Planning Report No. 57

A CHLORIDE IMPACT STUDY FOR SOUTHEASTERN WISCONSIN

Chapter 6

CHLORIDE CONDITIONS IN SOUTHEASTERN WISCONSIN

This Chapter utilizes information and data from a series of Technical Reports developed by the Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) for the Chloride Impact Study (Study). These reports include SEWRPC Technical Report No. 61, *Field Monitoring and Data Collection for the Chloride Impact Study*, September 2024 (TR-61); SEWRPC Technical Report No. 63, *Chloride Conditions and Trends in Southeastern Wisconsin*, Month 2026 (TR-63); and SEWRPC Technical Report No. 64, *Regression Analysis of Specific Conductance and Chloride on Concentrations*, May 2024 (TR-64);. Refer to these reports for additional details.

6.1 INTRODUCTION

This Chapter evaluates historical and existing chloride trends in the surface water and groundwater of southeastern Wisconsin. The analyses synthesize decades of chloride and specific conductance data (1960-2022) collected by various agencies and groups across 648 streams stations, 117 lakes, and 3,910 wells throughout the study area. By identifying where water resources are degrading, improving, or remaining stable, the analyses summarized in this Chapter (and detailed in TR-63, TR-64, and TR-61) provide the foundation necessary to help verify pollution sources, guide management goals, and evaluate the ongoing threat of chloride to the ecosystems and infrastructure of the Region.

6.2 CHLORIDE IMPACT STUDY MONITORING EFFORT

This section summarizes the SEWRPC monitoring effort completed as part of the Study. Field monitoring included continuous stream monitoring, monthly and event water quality grab sampling in streams, and quarterly lake monitoring efforts.

Why was water quality monitoring necessary for the Chloride Impact Study?

As part of the Chloride Impact Study, Commission staff initiated a monitoring effort to address significant gaps in existing water quality datasets. Previous studies revealed that available data were insufficient to accurately characterize overall chloride conditions of surface waters within the Southeastern Wisconsin Region (Region). Deficiencies in available data were particularly apparent during the critical winter months when the potential contributions of chloride to surface waters are likely to be greatest. By establishing a network of representative water quality monitoring sites at selected stream and lake locations, Commission staff aimed to supplement existing data to provide a more comprehensive assessment of current chloride conditions in the study area. Additionally, staff sought to pair continuously collected specific conductance data with discrete chloride samples to build regression models that could be used in future studies to estimate stream chloride concentrations from specific conductance measurements.

Monitoring Network Design

Which waterbodies were monitored for this Study and how were they chosen?

The monitoring network was designed to establish a high-resolution baseline of chloride conditions in surface waters that were representative of the diverse characteristics of the Region. Because the sources and amounts of chloride that enter the waterways differ greatly throughout the study area, monitoring site selection accounted for several key chloride contributors, including road salt and other deicing materials (public and private), domestic wastewater and water softener discharge to wastewater treatment facilities and private septic systems, industrial wastewater, and agricultural fertilizers. To capture a full range of impacts, the monitoring effort targeted waterbodies vulnerable to these potential sources as well as those less susceptible to pollution.

The land use near a stream as well as the land use throughout a contributing drainage area were important factors when considering potential stream sites to monitor for this Study. Monitoring sites were selected to represent a spectrum of land use conditions, encompassing highly urbanized, rural, agricultural, and mixed-use drainage areas. Where possible, stream monitoring sites were located near U.S. Geological Survey (USGS) stream gage stations to pair water quality data with reliable streamflow measurements. Additionally, some sites were positioned to bracket potential chloride sources, such as effluent from wastewater treatment facilities, to evaluate their impact. The final Study monitoring network included 41 stream sites across 12 major watersheds and six representative lakes. The locations of monitored waterbodies are displayed on Map 6.1. General monitoring site information is detailed in Table 6.1, and photographs of the stream monitoring locations are provided in Figure 2.1 in TR-61. Maps providing land use and other characteristics of the drainage areas of stream and lake monitoring sites can be found in Appendix B and Appendix C, respectively, of TR-61.

Continuous Stream Monitoring

What was the methodology for water quality monitoring of the selected stream and lake locations?

To capture short-term fluctuations in water quality conditions, automated sensors were deployed at all 41 stream monitoring sites to record specific conductance, water temperature, and water depth at five-minute intervals. As was discussed in Chapter 4, specific conductance can be used as a surrogate for estimating chloride levels. It was determined early in the Study that the available equipment for continuous monitoring for chloride were expensive and not robust enough to withstand field conditions. Figure 6.1 illustrates a typical installation of the continuous monitoring equipment used in the Study. The sensors utilized cellular telemetry to transmit data to a cloud-based platform, enabling staff to monitor equipment performance and water quality conditions in near real-time and coordinate field activities to collect discrete grab samples during significant weather events. During routine maintenance visits, staff performed calibration checks using a high-accuracy multiparameter sonde to ensure the accuracy of the data collected by the in-stream continuous monitoring sensors that were deployed year-round.

Discrete Water Quality Sampling in Streams

The continuous data were supplemented by a systematic discrete sampling program. From October 2018 through October 2020, Commission staff collected monthly grab samples at all 41 stream monitoring sites (see Figure 6.2). These samples underwent chemical analysis for concentrations of chloride and other major ions, including calcium, magnesium, potassium, sodium, and sulfate. In addition to routine monthly sampling, a targeted sampling effort was implemented to capture chloride spikes that can occur during and after winter weather events. The targeted weather event grab sampling program extended through the 2020-2021 winter season. Throughout the course of the Study, over 1,100 individual water quality grab samples were collected and analyzed.

Streamflow Measurements

Commission staff conducted manual streamflow surveys at 18 selected stream monitoring sites that were not located near permanent USGS stream gage stations. These surveys utilized portable electromagnetic flow meters to measure water velocity and depth at multiple points within an established cross section. The field measurements were used to estimate streamflow discharge. To better understand how the water depths recorded by the continuous sensors were related to the flow regime at a stream monitoring site, it was necessary to collect streamflow measurements at a range of water level conditions throughout the Study. This supplemental data supported the interpretation of the continuous stream monitoring dataset and water quality data collected at the sites.

Lake Water Quality Monitoring

Six lakes (Big Cedar, Geneva, Little Muskego, Moose, Silver, and Voltz) were selected to represent four distinct lake types: seepage, spring, drainage, and drained. Lake monitoring focused on characterizing seasonal trends and potential chemical stratification. Quarterly field visits included utilizing a multiparameter sonde to record vertical profiles of temperature and conductance at the deepest point of each lake. Using specialized depth-integrated samplers, Commission staff collected discrete water samples at multiple depths in the water column – typically near the surface, mid-depth, and near the lake bottom.[1] These sampling efforts continued year-round, with winter monitoring conducted through the ice to assess whether chloride-laden runoff had settled into the lower depths of the lakes (see Figure 6.3).

Quality Assurance and Quality Control

What steps were taken to make sure the data collected was accurate and the equipment was working correctly?

Rigorous quality control protocols were maintained throughout the Study to ensure the reliability of the monitoring data. Field blank and field replicate samples were collected to evaluate the quality of the sample collection and the precision of the laboratory analysis. For each monthly sampling period, approximately

---

[1] *The mid-depth sampling was located to capture a water sample within the lake's thermocline. The thermocline in a lake is a distinct middle layer of water where the temperature drops rapidly, separating the sun-warmed surface from the cold, deeper water below. This steep temperature gradient acts as a physical barrier that prevents the top and bottom layers from mixing during the summer months.*

five percent of the samples sent for laboratory analysis were collected as blanks and 5 percent were collected as replicates for randomly selected monitoring sites.[2]

Modifications to the continuous datasets were considered only after rigorous review determined there was strong evidence of sensor fouling (accumulation of biological or sediment materials on the equipment). In these cases, Commission staff applied mathematical corrections to account for data collected during the identified periods of fouling.

For a comprehensive technical overview of the field monitoring and data collection for the Chloride Impact Study – including site selection, monitoring sensors and sampling equipment, equipment maintenance, sampling protocols, and data management and quality assurance procedures – refer to TR-61.

6.3 EVALUATION OF MONITORING DATA COLLECTED FOR THE CHLORIDE IMPACT STUDY (2018-2021)

As described in the above Section, Commission staff collected water quality data at sites on numerous streams and lakes in southeastern Wisconsin. Several types of data were collected in both streams and inland lakes. Continuous conductance monitoring using in-stream sensors was conducted at stream monitoring sites. Water samples were collected periodically from stream sites and lakes and chemically analyzed for concentrations of chloride and other ions. The following section presents summary information and insights regarding chloride conditions and dynamics in southeastern Wisconsin streams and lakes from the monitoring conducted by the Commission during the Chloride Impact Study.

Conductance and Chloride Regression Analysis

Specific conductance measurements were used to estimate in-stream chloride concentrations using regression models developed for that purpose as part of the Study and documented in TR-64. These models were developed using paired measurements of specific conductance and chloride collected at the Study stream sampling sites.[3] Two models were developed and applied: a piecewise regression model and a linear mixed effects regression model. The performance of both models was evaluated using standard statistical

---

[2] *Distilled water, which was free of contaminants and dissolved solids, was used to fill the field blank sample bottles. Field replicate samples were independent water quality samples that were collected as close as possible to the same point in space and time as a field sample.*

[3] *Paired data was measured at the same stream location on the same day and time.*

approaches. Additionally, the piecewise regression was evaluated by comparison to measured chloride and specific conductance values from a separate dataset than was used to develop the model.

The piecewise regression model was developed using 818 paired samples at 30 stream monitoring sites (see Map 6.2 and Table 6.2). This model was statistically significant, did not overfit the training data, and variation in specific conductance accounted for over 98 percent of the variation in chloride concentration (see Figure 6.4). This model was applied to estimate chloride concentrations from the continuous specific conductance collected at the 30 stream monitoring sites.

During development of the piecewise regression model, Commission staff found that it systematically overestimated chloride concentration at 10 stream sites (see Map 6.2) The drainage areas associated with these sites had low percentages of urban land use, and specific conductance at these sites was low, rarely exceeding 1,000 microSiemens per centimeter (μS/cm). From these 10 sites, 253 paired samples were used to develop a linear mixed effects regression model that included a unique equation for converting specific conductance measurements to chloride for each stream site. At one site a model could not be developed to estimate chloride concentration from specific conductance (see Map 6.2).

Monitoring Effort Analysis (2018-2021)

Between October 2018 and August 2021, the Commission collected over 1,100 chloride samples and 8.9 million specific conductance observations across 41 monitoring sites on 31 streams within the Study Area. Applying the piecewise regression and linear mixed effects regression models discussed above to the specific conductance observations resulted in 8.7 million estimated chloride concentrations. These observations were analyzed to better understand how chloride concentrations vary across the Study Area, for how long sites exceed harmful thresholds, and how chloride dynamics are influenced by factors like weather events, stream discharge, and watershed land use.

Stream Chloride Conditions and Threshold Exceedance

Measured mean chloride concentrations among the stream monitoring sites ranged between 17.6 and 571.3 mg/l (see Map 6.3) while regression model estimated mean concentrations for the 40 stream sites ranged between 19.4 and 493.6 mg/l. In general, there was good correspondence between the estimated and measured concentrations of chloride. In grouping stream monitoring sites by their chloride characteristics, several unifying factors emerged: watershed land use, stream size, and the presence and size of winter spikes in chloride concentrations. The highest chloride concentrations observed were in small streams with highly urban watersheds while the least chloride-impacted streams were in watersheds with significant proportions of wetlands and woodlands.

As discussed in Chapter 5 of this Planning Report, Commission staff established seven chloride thresholds ranging from 10 mg/l to 1400 mg/l in order to evaluate harmful impacts from chloride on the Region's waterbodies. The estimated continuous chloride concentrations were analyzed to determine the percent of measurements (see Table 6.3) and longest contiguous durations that each site exceeded each threshold. A summary of the number of sites that exceeded the various thresholds can be found in Figure 6.5.

- Nearly all the monitored streams are currently experiencing chloride concentrations that are elevated above baseline conditions (less than 10 mg/l). All sites exceeded baseline conditions for the vast majority of the time and for extended contiguous periods.

- At most stream monitoring sites, estimated chloride concentrations were higher than 35 mg/l most of the time. This concentration is the lowest to negatively affect freshwater life among several trophic levels, including impacts to diatoms, fish, mussels, and zooplankton. Consequently, most of the monitored streams are potentially experiencing these negative impacts the majority of the time.

- The Canadian chronic chloride toxicity threshold, which is based on seven-day exposure for fish and macroinvertebrates, is 120 mg/l. Twenty-two sites had estimated chloride levels that exceeded this threshold for seven consecutive days at least once during the study period. Concentrations at 16 sites did not exceed this threshold during the monitoring period.

- The U.S. Environmental Protection Agency (USEPA) chronic toxicity threshold for chloride, which is based on a four-day average concentration, is 230 mg/l. Fifteen sites had estimated chloride levels that exceeded this threshold for four consecutive days at least once and five sites with highly urban drainage areas exceeded this threshold for more than half of the study period.

- The Wisconsin chronic toxicity criterion for chloride for fish and aquatic life, which is based on a four-day average of the daily maximum concentrations, is 395 mg/l. Ten sites exceeded this threshold for four consecutive days at least once with six sites exceeding this threshold more than 15 percent of the study period.

- The Wisconsin acute toxicity criterion for chloride for fish and aquatic life, which is based on a daily maximum concentration, is 757 mg/l. Nine sites exceeded this threshold at least once with six sites exceeding this threshold for more than 5 percent of the dataset. These six sites either had highly urban drainage areas or were likely influenced by impervious surfaces near the monitoring sites.

- The Commission established a severe impact threshold at 1,400 mg/l. Seven sites exceeded this threshold at least once while three sites exceeded this threshold for more than 5 percent of the dataset. These three sites, which were the most chloride-impacted sites within the Study, all had highly urban drainage areas.

Stream Chloride Dynamics and Influencing Factors

Commission staff also analyzed the continuous estimated chloride data to better understand stream chloride dynamics and how chloride concentrations respond to individual weather events. This analysis revealed that chloride concentrations are highly dynamic in streams and particularly in small streams draining urban areas. The following patterns in response to weather events were repeatedly observed throughout the Commission's continuous estimated chloride record and more details can be found in Chapter 3 of TR-63.

- Chloride concentrations in small streams can fluctuate by orders of magnitude within hours during and following winter storm events, with chloride generally spiking in urban watersheds. The most notable of these events occurred between midnight on January 11, 2020 and 3:25 p.m. January 13, 2020, when chloride concentrations in Lincoln Creek rose from 40 mg/l to nearly 4,000 mg/l following one freezing rain and two snowfall events (see Figure 6.6). These rapid spike events are likely driven by runoff of chloride salts applied to roads, parking lots, and other impervious surfaces. Although these spikes were most pronounced in highly urban watersheds, similar spikes were observed following winter events in more suburban and even some rural watersheds. Consequently, there appeared to be little delay between chloride application and stream impacts in some systems.

- Spring snow melt events can cause either spikes or dilutions in chloride concentrations, depending on preceding weather conditions and watershed land use. In rural watersheds, the influx of runoff during spring snow melt can dilute chloride concentrations in streams. In urban watersheds, spring snow melt can cause residual salt applied from preceding winter storm events to enter the stream and increase chloride concentrations.

- Prolonged dry periods, such as droughts, also can cause elevated chloride concentrations. These conditions were noted in the southern portion of the study area during summer 2021, when specific conductance values significantly exceeded those of the preceding summers for these monitoring sites. These elevated drought conductance measurements may represent groundwater chloride contributions to the stream, impacts of evaporation, or an influence in groundwater-sourced calcium and magnesium in the stream.

- Non-winter precipitation events typically caused lower chloride concentrations through dilution. Estimated chloride concentrations rebounded to the former higher concentrations within several hours to days depending on the size of the stream and its contributing drainage area, with smaller streams and watersheds rebounding more quickly and larger streams rebounding more slowly.

- Rivers with larger watersheds often have more drawn-out responses to precipitation events than streams with small watersheds. This effect was observed both in winter spikes and summer dilutions in chloride concentration, where small flashy streams would respond within hours to days while large rivers could exhibit a similar response over a week or more. This delay was likely due to the higher water volume in large rivers as well as the extended contribution of runoff from the more remote reaches of large watersheds.

Commission staff also evaluated other factors influencing stream chloride concentrations including watershed land use, seasonal patterns, streamflow, wastewater treatment plant effluent and other point source discharge, and propagation of chloride-laden water downstream. More details can be found in Chapter 3 of TR-63.

- Chloride concentrations were generally lowest in streams with little to no urban land uses in their watersheds and concentrations were highest with high percentages of urban land use. Mean stream chloride concentrations for the study period 2018-2021 rapidly increase with increasing percentage of urban land use as well as the percentage of land devoted to roads and parking lots in their contributing drainage areas (see Figure 6.7). These relationships suggest that deicing activities may be the major factor driving stream chloride concentrations, although other factors associated with urban lands such as water softeners, storm sewer systems, and wastewater treatment plants likely contribute as well.

- Seasonal patterns in stream chloride concentrations were highly influenced by watershed land use. For streams with urban watersheds, winter had the highest chloride concentrations followed by spring and then summer and fall. However, estimated chloride concentrations for streams with rural watersheds in winter months were not substantially higher than other seasons, and spring months may have had the lowest chloride concentrations due to dilution from snow melt and spring rains. With the exception of drought conditions, summer and fall months generally had low chloride concentrations for most stream monitoring sites.

- Increased streamflow generally decreased chloride concentration through dilution, as observed in nearly all non-winter precipitation events and even some winter precipitation events. Consequently, understanding patterns in streamflow was important for interpreting patterns in chloride concentrations.

- During prolonged dry periods, chloride from wastewater treatment facilities and other point sources can be a significant proportion of the total chloride load in streams. A more detailed analysis was conducted using wastewater effluent data combined with in-stream chloride and streamflow data for the Honey Creek near the Village of East Troy and the Fox River at Waukesha monitoring sites. The impact of wastewater treatment facilities on stream chloride concentrations depended on the amount of point source effluent discharged, the chloride concentration in the effluent, the volume of flow in the receiving stream, and whether other sources were delivering chloride into the receiving stream.

Lake Chloride Conditions

Commission staff collected 343 chloride samples in six lakes between August 2018 and February 2021 to better understand current chloride conditions in lakes that are representative of the Region. Each lake was sampled quarterly with samples collected at multiple water depths along a vertical profile. The lake chloride analyses were somewhat limited due to the small size and short time period of this dataset.

Mean chloride concentrations across the monitored lakes ranged from 35 mg/l for Voltz Lake in Kenosha County to 185 mg/l for Little Muskego Lake in Waukesha County. There was little variation in chloride concentrations with depth for all but one of the study lakes. Only Little Muskego and Voltz Lakes exhibited substantial seasonal differences in chloride concentrations. Despite the short sampling period, four lakes exhibited significant changes in annual mean chloride concentrations over time, with two lakes increasing and two lakes decreasing; the two lakes with no significant change in annual mean chloride concentrations had the longest lake residence times. As with the stream sites, mean study period lake chloride concentration was significantly correlated with the percentage of roads and parking lots in the watershed. However, in contrast to the stream sites, mean lake chloride concentration was not significantly correlated with the percentage of urban land uses. More details on the lake analyses can be found in Chapter 3 of TR- 63.

6.4 CHLORIDE CONDITIONS IN STUDY AREA STREAMS AND RIVERS

The following section summarizes the extensive analyses conducted to assess historical and existing chloride conditions and trends in streams and rivers of the study area. The analyses included water quality data from the 1960s through 2022 compiled by a variety of Federal, State, local agencies; universities; nonprofit organizations; and citizen monitoring groups. Specific conductance data were also collected to supplement and help interpret the chloride data and trends where necessary. The overarching goal of this analysis was to determine the extent to which streams and rivers in the study area have been impacted by chloride pollution and to what degree chloride conditions in these waterways are improving, becoming worse, or remaining stable.

Strategy for the Evaluation of Rivers and Streams in the Study Area

What were the sources for the water quality data used to assess chloride conditions and trends in streams and rivers?

Water quality data for streams and rivers in the study area were compiled from ten different agencies and organizations. The primary sources for chloride and/or specific conductance data included the Milwaukee Metropolitan Sewerage District (MMSD), WDNR, SEWRPC, U.S. Geological Survey (USGS), Milwaukee Riverkeeper, City of Racine Public Health Department, City of Oconomowoc, Eagle Spring Lake Management District, the University of Wisconsin-Milwaukee (UWM), and the U.S. Environmental Protection Agency (USEPA).

Developing Stream Assessment Reaches

How were rivers and streams evaluated for chloride conditions and historical trends?

To better understand the long-term trends and current health of the local waterways, Commission staff compiled all available data from the sources described above for a time period spanning more than 60 years. The Study analyzed nearly 100,000 chloride and specific conductance measurements. This data was collected from 1,152 unique locations on 230 distinct streams, providing a comprehensive historical record of how chloride levels in the Region’s waterways have shifted over the decades.

To turn this large amount of data into a clear analysis framework, Commission staff organized those portions of the study area streams that had chloride and/or specific conductance measurements into stream "assessment reaches." These assessment reaches were defined segments of rivers and streams grouped together based on similar water flow and physical characteristics. Using geographic information systems (GIS) and the State of Wisconsin hydrography databases, Commission staff grouped these river segments to account for both natural geography and human influence. For instance, the segments were specifically subdivided at WWTP discharge points as well as adjusted for surrounding land use patterns to ensure the analysis accurately reflects how different environments impact water quality.

The outcome of this effort was 412 distinct stream "assessment reaches" throughout the study area that allowed for the analysis of chloride conditions and trends over time. The location of these stream assessment reaches, represented as the midway point of each reach length, are shown on Map 6.4.[4] Stream assessment reaches were identified based on a two letter identifier for the major watershed (e.g. FX for the Fox River watershed) and a unique number identifier. Major watersheds are shown on Map 2.1 of this Report.

The Full Historical Record (1961-2022) and Recent Period (2013-2022) Datasets

The complete ("full") dataset was comprised of nearly 48,000 chloride samples and 51,000 specific conductance measurements, collected over more than six decades. While the total volume of data is massive, it was distributed unevenly across the 412 assessment reaches in the study area. For instance, while some assessment reaches have thousands of datapoints, over 150 reaches lack any chloride measurements at all, and 72 reaches had 10 or fewer chloride measurements. For assessment reaches with limited or no chloride data, specific conductance measurements were used as a general indicator of chloride conditions and trends.[5]

To understand existing chloride conditions in the study area, the Study used "recent" datasets of chloride and specific conductance measurements collected from 2013 through 2022, where available. During this recent period, 312 assessment reaches had either chloride and/or specific conductance samples. These reaches contained over 15,500 chloride samples and 21,000 specific conductance measurements.

---

[4] Details for each stream assessment reach, including reach name, water body identification code (WBIC), stream order, reach length, number of chloride and conductance samples, and date range of the samples can be found in Table 4.2 of SEWRPC Technical Report No. 63.

[5] Because conductance is easy and low cost to measure, there is often more conductance data available for streams than chloride data. Conductance acts as a fairly reliable proxy for chloride, sometimes allowing gaps in datasets to be filled.

Assessing Robustness and Balance of Assessment reaches

To ensure scientific integrity and valid comparisons across stream assessment reaches, chloride and specific conductance datasets were categorized as either "balanced" or "imbalanced." This classification was made separately for the full period of record and for the recent period of record based on specific criteria that accounted for inherent irregularities in sample size, time periods of sample collection, and seasonal coverage. These criteria were applied separately to the chloride and specific conductance datasets for each assessment reach. Full period and recent period datasets were evaluated for balance based on three primary factors:

- Volume: Minimum sample counts (20 samples for the full period of record; 10 samples for the recent period of record).
- Duration: Spread of sample dates (e.g., for the full record – at least a 15 year coverage and at least one sample collected in the year 2000 or later).
- Seasonality: Sufficient representation of winter conditions (road salt influence) versus summer/fall (baseline conditions).

The Study assessment reaches found to have balanced chloride and conductance datasets included the vast majority of all samples collected. For the full historical period (1961-2022), 74 assessment reaches had balanced chloride datasets, and 86 reaches had balanced conductance datasets. These balanced chloride datasets comprised 83 percent of all chloride data and the balanced conductance datasets comprised 80 percent of all conductance data. For the recent period (2013-2022), 84 assessment reaches had balanced chloride datasets and 133 had balanced conductance datasets, comprising 85 percent and 90 percent of the datapoints, respectively.

While imbalanced datasets can still offer valuable insights into conditions of an assessment reach, identifying them as imbalanced was crucial as their summary statistics might not be directly comparable to those from other assessment reaches. Some analyses in this Study used only balanced datasets to ensure comparability between assessment reaches.

An Overview of Chloride Conditions and Trends in the Streams and Rivers of the Study Area

Temporal, geographic, and seasonal trends in stream chloride conditions were assessed and summarized where sufficient data was available to do so for both the recent period and full datasets. To provide a comprehensive overview, the data was analyzed at multiple spatial scales: the study area as a whole, major watersheds within the study area, and the 412 individual localized stream assessment reaches detailed earlier. The discussion that follows is meant to give a general overview of historical and recent chloride conditions and trends in the entire study area. More detailed assessments for each major watershed in the study area will be provided later in this Section as well as in Chapter 4 of TR-63.

This assessment frequently uses median values of chloride and specific conductance for streams. The median value is a good representative of the baseline conditions of a stream and indicates that half of the measurements were above that concentration, and the other half were below. Median values are largely unaffected by significantly high or low values (outliers). Mean chloride or specific conductance levels represent the average of all measurements and are strongly influenced by outliers. Mean values were used in analyses when it was important to factor in extreme peaks in chloride values.

Map 6.5 displays the full period median chloride concentrations at assessment reaches throughout the study area, distinguishing between balanced datasets (represented by circles) and imbalanced datasets (represented by triangles). For stream assessment reaches with balanced datasets, median chloride concentrations ranged from 14 mg/l at Mukwonago River reach FX71 to 663 mg/l within the Mitchell Field Drainage Ditch (OC04). Geographically, the highest median concentrations were mostly clustered in Milwaukee County and eastern Waukesha County. Considering all reaches (balanced and imbalanced), maximum chloride concentrations varied from 8 mg/l on the Lower Pine River (RK71) to 9,800 mg/l at Noyes Creek (MN21).[6]

Median chloride concentrations for stream assessment reaches during the recent period of record are shown geographically on Map 6.6. In reaches with balanced datasets, median chloride concentrations ranged from 13 mg/l at an unnamed tributary to the Pike River (PK10) to 400 mg/l at Honey Creek in Wauwatosa (MN11). Considering the entire dataset, maximum chloride concentrations ranged from 19 mg/l at an unnamed tributary to Whitewater Creek (RK27) to 7,800 mg/l at the 43rd Street Ditch tributary (KK09) within the Kinnickinnic River watershed.[7] Similar to the full period of record, the highest median and maximum concentrations are generally found in Milwaukee County and eastern Waukesha County,

---

[6] *A maximum chloride concentration of 44,000 mg/l was observed at Wilson Park Creek (KK06) during the full period of record but was considered an outlier.*

[7] *A maximum chloride concentration of 26,300 mg/l was observed at Wilson Park Creek (KK06) during the recent period of record but was considered an outlier.*

suggesting consistently elevated concentrations through time. Summary statistics for individual assessment reaches for both the recent and full periods of record a can be found in their corresponding watershed sections in Chapter 4 of TR-63.

Commission staff established seven water quality and biological impact thresholds for chloride concentrations in surface waters ranging from 10 mg/l to 1400 mg/l in order to evaluate harmful impacts from chloride on the Region's waterbodies (see Table 5.2 in this Report for details of the thresholds). Figure 6.8 displays the distribution of stream chloride samples for the entire study area for the full period of record (1961-2022, 47,669 samples) and recent period of record (2013-2022, 15,565 samples), categorized by threshold ranges. Comparing the distributions between full period and recent period datasets reveals a general worsening of stream chloride conditions. Notably, streams at historical background chloride concentrations (≤10 mg/l) have virtually disappeared in the recent period in the study area, dropping from an already low 1.7 percent of samples in the full record to just 0.3 percent in the recent period. Similarly, the proportion of samples falling in the lower range of the onset of biological effects (10-35 mg/l) shrank from 11.5 percent to about 6 percent. While the mid-range threshold associated with considerable biological impacts (35-120 mg/l) remained stable – accounting for nearly half of all samples in both period datasets – the data shows a distinct upward migration of chloride samples into higher toxicity brackets for the recent period. This upward shift is most evident at the highest end of the spectrum. Total exceedances of the Wisconsin chronic chloride toxicity threshold (>395 mg/l) jumped from approximately 6 percent of the samples across the full record to almost 11 percent in the recent period. Furthermore, exceedances of the State's acute toxicity threshold (>757 mg/l) rose from just below 2 percent to above 3 percent of samples. Importantly, the portion of chloride samples that exceeded the threshold for biological harm while remaining below the threshold for potential regulatory action in the State (≥395 mg/l) was 92 percent of samples in the full record and 90 percent of samples in the recent period, raising questions as to whether the State's chloride guidelines provide enough protection.

What streams in the study area are considered impaired for chloride by the State of Wisconsin?

During the recent period of record there were 1,677 chloride samples in the study area (10.7 percent of all recent samples) that exceeded the State's chronic toxicity threshold of 395 mg/l and 506 samples (3.3 percent of all recent samples) that exceeded the acute toxicity threshold of 757 mg/l. It is important to note that single sample exceedances of these thresholds do not automatically result in a 303(d) impairment listing, as other criteria must also be met.[8]

[8] *The State of Wisconsin criteria for 303(d) chloride impairment listing are described in Chapter 5 of this Report.*

As of 2024, 33 waterbodies in the study area met the State's chloride impairment criteria. The locations of these impaired stream segments are shown on Map 6.7. Table 6.4 provides details for the State-listed chloride-impaired waterbodies in the study area, including segment extent, impairment type, listing date, associated Chloride Study assessment reaches, and the maximum recent chloride concentration observed in each segment. All 33 stream segments are impaired for chronic toxicity, and 23 of those are also impaired for acute toxicity (more details on the Wisconsin chloride standards can be found in Chapter 5 of this Report). These listed streams segments cover 61 of the Chloride Impact Study assessment reaches, 54 of which have recent chloride data. Among those 54 reaches, 43 are within streams with both chronic and acute impairments, while 11 are in streams with only chronic impairments. It is important to consider that of the roughly 3,880 miles of mapped perennial and intermittent streams in the study area, only 13 percent had chloride data collected in the recent period, and far fewer had sufficient data to assess water quality criteria impairments.

In addition to stream assessment reaches that were within chloride impaired streams, there were 26 stream assessment reaches that were not currently classified as chloride-impaired but have been identified by Commission staff as "high risk" for future impairment listing. This high risk classification was assigned to reaches with at least one recent-period chloride sample that was within 10 percent of the State's chronic toxicity threshold (> 355 mg/l). The locations of these high risk assessment reaches as well as reaches that fall within State-listed stream segments are shown on Map 6.8.

Temporal Trends

How have chloride conditions in streams and rivers changed over time?

Data from 1961 through 2022 reveals a clear, statistically significant upward trajectory in composite yearly median chloride concentrations within the study area, as displayed in Figure 6.9.[9] Statistical analysis shows an average increase, calculated from all chloride data in the full period of record, of approximately 1.6 mg/l per water year.[10] The lowest annual median of 14 mg/l was observed in 1961, the first year of the full period of record, while the highest annual median of 170 mg/l was observed in 2003. While recent years show a plateau or even a slight decrease in yearly median levels in Study streams, it is unclear if the lower median concentrations represent normal variability or are part of a more significant trend.

---

[9] It should be noted that annual medians for water years in 1961, 1962, 1963, 1966, and 1979 were sampled less frequently (less than 75 samples) when compared to other years, which may affect the yearly median values.

[10] Water year, running from October 1 through September 30, was used for this analysis because it keeps data for a single winter season logically intact rather than splitting winter data into two separate calendar years.

This Chapter sometimes uses box plot figures to visually display large amounts of data. An explanation of box plot symbols is given in Figure 6.10. To further evaluate chloride trends, the full period dataset was divided into five distinct time periods: 1961-1977, 1978-1986, 1987-1993, 1994-2012, and 2013-2022. Analysis confirmed a significant progressive increase in chloride levels across nearly all timeframes within the study area as illustrated in Figure 6.11. During the initial 1961-1977 period, the study area median sat at roughly 50 mg/l. The next two time periods from 1978 through 1993 show that more than 75 percent of the chloride concentrations observed were greater than 50 mg/l. By the 1994-2012 period, median chloride levels had more than doubled to a median near 110 mg/l. While the most recent decade (2013-2022) experienced the highest overall mean chloride concentration (203 mg/l) and some of the most extreme high-end outliers, the median concentration remained stable at 110 mg/l, reinforcing the potential recent plateau in chloride levels. It is unclear whether this plateau reflects natural environmental variability – such as shifting weather patterns and stream flows – or potentially the positive impact of more sustainable winter deicing practices.

Analysis of chloride conditions at stream assessment reaches throughout the study area also shows overarching statistical trends pointing to localized increasing chloride levels at many locations over the full study period. Map 6.9 illustrates that of the 74 assessment reaches with balanced chloride datasets during the full period of record, 60 reaches (81 percent) exhibited statistically significant long-term increasing trends in chloride concentrations (red up arrows), while only two balanced reaches showed statistically significant decreasing trends (dark green down arrows). In addition to trends in chloride, Map 6.9 shows additional assessment reaches with statistically significant trends in specific conductance – a strong indicator of chloride conditions – among stream assessment reaches with balanced datasets. There were 55 reaches (64 percent of reaches with balanced datasets) that had statistically significant increasing trends in specific conductance levels (orange up arrows) and two reaches that had decreasing trends (light green down arrows).[11] In nearly all cases, chloride and specific conductance trends moved in tandem.[12]

Similarly, Map 6.10 shows statistically significant trends in chloride and specific conductance for balanced stream assessment reaches over the recent period of 2013 through 2022. Compared to the full period of record, fewer reaches showed statistically significant trends in the recent period. Only one assessment reach

[11] *See Table 4.4 in TR-63 for trendline slopes (mg/l/year) indicating the extent of the increasing or decreasing trends over the full period of record.*

[12] *In cases were assessment reaches had the same statistically significant trend for chloride and specific conductance, only the trend in chloride concentration is shown on Map 6.9.*

showed a statistically significant increase in chloride and 14 reaches indicated a statistically significant increase in specific conductance. Conversely, 11 reaches indicated a statistically significant decrease in chloride and 10 showed a decrease in specific conductance.[13] While all trends for reaches shown on both Map 6.9 and Map 6.10 are statistically significant, many of the chloride and specific conductance datasets indicated substantial scatter around the trend line, underscoring the complex influence of seasonal variation, precipitation patterns, changes in land use, variations in stream flow, and/or the influence of Lake Michigan water levels.

Seasonal Trends

Do chloride conditions in streams fluctuate depending on the season?

Seasonal trends for streams in this Study were assessed in two ways – by month, and by simple season designations. Simple season designations in these analyses are represented by winter (December through February), spring (March through May), summer (June through August) and fall (September through November).

Stream chloride concentrations increased over time across all four seasons throughout the full period of record, as shown by upward trajectory of the trendlines in Figure 6.12. These increases are likely driven by two distinct seasonal mechanisms:

- Winter and Spring: These seasons observed the steepest increases, with stream chloride concentrations rising by an average of 4.3 mg/l/year and 2.9 mg/l/year, respectively. This pattern is consistent with the increased use of winter deicing materials over time.

- Summer and Fall: Concentrations rose steadily by 1.7 mg/l/year for both seasons. Because direct chloride inputs to surface water are lower during these warmer months, this persistent baseline increase suggests that winter salt applications may be infiltrating shallow groundwater, which sustain stream baseflow during these drier periods.

Again, there was considerable variation of the sample data around the trend lines shown in Figure 6.12, particularly during winter and spring. This variability likely reflects the acute spikes from active winter deicing

---

[13] *See Table 4.7 in TR-63 for trendline slopes (mg/l/year) indicating the extent of the increasing or decreasing trends over the recent period of record.*

activities as well as snowmelt events that can both increase chloride concentrations and dilute existing chloride levels in waterways.

Figure 6.13 illustrates chloride concentrations of samples by month across the full period of record, on a log scale. The data reveal clear seasonal patterns likely driven by deicing activities during winter weather events. Some trends indicated by Figure 6.13 include:

- Winter Peaks: Chloride concentrations and variability are highest in winter months, with February observing the highest chloride levels (median: 230 mg/l, mean: 526 mg/l).

- Summer Lows: Chloride levels steadily decreased from March to an August low (median: 69 mg/l, mean: 92 mg/l) before climbing again through the fall and winter.

- Deicing Event Spikes: Mean stream chloride concentrations exceed median concentrations year-round. This difference is most pronounced in December, January, and February, where the mean is 2.2 to 2.6 times higher than the median. These large differences suggest that winter averages are heavily skewed upwards by severe, short-term spikes from deicing activities.

- Toxicity Thresholds: Notably, chloride levels exceeded the Wisconsin chronic (orange dotted line) and acute toxicity (red dotted line) thresholds during every month of the year and were often substantially above levels known to cause biological harm. In January and February, over 25 percent of samples surpassed the chronic toxicity threshold.

While Figure 6.13 illustrates overarching winter peaks for the study area, examining seasonal trends at localized stream assessment reaches reveals additional trends. Urban streams consistently showed their highest chloride concentrations in winter, likely due to increased impervious surfaces that necessitate recurring deicing activities. Conversely, streams with rural drainage areas often observed their highest chloride concentrations in the fall (and occasionally summer), possibly due to impacts of lower stream flows, increased groundwater influence, and/or agricultural fertilizers.

Figure 6.14 highlights how seasonal deicing impacts stream health by tracking frequency of samples by month that exceeded the Wisconsin chronic toxicity threshold (395 mg/l) for the full period of record. Trends indicated by Figure 6.14 include:

- Cold Month Highs: The highest rates of chronic toxicity exceedance predictably occurred in colder months, peaking in February at over 34 percent of samples, followed by January (25.7 percent), March (19.0 percent), and December (11.4 percent).

- Warm Month Lows: Exceedance rates dropped significantly from April through October. The lowest rates occurred from August through October, when less than 1 percent of stream samples exceeded the chronic toxicity threshold.

- Year-Round Risks: Despite the sharp drop in the warmer months, it is notable that 387 samples exceeded the chronic threshold from June through November over the full period of record. This indicates that harmful chloride concentrations can occur in the Region's streams even outside of winter. Potential contributing factors during warmer months include runoff carrying agricultural fertilizers, leaching of residual deicing salts from soil, baseflow contributions from chloride-polluted shallow groundwater and wastewater treatment plant effluent.

Land Use Implications

Are there links between land use and chloride conditions in a stream?

Figure 6.15 illustrates the observed relationship between median chloride concentrations in stream assessment reaches during the recent period of record (2013-2022) and two land use categories: urban and roads and parking lots.[14] The data reveals a positive correlation between median chloride levels and both urban land use and road and parking lot coverage. As urban areas and impervious surfaces increase, chloride concentrations rise – likely due to winter deicing runoff. Median chloride concentrations generally reach or exceed 50 mg/l when urban land use surpasses 35 percent, however there is a fair amount of variation around these relationships driven by local, site-specific factors. These findings align with trends observed across the Chloride Impact Study's 41 stream monitoring sites (described in Section 6.3) and lake watersheds (described in Section 6.5).

---

[14] *In this analysis, "urban" land use is an overarching category that includes several more detailed land use designations, including roads and parking lots. See Table 2.3 in TR-61 for detailed land use categories.*

Map 6.11 and Map 6.12 geographically reinforce these land use trends shown in Figure 6.15. Map 6.11 highlights the clear link between urban land use and chloride concentrations: highly urbanized subwatersheds (shown as shades of red, orange, and yellow) align with assessment reaches that have higher median chloride concentrations (as indicated by circles and triangles), while less urbanized areas (shown as shades of green) have streams with lower median concentrations. A few exceptions exist in the middle portion of the Milwaukee River watershed in Washington County where several reaches show elevated chloride despite low urbanization, but those outliers stem from imbalanced datasets with winter only sampling.

Similarly, Map 6.12 demonstrates a general trend of increasing instream chloride concentrations with increasing percentages of roads and parking lots. Subwatersheds with higher percentages of roads and parking lots (indicated by orange and brown shades) correspond to stream assessment reaches with higher median chloride levels, whereas those with under 10 percent coverage (indicated by peach, yellow, and white) generally maintain concentrations below 100 mg/l. Aside from the same Washington County outliers discussed previously, these results are generally consistent with the relationships observed between percent roads and parking lots and chloride concentrations among the Chloride Impact Study's 41 stream monitoring sites and among lake watersheds, as described in Section 6.3 and Section 6.5 of this Report, respectively.

While overall chloride medians may be lower in rural assessment reaches, concerning chloride peaks were still observed. These typically occurred in streams in rural areas that were near large transportation corridors (e.g., Kilbourn Road Ditch reach DP08 in the Des Plaines watershed) or occasionally near WWTP discharge locations (e.g. Milwaukee River reach MK10, just downstream of the Fredonia Wastewater Treatment Plant).[15] Data indicated that consistent discharge from WWTPs during dry periods could potentially contribute to elevated summer and fall chloride conditions in some stream assessment reaches, however, it is difficult to accurately assess the impact of WWTPs on instream chloride concentrations without accurate flow monitoring and coordinated sampling immediately upstream and downstream of the facility discharge location.

[15] *See chloride time series plots for assessment reaches DP08 and MK10 in TR-63 Figure 4.25 and Figure 4.58, respectively.*

Stream Size

Are smaller streams more likely to have higher chloride concentrations?

"Strahler stream order" ranks waterways by their size and position within a drainage network, from small headwater streams (1st and 2nd order) to larger, downstream rivers (5th and 6th order).[16] Comparing chloride pollution across these different sizes is complex. While larger rivers gather higher total chloride loads from massive drainage areas, their larger water volumes dilute the salt, often lowering the actual chloride concentration. Figure 6.16 illustrates the distribution of chloride concentrations for the entire dataset by stream order. Breaking down the data reveals several key patterns:

- Dilution in Larger Streams: Median chloride concentrations generally decreased as stream size (stream order) increased. Medians range from a high of 130 mg/l in smaller 2nd order streams down to 50 mg/l in larger 6th order rivers.

- Averages Skewed by Spikes: Mean concentrations vary much more widely than the typical medians, ranging from 64 mg/l in 6th order streams to highs of 222 mg/l in 1st order and 284 mg/l in 2nd order streams. This gap between the mean and median indicates that smaller streams are heavily impacted by intense, temporary spikes in chloride pollution.

- Widespread Extremes: The outliers extending above the box plots show that extreme maximum chloride concentrations are elevated across waterways of all sizes. However, these severe maximums are particularly extreme in the smallest waterways (stream orders 1, 2, and 3).

Recent Chloride Conditions and Trends Within the Major Watersheds of the Study Areas

Figure 6.17 displays the distribution of chloride samples for the recent period of record (2013-2022) across the watersheds of the study area (also see Table 6.5 for recent period watershed summary statistics). The data reveals high variability between watersheds. Key observations from Figure 6.17 include:

- Highest Baseline Concentrations: The Oak Creek watershed (310 mg/l), Direct Drainage Area to Lake Michigan (229 mg/l), and Root River watershed (180 mg/l) exhibited the highest median chloride concentrations during the recent period of record.

---

[16] *More details on Strahler's stream order can be found in Chapter 4 of TR-63.*

- Lowest Baseline Concentrations: The Rock River watershed (56 mg/l) and Sauk Creek watershed (64 mg/l) maintained the lowest median chloride concentrations.

- Extreme Outliers: Most watersheds exhibit numerous outliers, indicating extreme chloride concentration values. The Kinnickinnic River, Milwaukee River, and Menomonee River watersheds show a large number of extreme high-concentration outliers, though this may partially reflect the higher frequency of sampling in these specific areas. The Milwaukee River watershed also contains numerous low-concentration outliers, indicating frequent periods of high dilution in some streams.

- Upward Skew: Across all watersheds, the recent period mean chloride concentration is consistently higher than the median concentration, demonstrating that extreme high chloride events are heavily skewing the overall averages upward.

- Rising Baseline Concentrations: Recent period median chloride concentrations have increased across every watershed compared to the full historical record (1961-2022).[17] The most significant increases in median chloride concentrations occurred in the Fox River watershed (99 percent), Oak Creek watershed (75 percent), and Des Plaines River watershed (75 percent).

Figure 6.18 displays the distribution of all recent period chloride samples (2013-2022) across 11 watersheds in the study area, categorized by the previously discussed water quality and biological impact thresholds. Comparing these distributions reveals several distinct contrasts in chloride conditions across study area watersheds:

- Widespread Biological Risk: Across almost all watersheds, a very minimal percentage of samples (in many cases zero) fall into the historical background level of ≤10 mg/l (light blue in pie charts). Instead, the vast majority of recent stream samples fall between 10 mg/l and 395 mg/l (yellow, orange, and dark orange categories). This illustrates a critical Study-wide trend: most stream samples are consistently at levels known to cause biological harm to aquatic life and exceed out-of-state guidelines, yet remain below Wisconsin's official regulatory threshold for impairment (395 mg/l).

[17] See Figure 4.4 in TR-63 for the distribution of all chloride samples observed during the full period of record by watershed and Table 4.3 for summary statistics by watershed.

- Highest Toxicity: The Oak Creek, Kinnickinnic River, Root River, and Direct Drainage Area to Lake Michigan watersheds exhibit the most severe impairment. These four areas feature the largest proportions of chloride samples exceeding Wisconsin's chronic (395 mg/l) and acute (757 mg/l) toxicity thresholds as well as the extreme impact threshold (1,400 mg/l). The Oak Creek watershed stands out as the most severely impacted overall, with over a third of all recent chloride samples exceeding State toxicity limits.

- Lowest Toxicity: Conversely, the Rock River and Sauk Creek watersheds represent the least impacted systems in the study area. While many samples in these watersheds still indicate potential for biological harm, the overwhelming majority remain in the lower impact tiers (10-120 mg/l), and neither watershed recorded a single sample exceeding State toxicity thresholds during the recent period.

The following sections provide summaries of the statistics, land-use factors, and seasonal trends driving the recent period chloride conditions within each specific watershed. For detailed analysis of the chloride and specific conductance datasets for each watershed, see Chapter 4 of TR-63.

Des Plaines River Watershed

Despite the predominantly rural landscape, the Des Plaines River watershed experienced severe, localized chloride spikes, likely driven by winter deicing runoff from IH 94 and surrounding development along the interstate corridor. While median chloride levels remained low (see Map 6.13), these seasonal extremes pose a significant threat to aquatic life and have led to a formal impairment designation for the Kilbourn Road Ditch. Key findings for the watershed during the recent period of record (2013-2022) include:

- Limited Dataset: Only 63 chloride samples were collected in the watershed during the recent period of record from just two stream reaches: the Des Plaines River (DP01) and Kilbourn Road Ditch (DP08).

- Low Medians, Extreme Peaks: Both assessment reaches maintained median chloride concentrations below 100 mg/l, but maximums spiked to 517 mg/l at DP01 and a severe 1,470 mg/l at DP08.

- The IH 94 Corridor: Kilbourn Road Ditch runs adjacent to IH 94 and intense winter runoff from the interstate and surrounding parking lots likely caused the extreme chloride peaks in the assessment reach.

- Prevalent Biological Risk: Nearly 86 percent of all recent period chloride samples exceeded thresholds associated with negative biological impacts to aquatic life (concentrations above 35 mg/l).

- Seasonal Peaks: All exceedances of the State's toxicity thresholds within the watershed occurred in January and February, confirming that winter deicing – not agricultural runoff – drives the elevated chloride conditions in these streams.

- Impaired Waters Listing: Because of the severe winter peaks, the entire length of Kilbourn Road Ditch (14.3 miles) is listed for being impaired for chronic chloride toxicity (see Table 6.4).

- High-Risk Streams: Commission staff designated the Des Plaines River mainstem reach DP01 as a stream at high risk for impairment listing because two samples with concentrations above the chronic toxicity threshold were recorded during the recent period of record.

- WWTP Effluent Receiving Streams Data Gaps: Two active WWTPs discharge treated wastewater into streams in the watershed, but a lack of instream sampling prevents an assessment of their specific chloride impacts.

Fox River Watershed

Several streams within the Fox River Watershed have experienced rising chloride levels. While severe winter spikes are strongly tied to urban development and road salt, the watershed faces an additional, year-round threat from WWTP discharges. Together, these sources are driving up baseline chloride concentrations (see Map 6.14) and posing significant risk to aquatic life at several locations. Key findings for the watershed during the recent period of record (2013-2022) include:

- Rising Baselines: Recent median chloride levels at assessment reaches were consistently higher than the those from the full period of record (1961-2022). Several streams – including the Pewaukee River (FX87), Honey Creek (FX34), and Mukwonago River (FX67) – saw median chloride concentrations jump by 200 percent or more.

- Widespread Biological Risk: Over 85 percent of recent period samples surpassed the conservative lower biological impact concentration (35 mg/l). Nearly 97 percent of recent samples exceeded thresholds associated with biological harm and/or established guidelines from agencies outside of Wisconsin while remaining below the State's regulatory action threshold.

- State Toxicity Threshold Exceedances: Approximately 3 percent of recent period samples (19 total) exceeded Wisconsin's chronic toxicity threshold (395 mg/l), and one sample surpassed the acute toxicity threshold (757 mg/l).

- Seasonal Peaks: All exceedances of the State chronic chloride toxicity threshold occurred in January, February, and March, directly linking the most severe spikes to winter deicing.

- Impaired and High-Risk Streams: Two stream segments in the watershed (Meadowbrook Creek and Pewaukee River above Pewaukee Lake) were listed as chloride-impaired as of 2024 (see Table 6.4 and Map 6.8). Four additional assessment reaches were considered high risk for impairment (Fox River mainstem reaches FX12 and FX09, Pewaukee River reach FX87, and Sussex Creek reach FX96).

- Urban Land Use Correlation: Streams in highly urbanized drainage areas with dense road and parking lot coverage (like Fox River reaches FX12, FX04, and FX16 and Pewaukee River reaches FX87 and FX88) consistently recorded the highest median and maximum chloride concentrations.

- Wastewater Impact: There were 15 active WWTPs discharging chloride-laden effluent to watershed streams in the recent period. A targeted monitoring effort for this Study on Honey Creek in Walworth County confirmed that WWTP discharges actively increase downstream chloride levels, likely due to salt from residential water softeners.

- Potential Summer Low-Flow Vulnerability: During dry summer months (July-September), treated wastewater effluent can account for over 80 percent of the Fox River flow at Waukesha. This lack of natural dilution can create a critical vulnerability for aquatic organisms, even outside of the winter season.

- Pinpointing WWTP Impact is Challenging: While chloride loads in stream reaches downstream of WWTPs are undoubtedly increased by upstream dischargers, specific chloride data collection locations and timing are required and are generally lacking in the study area.

Kinnickinnic River Watershed

Streams in the Kinnickinnic River watershed exhibit some of the most severe and widespread chloride pollution in the entire study area (see Map 6.15). Driven by highly urbanized land use and dense road infrastructure, heavy winter deicing runoff not only causes massive chloride spikes exceeding the acute toxicity threshold but also appears to infiltrate the shallow groundwater aquifer, resulting in harmful chloride levels that linger year-round. Key findings for the watershed during the recent period of record (2013-2022) include:

- Extreme Concentrations: All stream assessment reaches in the watershed recorded maximum chloride levels exceeding the State's acute toxicity threshold during the recent period of record. The watershed accounts for 12 of the 15 highest chloride measurements in the entire study area, including an extreme high of 26,300 mg/l at Wilson Park Creek (KK06).

- Widespread Biological Risk: Approximately 93 percent of recent period samples exceeded 35 mg/l, the threshold where biological damage to aquatic life begins.

- Severe Toxicity Exceedances: More than 17 percent of recent samples exceeded the Wisconsin chronic toxicity threshold, and over 6 percent surpassed the acute toxicity threshold. The Kinnickinnic River watershed recorded the second-highest toxicity exceedance rates in the study area, behind the Oak Creek watershed. The watershed accounted for a disproportionate share of total exceedances, representing 15 percent of chronic, 17 percent of acute, and 18 percent of extreme impact (1,400 mg/l) thresholds.

- Impaired and High Risk Streams: Four stream segments are officially on the 303(d) list as impaired for both chronic and acute chloride toxicity. These include the entire length (3 impaired segments) of the Kinnickinnic River mainstem, South 43rd Street Ditch, Wilson Park Creek, and Zablocki Park Creek. (see Table 6.4 and Map 6.8). Three additional assessment reaches were considered high risk for impairment (KK06, KK07, and KK08).

- Year-Round Concern: While toxicity predictably peaked during winter deicing months (84 percent of February samples exceeded chronic limits), harmful chloride levels lingered well into the summer and fall, with 84 recent period exceedances of the chronic toxicity threshold recorded between June and the end of November. This suggests that heavily salted winter runoff is entering the shallow groundwater aquifer and continuously feeding chloride back into the streams.

- The Lake Michigan Effect: The only reach that showed notably lower median chloride concentrations and fewer toxicity exceedances was the downstream portion of the Kinnickinnic River mainstem (KK01), which benefits from the diluting backwater effects of Lake Michigan.

Menomonee River Watershed

The Menomonee River watershed is one of the most heavily monitored and significantly impacted areas in the Study. Driven by highly urbanized land use and dense road infrastructure, heavy winter deicing runoff frequently pushed chloride concentrations to severe levels. While municipal salt reduction efforts or weather patterns may be helping some streams show recent improvements, the watershed still accounts for a large share of the study area's overall toxicity exceedances. Key findings for the watershed during the recent period of record (2013-2022) include:

- Robust Dataset: This watershed had extensive monitoring during the recent period of record, comprising 4,379 chloride samples.

- Extreme Peaks and High Medians: Maximum concentrations spiked to a sever 6,400 mg/l at Underwood Creek reach MN14 (the 7th highest concentration in the entire study area), while Honey Creek reach MN11 recorded the highest median concentration at 400 mg/l (see Map 6.16).

- Widespread Biological Risk: Over 98 percent of all recent chloride samples surpassed 35 mg/l, meaning nearly every water sample was at a level where initial biological damage to aquatic life begins. Additionally, almost 87 percent of all chloride samples collected in the watershed exceeded thresholds associated with biological impacts or established guidelines and regulatory thresholds from agencies outside of Wisconsin, while remaining below the threshold for potential regulatory action in the State.

- Severe Toxicity Exceedances: Over 13 percent of all samples exceeded Wisconsin's chronic toxicity threshold (395 mg/l), and almost 4 percent exceeded the acute toxicity threshold 757 mg/l). Notably, this watershed accounted for roughly 35 percent of chronic and 32 percent of acute exceedances across the entire study area, however this is likely due, in part, to the watershed having substantially more recent chloride monitoring data compared to other watersheds.

- Impaired and High-Risk Streams: As a result of the severe chloride pollution, 10 stream segments in the watershed were officially listed as chloride impaired under the 303(d) list as of 2024. Seven of these stream segments were listed for both chronic and acute toxicity (see Table 6.4 and Map 6.8). Five additional assessment reaches were considered high risk for impairment.

- Urban Land Use Correlation: High chloride levels coincide closely to urban development. Reaches with the highest median chloride concentrations drain subbasins with the most dense road and parking lot coverage, while the lowest concentrations were found in the rural upper portions of the watershed.

- Mixed Trends: While Honey Creek is experiencing the most rapid statistically significant increase in recent period chloride concentrations, five other reaches in the watershed actually show statistically significant decreasing trends (see Menomonee River mainstem reaches MN10, MN08 and MN01; Little Menomonee River reach MN19; and Burnham Canal reach MN29 on Map 6.10). This improvement may be due to several factors including a limited temporal dataset, changing weather patterns, and the influence of historically high Lake Michigan water levels. Localized reductions might also reflect efforts by municipal public works departments to minimize road salt applications.

- Year-Round Concerns: Toxicity predictably peaked during the winter months (February saw 49 percent of samples exceed chronic limits). However, 26 percent of all recent period chronic exceedances in the watershed occurred between June and November, indicating that chloride-laden winter runoff is infiltrating the shallow groundwater aquifers and continuously feeding chloride back into streams year-round.

Milwaukee River Watershed

The Milwaukee River watershed exhibits highly variable chloride conditions, strongly influenced by local land use and direct proximity to transportation infrastructure. While the massive volume of water in downstream portions of the Milwaukee River mainstem naturally dilutes chloride concentrations, smaller tributaries receiving runoff from urban centers and highways experience extreme chloride spikes, leading to likely biological impacts and regulatory toxicity impairments. Key findings for the watershed during the recent period of record (2013-2022) include:

- High Variability and Extreme Peaks: Median concentrations range from a near pristine 19 mg/l in rural reaches (East Branch Milwaukee River reach MK85) to 546 mg/l at the heavily impacted Gateway Drive Tributary to Ulao Creek (MK113) (see Map 6.17). Maximum concentrations reached a staggering 6,630 mg/l at MK113 – the 6th highest recent period concentration in the entire study area.

- Widespread Biological Risk: Approximately 91 percent of recent chloride samples surpassed the 35 mg/l threshold indicating widespread exposure to levels that cause initial biological damage to aquatic life.

- State Toxicity Threshold Exceedances: Almost 4 percent of samples exceeded Wisconsin's chronic toxicity threshold (395 mg/l), and just over 1 percent of samples surpassed the acute toxicity threshold (757 mg/l).

- Impaired and High Risk Streams: Eight stream segments in the lower portions of the watershed were officially listed as chloride impaired on the 2024 303(d) list, six of which were impaired for both chronic and acute toxicity. Nine additional assessment reaches were considered to be high risk for impairment after recording extreme peak chloride concentrations (see Table 6.4 and Map 6.8).

- Transportation Infrastructure Impacts: Extremely high chloride levels were not only tied to urban development but to direct proximity to major transportation infrastructure. For example, Ulao Creek and its tributaries experience extreme toxicity spikes from deicing runoff and snow piles associated with IH 43 and parking lots along the major transportation corridor.

- Dilution Factor: Despite flowing through highly urbanized areas, the large 5th order mainstem reaches of the Milwaukee River maintain relatively low median chloride concentrations because the large water volume effectively dilutes the incoming chloride loads.

- Improving Trends: Three balanced assessment reaches in the watershed, including downstream portions of the Milwaukee River mainstem (MK02 and MK01) and Ulao Creek (MK33), have observed statistically significant decreasing chloride trends over the recent period of record (2013-2022), indicating potential localized improvements. Similarly to the lower Menomonee River reaches, decreasing trends at MK02 and MK01 may, at least partially, be influenced by the record-high Lake Michigan water levels during the recent period.

- Seasonality and Wastewater: Chloride toxicity predictably peaked in winter seasons (February recorded the highest chronic toxicity threshold exceedance rate at almost 29 percent). However, localized spikes can occur from other sources. For example, sampling at Milwaukee River mainstream reach MK10, immediately downstream of the Fredonia Wastewater Treatment Plant, revealed a small cluster of chronic toxicity exceedances in an otherwise low-chloride reach.

Oak Creek Watershed

The Oak Creek watershed experienced some of the worst chloride conditions in the entire study area (see Map 6.18). Driven by heavily urbanized land use and dense road and parking lot infrastructure, heavy winter deicing runoff causes the highest rate of acute toxicity exceedances of any watershed evaluated in this Study. Severe chloride pollution in the watershed not only leads to toxic winter conditions in streams but also infiltrates the groundwater, maintaining harmful levels year-round. Key findings for the watershed during the recent period of record (2013-2022) include:

- Limited Data and Disproportionate Impacts: Despite having only one assessment reach with a balanced chloride dataset during the recent period of record (Oak Creek mainstem reach OC01) and comprising less than 5 percent of the study's total recent samples, the watershed accounted for over 15 percent of all chronic and almost 13 percent of all acute chloride toxicity exceedances in the study area.

- Extreme Concentrations: Every single assessment reach recorded maximum chloride levels above the State's acute toxicity threshold (757 mg/l) during the recent period. Peak concentrations reached a staggering 7,120 mg/l at Mitchell Filed Drainage Ditch reach OC04.

- Watershed-Wide Biological Risk: All but one recent period sample surpassed 35 mg/l. This means practically all streams sampled in the watershed are at a minimum at a level where initial biological damage to aquatic life begins.

- Highest Toxicity Rates: Approximately 35 percent of all recent samples exceeded Wisconsin's chronic toxicity threshold (395 mg/l), and nearly 9 percent exceeded the acute toxicity threshold. This is the highest proportion of exceedances of any watershed evaluated for this Study.

- Impaired and High Risk Streams: Consequently, three streams in the watershed – the entire Oak Creek mainstem, Mitchell Field Drainage Ditch, and North Branch Oak Creek – are officially listed on the 303(d) list as impaired for both chronic and acute chloride toxicity. Additionally, there is one assessment reach (Drexel Avenue Tributary OC08) considered high risk for chloride impairment due to recent extreme chloride samples (see Table 6.4 and Map 6.8).

- Urban Land Use and Transportation Infrastructure: The extreme maximum chloride concentrations recorded in this watershed are primarily driven by the heavily urbanized areas and highly dense road and parking lot networks in the watershed.

- Worsening Baselines: Recent median chloride concentrations are up to 61 percent higher than those of the full period of record. Furthermore, specific conductance (a strong proxy for chloride) showed statistically significant increasing trends across four assessment reaches over the recent period.

- Year-Round Toxicity: Winter toxicity rates were extremely high during the recent period, with 96 percent of February samples and 87 percent of January samples exceeding the chronic toxicity threshold). Concerningly, 56 chronic threshold exceedances occurred between June and November, supporting the conclusion that heavy chloride loads are infiltrating the shallow groundwater aquifer and continuously discharging chloride-laden water into streams long after the snow melts.

Pike River Watershed

Despite having limited monitoring data collected during the recent period of record, the Pike River watershed showed clear sings of severe seasonal chloride spikes likely caused by winter deicing in urbanized areas. These winter peaks have led to toxicity impairments for multiple streams. Key findings for the watershed during the recent period of record (2013-2022) include:

- Limited Monitoring Data: The recent period dataset was relatively small, comprising of 743 chloride samples with only three assessment reaches (PK01, PK02, and PK10) containing balanced datasets.

- Moderate Medians, High Peaks: The Pike River mainstem assessment reaches (PK01 and PK02) had median chloride concentrations around 145 mg/l (see Map 6.19). However, peak concentrations spiked as high as 1,255 mg/l.

- Widespread Biological Risk: Approximately 82 percent of recent period samples surpassed 35 mg/l, meaning the vast majority of stream samples were above the level known to cause initial biological damage to aquatic life.

- State Toxicity Exceedances: More than 5 percent of recent period samples exceeded Wisconsin's chronic chloride toxicity threshold (395 mg/l), and almost 1 percent surpassed the acute toxicity threshold (757 mg/l).

- Strictly Seasonal Toxicity: All of the State chronic toxicity exceedances occurred during the winter and spring seasons (January through May, peaking in February). This points towards winter and spring deicing operations being the biggest driver of harmful chloride levels in the streams of the watershed.

- Impaired Waters Listing: Due to the seasonal spikes in chloride concentrations, segments of three streams – the North Branch Pike River, an unnamed tributary, and the lower Pike River mainstem – are officially listed as chloride-impaired on the 303(d) list see Table 6.4 and Map 6.8).

- Urban Land Use and Transportation Infrastructure: Unsurprisingly, streams traversing drainage areas with moderate-to-high urban development and dense road/parking lot coverage consistently showed elevated chloride levels.

- The Dilution Anomaly: Despite draining a highly urbanized area, an unnamed tributary to the Pike River (PK10) recorded the lowest median chloride concentration during the recent period in the entire study area (only 13 mg/l) and showed a statistically significant decreasing trend. This anomaly is likely influenced by pumped groundwater: the stream runs along a retired landfill where gradient control pumps are likely discharging deep, unpolluted groundwater into the stream, heavily diluting the surface water chloride concentrations.

Rock River Watershed

Unlike the highly urbanized areas in some of the watersheds analyzed in this Study, the Rock River watershed exhibits generally low to moderate chloride conditions with zero exceedances of the State chloride toxicity thresholds. While low level biological risks remain throughout much of the watershed, the vast rural land and numerous in-line lakes help buffer against extreme winter spikes. However, discharges from WWTPs present a distinct, year-round vulnerability during low-flow summer and fall months. Key findings for the watershed during the recent period of record (2013-2022) include:

- Low to Moderate Concentrations: Median chloride concentrations remained comparatively low throughout the watershed during the recent period of record, ranging from 23 mg/l in rural Whitewater Creek (RK24) to 113 mg/l in the more urbanized Rubicon River (RK53) (see Map 6.20 and Map 6.21)

- Zero State Toxicity Exceedances: Unlike most other watersheds in the study area, not a single recent period sample exceeded the Wisconsin chronic or acute chloride toxicity threshold.

- No Impaired Waters: Because no samples rose to the level of the State's toxicity thresholds, zero streams in the watershed were listed as chloride-impaired under Clean Water Act's 303(d) list. Only one assessment reach (Bark River reach RK22) recorded chloride concentrations that rose to the level to consider at risk of impairment (see Map 6.8).

- Widespread Low-Level Biological Risk: While severe toxicity is largely absent from the streams of the watershed, low-level chloride pollution does persist in many streams. Over 99 percent of recent samples exceeded natural background levels (10 mg/l), and 86 percent of samples surpassed 35 mg/l – the concentration where initial biological damage to aquatic life can appear.

- The Complex Role of In-Line Lakes: The watershed is unique for its high number of in-line lakes, which may potentially moderate extreme chloride fluctuations in the streams flowing though them, though their exact long-term impact is unclear. For some systems (like Delavan Lake and Jackson Creek/Turtle Creek), the large lake water volume likely helps dilute sharp upstream spikes in chloride, buffering downstream reaches from extreme winter peaks. However, in chains of lakes, the dynamics seem to be more complex. As the Oconomowoc River flows downstream through its in-line lakes, baseline (median) chloride concentrations steadily rise. While the lakes themselves might be capturing and accumulating chloride, this downstream increase could also be driven by variations in sampling timing and frequency. Additionally, the Bark River maintains relatively consistent, moderately elevated chloride levels (medians ranging from 95 mg/l to 110 mg/l) both upstream and downstream of its major lakes (Nagawicka, the Nemahbins, and Crooked Lake), closely matching the chloride levels within the lakes themselves. Ultimately, additional targeted monitoring is needed to fully assess the impact of in-line lakes on chloride levels in associated streams.

- Improving Trends: Stream assessment reaches in the watershed showed zero statistically significant increasing chloride trends over the recent period. In fact, two reaches on the lower Oconomowoc River (RK34 and RK34) demonstrated statistically significant decreasing trends.

- Wastewater Vulnerabilities: Seven active WWTPs discharge treated wastewater into streams of the watershed. During dry summer and fall periods when streamflow is typically lowest, WWTP effluent can make up a larger portion of the total water volume in streams like the Rubicon River, Turtle Creek, and Bark River, acting as a primary contributor to chloride levels. More targeted sampling is necessary to identify the extent of impact these WWTPs have on streams in the watershed.

- Land Use Relationships: Similarly to the rest of the study area, the lowest chloride levels were consistently found in subbasins with very low urban development and minimal roads and parking lots. Conversely, the highest concentrations were located in streams near urban centers (like Hartford and Delafield) and major highway corridors (like IH 41, STH 16, and STH 60).

Root River Watershed

Despite a relatively limited recent period monitoring dataset (626 chloride samples), the Root River watershed exhibits severe and widespread chloride pollution (see Map 6.22). Winter runoff from urbanized and highway-dense subbasins appears to drive substantial toxicity spikes, while agricultural fertilizers, groundwater infiltration, and highly concentrated wastewater discharges create complex, year-round chloride inputs across both the urban and rural areas of the watershed. Key findings for the watershed during the recent period of record (2013-2022) include:

- Limited Data and Disproportionate Severity: Only three stream assessment reaches possessed balanced datasets, yet the watershed recorded the third-highest rates of acute and chronic toxicity in the entire study area, behind only the Kinnickinnic River and Oak Creek watersheds.

- Extreme Urban Spikes: In highly urbanized reaches like the upper Root River mainstem (RT06), median concentrations sat at an elevated 320 mg/l, with maximum peak concentrations hitting an extreme 3,600 mg/l.

- Widespread Biological Risk: All samples in the watershed exceeded natural background levels (10 mg/l), and approximately 98 percent surpassed 35 mg/l, meaning nearly the entire sampled watershed is persistently at a level where initial biological damage to aquatic life appears.

- State Toxicity Threshold Exceedances: Approximately 18 percent of all recent period samples exceeded Wisconsin's chronic chloride toxicity threshold (395 mg/l), and 7 percent surpassed the acute toxicity threshold (757 mg/l).

- Impaired and High Risk Streams: As a result of the severe chloride pollution, several segments of the Root River mainstem are officially listed under the 303(d) list as chloride impaired – the upper potion for both chronic and acute toxicity (including assessment reaches RT02, RT03, and RT04) and lower potion for chronic toxicity (including assessment reaches RT05, RT06, and RT07). Additionally, two assessment reaches (Root River mainstem reach RT04 and Hoods Creek reach RT08) were identified by Commission staff as high risk for impairment (see Table 6.4 and Map 6.8).

- Impacts of Transportation Corridors: Extreme chloride spikes are not limited to the most urbanized areas in the watershed. The middle Root River mainstem (RT04) traverses a relatively low-urbanized subbasin but recorded a severe maximum chloride peak of 800 mg/l, likely driven by direct runoff from the IH 94 corridor.

- Year-Round and Rural Seasonality: While toxicity predictably peaked in winter and early spring (January and March had about 50 percent of samples exceed chronic levels), elevated chloride levels persisted into the warmer months. Unlike many of the fully urban areas in the study area, the rural Root River Canal historically observed higher chloride concentrations in the summer and fall than in the spring, pointing to agricultural fertilizers and/or contaminated shallow groundwater as potentially significant off-season chloride sources.

- Wastewater Vulnerabilities: Two active WWTPs discharge treated wastewater into receiving waters in the watershed. From 2018-2021, the average chloride concentration in effluent from the Union Grove and Yorkville facilities was 339 mg/l and 577 mg/l, respectively. Notably, the Yorkville WWTP average chloride concentration exceeded the Wisconsin chronic toxicity threshold. While the plant holds a variance permit, this high-chloride discharge is likely a partial driver of elevated chloride baselines in the downstream Hoods Creek (RT08).

- Stagnant Trends: No assessment reaches in the watershed demonstrated statistically significant increasing or decreasing trends for either chloride or specific conductance during the recent period. However, it should be noted that only three assessment reaches had balanced datasets which were required for trend analysis.

Sauk Creek and Sheboygan River Watershed

Severe monitoring gaps in the recent period restrict our understanding of the Sauk Creek and Sheboygan River watersheds. In fact, the Sheboygan River watershed completely lacked recent period chloride monitoring data. Based on the very limited recent data available for the Sauk Creek watershed, the streams seem to avoid severe toxicity and chloride regulatory impairments observed in more urbanized watersheds, though low-level biological risks persist (see Map 6.23).

Key findings for the watershed during the recent period of record (2013-2022) include:

- Severe Data Limitations: The recent period chloride and specific conductance datasets were seriously limited. Sauk Creek only had 28 recent chloride samples and a single assessment reach with a balanced dataset (downstream Sauk Creek reach SK01). Even worse, the Sheboygan River watershed had zero chloride or specific conductance measurements collected during the entire 2013-2022 period.

- Zero State Toxicity Threshold Exceedances: Based on the available data, not a single chloride sample within the Sauk Creek watershed exceeded the Wisconsin chronic (395 mg/l) or acute (757 mg/l) toxicity thresholds. Therefore, as of the 2024 list of impaired waters, no streams in either the Sauk Creek or Sheboygan River watersheds were listed as impaired for chloride. However, Sauk Creek reach SK01 was identified by Commission staff as high risk for impairment because its maximum recorded concentration of 365 mg/l approached the chronic limit.

- Widespread Low-Level Biological Risk: Despite the lack of chloride samples reaching regulatory toxicity levels, persistent low-level pollution remains. All chloride samples within the Sauk Creek watershed exceeded the natural background levels (10 mg/l), and approximately 93 percent surpassed 35 mg/l, indicating consistent conditions that can cause initial biological damage to aquatic life.

- Urban Spikes and Rural Dilution: Land use appears to control the chloride conditions in the streams of the Sauk Creek watershed. Sauk Creek reach SK01 maintains a relatively low median chloride concentration (64 mg/l), likely because it receives dilution from rural upstream subbasins. However, winter peaks (365 mg/l) in the assessment reach are driven by the relatively dense road and parking lot networks of the City of Port Washington, which immediately surround the reach.

- Stagnant Trends: The single monitored reach with a balanced dataset (SK01) demonstrated no statistically significant increasing or decreasing trend for either chloride or specific conductance during the recent period.

Direct Drainage Area to Lake Michigan

Despite significant limitations in recent period chloride monitoring, the streams in the study area draining directly to Lake Michigan show evidence of severe, urban-driven chloride impacts. Relying heavily on a more robust specific conductance dataset as a proxy, widespread chloride toxicity risks are likely. Driven by dense urban infrastructure, these streams indicate intense winter deicing impacts that noticeably linger into the summer months.

- Severe Data Gaps but Clear Impacts: The direct chloride dataset is extremely limited for streams in the Direct Drainage Area to Lake Michigan, comprising just 196 samples during the recent period of record, with only a single assessment reach with a balanced recent chloride dataset (Pike Creek DD02, see Map 6.19). However, a relatively robust specific conductance dataset (1,474 measurements across 18 assessment reaches) acted as a fairly reliable proxy, pointing to widespread and severe chloride impacts across the drainage area.

- Extreme Peaks: The lone balanced assessment reach, Pike Creek (DD02), recorded an elevated median chloride concentration of 295 mg/l and an extreme maximum spike of 3,473 mg/l.

- Study's Highest Conductance Reading: An unnamed tributary to Lake Michigan (DD13) recorded a maximum specific conductance measurement of 24,900 µS/cm – the single highest recent measurement in the entire study area. Additionally, reaches like Klema Ditch (DD09) and unnamed tributary DD13 have been flagged by Commission staff for further evaluation because their median conductance levels surpass those of known chloride impaired streams (see Map 6.22 for locations of these stream assessment reaches).

- Near Drainage Area-Wide Biological Risk: Nearly all (99.5 percent) of recent chloride samples in the drainage area surpassed the 35 mg/l concentration where initial biological damage to aquatic life is known to begin.

- High Toxicity Rates: Over 18 percent of recent period chloride samples exceeded the Wisconsin chronic toxicity threshold (395 mg/l), and about 2 percent surpassed the acute toxicity threshold (757 mg/l). All acute exceedances were recorded within Pike Creek (DD01).

- Impaired and High Risk Waters: Pike Creek is officially listed under the Clean Water Act 303(d) list as chloride-impaired for both chronic and acute toxicity. Fish Creek reach DD03 was identified as high risk for impairment by Commission staff due to recording a peak chloride concentration of 650 mg/l, an alarming number considering its recent dataset had no sampling during the winter season (see Table 6.4 and Map 6.8).

- Urban Land Use Correlation: The streams within this area traverse predominantly urbanized subbasins with high densities of road networks and parking lots. This land use and the related winter deicing activities were suspected to be the primary driver of elevated chloride and conductance levels across these reaches.

- Lingering Spring and Summer Toxicity: While chloride toxicity predictably peaked in the winter and early spring (March recorded a 49 percent exceedance rate), a notably 9 percent exceedance rate persisted into June. This indicated that heavy winter deicing applications continue to severely impact these streams well into early summer.

- Stagnant Trends: No assessment reaches demonstrated statistically significant increasing or decreasing trends for either chloride or specific conductance during the recent period of record.

Data Gaps and Future Monitoring

While there were over 47,000 chloride samples and 50,000 specific conductance samples collected in the study area during the full period of record (1961-2022), a comprehensive Regional analysis is constrained by data gaps. Datasets with long-term, multi-year, and seasonal coverage were very limited. Additionally, accurately measuring the impact of WWTPs remains difficult without coordinated upstream and downstream sampling coupled with precise flow monitoring. Furthermore, streams draining directly to Lake Michigan lack sufficient chloride data – despite specific conductance readings indicating probable impairment in at least four streams – and additional sampling is required to determine whether in-line lakes are diluting or mirroring local stream chloride levels.

6.5 CHLORIDE CONDITIONS IN STUDY AREA LAKES

The following section summarizes the extensive analyses conducted to assess historical and existing chloride conditions and trends in the study area lakes. The analyses included water quality data from the 1960s through 2022 compiled by a variety of Federal, State, local agencies; universities; nonprofit organizations; and citizen monitoring groups. Specific conductance data were also collected to supplement and help interpret the chloride data and trends where possible.

Lake ecosystems reflect external inputs and pollutants relative to their surrounding land uses and combined with their generally long residence times[18], makes lakes sentinels for indicators of long-term trend changes at local and regional scales. Hence, as an early warning indicator inland lakes in Southeastern Wisconsin have been shown to be increasing in chloride concentrations due to cultural effects for over 100 years. Even Lake Michigan, despite its great volume compared to the inland lakes of this Study, has also been shown to be increasing in chloride levels (see Section 6.6 below). Results of this Study show that since the 1960s, nearly every study area lake (regardless of lake type, size, or geographic location) had rising chloride concentrations over time. While the exact sources of the chloride accumulating in the study area lakes have not been definitely determined, they are most likely due to winter deicing, human and animal wastes, water softening, and agricultural fertilizers. However, winter deicing maintenance activities appear to be the most important factor, as detailed in Chapter 3 of this Report, as the largest Regional source of chloride to the environment. This increase in lake chloride content is due to a combination of increased salt usage coupled with the expansion of urban development (i.e., increases in road density and impervious surfaces) within the study area since the 1950s and 1960s. In addition, the relationship between chloride concentrations and specific conductance among these lakes seems to be changing over time, which also seems to be driven mostly by changes (increases) in urban land uses.

Strategy for the Evaluation of Study Area Lakes

What were the sources for the water quality data used to assess chloride conditions and trends in study area lakes?

The oldest water quality lake data was sourced from Birge and Juday (University of Wisconsin-Madison pioneers in the study of lakes in the early 1900s) and lake use reports developed by the WDNR and the Commission in the early 1960s. Lakes of southeastern Wisconsin prior to 1910 have historically had naturally low levels of chloride, typically 10 mg/l or less, so this concentration was determined to be the baseline or background concentration for lakes in this Study. This historical data was combined with more recent chloride and/or specific conductance data from the USEPA, USGS, and WDNR. More details on the lake data sources can be found in TR-63 Chapter 5.

[18] Lake residence time is the amount of time required for natural water sources, under typical weather conditions, to fill a lake one time. Natural water sources include runoff from the surrounding areas, precipitation falling directly upon a lake, water entering from tributary streams, and water contributed to a lake by groundwater.

The Full Historical Record (1960-2022) and Recent Period (2013-2022) Datasets

How were lakes evaluated for chloride conditions and historical trends?

The final dataset for this Study included measurements of either chloride or specific conductance from a total of 191 inland lakes. At least one chloride sample was collected from 116 lakes, and 157 lakes have at least one specific conductance sample. The locations of the lakes sampled for chloride in the study area are shown on Map 6.24, while the locations for specific conductance measurements are displayed on Map 6.25. Notice from the two maps that most lakes within the study area have no chloride or specific conductance data at all. While the oldest data records were used to establish baseline chloride conditions for inland lakes in this study area as mentioned above, the most complete water chemistry data analyzed for this study spanned the years 1960 through 2022, defined as the full period of record, and comprised 2,665 chloride measurements and 80,685 specific conductance measurements. To assess the recent chloride conditions in the study area lakes, data from the recent ten-year period (2013 to 2022) were aggregated to represent the most recent levels. A total of 45 lakes were identified as having recent chloride data comprising 735 individual chloride samples and 51 lakes comprising 16,122 recent specific conductance measurements data.

Chloride Conditions and Trends in Study Area Lakes (1960-2022)

Figure 6.19 shows a comprehensive look at the chloride and specific conductance annual lake means for all 116 lakes and 157 lakes, respectively, from 1960 to 2022. While there are some gaps with these datasets, it does indicate that there has been an overall increase in the annual mean concentration of both chloride and specific conductance in study area lakes. Annual mean concentrations were used to analyze the lakes as chloride concentrations do not change much for most lakes in a year, and it was a way to more easily compare the data. The trend line on the figure indicates that mean chloride concentrations for the inland lakes increased from about 5 mg/l to about 60 mg/l over this time period and specific conductance concentrations increased from about 375 μS/cm to about 625 μS/cm. Despite this overall increase in mean concentration, some lakes continue to have chloride concentrations below 10 mg/l, which is indicative of sustained background conditions. In general, the highest mean lake concentrations observed were all within the more recent years (since about 2005). There seems to be a leveling out of the highest mean lake chloride concentrations in Figure 6.19 since about 2010, which is also consistent for the highest mean lake specific conductance concentrations.

When analyzing chloride trends among individual lakes for the full period of record, a total of 72 lakes with at least 9 years of data showed that the vast majority (87 percent) are increasing in concentration, and the remaining lakes were not changing with time (see Table 6.6). Further refining the trend lakes, Figure 6.20

shows a total of 51 lakes with at least six years of chloride data. The figure indicates there is a large variability in the rates of chloride concentration changes among individual lakes, but all of these lakes emanate from less than 10 mg/l background chloride concentrations via samples or by extrapolation of the trend line for each lake.

The 51 study area trend lakes were divided into three groups (low, moderate, and high) based on the range of observed annual maximum chloride concentrations over the full period of record and are described briefly below (more detail can be found in Chapter 5 of TR-63):

- Low chloride concentration lakes have not exceeded 50 mg/l – These 24 lakes represent the lowest salinization lake chloride trends of the study area lakes, which experienced chloride concentration increases at rates ranging from 0.1 to 1.0 mg/l/year, contained a mean of 24.5 percent urban land use, and 4.5 percent roads and parking lots at the watershed scale. Lake Wandawega is highlighted in Figure 6.20 for this group.

- Moderate chloride concentration lakes range between 50 and 100 mg/l – For these 19 lakes chloride concentrations increased at rates ranging from 0.31 to 1.93 mg/l/year in chloride, contained a mean of 30 percent urban land use, and 6.2 percent roads and parking lots at the watershed scale. Geneva Lake is highlighted in Figure 6.20 for this group.

- High chloride concentration lakes exceeding 100 mg/l - These eight lakes represent the most extreme salinization lake chloride trends of the study area lakes, had chloride concentrations increase at rates ranging from 1.7 to 9.9 mg/l/year, contained a mean of 48 percent urban land use, and 12.8 percent roads and parking lots at the watershed scale. Little Muskego Lake is highlighted in Figure 6.20 for this group.

As discussed in Chapter 5 of this Report, Commission staff established seven chloride thresholds ranging from 10 mg/l to 1,400 mg/l in order to evaluate harmful impacts from chloride on the Region's waterbodies. In contrast to the high levels of chloride concentrations observed in streams throughout the study area as summarized in Chapter 4 of TR-63, Figure 6.19 illustrates that no sampled lake annual mean concentration exceeded the State's chronic toxicity concentration threshold of 395 mg/l during the full period of record (1960-2022). However, Figure 6.19 does show that the annual average lake chloride levels exceed the thresholds of 10, 35, 120, and 230 mg/l and the proportions of these exceedances generally increase from 1960 to 2022. This is an important finding, because as summarized in Chapter 4 of this Report, chloride can harm aquatic ecosystems at levels well below regulatory toxicity thresholds. As illustrated in Figures 4.9 and 4.10 these effects can be from lethal impacts to subtle changes in behavior, physiology, and/or developmental abnormalities at chloride concentrations between 10 mg/l and 395 mg/l.

The lake chloride dataset for the study area (see Figure 6.21) for the full period of record (1960-2022) revealed that more than 80 percent of all lake chloride samples exceeded the Historical Background Concentration 10 mg/l threshold, about 30 percent exceeded the Conservative Lower Impact Concentration 35 mg/l threshold, and one percent exceeded the Canadian Chronic Toxicity threshold of 120 mg/l.

Map 6.26 and Map 6.27 show good correspondence between observed maximum chloride concentrations and maximum specific conductance concentrations for lakes over the full period of record, respectively. Highest maximum chloride concentrations and specific conductance levels were predominantly observed in Milwaukee County and eastern Waukesha County, as shown by the orange to dark red colors on the maps.

The overall full period of record dataset (1960-2022) for lake specific conductance, as shown in Figure 6.22, indicates that there has been a dramatic shift in the overall specific conductance distribution for the three different time periods of before 1975, 1975-2005, and after 2005. These distributions demonstrate an overall increase in the mean lake specific conductance over time. Also, the relationship between chloride concentrations and specific conductance for lakes is changing with time, as discussed in Chapter 5 of TR- 63, which likely means that chloride concentrations are comprising greater amounts of the overall specific conductance within lakes.

Finally, the Figure 6.23 comparison of the earliest versus the most recent chloride concentrations for the long-term trend lakes indicated that chloride levels in these lakes increased at an average rate of about 3.9 mg/l per year compared to the starting concentration. This is also consistent with the overall historical and concentration changes with time observations summarized above (see Figure 6.19). This rise in lake chloride levels is likely driven by increased proportions of impervious surfaces over time in these watersheds and the need to apply salts to such surfaces. Hence, even if salting application rates remain unchanged over time, the increased amounts of impervious surfaces associated with urban growth in these watersheds will drive increased salting loads and increased salinization of the lakes within the study area.

Recent Lake Conditions (2013-2022)

The average chloride concentration across all 45 lakes with recent data was 61.4 mg/l, although measured values ranged significantly from as low as 3.8 mg/l in Mueller Lake (Milwaukee River watershed) to 218.3 mg/l in Bass Bay Lake (Fox River watershed) (see Table 6.7). Table 6.7 also lists the characteristics for the 45 lakes analyzed for the recent period. The table illustrates that for the lakes sampled in the recent period the mean lake levels did not exceed the State's chronic toxicity concentration threshold of 395 mg/l. However, comparison with the full period of record (in Figure 6.21) indicates that for the recent period (2013-2022) a greater proportion of lakes were exceeding the chloride concentration thresholds of 10, 35, 120, and 230 mg/l which are harmful to aquatic ecosystems. While it is a positive result that a few study area lakes within the recent time period continue to sustain chloride concentrations within historical background concentration of less than 10 mg/l, a majority of the lakes currently exceed this concentration.

The larger proportions of lakes with higher chloride concentrations for the recent period in Figure 6.21 are directly related to increases in percent urban land use and/or roads and parking lots. Hence, it is not surprising that many of these lakes, particularly those at the higher end of the chloride range, are located near population centers and often have highly urbanized watersheds (see Table 6.7). Hence, the majority of these lakes within the study area have achieved their highest chloride concentrations within this most recent time period from 2013-2022 (see Figure 6.20), because urbanization is tied to population and economic growth. More details on the association between recent land use and chloride concentrations are discussed further in the section below.

Relationship of Chloride to Lake and Watershed Characteristics

Commission staff examined potential explanatory variables for chloride conditions in the study area lakes using the recent period (2013-2022) average chloride concentrations in the 45 lakes. This analysis included both lake morphological and hydrological variables, as well as watershed characterization variables as listed in Table 6.7. No significant relationship was found between recent average lake chloride concentrations with lake type, natural community, lake surface area, maximum depth, residence time, watershed size, and the percentage of agricultural land within the lake watershed. All the statistically significant variables were related to urban land use in some manner. The percentage of roads and parking lots and percent of urban land uses in the lake watershed contained the strongest relationships with chloride concentrations (see Figure 6.24). These relationships indicate that watershed land use changes are an important determinant of lake chloride concentrations and suggest that salt sources stemming from urban land uses, such as salt application on roads, sidewalks, and parking lots, as well as chloride generated from residential households (e.g., via septic systems) and commercial or industrial uses are good predictors of higher mean chloride concentrations within the study area lakes. More details on the land use influences on inland lakes of the study area can be found in Chapter 5 of TR-63.

While it is not surprising, it is important to note that among these 45 Study lake watersheds, the percentage of urban land is highly correlated with percent roads and parking lots. The percent urban land use in lake watersheds ranged from 6 percent to a high of 69 percent, and the percent roads and parking lots ranged from 2 percent to a high of 24 percent (see Table 6.7 and Figure 6.25). Figure 6.25 also shows that the worst six lakes (mean exceeding the 120 mg/l chloride concentration threshold) generally have at least 40 percent or greater percent urban land use and/or have at least 7.5 percent roads and parking lots or more. Hence, it appears that either of these thresholds or combination of both percent urban land and percent roads and parking lots are viable as predictors of the low versus high mean chloride lakes in the recent period.

Additional Considerations for Inland Lakes

Chapter 5 of TR-63 contains many more details for the analysis of chloride in inland lakes of the study area. Below are a few additional points from the Study lake work related to vulnerability to chloride toxicity, groundwater impacts, and data gaps.

Vulnerability to Chloride Toxicity

- Lakes can have a diluting effect and/or dampening effect on the seasonal oscillations in river chloride concentrations in downstream river reaches and downstream lakes, but that dilution effect was not always obvious and was likely being obscured by increasing chloride concentrations in the shallow groundwater sustaining baseflows.

- Although the Study did not detect any patterns for chloride levels by lake type within the study area lakes, in terms of vulnerability seepage and spring lakes are more susceptible than other lake types (assuming percent urban land use and/or percent roads and parking lots were the same), because they have no lake outlet. Hence, chloride salts have limited ability to be washed out or diluted compared to drainage lakes with an outlet. In addition, lakes with shorter residence times (high flushing rates) are more vulnerable to chloride toxicity concentrations than lakes with longer residence times.

Groundwater Impacts

- Recent mean annual chloride sampling in the chain of lakes on the Oconomowoc River seem to reflect mean annual stream chloride concentrations, and these observations are likely being driven by increasing chloride concentrations of the shallow groundwater sustaining baseflows. However, more targeted sampling would be necessary to confirm river versus lake differences in concentration.

- It is not clear how much groundwater influences the overall concentrations of chlorides in lakes.However, considering that chloride concentrations within lakes have not decreased, but were at least sustained and consistent, seems to suggest that groundwater is having an influence on the steadiness of lake chloride concentrations over time. This observation is consistent with the findings in Section 6.6 that chloride concentrations are increasing in the shallow aquifers as recorded in the municipal well data.

Data Gaps

The lake data used for analysis of chloride conditions and trends in this Study were compiled from various organizations under various monitoring programs. Consequently, the lake chloride dataset is incomplete and inconsistent, with significant gaps in spatial coverage, time, and season for comparison against influencing factors such as land use. The most notable considerations of the compiled dataset were a bias toward large lakes, particularly those with public access; a lack of data for lakes with highly urban watersheds; and limited data available for evaluation of seasonality in chloride concentrations. These considerations are discussed below.

- Chloride and conductance data were not comprehensively available for the entire study area. The most complete datasets were from lakes monitored by USGS, WDNR, the Commission (as part of this Study), and various local municipalities for some portion of the full period of record (1960-2022).

- Datasets with long-term, multi-year, and seasonal data were very limited, particularly for seasonal chloride data.

- Large lakes were overrepresented in this analysis; small lakes (surface area < 50 acres) have almost no data.

- There were few highly urban lakes (i.e., greater than 69 percent urban land use) in the study area and many of those waterbodies have limited or no chloride and specific conductance data.

Chloride Conditions for Lake Michigan

While Lake Michigan is not technically within the study area of this project, the Lake is adjacent to the eastern boundary of the study area and is impacted by chloride pollution generated within the study area. Lake Michigan receives flow from the streams and rivers of the following major watersheds within the study area: the Menomonee River, Milwaukee River, Oak Creek, Pike River, Root River, Sauk Creek, and Sheboygan River watersheds, as well as the areas along the coast that drain directly to the Lake.

Data was compiled from three nearshore sampling sites and four sites located farther offshore to build a dataset representative of chloride concentrations for Lake Michigan, as shown on Map 6.28. The observed chloride concentrations for the offshore sites ranged from 5.5 mg/l in 1962 to 13.8 mg/l in 2021. For the nearshore sites, chloride concentrations ranged from 6.2 mg/l in 1987 to 20.0 mg/l in 2024. Figure 6.26 presents all the chloride data collected at these sampling sites between 1962 and 2024. An analysis of the farthest offshore site (MI-23) indicated that chloride concentrations in the middle of Lake Michigan have been increasing by approximately 0.14 mg/l per year since 1983. Based on a review of previous studies, it appears that this rate of increase in Lake Michigan chloride concentrations has been fairly consistent since the 1960s. Water level fluctuations in Lake Michigan did not appear to have an influence on observed chloride concentrations in the Lake.

6.6 CHLORIDE CONDITIONS IN STUDY AREA GROUNDWATER

Chloride in groundwater can come from natural sources and anthropogenic sources. Due to the rarity of chloride-containing minerals in the bedrock of southeastern Wisconsin, natural groundwater chloride concentrations are quite low.[19] A threshold of 20 mg/l was used to represent the highest natural groundwater concentrations in this study. The anthropogenic sources of chloride to groundwater are similar to the sources to surface waters and are introduced to groundwater via soil or surface waters. Groundwater can also contaminate surface waters with chloride, as indicated by increases in chloride concentrations in

[19] *P.A. Kammerer, Jr.,* Information Circular 39: Ground Water-Quality Atlas of Wisconsin*, United States Geological Survey and University of Wisconsin Geological and Natural History Survey, 1981.*

baseflow of urban streams.[20] Due to the long residence time of groundwater aquifers and the lack of a natural removal process for chloride, concentrations of chloride in groundwater can accumulate over time with repeated additions at the surface. These same features also suggest that if salt applications in a watershed are reduced, contributions of chloride in baseflow to surface waterbodies will continue for a considerable period of time, resulting in delays in ecological improvements.

Recognizing the harmful impacts of chloride in groundwater, Wisconsin has established a preventive action limit at 125 mg/l and an enforcement standard of 250 mg/l (see discussion of these standards in Chapter 5).[21] Sodium, which is often highly correlated with chloride in groundwater due to application of winter deicing salts (sodium chloride), has a health-based drinking water advisory of 20 mg/l. [22]

Major sources of groundwater chloride data for the study area included the Wisconsin Department of Natural Resources (WDNR), the United States Geological Survey (USGS), the Milwaukee Metropolitan Sewerage District (MMSD), and the University of Wisconsin – Stevens Point (UWSP) in collaboration with the University of Wisconsin – Extension. Commission staff compiled groundwater well data from the WDNR, USGS, MMSD, and UWSP into one comprehensive dataset. Due to security concerns, the exact locations of private wells are not reported in WDNR datasets; instead, the well location is identified by which Public Land Survey System (PLSS) Section it falls within.[23] Consequently, all spatial analyses were conducted using the PLSS Section to aggregate the groundwater chloride data. The groundwater chloride dataset, which encompassed groundwater chloride samples from all wells at any depth across the study area, was then split into separate analyses for shallow wells (less than or equal to 300 feet deep) and municipal drinking water supply wells.

[20] *See, for example, S. Kaushal, P.M. Groffman, G.E. Likens, K.T. Belt, W.P. Stack, L.E. Band, and G.T. Fisher, "Increased Salinization of Fresh Water in the Northeastern United States,"* Proceedings of the National Academy of Sciences, *102:13,517-13,520, 2005 and S.R. Corsi, L.A. DeCicco, 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.*

[21] Wisconsin Administrative Code *Chapter NR 140, "Groundwater Quality."*

[22] *U.S. Environmental Protection Agency,* Drinking Water Advisory: Consumer Acceptability and Health Effects Analysis on Sodium*, EPA 822-R-03-006, 2003.*

[23] *A PLSS section is approximately a square mile (640 acres) and designated as Township, Range, Section.*

Chloride in Shallow Groundwater

Commission staff compiled 73,690 chloride observations from 5,938 unique shallow wells in 1,397 Public Land Survey System (PLSS) sections (representing 44.5 percent of the study area) from 1945 to 2022. Chloride concentrations in shallow groundwater ranged widely, with concentrations varying from 0 to 6,310 mg/l and an overall median chloride concentration of 28.0 mg/l.[24] Much of this groundwater dataset is sparsely distributed throughout time and across the study area. Just over half of the 5,938 wells with chloride data only had a single chloride observation and 75 percent of the wells had data spanning less than ten years. Similarly, many PLSS sections (509 sections or 36.4 percent) only had one chloride observation to represent conditions within that area. The eastern portion of the study area, including Milwaukee County, was more highly represented in this dataset than other parts of the study area.

Despite the limitations of the dataset, Commission staff were able to discern representative conditions in shallow groundwater chloride for the study area. Across the entire dataset, the majority (58.9 percent) of groundwater observations exceeded 20 mg/l, including forty-two percent of the PLSS sections with data (see Map 6.29).[25] Consequently, this implies that much of the shallow groundwater within the study area has experienced chloride contamination from human activities. Compared to groundwater standards, nineteen percent of the groundwater chloride observations exceeded the preventive action limit of 125 mg/l and nine percent of observations exceeded the drinking water enforcement standard of 250 mg/l (see Table 6.8).[26] Two hundred and ninety-four wells had median chloride concentrations exceeding the 250 mg/l enforcement standard, however 95 of these wells only had one chloride observation. Thirty-seven PLSS sections had median chloride concentrations exceeding the 250 mg/l drinking water standard, but the chloride data in 13 of these sections was only comprised of one sample.

These analyses were repeated for recently collected data (2013 through 2022), which was comprised of 5,214 observations from 1,287 wells across 561 PLSS sections (18 percent of the study area). These recent

---

[24] The relatively low median concentration reflects the high percentage of samples in the dataset from private wells, which are more prominent in rural areas that are less impacted by chloride. In contrast, the highly urban areas of the Region that are likely the most chloride impacted have fewer private wells as most of these areas are supplied by municipal wells.

[25] A 1981 study found that the highest average chloride concentrations in the shallow aquifers present within the Region were 17 mg/l. Consequently, 20 mg/l was established as the natural background concentration in shallow groundwater for this study. For more information, see P.A. Kammerer, Jr., Information Circular 39: Ground Water-Quality Atlas of Wisconsin, United States Geological Survey and University of Wisconsin Geological and Natural History Survey, 1981.

[26] Refer to Chapter 5 of this Planning Report for a discussion of groundwater standards.

concentrations indicate that chloride contamination in shallow groundwater continues to be a concern across the study area. Chloride concentrations in the recently collected data ranged from 0 to 4,100 mg/l, with a median chloride concentration of 39.0 mg/l (nearly twice the natural background concentration).

A detailed spatial analysis of the recent well data was not feasible due to the limitations of the dataset, including the combining of well data to the PLSS section and the uneven spread of data across the study area. Sections with the highest median and maximum well chloride concentrations were spread across the study area, although these sections were generally in more urbanized areas or contained facilities such as landfills, wastewater treatment facilities, and/or food manufacturers. Shallow groundwater near urban areas as well as chloride-discharging facilities are more likely to have high chloride concentrations, particularly if the soil in these areas is highly susceptible to groundwater contamination (see Map 6.5 of TR-63).

In order to evaluate trends in chloride concentrations over time, Commission staff filtered the shallow groundwater data to only include wells with substantial long-term datasets, which was defined as a well dataset containing at least 20 samples spanning 20 years with the most recent sampling date since 2000. A total of 338 wells were included in this analysis, which comprised 22,008 chloride observations collected between 1972 and 2020 across 46 PLSS sections (1.4 percent of the study area). For each well, Commission staff evaluated whether there were statistically significant increases or decreases in chloride concentrations. In total, 89 of the 338 wells (26 percent) were categorized as "No Significant Trend" while 156 wells (46 percent) were designated "Significant Increase" and 93 wells (28 percent) were designated "Significant Decrease" (see Map 6.30). Examples of wells showing "Significant Increase", "No Significant Trend," and "Significant Decease" are illustrated in Figure 6.9 of TR-63.

Visual examination of wells in the trend dataset with long chloride time series shows that the chloride concentrations in many individual wells are quite dynamic over time. These fluctuations may be driven by changes in chloride loading, well depth, dilution from increased water levels, or other factors. These changes are particularly notable in very shallow wells (less than 25 feet deep), where chloride concentrations in winter were observed to be higher than the average annual concentration for a given year. Thus, shallow groundwater may reflect seasonal differences in chloride loading to the environment, with higher concentrations during winter and early spring potentially indicative of road salt and deicer use.

Across the study area, shallow groundwater chloride concentrations are highly variable with differences within wells over time, between wells within the same PLSS section, and between PLSS sections. However, most observations and monitored wells indicate that groundwater chloride concentrations have increased from natural conditions, with the highest observed concentration 315 times higher than the natural concentrations for southeastern Wisconsin. Additionally, more wells were designated as significantly increasing in chloride concentrations than either significantly decreasing or not showing a trend. These increases likely reflect inputs from anthropogenic chloride sources, such as road salts and other deicers, wastewater treatment, fertilizers, and waste from industrial and food processing facilities. This general increase in shallow groundwater chloride concentrations across much of southeastern Wisconsin has likely affected surface water chloride concentrations, especially for waterbodies where groundwater is a main water source such as spring-fed lakes and stream baseflows.

Chloride concentrations in monitoring wells of some food manufacturers and industrial facilities have rapidly declined over the past two decades, likely reflecting changing practices at these facilities. In some instances, these changes were likely driven by WDNR in response to the monitoring wells at that facility exceeding the preventive action limits and enforcement standards.

As demonstrated in Chapter 6 of TR 63, non-point sources of chloride, such as winter deicing activities, are likely to strongly impact shallow groundwater chloride concentrations. Reductions in high chloride loading activities, including winter maintenance, may result in a marked decline in shallow groundwater chloride concentrations. However, the long residence time of groundwater aquifers means that elevated chloride concentrations will likely continue to contaminate surface waters and private drinking water wells for decades or centuries to come.

Chloride in Municipal Drinking Water Supply Wells

Municipal drinking water well data was reviewed in detail to further evaluate the groundwater chloride conditions in the study area. A total of 46 municipalities in the study area reported chloride concentration data for their drinking water wells during the period from 1977 to 2025. While most of the 46 municipalities in the study area only had one or two chloride samples over that period, six communities with more robust datasets were selected for a detailed analysis of their drinking water well data. These included the Cities of Brookfield, West Bend, and Whitewater as well as the Villages of Grafton, Hartford, and Slinger. These communities were chosen based on their longer chloride dataset period of record, range of well depths, and to provide good geographical coverage of the study area. Wells were categorized as shallow (depth less than 300 feet), mid-depth (depths between 300 feet and 700 feet), and deep (depths greater than 700 feet). More details on the municipal well evaluation can be found in Chapter 6 of TR-63.

The analysis for these six communities revealed that shallow drinking water wells generally had higher chloride concentrations than deeper wells. Chloride data for the shallow wells exhibited much more variability than for mid-depth and deep wells. Shallow well chloride concentrations often exceeded the groundwater preventive action limit (PAL) of 125 mg/l and occasionally exceeded the drinking water enforcement standard (DWSE) of 250 mg/l.[27] Mid-depth well chloride concentrations rarely exceeded the groundwater preventive action limit. The analysis also indicated that chloride concentrations in most shallow and mid-depth wells have been increasing over time. In contrast, chloride concentrations in deep wells remain low and have not shown increasing trends over time. Chloride samples collected from the deep wells never exceeded the groundwater preventive action limit. Due to the time scales involved in groundwater flow, the observed chloride trends in shallow and mid-depth wells are anticipated to produce future upward chloride concentration trends in the deep aquifer.

Figure 6.27 presents an example of municipal well chloride concentration trends for the City of Brookfield. Brookfield maintains wells in all three well depth categories, however the City's shallow wells are deeper than most of the six municipal well datasets reviewed in detail. The four shallow wells in the City exceeded the PAL and two of the shallow wells exceeded the DWES. None of the mid-depth and deep wells exceeded the PAL or DWES. The shallow wells experienced the largest increases in chloride concentration, while the City's deep wells had minimal change in chloride concentration. Similar chloride concentration graphs can be found in TR-63 for the wells in the other five municipalities reviewed in detail.

Planning Report No. 57

A CHLORIDE IMPACT STUDY FOR SOUTHEASTERN WISCONSIN

Chapter 6

CHLORIDE CONDITIONS IN SOUTHEASTERN WISCONSIN

TABLES

Table 6.1
Stream Monitoring Sites for the Chloride Impact Study

SEWRPC Site ID[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	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	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	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	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	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	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	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)

Table continued on next page.

Table 6.1 (Continued)

SEWRPC Site ID[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
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	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)
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	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	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)

Table continued on next page.

Table 6.1 (Continued)

SEWRPC Site ID[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
47	Fox River at Rochester	Fox River	Racine	Waukesha, Racine, Walworth, Jefferson, Milwaukee, Washington	455.6	10032438	05544475[c]	42.74014301	-88.22477829	Fox River about 1,700 feet upstream of Rochester Dam near USGS Gage 05544475 at Rochester (Village of Rochester)
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	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	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	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	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] *See Map 6.1 for locations and Figure 6.1 for photographs of each monitored stream.*

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

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

Source: SEWRPC

Table 6.2
Piecewise Regression Model for Estimating Chloride Concentration from Specific Conductance

Specific Conductance Range (µS/cm at 25°C)[a]	Equation to Estimate Chloride Concentration (mg/l)
SC ≤ 103	$[Cl^-] = 0$
103 < SC ≤ 732	$[Cl^-] = 0.1171 \times SC - 12.0$
732 < SC ≤ 2,123	$[Cl^-] = 0.3084 \times SC - 151.9$
SC > 2,123	$[Cl^-] = 0.3687 \times SC - 280.0$

Range of Values[b]	
Specific Conductance (µS/cm at 25°C)	Chloride (mg/l)
200 – 12,050	11 – 4,163

Note: SC indicates specific conductance. $[Cl^-]$ indicates chloride concentration.

[a] *The standard temperature used for adjusting conductivity to calculate specific conductance is 25°C, which is equivalent to 77°F.*

[b] *Estimates outside the range of data used to develop the regression model should be treated as less reliable due to extrapolating beyond the range of values used to develop the model.*

Source: SEWRPC

Table 6.3
Percentage of Measurements in Which Estimated Chloride Concentration Exceeded Various Thresholds

SEWRPC Site ID	Monitoring Site Name	Estimated Chloride Measurements Exceeding Concentration Threshold (percent) 10 mg/l	35 mg/l	120 mg/l	230 mg/l	395 mg/l	757 mg/l	1,400 mg/l
1	Fox River at Waukesha	99.9	99.9	91.0	49.0	2.7	<0.1	0.0
2	Fox River at New Munster	99.9	99.7	29.6	1.5	0.0	0.0	0.0
3	Mukwonago River at Mukwonago	99.2	99.0	0.0	0.0	0.0	0.0	0.0
4	Sugar Creek	100.0[a]	89.1	0.0	0.0	0.0	0.0	0.0
6	White River near Burlington	99.5	95.0	0.0	0.0	0.0	0.0	0.0
8	Pewaukee River	99.4	99.4	71.3	3.9	0.3	0.0	0.0
9	Oak Creek	99.4	95.7	82.8	57.2	16.9	5.2	0.8
10	Pike River	99.1	90.6	16.0	7.0	1.4	0.0	0.0
11	Bark River Upstream	100.0[a]	100.0	19.0	0.0	0.0	0.0	0.0
12	Lincoln Creek	98.1	96.0	87.4	72.9	29.2	12.8	5.5
13	Ulao Creek	99.9	98.1	54.1	12.4	2.0	0.3	0.0
14	Sauk Creek	99.1	91.2	5.5	0.3	<0.1	0.0	0.0
15	Kilbourn Road Ditch	99.9	93.7	18.2	7.5	1.8	0.5	0.2
16	Jackson Creek	99.6	95.0	12.7	0.0	0.0	0.0	0.0
18	Oconomowoc River Upstream	99.8	99.5	0.0	0.0	0.0	0.0	0.0
20	Oconomowoc River Downstream	98.7	98.6	0.0	0.0	0.0	0.0	0.0
21	East Branch Milwaukee River	99.2	0.0	0.0	0.0	0.0	0.0	0.0
23	Milwaukee River Downstream of Newburg	100.0[a]	98.4	1.6	0.0	0.0	0.0	0.0
25	Root River Canal	96.1	89.0	22.7	1.2	0.0	0.0	0.0
28	East Branch Rock River	99.9	98.9	0.0	0.0	0.0	0.0	0.0
30	Des Plaines River	95.1	91.7	29.4	3.0	0.5	0.0	0.0
32	Turtle Creek	99.0	98.9	0.0	0.0	0.0	0.0	0.0
33	Pebble Brook	100.0[a]	99.9	58.6	0.1	0.0	0.0	0.0
35	Honey Creek Upstream of East Troy	100.0[a]	51.0	0.0	0.0	0.0	0.0	0.0
36	Honey Creek Downstream of East Troy	100.0[a]	98.8	0.0	0.0	0.0	0.0	0.0
38	North Branch Milwaukee River	100.0[a]	71.9	0.0	0.0	0.0	0.0	0.0
40	Stony Creek	97.1	20.5	0.0	0.0	0.0	0.0	0.0
41	Milwaukee River near Saukville	99.1	97.2	0.0	0.0	0.0	0.0	0.0
45	Mukwonago River at Nature Road	98.4	<0.1	0.0	0.0	0.0	0.0	0.0
47	Fox River at Rochester	98.7	98.7	43.0	0.6	0.0	0.0	0.0
48	White River at Lake Geneva	91.0	45.2	0.0	0.0	0.0	0.0	0.0
51	Rubicon River	99.8	98.9	18.3	0.4	0.0	0.0	0.0
52	Cedar Creek	100.0[a]	99.4	0.9	0.0	0.0	0.0	0.0
53	Honey Creek at Wauwatosa	99.4	96.7	86.1	77.0	40.2	14.7	6.3
54	Whitewater Creek	98.3	0.0	0.0	0.0	0.0	0.0	0.0
55	Bark River Downstream[b]	--	--	--	--	--	--	--
57	Menomonee River at Wauwatosa	98.7	97.2	78.7	35.9	17.8	6.0	1.3
58	Milwaukee River at Estabrook Park	98.8	98.3	6.8	0.1	0.0	0.0	0.0
59	Root River near Horlick Dam	95.8	92.0	37.2	8.0	0.8	0.0	0.0
60	Root River at Grange Avenue	99.8	99.4	93.3	82.5	48.5	15.9	5.9
87	Underwood Creek	92.6	92.2	86.7	74.3	35.4	7.6	2.5

[a] *Percentage of chloride concentrations exceeding 10 mg/l were 100.0 percent with rounding.*

[b] *Chloride concentration could not be estimated for this site due to lack of a valid regression relationship between specific conductance and chloride.*

Source: SEWRPC

Table 6.4
Waterbodies Listed as Impaired Due to Chloride in the Chloride Impact Study Area: 2024

Stream Name	Extent (River mile)[a]	Impairment		Listing Date	Chloride Assessment Reaches Included in Impairment	Max Recent Chloride Observed (Reach, Concentration, Date)
		Acute Toxicity	Chronic Toxicity			
Des Plaines River Watershed						
Kilbourn Road Ditch	0-14.3	--	X	2022	DP08, DP07	DP08, 1,470 mg/l, 2/23/2021
Fox River Watershed						
Meadowbrook Creek	0.00-3.14	--	X	2018	FX91	FX91, 529 mg/l, 1/20/2015
Pewaukee River above Pewaukee Lake	0.00-4.45	--	X	2020	FX88	FX88, 991 mg/l, 2/20/2014
Kinnickinnic River Watershed						
Kinnickinnic River[b]	5.49-9.93	X	X	2018	KK03, KK04	KK03, 3,200 mg/l, 2/21/2019
Kinnickinnic River	3.16-5.49	X	X	2014	KK02	KK02, 6,200, mg/l, 2/19/2014
Kinnickinnic River	0.00-3.16	X	X	2018	KK01	KK01, 870 mg/l, 2/11/2013
South 43rd Street Ditch	0.00-1.16	X	X	2022	KK09	KK09 7,800 mg/l, 2/19/2014
Wilson Park Creek	0.0-3.5	X	X	2018	KK05	KK05, 2,400 mg/l, 12/21/2019
Zablocki Park Creek	0.0-0.9	X	X	2022	KK10	KK10, 2,240 mg/l, 2/13/2019
Menomonee River Watershed						
Butler Ditch	0.00-2.85	--	X	2020	MN23	MN23, 1,050 mg/l, 1/20/2018
Dousman Ditch	0.00-2.50	X	X	2022	MN18	MN18, 3,020, mg/l, 2/3/2020
Honey Creek	0.00-8.96	X	X	2018	MN11, MN12, MN13	MN11, 4,580 mg/l, 2/22/2021
Lilly Creek	0.00-4.70	--	X	2016	MN25	MN25, 739 mg/l, 2/22/2014
Little Menomonee River	0.0-9.0	X	X	2016	MN19, MN20 *(partial)*	MN19, 4,190 mg/l, 1/28/2013
Menomonee River	0.00-24.81	X	X	2018	MN01, MN02, MN03, MN04, MN05, MN06, MN07, MN08	MN02, 2,240 mg/l, 1/24/2020
Nor-X-Way Channel	0.0-4.9	--	X	2020	MN26	MN26, 795 mg/l, 2/19/2018
Noyes Creek	0.00-3.54	X	X	2020	MN21	MN21, 3,080 mg/l, 1/31/2017
South Branch of Underwood Creek	0.00-1.11	X	X	2018	MN16	MN16, 1,100 mg/l, 3/25/2014
Underwood Creek	0.00-8.54	X	X	2018	MN14, MN15	MN14, 6,400 mg/l, 2/18/2014
Milwaukee River Watershed						
Beaver Creek	0.00-2.65	--	X	2020	MK26	MK26, 794 mg/l, 1/31/2017
Brown Deer Park Creek	0.00-2.30	X	X	2018	MK25	MK25, 1,290 mg/l, 2/1/2017
Crestwood Creek	0.00-1.35	X	X	2020	MK23	MK23, 1,130 mg/l, 3/14/2017
Gateway Tributary to Ulao Creek	0.00-0.85	--	X	2024	MK113	MK113, 6,630 mg/l, 2/23/2021
Indian Creek	0.00-2.63	X	X	2018	MK24	MK24, 3,340 mg/l, 1/16/2017
Lincoln Creek	0.0-9.7	X	X	2014	MK21, MK22	MK21, 4,770 mg/l, 2/26/2007
Southbranch Creek	0.00-2.36	X	X	2018	MK107	MK107, 1,200 mg/l, 3/9/2022
Ulao Creek	0.0-8.6	X	X	2016	MK32, MK33, MK34, MK35	MK33, 3,030 mg/l, 1/28/2013
Oak Creek Watershed						
Oak Creek	0.00-13.32	X	X	2014	OC01, OC02, OC03	OC01, 2,080 mg/l, 2/25/2021
Michell Field Drainage Ditch	0.00-2.3	X	X	2020	OC04	OC04, 7,120 mg/l, 2/1/2021
North Branch Oak Creek	0.0-5.7	X	X	2018	OC05, OC06[c], OC07	OC05, 2,600 mg/l, 3/1/2022
Pike River Watershed						
Pike River	0.00-9.50	X	X	2016	PK01, PK02	PK01, 1,255 mg/l, 5/1/2018
North Branch Pike River	5.23-7.87	--	X	2018	PK04	PK04, 572 mg/l, 3/24/2015

Table continued on next page.

Table 6.4 (Continued)

Stream Name	Extent (River mile)[a]	Impairment: Acute Toxicity	Impairment: Chronic Toxicity	Listing Date	Chloride Assessment Reaches Included in Impairment	Max Recent Chloride Observed (Reach, Concentration, Date)
Pike River Watershed (continued)						
Unnamed Tributary to North Branch Pike River	0.0-0.58	--	X	2016	PK05	PK05, 234 mg/l, 4/10/2013[d]
Root River Watershed						
Root River	5.82-20.48	--	X	2022	RT02, RT03, RT04[e]	RT04, 800 mg/l, 3/1/2022
Root River	25.80-43.69	X	X	2014	RT05, RT06, RT07	RT06, 3,600 mg/l, 2/22/2021
Direct Drainage to Lake Michigan						
Pike Creek	0.0-3.69	X	X	2016	DD02	DD02, 3,473 mg/l, 3/6/2013

Note: Burnham Canal (Menomonee River watershed) and Fish Creek (Lake Michigan Direct Drainage Area) were listed for chronic chloride toxicity in 2018, but both were removed during the 2024 cycle. However, based on the draft 2026 303(d) list, Burnham Canal is now proposed for re-listing.

[a] *River mile is measured upstream from the confluence with whatever the waterbody drains into.*

[b] *For the Chloride Impact Study, the segment from 7.9 miles to 9.93 miles that is sometimes considered part of the Kinnickinnic River is referred to as Lyons Park Creek.*

[c] *No chloride samples were collected in the OC06 assessment reach during the recent period of record (2013-2022).*

[d] *No chloride sample collected from PK05 in the recent period of record has exceeded the chronic toxicity threshold. However, two samples in 2012 (427 mg/l and 411 mg/l) exceeded it.*

[e] *Root River mainstem assessment reach RT04 (17.1 to 25.8 miles) is partially within this 303(d) listed impaired reach.*

Source: WDNR and SEWRPC

#281174 – PR-57 Table 6.WatershedSummaryStats_Recent
200-1100
AWO/LKH/ko
6/3/2026, 6/8/26

Table 6.5
Chloride Summary Statistics for Streams by Watershed for the Recent Period of Record: 2013-2022

		Chloride Concentration (mg/l)			
Watershed	**Number of Samples**	Minimum	Mean	Median	Maximum
Des Plaines River	63	18	187	81	1,470
Fox River	577	11	127	99	991
Kinnickinnic River	2,523	13	298	130	26,300
Menomonee River	4,379	13	236	160	6,400
Milwaukee River	4,856	3	115	76	6,630
Oak Creek	730	30	422	310	7,120
Pike River	743	5	169	137	1,255
Rock River	844	9	62	56	363
Root River	626	12	291	180	3,600
Sauk Creek	28	22	80	64	365
Sheboygan River	--	--	--	--	--
Direct Drainage Area to Lake Michigan	196	29	305	229	3,473

Source: SEWRPC

#281269 – Table 6.6 Lake Chloride Trends
200-1100
ko
6/23/26

Table 6.6
Lake Trends for Chloride Data: 1960-2022

Official Name	WBIC	Number of Samples	Start Date	End Date	Annual Mean Rate (mg/l/year)[a]	Trend Direction
Amy Bell Lake	774000	10	9/6/1979	11/9/2022	0.0	Flat
Auburn Lake	42400	9	4/22/1963	8/13/2019	0.2	Flat
Bass Bay Lake	763200	15	5/7/1996	4/23/2014	9.9	Increasing
Beaver Lake	774400	46	9/19/1973	11/20/2022	1.4	Increasing
Beechwood Lake	8000	6	2/24/1976	10/31/1985	0.5	Flat
Benedict Lake	743900	8	3/30/1966	4/10/2000	1.5	Increasing
Big Muskego Lake	762400	10	5/17/1965	4/23/2014	1.7	Increasing
Booth Lake	740400	32	5/12/1960	11/14/2022	0.2	Increasing
Browns Lake	750300	31	4/14/1960	8/8/2018	1.3	Increasing
Camp Lake	747100	22	4/19/1966	10/13/2016	1.0	Increasing
Big Cedar Lake	25300	95	4/2/1968	5/11/2022	1.0	Increasing
Center Lake	747300	23	4/19/1966	10/13/2016	1.1	Increasing
Crooked Lake	826800	5	5/2/1965	7/10/2012	2.3	Increasing
Crooked Lake	37900	9	2/24/1976	5/1/1997	0.2	Increasing
Delavan Lake	793600	193	4/17/1984	4/28/2022	-0.2	Flat
Druid Lake	855200	29	5/11/1973	4/24/1996	0.4	Increasing
Eagle Lake	759800	18	4/14/1960	4/12/2017	0.7	Increasing
Eagle Spring Lake	768600	19	3/27/1966	4/17/2001	0.3	Increasing
Elizabeth Lake	742800	29	4/14/1960	7/12/2012	1.3	Increasing
Forest Lake	8900	13	4/1/1968	4/19/2005	0.1	Increasing
Fowler Lake	849400	40	9/18/1973	12/15/2020	0.9	Increasing
Geneva Lake	758300	129	5/12/1960	4/28/2022	0.8	Increasing
Golden Lake	775900	57	9/17/1973	11/14/2022	0.5	Increasing
Green Lake	755800	28	4/28/1968	11/2/1994	0.5	Increasing
Jackson Park Pond	15800	3	4/8/1981	8/30/2004	-0.6	Flat
Lac La Belle	848800	28	9/18/1973	5/1/2000	1.0	Increasing
Lake Beulah	766600	193	9/18/1973	11/2/2022	0.4	Increasing
Lake Denoon	761300	16	4/9/1991	4/23/2014	1.6	Increasing
Lake Ellen	32500	8	4/3/1968	5/1/1997	1.0	Increasing
Lake Keesus	852400	30	9/19/1973	8/14/2018	0.8	Increasing
Lake Mary	743000	29	4/19/1966	8/7/2018	2.2	Increasing
Lake Seven	37800	6	2/24/1976	10/31/1985	0.2	Flat
Lake Twelve	29700	5	5/28/1968	10/30/1985	0.2	Increasing
Lake Wandawega	740700	8	8/24/1966	11/26/2018	0.1	Flat
Lilly Lake	740900	5	1/3/1966	4/2/1998	0.4	Increasing
Little Cedar Lake	25100	37	4/2/1968	5/4/2012	1.1	Increasing
Little Muskego Lake	762700	122	4/10/1963	2/2/2021	3.3	Increasing
Long Lake	38700	35	4/2/1968	7/19/2022	0.4	Increasing
Long Lake	761100	14	4/13/1966	4/10/1996	0.4	Increasing
Lower Phantom Lake	765800	29	3/27/1966	8/8/2018	0.6	Increasing
Lulu Lake	768800	22	4/5/1966	4/16/2019	0.2	Increasing
Mauthe Lake	38200	6	5/2/1965	8/13/2019	0.3	Increasing
Middle Genesee Lake	778300	35	4/10/1996	4/3/2017	1.9	Increasing

Table continued on next page.

Table 6.6 (Continued)

Official Name	WBIC	Number of Samples	Start Date	End Date	Annual Mean Rate (mg/l/year)[a]	Trend Direction
Middle Lake	755700	28	9/18/1973	4/11/2005	0.6	Increasing
Mill Lake	755600	31	4/5/1966	11/2/1994	0.6	Increasing
Moose Lake	778400	60	9/4/1979	2/2/2021	1.2	Increasing
Nagawicka Lake	828000	26	9/8/1973	8/14/2018	1.0	Increasing
North Lake	850800	21	9/20/1973	11/26/2022	0.6	Increasing
Oconomowoc Lake	849600	93	9/17/1973	5/11/2022	1.0	Increasing
Okauchee Lake	850300	66	9/17/1973	5/4/2022	0.9	Increasing
Paradise Valley Lake	36000	5	4/30/1968	10/30/1985	0.6	Increasing
Peters Lake	741400	3	4/25/1966	6/14/2017	0.1	Flat
Pewaukee Lake	772000	30	7/7/1963	8/9/2018	2.2	Increasing
Phantom Lake	766000	35	3/27/1966	7/4/2017	0.7	Increasing
Pike Lake	858300	31	9/19/1973	5/11/2000	1.9	Increasing
Pine Lake	779200	25	9/18/1973	4/12/2006	0.6	Increasing
Potter Lake	753800	27	5/12/1960	5/7/2020	1.0	Increasing
Powers Lake	744200	53	3/30/1966	4/20/2021	0.8	Increasing
Pretty Lake	779300	18	9/5/1979	11/7/2022	0.1	Flat
Random Lake	30300	7	4/3/1968	5/1/1997	0.8	Increasing
School Section Lake	825000	28	9/5/1979	11/7/2022	0.4	Increasing
Silver Lake	779800	43	4/2/1968	11/12/2022	2.5	Increasing
Silver Lake (Paradise Valley)	36200	62	10/30/1985	2/3/2021	0.7	Increasing
Spring Lake	30500	6	5/3/1968	5/6/1997	0.4	Increasing
Tichigan Lake	763600	58	4/13/1966	4/2/1998	2.8	Increasing
Upper Nemahbin Lake	827100	33	9/17/1973	4/13/2005	1.5	Increasing
Voltz Lake	746300	48	4/25/1966	1/21/2021	0.5	Increasing
Wallace Lake	28300	9	4/3/1968	5/6/1997	1.1	Increasing
Waubeesee Lake	760900	17	4/13/1966	4/10/1996	0.4	Increasing
Whitewater Lake	816800	23	9/18/1973	4/12/2000	0.3	Increasing
Wind Lake	761700	75	4/13/1966	5/4/2022	2.1	Increasing

Notes: Trend Data was defined for any lake with 2 data points over 9 years.

[a] *Annual mean rate of mg/l/year were calculated for each lake from its individual regression equation.*

Source: SEWRPC

#281270 – Table 6.7 Lake Chloride – Recent Conditions
200-1100
ko
6/23/26

Table 6.7
Lake Chloride Concentrations, Physical Characteristics, and Watershed Land Use for Recent Conditions Dataset: 2013-2022

	Lake						Watershed[a]						1,000-Foot Shoreline Buffer		
Lake Name	WBIC	County	Mean Chloride (mg/l)	Surface Area (Acres)	Residence Time (year)[d]	Max. Depth (feet)	Total Area (Square Miles)	Urban Lands (%)	Roads and Parking Lots (%)	Agricultural Lands (%)	Change in Urban Lands (%)[b]	Change in Roads and Parking Lots (%)[b]	Urban Lands (%)	Roads and Parking Lots (%)	Urban Area Served by Sewer (%)
Auburn Lake	42400	Fond Du Lac	17.5	90.0	0.74	29	6.34	6.3	2.6	28.5	N/A	N/A	14.2	2.6	0.0
Long Lake	38700	Fond Du Lac	25.0	423.6	0.80	23	20.70	8.5	3.0	46.6	N/A	N/A	26.5	4.9	0.0
Mauthe Lake	38200	Fond Du Lac	21.7	70.2	0.23	47	34.40	6.6	2.6	38.3	N/A	N/A	16.7	0.9	0.0
Camp Lake	747100	Kenosha	70.3	439.5	0.65	19	8.96	26.9	6.5	34.4	9.0	1.8	51.3	12.6	52.6
Center Lake	747300	Kenosha	74.9	126.5	0.84	28	4.04	28.5	6.4	36.8	12.7	2.4	54.6	9.8	61.0
Lake Mary	743000	Kenosha	123.0	327.5	1.92	33	2.42	41.0	9.6	29.2	15.1	2.6	74.5	18.0	74.7
Powers Lake	744200	Kenosha	47.5	451.6	4.20	33	3.35	24.8	4.8	29.7	9.1	1.1	64.0	12.2	0.0
Voltz Lake	746300	Kenosha	35.3	61.3	2.20	24	0.54	15.7	3.5	39.9	-2.7	-0.4	31.4	7.9	25.4
Unnamed[c]	5588789	Milwaukee	191.0	9.1	NC	6	--	--	--	--	--	--	52.8	24.2	63.2
Browns Lake	750300	Racine	97.4	397.4	NC	44	1.33	40.8	7.0	3.4	4.5	-0.4	80.4	16.0	71.6
Eagle Lake	759800	Racine	56.2	529.5	NC	11	6.82	16.6	3.8	53.4	6.0	0.4	49.3	9.5	50.5
Wind Lake	761700	Racine	121.3	919.5	0.60	47	41.20	33.5	8.9	23.5	19.7	5.9	57.3	11.9	58.8
Booth Lake	740400	Walworth	16.6	118.1	NC	24	0.45	31.8	4.8	8.0	5.2	0.4	39.6	6.2	0.0
Delavan Lake	793600	Walworth	56.7	1,907.1	2.00	52	40.60	19.2	6.0	59.3	9.0	3.1	56.5	9.2	60.4
Geneva Lake	758300	Walworth	50.7	5,403.8	13.90	135	28.50	30.4	6.3	15.1	8.4	2.0	69.3	10.4	42.5
Honey Lake (Vienna)	752300	Walworth	51.7	40.0	0.02	6	71.70	12.3	4.5	58.5	7.5	2.2	47.0	12.0	0.0
Lake Beulah	766600	Walworth	25.5	812.3	3.34	58	10.10	21.0	4.1	25.9	8.0	0.8	44.3	6.6	0.1
Lake Wandawega	740700	Walworth	6.6	119.6	2	8	1.61	30.9	4.9	20.7	16.7	1.1	56.3	7.7	0.0
Lulu Lake	768800	Walworth	12.8	95.2	0.55	40	17.40	14.2	3.5	37.1	10.1	1.5	3.9	- -	0.0
Peters Lake	741400	Walworth	6.4	57.8	NC	8	5.08	7.9	2.3	62.6	4.9	0.5	35.9	0.6	0.0
Potter Lake	753800	Walworth	65.3	154.7	NC	26	1.43	44.1	8.6	26.1	16.4	3.6	55.8	9.0	52.3
Amy Bell Lake	774000	Washington	6.3	30.1	NC	37	0.36	42.1	5.8	5.7	17.4	1.9	56.9	7.9	0.0
Big Cedar Lake	25300	Washington	58.8	937.2	5.52	105	9.39	22.9	5.6	27.9	11.4	2.0	44.8	8.3	0.0
Mueller Lake	778900	Washington	3.8	12.4	NC	33	0.62	31.2	15.1	7.0	17.9	8.0	39.1	6.6	0.0
Silver Lake	36200	Washington	35.6	122.4	3.20	47	1.06	41.3	7.5	8.6	23.3	1.8	49.4	7.9	31.3
Bass Bay Lake	763200	Waukesha	218.3	104.2	1.32	23	2.49	69.0	15.3	8.2	53.8	11.7	38.8	6.4	32.3
Beaver Lake	774400	Waukesha	73.3	313.5	2.60	46	2.44	45.2	5.8	15.2	22.4	2.1	57.5	6.1	0.0

Table continued on next page.

Table 6.7 (Continued)

	Lake						Watershed[a]						1,000-Foot Shoreline Buffer		
Lake Name	WBIC	County	Mean Chloride (mg/l)	Surface Area (Acres)	Residence Time (year)[d]	Max. Depth (feet)	Total Area (Square Miles)	Urban Lands (%)	Roads and Parking Lots (%)	Agricultural Lands (%)	Change in Urban Lands (%)[b]	Change in Roads and Parking Lots (%)[b]	Urban Lands (%)	Roads and Parking Lots (%)	Urban Area Served by Sewer (%)
Big Muskego Lake	762400	Waukesha	110.3	2,194.7	0.48	23	28.00	39.4	10.5	16.5	23.4	7.2	13.2	2.1	8.3
Fowler Lake	849400	Waukesha	52.3	96.6	0.02	50	88.80	25.2	5.4	31.0	15.3	2.3	81.5	22.0	82.1
Golden Lake	775900	Waukesha	37.6	199.7	NC	44	1.26	15.1	3.4	24.5	3.6	0.5	28.2	6.1	0.0
Lake Denoon	761300	Waukesha	64.8	167.2	3.60	55	1.11	34.2	6.2	30.0	19.0	2.8	52.9	9.0	58.0
Lake Keesus	852400	Waukesha	45.6	235.3	2.00	42	4.01	41.9	5.8	28.8	30.9	2.9	56.2	7.2	0.0
Little Muskego Lake	762700	Waukesha	185.7	469.8	0.90	65	11.60	51.7	15.1	15.2	26.7	10.3	95.2	19.9	97.2
Lower Phantom Lake	765800	Waukesha	34.2	373.1	0.04	12	70.80	27.6	5.4	29.5	19.1	2.8	51.0	11.2	27.2
Middle Genesee Lake	778300	Waukesha	57.0	98.1	NC	40	2.13	38.8	11.5	34.3	28.7	8.7	43.7	7.7	0.0
Moose Lake	778400	Waukesha	61.9	83.3	NC	61	0.96	29.1	6.1	7.2	12.9	1.9	48.1	9.2	0.0
Nagawicka Lake	828000	Waukesha	43.2	981.2	0.80	90	46.40	44.8	9.3	19.8	34.1	6.1	68.8	9.9	74.2
North Lake	850800	Waukesha	45.2	440.6	0.80	78	69.90	21.8	4.5	34.8	14.8	1.9	40.0	5.5	0.0
Oconomowoc Lake	849600	Waukesha	55.0	795.5	0.41	60	86.80	24.3	5.1	31.7	15.2	2.1	58.7	9.1	8.1
Okauchee Lake	850300	Waukesha	47.5	1,210.6	0.90	90	80.20	23.4	4.9	33.0	15.1	2.0	68.9	11.6	25.0
Pewaukee Lake	772000	Waukesha	146.0	2,437.8	2.30	45	26.90	49.2	11.7	12.3	32.7	6.9	71.1	11.1	77.1
Phantom Lake	766000	Waukesha	41.9	110.3	0.99	29	0.91	40.2	6.0	20.1	17.1	2.3	60.8	7.3	0.0
Pretty Lake	779300	Waukesha	21.8	64.9	3.30	31	0.20	38.9	3.8	0.1	4.1	0.3	41.0	5.4	0.0
School Section Lake	825000	Waukesha	29.0	122.1	0.14	8	7.01	15.7	2.8	28.3	10.6	0.9	28.7	5.4	0.0
Silver Lake	779800	Waukesha	128.6	217.1	NC	40	2.45	66.2	23.8	9.7	51.8	21.0	53.1	8.9	42.7

[a] *Watersheds were automatically delineated using the WDNR Water Explorer (WEx) tool.*

[b] *The Commission does not have 1963 land use data for Fond du Lac County so these metrics were not calculated for Fond du Lac County lakes.*

[c] *This lake was too small for WEx to delineate a watershed for it so there are no values for the watershed characteristics of it.*

[d] *NC inserted where a residence time has not been calculated, therefore, for lakes with no residence time information, the relationship analysis was not done.*

Source: SEWRPC

Table 6.8
Comparison of Chloride Samples, Wells, and Sections to Existing Groundwater Thresholds: 1945-2022

	Observation Exceeds Threshold		Median Concentration Exceeds Threshold			
Threshold	Number of Observations	Percent of Observations	Number of Wells	Percent of Wells (of those with chloride data)	Number of Sections	Percent of Sections (of those with chloride data)[a]
Highest Natural Levels (20 mg/)	43,407	58.9	2,890	48.7	593	42.4
Preventive Action Limit (125 mg/l)	14,123	19.1	702	11.8	82	5.9
Enforcement Standard (250 mg/l)	6,384	8.7	294	5.0	37	2.6

[a] *Of the 3,133 PLSS sections in the study area, only 1,397 sections had groundwater chloride data.*

Source: MMSD, WDNR, UWSP, and SEWRPC

Planning Report No. 57

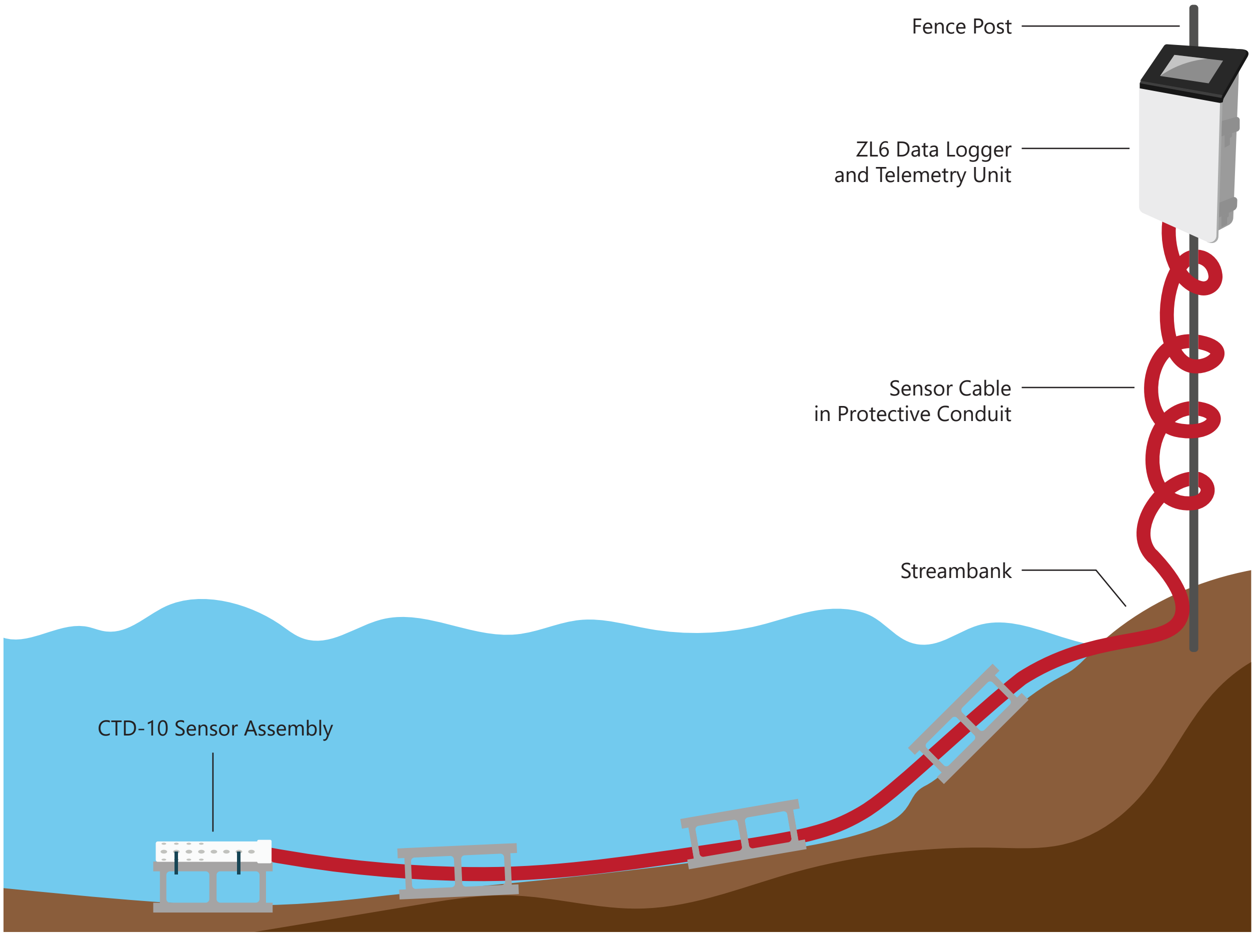
A CHLORIDE IMPACT STUDY FOR SOUTHEASTERN WISCONSIN

Chapter 6

CHLORIDE CONDITIONS IN SOUTHEASTERN WISCONSIN

FIGURES

Figure 6.1
Illustration of Continuous Stream Monitoring Equipment Installation



Source: SEWRPC

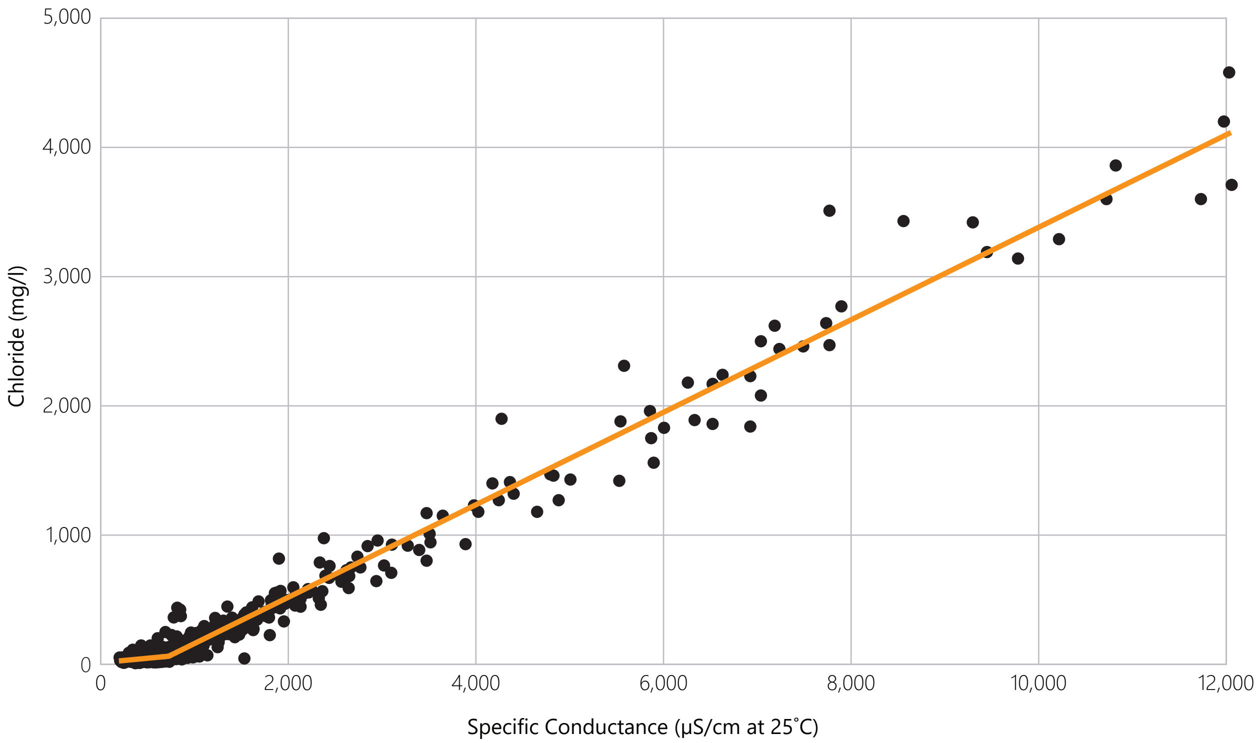
Figure 6.2
Discrete Water Sampling at Stream Monitoring Site

Source: SEWRPC

Figure 6.3
Winter Lake Sampling

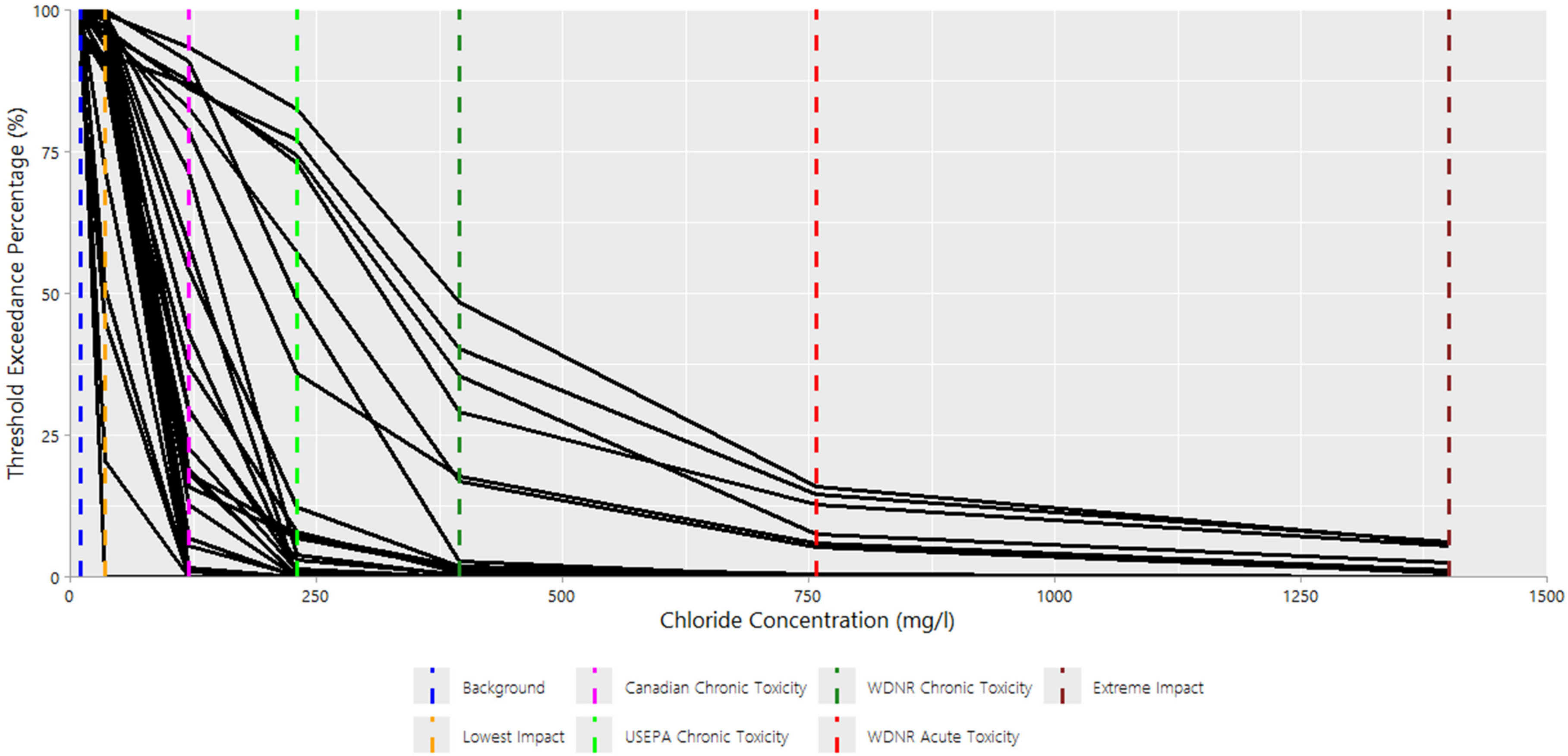
Source: SEWRPC

Figure 6.4
Preliminary Piecewise Regression of Chloride Versus Specific Conductance



Source: SEWRPC

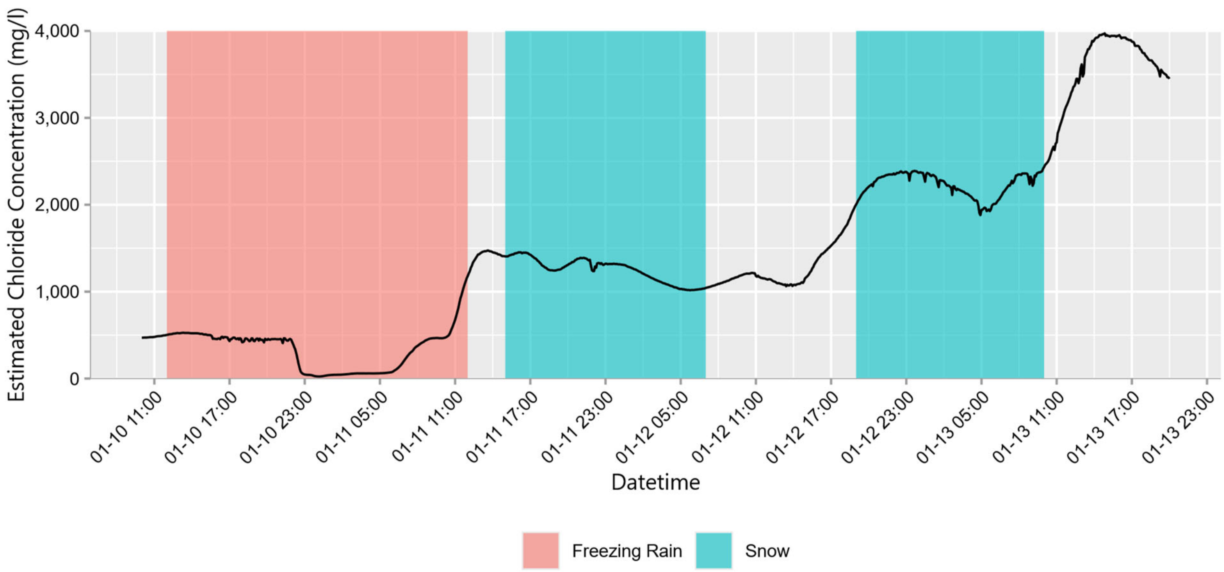
Figure 6.5
Percent of Measurements in Which Estimated Chloride Concentrations Exceeded Thresholds by Site



Note: Each black line represents a SEWRPC stream monitoring site.

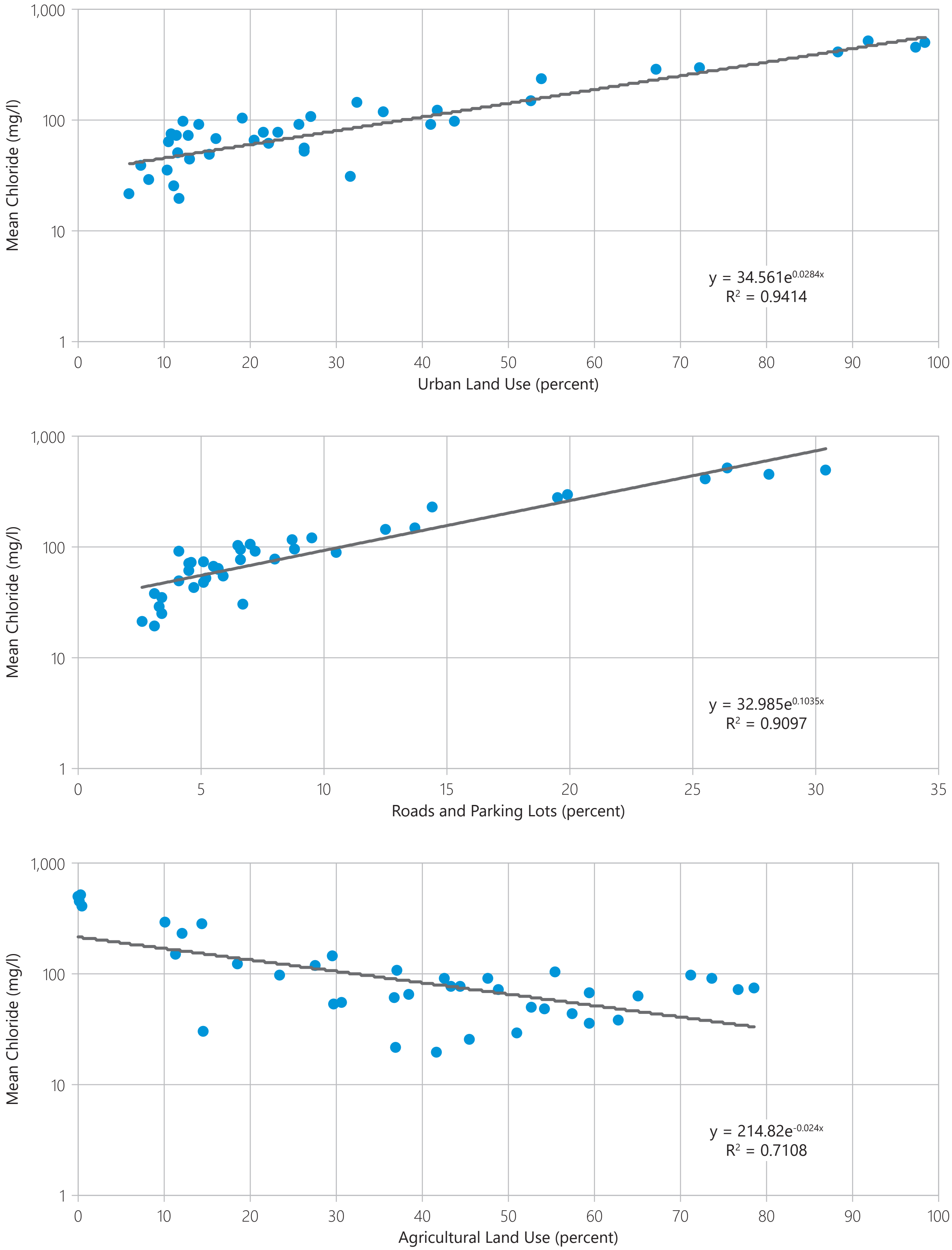
Source: SEWRPC

Figure 6.6
Rapid Succession of Dilution and Winter Spike in Estimated Chloride Concentrations: Site 12 Lincoln Creek



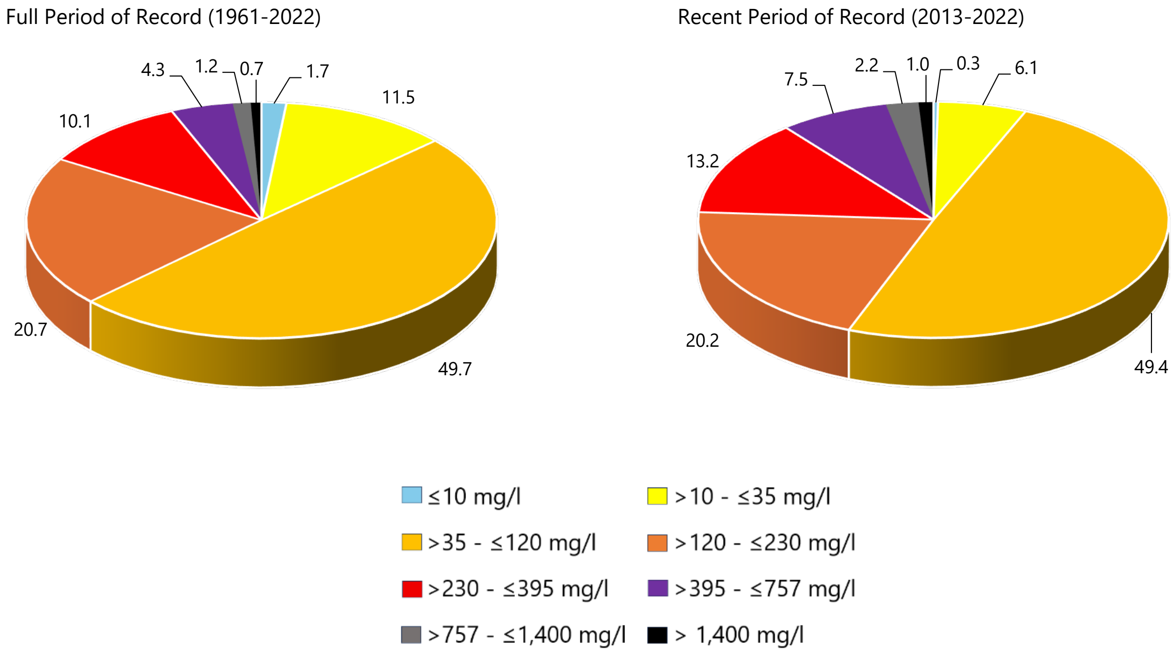
Source: SEWRPC

Figure 6.7
Relationships Between Drainage Area Land Use and Mean Chloride Concentration at Chloride Impact Study Stream Monitoring Sites



Source: SEWRPC

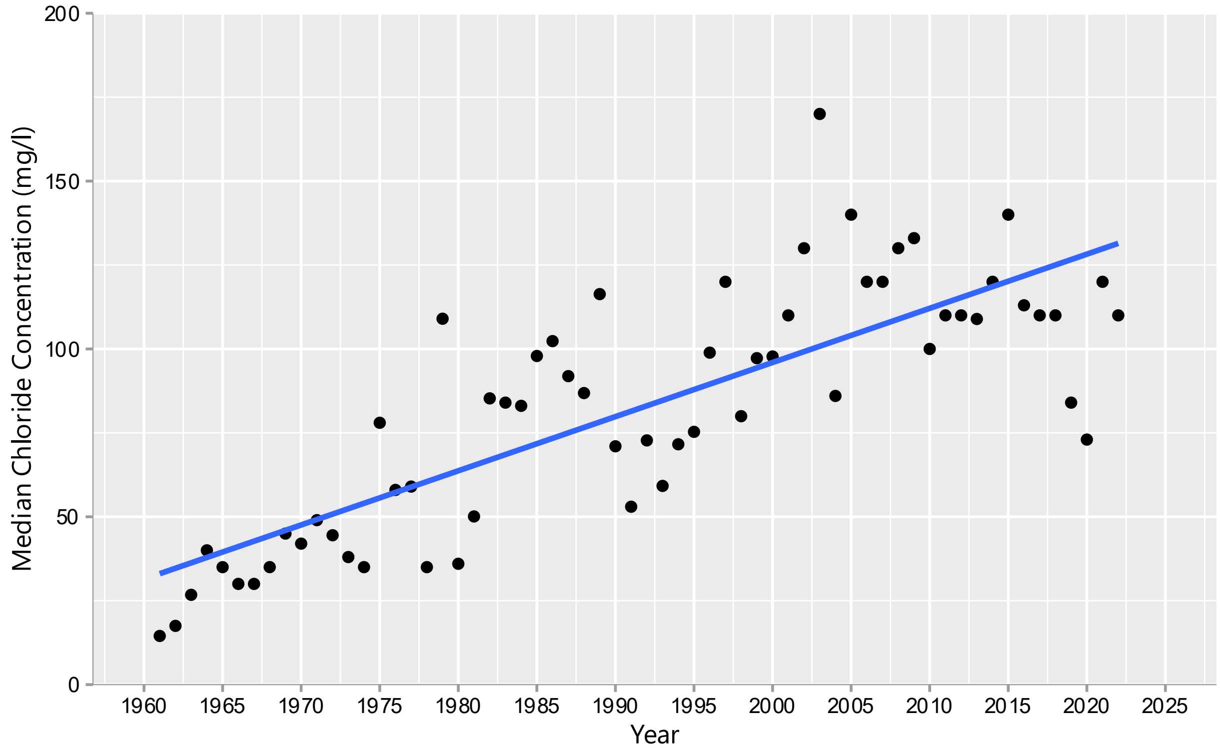
Figure 6.8
Percent of Stream Chloride Samples Collected in the Study Area Within Various Thresholds of Water Quality



Note: There were 47,669 stream chloride samples collected in the study area during the full period of record and 15,565 samples collected during the recent period of record. For descriptions of thresholds shown in this figure, see Table 5.2 in Chapter 5 of this Report.

Source: SEWRPC

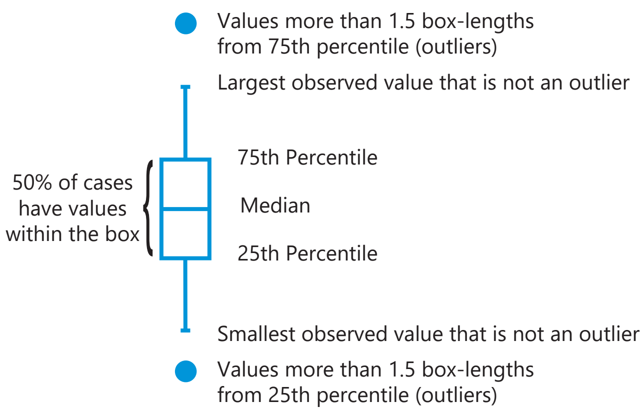
Figure 6.9
Trend in Yearly Median Chloride Concentrations in the Study Area for the Full Period of Record: 1961-2022



Notes: This figure represents all chloride samples for all streams collected during the full period of record. The blue line represents the trendline based on linear regression analysis.

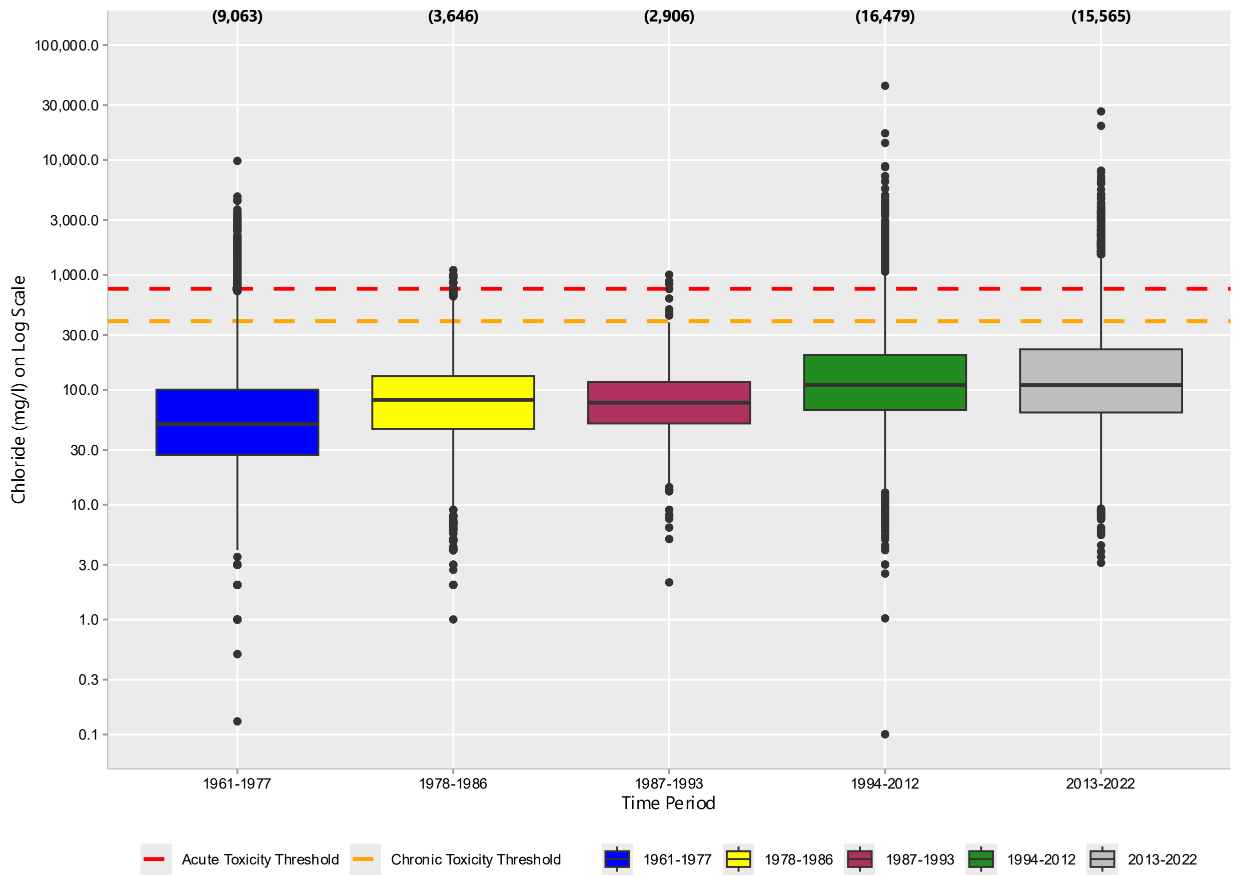
Source: SEWRPC

Figure 6.10
Explanation of Symbols in Box Plot Figures



Source: SEWRPC

Figure 6.11
Distribution of All Chloride Samples by Time Period for the Study Area: 1961-2022



Note: This figure represents all chloride samples collected during the full period of record. The number in parentheses above each box plot represents the number of chloride samples collected in the study area during that time period.

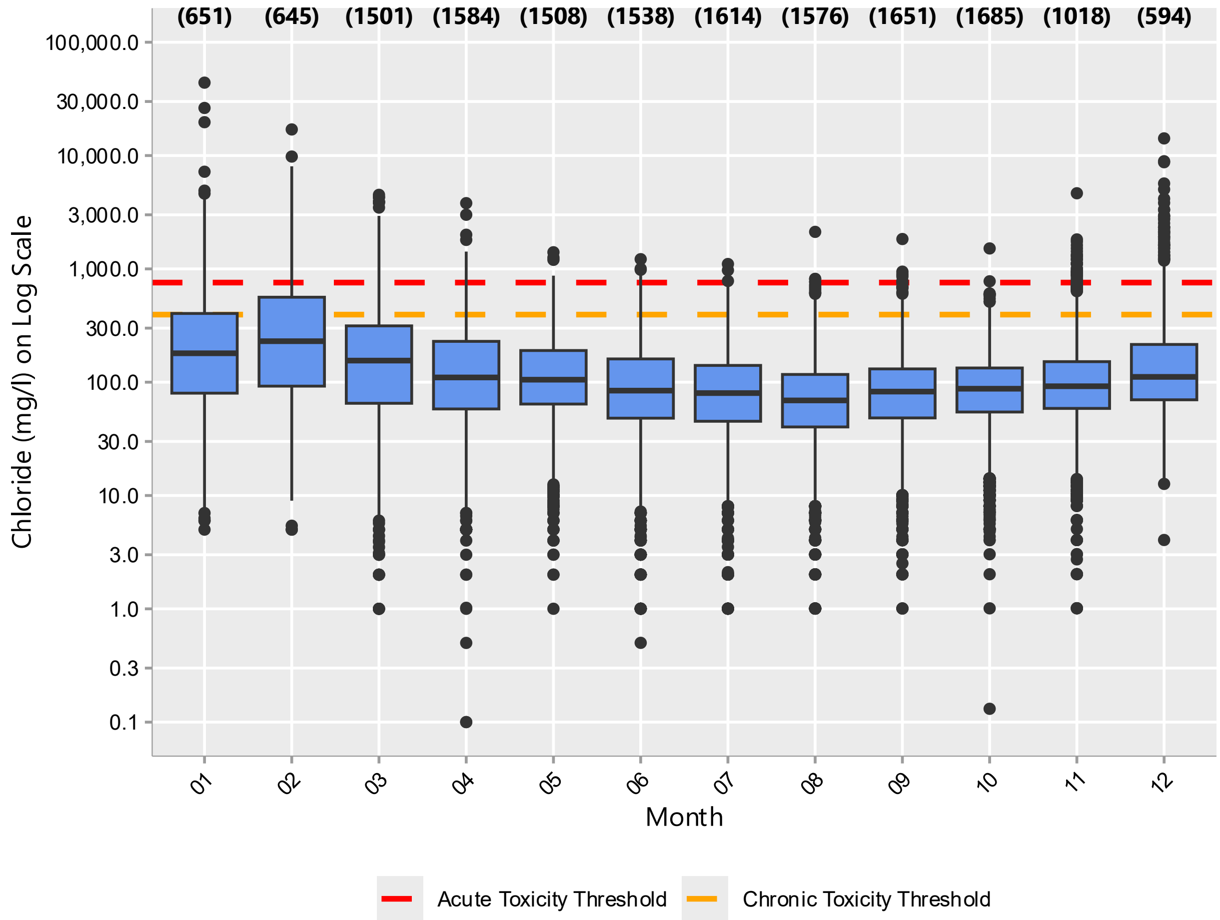
Source: SEWRPC

Figure 6.12
Trends in Chloride Concentration by Season Among All Samples Collected During the Full Period of Record: 1961-2022

Note: This figure represents all chloride samples collected in streams during the full period of record. The blue lines represent the chloride trend for the seasonal dataset based on linear regression analysis.

Source: SEWRPC

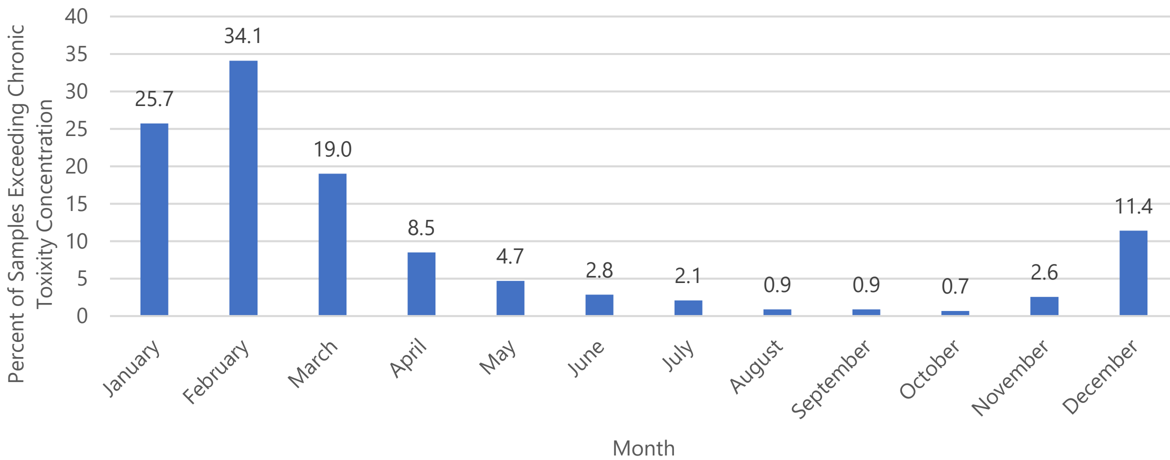
Figure 6.13
Distribution of Chloride Concentrations by Month for All Samples Collected During the Full Period of Record: 1961-2022



Note: This figure represents all chloride samples collected during the full period of record. The number in parentheses above each box plot represents the number of samples collected for each respective month.

Source: SEWRPC

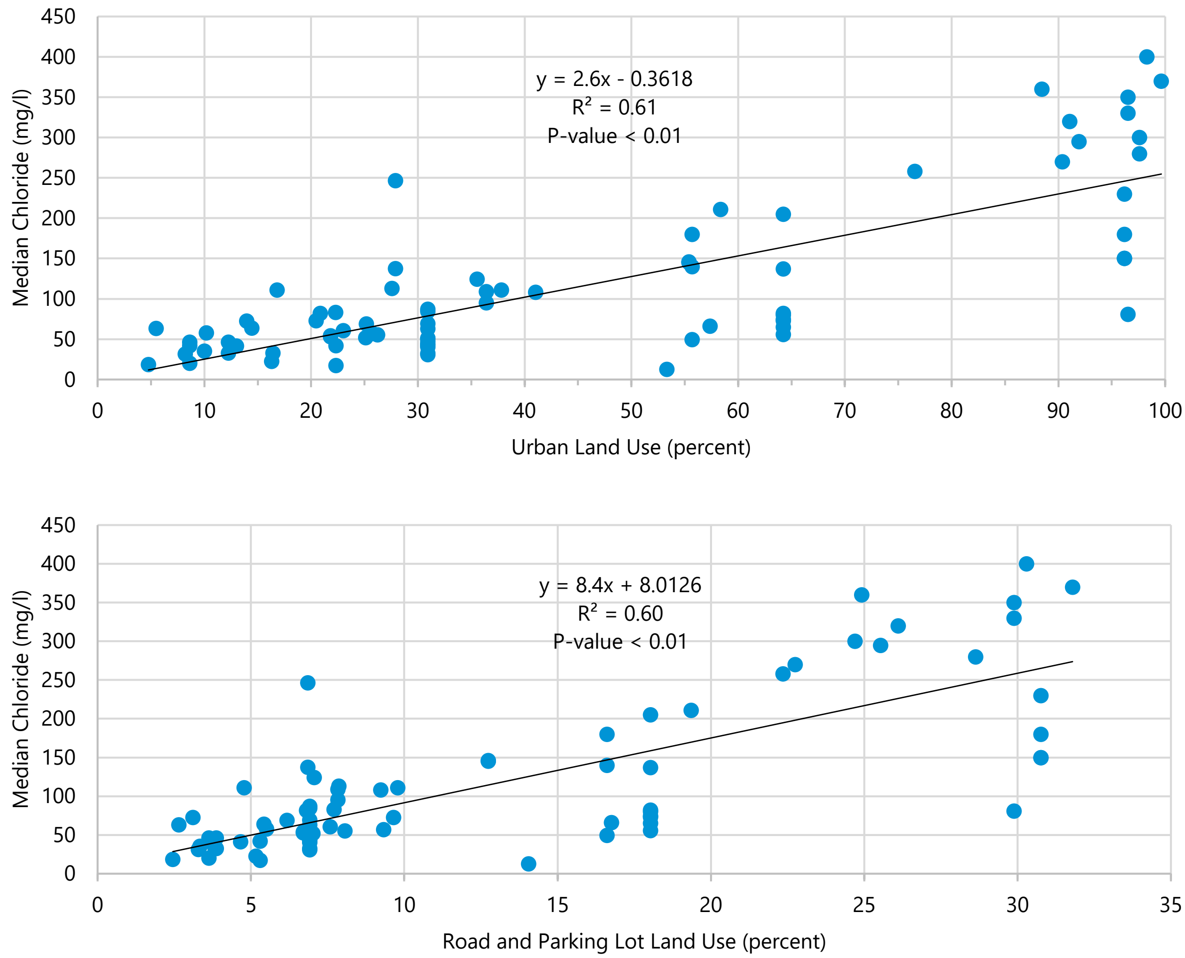
Figure 6.14
Percent of Chloride Samples Exceeding Chronic Toxicity Concentration Among All Samples Collected During the Full Period of Record: 1961-2022



Note: This dataset represents all chloride samples collected during the full period of record. Many of the samples represented in this figure that exceeded the State chronic toxicity threshold were collected prior to the establishment of the chloride toxicity criterion.

Source: SEWRPC

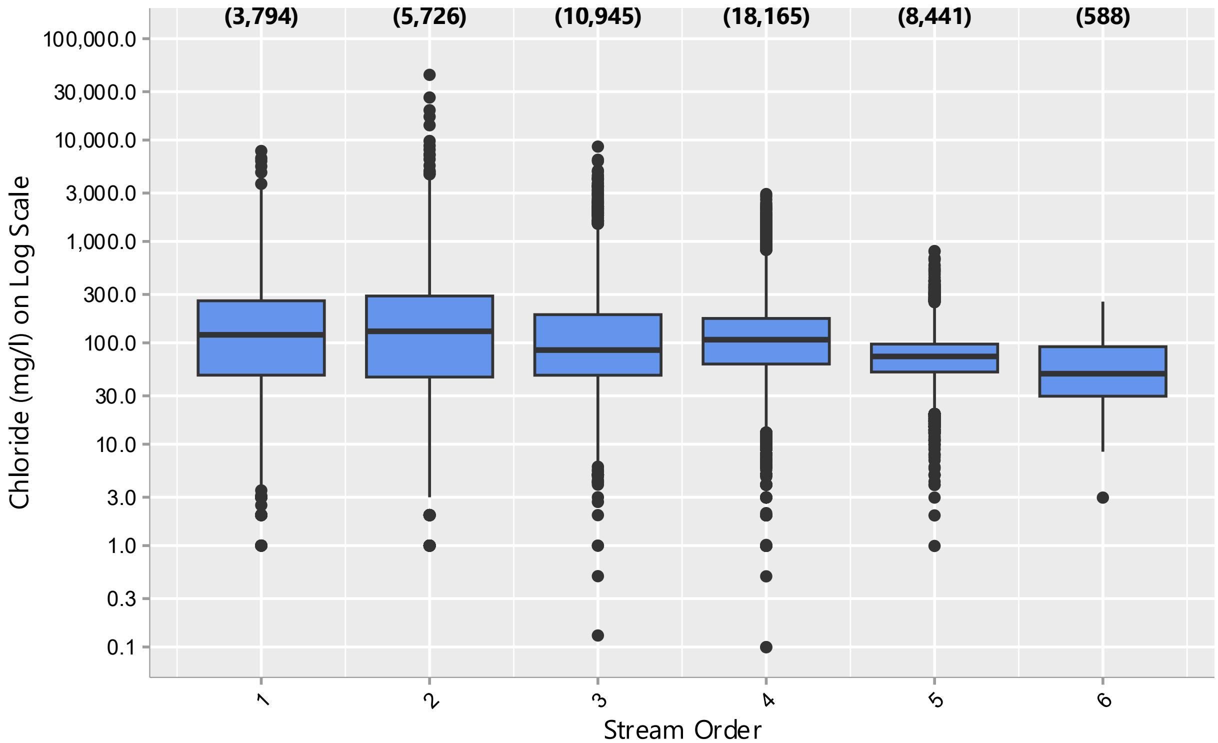
Figure 6.15
Relationships Between Subwatershed Land Use and Median Chloride Concentration at Balanced Assessment Reaches During the Recent Period of Record: 2013 - 2022



Note: Both plots have different x-axis scales to better fit the maximum amounts of land use observed within the subwatersheds for each category. Data points represent assessment reaches determined to have balanced datasets for the recent period of record (2013 through 2022). The amount of each land use category represents 2015 conditions based on the subwatershed for each assessment reach.

Source: SEWRPC

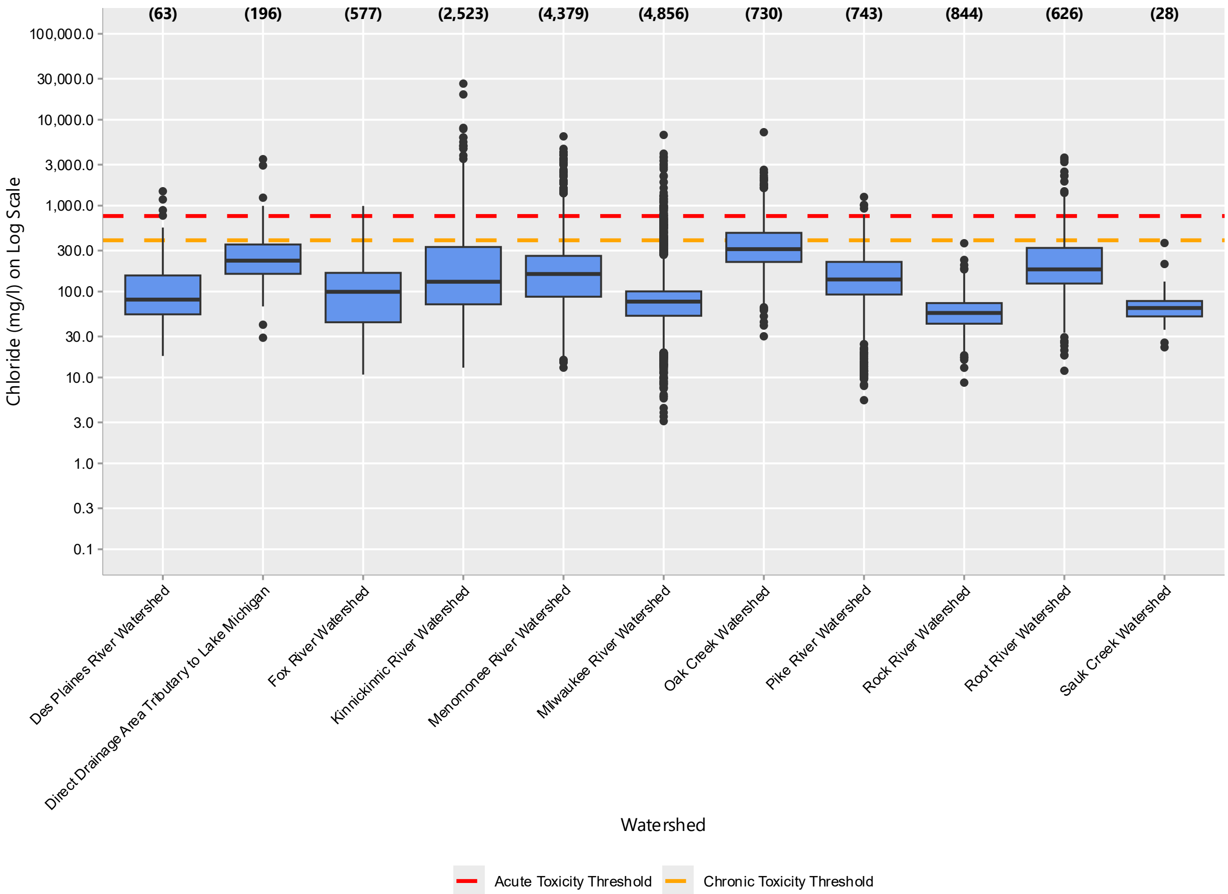
Figure 6.16
Distribution of Chloride Concentration by Stream Order for All Samples Collected During the Full Period of Record: 1961-2022



Note: This figure represents all chloride samples collected during the full period of record. The number in parentheses above each box plot represents the number of chloride samples collected in streams of that order.

Source: SEWRPC

Figure 6.17
Distribution of Chloride Concentration by Watershed for All Samples Collected During the Recent Period of Record: 2013-2022



Note: This figure represents all chloride samples collected during the recent period of record. The number in parentheses above each box plot represents the number of chloride samples collected within each watershed during the recent period of record. The Sheboygan River watershed did not have any recent chloride samples collected and therefore does not appear on this figure.

Source: SEWRPC

Figure 6.18
Percent of Stream Chloride Samples Collected in the Study Area Watersheds Within Various Thresholds of Water Quality During the Recent Period of Record: 2013-2022

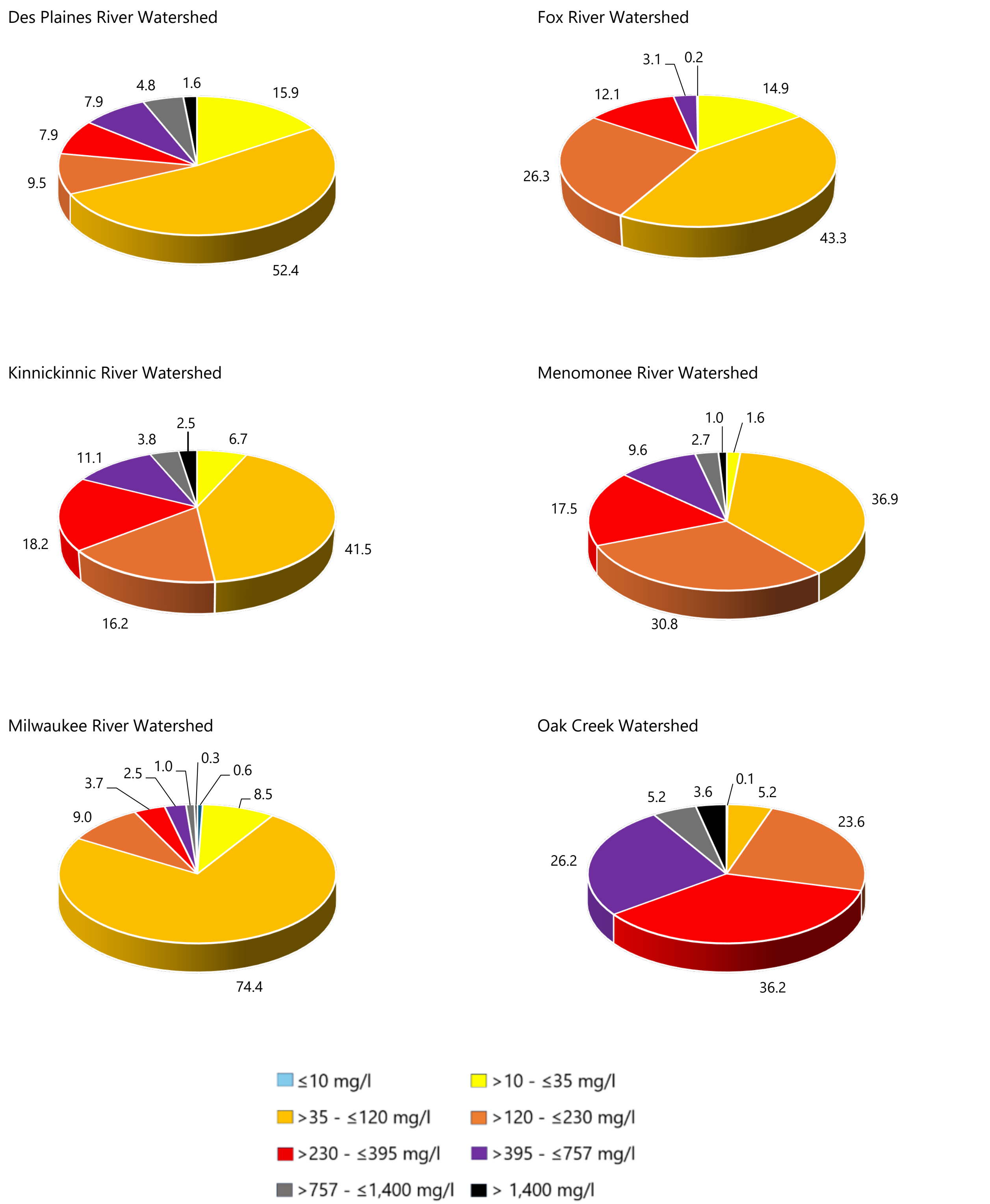
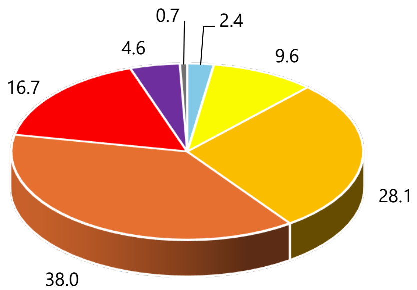
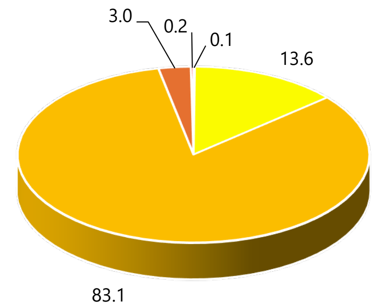


Figure 6.18 (Continued)

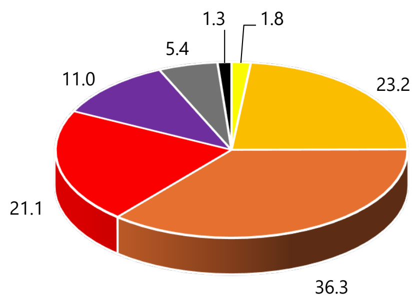
Pike River Watershed



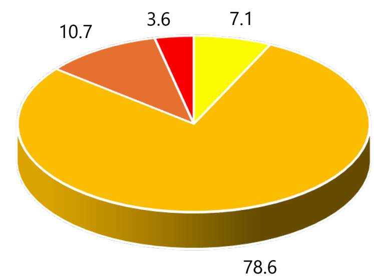
Rock River Watershed



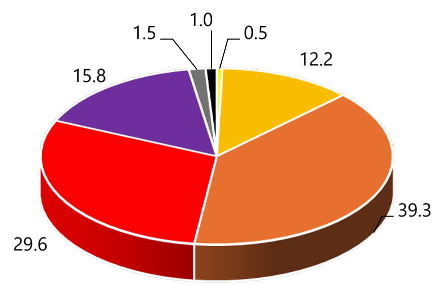
Root River Watershed

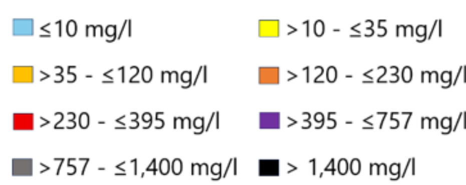


Sauk Creek Watershed



Direct Drainage Area to Lake Michigan



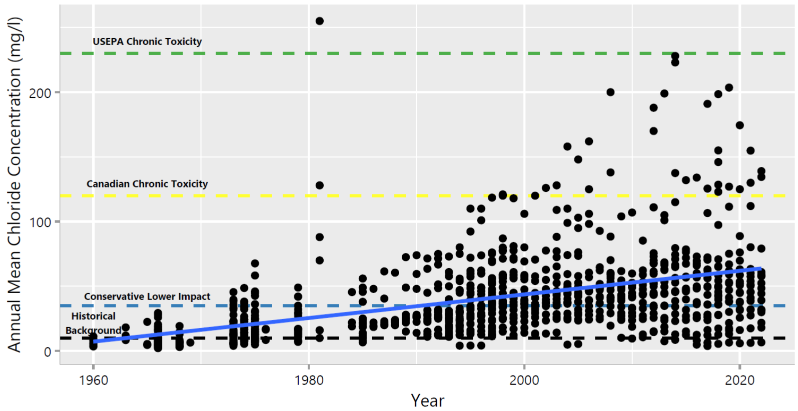


Note: Total number of chloride samples in the recent period of record for each watershed include: Des Plaines River watershed (63), Fox River watershed (577), Kinnickinnic River watershed (2,523), Menomonee River watershed (4,379), Milwaukee River watershed (4,856), Oak Creek watershed (730), Pike River watershed (743), Rock River watershed (844), Root River watershed (626), Sauk Creek watershed (28), and Direct Drainage Area to Lake Michigan (196). The study area portion of the Sheboygan River watershed had no chloride samples from the recent period of record.

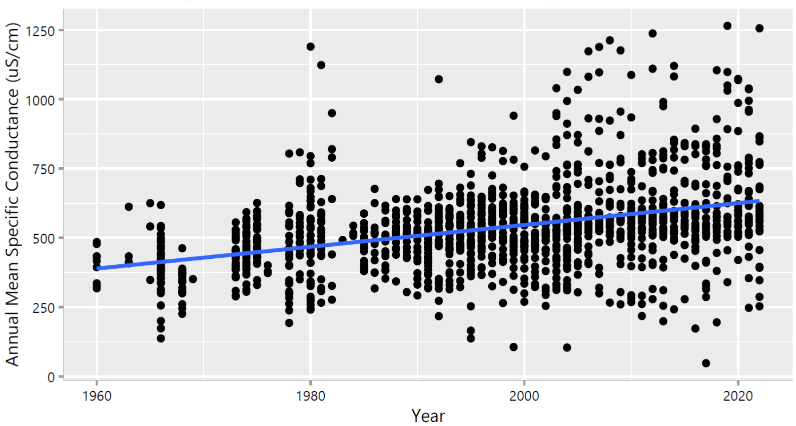
Source: SEWRPC

Figure 6.19
Mean Annual Chloride Concentrations and Mean Annual Specific Conductance of Study Area Lakes for the Full Period of Record: 1960-2022

Annual Mean Chloride Across All Lakes in Study Area: 1960 - 2022



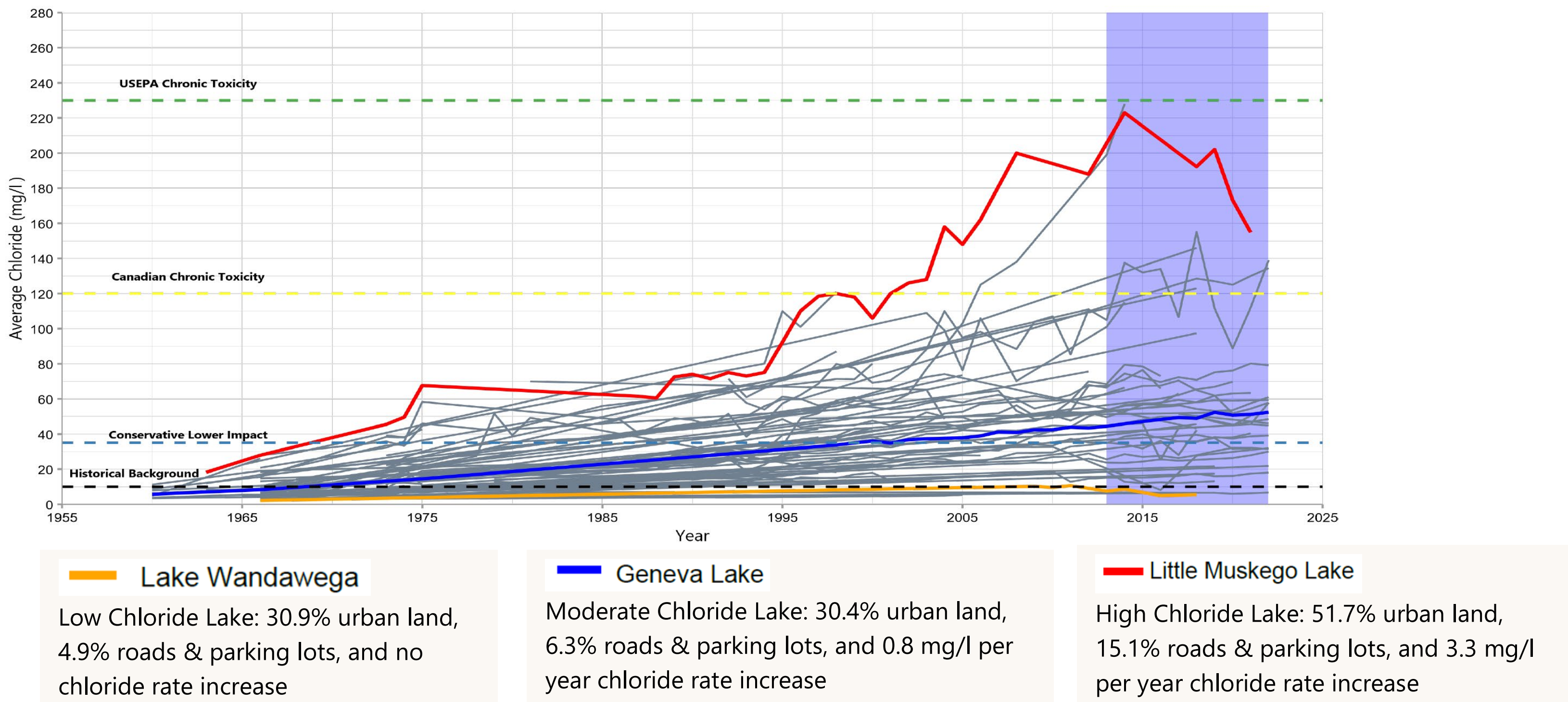
Annual Mean Specific Conductance Across All Lakes in Study Area: 1960 - 2022



Note: The blue lines represent the trend line based on linear regression analysis.

Source: SEWRPC

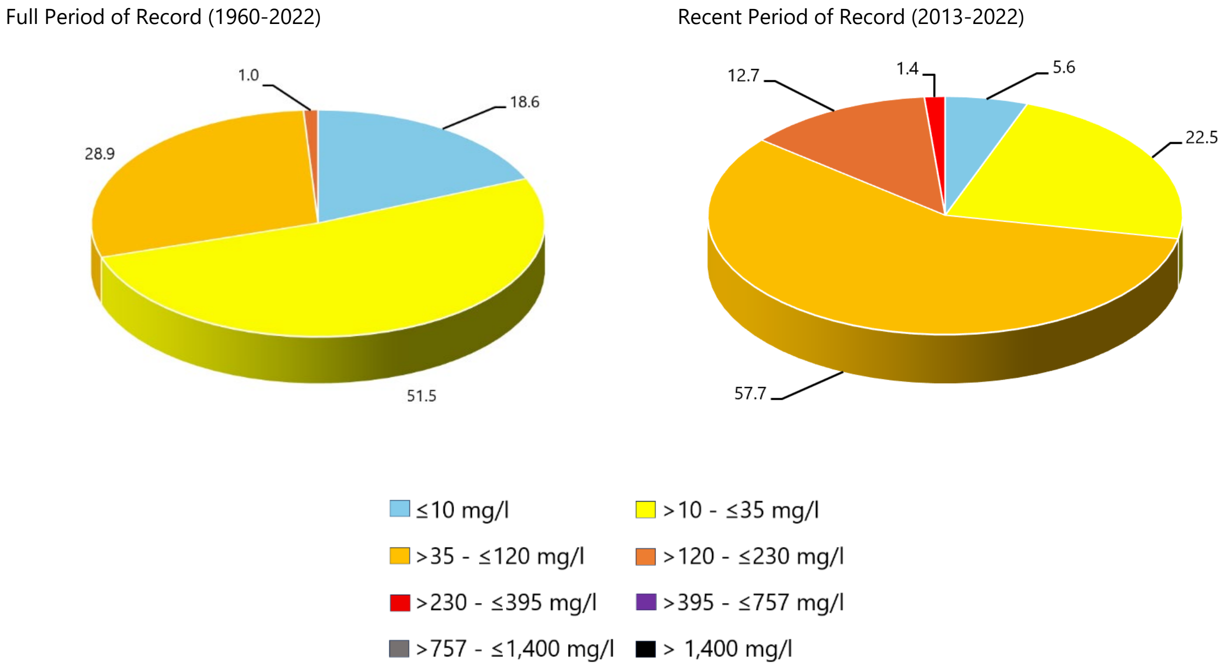
Figure 6.20
Annual Average Chloride Concentrations Among Study Area Lakes Compared to Biological Thresholds: 1960–2022



Note: The shaded blue area indicates the recent conditions (2013 through 2022) used for this study. The colored dashed lines indicate the natural background concentrations for the Region (background) or the various biological impacts of increasing chloride concentrations. Each lake is represented by a grey line or a colored line to highlight individual lakes.

Source: SEWRPC

Figure 6.21
Percent of Lake Chloride Samples Collected in the Study Area Within Various Thresholds of Water Quality

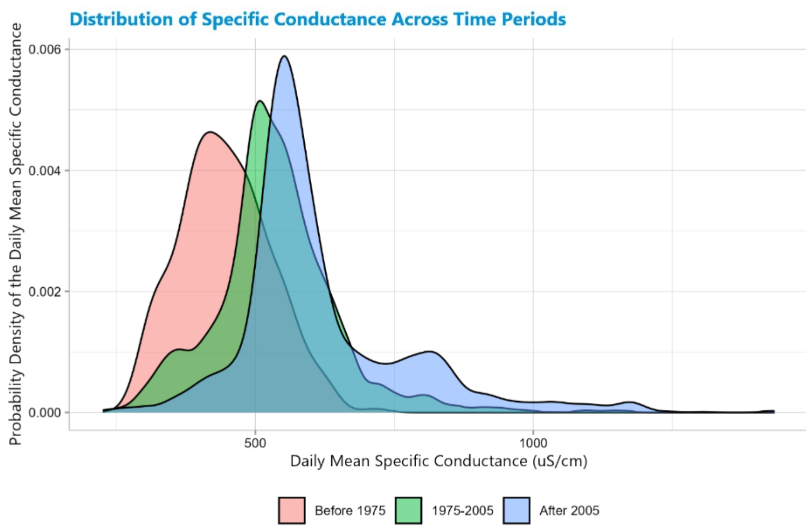


Note: There were 2,665 chloride samples collected in the study area lakes during the full period of record and 733 samples collected during the recent period of record. For descriptions of thresholds shown in this figure, see Table 5.2 in Chapter 5 of this Report.

Source: SEWRPC

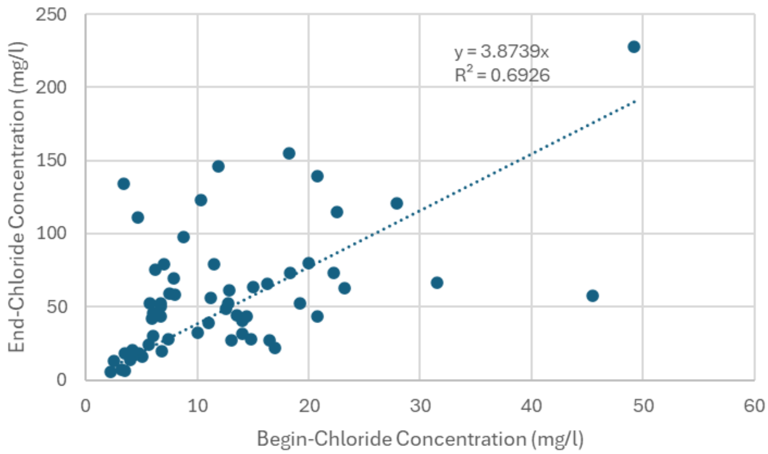
Figure 6.22

Changes in Specific Conductance Over Time Periods Among Study Areas Lakes Over the Full Period of Record (1960-2022)



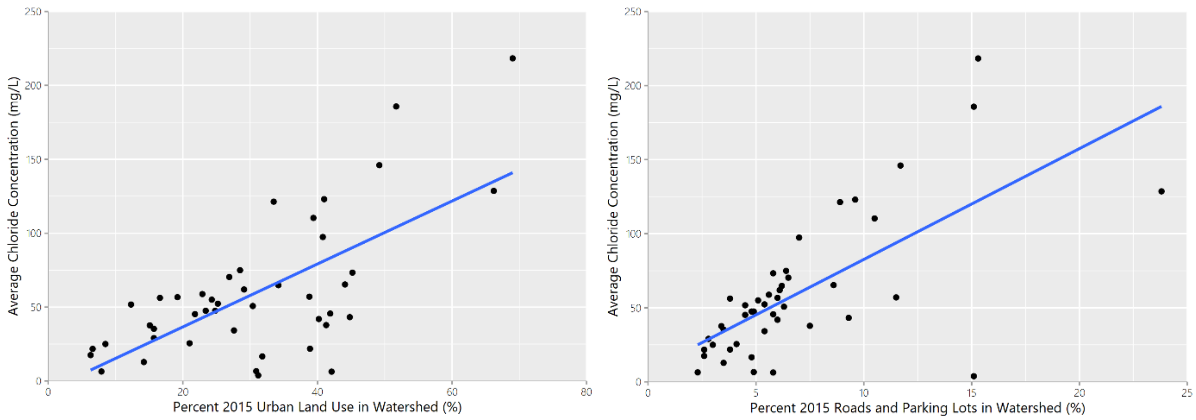
Source: SEWRPC

Figure 6.23
Begin Year Versus End Year Period of Record of Chloride Concentrations for Each Long-Term Trend (1960-2022) Lake Within the Study Area



Source: SEWRPC

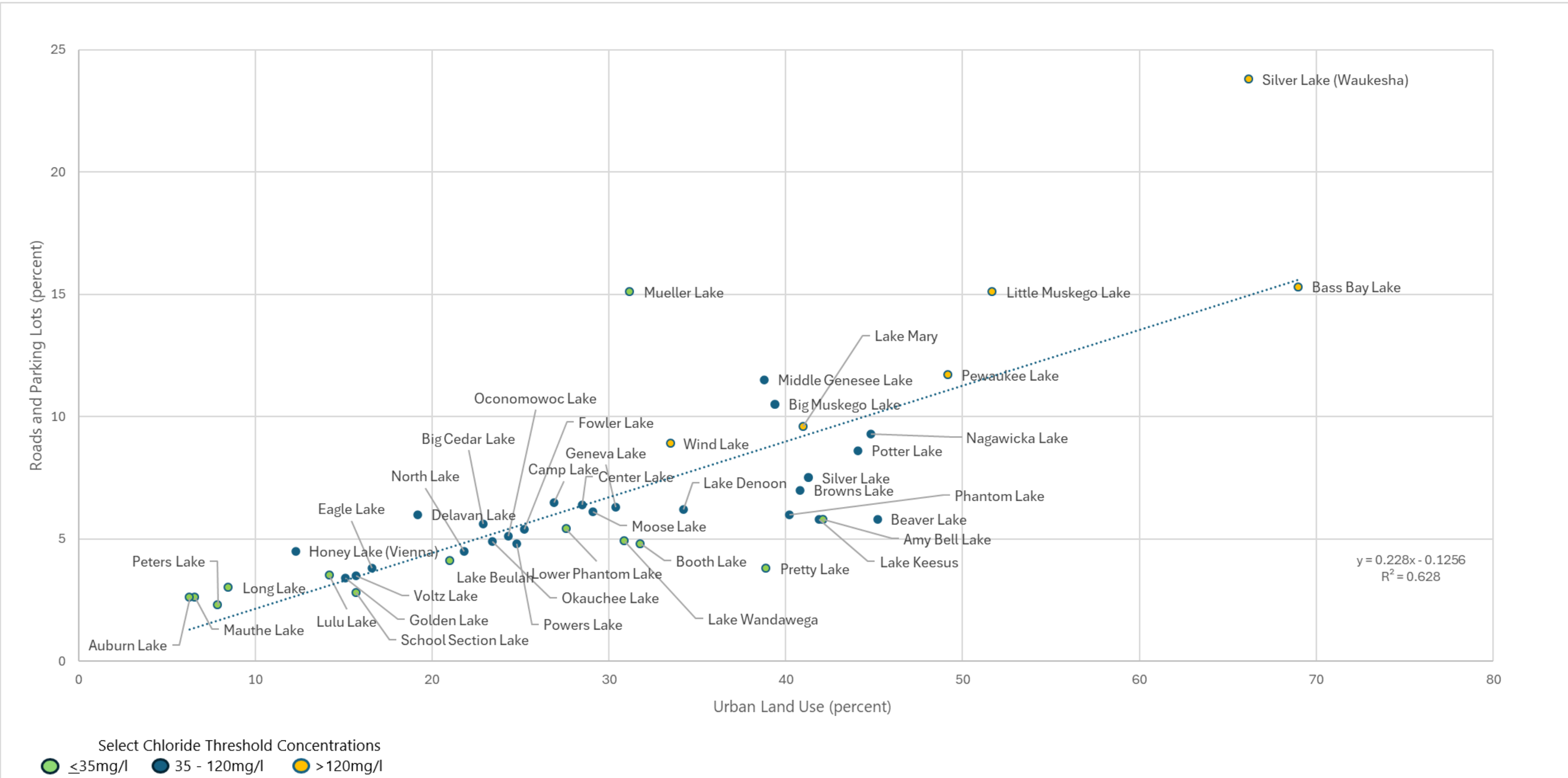
Figure 6.24
Scatterplots of Percent Urban Land Use and Percent Roads and Parking Lots in Lake Watershed by Recent Average Chloride Concentration: 2013-2022



Note: The blue lines represent the trend line based on linear regression analysis.

Source: SEWRPC

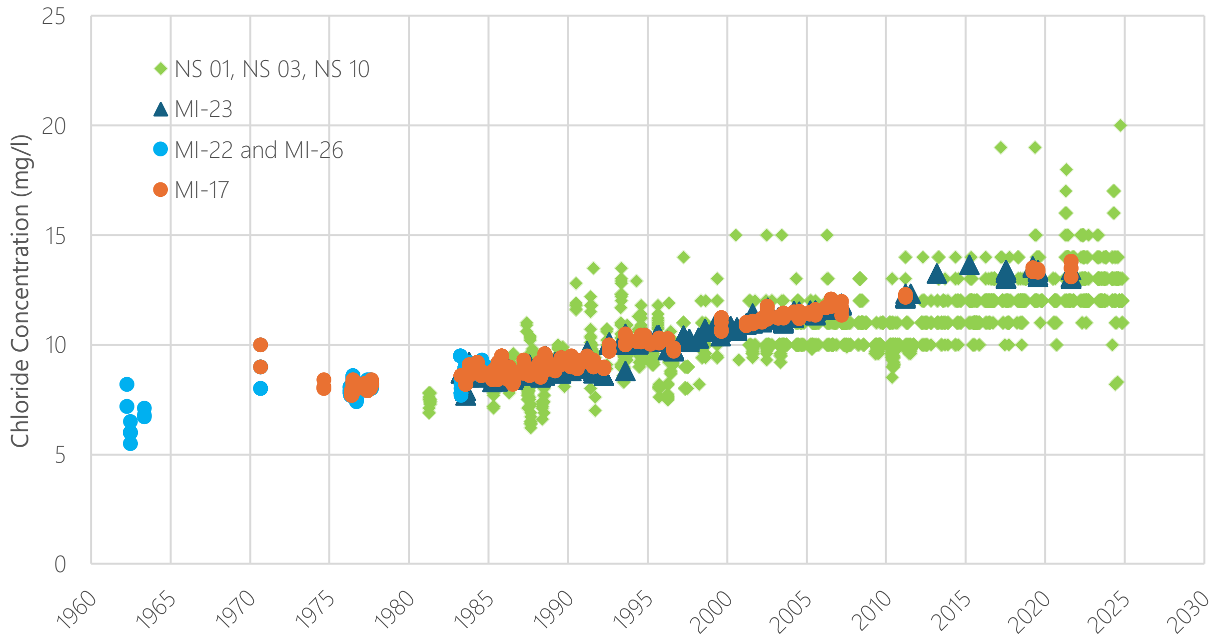
Figure 6.25
Relationship of Watershed Percent Urban Land Use Versus Percent Roads and Parking Lots and Select Mean Lake Chloride Threshold Concentrations: 2013-2022



Note: The blue dotted line represents the trend line based on linear regression analysis.

Source: SEWRPC

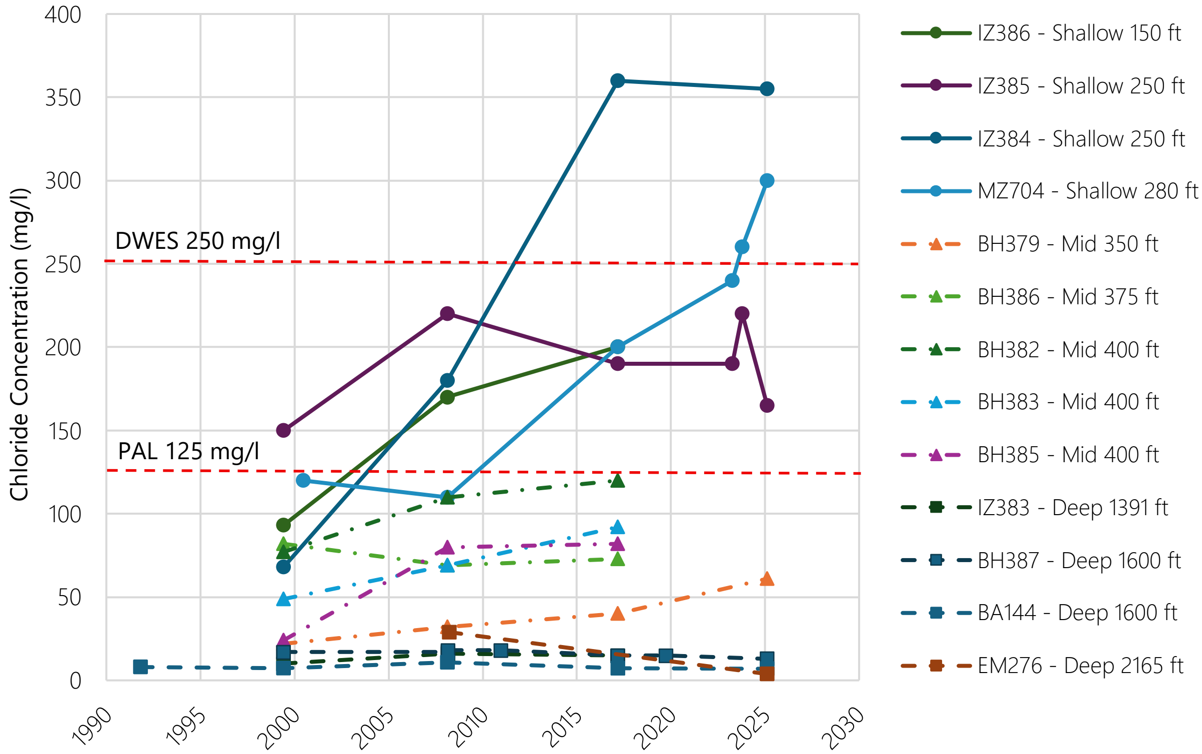
Figure 6.26
Lake Michigan Chloride Concentrations: 1962-2024



NOTE: The Lake Michigan sampling site locations are shown on Map 6.28.

Source: MMSD, USEPA, and SEWRPC

Figure 6.27
Municipal Well Chloride Data and Trends – City of Brookfield: 1991-2025



Source: WDNR, City of Brookfield, and SEWRPC

Planning Report No. 57

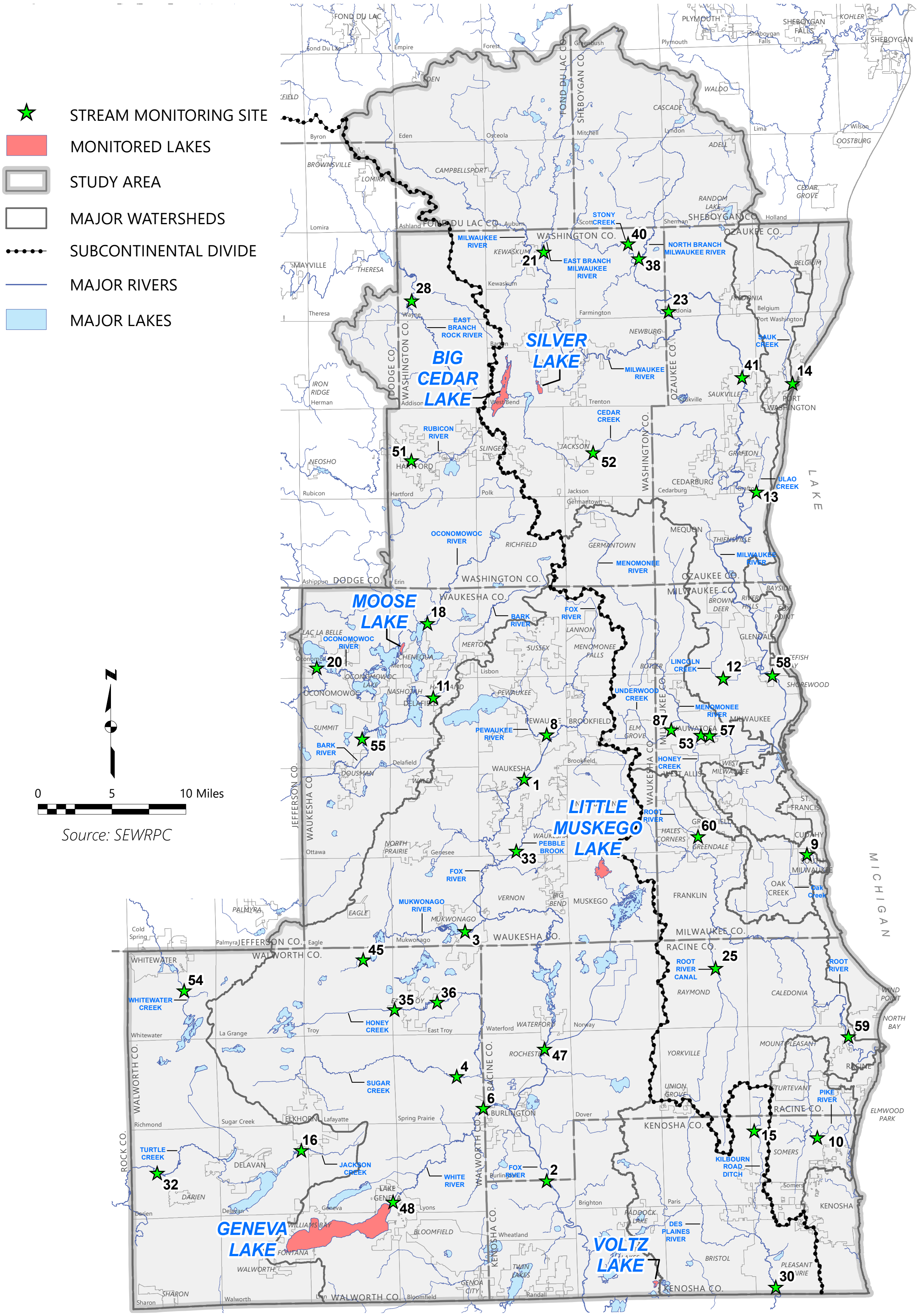
A CHLORIDE IMPACT STUDY FOR SOUTHEASTERN WISCONSIN

Chapter 6

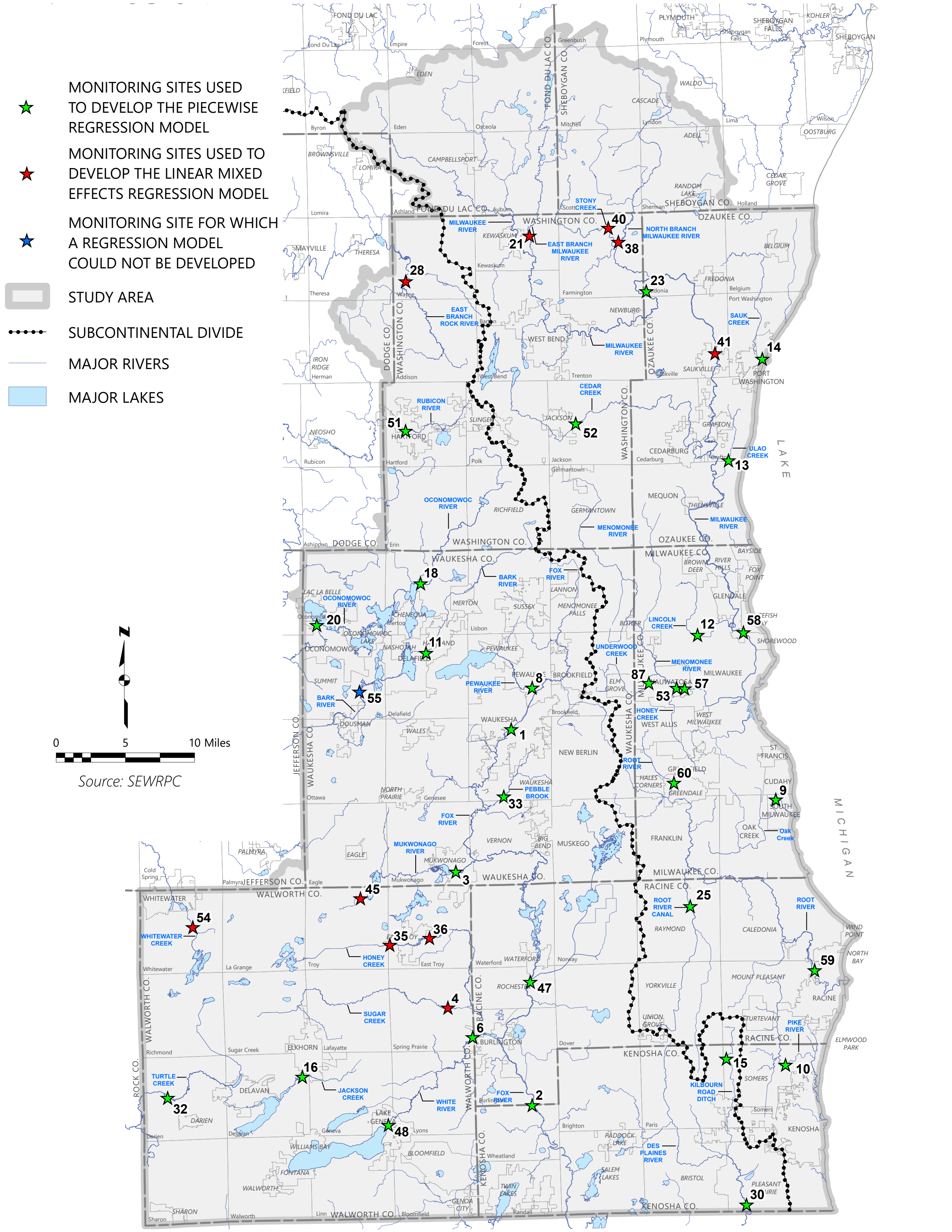
CHLORIDE CONDITIONS IN SOUTHEASTERN WISCONSIN

MAPS

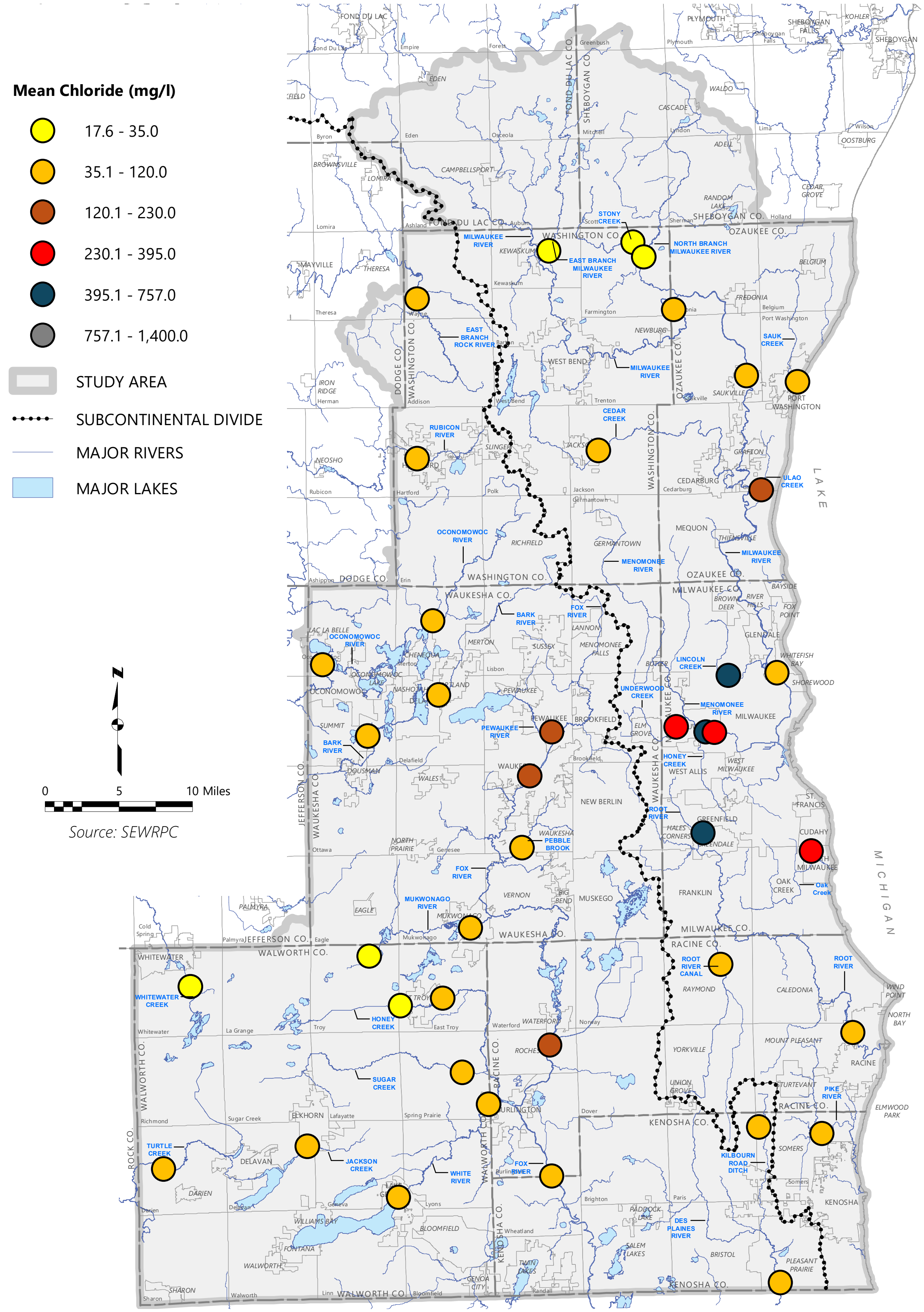
Map 6.1
Stream and Lake Monitoring Sites for the Chloride Impact Study



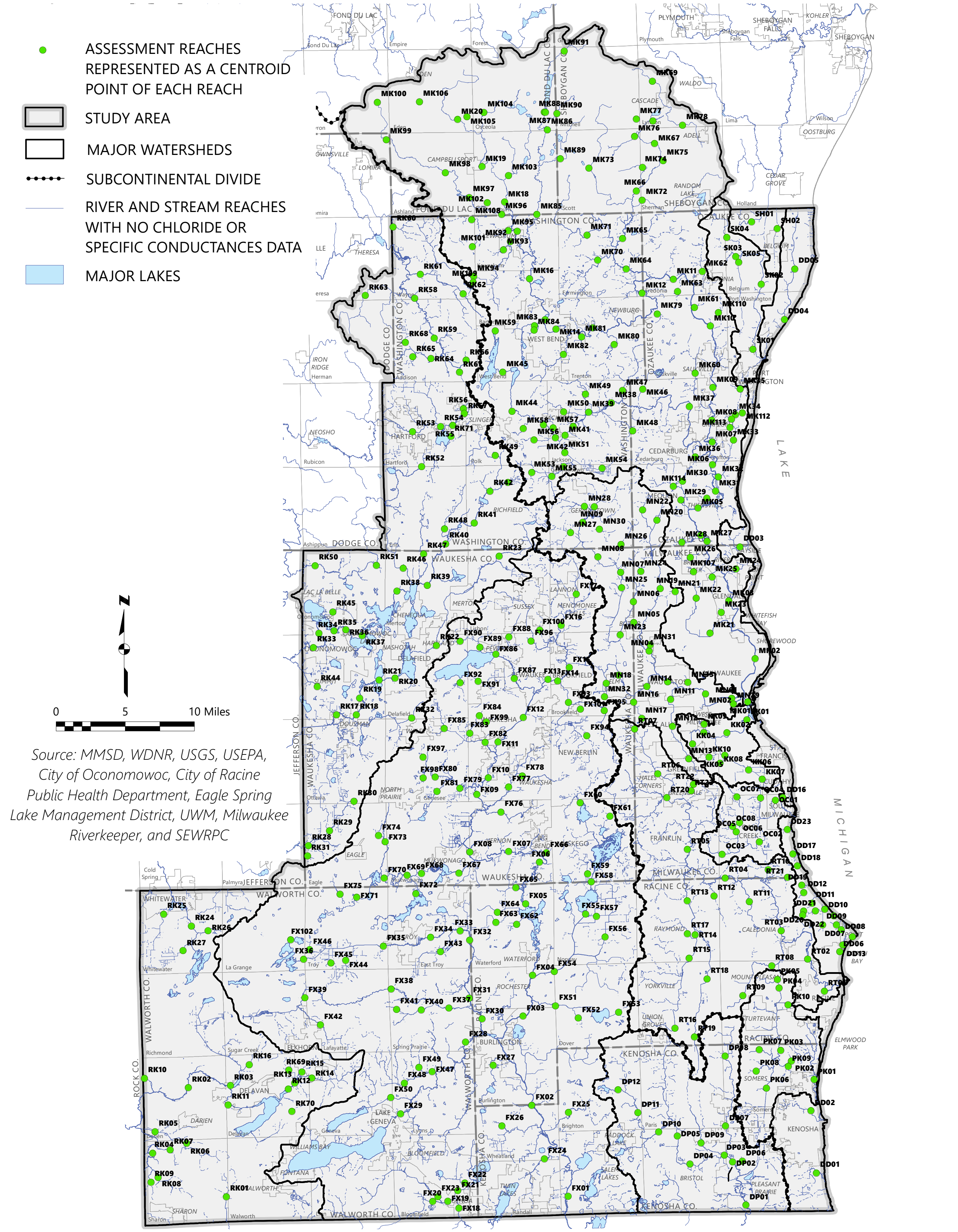
Map 6.2
SEWRPC Stream Monitoring Sites Used for Developing Regression Models for the Chloride Impact Study



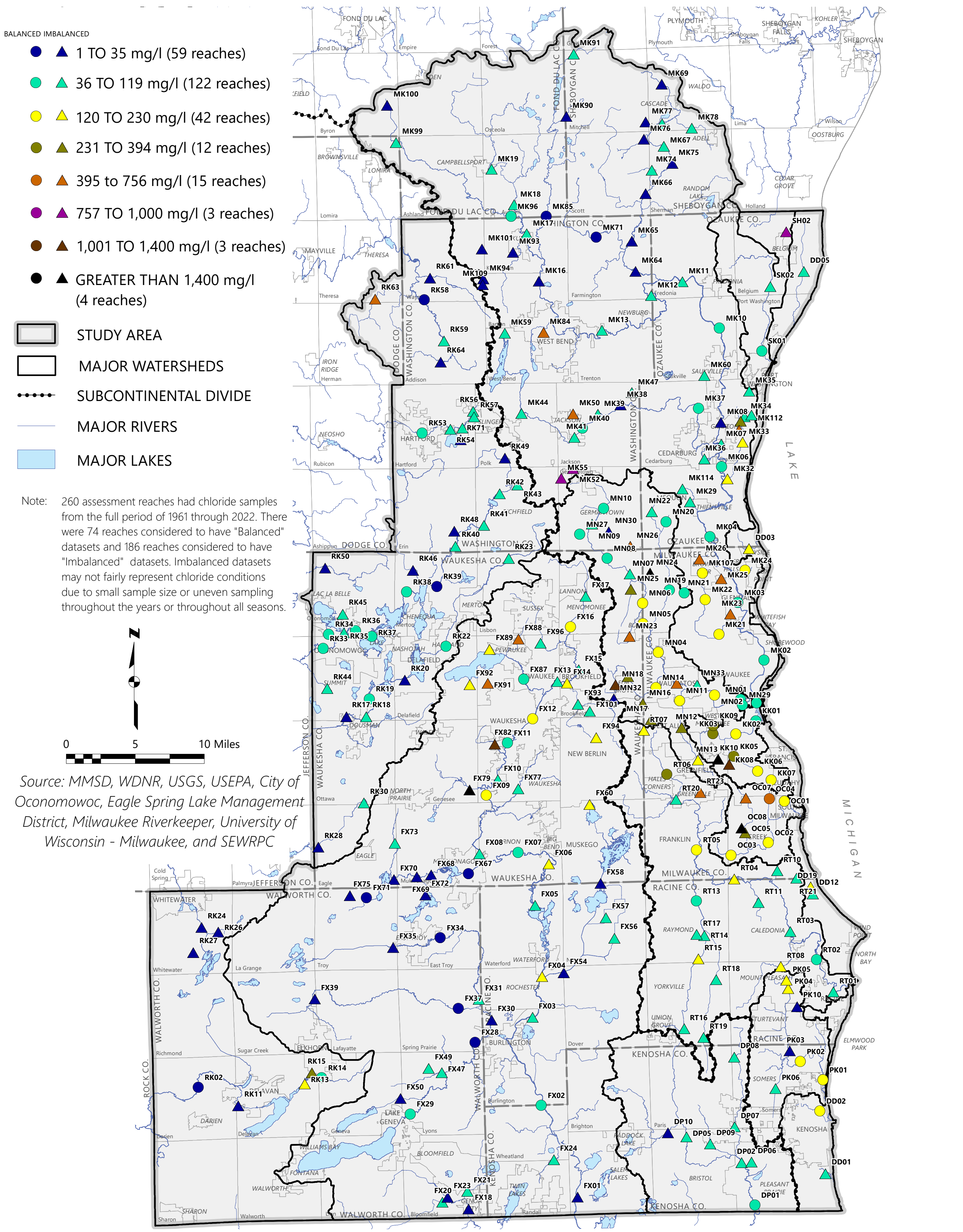
Map 6.3
Mean Chloride Concentrations at Chloride Impact Study Stream Monitoring Sites: 2018 - 2021



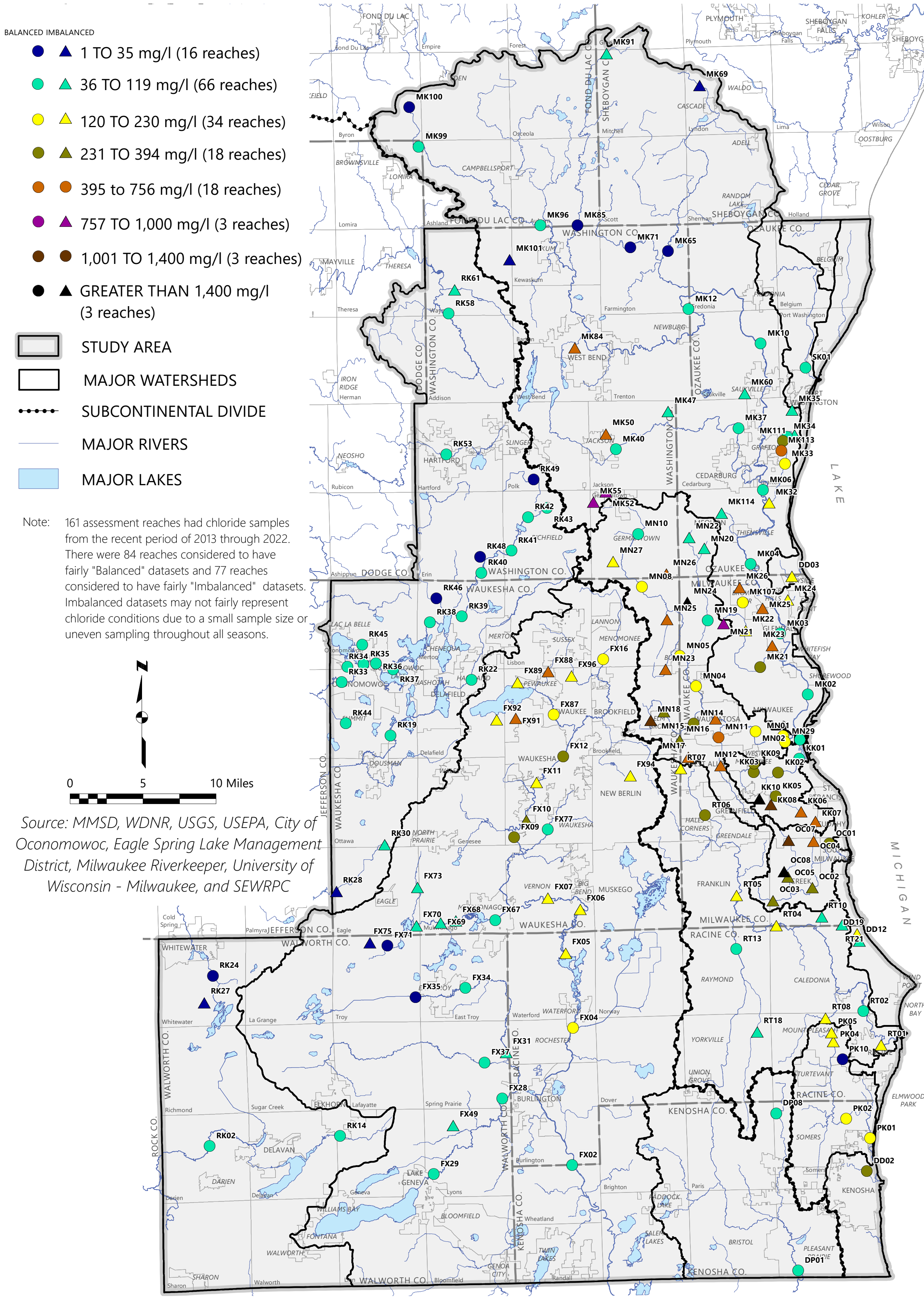
Map 6.4
Assessment Reaches Represented as the Midway Point of Each Assessment Reach Length



Map 6.5
Median Chloride Concentration Among Assessment Reaches for the Full Record: 1961-2022



Map 6.6
Recent Median Chloride Concentration Among All Assessment: 2013-2022



Map 6.7
Waterbodies Impaired for Chloride: 2024

STUDY AREA

MAJOR WATERSHEDS

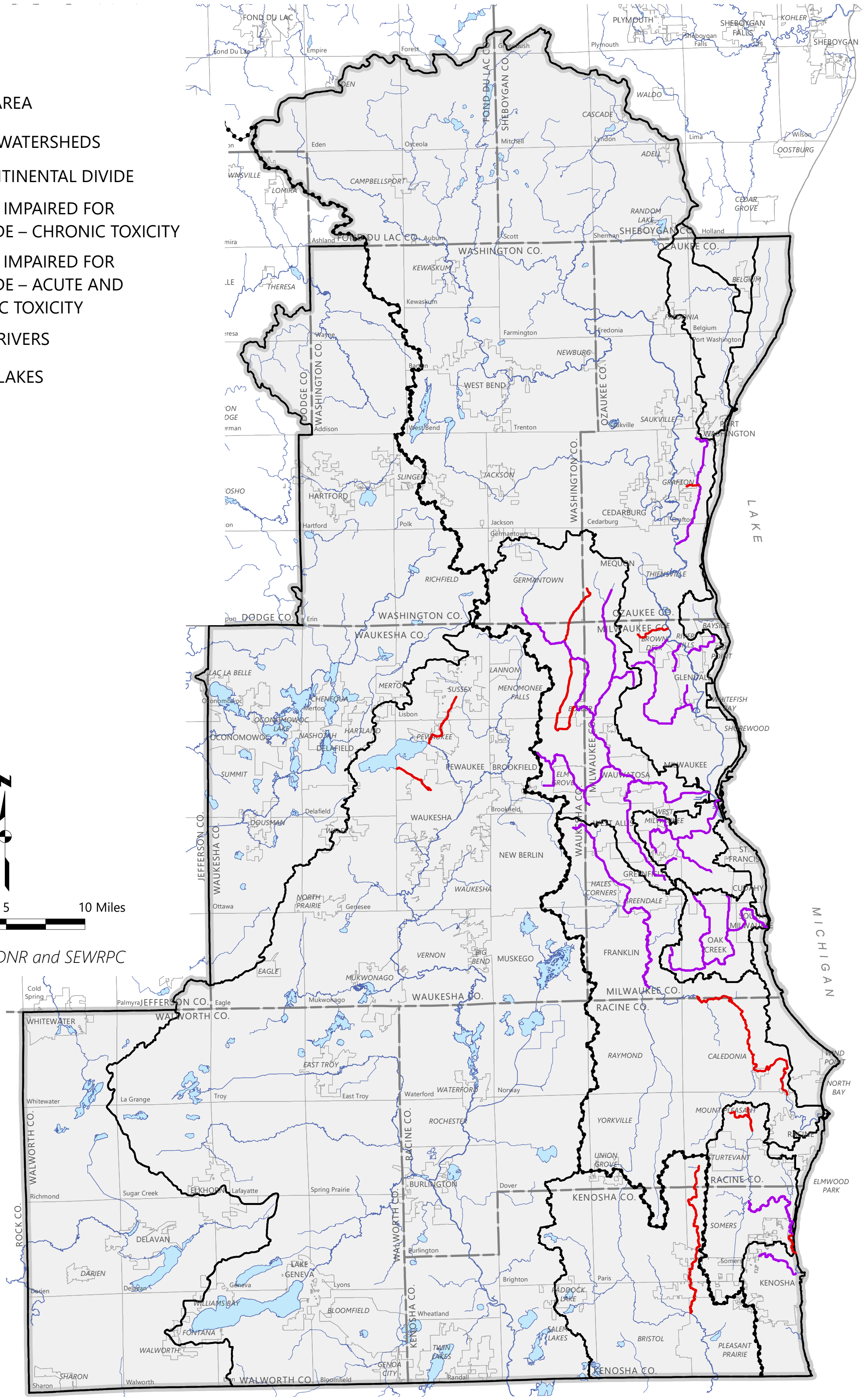
SUBCONTINENTAL DIVIDE

STREAM IMPAIRED FOR CHLORIDE – CHRONIC TOXICITY

STREAM IMPAIRED FOR CHLORIDE – ACUTE AND CHRONIC TOXICITY

MAJOR RIVERS

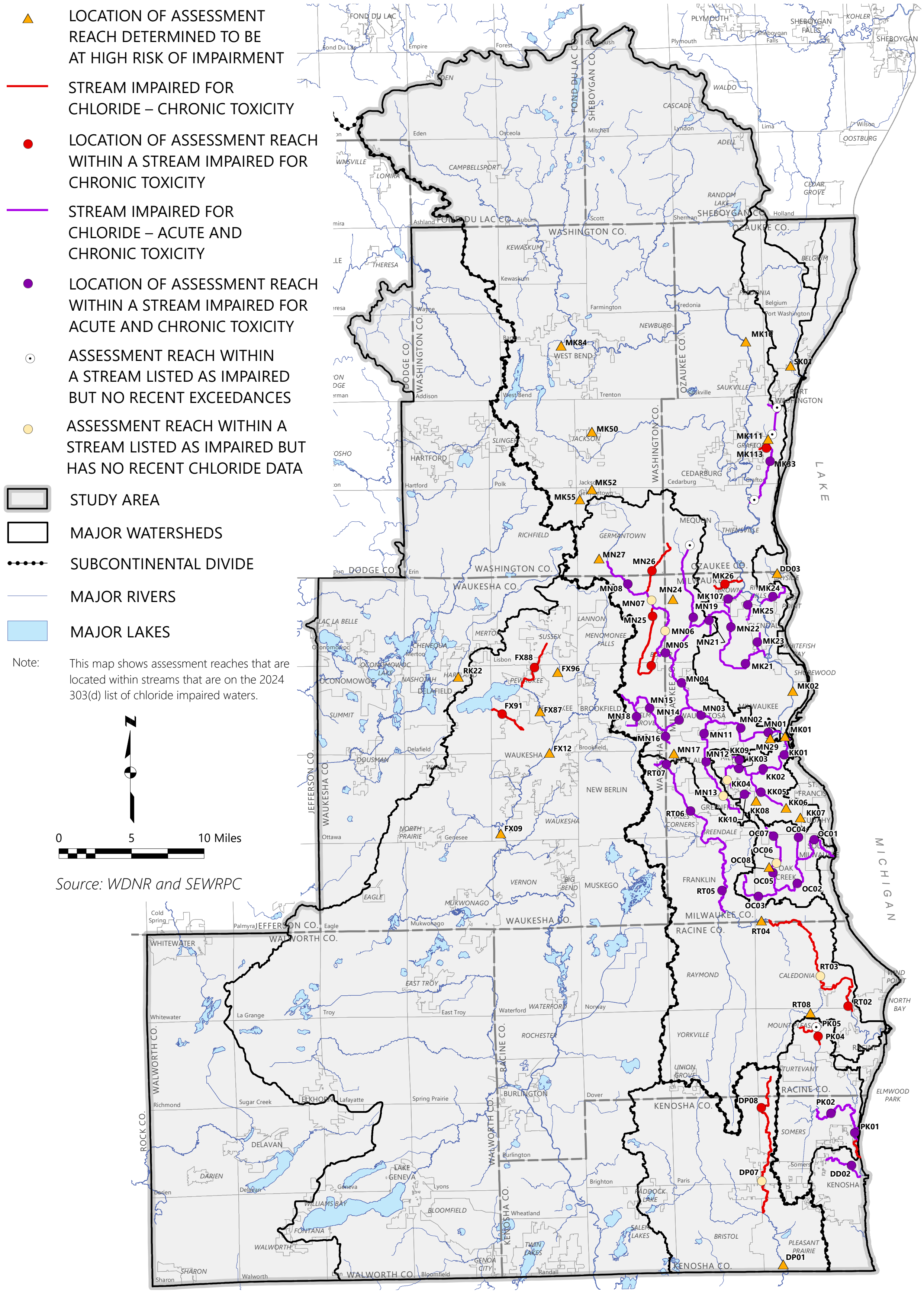
MAJOR LAKES



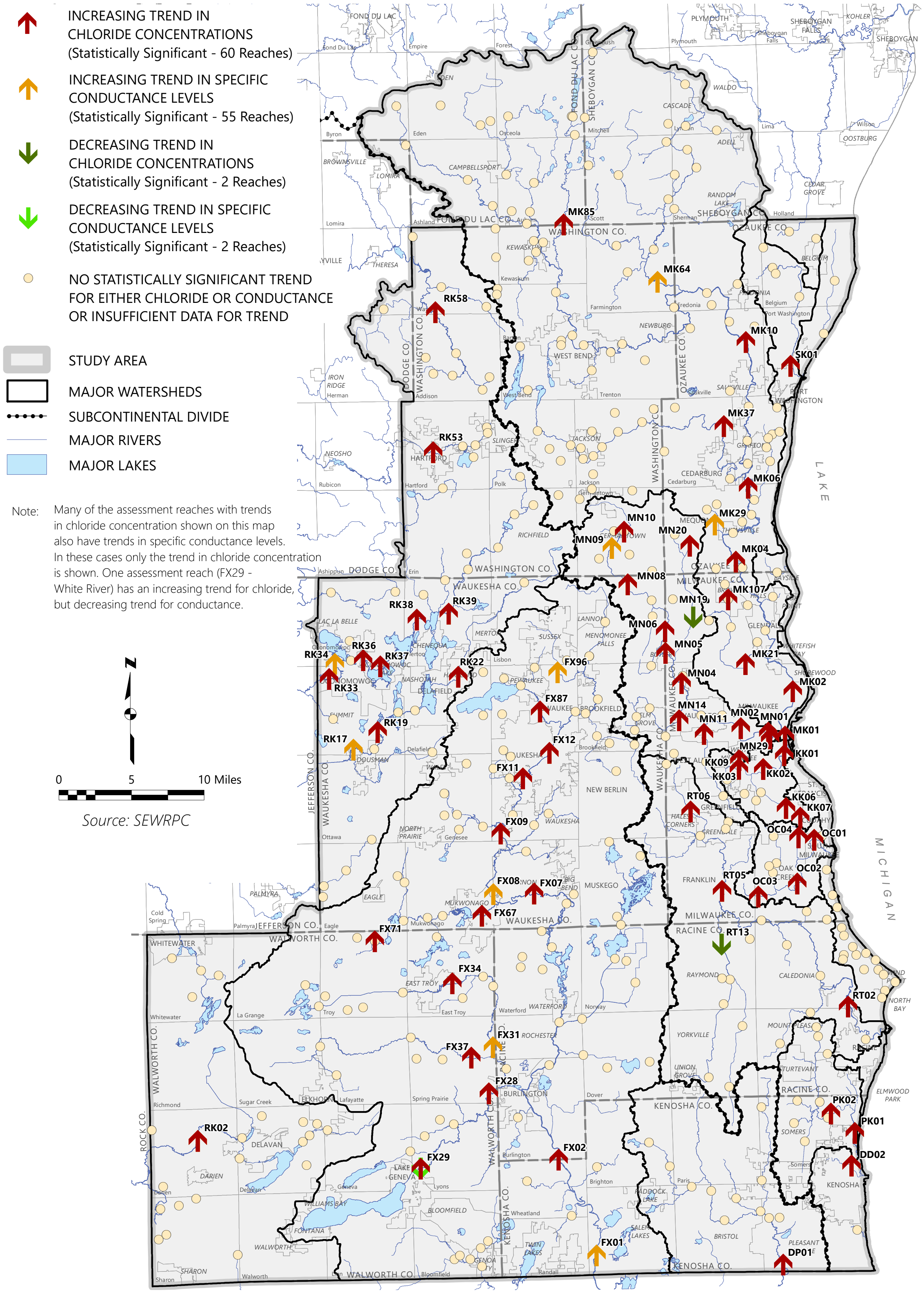
0 5 10 Miles

Source: WDNR and SEWRPC

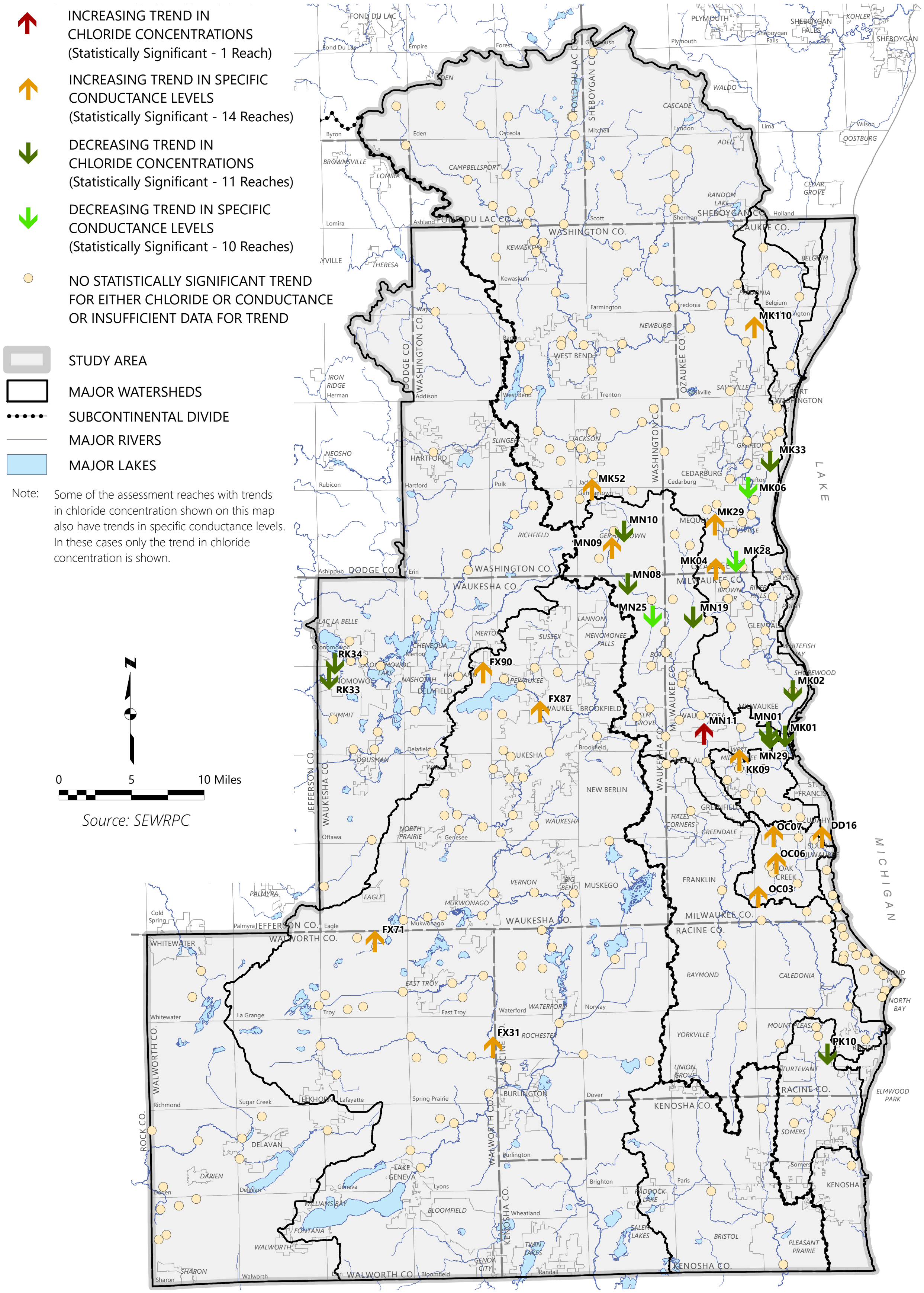
Map 6.8
Stream Assessment Reaches Determined to be High Risk for Impairment and Assessment Reaches Within Streams That are Impaired for Chloride Toxicity (Recent Period of Record)



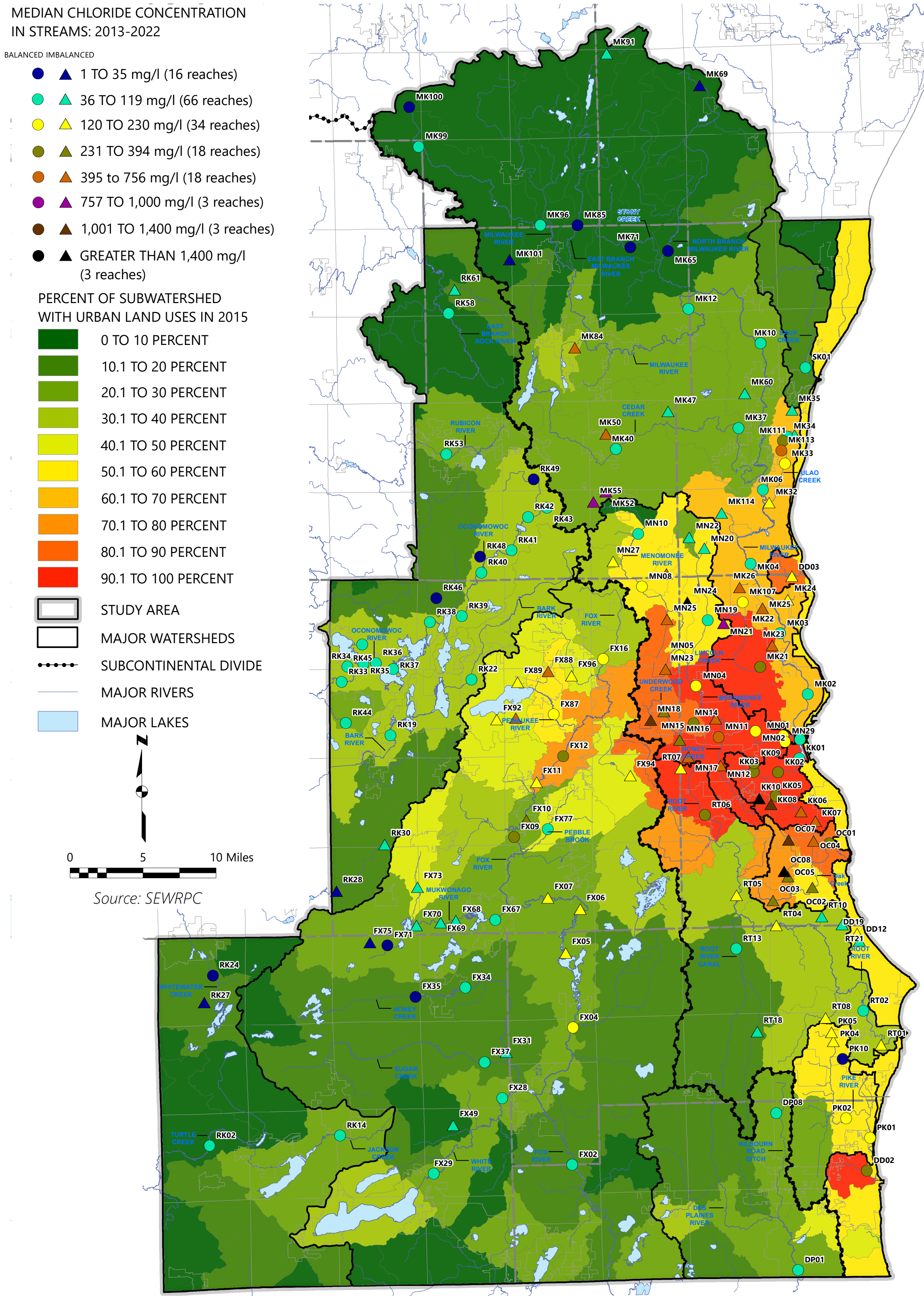
Map 6.9
Statistically Significant Trends in Chloride and Specific Conductance Among Balanced Stream Assessment Reaches over the Full Period of Record: 1961-2022



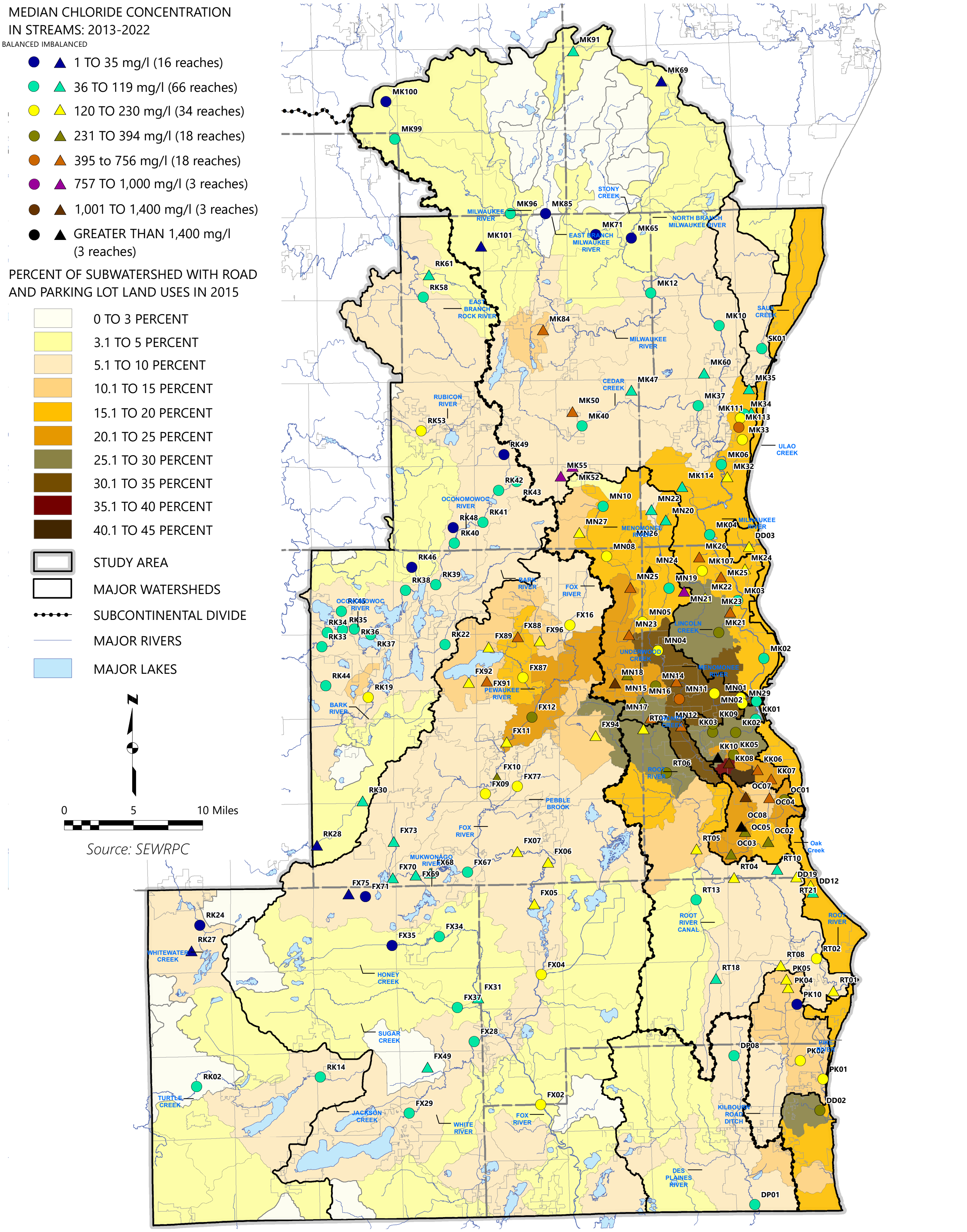
Map 6.10
Trends in Chloride and Specific Conductance Among Balanced Stream Assessment Reaches over the Recent Period of Record: 2013-2022



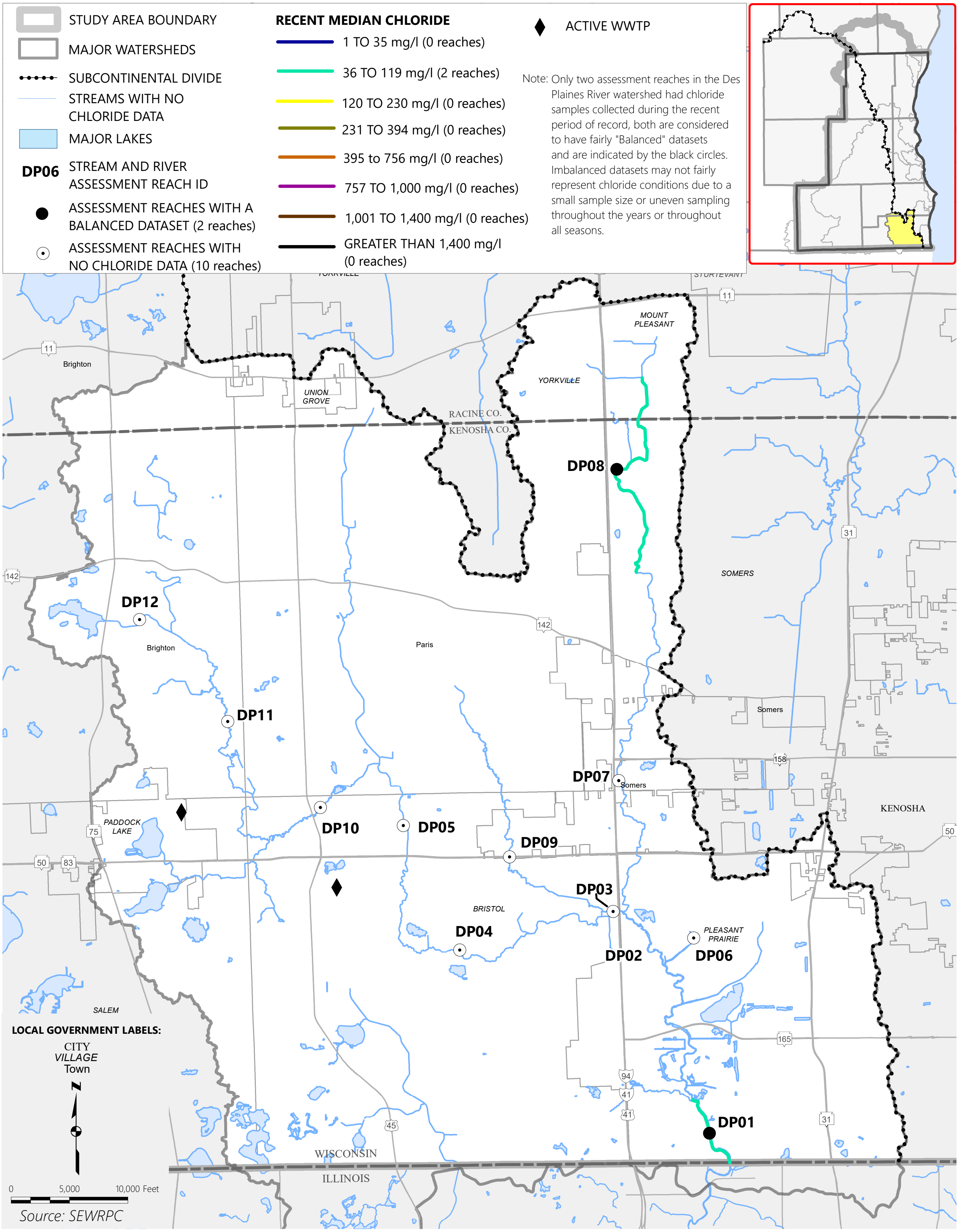
Map 6.11
Recent Median Chloride Concentrations in All Stream Assessment Reaches and Percent Urban Land Use by Subwatershed



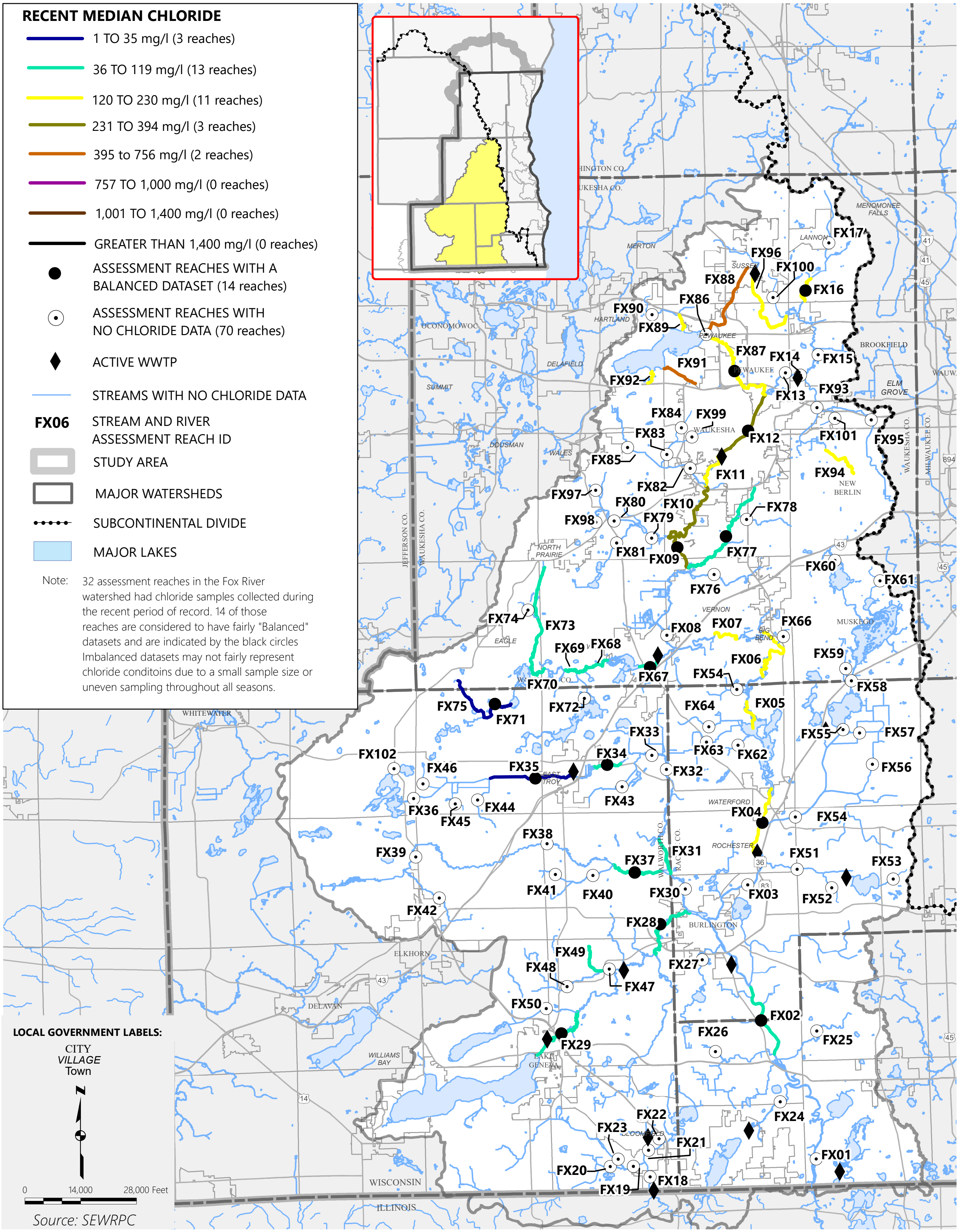
Map 6.12
Recent Median Chloride Concentrations in All Stream Assessment Reaches and Density of Roads and Parking Lots by Subwatershed



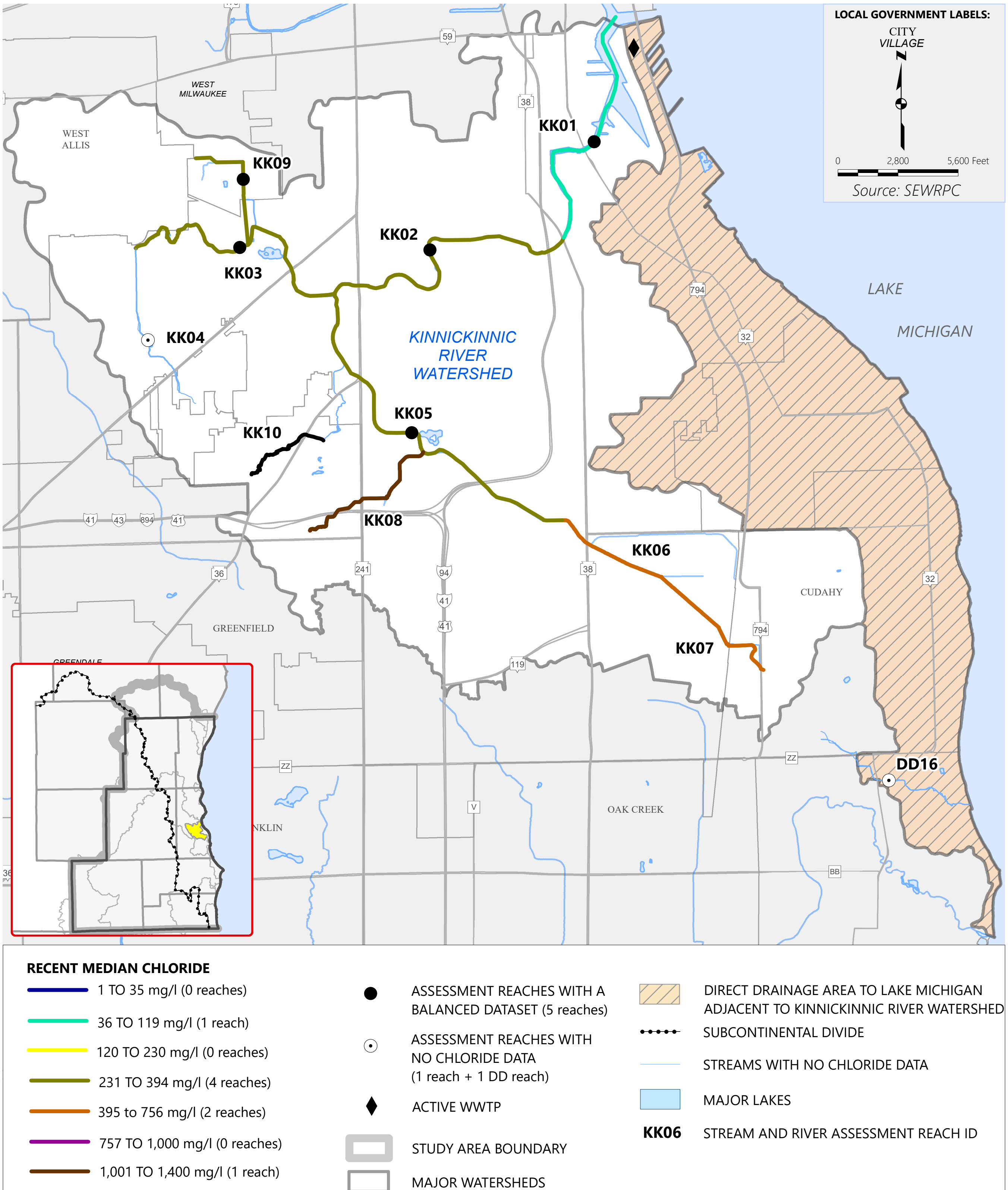
Map 6.13
Recent Median Chloride Concentrations Within the Des Plaines River Watershed: 2013-2022



Map 6.14
Recent Median Chloride Concentrations Within the Fox River Watershed: 2013-2022

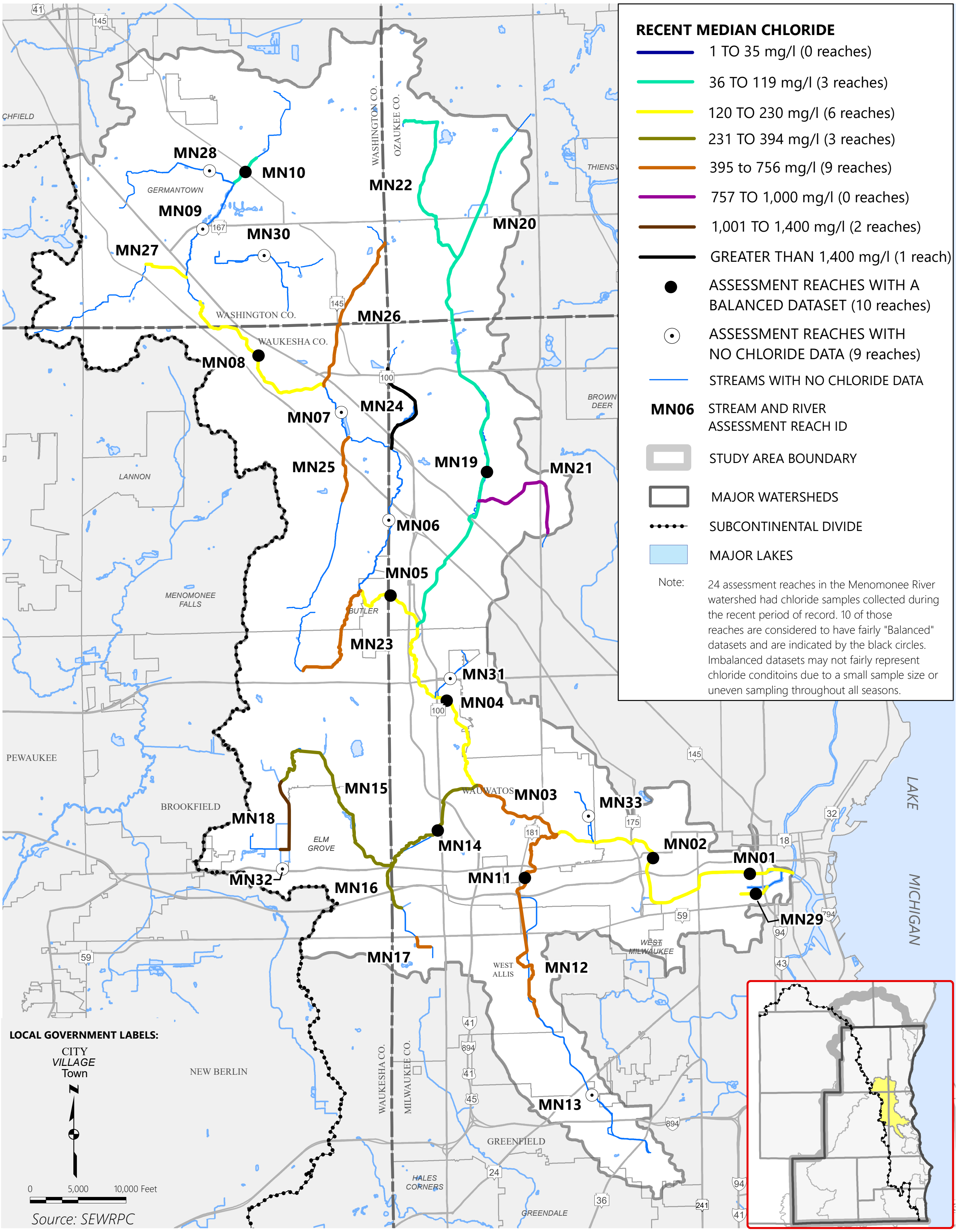


Map 6.15
Recent Median Chloride Concentration Within the Kinnickinnic River Watershed and Adjacent Portion of the Direct Drainage Area to Lake Michigan: 2013-2022

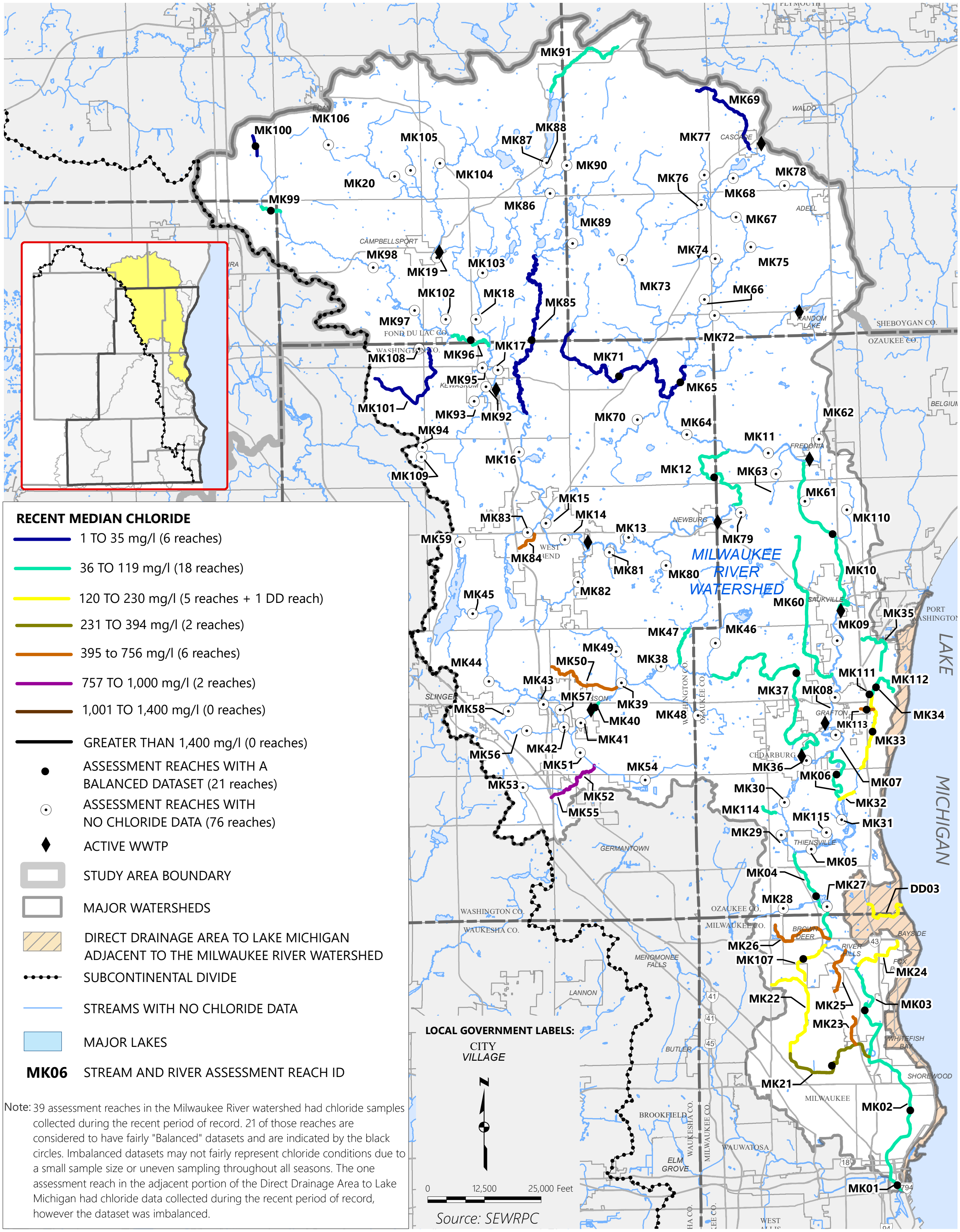


Note: Nine assessment reaches in the Kinnickinnic River watershed had chloride samples collected during the recent period of record. Five of those reaches are considered to have fairly "Balanced" datasets and are indicated by the black circles. Imbalanced datasets may not fairly represent chloride conditions due to a small sample size or uneven sampling throughout the years or throughout all seasons. One assessment reach in the watershed and one reach in the adjacent Direct Drainage to Lake Michigan did not have any chloride data in the recent period, but both did have conductance data that may be helpful for indicating chloride conditions in those stream reaches.

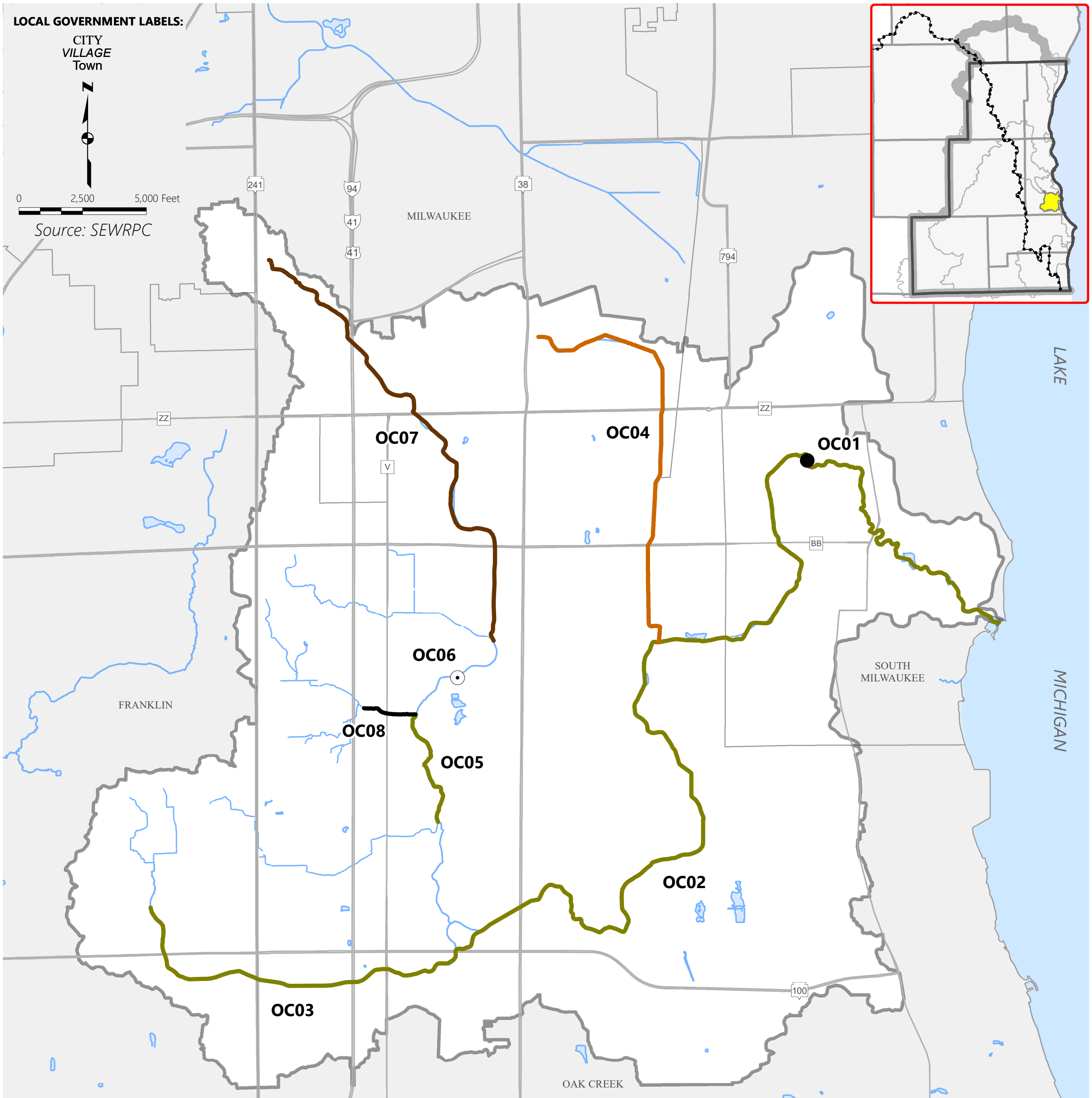
Map 6.16
Recent Median Chloride Concentrations Within the Menomonee River Watershed: 2013-2022



Map 6.17
Recent Median Chloride Concentrations Within the Milwaukee River Watershed and Adjacent Direct Drainage Area to Lake Michigan: 2013-2022



Map 6.18
Recent Median Chloride Concentrations Within the Oak Creek Watershed: 2013-2022



RECENT MEDIAN CHLORIDE

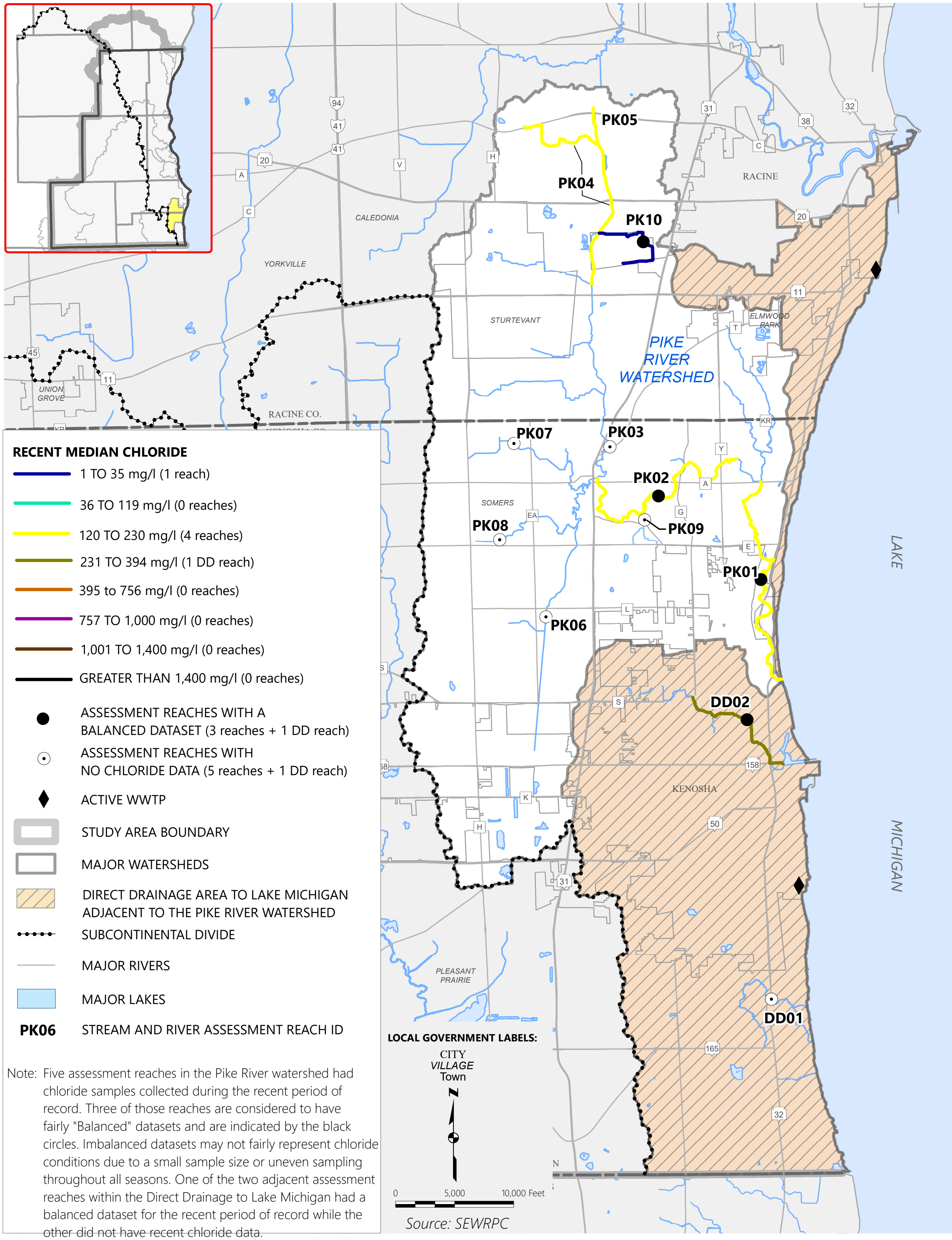
- 1 TO 35 mg/l (0 reaches)
- 36 TO 119 mg/l (0 reaches)
- 120 TO 230 mg/l (0 reaches)
- 231 TO 394 mg/l (4 reaches)
- 395 to 756 mg/l (1 reach)
- 757 TO 1,000 mg/l (0 reaches)
- 1,001 TO 1,400 mg/l (1 reach)
- GREATER THAN 1,400 mg/l (1 reach)

- ASSESSMENT REACHES WITH A BALANCED DATASET (1 reach)
- ASSESSMENT REACHES WITH NO CHLORIDE DATA (1 reach)
- OC06 STREAM AND RIVER ASSESSMENT REACH ID

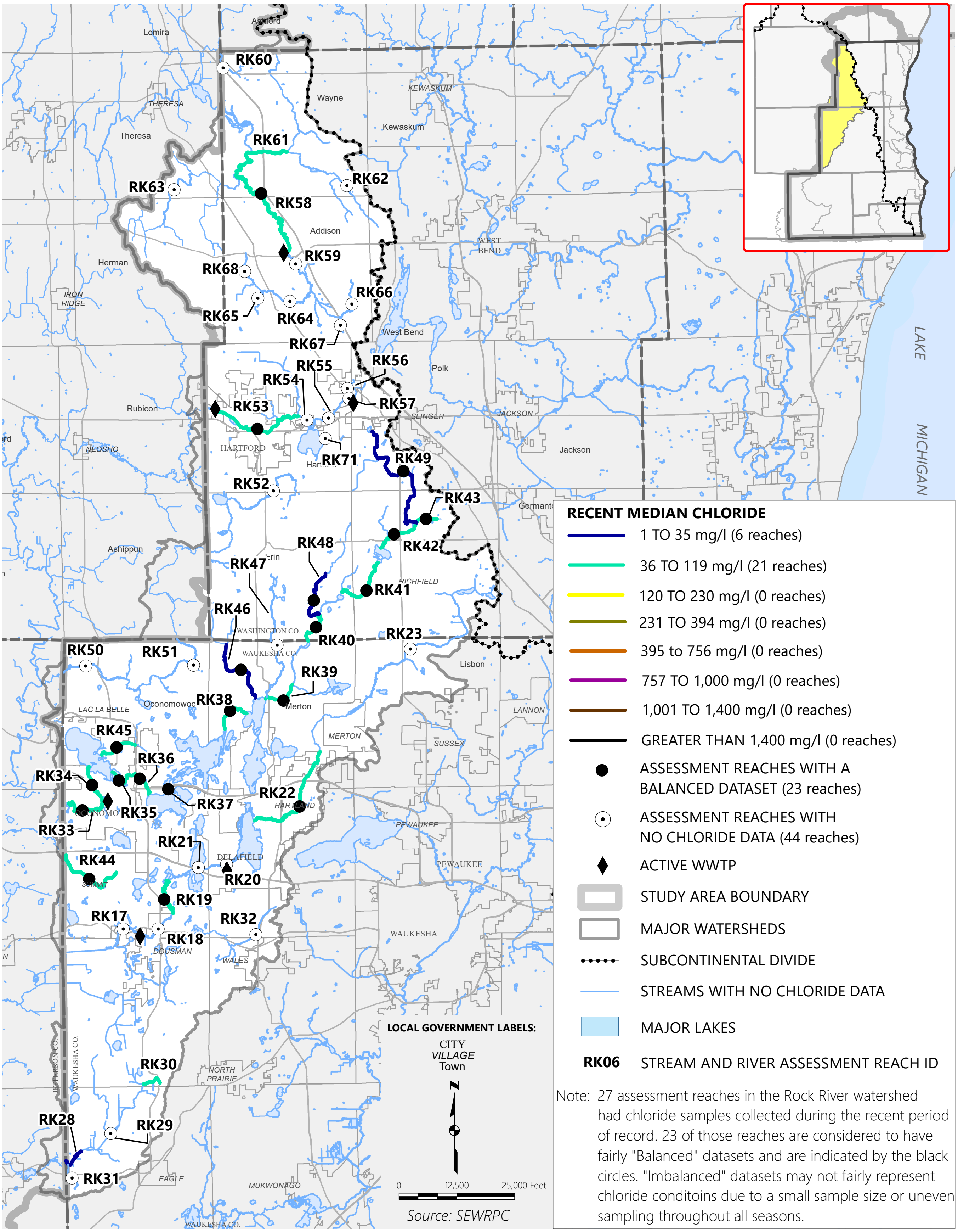
- STUDY AREA BOUNDARY
- MAJOR WATERSHEDS
- SUBCONTINENTAL DIVIDE
- MAJOR RIVERS
- MAJOR LAKES

Note: Seven assessment reaches in the Oak Creek watershed had chloride samples collected during the recent period of record. One of those reaches was considered to have a fairly "Balanced" dataset and is indicated by the black circle. Imbalanced datasets may not fairly represent chloride conditions due to a small sample size or uneven sampling throughout all seasons. Reach OC06 did not have recent chloride data but did have specific conductance data that may be helpful for indicating chloride conditions in that stream reach.

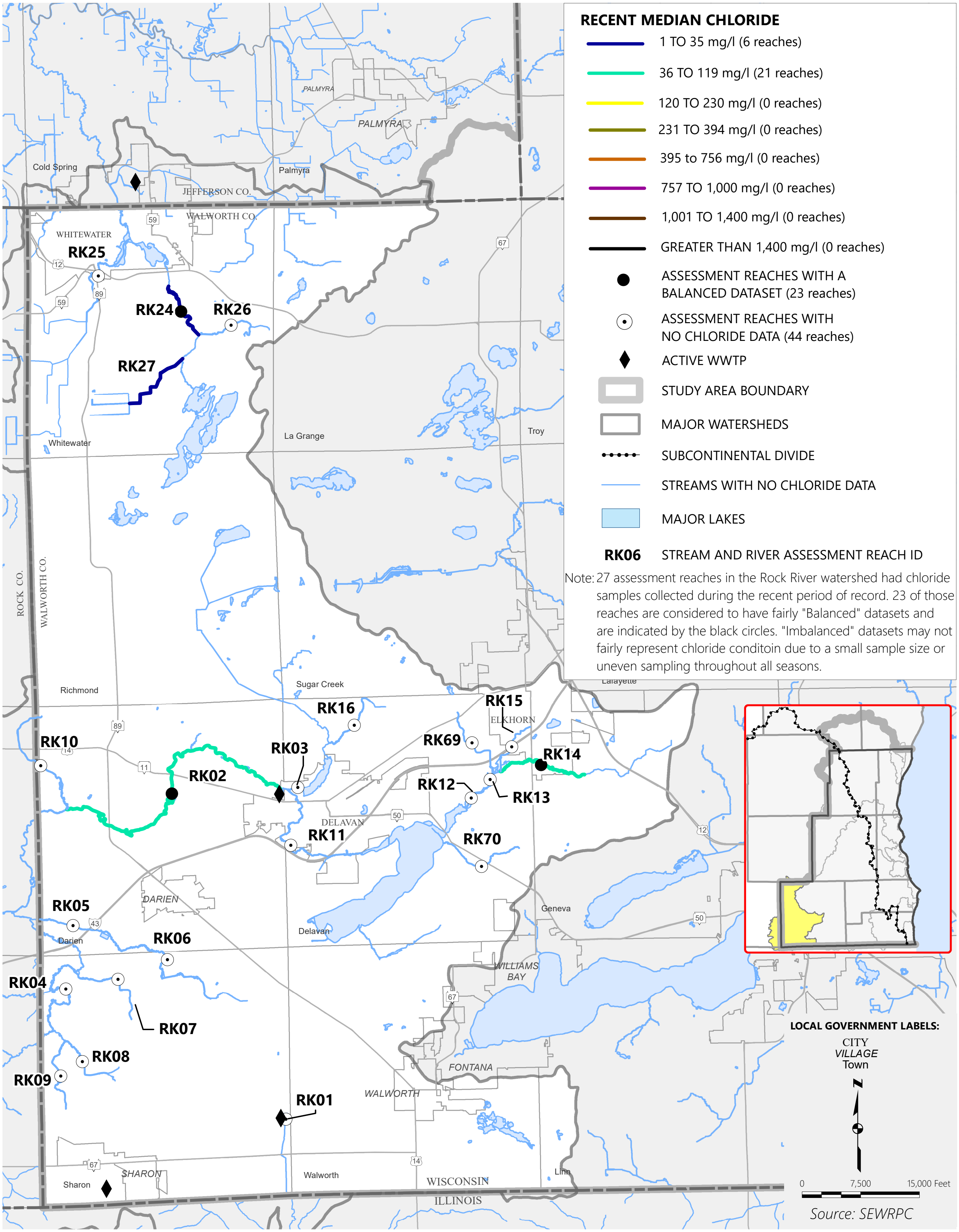
Map 6.19
Recent Median Chloride Concentrations Within the Pike River Watershed and Adjacent Portion of the Direct Drainage Area to Lake Michigan: 2013-2022



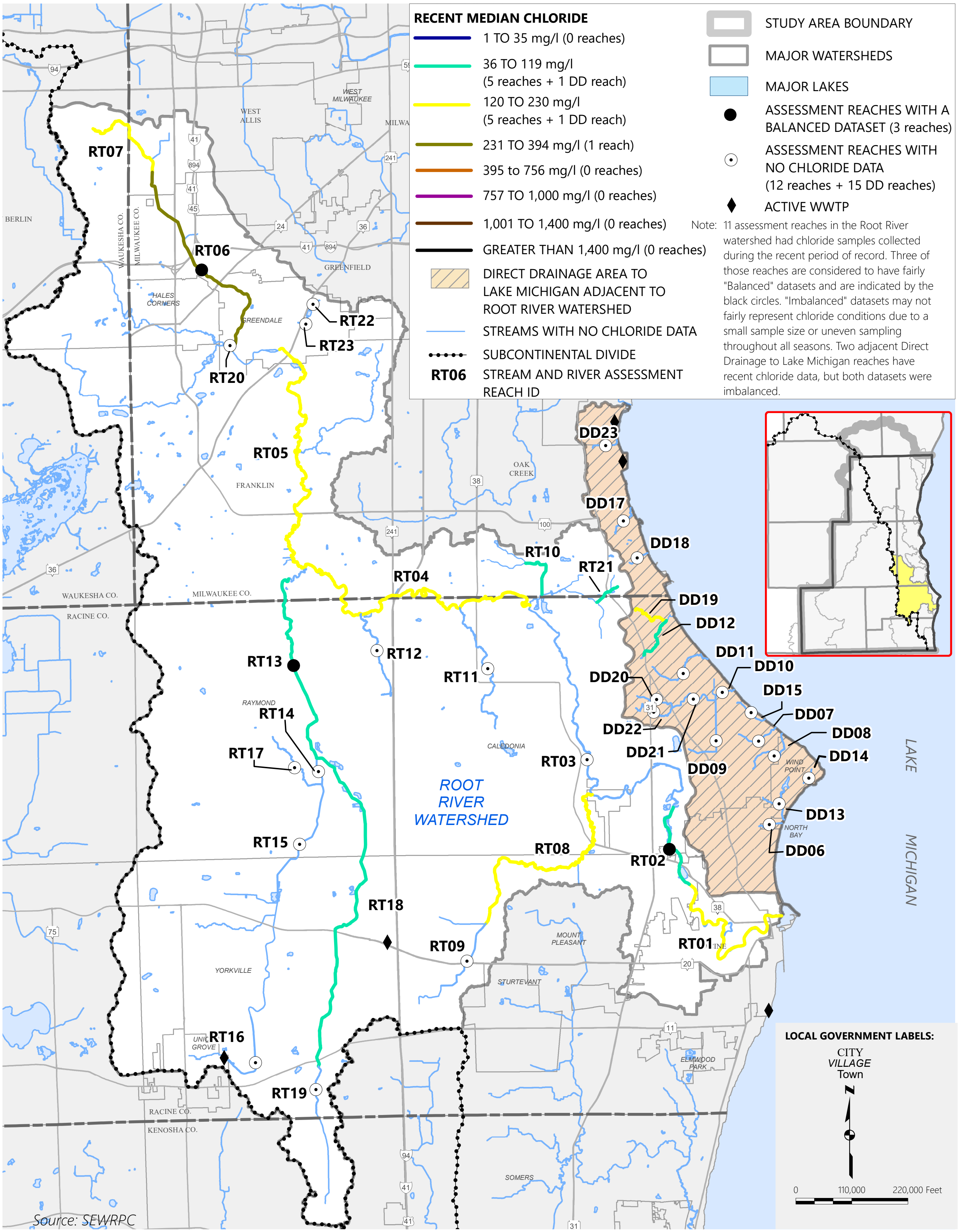
Map 6.20
Recent Median Chloride Concentrations Within the Rock River Watershed (North): 2013-2022



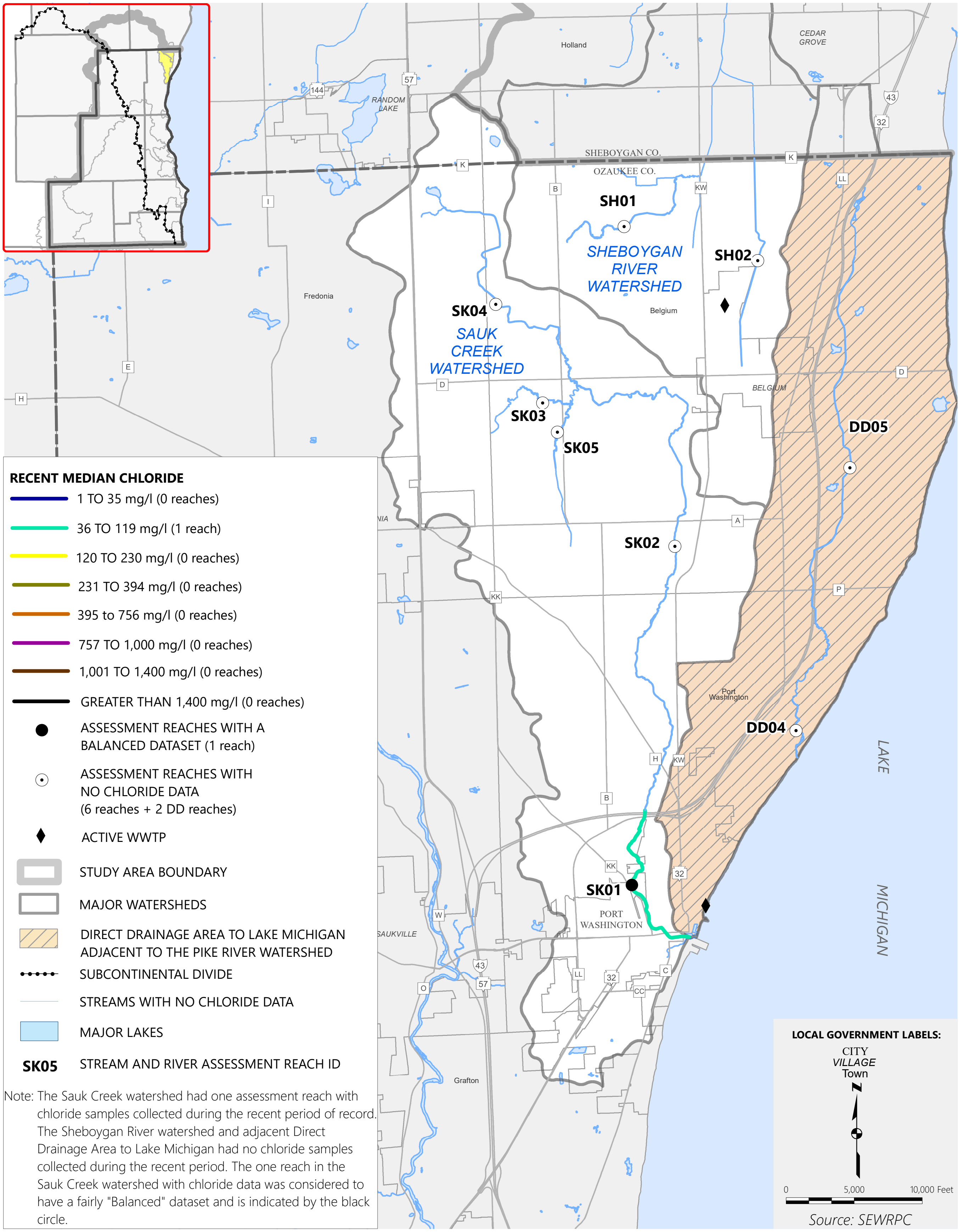
Map 6.21
Recent Median Chloride Concentrations Within the Rock River Watershed (South): 2013-2022



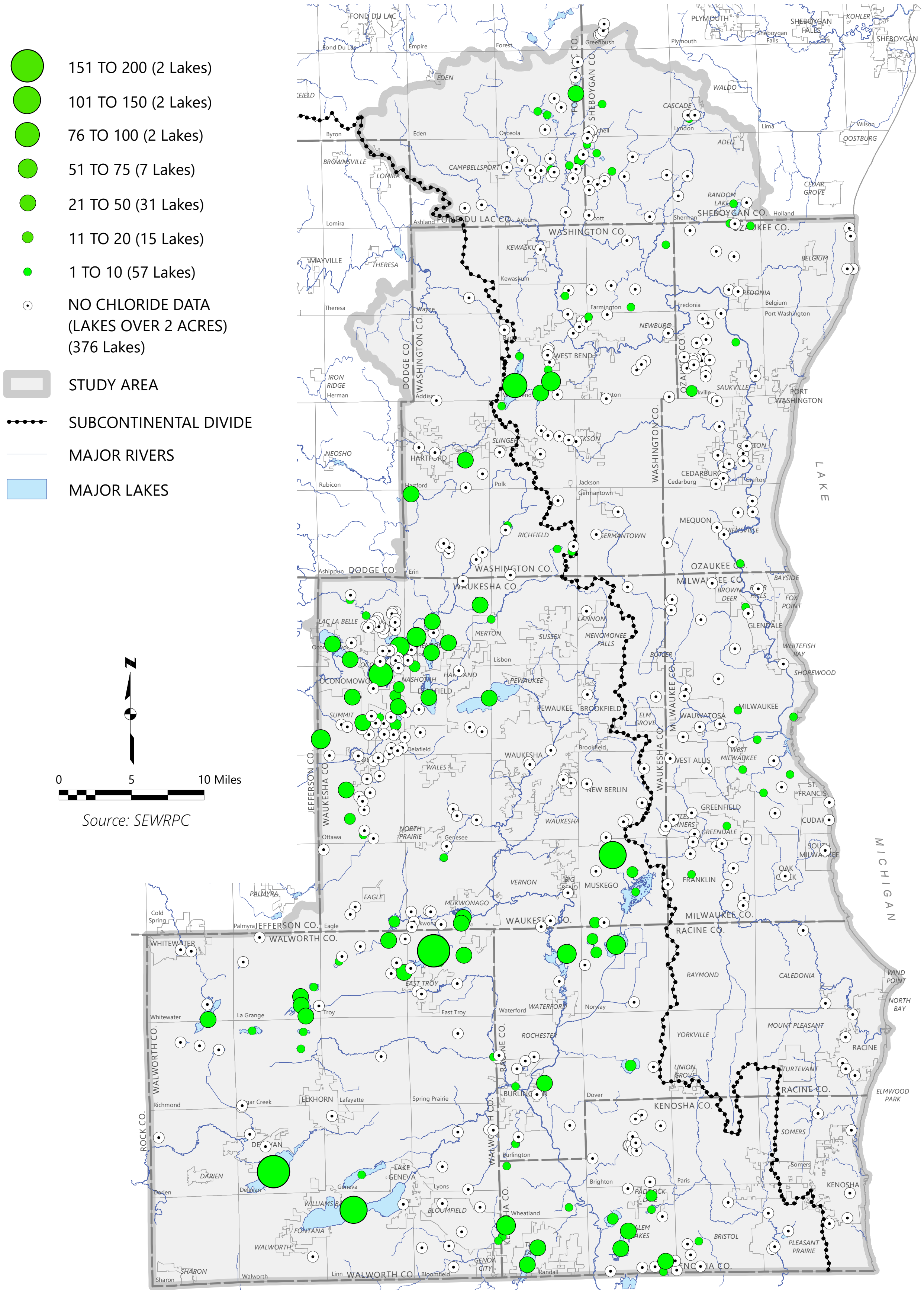
Map 6.22
Recent Median Chloride Concentrations Within the Root River Watershed and Adjacent Direct Drainage Area to Lake Michigan: 2013-2022



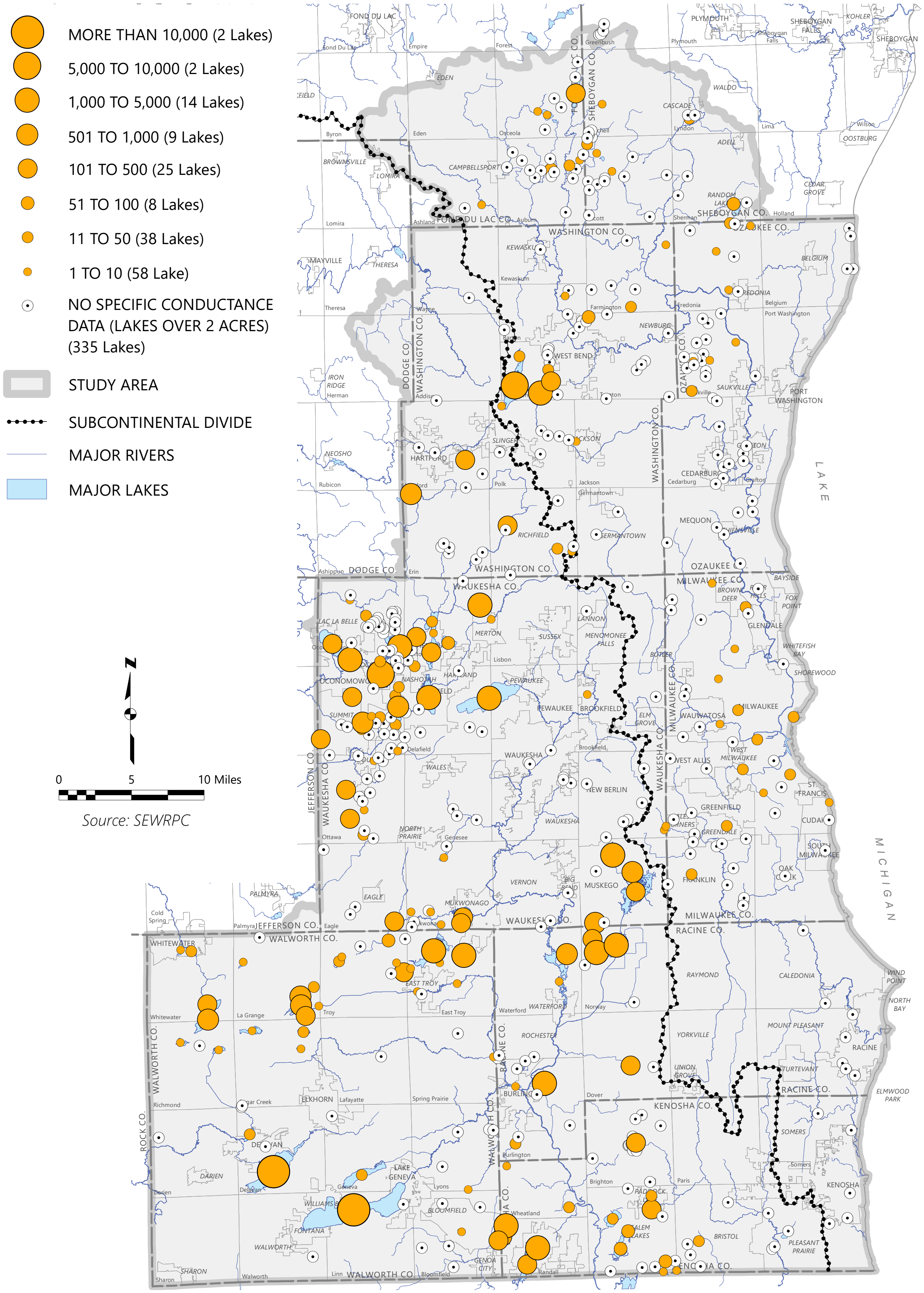
Map 6.23
Recent Median Chloride Concentrations Within the Sauk Creek and Sheboygan River Watersheds and Adjacent Portion of the Direct Drainage Area to Lake Michigan: 2013-2022



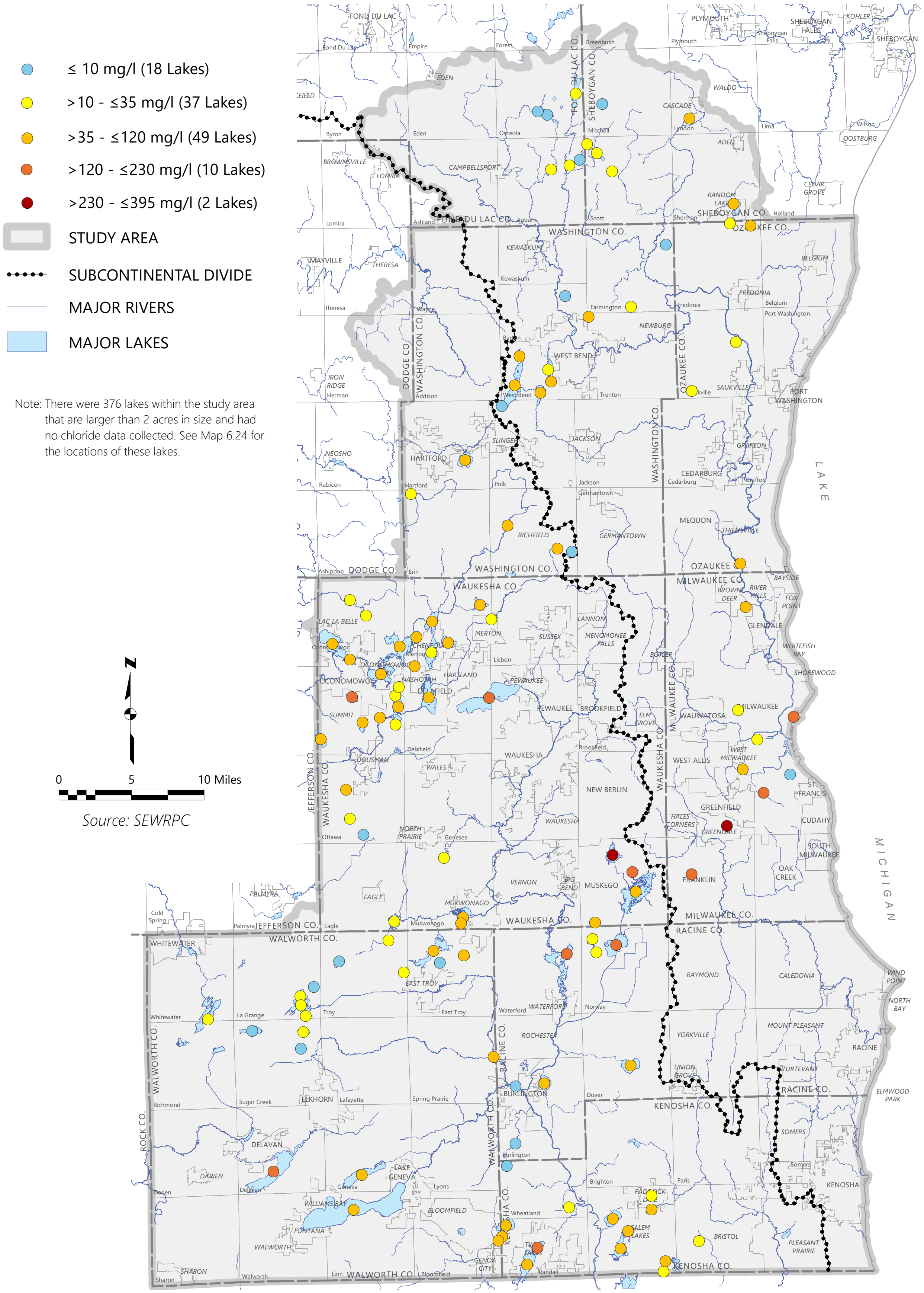
Map 6.24
Total Number of Chloride Samples Among Lakes: 1960-2022



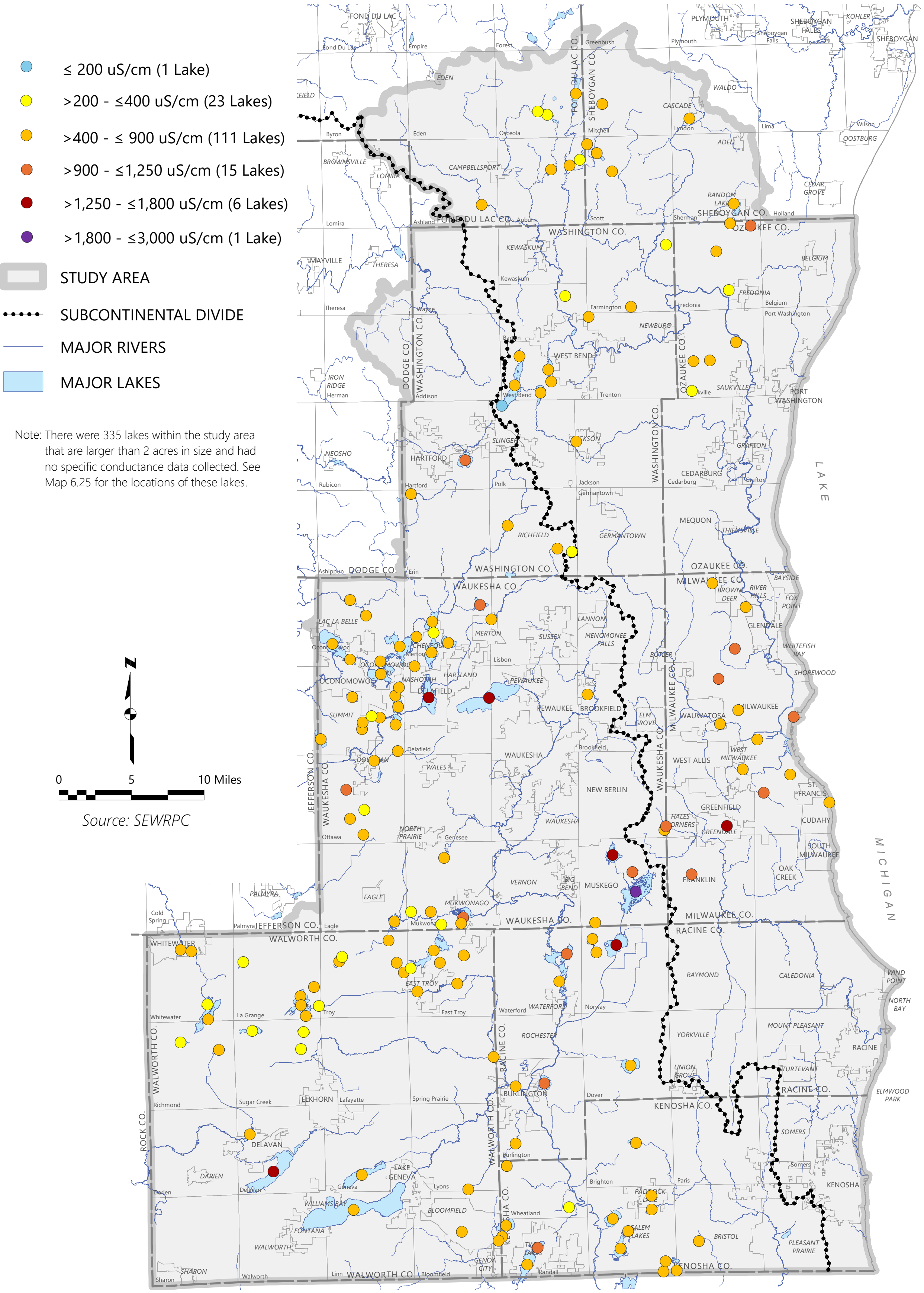
Map 6.25
Total Number of Specific Conductance Samples Among Lakes: 1960-2022



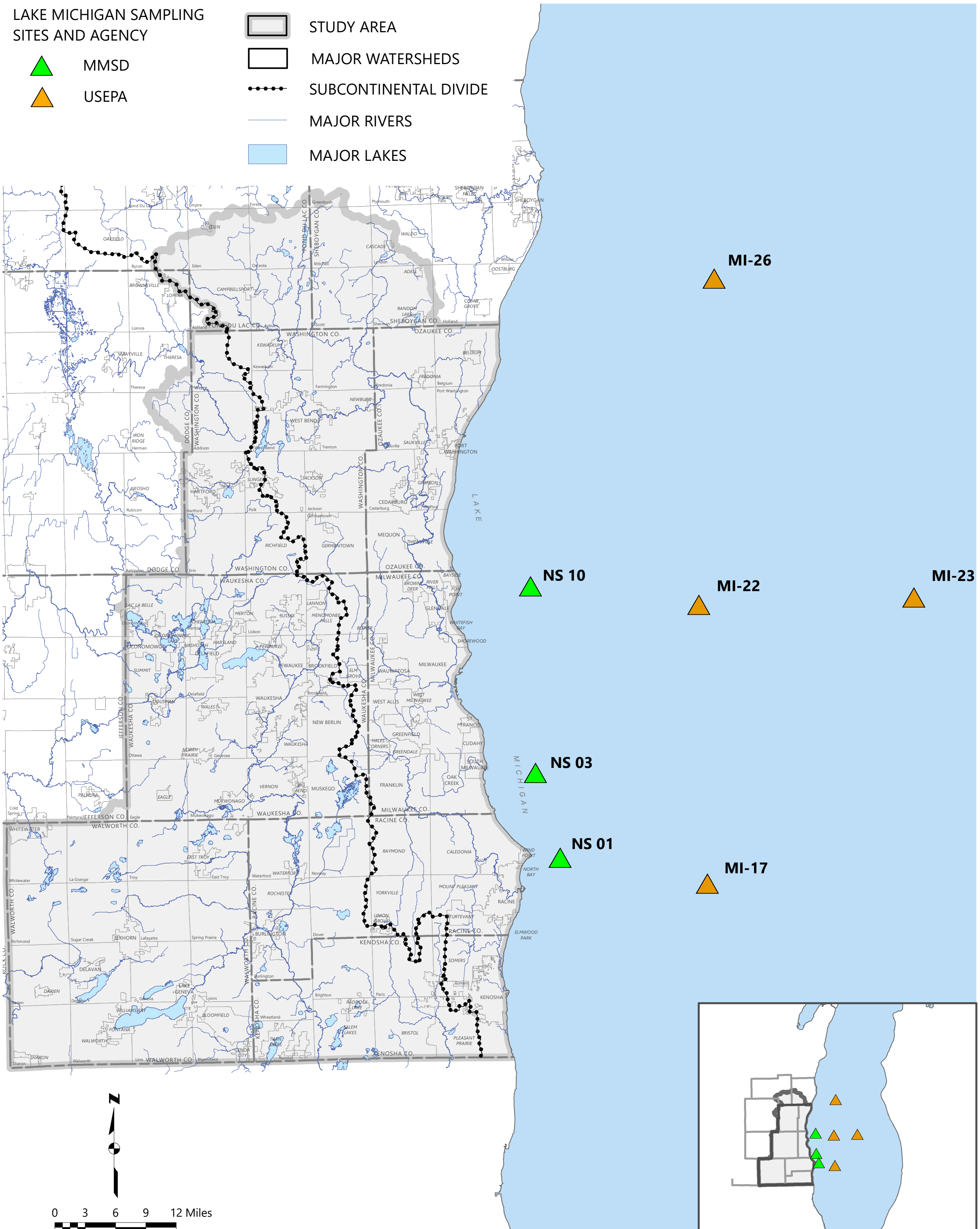
Map 6.26
Maximum Chloride Concentration Among Lakes: 1960-2022



Map 6.27
Maximum Specific Conductance Among Lakes: 1960-2022

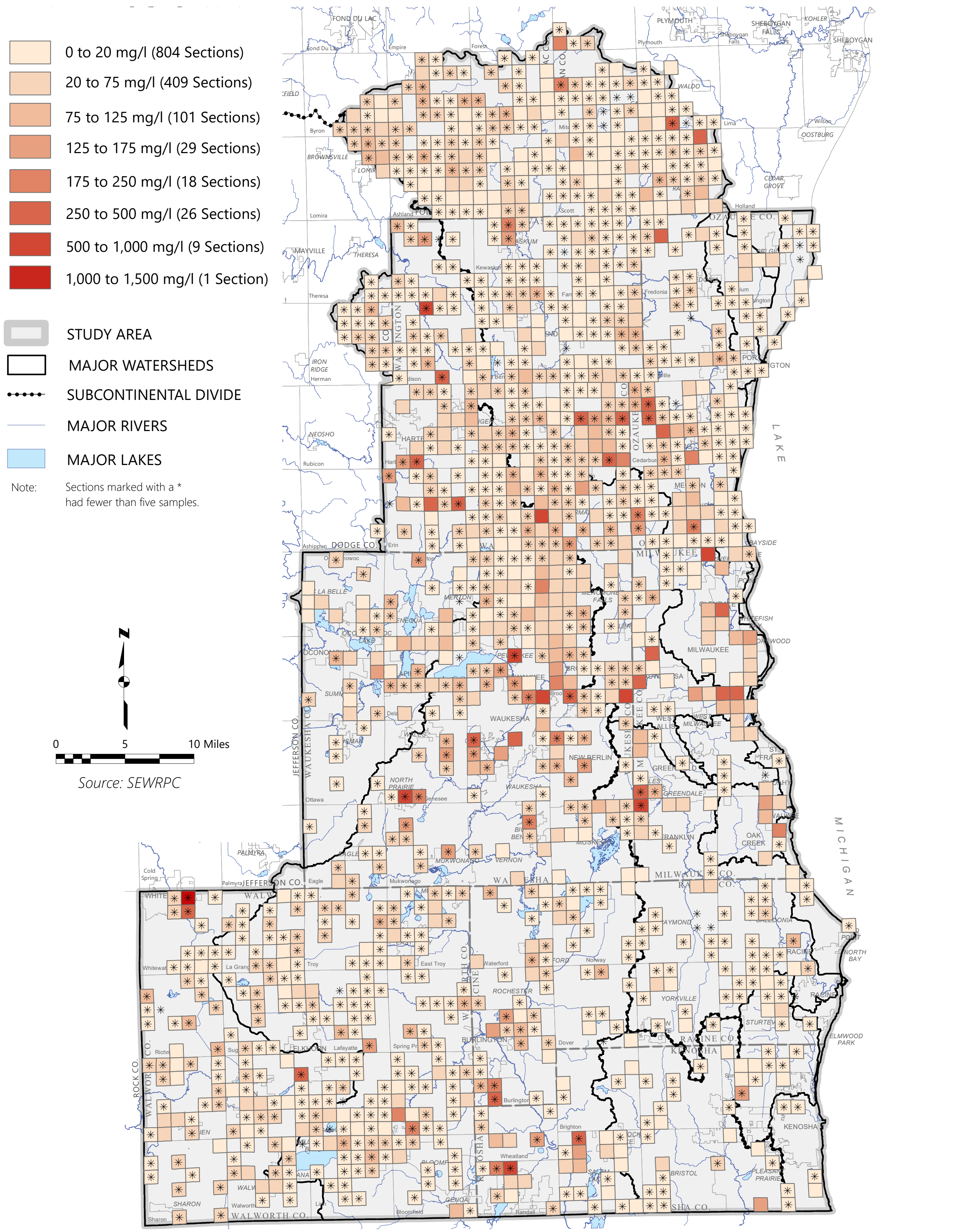


Map 6.28
Lake Michigan Monitoring Stations with Chloride Samples



Source: MMSD, USEPA, and SEWRPC

Map 6.29
Median Shallow Groundwater Chloride Concentrations Among PLSS Sections: 1945–2022



Source: SEWRPC

Map 6.30
Percent of Shallow Wells in PLSS Sections with Increasing Chloride Concentrations: 1972-2020

PERCENT OF INCREASING WELLS

- 0% (9 Sections)
- 1 to 25% (8 Sections)
- 25 to 50% (9 Sections)
- 50 to 75% (10 Sections)
- 75 to 99% (2 Sections)
- 100% (8 Sections)

- STUDY AREA
- MAJOR WATERSHEDS
- SUBCONTINENTAL DIVIDE
- MAJOR RIVERS
- MAJOR LAKES

Note: Only wells with at least 20 samples spanning 20 years and with the most recent sampling date since 2000 were used for trend analysis.

0 5 10 Miles

Source: SEWRPC