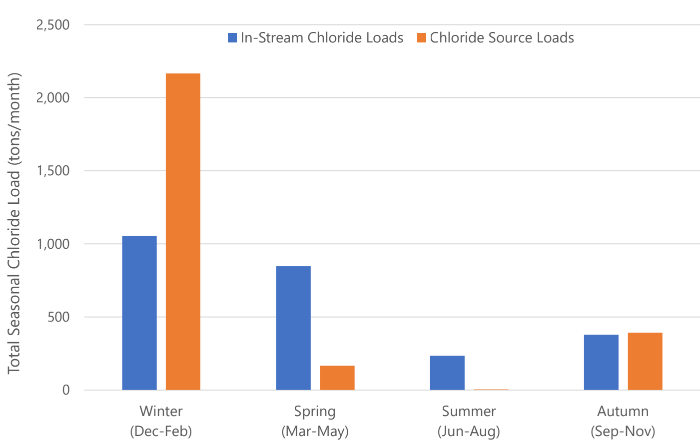
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 9

Chloride mass balance over the study period

- **8.3%** (sources > in-stream)

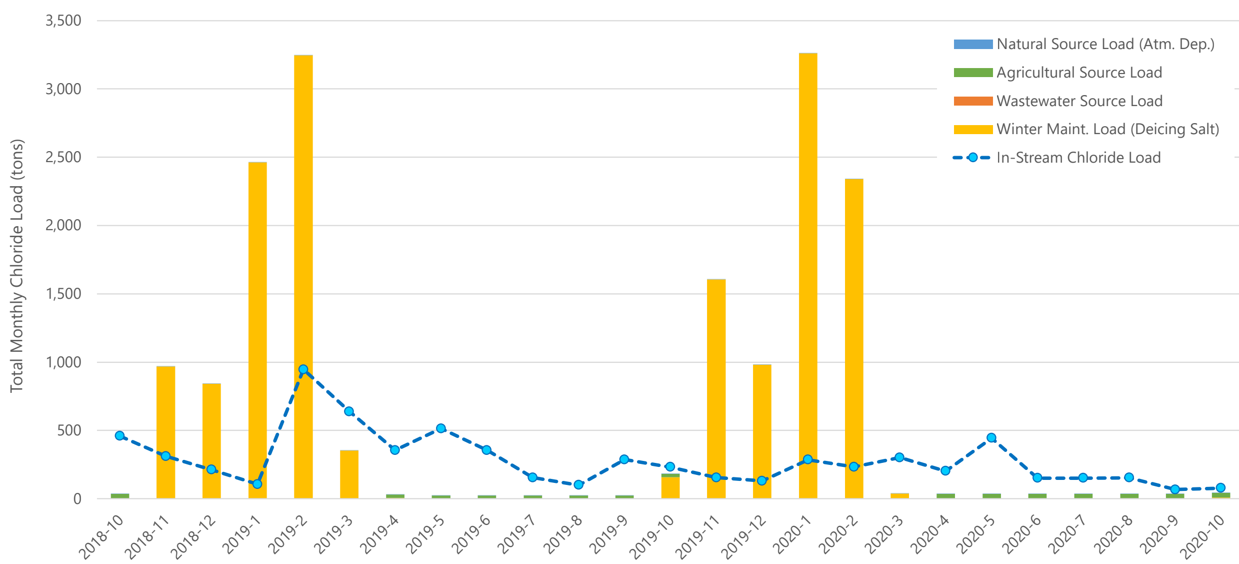
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **99.8%**
- Winter 2019-2020 = **63.5%**

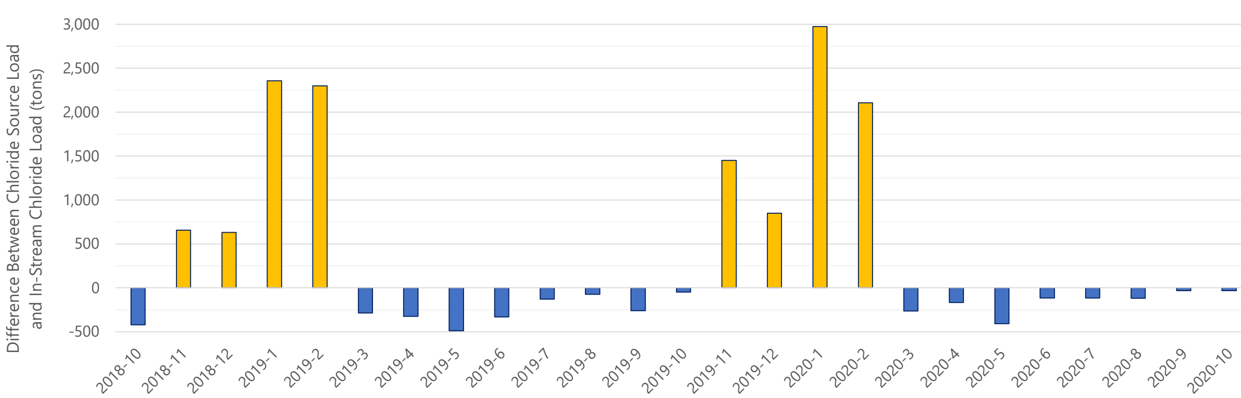
Source: SEWRPC

Figure C.5
Chloride Loads and Mass Balance Analysis Results at Site 10 Pike River

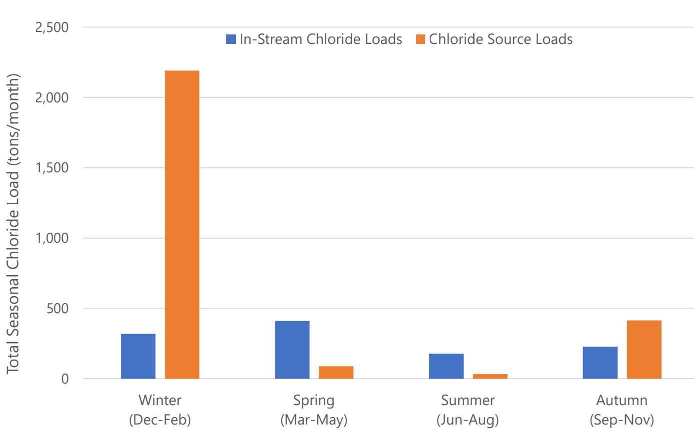
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 10

Chloride mass balance over the study period

- **138.3%** (sources > in-stream)

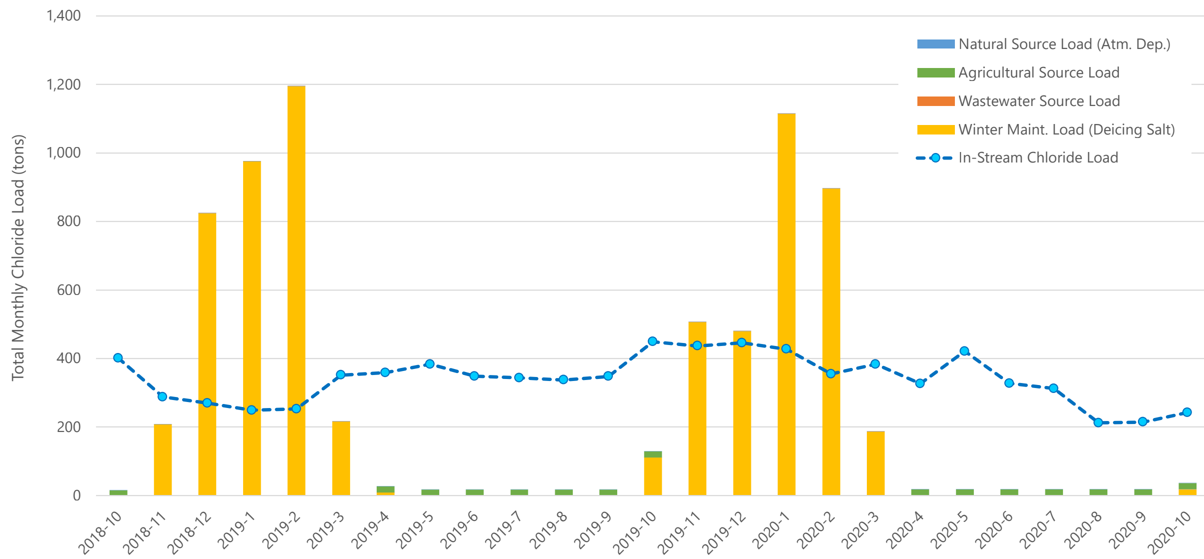
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **32.6%**
- Winter 2019-2020 = **16.9%**

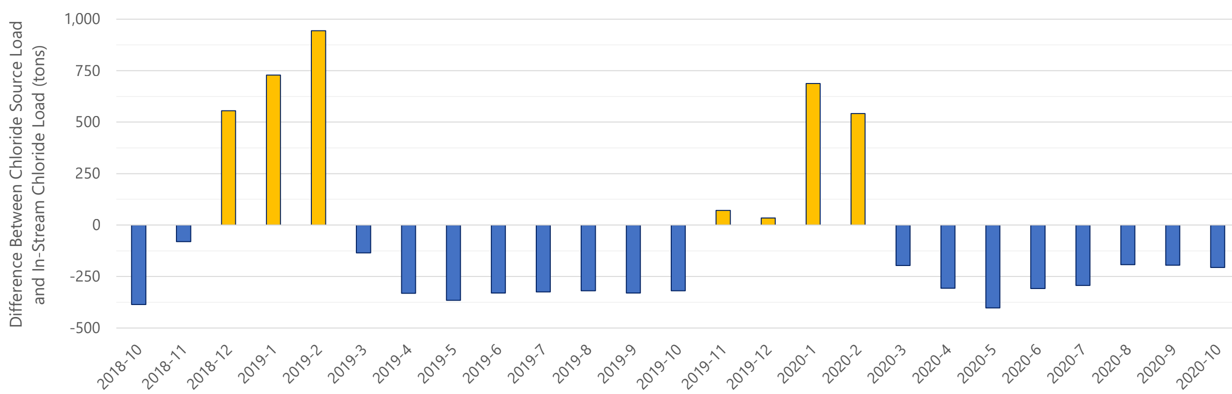
Source: SEWRPC

Figure C.6
Chloride Loads and Mass Balance Analysis Results at Site 11 Bark River Downstream

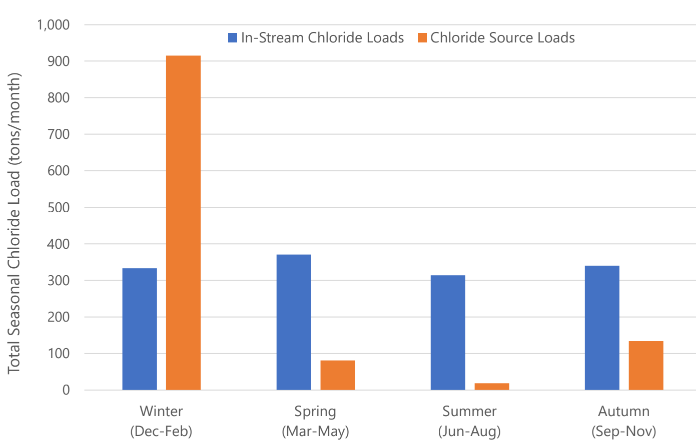
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 11

Chloride mass balance over the study period

- **-17.2%** (in-stream > sources)

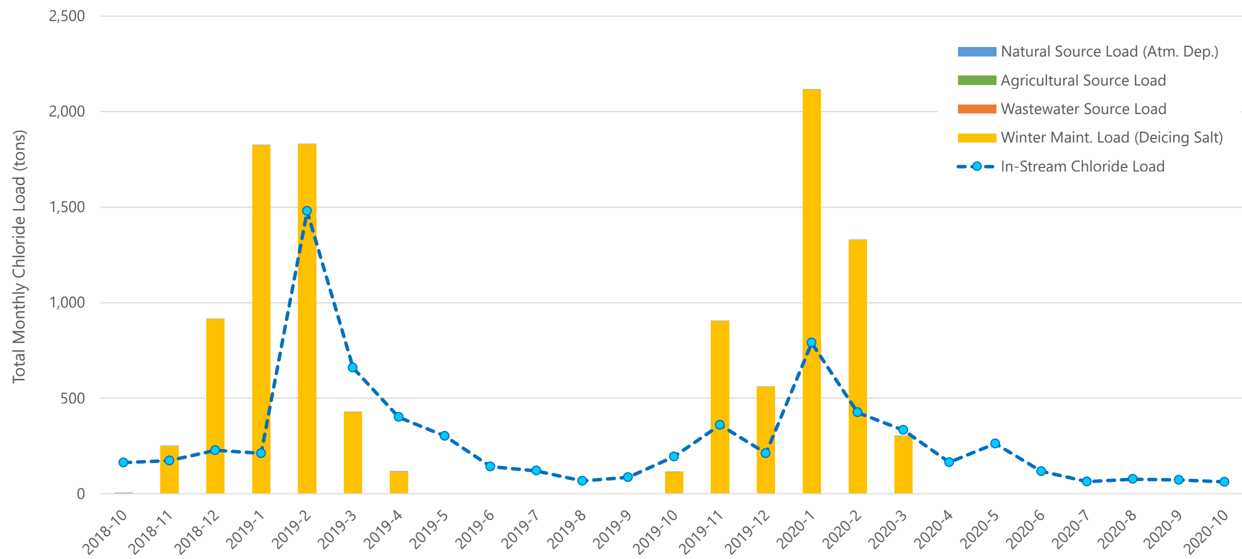
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **110.3%**
- Winter 2019-2020 = **157.1%**

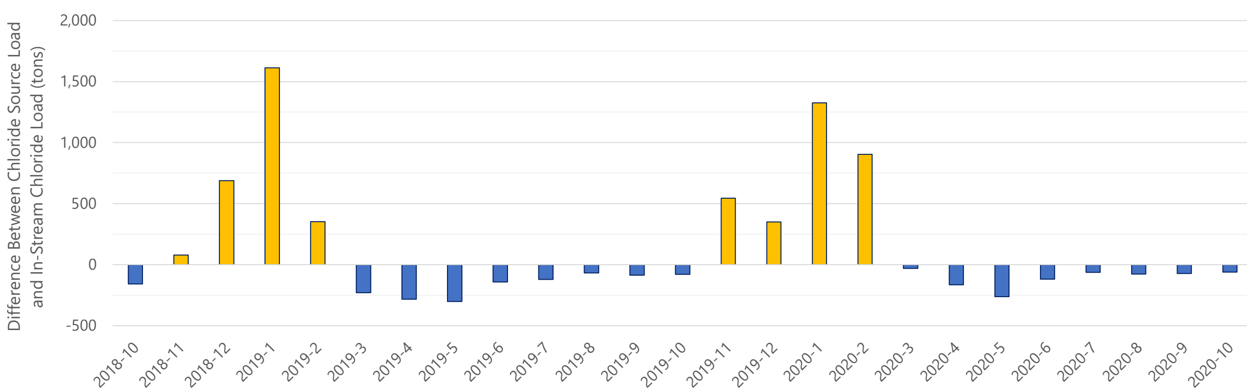
Source: SEWRPC

Figure C.7
Chloride Loads and Mass Balance Analysis Results at Site 12 Lincoln Creek

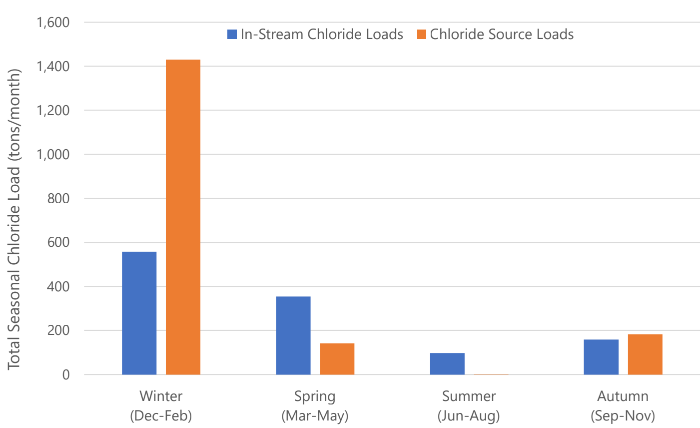
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 12

Chloride mass balance over the study period

- **49.5%** (sources > in-stream)

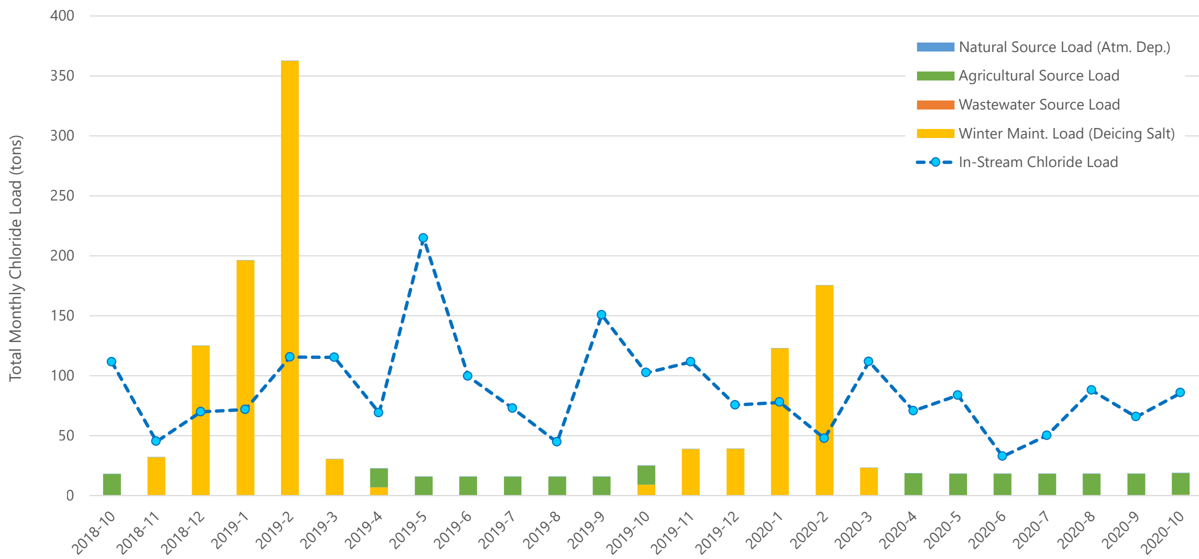
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **47.9%**
- Winter 2019-2020 = **27.1%**

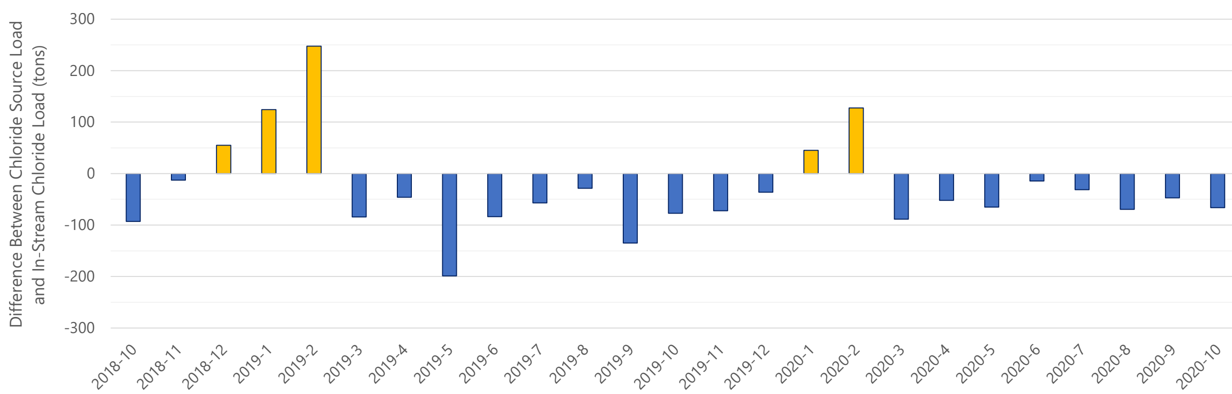
Source: SEWRPC

Figure C.8
Chloride Loads and Mass Balance Analysis Results at Site 16 Jackson Creek

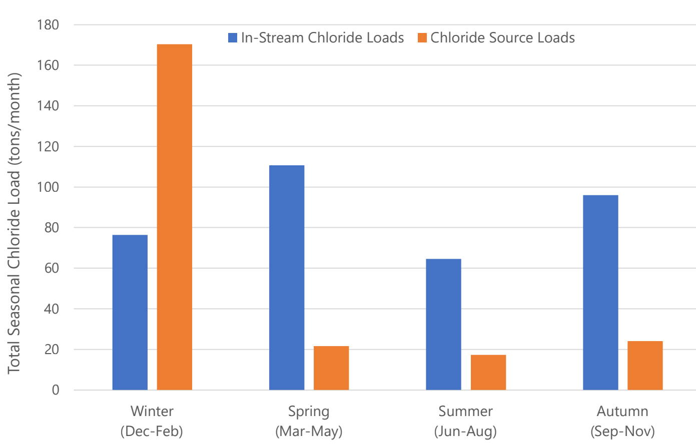
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 16

Chloride mass balance over the study period

- **-34.7%** (in-stream > sources)

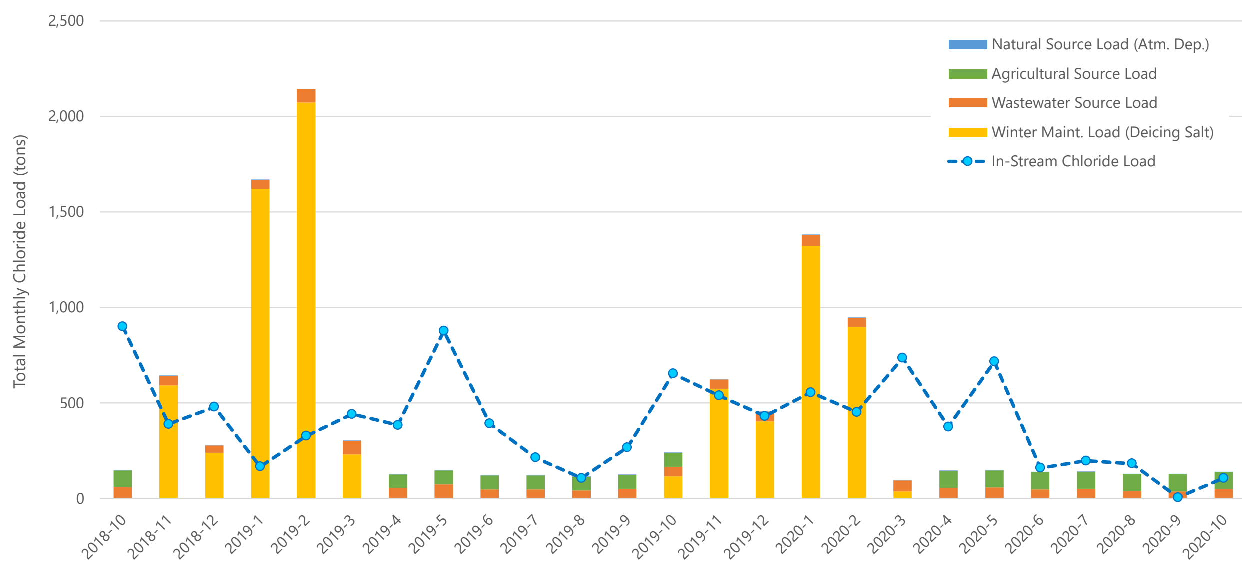
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **191.6%**
- Winter 2019-2020 = **250.5%**

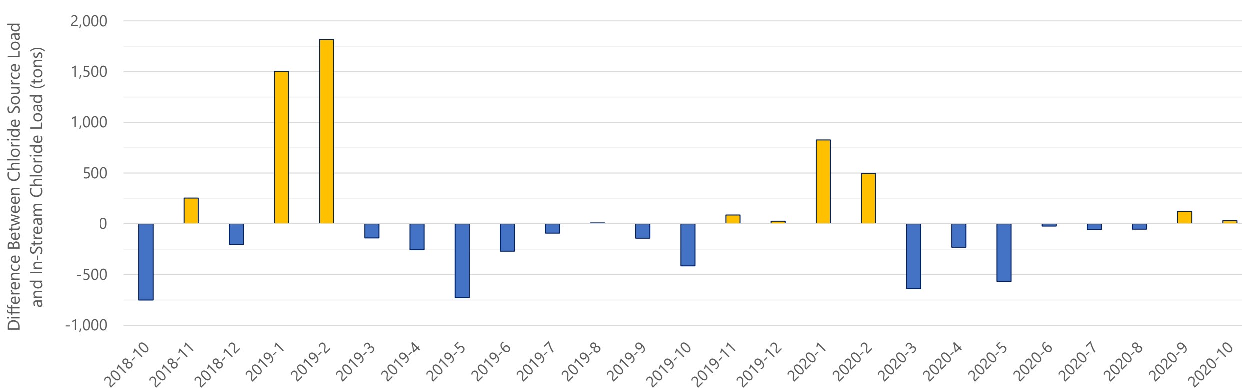
Source: SEWRPC

Figure C.9
Chloride Loads and Mass Balance Analysis Results at Site 25 Root River Canal

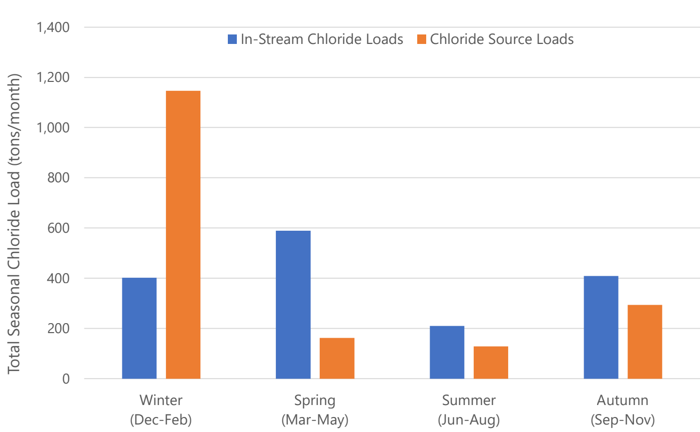
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 25

Chloride mass balance over the study period

- **6.1%** (sources > in-stream)

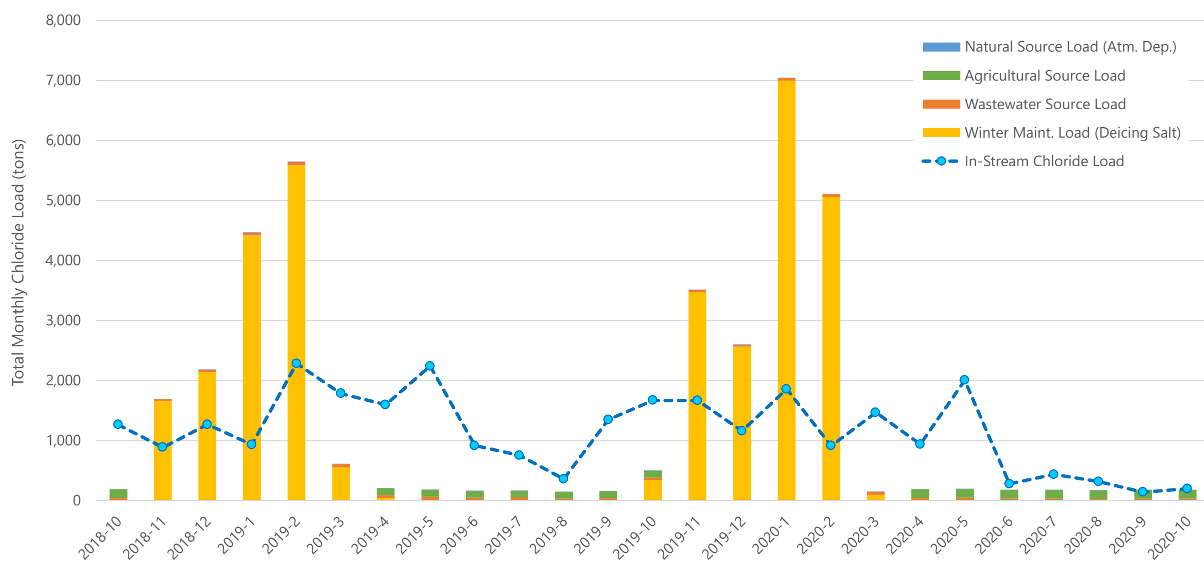
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **60.2%**
- Winter 2019-2020 = **109.3%**

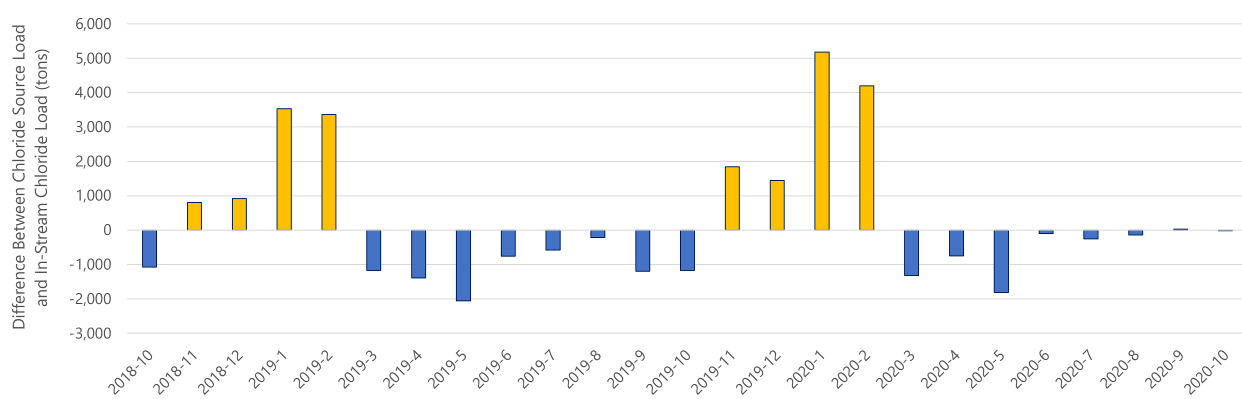
Source: SEWRPC

Figure C.10
Chloride Loads and Mass Balance Analysis Results at Site 30 Des Plaines River

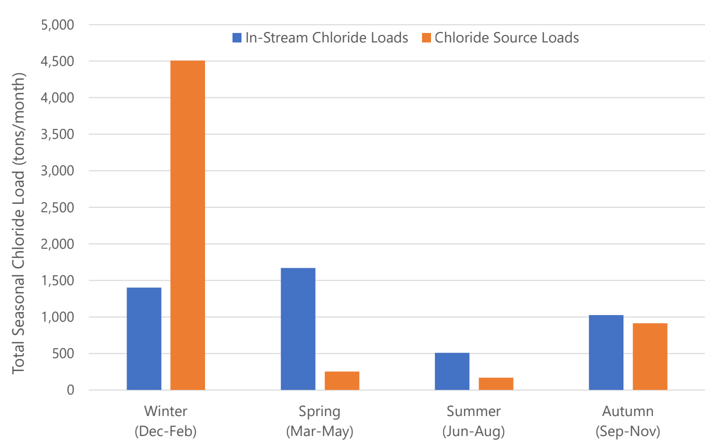
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 30

Chloride mass balance over the study period

- **25.7%** (sources > in-stream)

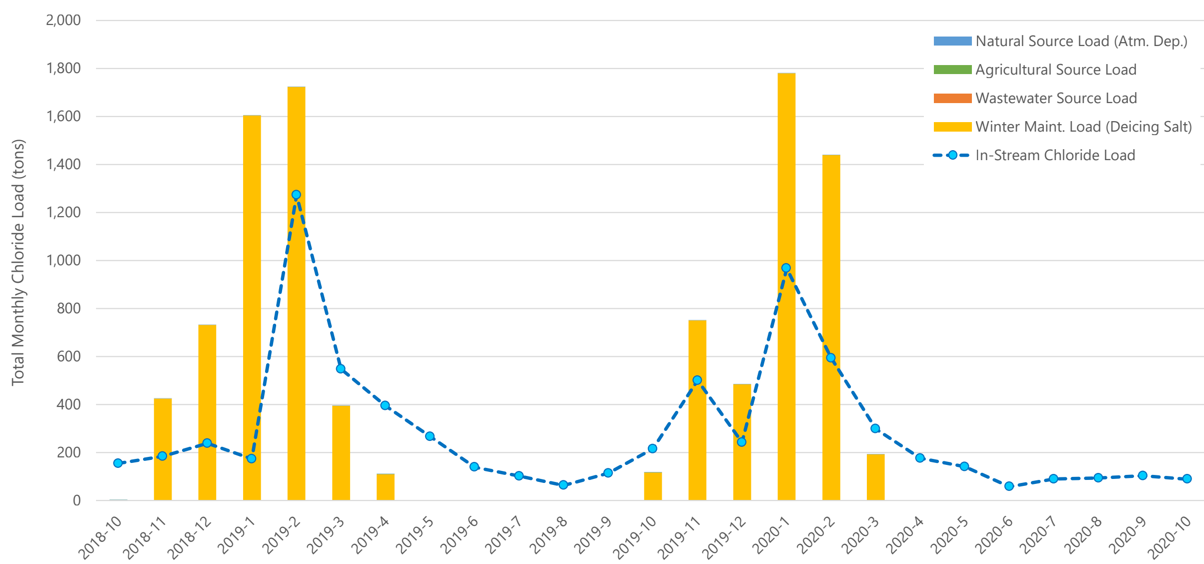
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **98.8%**
- Winter 2019-2020 = **34.3%**

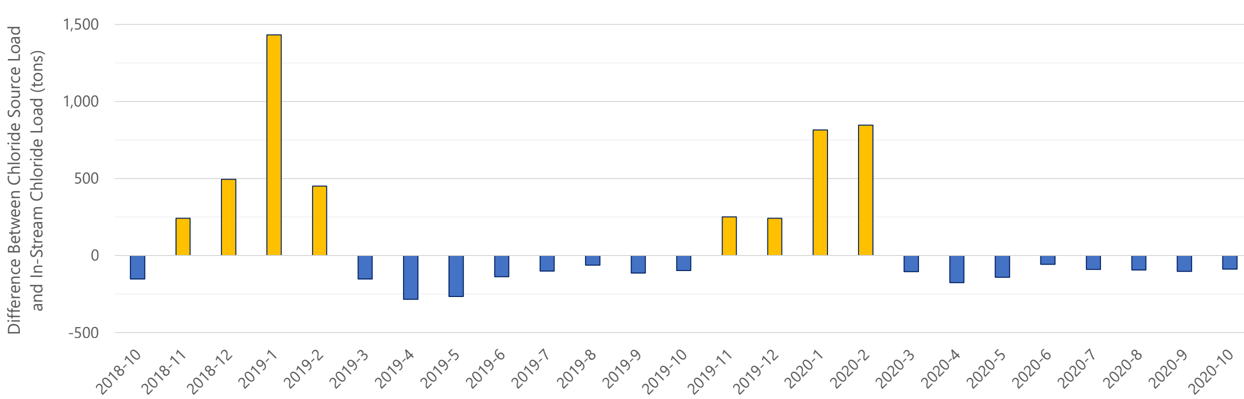
Source: SEWRPC

Figure C.11
Chloride Loads and Mass Balance Analysis Results at Site 53 Honey Creek at Wauwatosa

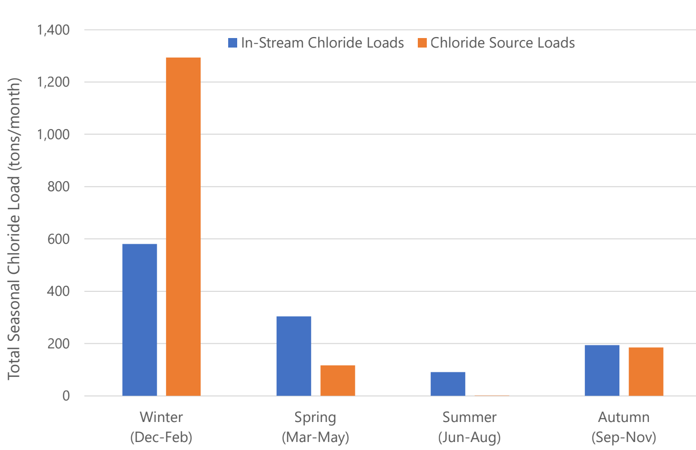
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 53

Chloride mass balance over the study period

- **35.3%** (sources > in-stream)

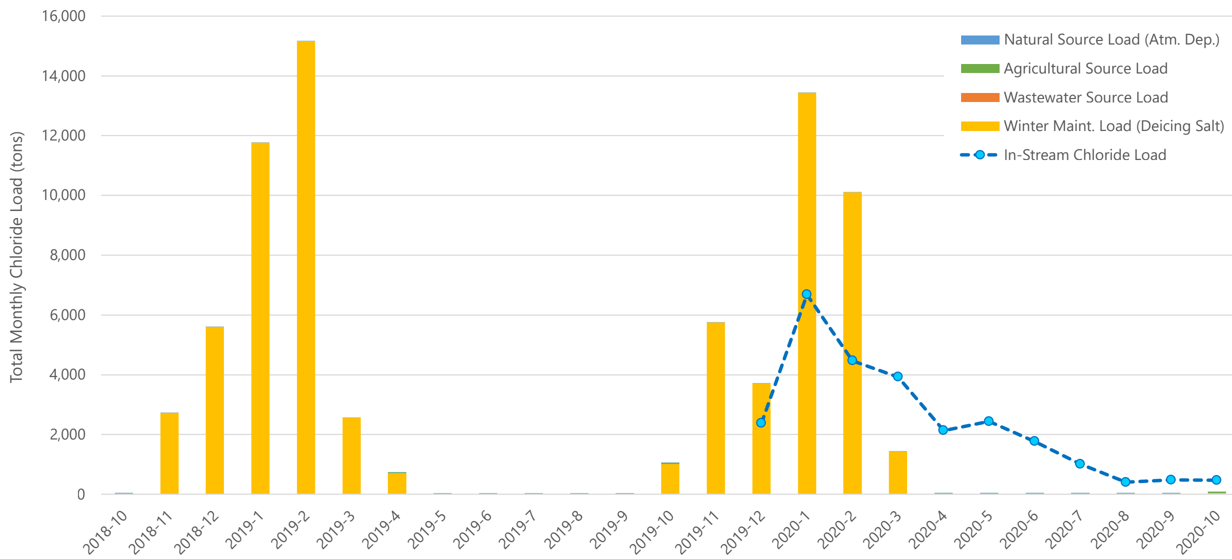
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **46.4%**
- Winter 2019-2020 = **39.6%**

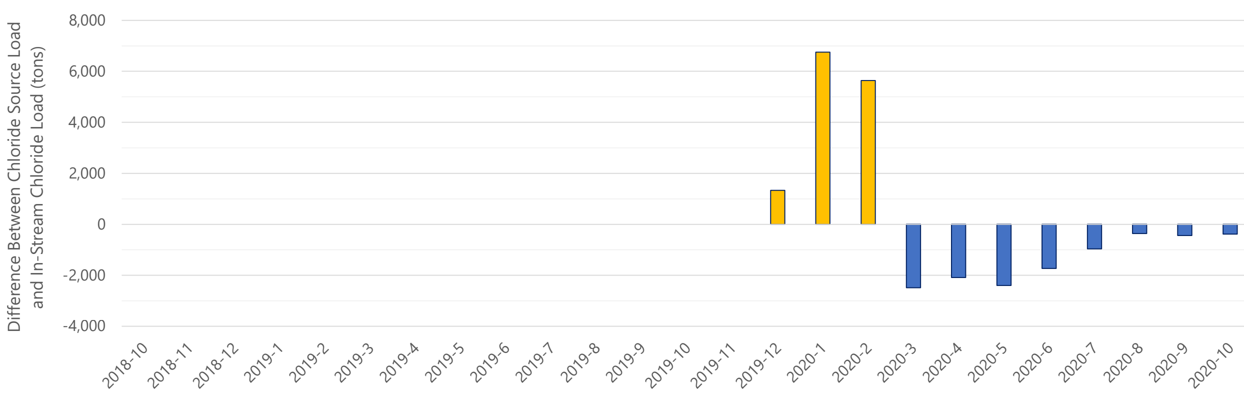
Source: SEWRPC

Figure C.12
Chloride Loads and Mass Balance Analysis Results at Site 57 Menomonee River at Wauwatosa

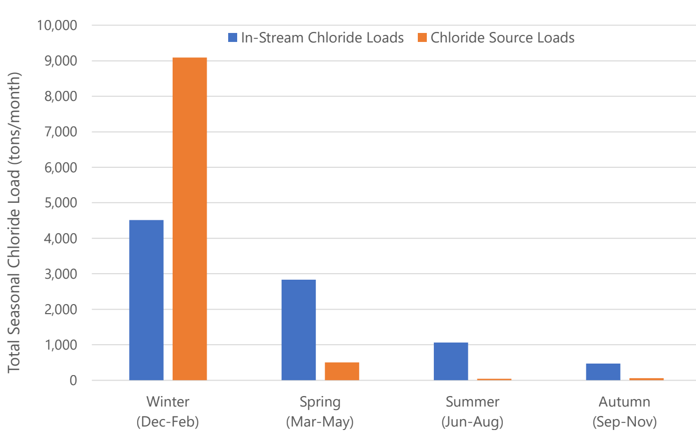
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 57

Chloride mass balance over the study period

- **10.9%** (sources > in-stream)

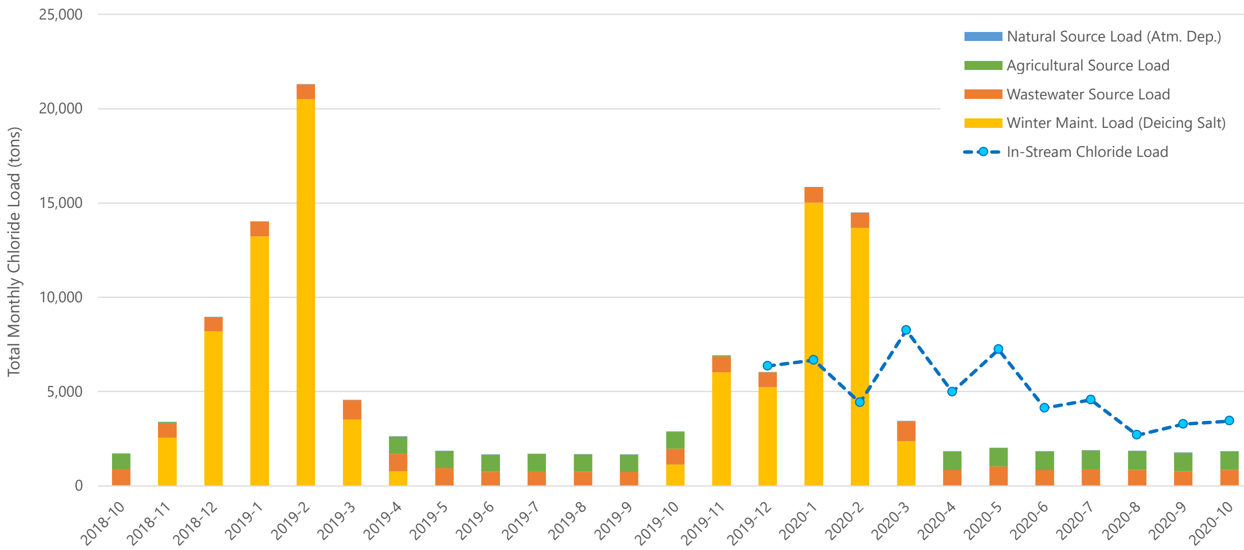
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = N/A
- Winter 2019-2020 = **79.2%**

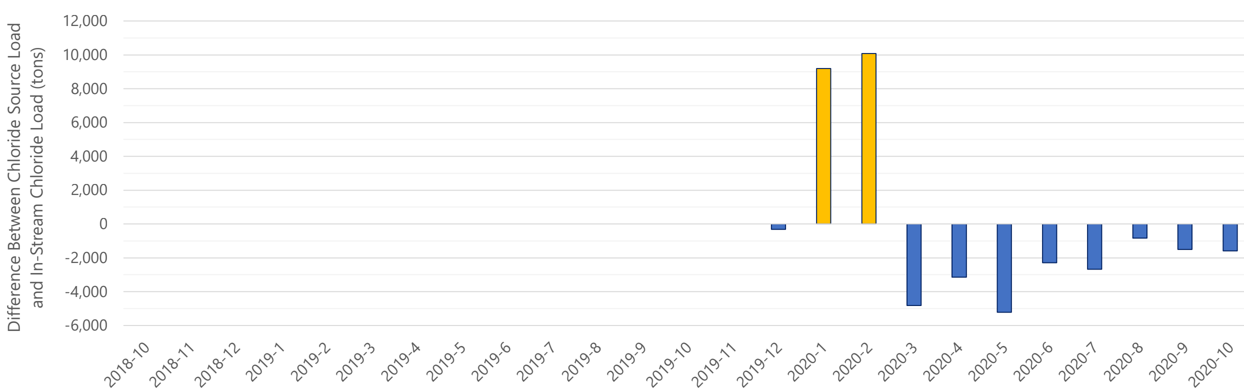
Source: SEWRPC

Figure C.13
Chloride Loads and Mass Balance Analysis Results at Site 58 Milwaukee River at Estabrook Park

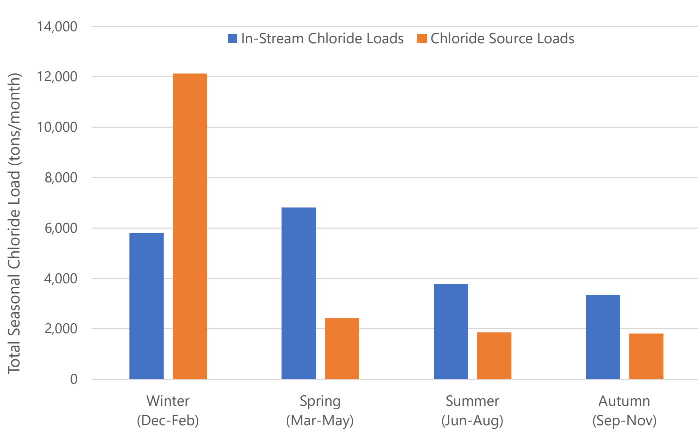
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 58

Chloride mass balance over the study period

- **-5.5%** (in-stream > sources)

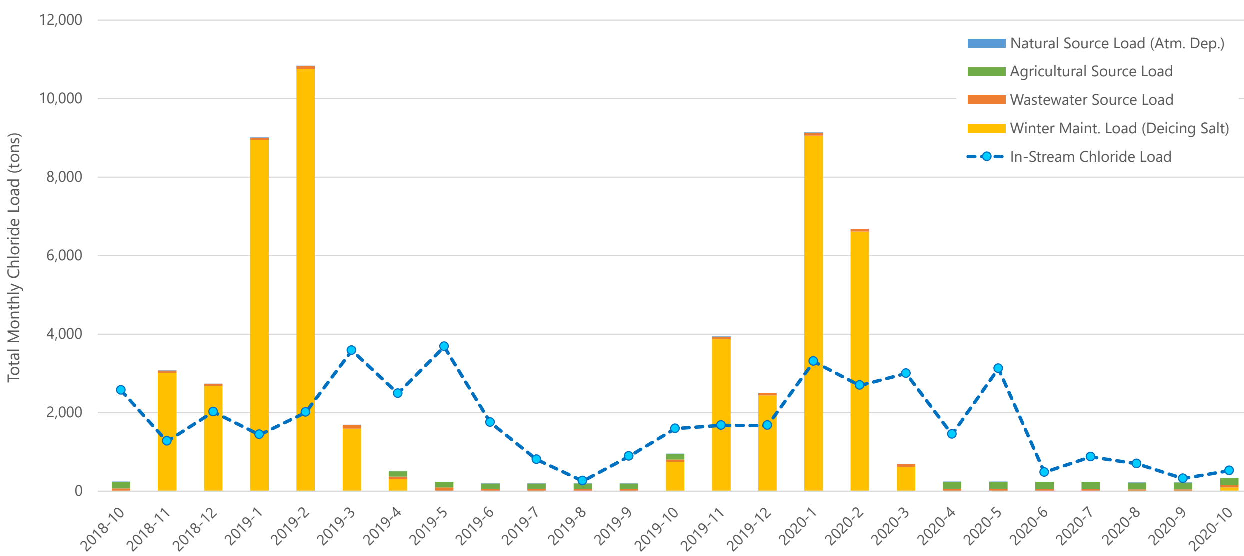
Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = N/A
- Winter 2019-2020 = **114.3%**

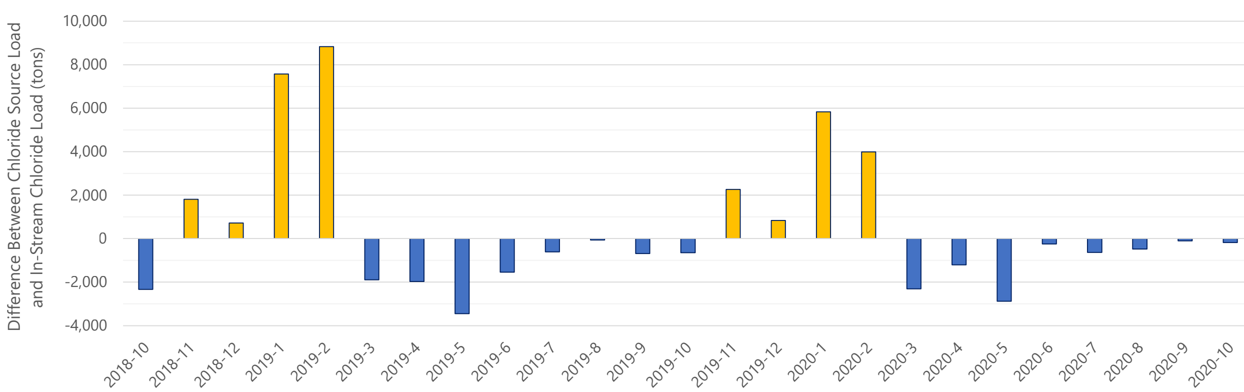
Source: SEWRPC

Figure C.14
Chloride Loads and Mass Balance Analysis Results at Site 59 Root River near Horlick Dam

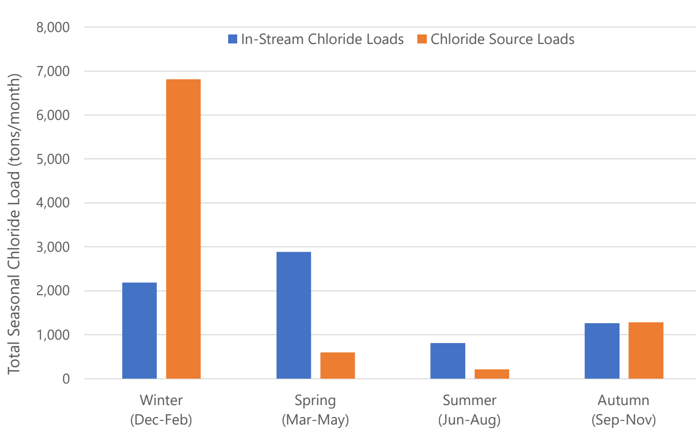
(a) Monthly Chloride Source Loads Versus In-Stream Chloride Loads



(b) Monthly Excess Chloride Loads



(c) Seasonal Chloride Load Comparison



Additional Results for Site 59

Chloride mass balance over the study period

- **24.1%** (sources > in-stream)

Percent of the winter excess chloride load accounted for by excess in-stream chloride load over the following non-winter months

- Winter 2018-2019 = **57.4%**
- Winter 2019-2020 = **62.1%**

Source: SEWRPC