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Technical Report No. 63

CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 3

ANALYSIS OF MONITORING DATA COLLECTED FOR THE CHLORIDE IMPACT STUDY: 2018-2021

3.1 INTRODUCTION

As part of the Study, Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) staff collected water quality data at sites on several streams and lakes in southeastern Wisconsin. Several types of data were collected in both streams and inland lakes. Continuous monitoring using in-stream sensors was conducted at stream monitoring sites. Water samples were collected from stream sites and lakes and chemically analyzed for concentrations of chloride and other ions. And finally, vertical profile data of temperature and specific conductance were collected from study area lakes.

3.2 STREAM MONITORING SITE DESCRIPTION AND DATA COLLECTION

This section will briefly summarize the stream monitoring sites used in the Study, as well as their associated drainage areas; the climate and weather conditions for the Study; and the continuous and discrete water quality data collection conducted during the Study. A description of the process used to select sites for monitoring for the Study is given in a separate technical report.[1] That report also provides more complete descriptions of the monitoring sites and their contributing drainage areas as well as the data collection methods utilized in the Study.

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

Stream Sampling Sites

Commission staff conducted water quality monitoring at 41 sampling sites on 31 streams within the Southeastern Wisconsin Region. These sites are shown on Map 3.1 and described in Table 3.1. Sites were selected to ensure a balanced geographic distribution of monitoring locations among the counties and watersheds in the study area. In addition, monitoring sites were selected to provide a set of locations that are representative of the variety of stream conditions within the Region. Factors considered in the selection of sites included:

- Land use in the areas draining to the monitoring sites from the SEWRPC 2015 land use inventory
- The presence and absence of wastewater treatment facilities and stormwater management systems discharging into streams[2]
- The size of streams, including both stream order and observed or modeled stream discharge[3]
- The locations of U.S. Geological Survey (USGS) stream gages
- Sources of water supply in areas draining to monitoring sites
- Presence of chloride-related impaired water designations pursuant to Section 303(d) of the Federal Clean Water Act
- Availability of historical water quality monitoring data
- Conditions within the stream and riparian area
- Legal and safe access to monitoring sites

The drainage areas contributing to the stream monitoring sites represent a wide range of land uses (see Table 3.2). Some drainage areas contain high percentages of urban land uses. Sites 53 Honey Creek at

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[2] *Wastewater treatment facility information was provided by the Wisconsin Department of Natural Resources.*

[3] *Modeled stream discharge information was provided by the WDNR while measured stream discharge was provided by the United States Geological Survey.*

Wauwatosa, 12 Lincoln Creek, and 60 Root River at Grange Avenue are the sites with the most urbanized drainage areas, with 98.5 percent, 97.4 percent, and 91.9 percent urban land use, respectively. These drainage areas also contain relatively high percentages of land devoted to roads and parking lots. Drainage areas to other sites contain relatively low levels of urban development. Sites 21 East Branch Milwaukee River, 38 North Branch Milwaukee River, and 40 Stony Creek are the sites with the least urbanized drainage areas, with 6.0 percent, 7.4 percent, and 8.3 percent urban land use, respectively.

Streamflows at 16 stream monitoring sites includes contributions from discharges by wastewater treatment plants (WWTPs) (see Table 3.2). Most of the affected sites have only one or two WWTPs in their drainage areas; however, stream flows at some sites along the mainstems of the Fox and Milwaukee Rivers include effluent from a larger number of WWTPs.

The drainage areas to the stream monitoring sites also vary in the percentage of land used for agricultural purposes (see Table 3.2). The percentage of agricultural land use at stream monitoring sites ranges from less than 0.5 percent in several highly urbanized drainage areas to over 75 percent in two of the most rural drainage areas (Site 14 Sauk Creek and Site 16 Jackson Creek).

Climate and Weather Conditions

Climate and weather data used for the Study were provided by the Wisconsin State Climatology Office and the National Oceanic and Atmospheric Administration (NOAA).

Normal Climate Conditions: 1991-2020

Table 3.3 shows 30-year averages for the years 1991-2020 for average daily temperature, monthly precipitation, and monthly snowfall for southeastern Wisconsin. Average daily temperature varies by month, from 20.7 degrees Fahrenheit (°F) in January to 71.3°F in July. On average, southeastern Wisconsin receives 35.28 inches of precipitation per year. The months of December through February tend to be the driest, with less than 2.0 inches of precipitation per month. The months of April through August tend to be the wettest with over 3.5 inches of rain per month. On average, southeastern Wisconsin receives 42.3 inches of snow per year. Most snow falls in the months of December through February.

Weather Conditions During Study: 2018-2021

The years during which much of the Study was conducted were relatively wet. During 2018 southeastern Wisconsin received a total of 44.86 inches of precipitation (rain and snow represented as liquid water equivalent). This total made that year the second wettest year observed in the Region during the period

1895 through 2023. The following year, 2019, was the wettest year observed during that period with a total of 45.02 inches of precipitation. To complete the study period, precipitation totals were near normal in 2020 (36.76 inches) and significantly below normal in 2021 (25.25 inches).

The first half of the study period (2018-2019) experienced fairly normal average monthly temperatures. The latter part of the study period was relatively warm. The year 2020 was the 14th warmest year and 2021 was the seventh warmest observed during the period 1895 through 2023.

Stream Data Collection

This subsection describes the continuous and discrete water quality data collection conducted during the Study, including a summary of the equipment, methods, and parameters of interest. A more complete description of the data collections effort is presented in a separate technical report.[4]

Continuous Data Collection

Commission staff collected continuous data at stream monitoring sites using METER Group, Inc. USA CTD-10 sensors.[5] These CTD-10 sensors were placed in a protective housing and installed at all 41 monitoring sites. Sensors were installed at sites within the monitored reaches that had channel substrates stable enough to support the sensor and sufficient water depth to prevent the sensor from freezing during the winter. Each sensor was paired with a telemetry unit that transmitted in-stream data to the METER Group's proprietary ZENTRA Cloud online data management platform. Using this platform, Commission staff were able to remotely monitor and visualize data in near-real time, download data, and troubleshoot equipment issues.

The CTD-10 sensors took measurements once every five minutes. Data were collected on three parameters: water level above the sensor, water temperature, and electrical conductivity. Software within the sensor automatically converted electrical conductivity to specific conductance. This was done by adjusting electrical conductivity to the equivalent conductivity at 25 degrees Celsius (77°F).

Table 3.4 shows the periods during which continuous monitoring was conducted at each of the stream monitoring sites. Monitoring was done at most sites for at least 25 months from October 2018 through October 2020. The monitoring period was extended at several sites to enable collection of additional paired

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

[5] *METER Group Inc, USA,* CTD-10 Electrical Conductivity, Temperature & Depth Sensor, Product Manual, Version 13869-4, *Pullman, Washington, June 6, 2018.*

specific conductance-chloride samples during winter storm and spring snowmelt events. These paired samples were collected to capture the full range of chloride concentrations and specific conductance levels that occur at monitoring sites within the Region. During the course of data collection for the Study Commission staff installed an additional four monitoring sites. These additional monitoring sites were deemed necessary after the Milwaukee Metropolitan Sewerage District (MMSD) determined that their continuous water quality monitoring equipment at several locations would need to be removed during the winter season. Subsequently, data were collected at these four sites (Sites 57, 58, 60, and 87) for shorter durations.

The continuous data record at each site was examined by Commission staff and adjusted when necessary to address sensor fouling. Data adjustments were conducted using methods modified from the USGS Guidelines and Standard Procedures for Continuous Water-Quality Monitors.[6] A description of the continuous record examination and adjustments are provided in a separate technical report.[7] Across the entire Study, a total of 8,960,021 specific conductance observations from the continuous data sensors were included in the analysis dataset.

Continuous Data Example

Figure 3.1 shows continuously collected water depth and specific conductance data for an eight-day period at one stream monitoring station, Site 15 Kilbourn Road Ditch. Water depth on the figure indicates the height of the water over the CTD-10 sensor. The rise and fall of water level and specific conductance indicate responses to meteorological events. This example shows the in-stream response over a period during which snowfall occurred on several days and air temperatures alternated between above freezing during the days and below freezing during the nights. The identification of events like the one shown in Figure 3.1 is important in assessing the impacts of various factors on in-stream chloride dynamics. Examples of in-stream responses of chloride concentration to meteorological events will be discussed later in this chapter.

Figure 3.1 shows a short portion of the CTD-10 data record for one site. The data records at all the monitored stream sites are considerably longer than what is shown in the figure, ranging between 10 and 35 months,

[6] *R.J. Wagner, R.W., Boulger, Jr., C.J. Oblinger, and B.A., Smith,* Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Station Operation, Record Computation, and Data Reporting*, U.S. Geological Survey Techniques and Methods 1-D3, 2006.*

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

depending on the site (see Table 3.4). Much of the discussion in the following sections seeks to summarize the entire sampling record at each site. Later discussions will focus on smaller portions of individual records.

Discrete Sampling

Water quality samples were also collected at stream monitoring sites. Chemical analysis of the water samples was conducted by the Wisconsin State Laboratory of Hygiene (WSLH). Stream samples were analyzed for seven water quality constituents: chloride, calcium, magnesium, potassium, sodium, sulfate, and hardness. A more detailed description of water quality sampling conducted for the Study is given in a separate technical report.[8]

Water samples were collected monthly at each of the established stream monitoring sites over the 25-month main study period from October 2018 through October 2020.[9] A total of 988 monthly stream water quality samples were collected. Water samples were typically collected during the middle two weeks of each month, regardless of weather conditions, to develop a water quality dataset that captured the variety of conditions representative of each stream monitoring site.

In order to supplement stream data collected during regular monthly sampling, Commission staff employed a targeted winter event sampling program through the 2020-2021 winter season to capture specific conductance peaks that were likely representative of high chloride concentrations in the study area waterways. A total of 106 event samples were collected.

Most water samples were collected at the location of the corresponding CTD-10 sensor. Occasionally, site conditions such as high streamflow, in-stream ice cover, or hazardous conditions along the streambanks did not allow Commission staff to enter the streams to collect samples by hand at the location of the CTD-10 sensors. In these instances, samples were collected from a safe location as close to the sensor location as conditions allowed.

Combined Data Collection Example

Figure 3.2 provides an example of the primary continuous and discrete data collection elements at each monitoring site using Site 1 Fox River at Waukesha. The continuous specific conductance record measured

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

[9] *Additional monthly water samples were collected through August 2021 at select stream monitoring sites to expand the dataset for sites that were established later in the project.*

at five minute intervals is shown alongside the discrete chloride samples, which are distinguished as either monthly or event samples. The October 2018 through October 2020 primary study period is illustrated along with an extended monitoring period from November 2020 to February 2021. As detailed in Table 3.4, not every site had an extended monitoring period nor event samples collected as these study elements were generally limited to sites with spikes in winter specific conductance and chloride concentrations. The extended monitoring period was added at specific sites to ensure that the chloride grab samples at those sites represented the observed range of specific conductance values.

Estimated Chloride from Specific Conductance

Specific conductance measurements were used to estimate in-stream chloride concentrations using regression models developed for that purpose as part of the Study.[10] These models were developed using paired samples of specific conductance and chloride collected at the Study stream sampling sites. Two models were developed and used. A piecewise regression model was developed and used to estimate chloride concentration at 30 stream monitoring sites. During development of this model, Commission staff found that it systematically overestimated chloride concentration at 10 sites. The drainage areas associated with these sites had low percentages of urban land use, and specific conductance at these sites rarely exceeded 1,000 microSiemens per centimeter (µS/cm). Paired samples from these 10 sites were used to develop a linear mixed effects regression model. At one site a model could not be developed to estimate chloride concentration from specific conductance. Information on the development, evaluation, and application of these models is given in a separate technical report.[11]

3.3 CHLORIDE CONDITIONS IN MONITORED STREAMS: OCTOBER 2018 THROUGH APRIL 2021

The following section presents summary information and insights regarding chloride conditions and dynamics in southeastern Wisconsin streams from the monitoring conducted by the Commission during the Chloride Impact Study.

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

[11] Ibid.

Stream Monitoring Site Summary Statistics

Table 3.5 shows summary statistics for specific conductance, chloride concentration estimated from specific conductance, and chloride concentration from water quality samples collected at all Chloride Impact Study monitoring sites between October 2018 and August 2021. The table also shows summary statistics for measured chloride samples based on only the monthly sampling. These statistics are based on data collected at 41 sampling sites located on 31 streams and constitute estimates of average and extreme conditions within streams of the study area.

Three components of Table 3.5 require explanation. First, the statistics for estimated chloride concentration are based on over 203,000 fewer measurements than the statistics for specific conductance. This reflects the fact that a regression model for estimating chloride concentration from specific conductance could not be developed for data from one of the monitoring sites.[12]

Second, for all four sets of data shown in Table 3.5, mean values are higher than median values. Given that the mean as a statistic is more sensitive to outliers than the median, this suggests that a relatively small number of unusually high measurements are responsible for higher mean values.

Third, the mean measured chloride concentration shown in Table 3.5 is based on all samples is almost twice the mean concentration estimated from specific conductance. This reflects the fact that the data from which the summary statistics for measured chloride were calculated include event samples as well as regular monthly samples. This mean concentration difference is not surprising as the purpose of event sampling was to collect water samples near peak specific conductance levels to extend the ranges of values used for developing the regression models. When the event samples were removed and the calculations were based on only the regular monthly sampling, both mean and median chloride concentrations and the standard deviation in chloride concentration were very close to those based on the estimated chloride. This reflects the fact that the most appropriate sampling strategy for determining average values of water quality constituents is to sample regularly on a fixed interval.[13] When continuous sampling is not employed, determining extremes values such as the minimum and maximum requires a sampling strategy that targets times or events during which extreme values are likely to occur.

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

[13] *D.M. Robertson, "Influence of Different Temporal Sampling Strategies on Estimating Total Phosphorus and Suspended Sediment Concentration and Transport in Small Streams,"* Journal of the American Water Resources Association, *39:1,271-1,308, 2003.*

The use of event samples has two implications for the interpretation of the measured chloride samples. First, the average chloride concentration in streams of the study area is better represented by the mean or median calculated from only the regular monthly samples. Event samples should not be included in the calculation of these statistics. Second, extreme values of chloride such as minimum and maximum values are better represented by the values calculated from the full dataset.

Specific Conductance Levels and Chloride Concentrations By Site

Table 3.6 shows summary statistics for specific conductance at Study stream monitoring sites. Levels of specific conductance varied considerably among sites. The minimum levels of specific conductance ranged between 42 μS/cm at Site 59 Root River near Horlick Dam and 454 μS/cm at Site 47 Fox River at Rochester. Maximum levels of specific conductance ranged between 603 μS/cm at Site 21 East Branch Milwaukee River and 14,689 Site 12 Lincoln Creek. Mean values of specific conductance ranged between 362 μS/cm at Site 48 White River at Lake Geneva and 2,078 μS/cm at Site 60 Root River at Grange Avenue. For most sites, median values of specific conductance were very similar to mean values and ranged between 366 μS/cm at Site 48 White River at Lake Geneva and 1,746 μS/cm at Site 60 Root River at Grange Avenue.[14]

The amount of variability in specific conductance differed among the monitoring sites. Standard deviation in specific conductance ranged between 37.8 μS/cm at Site 3 Mukwonago River at Mukwonago and 1,510.7 μS/cm at Site 53 Honey Creek at Wauwatosa. The differences in variability reflect several factors including differences in flashiness among streams and differences in the amount of urban development in the drainage areas contributing to each monitoring site.

Table 3.7 shows summary statistics for estimated and measured concentrations of chloride at Study stream monitoring sites. Estimated concentrations were calculated from specific conductance using regression models developed as part of the Study.[15] Measured concentrations were calculated from the results of regular monthly sampling only. Concentrations from event samples are not included in these statistics because they would introduce bias into the calculation of mean values.[16]

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[14] *Mean and median values of specific conductance and estimated chloride were very similar at most monitoring sites and most sites also approximated normal distributions. Consequently, Commission staff decided to report averaged values as means instead of medians.*

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

[16] *Robertson 2003,* op. cit.

The average concentration of chloride varies among streams in the study area (see Table 3.7). Measured mean concentrations range between 17.6 mg/l at Site 45 Mukwonago River at Nature Road to 571.3 mg/l at Site 53 Honey Creek at Wauwatosa (see Map 3.2). Estimated mean concentrations range between 19.4 mg/l at Site 45 Mukwonago River at Nature Road to 493.6 mg/l at Site 53 Honey Creek at Wauwatosa (see Map 3.3). In general, there is good correspondence between the estimated and measured concentrations of chloride in these streams. Time series of the estimated and measured chloride concentrations at each monitoring site are presented in Appendix A.

Table 3.8 shows summary statistics for measured chloride concentrations at Study stream monitoring sites based on all collected data, including event samples. Minimum concentrations range between 8.7 mg/l at Site 54 Whitewater Creek to 162.0 mg/l at Site 87 Underwood Creek. Maximum concentrations range between 20.1 mg/l at Site 45 Mukwonago River at Nature Road to 4,580.0 mg/l at Site 53 Honey Creek at Wauwatosa.

Background chloride concentrations in streams and rivers from natural sources are generally low. This is especially the case in southeastern Wisconsin where chloride is not a major component of the bedrock underlying the Region. Historically, the mean chloride concentration of river water in North America was on the order of about 8-20 mg/l.[17] The summary statistics presented in Tables 3.7 and 3.8 suggest that anthropogenic contributions have affected chloride concentrations in most of the streams monitored as part of this Study. If these 41 sites are representative of streams and rivers of southeastern Wisconsin, it implies that chloride concentrations in most of the streams and rivers in the Regions have been similarly affected.

Grouping Sites with Similar Chloride Characteristics

Commission staff evaluated the characteristics of chloride concentration dynamics at each of the 41 monitoring sites in the Study and grouped sites that shared similar characteristics (see Table 3.9 and Map 3.4). This section will provide a summary of these site groupings as well as shared site characteristics and chloride behavior. As these sites were originally selected to represent a broader population of streams across the study area, describing the behavior at these sites is intended to provide understanding of how similar streams in the Region may behave. Stream behavior and chloride dynamics in response to types of

[17] *J.E. Raymont,* Plankton Productivity in the Oceans, *Pergamon Press, Toronto, 1967; R. G. Wetzel,* Limnology, *Saunders College Publishing, Toronto, 1983; W.D. Hintz, and R.A. Relyea, "A Review of the Species, Community, and Ecosystems Impacts of Road Salt Salinization in Freshwater,"* Freshwater Biology, *64:1,081-1,097, 2019.*

meteorological events and other influencing factors are discussed in greater detail later in this Chapter. Appendix A provides time series figures with estimated chloride from continuous specific conductance as well as measured chloride from grab samples at each monitoring site in the Study.

Group 1: Streams with Highly Urban Watersheds and Large Winter Spikes

Comprised of six monitoring sites, this group had the highest chloride concentrations observed during the chloride study and likely represent some of the most chloride-impacted streams within the Region. These monitoring sites were located on relatively small streams and rivers in highly urban watersheds (67 to 99 percent urban land use) within the census-defined Milwaukee Urbanized Area. All these sites exhibited significant winter spikes in chloride concentrations, which may be indicative of surface runoff containing salts or chloride-containing deicers from roads, parking lots, driveways, and sidewalks within their watersheds. During these spikes, the chloride concentrations could rise up to 700 percent of the winter baseline concentrations, which were also elevated compared to non-winter baseline concentrations, and many spikes exceeded the WDNR acute toxicity standard of 757 mg/l.[18] Most spikes began with a very rapid increase in chloride concentrations during or immediately following a winter precipitation event, with some sites experiencing chloride concentration increases up to 2,000 mg/l within a day of the start of the precipitation event. These spikes generally lasted from 16 hours to several days depending on the site and sometimes several spikes occurred in close succession, resulting in extended periods with extremely high chloride concentrations.

During and immediately following non-winter precipitation events, runoff creates high water levels and the estimated chloride at these sites would rapidly plummet to exceedingly low concentrations and occasionally to an estimated concentration of 0 mg/l.[19] The exceedingly low chloride during these periods may reflect that many of these highly urban streams have limited interaction with mineral-rich groundwater and thus the stream water predominantly originated from runoff due to the precipitation event. As precipitation contains little chloride or other ions, this influx of low-ion water would strongly dilute chloride concentrations within the stream. Due to these sharp dilutions, many of the sites with the highest estimated chloride concentrations in the Study also had some of the lowest chloride concentrations during the

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[18] All of the streams located in this grouping of sites are already designated as impaired for chloride on the 303(d) impaired waters list.

[19] The actual chloride concentrations were unlikely to be 0 mg/l during these periods, but the observed specific conductance values were below the 103 µs/cm threshold for which the piecewise regression model estimated a chloride concentration of zero or less.

monitoring study period. These dilutions could occur in close proximity with the winter spike events, and an example is shown for Site 12 Lincoln Creek in Figure 3.3. The figure shows that the site concentrations dropped to 40 mg/l at midnight on January 11, 2020 during a freezing rain event and then rose to 3,953 mg/l by 3:25 p.m. on January 13, 2020 following and during two separate snowfall events. Thus, some monitoring sites could experience nearly the full range of chloride conditions observed across the study area within a few days in winter.

Group 2: Small Streams with Mixed Urban and Rural Watersheds and Moderate Winter Spikes

This group consists of six monitoring sites characterized by generally smaller streams and rivers in watersheds with mixed urban and rural land uses. All these sites also exhibited moderate winter spikes in chloride concentrations, although the spikes did not increase chloride concentrations to the same extent as the those in Group 1. Like the sites in Group 1, most of the monitoring sites in this group had watersheds at least partially comprised of dense urban lands and all were outside of Milwaukee County. Unlike the sites in Group 1, these had substantial proportions of rural lands that comprised between 46 and 67 percent the watershed. The estimated chloride time series at these sites look like buffered versions of the sites in Group 1, with smaller spikes following winter precipitation and snowmelt events but also smaller decreases or dilutions following non-winter precipitation events. These spikes could cause chloride to increase up to 500 mg/l and with concentrations remaining above the winter baseline concentrations for several hours to days. A few of these monitoring sites represent streams in the urbanizing areas of eastern Waukesha County, which may be among the most susceptible to future increases in chloride concentrations with continued urban development. Of particular interest in this group is Site 1 Fox River at Waukesha, which had the highest mean chloride concentration of any monitoring site that does not ultimately drain to Lake Michigan.

Group 3: Small Streams with Rural Watersheds and Moderate Winter Spikes

This group contains nine sites that had predominately rural watersheds (between 65 and 89 percent rural land use) but still exhibited the winter spikes in chloride that were characteristic of sites with more urban watersheds. In these predominantly rural watersheds, many of these sites had immediate drainage areas with substantial winter deicing chloride sources such as a dense urban area (e.g., Site 14 Sauk Creek, Site 51 Rubicon River, and Site 52 Cedar Creek) or a major roadway (e.g., Site 15 Kilbourn Road Ditch, Site 30 Des Plaines). Like the sites in Groups 1 and 2, these sites had winter chloride spikes between approximately 200 and 800 percent from winter baseline concentrations and ranged in duration from a few hours to several days. Consequently, the proximity of these land uses to the monitored stream site may have an outsized influence on chloride concentrations than expected based on the overall stream watershed characteristics.

Group 4: Streams with Rural Watersheds, Small or No Winter Spikes, and Moderate Chloride

The ten sites in this group shared characteristics of having largely rural watersheds with moderately high chloride concentrations (compared to natural background concentrations of 5 to 10 mg/l) but did not exhibit winter spikes in chloride. Most of the sites within this group maintained relatively consistent chloride concentrations with the most significant fluctuations occurring as decreases during non-winter precipitation events. In most instances, the monitoring site quickly returned from this decline to its baseline condition. The maintenance of an elevated baseline chloride concentration may indicate the contributions of chloride-enriched groundwater to the stream that becomes diluted with significant precipitation events. A few of these sites, such as Sites 18, 36, and 40, did exhibit small winter spikes (less than 20 mg/l) during a subset of the recorded precipitation events for the site. Site 32 Turtle Creek had an erratic time series with rapid, significant fluctuations in estimated chloride concentrations that did not match with seasonal patterns or individual precipitation events.

Group 5: Streams with Rural Watersheds, No Winter Spikes, and Low Chloride

The four sites in this group are likely to represent some of the least chloride-impacted streams within the southeastern Wisconsin region as mean chloride concentrations were among the lowest of any monitoring site in the Study. These sites are not only in highly rural watersheds, but their watersheds also contain significant proportions of natural land uses such as wetlands, woodlands, and surface waters. Substantial portions of these natural areas are currently protected from development by their inclusion in units of the Kettle Moraine State Forest. These sites did not generally exhibit winter spikes and the most significant chloride fluctuations occurred during non-winter precipitation events when the estimated chloride would decline for several hours to a few days before rising to the baseline concentration. However, Site 45 Mukwonago River at Nature Road did have winter spikes with chloride increasing by up to 12 mg/l, showing that even these less-impacted sites may still be influenced by chloride-containing runoff during winter. Although low compared to the other monitored streams, the estimated chloride concentrations in these streams were still higher than the 5 to 10 mg/l that would be expected from undisturbed natural conditions. Consequently, the relatively steady but slightly increased concentrations in these streams may reflect chloride contributions from groundwater with higher chloride concentrations.

Group 6: Large Rivers with Mostly Rural Watersheds and No Winter Spikes

This group is only comprised of two monitoring sites: Site 2 Fox River at New Munster and Site 41 Milwaukee River near Saukville. These sites were on sixth-order and fifth-orders rivers with watersheds of 807 and 448 square miles, respectively. The land use within each watershed is predominantly rural although both watersheds are so large that they do contain sizable urban areas further upstream, such as the City of

Waukesha for Site 2 and the City of West Bend for Site 41. Due to the large volumes of water and lack of nearby strong chloride sources, these sites did not exhibit sharp increases in chloride concentrations during winter or spring precipitation events, and instead only had small decreases in chloride followed by a gradual increase in the days after the event. Large summer and fall precipitation events caused substantial declines in chloride concentrations that would rebound to former concentrations within a week or so after the event.

Group 7: Large Rivers with Mostly Rural Watersheds and Winter Spikes

This group consists of three monitoring sites: Site 23 Milwaukee River Downstream of Newburg, Site 47 Fox River at Rochester, and Site 58 Milwaukee River at Estabrook Park. These sites are located on the same rivers as Group 6, but Site 47 is upstream of Site 2 on the Fox River while Site 23 is upstream and Site 58 is downstream of Site 41 on the Milwaukee River. What sets this group apart from the previous group is the presence of winter spikes in chloride concentrations, which are notable although more muted and occurring over longer time periods than on smaller streams. These monitoring sites are closer to highly urbanized areas than the sites in Group 6, so these chloride spikes are likely occurring due to runoff from these urban areas. At the Milwaukee River sites, these winter spikes lasted between 12 and 20 hours, while these spikes in chloride concentration lasted for several days at Site 47 on the Fox River. Baseline winter chloride concentrations between the spikes were higher at each site than in other seasons. Non-winter precipitation events caused decreases in chloride concentrations that would often extend for several days following the event.

Concentrations of Other Ions By Site

As previously noted, water quality sampling at stream monitoring sites included several other water quality constituents other than specific conductance and chloride concentrations. These concentrations varied substantially between the stream monitoring sites, with patterns related to chloride concentrations and land use within the site drainage areas. Commission staff compiled summary statistics of the other ion concentrations in Appendix B.

Some patterns were observed among concentrations of ions. Figure 3.4 shows the relationship between in-stream chloride concentrations and sodium concentrations. The concentrations of these two ions were highly correlated with one another (R^2 of 0.99). Figure 3.5 shows the relationship between in-stream chloride concentrations and calcium concentrations. While high chloride concentrations are associated with high calcium concentrations, the relationship is not as strong as that between chloride and sodium (R^2 of 0.23). The relationships between chloride and magnesium, chloride and potassium, and chloride and sulfate were similar to that between chloride and calcium. The difference in the relationship between chloride and sodium and the relationships between chloride and the other ions that were sampled suggests that much of the chloride entering streams in southeastern Wisconsin is entering in the form of sodium chloride. The relationships between chloride and the other three cations suggest that chloride may be entering stream in the form of some other chloride salts, such as calcium chloride or magnesium chloride, but that these compounds are not the dominant form in which chloride enters streams of the study area.

Concentrations of some ions were also related to land use in the drainage areas upstream of the stream monitoring sites. Table 3.10 shows the results of a correlation analysis examining the relationships between several water quality constituents and three broad land use categories for monitoring site drainage areas. The data show strong positive correlations (greater than 0.7) between the percentage of the drainage area consisting of urban land use and the mean concentrations of chloride and sodium. Comparatively, the correlation strength between the percentage of the drainage area consisting of roads and parking lots and the mean concentrations of chloride and sodium at stream monitoring sites are marginally stronger than percentage urban land use. By contrast, the correlation strength between the percentage of urban land use or percentage of roads and parking lots with the mean concentrations of the cations calcium, magnesium, and potassium are weak (less than 0.3). Except for potassium, the mean concentration of all ions listed in Table 3.10 show negative correlations with increasing percentages of agricultural land use, indicating a tendency toward lower mean concentrations of ions at higher percentages of agricultural land use. However, the strength of these negative correlations is weak for calcium, hardness, magnesium, and moderate for chloride and sodium. While the correlation between mean potassium concentration and the percentage of agricultural land use is positive, it is so low that it suggests that the mean potassium concentration is independent of the fraction of agricultural land use in the drainage area.

The correlations between land use types and mean ion concentrations suggest several generalizations regarding sources of ions to streams of southeastern Wisconsin. The strong relationships between urban land use, especially roads and parking lots, and concentrations of chloride and sodium suggest that the presence of roads and parking lots is a strong driver of the average concentrations of these ions in stream water. This will be further explored later in this Chapter.

These relationships also suggest that much, if not most, of the chloride entering streams is entering in the form of sodium chloride. This also suggests that salt from sources such as winter deicing, water softening, and wastewater treatment plants may be major factors influencing chloride concentrations in these streams. The weaker correlations between urban land use and the other cations shown in Table 3.10 indicate that their in-stream concentrations are less driven by the percentages of urban land use and roads and parking lots in their upstream drainage areas. Geological factors likely underlie some of these relationships. For example, it is likely the dolomite bedrock underlying much of southeastern Wisconsin has a strong influence on in-stream calcium and magnesium concentrations.[20]

Stream Chloride Dynamics and Influencing Factors

The following subsection examines how stream chloride dynamics are influenced by meteorological events as well as driving factors such as stream discharge, watershed land use, and other factors that influence chloride concentrations. Examples from various monitoring sites across the Region were selected to highlight these responses and influences.

Responses to Meteorological Events

Winter Storms

In-stream chloride concentrations can change markedly during winter storms. During such an event, chloride salts may be applied to roads, parking lots, and other impervious surfaces to prevent ice from forming and to remove snow and ice. Such anti-icing and deicing activities can produce runoff that reaches nearby waterbodies, either through overland flow or through stormwater infrastructure such as storm sewers. This runoff can contain high concentrations of deicing salts that affect in-stream chloride concentrations. This section examines the response of in-stream water levels and chloride concentrations to winter storm events at Site 15 Kilbourn Road Ditch during late-January 2020.

Table 3.11 shows data from two weather stations located near the stream monitoring site. At both stations, air temperatures were near freezing (32°F), generally rising above freezing during the daytime and dropping below freezing during the night. Snowfall was also recorded at both stations, with over three inches of snow being recorded at Kenosha and almost five inches being recorded at Union Grove. Despite the additional snowfall, the depth of snow on the ground decreased at both stations as the snow compressed and melted due to the relatively warm daytime conditions. It is likely that much of the melted snow entered the stream as runoff due to the ground remaining frozen.

Figure 3.6 shows the in-stream response to runoff entering the stream at Site 15 Kilbourn Road Ditch. Beginning around midday on January 23, water levels in the stream began rising. This was accompanied by an increase in chloride concentration. Toward the end of the initial period of rising water level, estimated in-stream chloride concentration decreased to a level slightly above its initial magnitude. This first small rise

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

in estimated chloride concentration with only a minor rise in water level was probably due to deicing runoff from the immediate adjacent roadways of Interstate Highway 94 (IH-94) or State Trunk Highway 11 (STH-11) to the monitoring site. Late in the evening of January 23, in-stream chloride concentration began to increase again. This may reflect new runoff containing road salt from IH-94 or STH-11 first entering the stream. Beginning around midday on January 24 and lasting into the early morning on January 25, water levels rapidly increased in the stream. During the same period, chloride concentrations increased markedly. Following this, both water level and in-stream chloride concentration decreased. Water level and estimated chloride concentration rose again beginning late in the morning on January 25, with water level and chloride concentration peaking late that evening and early the following morning, respectively. Following the peaks early January 26, both water level and chloride concentration in the stream decreased steadily through January 30. This reduction in both water level and estimated chloride concentration corresponds well with the end of the snow events on January 26.

Figure 3.1 illustrates one type of relationship between water level and chloride concentration. In this example, chloride concentration tended to rise and fall in concert with increases and decreases in water level. This reflects the fact that this event occurred during active winter weather. It is likely that water entering the stream contained high concentrations of chloride due to deicing activities occurring during the snowfall on January 23-26. The melting of snow piles adjacent to roads may also have contributed chloride. Under different circumstances, an increase in water level might be accompanied by a decrease in in-stream chloride concentrations. An example of this might occur during a late-summer rainstorm. Under those conditions, relatively chloride-free water from precipitation could act to dilute chloride in the stream, lowering in-stream concentrations.

Spring Snow Melt

Spring weather events can affect chloride concentrations in streams. Figure 3.7 shows the impacts of two events that occurred between March 7, 2019, and March 27, 2019, on water levels and estimated chloride concentrations at Site 6 White River near Burlington. In early March 2019, air temperatures in Burlington were below freezing until March 9 and 10, when daily high air temperatures rose above freezing. In addition, about one-half inch of precipitation fell on March 10. Runoff from precipitation and from melting snow entered the White River, raising the water level in the river by almost six inches (see first event in Figure 3.7). This runoff diluted the chloride in the river and chloride concentration fell by about 28 percent (from 73.6 mg/l to 53.2 mg/l). Water levels receded following this event and chloride concentrations rose.

A major spring thaw began on March 13, 2019 for Site 6. High air temperatures reached 59°F on March 15. The snow that was on the ground melted between March 9 and March 14. In addition, about one-half inch of precipitation fell between March 13 and March 14. Water levels in the White River increased by over 30 inches (see second event in Figure 3.7). At the same time, chloride concentrations in the White River fell by about 63 percent (from 60.3 mg/l to 22.3 mg/l) due to runoff from precipitation and melting snow. Following this event, water levels receded, initially decreasing rapidly, but becoming more gradual by March 20. As the water level decreased, chloride concentration increased at Site 6. By March 20, chloride concentration reached about 95 percent of the peak value that was observed on March 12. For the rest of March 2019, water levels in the White River continued to gradually decrease and chloride concentration continued to gradually increase.

The March 2019 events in the White River illustrate several factors that can affect stream chloride concentrations. In this case, large inputs of runoff from precipitation and snow melt during the spring acted to dilute in-stream chloride concentrations. Whether spring precipitation and snow melt have this effect is strongly influenced by land use in the contributing drainage area to the stream. The watershed draining to Site 6 White River near Burlington is highly rural. About 21 percent of its area is devoted to urban development, and less than 6 percent of its area consists of roads and parking lots (see Table 3.2). In contrast, the response of chloride concentration to spring precipitation and snow melt at a site in a highly urbanized watershed where residual salt may be present on roads, parking lots and driveways, and in snow piles might be quite different. If enough salt were present on the landscape, in-stream chloride concentration could increase as a result of runoff from a spring thaw.

An example of an increase in chloride concentration with a spring thaw occurred in late February 2021 at Site 60 Root River at Grange Avenue. The watershed for Site 60 is highly developed with 91.9 percent of its watershed in urban land uses, including 26.4 percent as roads and parking lots. On February 21, 2021, the Region experienced a significant snowfall event with two to four inches of snow accumulation. Beginning around noon on February 23, air temperatures reached the mid-40s across most of the study area causing a significant snowmelt event. Chloride concentrations at Site 60 rose from 2,090 mg/l at noon on February 23 to 3,233 mg/l by 1 p.m. on February 24 as the residual salt-laden snow melted and entered the Root River.

<u>Winter and Spring Rain Events</u>

For Study monitoring sites the impacts of winter and spring rain events depend on the timing of these events through the seasons and the land use of the contributing watershed. Early winter rain events, such as those on January 7-8, 2019, caused chloride concentrations to briefly spike and then significantly decline compared to pre-event concentrations in more urban sites such as Site 1 Fox River at Waukesha and Site 12 Lincoln Creek (see Figure 3.8). Note that the chloride concentration ranges on Figure 3.8 differ between sites. However, these events had little long-term impacts on chloride concentrations at all sites on the figure, which typically returned to pre-event levels within one day following the onset of precipitation. At nearby sites with more suburban or rural watersheds, such as Site 11 Bark River Upstream and Site 18 Oconomowoc River Upstream, these same early winter rain events either had little impact on chloride concentrations (e.g., at Site 11) or caused declines in chloride concentrations without a preceding spike event (e.g., at Site 18).

Mid-winter rainfall events typically caused significant increases in chloride concentrations for monitoring sites with more urban watersheds, particularly if these rain events were mixed with snow or freezing rain. At Site 1 Fox River at Waukesha, warming air temperatures combined with a mid-winter rainfall on February 3-4, 2019 caused chloride concentrations to increase from approximately 375 mg/l at midnight to 655 mg/l by 3 p.m. of February 3 (see Figure 3.9). As the rain continued, the chloride concentration decreased to 480 mg/l at 8 a.m. on February 4 before attaining a secondary peak of 588 mg/l at 4 p.m. on February 4 and then returning to pre-event concentrations by 6 p.m. on February 5 for Site 1. This same rain event caused a similar but more pronounced peak at Site 12 Lincoln Creek, with chloride concentrations increasing by approximately 2,040 mg/l within twelve hours before returning to pre-event concentrations after 20 hours following the onset of precipitation. These large increases in chloride concentration may be due to the contribution of remnant road salts and deicers from previous snow events into these surface waters or due to the additional application of deicers in anticipation of hazardous driving conditions.

In more suburban and rural watersheds, mid-winter rainfall events caused small spikes in chloride concentrations or caused chloride concentrations to decline. At Site 11 Bark River Upstream, the February 3-4, 2019 rain event caused chloride to increase by approximately 30 mg/l within 21 hours after the onset of precipitation before returning to pre-event levels after 30 hours (see Figure 3.9). For Site 18 Oconomowoc River Upstream, this rain event caused chloride concentrations to steadily decline from 65 mg/l at midnight February 3 to 54 mg/l by midnight February 5. Following the cessation of precipitation, chloride concentrations at Site 18 continued to decline to 47 mg/l at 10 p.m. on February 5 before beginning to increase again.

Late winter and spring rain events had little effect or decreased in-stream chloride concentrations at most Study monitoring sites, particularly if the rain was not preceded by a snowfall that became rain as temperatures warmed. Rainfall events on April 7, 2019, March 27, 2020, and April 7, 2020 caused small declines in chloride concentrations at most Study sites regardless of watershed land uses. Snowfall that transitioned into rainfall with warming temperatures, such as on April 11, 2019, did cause small spikes in chloride concentrations at Sites 1 and 12 but did not cause spikes at Sites 11 or 18.

Summer and Fall Rain Events

Summer and fall rain events caused estimated chloride concentrations to decrease in nearly every monitoring site for a short duration immediately following the event. Estimated chloride concentrations rebounded to the former 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. The magnitude of the decrease was also affected by stream and watershed size as well as by the precipitation amount.

As an example of responses to small summer and fall rainfall events, Site 12 Lincoln Creek, a small stream with a highly urban watershed, experienced a short, 0.2-inch precipitation event shortly after midnight on June 5, 2019 that decreased the in-stream estimated chloride concentrations from approximately 375 mg/l to 18 mg/l within two hours (see Figure 3.10). Note that the chloride concentration ranges on Figure 3.10 differ between sites. Following the cessation of that event, the chloride concentration in the stream climbed fairly steadily until it attained a concentration of approximately 365 mg/l by 10:35 p.m. on June 6, 2019. Similar patterns in chloride dynamics were observed with this event in other small streams, such as Site 9 Oak Creek where chloride decreased from 260 mg/l to 60 mg/l within four hours and rebounded to 265 mg/l after 11 hours, and at Site 45 Mukwonago River at Nature Road where chloride decreased from 18 mg/l to 9 mg/l after 7 hours and then rebounded to 18 mg/l after 24 hours. In contrast, some streams with larger watersheds, such as Site 11 Bark River Upstream, did not experience a notable increase in water levels or corresponding decline in estimated chloride concentrations from this small precipitation event.

Late on August 2, 2020, much of southeastern Wisconsin experienced heavy rainfall, with most of the study area receiving at least one inch of rainfall and localized pockets receiving significantly more, including Milwaukee receiving nearly five inches.[21] This rainfall event caused flash flooding in several areas and significantly elevated water levels at many of the Study monitoring stations. This substantial rainfall caused rapid declines in chloride concentrations in the smaller streams, such as Site 9 Oak Creek and Site 12 Lincoln

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[21] *National Weather Service Event Summary: Milwaukee County and SE Wisconsin Flooding,* "August 2, 2020: Southeast Wisconsin Flash Flooding and Heavy Rain Event," *www.weather.gov/mkx/MilwaukeeCountyFlooding, date accessed August 6, 2025.*

Creek, as were observed for the smaller precipitation events, but the chloride concentrations took longer to recover to its pre-event concentrations than smaller storm events (see Figure 3.11). This larger event also caused significant declines in estimated chloride concentrations in larger streams such as Site 2 Fox River at New Munster, which decreased from approximately 100 mg/l to 65 mg/l within two hours on August 2 and did not recover to its pre-event chloride concentration until midday of August 8. Site 58 Milwaukee River at Estabrook Park also experienced a delayed rebound in chloride concentrations for this rain event, which decreased from 70 mg/l to 52 mg/l after 3.5 days and then predominantly recovered almost 10 days after the initial precipitation event. Consequently, larger rainfall events can substantially decrease chloride concentrations in both small and large watersheds, but the dilution effects tend to last substantially longer for the larger watersheds compared to the smaller watersheds due to the extended contribution of runoff from the more remote reaches of the larger watersheds.

Drought

Although the extended monitoring period for the Study ended in February 2021, Commission staff retained several CTD-10 units in select streams across the study area throughout summer 2021. This specific conductance monitoring period from March 2021 to August 2021 was not supported by grab samples to measure chloride concentrations or periodic maintenance of the CTD-10 units. Throughout summer 2021, the study area experienced a prolonged drought that was punctuated by few rainfall events. As defined by the National Drought Information System, the entire study area was at least in Moderate (D1) Drought throughout June and July 2021 with much of Kenosha, Racine, and Walworth Counties experiencing Severe (D2) or Extreme (D3) Drought.[22]

During summer 2021, Commission staff noted that the specific conductance measurements continued to climb, particularly for streams within these Counties such as Site 2 Fox River at New Munster, Site 10 Pike River, Site 15 Kilbourn Road Ditch, Site 25 Root River Canal, and Site 30 Des Plaines River. These specific conductance measurements were notably higher than measurements at the same sites in the previous summers. Also, active sites not located in the southeastern portion of the study area did not exhibit a similar climb in conductance in summer 2021. At Site 25 and Site 30, these summer specific conductance measurements nearly met or exceeded the spikes following precipitation events the previous winter. These elevated drought conductance measurements likely represent groundwater chloride contributions to the stream, as the stream discharge during these drought conditions would predominantly be sourced from

[22] *National Integrated Drought Information System, U.S. Drought Monitor (2000 – Present), www.drought.gov/historical-information?state=wisconsin&dataset=0&selectedDateUSDM=20210622, accessed August 6, 2025.*

shallow groundwater. Stream chloride concentrations may also be slightly elevated above the source groundwater concentrations due to evaporation. However, specific conductance measurements may also be influenced by increases in calcium and magnesium concentrations from mineral-rich groundwater.

Propagation of Events Down River Systems

Several monitoring sites were located on the same stream, which enabled Commission staff to evaluate how high chloride concentration events propagated down these stream systems. The most evident example of this propagation occurred on the Fox River, which has a large urban area with significant seasonal chloride loads located upstream near its headwaters while the remainder of the watershed is more rural with less seasonal chloride loading (see Figure 3.12). This watershed configuration resulted in high winter chloride spikes that would travel downstream and could be detected at downstream monitoring sites.

Short-lived winter spikes in estimated chloride concentrations, representing a pulse of chloride-rich waters entering the stream, were originally observed at Site 1 Fox River at Waukesha; these spikes are likely the result of winter runoff from salts and deicers applied to roads, parking lots, and other impervious surfaces in the greater Waukesha urban area. In February 2019, a pulse of chloride-rich water moved downstream from Site 1 and was detected a few days later at Site 47 Fox River at Rochester. However, instead of the sharp spike observed at Site 1, the chloride concentrations were observed as a lower and longer peak in chloride concentrations at Site 47. This change in chloride signature likely occurred due to travel time and contributions from less chloride-rich waters, such as the Mukwonago River, diluting the overall concentrations in the stream. A few days after the February 2019 pulse passed through Site 47, a slight rise in chloride concentrations was observed at Site 2 Fox River at New Munster, which was the furthest downstream monitoring site on the Fox River. As observed between Site 1 and Site 47, the pulse had been stretched and diluted even further resulting in longer but lower chloride concentrations. At each Fox River site, the arrival of the chloride-rich waters approximately met the expected travel time of water based on stream velocities, the residence time of the Waterford impoundment, and the distances between the monitoring sites.

A similar pattern occurred in late January 2020, with an initial spike at Site 1 extending from January 23 to January 29. This spike was observed as a more stretched and diluted rise in estimated chloride concentrations at Site 47 a few days later followed by an even more muted increase at Site 2.

Other watersheds with Study monitoring sites in series along the same streams, such as the Bark, Milwaukee, Mukwonago, and Oconomowoc Rivers, did not display chloride concentration propagation events as clearly as the Fox River system for several reasons. Unlike the Fox River watershed, these other watersheds did not have an intense chloride source, such as large urban areas, near their headwaters generating pulses of chloride-rich waters that could be traced downstream. Additionally, the Bark, Mukwonago, and Oconomowoc Rivers all had large lakes with lengthy residence times located between the Study monitoring sites, which significantly delayed travel time of the water between the sites and resulted in any chloride spikes blending into the lake water and losing that signature spike in the time series data

Although the Root River watershed does have a substantial urban area in the northern part of its watershed, the significant chloride concentration spikes observed at Site 60 Root River at Grange Avenue could not be as clearly traced downstream to Site 59 Root River near Horlick Dam. This lack of distinction may be due to dilution of chloride pulses observed at Site 60 by waters contributed from the large rural areas of the watershed, such as those waters monitored at Site 25 Root River Canal. Additionally, the presence of urban areas near Site 59 may contribute to chloride concentration spikes and thus may interfere with observing chloride pulses from upstream areas on the Root River.

Seasonal Patterns

As detailed earlier in this Chapter, each monitored site in the Study exhibited fluctuations in estimated chloride concentrations in response to individual weather events. These responses were determined by both the season in which the event occurred (i.e., a rain event in winter may cause an increase in chloride concentrations while a rain event in summer may cause a decrease in concentrations) as well as the watershed characteristics for the site (e.g., the predominant land use and presence of chloride point sources). The summation of all the individual responses for each site result in seasonal patterns in chloride concentrations. Commission staff developed monthly boxplots of estimated chloride concentrations for the study period (October 2018 to October 2020) to illustrate the seasonal patterns at each site (see Appendix C).

Chloride concentration seasonal patterns in streams are largely dictated by the watershed land use for each site. Sites with highly urban watersheds, such as those in Groups 1 and 2 (Table 3.9), have higher concentrations in winter months (December through February) that are likely a reflection of increased loading from salts and deicers applied to roads, parking lots, driveways, and sidewalks in these urban areas. These chloride spikes as well as increased baseline concentrations result in higher winter chloride concentrations than observed during non-winter months, with the highest monthly median chloride concentrations typically occurring in January or February. In contrast, sites with largely rural watersheds, such as those in Groups 4 through 7, either exhibit small or no winter spikes in chloride concentration and generally do not have elevated baseline chloride concentrations in winter. Consequently, winter months at these sites did not have substantially higher chloride concentrations than non-winter months and for some sites the median winter month chloride concentrations were lower than other months.

Chloride patterns in spring months (March through May) varied significantly across the season and between monitoring sites. As these months are among the wettest in southeastern Wisconsin, the chloride dynamics at each site were largely driven by responses to the frequent precipitation events and winter salting patterns. At sites with significantly higher winter chloride concentrations, concentrations in March often remained elevated, which may reflect continued runoff of salt applied in response to winter precipitation events. These concentrations decreased throughout spring as successive precipitation events removed and diluted chloride sources on the landscape. At sites without significant winter salting activity, spring months often had the lowest median chloride concentrations as the frequent rainfall events diluted chloride contributions from groundwater or other sources. These more rural sites did not exhibit a substantial change in chloride dynamics throughout the spring season.

With a decrease in the frequency of precipitation events and an increase in evapotranspiration, summer months (June through August), and particularly late summer, are among the lowest streamflow months for many streams in southeastern Wisconsin. During these dry periods, groundwater contributions can constitute most of the streamflow and the stream chemistry reflects local groundwater conditions. Sites 11, 14, 16, 20, 23, 33, and 52, experienced their highest median monthly chloride concentrations during summer months. Most of these sites have watersheds with predominantly rural land use and consequently did not exhibit high chloride concentrations during winter. The increased chloride concentrations during summer may reflect substantial chloride contributions from groundwater that were concentrated with lower streamflow and greater evaporation. When rainfall does occur, nearly every site listed above would experience fairly sharp declines in chloride concentrations with dilution from runoff. Aside from these rainfall-driven declines, summer typically had the most consistent chloride concentrations of any season at most Study monitoring sites.

Like spring, fall months (September through November) varied significantly across the season and between Study monitoring sites (see Appendix C). For most sites, chloride dynamics in September and October behaved similarly to summer months, with increased chloride concentrations during dry periods punctuated by sharp declines with rainfall. During the study period (October 2018 to October 2020), there were several November snow events that influenced the stream chloride dynamics. Some monitoring sites, particularly those in Groups 1 through 3, exhibited increased chloride concentrations during and following these events, likely in response to salting activity preceding the event. At most rural sites there was not a similar increase in chloride concentrations and the chloride dynamics were similar to the preceding summer and fall months.

Stream Discharge

Chloride concentrations, like many other pollutants, are influenced by the streamflow (i.e., volume of water per unit of time, predominantly recorded as cfs) within a stream or river. Given the same amount of chloride, higher streamflow would result in lower concentrations (i.e., a dilution) while lower streamflow would result in higher concentrations. Understanding patterns in streamflow is therefore important for interpreting patterns in chloride concentrations. In southeastern Wisconsin, streamflow is typically highest in late winter through mid-spring following snowmelt and rainfall events, particularly when the ground is saturated or still frozen. Streamflow often declines in late spring through summer as precipitation decreases and evapotranspiration increases with warming temperatures. Much of the streamflow in summer may be from groundwater contributions or from other non-precipitation-driven sources, such as wastewater treatment effluent. As temperatures decline and deciduous vegetation senesces throughout fall and early winter, the evapotranspiration demand reduces and streamflows increase.

Precipitation events can have significant impacts on chloride concentrations in streams either by increasing chloride loading to streams through runoff or by diluting or concentrating in-stream chloride concentrations. In summer, when there is little chloride on the ground that could be carried into streams via surface runoff, precipitation events tend to cause dilution of chloride concentrations as streamflow increases. In winter and spring, when chloride loading from surface runoff is higher, precipitation events can cause an initial increase in chloride concentrations (a "first flush") before the increase in streamflow results in a slight dilution of concentrations. Consequently, the peak chloride concentration in a stream chloride time series often occurs before the peak streamflow for winter and spring chloride loading events.

Due to the inherent relationship between chloride concentrations and streamflow, smaller streams are more susceptible to exceeding concentration-based water quality standards than larger streams as exceedance requires a smaller amount of chloride. Small, flashy streams, which are those where the streamflow quickly rises and falls following a precipitation event, may be among the most susceptible to chloride water quality standard exceedances as these streams often exhibit strong "first flush" effects that can cause short but significant increases in concentrations before a rapid dilution. Small streams with watersheds comprised of steep gradients and/or impervious surfaces are more likely to be flashy as the precipitation falling across the watershed will reach the stream more quickly than a low-gradient watershed with predominantly pervious land surfaces.

The continuous water level measurements collected during the Study were not reliable enough to develop streamflow estimates. As described in the forthcoming Technical Report No. 65, streamflow data collected by USGS was utilized to estimate in-stream chloride loads for Study monitoring sites located near USGS streamflow gages.

Land Use

Figure 3.13 shows relationships between mean chloride concentration and land use in the upstream drainage areas at the 40 stream monitoring sites for the study period (October 2018 to October 2020). Chloride concentrations at the Study sites were estimated from continuously monitored specific conductance using regression models developed from paired specific conductance-chloride data collected at these sites.[23] Figure 3.14 shows relationships between maximum chloride concentration and land use in upstream drainage areas at the same sites. These figures examine relationships between chloride and three categories of land use: urban land use, roads and parking lots, and agricultural land use. These land use characteristics for the monitoring sites are given in Table 3.2. Note that the y-axes on these graphs have logarithmic scales.

Both mean and maximum in-stream chloride concentration rapidly increase with increasing percentage of urban land use in the contributing drainage area for Study monitoring sites (see Figure 3.13 and 3.14). This strong correlation reflects the fact that the amount of impervious surface tends to increase with increasing amounts of urban development. This leads to greater amounts of runoff entering waterbodies. In addition, highly urbanized areas tend to be served by municipal separate storm sewer systems which deliver runoff to receiving waters relatively rapidly. While these systems include best management practices (BMPs) to remove pollutants from runoff, such treatments do not remove chloride due to its high solubility in water. Finally, many urban areas are also served by wastewater treatment plants (WWTPs) that discharge chloride into receiving waters. The potential impacts of WWTPs on receiving waters are discussed later in this Chapter.

Mean and maximum in-stream chloride concentration rapidly increase with increasing percentage of drainage area devoted to roads and parking lots (see Figures 3.13 and 3.14). These relationships are almost as strong as the relationships between the percentage of urban land use in the drainage area and mean and maximum in-stream chloride concentrations. This likely reflects the fact that much of the impervious surface within urban areas consists of roads and parking lots. In addition, roads and parking lots are the

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

main areas that are treated with deicing salts during and following winter weather events. This suggests that deicing activities may be the major factor driving these relationships.

Figures 3.13 and 3.14 also show the relationships between estimated mean and maximum chloride concentration and the percentage of contributing drainage area devoted to agricultural land uses. Mean and maximum in-stream chloride concentrations decrease with increasing percentages agricultural land uses. Greater variability is associated agricultural land use than with the relationships between chloride concentration and urban land use and roads and parking lots. The higher variability likely reflects differences in the other types of land use present in each drainage area. The decreasing relationships between agricultural land use and mean and maximum chloride concentration suggests that the use of predominantly potash fertilizers, which consist mostly of potassium chloride, may not have as large an influence on overall in-stream concentrations or chloride in southeastern Wisconsin as the use of deicing salts or WWTPs. This does not rule out the possibility that potash fertilizer use might have greater influence during certain times of the year.

Wastewater Treatment Plant Effluent

Wastewater treatment plants (WWTPs) are one example of a point source that may contribute chloride to the environment. Wastewater entering the plant can contain chloride from water softening, food preparation, household cleaning products, and human excreta. Standard wastewater treatment technology does not remove chloride from water, so chloride present in wastewater will be present in effluent discharged from the plant. When WWTP effluent is discharged into surface waters, the chloride it contains may affect the concentration of chloride in the receiving stream. This section examines impacts of WWTP discharges at two locations in southeastern Wisconsin.

Honey Creek near East Troy

The impact of one WWTP on its receiving waterbody was examined using data from two Chloride Impact Study continuous monitoring sites. Sites 35 Honey Creek Upstream of East Troy and 36 Honey Creek Downstream of East Troy bracket the Village of East Troy and its WWTP (see Map 3.1). The monitoring sites were about four river miles apart from one another, with the East Troy WWTP about midway between them. Between the two monitoring sites, Honey Creek is a fourth order stream. Table 3.12 shows estimated flows in Honey Creek at the two monitoring sites for several exceedance levels.[24] In any exceedance level, estimated flows at the downstream site are about 18 to 21 percent higher than those at the upstream site. According to discharge monitoring data from the WDNR, the East Troy WWTP treated an average of 0.429 million gallons per day (mgd) of wastewater between October 2018 and October 2020. This constitutes about 7 percent of the estimated 90 percent exceedance flows and about 3 percent of the estimated 50 percent exceedance (median) flows for the two Honey Creek monitoring sites.

Figure 3.15 shows monthly estimated mean chloride concentrations in Honey Creek at the two monitoring stations during the monitoring period of October 2018 through October 2020. On average, the monthly mean chloride concentration at the downstream station (Site 36) was 13.0 mg/l higher than that at the upstream station (Site 35). While the difference between the two sites in average chloride concentration varied slightly among months, it remained fairly consistent throughout the year. Similar relationships were observed for the differences between other statistics at the Honey Creek sites, with the average monthly minimum and median concentrations at the downstream site being 13.1 mg/l higher and the average monthly maximum concentrations at the downstream site being 13.7 mg/l higher than those at the upstream site.

Examination of concentrations of other ions in Honey Creek during the Study period suggests that much of the increase in chloride concentration is due to inputs of sodium chloride. The mean concentration of sodium at the downstream site was 8.2 mg/l higher than that at the upstream site (see Table B.1 in Appendix B).The ratio of the increase in average chloride concentration to the increase in average sodium concentration was 1.57. This is very close to the ratio of chloride to sodium in NaCl of 1.54. In addition, the average difference in the concentration of potassium between the upstream and downstream sites was only 0.03 mg/l (see Table B.2 in Appendix B). This suggests that potash fertilizers were not a major source of the increase in chloride concentration between the two sites. While the concentrations of calcium and magnesium both increased slightly between the two sites (see Tables B.3 and 3.4 in Appendix B), these increases were not sufficient to account for the increase in chloride concentration observed between Site 35 and Site 36.

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[24] *The 90 percent, 50 percent, and 10 percent exceedance flows represent low-flow, average-flow, and high-flow conditions in the stream, respectively. Values of these flows at the two monitoring sites were estimated by a model developed by the WDNR to classify stream reaches into their biotic community by fish occurrence and abundance and constitutes a general estimate of stream size. For a description of the model see J. Lyons,* An Overview of the Wisconsin Stream Model, *Wisconsin Department of Natural Resources, 2007.*

According to data submitted by the plant operator to the WDNR, the average concentration of chloride in effluent discharged from the East Troy WWTP during the period October 2018 through October 2020 was 436 mg/l. Based on the average volume of water treated during this period of 0.429 mgd, this suggests that the plant discharged an average of about 1,560 pounds (lb) of chloride per day into Honey Creek. Whether this amount of chloride is enough to account for the increase in concentration between the two sites depends upon the amount of flow in the stream.

Table 3.13 shows estimated amounts of chloride that would be required to increase the chloride concentration in Honey Creek between the two monitoring stations by 13 mg/l at different flow levels. Between the 50-percent and 25-percent exceedance flow levels, the average amount of chloride discharged from the East Troy WWTP fully accounts for the average increase in chloride concentration between the two monitoring stations. At lower flows such as the 95- and 90-percent exceedance flows, the average amount of chloride discharged by the WWTP would be greater than the amount required to raise stream levels 13 mg/l. At flows higher than the 25-percent exceedance level, chloride from additional sources would be needed to account for the mean monthly increase in chloride concentrations observed between the two monitoring stations.

These data suggest that effluent discharged from the Village of East Troy WWTP is raising chloride concentrations in Honey Creek. The persistence and relative stability of the concentration difference between the upstream and downstream sites throughout the year (see Figure 3.15) indicates that much of the chloride entering the stream between these two stations is contributed continuously rather than seasonally. This suggests that a continuous discharge, such as a WWTP, is a major source of chloride entering the stream between Site 35 and Site 36 on Honey Creek.

It is likely that there are other sources that contribute chloride to Honey Creek between these two stations. Closer examination of Figure 3.15 shows that the difference in mean monthly concentration of chloride between the two monitoring stations is slightly higher during the months of November through March when road deicing is likely to occur than during the months of April through October when deicing activities are less likely. The mean monthly chloride concentration at the downstream site (Site 36) is 13.7 mg/l higher than that at the upstream site (Site 35) during the months when deicing is likely to occur. The mean chloride concentration at Site 36 during months when deicing is not likely to occur was 12.6 mg/l higher than that at Site 35. This seasonal difference suggests that deicing activities are also contributing to the increase in average monthly chloride concentration between the two sites. It is likely that the impacts of contributions of chloride from road deicing and other intermittent sources in this section of Honey Creek would be more apparent in an examination of in-stream chloride dynamics that focused on shorter time scales.

It should be noted that this discussion has several limitations. The analysis is based on monthly averages and averages over a 25-month period. This level of analysis can obscure the details of dynamics in chloride concentrations within the stream that occur at shorter time scales, such as concentration fluctuations during a winter storm or snowmelt. This analysis also provides an example of one specific situation. While point sources may have an impact on in-stream chloride concentrations at other locations, the magnitudes of such impacts will depend on several factors including the magnitude of discharge and concentration of chloride in the stream, the amount of effluent discharged by the point source, the concentration of chloride in the effluent, and the types of land use in the drainage area to the stream. Also, the exceedance flow levels shown in Table 3.12 are estimates generated by an uncalibrated model. The analysis in this section is also limited to the impacts on chloride concentration dynamics between the two monitoring stations. Despite these limitations, this analysis provides an example of the impact that a WWTP point source can have on chloride concentrations in a stream.

Fox River at Waukesha

Depending on flow conditions within a stream receiving discharge from a point source, the effects on in-stream chloride concentrations could adversely impact organisms in the stream. The comparison of stream discharge in the Fox River at the USGS stream gage at Waukesha (Site 1) to the combined discharge from the Sussex and Brookfield WWTPs as shown in Figure 3.16 illustrates this potential.[25] For the stream gage, the data were disaggregated into months and the flow values of the 10th percentile, 25th percentile, 50th percentile, 75th percentile, and 90th percentile ranks were determined for each month's data.[26] Flow data from 1963 to 2023 for this USGS stream gage was used for these calculations. These percentile ranks were plotted by month as shown in Figure 3.16. These monthly flow percentiles were compared to the combined average monthly flow from the two WWTPs upstream from the gage. Mean daily streamflow at the Waukesha stream gage over its period of record was about 75 mgd.

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[25] *A map for the Fox River stream gage and upstream WWTPs locations can be found in Map B.2 of SEWRPC TR-61,* op. cit.

[26] *A percentile rank is a percentage of values which are lower than a given value. For example, the 10th percentile represents the upper boundary of the lowest 10 percent of the data. The interpretation of this statistic is that on 10 percent of the dates in this month during the period of record, average daily discharge at this gage was less than or equal to this value. Similarly, the 90th percentile represents the lowest 90 percent of the data and is interpreted in a similar manner.*

The 50th percentile line shown in Figure 3.16 represents monthly median daily flows and describes average discharge at the stream gage. The lowest monthly median daily flows at the gage at Waukesha is 28.4 mgd and occurs during the months of August and September. The highest monthly median daily flow at the gage is 106 mgd and occurs during the month of April. The lowest percentile flows at the gage typically occur during the late summer or early fall. Discharge increases relatively slowly over the fall and winter. In early spring, stream flows increase rapidly as a result of snowmelt and spring rains, with the highest flows typically occurring during April. Following this, flow decreases over late spring and summer until late summer or early fall.

Two publicly owned WWTPs, the Brookfield and Sussex plants, discharge to the Fox River or its tributaries upstream from the gage at Waukesha. On average, these facilities contributed 11.0 mgd of treated effluent to the Fox River during the period 1999 through 2023. When computed on a monthly basis, the highest combined mean monthly discharge was 14.1 mgd and occurred during April. The lowest combined mean monthly discharge from the WWTPs was 9.4 mgd and occurred during November.

Figure 3.16 compares percentile ranks of flows at the gage at Waukesha to the average daily discharges from the WWTPs upstream from the gage on a monthly basis. At lower percentile rank discharges, treated wastewater treatment plant effluent may comprise a higher percentage of flow at this stream gage site. This is especially the case during summer and fall when flows in the river tend to be lower than during other times of the year. At the 10th percentile flows in the Fox River, treated effluent discharged from the WWTPs upstream from the gage may represent over 80 percent or more of the flow during July through September. This indicates that during these months, treated effluent may represent more than 80 percent of the flow at the gage about 10 percent of the time. In addition, at the 10th percentile effluent from the WWTPs represent nearly 80 percent of flow during October. The values indicated above concerning the amount of WWTP effluent discharge as a percent of streamflow are conservatively high as they assume the treated effluent additions are cumulative and conservative in the river. This is not the case, in part, because of flow interaction between the river and groundwater as well as flow additions or subtractions from large stone quarries located in the Waukesha and Sussex-Lannon-Lisbon areas.

The comparisons provided in Figure 3.16 suggest that treated WWTP effluent may constitute a major component of baseflow to the Fox River in the study area, especially in upstream reaches. In the summer and fall during periods when flow is at or below the 10th percentile, treated effluent from the WWTPs upstream from the Waukesha gage may account for most the flow reported at the gage. Treated effluent likely represents an even larger fraction of flow in much of the Fox River upstream from the Waukesha gage.

Several tributary streams join the Fox River between the points at which the two WWTP effluents enters the river and the Waukesha gage.[27] For example, Poplar Creek joins the Fox River downstream of the Sussex WWTP and the Pewaukee River and Frame Park Creek join the river downstream of both plants. Given that no other major known point sources discharge into these streams, the water they add to the Fox River will tend to dilute the chloride contributed by the two WWTPs.

The average chloride concentration in effluent from the Brookfield and Sussex WWTPs during the period October 2018 through October 2020 was 492 mg/l and 423 mg/l, respectively. The average concentration of chloride in WWTP effluent entering the Fox River upstream of the Waukesha gage during that period, weighted by the volume of effluent discharged by each plant, was 479 mg/l.

Summary of Honey Creek and Fox River WWTP review

The analysis in the preceding paragraphs suggests that late summer and early fall during dry periods may be critical times for aquatic organisms in streams receiving chloride-containing discharges from point sources. Such discharges could potentially increase in-stream chloride concentrations to levels that could be stressful or harmful to aquatic organisms. This may be a concern despite the fact that effluent limitations in discharge permits are set to ensure that in-stream water quality meets water quality criteria. As of January 2024, 14 WWTPs in southeastern Wisconsin, including the Brookfield and Sussex WWTPs, were operating under water quality standards variances for chloride. While these variances require that the plants reduce chloride concentrations in their discharge, they temporarily allow them to discharge chloride at concentrations that may lead to some exceedances of water quality criteria. Also, the current Wisconsin water quality criteria for chloride may not be fully protective of aquatic communities.[28]

This WWTP analysis has some limitations. It does not account for any potential losses of chloride from the Fox River and Spring Creek between the WWTPs and the gage at Waukesha. Such losses could occur due to water moving from the waterbody into groundwater. Also this analysis is based on monthly statistics. This level of analysis can obscure the details and timing of dynamics in chloride concentrations within the stream that occur at shorter time scales, such as concentration fluctuations during precipitation events.

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[27] *The Sussex WWTP discharges into Spring Creek which joins the Fox River upstream of W. Capitol Drive in the City of Brookfield. The Brookfield WWTP discharges into the Fox River downstream from N. Barker Road in the City of Brookfield.*

[28] *See the discussion in Chapter 2 of this report.*

Implications for Other Sites

The Honey Creek example shows that discharges of chloride from point sources can raise in-stream chloride concentrations. The Fox River example shows that such discharges could potentially raise in-stream chloride concentrations to levels that could cause adverse impacts to aquatic organisms. These examples show potential effects of point source discharges on in-stream chloride concentrations.

The effects of a point source discharge on chloride concentrations and impacts in a stream are likely to depend on the details of the individual situation. These details include 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 are delivering chloride into the receiving stream. Higher amounts of effluent discharged with higher chloride concentrations will result in greater impacts on the receiving stream. Lower in-stream flows will also lead to greater impacts. Since streamflow tends to vary both seasonally and from year to year, this could lead to the occurrence of periods when in-stream chloride concentrations exceed standards or are high enough to impact biota. Finally, the in-stream concentrations of chloride and its impacts on in-stream conditions point to the cumulative effects of all sources to the stream. The impact of discharges from an individual point source depends on the number and magnitude of chloride contributions from other sources.

Examining Concentration-Durations Using Continuous Estimated Chloride

The Study stream monitoring data was analyzed by evaluating the duration of events during which each site contiguously exceeded specific chloride concentration thresholds. The concentration-durations were examined using chloride concentrations estimated from specific conductance. Seven chloride concentrations were selected to use as thresholds as discussed in Table 2.ChlorideThresholds for Analysis:

- 10 mg/l: This concentration, which is based on observations in the early 1900s, represents a surface water baseline level of chloride for inland freshwater bodies that are unimpacted by human influences.[29]

- 35 mg/l: This concentration is the lowest to negatively affect freshwater life among several trophic levels, including impacts to diatoms, fish, mussels, and zooplankton.[30]

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[29] *See references in Table 1 of W.D. Hintz and R.A. Relyea, "A Review of the Species, Community, and Ecosystem Impacts of Road Salt Salinization in Freshwater,"* Freshwater Biology, *64:1,081-1,097, 2019.*

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

- 120 mg/l: This concentration is the Canadian chronic chloride toxicity threshold, which is based on seven day exposure for fish and macroinvertebrates.[31]

- 230 mg/l: This concentration is the U.S. Environmental Protection Agency (USEPA) chronic toxicity threshold for chloride, which is based on a four-day average concentration.[32]

- 395 mg/l: This concentration is the Wisconsin chronic toxicity criterion for chloride for fish and aquatic life based on a four-day average of the daily maximum concentrations.[33]

- 757 mg/l: This concentration is the Wisconsin acute toxicity criterion for chloride for fish and aquatic life based on a daily maximum concentration.[34]

- 1,400 mg/l: This concentration was chosen to represent chloride concentration at a severe level of impact.[35]

The continuous estimated chloride values were examined to remove potential spurious event durations, which included gaps in the data record. When the in-stream chloride concentration was above the concentration threshold at the beginning of a data gap, the record was trimmed back to when in-stream concentration was below the threshold. Similarly, when in-stream chloride concentration was above the concentration threshold at the end of a data gap, the data record was trimmed forward to when the in-stream concentration dropped below the concentration threshold. The review and adjustment of the data and subsequent calculations were done using scripts written in the R programing language.[36]

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[31] *Canadian Council of Minsters of the Environment,* Canadian Water Quality Guidelines for the Protection of Aquatic Life: Chloride, *2011.*

[32] *U.S. Environmental Protection Agency*, Ambient Water Quality for Chloride – 1988, EPA 440/5-88-01*, 1988.*

[33] *Wisconsin Department of Natural Resources,* Wisconsin Consolidated Assessment and Listing Methodology (WisCALM): 2024*, Guidance No. 3200-2023-04, April 10, 2023.*

[34] Ibid*.*

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

[36] *R Core Team,* R: A Language and Environment for Statistical Computing*, R Foundation for Statistical Computing, cran.r-project.org.*

For each threshold concentration, the time course record was reviewed to identify events and their durations. Figure 3.17 shows a hypothetical portion of a time course record with three events exceeding a threshold. An event begins when in-stream chloride concentration equals or exceeds the threshold concentration. It ends when in-stream chloride concentration drops below the threshold concentration. Three events and their durations are shown in the figure. The durations are indicated as D_1, D_2, and D_3. The R script created a list of durations of each event in which chloride concentration exceeded the chosen threshold value. This list was ranked by event duration, with the longest event ranked 1.

Comparison of In-stream Chloride Concentrations to Concentration Thresholds

Table 3.14 shows for each monitoring site the percentage of chloride concentrations estimated from specific conductance that exceeded the concentration thresholds discussed previously, while Table 3.15 represents the total time duration for those exceedances. Table 3.16 shows for each monitoring location the length of the longest period during which chloride concentration exceeded each threshold. Together, these tables give a sense of in-stream chloride dynamics at each of the monitoring stations. No data is presented for Site 55 Bark River Downstream because a regression relationship for estimating chloride concentration from specific conductance could not be developed for this site.[37]

<u>Exceedances of the 10 mg/l Threshold</u>

Estimated chloride concentrations at all the monitoring stations were higher than 10 mg/l for the vast majority of the Study period, with the percentage of measurements exceeding 10 mg/l ranging between 91 percent and almost 100 percent (see Table 3.14). At all sites, estimated chloride concentrations stayed above 10 mg/l for extended periods (see Table 3.16). It is notable that these periods were relatively short at some highly impacted sites such as Site 12 Lincoln Creek and Site 53 Honey Creek at Wauwatosa. This likely reflects the flashiness of these individual streams. In a flashy stream, discharge can increase rapidly during storm events. If chloride salts are not present on the land surface during the storm, water entering the stream from runoff and precipitation can dilute chloride in the stream, markedly lowering its concentration. During many storm events, discharge levels decrease relatively rapidly and chloride concentration rebounds to near its previous level. As a result, the periods during which chloride concentrations in a flashy stream may be below 10 mg/l is likely to be short. Thus, even though average concentrations of chloride are quite high at highly impacted sites such as Site 12 Lincoln Creek and Site 53 Honey Creek at Wauwatosa (see Table 3.7), the length of time during which concentrations stay above 10 mg/l can be shorter than that in a less-impacted stream.

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

Exceedances of the 35 mg/l Threshold

At most stream monitoring sites, estimated chloride concentration was higher than 35 mg/l most of the time, with the percentage of measurements exceeding 35 mg/l ranging between 0 percent and 100.0 percent (see Table 3.14) Chloride concentrations did not exceed this threshold at two sites during the Study monitoring period, Site 21 East Branch Milwaukee River and Site 54 Whitewater Creek. In addition, estimated chloride concentrations at Site 45 Mukwonago River at Nature Road exceeded 35 mg/l very rarely, with less than 0.1 percent of measurements exceeding this threshold.

The percentage of samples at Sites 35 Honey Creek Upstream of East Troy and 36 Honey Creek Downstream of East Troy in which chloride concentration is greater than 35 mg/l present an interesting contrast between the two sites. Estimated chloride concentrations exceed 35 mg/l for 51 percent of the dataset at the upstream site but almost 99 percent at the downstream site (see Table 3.14). In addition, the longest period over which chloride concentrations exceed 35 mg/l at the downstream site is almost six times the length of that at the upstream site (see Table 3.16). The two sites are about four river miles apart from one another and the East Troy WWTP discharges into Honey Creek about midway between them. This suggests, as was discussed previously, that discharges from the East Troy WWTP may act to increase concentrations of chloride in Honey Creek.

Exceedances of the 120 mg/l Threshold

The percentage of time the Study sites had estimated chloride concentrations greater than 120 mg/l ranged from 0 percent to about 93 percent (see Table 3.14). Concentrations at 16 sites did not exceed this threshold during the monitoring period. Twenty-two sites exceeded this threshold for seven consecutive days at least once, which is the period that the Canadian 120 mg/l toxicity threshold is based on (see Table 3.16). The longest continuous exceedance of this threshold was 169 consecutive days at Site 2 Fox River at New Munster, a large river with a predominantly rural watershed. This exceedance began in September 2020 and continued through the remainder of the extended study period, which ended in February 2021.[38] The second longest exceedance of this threshold was approximately 115 days between December 2020 and April 2021 at Site 60 Root River at Grange Avenue, a small stream with a highly urban watershed. In general, chloride concentrations at sites with more urban land use in their drainage areas tended to exceed 120 mg/l more often than did concentrations at sites with more rural land use.

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[38] *Although not supported by chloride grab samples or maintenance, Site 2 Fox River at New Munster continued to collect specific conductance data until September 2021. Based on this data, the continued exceedance above 120 mg/l beginning in September 2020 appears to have continued until May 2021.*

Exceedances of the 230 mg/l Threshold

The percentage of time in which estimated chloride concentrations were greater than 230 mg/l ranged from 0 percent to about 83 percent (see Table 3.14). Estimated concentrations at 20 sites did not exceed this threshold during the monitoring period. Fifteen sites exceeded this threshold for four consecutive days at least once, which is the period that the USEPA chronic chloride toxicity threshold is based on. The longest continual exceedance was approximately 97 days between December 2020 and February 2021 at Site 60 Root River at Grange Avenue (see Table 3.16). The second longest exceedance was approximately 76 days at Site 57 Menomonee River at Wauwatosa, which also occurred between December 2020 and February 2021.

At five sites, estimated chloride concentrations were higher than 230 mg/l more than 50 percent of the time. These five sites all had highly urbanized drainage areas, with the percentage of urban land use ranging from about 72 percent to about 98 percent (see Table 3.2). At two other sites, estimated chloride concentrations were higher than 230 mg/l more than 25 percent of the study period. The percentage of urban land use in their drainage areas ranged between 54 and 67 percent. Lower percentages of urban land use correspond with the remaining sites with low exceedances of 230 mg/l.

It should be noted that the low percentage of estimated chloride concentrations exceeding 230 mg/l can be misleading as to the number of times this threshold was exceeded. For example, chloride concentrations at Site 25 Root River Canal were higher than 230 mg/l about 1.2 percent of the dataset. Given that over 244,000 specific conductance measurements were taken at this monitoring station, this means that estimated chloride concentrations at this site exceeded 230 mg/l for a total of over 240 hours during the 29-month monitoring period. Similarly, the 0.4 percent exceedance rate at Site 51 Rubicon River translates to a total of about 80 hours that estimated chloride concentrations at this site exceeded 230 mg/l over a 28-month monitoring period.

Exceedances of the 395 mg/l Threshold

The percentage of the dataset in which estimated chloride concentrations were greater than 395 mg/l ranged from 0 percent to about 48 percent (see Table 3.14). Estimated concentrations at 26 sites did not exceed this threshold during the monitoring period. Ten sites exceeded this threshold for four consecutive days at least once, which is the period that the WDNR chronic toxicity threshold is based on. As with the 230 mg/l threshold, the site with the longest continued exceedance of this threshold was Site 60 Root River at Grange Avenue, which had an approximately 68 day exceedance between late December 2020 and

February 2021. Site 53 Honey Creek at Wauwatosa had the second-longest continual exceedance of approximately 61 days during the same time period.

At six sites, estimated chloride concentrations were higher than 395 mg/l in more than 15 percent of the dataset. These six sites all had highly urbanized drainage areas, with the percentage of urban land use ranging from about 67 percent to about 98 percent (see Table 3.2). In addition, chloride concentrations above 395 mg/l at these six sites occasionally persisted for extended periods of time. The maximum length of time during the study period at which chloride concentrations at the highly urban sites stayed above this threshold ranged between 33 and 68 days (see Table 3.16).

Exceedances of the 757 mg/l Threshold

Estimated chloride concentrations were greater than 757 mg/l ranged from 0 percent to about 16 percent of the dataset (see Table 3.14). Concentrations at 31 sites did not exceed this threshold during the monitoring period. At six sites, estimated chloride concentrations were higher than 757 mg/l in more than 5 percent of the dataset. With two exceptions, all the sites at which some chloride concentrations exceeded this threshold had highly urbanized drainage areas (see Table 3.2). One exception occurred at Site 15 Kilbourn Road Ditch (12.3 percent urban). Two factors likely explain this. First, there has been considerable development in the drainage area to this site since the land use inventory in 2015. Thus, the percentages of urban land use and roads and parking lots given in Table 3.2 underestimate the amounts of these land use categories in the drainage area during the monitoring period. Second, a drainage ditch that carries runoff from IH-94 enters Kilbourn Road Ditch near the monitoring site. At times, this introduces chloride laden water from deicing activities into this stream. Site 13 Ulao Creek was the other less urban site (32.5 percent urban) with exceedances of this threshold. Salt-laden water in runoff from commercial development and from IH-43 likely introduce chloride into this stream and its tributaries.

Exceedances of the 1,400 mg/l Threshold

Estimated chloride concentrations greater than 1,400 mg/l ranged from 0 percent to over 6 percent of the monitoring period for the sites (see Table 3.14). Estimated concentrations at 33 sites did not exceed this threshold during the monitoring period. With one exception, all the sites at which estimated chloride concentrations exceeded this threshold had highly urbanized drainage areas (see Table 3.2). Possible explanations for why chloride concentrations at Site 15 Kilbourn Road Ditch were occasionally higher than 1,400 mg/l were discussed in the section on exceedances of the 757 mg/l threshold. The site with the longest continued exceedance of this threshold was Site 12 Lincoln Creek, which had an approximately 9 day exceedance in February 2021.

Estimated Water Quality Criteria Exceedance at Stream Monitoring Sites

Wisconsin has promulgated two surface water quality criteria for chloride. According to the acute criterion for fish and aquatic life the daily maximum concentration of chloride is not to exceed 757 mg/l more than once over a three-year period. Similarly, according to the chronic criterion for fish and aquatic life the four-day average of daily maximum concentrations of chloride is not to exceed 395 mg/l more than once over a three-year period. Waterbodies that exceed either of these criteria are considered to be impaired under Section 303(d) of the Federal Clean Water Act (CWA) and are entered onto a list that the State must submit to the U.S. Environmental Protection Agency (USEPA) in even-numbered years. This list is known as the Impaired Waters List or the 303(d) list. These water quality standards are discussed in greater detail in Chapter 2 of this report.

Monitoring data collected by Commission staff for the Study were examined to identify potentially impaired waterbodies. The results of this examination were compared to the 2024 Impaired Waters List (see Table 2.8) to see how sampling results compared to the listing determinations made by the WDNR.

In general, the impairment status suggested by data collected for the Study agreed with the listing determinations made by the WDNR. Study data suggested that an impairment for chronic toxicity was present at each of the monitored stream reaches in southeastern Wisconsin that are currently listed as being impaired for chronic toxicity due to chloride (compare Table 2.8 to Table 3.16). Chloride concentrations estimated from continuous monitoring of specific conductance suggested that 10 streams or stream reaches might be impaired for chronic toxicity due to chloride (see Table 3.16). All but one of these streams are listed on the 2024 Impaired Waters List for that impairment. In addition, supplemental water quality sampling conducted in the headwaters of the Ulao Creek watershed as part of the Study suggested that the Gateway Drive Tributary to Ulao Creek (Site 74) may also be impaired for chronic toxicity due to chloride (see Table 3.17). This stream is currently listed for this impairment.

Study data also suggested that an impairment for acute toxicity was present at each of the monitored stream reaches in southeastern Wisconsin that are currently listed as being impaired for acute toxicity due to chloride (compare Table 2.8 to Table 3.14). Continuous monitoring data suggested that nine monitored streams or stream reaches might be impaired for acute toxicity due to chloride (see Table 3.14). All but two of these streams are included in the 2024 Impaired Waters List for this impairment (Fox River at Waukesha, Kilbourn Road Ditch). Supplemental water quality sampling also showed that the Gateway Drive Tributary to Ulao Creek may also be impaired for acute toxicity due to chloride. This stream is not currently listed for this impairment.

Additional Potential Impairments Suggested by Study Data

Study data suggested that additional impairments due to chloride might be present in four streams in southeastern Wisconsin. It is suggested that the WDNR evaluate these data and the impairment status of these streams during the 2026 assessment and listing cycle.

<u>Site 1 Fox River at Waukesha</u>

The Fox River is not currently listed as having any impairments due to chloride (see Table 2.8). Chloride concentrations estimated from specific conductance indicate that the maximum concentration of chloride at this site during the study period was about 852 mg/l (see Table 3.7). In addition, there were 17 events during the 29 months of monitoring during which the concentration of chloride at this site was greater than the water quality criterion of 757 mg/l. The longest duration event lasted about one-half hour. Despite this, chloride concentrations in the 29 water samples collected from this site were below the acute criterion (see Table 3.17). Nevertheless, the data suggest that this section of the Fox River may be impaired due to acute toxicity from chloride.

It is less certain whether an impairment related to chronic toxicity due to chloride may be present at this site. About 2.7 percent of chloride concentrations estimated from measurements of specific conductance at this site were higher than 395 mg/l (see Table 3.14). This is supported by the fact that chloride concentrations in four out of 29 water samples collected at this site during the study period were higher than 395 mg/l (see Table 3.17). Despite this, the longest period over which chloride remained above 395 mg/l was about 3.5 days (see Table 3.16). The criterion indicated that an impairment is present when the average of the daily maximum chloride concentrations over a four-day period are greater than 395 mg/l. WDNR listing guidance notes that the minimum data needed to make a determination is two samples and that a chronic toxicity determination can be made for a waterbody if a single data point is available over a four-day period.[39] Given these considerations, an impairment for chronic toxicity due to chloride might be present in this reach of the Fox River.

<u>Site 15 Kilbourn Road Ditch</u>

Kilbourn Road Ditch is currently listed as impaired for chronic toxicity due to chloride and is not listed for acute toxicity due to chloride (see Table 2.8). Chloride concentrations estimated from specific conductance indicate that chloride concentration was above 757 mg/l in about 0.5 percent of the measurements taken during the study period. The longest period over which the maximum concentration of chloride at this site

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[39] *WDNR WisCALM, 2023,* op. cit.

exceeded this criterion during the study period was 4.3 days (see Table 3.16). In addition, the maximum concentration of chloride at site was 2,156 mg/l (see Table 3.7). These data are supported by the fact that chloride concentration was higher than 757 mg/l in four out of 33 water quality samples collected at this site during the study period (see Table 3.17). These data suggest that Kilbourn Road Ditch may also be impaired for acute toxicity due to chloride.

Site 30 Des Plaines River

The Des Plaines River is not currently listed as impaired for chronic or acute toxicity due to chloride (see Table 2.8). Analysis of continuous monitoring data for the site suggests that the site had estimated chloride concentrations greater than 395 mg/l for a period of four or more days (see Table 3.16). The maximum concentration of chloride detected at this site during the study period through continuous monitoring was about 498 mg/l (see Table 3.7). These data are supported by the fact that chloride concentrations in two out of 30 water samples collected at this site during the Study were above 395 mg/l, with a maximum concentration of 517 mg/l (see Tables 3.17 and 3.8). These data suggest that the Des Plaines River might be impaired for chronic toxicity due to chloride. Given that chloride concentrations at this site did not exceed 757 mg/l in either continuous monitoring or water samples, it is unlikely that an impairment is present for acute toxicity due to chloride.

Gateway Drive Tributary to Ulao Creek

The Gateway Tributary to Ulao Creek is currently listed as impaired for chronic toxicity due to chloride and is not listed for acute toxicity due to chloride (see Table 2.8). Chloride concentrations in eight out of 12 water samples collected at this site in 2020 and 2021 were higher than 757 mg/l (see Table 3.17). This suggests that this stream may also be impaired due to acute toxicity from chloride.

Evaluation of the Potential of Continuous Monitoring for Assessing Compliance with Water Quality Criteria

The Chloride Impact Study continuous dataset illustrates the potential of the use of continuous monitoring of specific conductance as a means of assessing compliance with the water quality criteria for chloride. The analysis also shows the potential for the use of examining the contiguous concentration-durations of events above indicator thresholds in interpreting such data.

Continuous monitoring of specific conductance, especially over short monitoring intervals such as five or 10 minutes, has several advantages over collection of water samples for chemical analysis. Monitoring in-stream conditions continuously allows for the collection of much more data than could be gathered through collecting water samples. Continuous monitoring data can be collected at far lower cost than data obtained through water quality sampling.[40] Continuous monitoring allows for the collection of data on much finer time scales. This can provide insight into both short-term and long-term dynamics of in-stream chloride concentrations. When coupled with telemetry, continuous monitoring can provide real-time or near real-time indications of in-stream conditions. Finally, data from continuous monitoring using a short monitoring interval can be analyzed using techniques such as constructing concentration-duration tables. Such analysis methods can reduce large amounts of data to a single table that analyzes how long concentrations contiguously exceeded key thresholds.

Continuous monitoring and analysis may also permit regulatory authorities to better assess which impairments are present in a waterbody. The 2024 Wisconsin Impaired Waters List includes 50 stream reaches on 42 streams in the State that have impairments related to chloride. Impairments are present for chronic toxicity alone in 16 stream reaches and for both chronic and acute toxicity on 34 stream reaches. While the Wisconsin water quality criteria for chloride indicate that it is possible for a waterbody to be impaired for acute toxicity for chloride without also having an impairment for chronic toxicity, no such combination of chloride impairments by stream reach has been identified. This may be due, in part, to the difficulties involved in assessing the presence of water quality impairments related to chloride through water sampling and chemical analysis. The discussion of Site 1 Fox River at Waukesha earlier in this chapter suggests that the use of continuous monitoring may make it easier to distinguish among waterbodies where impairments are present for only chronic toxicity, only acute toxicity, or both forms of toxicity.

Several issues need to be considered if continuous monitoring is to be used to assess whether conditions in waterbodies comply with water quality standards. While the costs associated with continuous monitoring are less than those associated with collecting and processing water samples, they are appreciable. In addition to the capital cost of obtaining and installing monitoring equipment, continuous monitoring generates costs for telemetry and online data storage as well as staff time for cleaning and maintaining monitoring equipment, reviewing telemetry, and proofing and post-processing of data. These issues are discussed more fully in an accompanying Study technical report.[41]

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[40] *For example, the continuous monitoring conducted as part of this Study collected about 13 million measurements of specific conductance. At $25 a sample, laboratory processing of this number of chloride samples would cost about $325 million.*

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

Using specific conductance as a surrogate for chloride requires that models for estimating chloride concentration from specific conductance be developed. The development of such models generally requires collecting paired samples of these two water quality constituents. Such collection should occur both at regular intervals and during winter storm and spring snowmelt events. As of 2025, it is not clear just how good these models need to be or what characteristics they should have in order to be used for assessing compliance with water quality standards. Ultimately, regulatory authorities such as the USEPA and WDNR will need to specify the quality and characteristics required for such models if they are to be used for purposes related to implementation of the CWA and associated State laws and regulations such as assessment and listing, permit issuance, and TMDL development. In the absence of such guidance from regulatory authorities, such models may still be useful for other purposes such as guiding and evaluating management efforts.

3.4 CHLORIDE DATA COLLECTION AND CONDITIONS IN MONITORED LAKES

While most of the data collection efforts for the Chloride Impact Study focused on streams, Commission staff also collected chloride data on lakes to better understand current chloride conditions in lakes that are representative of the Region. Additionally, it was envisioned that collection of chloride and specific conductance data will help illustrate how chloride moves through lakes and how it may impact the seasonal functions and ecology of the lakes in the Region. This Section will include a brief review lake selection, chloride sampling efforts, and the chloride conditions observed during the Study.

Lake Selection

Commission staff conducted water quality monitoring at six lakes within the Region. These lakes were selected to provide a balanced geographic spread across the Region. They also included lakes of the four main types found in Wisconsin: seepage, spring, drainage, and drained lakes. The locations of these lakes are shown on Map 3.5 and described in Table 3.18.

The drainage areas for the lakes represent a wide range of land uses (see Table 3.19). The percentage of urban land use in the drainage areas ranged between about 18 percent and 58 percent. The percentage of agricultural land in the drainage areas ranged between none and about 49 percent. None of these lakes have WWTPs located in their drainage areas. More information about these lakes and their drainage areas is available in a separate technical report.[42]

[42] Ibid.

Lake Data Collection

Water quality data were collected quarterly from each of the six lakes selected for the Study, from August 2018 through February 2021. The sampling locations for each lake were positioned at the deepest part of the lake, often referred to as the "deep hole." Depths to be sampled for each lake at all quarterly visits were determined during the first summer visit in August 2018, when the lakes were thermally stratified.[43] Data were collected on three water quality constituents. Water temperature and specific conductance were measured along a vertical profile at the deepest location in the lake. In addition, water samples were collected at multiple selected depths along the same profile. These samples were analyzed for chloride concentration by the WSLH.

Water quality samples were collected from all lakes at a depth of three feet. Additional sampling depths were selected at the depths determined to be directly above the thermocline, directly below the thermocline, and as close to the lake bottom as possible without disturbing sediments.[44] The typical depths sampled for each lake included:[45]

- Big Cedar Lake: 3 feet, 30 feet, 55 feet, 80 feet, 95 feet

- Geneva Lake: 3 feet, 30 feet, 50 feet, 70 feet, 90 feet, 135 feet

- Little Muskego Lake: 3 feet, 10 feet, 30 feet, 40 feet, 50 feet, 65 feet

[43] *Stratification is a natural condition in a lake when temperature differences and associated density differences between surface waters (the epilimnion), the transitional zone (the metalimnion), and deep waters (the hypolimnion) are great enough to form thermal layers that can impede mixing of gases and dissolved substances between these layers.*

[44] *The thermocline is a layer within the metalimnion that separates the warmer, less dense epilimnion from the cooler, denser hypolimnion. Typically, the depth of the thermocline can range from less than 10 feet to greater than 20 feet below the surface for lakes in southeastern Wisconsin, with depth varying by lake, month, and year. The thermocline is generally characterized by a temperature change of about 0.5°F per foot of water depth.*

[45] *Exact sampling depth varied slightly due to field conditions such as wind, waves, lake water levels, and other environmental variables. Exact depths of each sample are recorded in field documentation and lab analysis data. Samples were occasionally collected at additional depths for exploratory analysis.*

- Moose Lake: 3 feet, 15 feet, 30 feet, 40 feet, 55 feet

- Silver Lake: 3 feet, 10 feet, 25 feet, 35 feet, 45 feet

- Voltz Lake: 3 feet, 10 feet, 15 feet, 20 feet

Lake Chloride Conditions: 2018 – 2021

Summary statistics for chloride sampling in the six lakes between August 2018 and February 2021 are presented in Table 3.20. Using all samples, Little Muskego had the highest mean and maximum chloride concentrations observed at 185.2 mg/l and 270 mg/l, respectively. With a minimum concentration of 139 mg/l, Little Muskego had the greatest range in observed chloride concentrations and consequently had substantially higher standard deviations than any other lake. Voltz and Silver Lakes had the lowest mean chloride concentration for all samples at 35.3 and 37.3 mg/l, respectively.

Profiles of the lake chloride sampling with depth are presented in Figure 3.18. Note that the chloride concentration x-axis range varies by lake. Profiles were colored based on season (e.g. winter (December, January, February) is blue) and symbolized based on year. Dashed lines indicated more than one sample in a season for the year. As shown in the figure, very little spring (March, April, May) sampling was done in the six lakes as it was difficult to find boats to do the work. In all lakes except Little Muskego, there were no significant differences in chloride concentrations between samples collected less than 20 feet deep and those collected in depths equal to or greater than 20 feet deep.[46] In Little Muskego, the deeper samples had statistically significantly higher chloride concentrations than the shallower samples. In the other study lakes, there was little variation in chloride concentrations with depth across most of the sampling periods. The lake profiles showed some differences by season, with winter sampling predominantly having the highest chloride concentrations across five of the six lakes; however, there was no statistically significance difference between seasons across all lakes. For all but Muskego Lake and Voltz Lake these seasonal differences were small (less than 5 mg/l).

Even across this relatively short 3-year sampling period, several of the lakes studied had significant changes in mean shallow chloride concentration over time (see Figure 3.19). Moose and Silver Lakes had significant increases in shallow (equal to or less than 20 feet deep) chloride concentrations over time across the study

[46] *Voltz Lake was excluded from this analysis as most samples were collected in depths of 20 feet or shallower.*

period while Little Muskego and Voltz had significant decreases. There were no significant changes in mean shallow chloride concentrations over time for Big Cedar Lake or Geneva Lake, which had the longest residence times of the monitored lakes.

Commission staff evaluated the potential correlations with watershed land uses on overall mean chloride concentrations (see Figure 3.20). Across the six lakes, the mean chloride concentration was significantly correlated with the percentage of roads and parking lots in the watershed (p-value = 0.02, R^2 = 0.78) but not with the percentage of urban lands (p-value = 0.41, R^2 = 0.17) or the percentage of agricultural lands (p-value = 0.75, R^2 = 0.03) in the watershed. Commission staff also calculated the coefficient of variation (CV), which is computed by dividing the concentration standard deviation by the mean concentration, to evaluate how chloride concentrations varied within each lake. Commission staff hypothesized that lakes with higher residence times would have reduced CV values, while lakes with shorter residence times would have higher CV values. However, a linear regression of residence time against the CV value for each lake was not statistically significant (p-value = 0.24, R^2 = 0.41).[47]

3.5 SUMMARY

The main insights from the Study analysis of the continuous stream chloride data include:

- Nearly all the monitored streams are currently experiencing chloride concentrations that are elevated above baseline conditions and potentially harmful to aquatic life.

- Chloride is highly dynamic in stream systems, particularly in small streams.

  - Chloride concentrations in small streams can fluctuate by orders of magnitude within hours during and following winter storm events.

  - Winter precipitation events, particularly in urban watersheds, tend to cause spikes in chloride concentrations.

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[47] *To the knowledge of Commission staff, the residence time of Moose Lake has not been calculated. Consequently, this regression only utilized five lakes with Moose Lake excluded.*

    - Spring snow melt events can cause either spikes or dilutions in chloride concentrations, depending on preceding weather conditions.

    - Prolonged dry periods, such as droughts, also can cause elevated chloride concentrations.

    - Non-winter precipitation events typically cause dilutions in chloride concentrations.

    - Rivers with larger watersheds often have more drawn-out responses to precipitation events than streams with small watersheds.

- Chloride concentrations are influenced by numerous factors, including watershed land use, seasonal patterns, streamflow, wastewater treatment plant effluent and other point source discharge, and propagation of chloride-laden water downstream.

    - Chloride concentrations are generally lowest in streams with little to no urban land uses in their watersheds and concentrations are highest with high percentages of urban land use.

    - Chloride concentrations are generally highest in winter, particularly in streams with urban watersheds that experience chloride spikes following precipitation.

    - Increased streamflow generally decreases chloride concentration.

    - 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.

- Continuous monitoring can be a useful tool for assessing waterbody impairment, particularly where collecting samples during chloride spikes is not feasible.

    - Continuous monitoring also allows for examining how long events last above specific thresholds, which can be important for interpreting likely ecological responses.

The lake chloride analyses are somewhat limited due to the small size and short time period of this dataset. However, despite these limitations, this Study observed that watershed land use can have a significant impact on lake chloride concentrations, that chloride concentrations generally do not increase with water depth, and how readily the chloride concentration can change may be influenced by lake residence time. Long-term trends and influencing factors on lake chloride concentrations across the study area are explored more fully in Chapter 5 of this Technical Report.

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CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 3

ANALYSIS OF MONITORING DATA COLLECTED FOR THE CHLORIDE IMPACT STUDY: 2018-2021

TABLES

Table 3.1
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
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
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
4	Sugar Creek	Fox River	Walworth	Walworth	60.5	10029083	--	42.71494642	-88.34238151	Sugar Creek about 60 feet upstream of Potter Road near 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
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
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 Oak Creek
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
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
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
13	Ulao Creek	Milwaukee River	Ozaukee	Ozaukee	9.2	10050932	--	43.28115708	-87.92473975	Ulao Creek about 40 feet downstream of CTH W
14	Sauk Creek	Sauk Creek	Ozaukee	Ozaukee, Sheboygan	31.7	10030655	--	43.38648777	-87.87253643	Sauk Creek about 400 feet upstream of Wisconsin Street
15	Kilbourn Road Ditch	Des Plaines River	Kenosha	Racine, Kenosha	8.5	10051686	--	42.65507120	-87.94899341	Kilbourn Road Ditch at CTH A
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

Table continued on next page.

Table 3.1 (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
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
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
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
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
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 (CTH G)
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
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)
32	Turtle Creek	Rock River	Walworth	Walworth	94.0	10051690	--	43.31952281	-88.38667623	Turtle Creek about 230 feet upstream of USH 14
33	Pebble Brook	Fox River	Waukesha	Waukesha	16.0	10008183	--	42.93472331	-88.25683580	Pebble Brook about 300 feet upstream of CTH XX
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
36	Honey Creek Downstream of East Troy	Fox River	Walworth	Walworth	44.6	653244	--	42.78823546	-88.36653679	Honey Creek at Carver School Road
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
40	Stony Creek	Milwaukee River	Washington	Washington, Sheboygan, Fond Du Lac	17.8	673267	--	43.52741053	-88.08937392	Stony Creek at CTH X
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) near 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
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
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
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
52	Cedar Creek	Milwaukee River	Washington	Washington, Ozaukee	53.6	673048	--	43.32350934	-88.14256630	Cedar Creek about 150 feet upstream of STH 60, east of Jackson

Table continued on next page.

Table 3.1 (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
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
54	Whitewater Creek	Rock River	Walworth	Walworth	18.8	653291	--	43.04745799	-88.45981016	Whitewater Creek about 30 feet upstream of Millis Road near 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
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 in 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
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
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
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

[a] *See Map 3.1 for locations of each monitored site.*

[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 3.2
Urban and Agricultural Land Use and Wastewater Treatment Plants for Drainage Areas of Monitored Streams: 2015

SEWRPC Site ID	Monitoring Site Name	Land Use: Urban (percent)	Land Use: Roads and Parking Lots (percent)	Land Use: Agricultural (percent)	WWTPs Discharging in Drainage Area
1	Fox River at Waukesha	54.0	14.4	12.1	2
2	Fox River at New Munster	27.1	7.0	37.1	10[a]
3	Mukwonago River at Mukwonago	26.4	5.2	29.7	--
4	Sugar Creek	13.1	4.7	57.5	--
6	White River near Burlington	20.6	5.7	38.4	1[a]
8	Pewaukee River	52.7	13.7	11.3	--
9	Oak Creek	72.3	19.9	10.1	--
10	Pike River	41.1	10.5	47.6	--
11	Bark River Upstream	43.9	8.8	23.5	--
12	Lincoln Creek	97.4	28.1	0.1	--
13	Ulao Creek	32.5	12.5	29.6	--
14	Sauk Creek	11.5	4.6	76.7	--
15	Kilbourn Road Ditch	12.3	6.6	71.3	--
16	Jackson Creek	10.9	5.1	78.6	--
18	Oconomowoc River Upstream	22.3	4.5	36.8	--
20	Oconomowoc River Downstream	26.4	5.9	30.7	--
21	East Branch Milwaukee River	6.0	2.6	36.9	--
23	Milwaukee River Downstream of Newburg	12.9	4.5	48.9	4
25	Root River Canal	14.2	4.1	73.7	1
28	East Branch Rock River	10.6	5.7	65.2	1
30	Des Plaines River	19.2	6.5	55.5	2
32	Turtle Creek	16.2	5.5	59.5	1
33	Pebble Brook	41.9	9.5	18.6	--
35	Honey Creek Upstream of East Troy	10.4	3.4	59.4	--
36	Honey Creek Downstream of East Troy	15.3	5.1	54.2	1
38	North Branch Milwaukee River	7.4	3.1	62.9	2[b]
40	Stony Creek	8.3	3.3	51.0	--
41	Milwaukee River near Saukville	11.7	4.1	52.7	7[b]
45	Mukwonago River at Nature Road	11.8	3.1	41.7	--
47	Fox River at Rochester	35.6	8.7	27.6	5
48	White River at Lake Geneva	31.8	6.7	14.6	--
51	Rubicon River	25.8	7.2	42.6	1
52	Cedar Creek	23.3	8.0	43.4	1
53	Honey Creek at Wauwatosa	98.5	30.4	0.0	--
54	Whitewater Creek	11.2	3.4	45.5	--
55	Bark River Downstream	43.3	9.3	19.7	--[c]
57	Menomonee River at Wauwatosa	67.3	19.5	14.4	--
58	Milwaukee River at Estabrook Park	21.7	6.6	44.4	11[b]
59	Root River near Horlick Dam	35.0	9.4	46.3	2
60	Root River at Grange Avenue	91.9	26.4	0.3	--
87	Underwood Creek	88.4	25.5	0.5	--

Note: For detailed land use data and drainage area characteristics, see SEWRPC Technical Report 61 Table 2.12 and Appendix B.

[a] *The drainage area for this site also includes the Lake Geneva WWTP which discharges to groundwater, not shown in the table.*

[b] *The drainage area for this site also includes the Town of Scott which discharges to groundwater, not shown in the table.*

[c] *The Delafield-Hartland Water Pollution Control Commission WWTP is located in this drainage area but discharges downstream of Site 55.*

Source: SEWRPC

Table 3.3
Thirty-Year Climate Normals for Southeastern Wisconsin: 1991-2020

Month	Mean Temperature (°F)	Precipitation (inches)	Snowfall (inches)
January	20.7	1.64	12.6
February	24.2	1.56	10.7
March	34.3	2.05	5.3
April	45.4	3.67	1.7
May	56.7	3.96	0.1
June	66.7	4.60	0.0
July	71.3	3.67	0.0
August	69.6	3.80	0.0
September	62.3	3.33	0.0
October	50.2	2.91	0.2
November	37.5	2.22	2.1
December	26.3	1.87	9.8
Total	--	35.28	42.3

Source: Wisconsin State Climatology Office and National Oceanic and Atmospheric Administration

Table 3.4
Periods of Record for Stream Sites Monitored for the Chloride Impact Study

SEWRPC Site ID	Monitoring Site Name	Continuous Monitoring Began	Ended	Months Monitored	Water Samples Collected
1	Fox River at Waukesha	October 2018	February 2021	29	29
2	Fox River at New Munster	October 2018	February 2021	29	26
3	Mukwonago River at Mukwonago	October 2018	October 2020	25	25
4	Sugar Creek	October 2018	October 2020	25	25
6	White River near Burlington	October 2018	October 2020	25	25
8	Pewaukee River	October 2018	October 2020	25	26
9	Oak Creek	October 2018	February 2021	29	33
10	Pike River	October 2018	February 2021	29	29
11	Bark River Upstream	October 2018	October 2020	25	25
12	Lincoln Creek	October 2018	February 2021	29	35
13	Ulao Creek	October 2018	August 2021	35	39
14	Sauk Creek	October 2018	February 2021	29	28
15	Kilbourn Road Ditch	October 2018	February 2021	29	33
16	Jackson Creek	October 2018	October 2020	25	26
18	Oconomowoc River Upstream	October 2018	October 2020	25	25
20	Oconomowoc River Downstream	October 2018	October 2020	25	25
21	East Branch Milwaukee River	October 2018	October 2020	25	25
23	Milwaukee River Downstream of Newburg	October 2018	October 2020	25	26
25	Root River Canal	October 2018	February 2021	29	28
28	East Branch Rock River	October 2018	October 2020	25	26
30	Des Plaines River	October 2018	February 2021	29	30
32	Turtle Creek	October 2018	October 2020	25	26
33	Pebble Brook	October 2018	October 2020	25	25
35	Honey Creek Upstream of East Troy	October 2018	October 2020	25	26
36	Honey Creek Downstream of East Troy	October 2018	October 2020	25	25
38	North Branch Milwaukee River	October 2018	October 2020	25	25
40	Stony Creek	October 2018	October 2020	25	25
41	Milwaukee River near Saukville	October 2018	October 2020	25	25
45	Mukwonago River at Nature Road	October 2018	October 2020	25	25
47	Fox River at Rochester	October 2018	October 2020	25	26
48	White River at Lake Geneva	October 2018	October 2020	25	25
51	Rubicon River	October 2018	January 2021	28	27
52	Cedar Creek	October 2018	October 2020	25	26
53	Honey Creek at Wauwatosa	October 2018	February 2021	29	40
54	Whitewater Creek	October 2018	October 2020	25	26
55	Bark River Downstream	October 2018	October 2020	25	25
57	Menomonee River at Wauwatosa	December 2019	May 2021	18	28
58	Milwaukee River at Estabrook Park	December 2019	May 2021	18	19
59	Root River near Horlick Dam	October 2018	February 2021	29	37
60	Root River at Grange Avenue	November 2020	August 2021	10	16
87	Underwood Creek	November 2020	August 2021	10	17

Source: SEWRPC

Table 3.5
Specific Conductance and Chloride Concentration at Chloride Impact Study Sampling Sites: 2018-2021

Statistic	Specific Conductance Observations (μS/cm)	Estimated Chloride[a] (mg/l)	Measured Chloride[b] (all samples) (mg/l)	Measured Chloride[b] (event samples removed) (mg/l)
Observations and Samples	8,960,021	8,756,461	1,141	1,030
Minimum	42	0.0	8.7	10.8
Mean	833	118.0	232.0	121.9
Median	702	66.8	77.1	67.3
Maximum	14,689	5,135.8	6,630.0	1,890.0
Standard Deviation	579.9	192.2	533.8	171.6

[a] *Chloride concentration was estimated from specific conductance using regression models developed as part of the Chloride Impact Study.*

[b] *Chloride concentration was determined by chemical analysis of water samples.*

Source: SEWRPC

Table 3.6
Summary Statistics for Specific Conductance at Chloride Impact Study Stream Monitoring Sites

SEWRPC Site ID	Monitoring Site Name	Months Monitored	Observations	Minimum (µS/cm)	Mean (µS/cm)	Maximum (µS/cm)	Standard Deviation (µS/cm)
1	Fox River at Waukesha	29	253,768	327	1,234	3,069	277.8
2	Fox River at New Munster	29	253,965	371	815	1,274	175.3
3	Mukwonago River at Mukwonago	25	217,683	368	547	638	37.8
4	Sugar Creek	25	219,447	277	640	948	104.0
6	White River near Burlington	25	219,447	121	646	955	112.2
8	Pewaukee River	25	218,117	340	972	2,123	159.0
9	Oak Creek	29	253,637	56	1,415	7,112	740.9
10	Pike River	29	252,251	87	706	2,698	311.4
11	Bark River Upstream	25	219,446	366	795	1,191	88.0
12	Lincoln Creek	29	250,289	48	1,875	14,689	1,420.2
13	Ulao Creek	32	280,499	95	944	3,412	307.0
14	Sauk Creek	29	253,432	62	661	2,432	175.7
15	Kilbourn Road Ditch	29	254,009	118	723	6,607	394.4
16	Jackson Creek	25	219,271	67	670	1,067	158.9
18	Oconomowoc River Upstream	25	219,121	258	625	773	57.1
20	Oconomowoc River Downstream	25	216,592	371	568	731	43.5
21	East Branch Milwaukee River	25	217,977	213	453	603	53.3
23	Milwaukee River Downstream of Newburg	25	219,435	238	676	1,426	111.5
25	Root River Canal	29	244,243	122	739	1,644	214.4
28	East Branch Rock River	25	219,337	107	865	1,191	155.4
30	Des Plaines River	29	241,511	285	794	2,109	221.0
32	Turtle Creek	25	217,154	394	660	925	87.0
33	Pebble Brook	25	219,434	367	877	1,288	118.4
35	Honey Creek Upstream of East Troy	25	219,449	235	598	877	53.7
36	Honey Creek Downstream of East Troy	25	219,443	283	648	1,064	57.1
38	North Branch Milwaukee River	25	219,449	201	669	841	98.3
40	Stony Creek	25	213,526	146	521	1,060	119.8
41	Milwaukee River near Saukville	25	217,516	222	577	778	100.1
45	Mukwonago River at Nature Road	25	219,011	274	544	807	58.4
47	Fox River at Rochester	25	216,656	454	860	1,334	136.4

Table continued on next page.

Table 3.6 (Continued)

SEWRPC Site ID	Monitoring Site Name	Months Monitored	Observations	Minimum (µS/cm)	Mean (µS/cm)	Maximum (µS/cm)	Standard Deviation (µS/cm)
48	White River at Lake Geneva	25	212,322	92	362	705	109.7
51	Rubicon River	28	245,477	215	762	1,702	141.1
52	Cedar Creek	25	219,364	206	726	1,197	75.8
53	Honey Creek at Wauwatosa	29	253,829	45	1,994	14,322	1,510.7
54	Whitewater Creek	25	216,444	321	625	743	47.4
55	Bark River Downstream	25	203,560	56	686	811	62.4
57	Menomonee River at Wauwatosa	18	157,693	88	1,357	7,362	839.6
58	Milwaukee River at Estabrook Park	18	157,223	332	705	1,538	116.8
59	Root River near Horlick Dam	29	283,811	42	844	2,612	272.2
60	Root River at Grange Avenue	10	87,987	80	2,078	11,092	1,306.4
87	Underwood Creek	10	57,196	148	1,786	9,462	949.4

Source: SEWRPC

#272933 – TR-63 (Chloride Study Conditions and Trends) Table 3.7 - Cl Summary Stats by Site
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Table 3.7
Summary Statistics for Estimated and Measured Chloride Concentrations at Chloride Impact Study Stream Monitoring Sites

SEWRPC Site ID	Monitoring Site Name	Chloride Concentration Estimated from Specific Conductance (mg/l)					Measured Chloride Concentration from Monthly Samples (mg/l)				
		Observations	Minimum	Mean	Maximum	Standard Deviation	Samples	Minimum	Mean	Maximum	Standard Deviation
1	Fox River at Waukesha[a]	253,768	26.3	229.2	851.5	85.04	24	105.0	226.5	374.0	61.7
2	Fox River at New Munster[a]	253,965	31.4	105.4	241.0	46.32	25	63.4	96.0	162.0	19.44
3	Mukwonago River at Mukwonago[a]	217,683	31.1	52.1	62.7	4.43	25	30.5	43.3	83.4	11.11
4	Sugar Creek[b]	219.447	21.2	43.1	61.7	6.27	25	33.6	43.7	61.5	8.12
6	White River near Burlington[a]	219,447	2.2	64.0	142.6	13.62	25	27.8	53.5	73.2	8.19
8	Pewaukee River[a]	218,117	27.8	148.2	502.8	48.33	25	133.0	225.3	441.0	77.22
9	Oak Creek[a]	253,637	0.0	295.9	2,342.2	242.16	25	51.4	273.0	818.0	166.03
10	Pike River[a]	252,251	0.0	89.4	714.8	80.59	25	29.3	114.0	366.0	75.95
11	Bark River Upstream[a]	219,446	30.9	95.8	215.4	22.94	25	71.0	106.2	363.0	54.92
12	Lincoln Creek[a]	250,289	0.0	452.7	5,135.8	500.95	25	133.0	473.8	1,880.0	423.02
13	Ulao Creek[a]	280,499	0.0	144.2	978.0	90.52	35	40.8	175.8	915.0	140.37
14	Sauk Creek[a]	253,432	0.0	72.3	616.8	32.18	25	22.3	61.3	130.0	22.02
15	Kilbourn Road Ditch[a]	254,009	1.8	95.1	2,156.0	116.25	25	17.8	82.4	314.0	74.04
16	Jackson Creek[a]	219,271	0.0	73.3	177.2	31.59	25	37.0	64.9	111.0	17.56
18	Oconomowoc River Upstream[a]	219,121	18.2	61.2	86.5	6.68	25	37.1	45.5	51.4	3.57
20	Oconomowoc River Downstream[a]	216,592	31.4	54.5	73.6	5.09	25	54.2	61.6	68.5	3.07
21	East Branch Milwaukee River[b]	217,977	6.8	21.3	30.3	3.21	25	13.5	18.7	25.4	2.62
23	Milwaukee River Downstream of Newburg[a]	219,435	15.8	70.9	287.8	19.38	25	26.8	55.3	308.0	53.13
25	Root River Canal[a]	244,243	2.3	91.2	355.1	48.27	25	11.9	77.9	217.0	45.11
28	East Branch Rock River[b]	219,337	16.8	62.5	82.1	9.37	25	31.1	55.8	71.9	11.10
30	Des Plaines River[a]	241,511	21.4	103.0	498.5	55.91	25	23.6	83.2	237.0	44.83
32	Turtle Creek[a]	217154	34.2	66.7	133.4	12.69	25	50.8	64.9	87.8	9.03
33	Pebble Brook[a]	219,434	31.0	120.5	245.3	31.62	25	75.6	108.2	178.0	21.24
35	Honey Creek Upstream of East Troy[b]	219,449	13.1	34.9	51.7	3.24	25	19.5	32.4	36.6	3.99
36	Honey Creek Downstream of East Troy[b]	219,443	25.9	47.8	72.9	3.44	25	26.1	46.2	56.9	6.64
38	North Branch Milwaukee River[b]	219,449	9.6	37.8	48.2	5.92	25	20.6	33.7	46.3	6.62
40	Stony Creek[b]	213,526	6.4	29.0	61.5	7.22	25	19.1	31.2	42.9	5.09
41	41-Milwaukee River near Saukville[b]	217,516	27.9	49.3	61.4	6.03	25	26.8	50.7	97.2	13.45
45	45-Mukwonago River at Nature Road[b]	219,011	3.1	19.4	35.2	3.52	25	10.8	17.6	20.1	1.88

Table continued on next page.

Table 3.7 (Continued)

SEWRPC Site ID	Monitoring Site Name	Chloride Concentration Estimated from Specific Conductance (mg/l)					Measured Chloride Concentration from Monthly Samples (mg/l)				
		Observations	Minimum	Mean	Maximum	Standard Deviation	Samples	Minimum	Mean	Maximum	Standard Deviation
47	47-Fox River at Rochester[a]	216,656	41.2	116.2	259.4	37.47	25	81.1	139.2	257.0	35.03
48	48-White River at Lake Geneva[a]	212,322	0.0	30.4	70.6	12.85	25	49.0	54.2	92.5	8.60
51	51-Rubicon River[a]	245,477	13.2	91.2	373.0	33.05	25	62.3	109.1	148.0	24.89
52	52-Cedar Creek[a]	219,364	12.1	77.6	217.2	14.75	25	55.8	85.1	213.0	30.16
53	53-Honey Creek at Wauwatosa[a]	253,829	0.0	493.6	5,000.5	532.97	25	143.0	571.3	1,890.0	413.57
54	54-Whitewater Creek[b]	216,444	6.7	25.0	32.1	2.86	25	18.0	22.1	24.2	1.72
55	55-Bark River Downstream[c]	--	--	--	--	--	25	93.3	107.9	132.0	8.51
57	57-Menomonee River at Wauwatosa[a]	157,693	0.0	278.4	2,434.4	281.93	18	129.0	255.2	750.0	141.67
58	58-Milwaukee River at Estabrook Park[a]	157,223	26.9	76.7	322.4	26.39	18	39.4	63.8	103.0	16.18
59	59-Root River near Horlick Dam[a]	243,811	0.0	117.7	683.0	73.01	34	20.6	108.7	262.0	51.46
60	60-Root River at Grange Avenue[a]	87,987	0.0	515.3	3,809.6	462.80	10	45.5	444.8	1,460.0	392.46
87	87-Underwood Creek[a]	57,196	5.3	411.4	3,208.6	332.45	10	162.0	360.9	546.0	98.04

[a] *Chloride concentration was estimated using the piecewise linear regression model.*

[b] *Chloride concentration was estimated using the linear mixed effects regression model.*

[c] *A model could not be developed for estimating chloride concentration at this site.*

Source: SEWRPC

Table 3.8
Summary Statistics for Measured Chloride Concentrations at Chloride Impact Study Stream Monitoring Sites Including Event Samples

Site ID	Monitoring Site Name	Total Samples	Event Samples	Minimum (mg/l)	Mean (mg/l)	Maximum (mg/l)	Standard Deviation (mg/l)
1	Fox River at Waukesha	29	5	105.0	280.8	669.0	139.13
2	Fox River at New Munster	26	1	63.4	97.4	162.0	20.38
3	Mukwonago River at Mukwonago	25	0	30.5	43.3	83.4	11.11
4	Sugar Creek	25	0	33.6	43.7	61.5	8.12
6	White River near Burlington	25	0	27.8	53.5	73.2	8.19
8	Pewaukee River	26	1	133.0	238.5	568.0	101.20
9	Oak Creek	33	8	51.4	497.6	2,080.0	512.99
10	Pike River	29	4	29.3	170.1	683.0	172.77
11	Bark River Upstream	25	0	71.0	106.2	363.0	54.92
12	Lincoln Creek	35	10	133.0	989.5	3,710.0	1,068.58
13	Ulao Creek	39	4	40.8	230.0	926.0	216.50
14	Sauk Creek	28	3	22.3	79.6	365.0	66.65
15	Kilbourn Road Ditch	33	8	17.8	242.8	1,470.0	354.26
16	Jackson Creek	26	1	28.7	63.5	111.0	18.60
18	Oconomowoc River Upstream	25	0	37.1	45.5	51.4	3.57
20	Oconomowoc River Downstream	25	0	54.2	61.6	68.5	3.07
21	East Branch Milwaukee River	25	0	13.5	18.7	25.4	2.62
23	Milwaukee River Downstream of Newburg	26	1	26.8	72.4	308.0	58.11
25	Root River Canal	28	3	11.9	89.5	318.0	63.46
28	East Branch Rock River	26	1	31.1	56.1	71.9	11.05
30	Des Plaines River	30	5	23.6	124.7	517.0	116.61
32	Turtle Creek	26	1	45.8	64.2	87.8	9.61
33	Pebble Brook	25	0	75.6	108.2	178.0	21.24
35	Honey Creek Upstream of East Troy	26	1	13.2	31.7	36.6	5.43
36	Honey Creek Downstream of East Troy	25	0	26.1	46.2	56.9	6.64
38	North Branch Milwaukee River	25	1	20.6	33.7	46.3	6.62
40	Stony Creek	25	0	19.1	31.2	42.9	5.09
41	Milwaukee River near Saukville	25	0	26.8	50.7	97.2	13.45
45	Mukwonago River at Nature Road	25	0	10.8	17.6	20.1	1.88
47	Fox River at Rochester	26	1	81.1	140.0	257.0	34.59
48	White River at Lake Geneva	25	0	49.0	54.2	92.5	8.60
51	Rubicon River	27	2	62.3	116.5	232.0	36.23
52	Cedar Creek	26	1	55.8	87.3	213.0	31.59
53	Honey Creek at Wauwatosa	40	15	143.0	1,358.9	4,580.0	1,270.17
54	Whitewater Creek	26	1	8.7	21.6	24.2	3.13
55	Bark River Downstream	25	0	93.3	107.9	132.0	8.51
57	Menomonee River at Wauwatosa	28	10	129.0	564.9	2,240.0	548.10
58	Milwaukee River at Estabrook Park	19	1	39.4	71.1	203.0	35.60
59	Root River near Horlick Dam	37	3	20.6	133.7	686.0	113.56
60	Root River at Grange Avenue	16	6	45.5	1,118.3	3,600.0	1,139.52
87	Underwood Creek	17	7	162.0	921.9	3,510.0	914.94

Source: SEWRPC

Table 3.9
Groups of Stream Monitoring Sites with Similar Chloride Characteristics

Group Number	Group Description	Monitoring Sites in Group
1	Small stream, urban watershed, large winter spikes, and high to very high chloride	9, 12, 53, 57, 60, 87
2	Small stream, mixed urban and rural watershed, moderate winter spikes, and high chloride	1, 8, 10, 11, 13, 33
3	Small stream, rural watershed, moderate winter spikes, and moderate to high chloride	6, 14, 15, 16, 25, 30, 51, 52, 59
4	Small stream, rural watershed, no winter spikes, and moderate chloride	3, 4, 18, 20, 28, 32, 35, 36, 40, 48
5	Small stream, rural watershed, no winter spikes, and low chloride	21, 38, 45, 54
6	Large river, rural watershed, no winter spikes, and low chloride	2, 41
7	Large river, rural watershed, winter spikes, and moderate chloride	23, 47, 58

Note: Site 55 Bark River Downstream is not included in this table as chloride could not be reliably estimated from specific conductance measurements at this site.

Source: SEWRPC

Table 3.10
Correlations Between Mean Concentrations of Water Quality Constituents and Percent Land Use in Drainage Areas at Stream Monitoring Sites[a]

Water Quality Constituent	Percent Urban Land Use	Percent Roads and Parking Lots	Percent Agricultural Land Use
Calcium (mg/l)	0.220	0.189	-0.178
Chloride (mg/l)[b]	0.815	0.859	-0.513
Hardness (mg/l as $CaCO_3$)	0.218	0.190	-0.189
Magnesium (mg/l)	0.143	0.098	-0.210
Potassium (mg/l)	0.243	0.315	0.068
Sodium (mg/l)	0.808	0.858	-0.506
Sulfate (mg/l)	0.499	0.493	-0.201

[a] *Correlations calculated using the Spearman ρ rank correlation coefficient. Correlation coefficients are a unitless measure of the strength and direction of the relationship between two variables. Values range from -1 to +1 indicating perfect negative and positive relationships, respectively. Correlation coefficient strength can be interpreted as such:*

0 to 0.1: no correlation
0.1 to 0.3: weak correlation
0.3 to 0.5: moderate correlation
0.5 to 0.7: strong correlation
0.7 to 1: very strong correlation

For example, results in this table can be interpreted as: increasing chloride concentrations in water at stream monitoring sites is very strongly correlated with a higher percentage of urban land use in a drainage area. On the other hand, decreasing chloride concentrations in water at stream monitoring sites is moderately correlated with a higher percentage of agricultural land use within a drainage area.

[b] *Correlation analysis of chloride was based on measured concentrations from water quality sampling and does not include concentrations estimated from specific conductance.*

Source: SEWRPC

Table 3.11
Air Temperature, Precipitation, and Snowfall at Weather Stations Near Site 15 Kilbourn Road Ditch: January 23-30, 2020

Date	Low Temperature (°F)	High Temperature (°F)	Precipitation (inches)	Snowfall (inches)	Snow on Ground (inches)
Kenosha					
January 23, 2020	29	35	0.19	1.5	2
January 24, 2020	32	36	0.68	1.5	3
January 25, 2020	32	36	0.18	0.2	2
January 26, 2020	29	34	--	--	--
January 27, 2020	29	35	--	--	--
January 28, 2020	28	33	--	--	--
January 29, 2020	27	31	--	--	--
January 30, 2020	28	33	--	--	--
Union Grove					
January 23, 2020	24	32	0.08	1.0	5
January 24, 2020	28	34	0.19	1.0	6
January 25, 2020	31	35	0.44	1.9	6
January 26, 2020	31	34	0.13	1.0	6
January 27, 2020	27	34	--	T	6
January 28, 2020	28	33	--	T	5
January 29, 2020	24	29	--	--	5
January 30, 2020	25	30	--	--	4

Note: T indicates that less than 0.01 inch of precipitation or 0.1 inch of snowfall.

Source: National Oceanic and Atmospheric Administration Centers for Environmental Information.

Table 3.12
Estimated Stream Discharge in Honey Creek

Exceedance Flow (percent)[a]	Discharge at Site 35 (mgd)	Discharge at Site 36 (mgd)
95	4.4	5.3
90	6.1	7.2
75	8.5	10.0
50	11.7	14.0
25	19.7	23.7
10	29.8	36.0
5	40.0	48.4

[a] *An exceedance flow represents the flow which is exceeded at a certain probability. For example, the 90 percent exceedance flow is lower than 90 percent of all flows in the stream.*

Source: Wisconsin Department of Natural Resources

Table 3.13
Daily Chloride Load Required to Raise the Concentration in Honey Creek by 13.0 mg/l

Exceedance Flow (percent)	Chloride (pounds)
95	520
90	715
75	997
50	1,387
25	2,351
10	3,565
5	4,789

[a] *An exceedance flow represents the flow which is exceeded at a certain probability. For example, the 90 percent exceedance flow is lower than 90 percent of all flows in the stream.*

Source: SEWRPC

Table 3.14
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 3.15
Equivalent Cumulative Duration for Chloride Threshold Exceedance Percentages

SEWRPC Site ID	Monitoring Site Name	Total Duration for Chloride Measurements Exceeding Concentration Threshold (days)[a]						
		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	881.1	881.1	802.8	431.9	23.5	0.1	0.0
2	Fox River at New Munster	881.8	879	261.3	12.9	0	0	0.0
3	Mukwonago River at Mukwonago	755.8	754.6	0	0	0	0	0.0
4	Sugar Creek	762	679.2	0	0	0	0	0.0
6	White River near Burlington	758.4	724.2	0.3	0	0	0	0.0
8	Pewaukee River	757.4	757.3	543.3	29.4	2.4	0	0.0
9	Oak Creek	877	843.8	730	504.9	149.2	46.2	6.6
10	Pike River	874.4	799.1	140.8	61.6	12.1	0	0.0
11	Bark River Upstream	762	761.8	144.7	0	0	0	0.0
12	Lincoln Creek	865.2	846.8	770.7	643	257.3	112.5	48.8
13	Ulao Creek	973	955.3	526.8	121	19.8	2.9	0.0
14	Sauk Creek	873.6	804.7	48.2	2.7	0.5	0	0.0
15	Kilbourn Road Ditch	880.8	826.8	160.3	66.2	15.9	4.7	1.6
16	Jackson Creek	759.3	724.2	96.7	0	0	0	0.0
18	Oconomowoc River Upstream	760.8	758.4	0	0	0	0	0.0
20	Oconomowoc River Downstream	752.1	751.4	0	0	0	0	0.0
21	East Branch Milwaukee River	755.9	0	0	0	0	0	0.0
23	Milwaukee River Downstream of Newburg	761.9	749.6	11.9	0.2	0	0	0.0
25	Root River Canal	847.8	784.6	200.5	10.9	0	0	0.0
28	East Branch Rock River	761.6	753.4	0	0	0	0	0.0
30	Des Plaines River	838.6	808.8	259.2	26.7	4.2	0	0.0
32	Turtle Creek	754	753.8	0	0	0	0	0.0
33	Pebble Brook	761.9	761.5	446.2	0.4	0	0	0.0
35	Honey Creek Upstream of East Troy	762	388.9	0	0	0	0	0.0
36	Honey Creek Downstream of East Troy	762	753.2	0	0	0	0	0.0
38	North Branch Milwaukee River	761.9	548	0	0	0	0	0.0
40	Stony Creek	740	156.1	0	0	0	0	0.0
41	Milwaukee River near Saukville	755.3	741	0	0	0	0	0.0
45	Mukwonago River at Nature Road	749.5	0	0	0	0	0	0.0
47	Fox River at Rochester	752.3	752.3	327.5	4.5	0	0	0.0
48	White River at Lake Geneva	693.6	344.7	0	0	0	0	0.0
51	Rubicon River	852.4	844.5	156	3.1	0	0	0.0
52	Cedar Creek	761.7	757.6	7.2	0	0	0	0.0
53	Honey Creek at Wauwatosa	876.7	853.1	759.5	678.7	354.8	129.4	55.9
54	Whitewater Creek	749.1	0	0	0	0	0	0.0
55	Bark River Downstream[b]	0	0	0	0	0	0	0.0
57	Menomonee River at Wauwatosa	546.5	537.9	435.7	198.9	98.3	33.4	7.1
58	Milwaukee River at Estabrook Park	545.9	543.1	37.5	0.5	0	0	0.0
59	Root River near Horlick Dam	844.9	811.1	328	71	7	0	0.0
60	Root River at Grange Avenue	305	303.8	285	252.1	148.2	48.4	18.0
87	Underwood Creek	198.6	197.8	186	159.3	75.8	16.2	5.3

[a] *See Table 3.16 for total sampling duration.*

Source: SEWRPC

Table 3.16
Maximum Length of Time that Chloride Concentration Exceeded Various Thresholds

Site ID	Monitoring Site Name	Length of Record (days)	Maximum Duration that Chloride Concentration was Above the Threshold (days)						
			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	883	758.9	300.7	94.2	67.9	3.5	<0.1	D
2	Fox River at New Munster	883	494.2	387.6	169.0	6.8	D	D	D
3	Mukwonago River at Mukwonago	763	250.6	192.1	D	D	D	D	D
4	Sugar Creek	763	762.0	155.1	D	D	D	D	D
6	White River near Burlington	763	393.5	214.5	0.2	D	D	D	D
8	Pewaukee River	763	698.4	584.3	61.9	6.9	0.8	D	D
9	Oak Creek	883	281.9	268.8	97.3	65.8	36.5	11.1	3.7
10	Pike River	883	304.0	94.9	59.6	27.9	5.6	D	D
11	Bark River Upstream	763	762.0	613.2	27.9	D	D	D	D
12	Lincoln Creek	883	190.2	131.0	65.2	56.8	46.6	26.2	8.6
13	Ulao Creek	975	594.7	319.4	67.7	22.1	4.9	1.2	D
14	Sauk Creek	883	182.3	43.9	7.3	0.6	0.3	D	D
15	Kilbourn Road Ditch	883	673.0	190.6	58.0	21.6	6.6	4.3	1.1
16	Jackson Creek	763	283.9	184.9	30.1	D	D	D	D
18	Oconomowoc River Upstream	763	569.3	381.0	D	D	D	D	D
20	Oconomowoc River Downstream	763	466.3	466.3	D	D	D	D	D
21	East Branch Milwaukee River	763	414.7	D	D	D	D	D	D
23	Milwaukee River Downstream of Newburg	763	739.4	367.0	1.7	0.2	D	D	D
25	Root River Canal	883	417.2	143.4	52.8	4.4	D	D	D
28	East Branch Rock River	763	414.6	272.0	D	D	D	D	D
30	Des Plaines River	883	339.3	211.2	63.1	10.8	4.2	D	D
32	Turtle Creek	763	615.0	321.8	<0.1	D	D	D	D
33	Pebble Brook	763	761.9	347.8	72.0	0.3	D	D	D
35	Honey Creek Upstream of East Troy	763	762.0	33.5	D	D	D	D	D
36	Honey Creek Downstream of East Troy	763	743.6	180.9	D	D	D	D	D
38	North Branch Milwaukee River	763	595.7	62.3	D	D	D	D	D
40	Stony Creek	763	179.8	21.1	D	D	D	D	D
41	Milwaukee River near Saukville	763	407.4	195.0	D	D	D	D	D
45	Mukwonago River at Nature Road	763	161.0	<0.1	D	D	D	D	D
47	Fox River at Rochester	763	341.4	341.4	59.8	2.7	D	D	D
48	White River at Lake Geneva	763	197.7	71.6	D	D	D	D	D
51	Rubicon River	855	586.5	164.2	30.2	1.1	D	D	D
52	Cedar Creek	763	433.2	199.9	2.0	D	D	D	D
53	Honey Creek at Wauwatosa	883	214.8	152.1	77.4	75.6	60.5	17.2	4.1
54	Whitewater Creek	763	283.5	D	D	D	D	D	D
55	Bark River Downstream[a]	763	--	--	--	--	--	--	--
57	Menomonee River at Wauwatosa	555	221.4	174.0	88.4	75.9	49.8	6.7	3.1
58	Milwaukee River at Estabrook Park	554	271.2	181.5	9.5	0.3	D	D	D
59	Root River near Horlick Dam	883	201.1	196.7	55.1	22.4	2.9	D	D
60	Root River at Grange Avenue	307	193.8	120.1	114.8	96.5	68.2	39.2	6.7
87	Underwood Creek	216	142.6	139.6	39.6	38.1	33.2	5.4	2.0

Note: D indicates that chloride concentration did not exceed this threshold during the monitoring period.

[a] *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 3.17
Number of Water Samples with Chloride Concentrations Higher than Wisconsin Water Quality Criteria: 2018-2021

SEWRPC Site ID	Monitoring Site Name	Total Samples	Samples with Chloride Concentration Higher than Water Quality Criteria	
			Chronic (395 mg/l)	Acute (757 mg/l)
1	Fox River at Waukesha	29	4	0
2	Fox River at New Munster	26	0	0
3	Mukwonago River at Mukwonago	25	0	0
4	Sugar Creek	25	0	0
6	White River near Burlington	25	0	0
8	Pewaukee River	26	2	0
9	Oak Creek	33	11	7
10	Pike River	29	3	0
11	Bark River Upstream	25	0	0
12	Lincoln Creek	35	17	13
13	Ulao Creek	39	5	2
14	Sauk Creek	28	0	0
15	Kilbourn Road Ditch	33	7	4
16	Jackson Creek	26	0	0
18	Oconomowoc River Upstream	25	0	0
20	Oconomowoc River Downstream	25	0	0
21	East Branch Milwaukee River	25	0	0
23	Milwaukee River Downstream of Newburg	26	0	0
25	Root River Canal	28	0	0
28	East Branch Rock River	26	0	0
30	Des Plaines River	30	2	0
32	Turtle Creek	26	0	0
33	Pebble Brook	25	0	0
35	Honey Creek Upstream of East Troy	26	0	0
36	Honey Creek Downstream of East Troy	25	0	0
38	North Branch Milwaukee River	25	0	0
40	Stony Creek	25	0	0
41	Milwaukee River near Saukville	25	0	0
45	Mukwonago River at Nature Road	25	0	0
47	Fox River at Rochester	26	0	0
48	White River at Lake Geneva	25	0	0
51	Rubicon River	27	0	0
52	Cedar Creek	26	0	0
53	Honey Creek at Wauwatosa	40	30	20
54	Whitewater Creek	26	0	0
55	Bark River Downstream	25	0	0
57	Menomonee River at Wauwatosa	28	12	6
58	Milwaukee River at Estabrook Park	19	0	0
59	Root River near Horlick Dam	37	1	0
60	Root River at Grange Avenue	16	11	7
87	Underwood Creek	17	9	6
Supplemental Sampling in Ulao Creek Watershed				
71	Ulao Creek Upstream	11	1	1
72	Helm's Creek	11	0	0
74	Gateway Drive Tributary	12	12	8

Source: SEWRPC

Table 3.18
Characteristics of Lakes Monitored for the Chloride Impact Study

Lake	Lake Type	Surface Area (acres)	Maximum Depth (feet)	Mean Depth (feet)	Drainage Area Size (acres)	Average Water Residence Time (years)
Big Cedar Lake	Spring	955	105	34	5,318	5.5
Geneva Lake	Spring	5,422	140	61	13,029	13.9
Little Muskego Lake	Drainage	478	65	14	6,735	0.9
Moose Lake	Seepage	87	61	40	571	--[a]
Silver Lake	Spring	125	48	18	180	3.2
Voltz Lake	Drained	63	24	7	317	2.2

[a] *Average water residence time has not been calculated for Moose Lake. Average residence times in other seepage lakes in Southeastern Wisconsin range between 2.0 and 4.2 years.*

Source: SEWRPC

#273068 – TR-63 (Chloride Study Conditions and Trends) Table 3.19 - Land Use Features: Lakes
200-1100
JEB/mid
5/6/24

Table 3.19
Urban and Agricultural Land Use for Drainage Areas for Monitored Lakes: 2015

Title	Urban (percent)	Roads and Parking Lots (percent)	Agricultural (percent)
Big Cedar Lake	27.2	7.5	31.9
Geneva Lake	43.9	9.1	21.2
Little Muskego Lake	53.5	15.4	16.9
Moose Lake	32.4	7.0	12.0
Silver Lake	58.4	9.3	0.0
Voltz Lake	18.5	4.7	48.8

Source: SEWRPC

Table 3.20
Chloride Concentrations in Lakes Monitored for the Chloride Impact Study: 2018-2020

Lake	Depth (feet)[a]	Samples	Minimum (mg/l)	Mean (mg/l)	Maximum (mg/l)	Standard Deviation (mg/l)
Big Cedar Lake	All samples	53	56.7	58.9	61.8	1.15
	0-20	11	56.8	59.2	60.9	1.20
	> 20	42	56.7	58.9	61.8	1.14
Geneva Lake	All samples	62	48.1	51.2	54.9	1.76
	0-20	12	48.1	51.1	54.2	2.10
	> 20	50	48.4	51.2	54.9	1.69
Little Muskego Lake	All samples	68	139.0	185.2	270.0	32.38
	0-20	25	139.0	161.9	204.0	17.23
	> 20	43	151.0	198.7	270.0	31.50
Moose Lake	All samples	58	56.6	61.9	66.3	2.26
	0-20	21	56.6	61.7	66.3	2.27
	> 20	37	56.7	61.9	66.1	2.28
Silver Lake	All samples	57	33.7	37.3	41.9	1.65
	0-20	23	33.7	37.3	40.3	1.67
	> 20	34	34.4	37.3	41.9	1.65
Voltz Lake	All samples	45	25.6	35.3	43.7	5.68
	0-20	43	25.6	34.9	43.7	5.59
	> 20	2	41.7	42.3	42.9	0.85

[a] *The depth of the thermocline during stratification is estimated to be about 20 feet in these lakes.*

Source: SEWRPC

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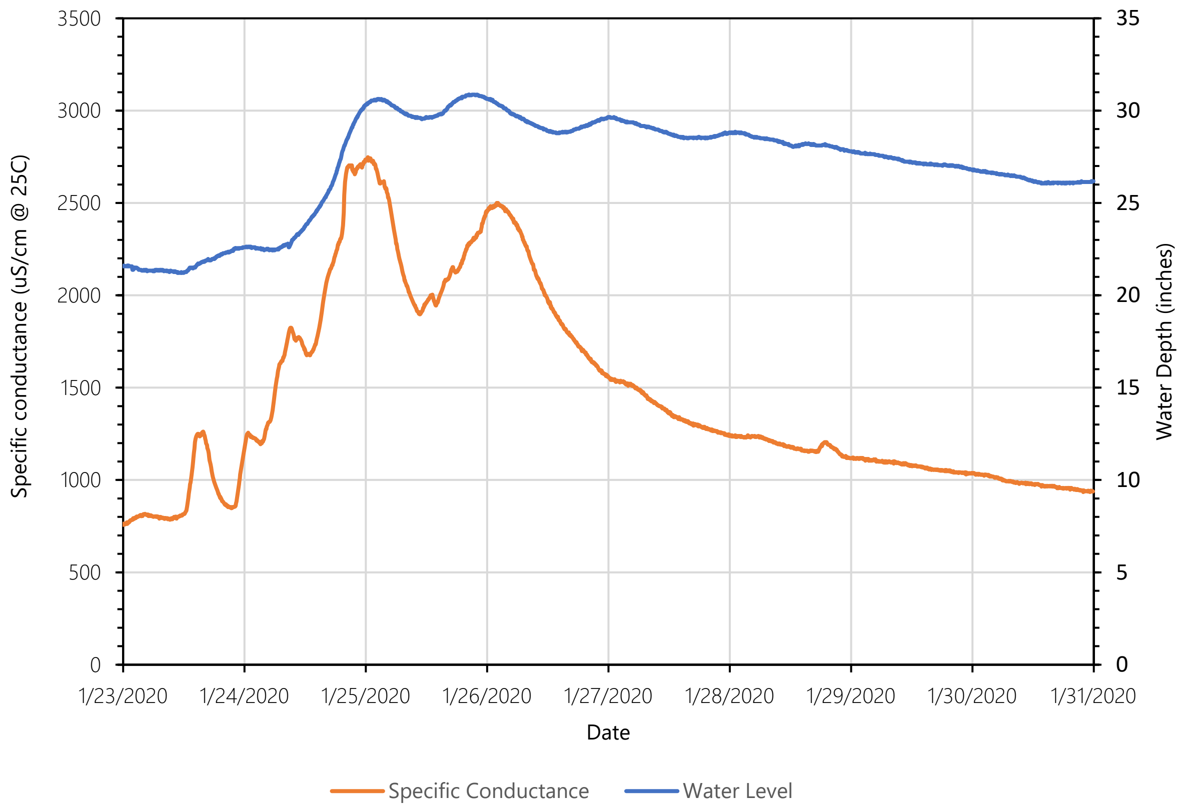
CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 3

ANALYSIS OF MONITORING DATA COLLECTED FOR THE CHLORIDE IMPACT STUDY: 2018-2021

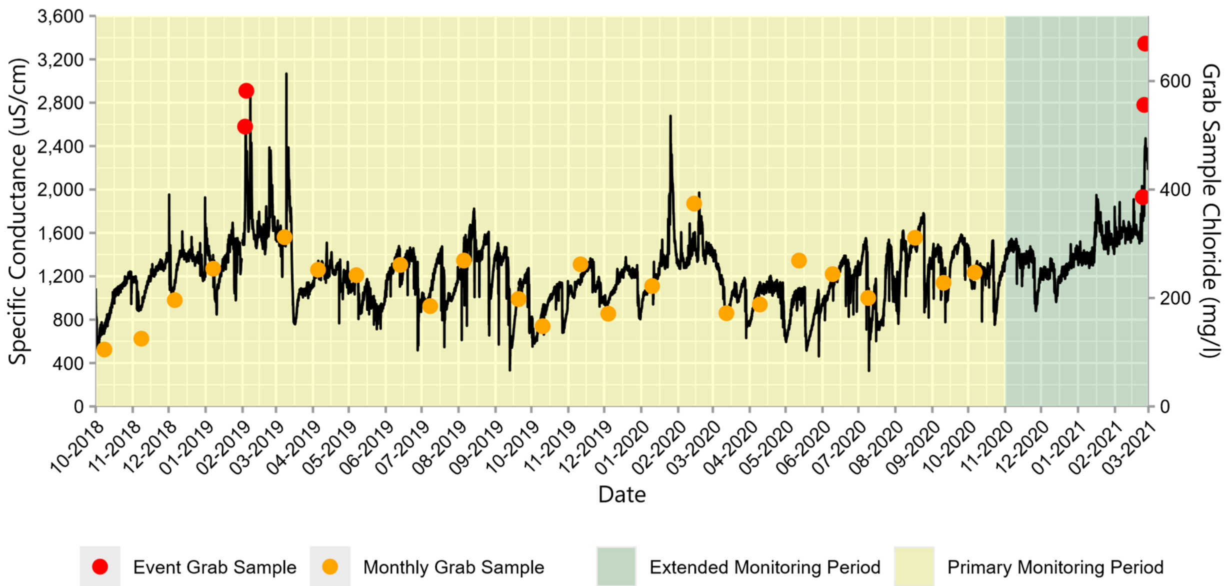
FIGURES

Figure 3.1
Example of Continuous Specific Conductance and Water Level Data: Site 15 Kilbourn Road Ditch



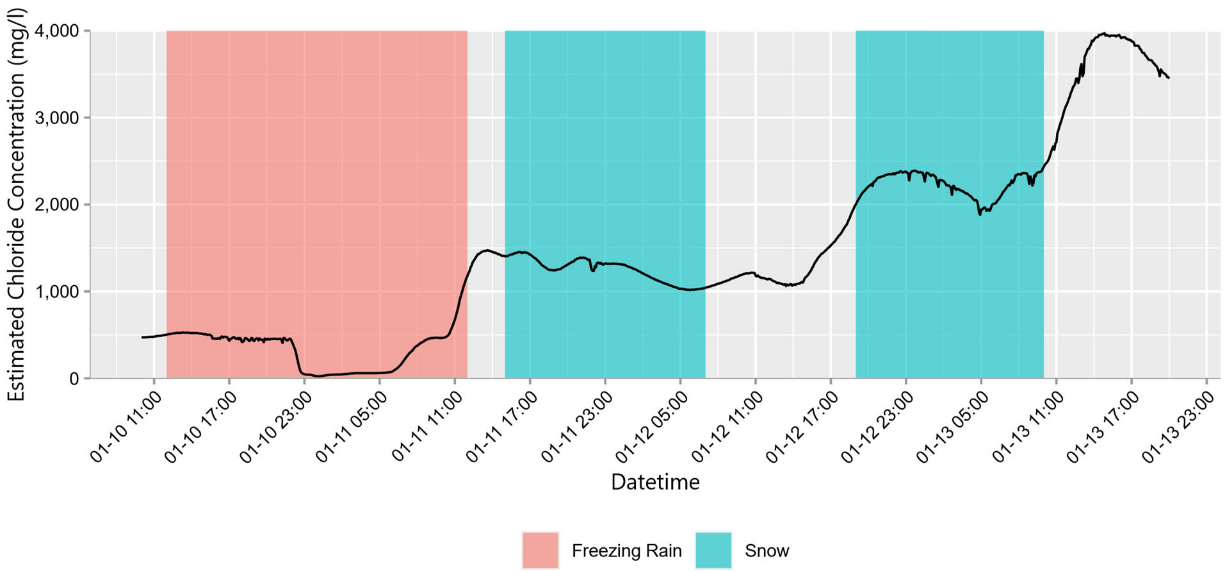
Source: SEWRPC

Figure 3.2
Continuous and Discrete Data Collection for Chloride Impact Study: Site 1 Fox River at Waukesha



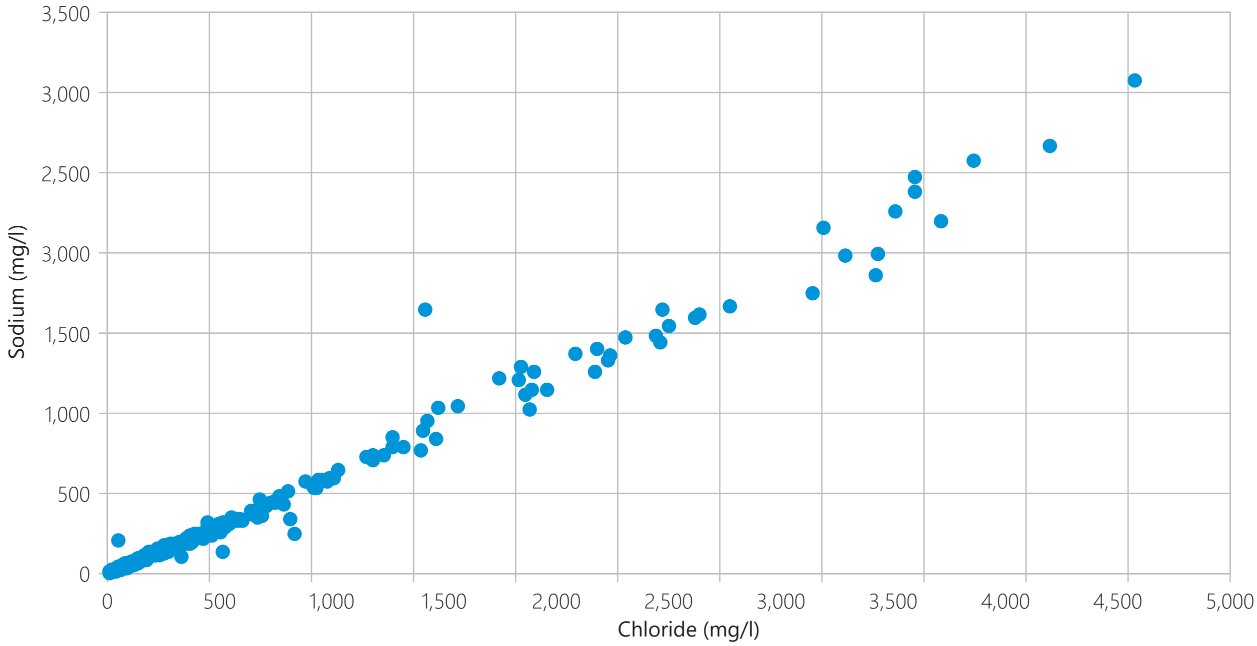
Source: SEWRPC

Figure 3.3
Rapid Succession of Dilution and Winter Spike in Estimated Chloride Concentrations: Site 12 Lincoln Creek



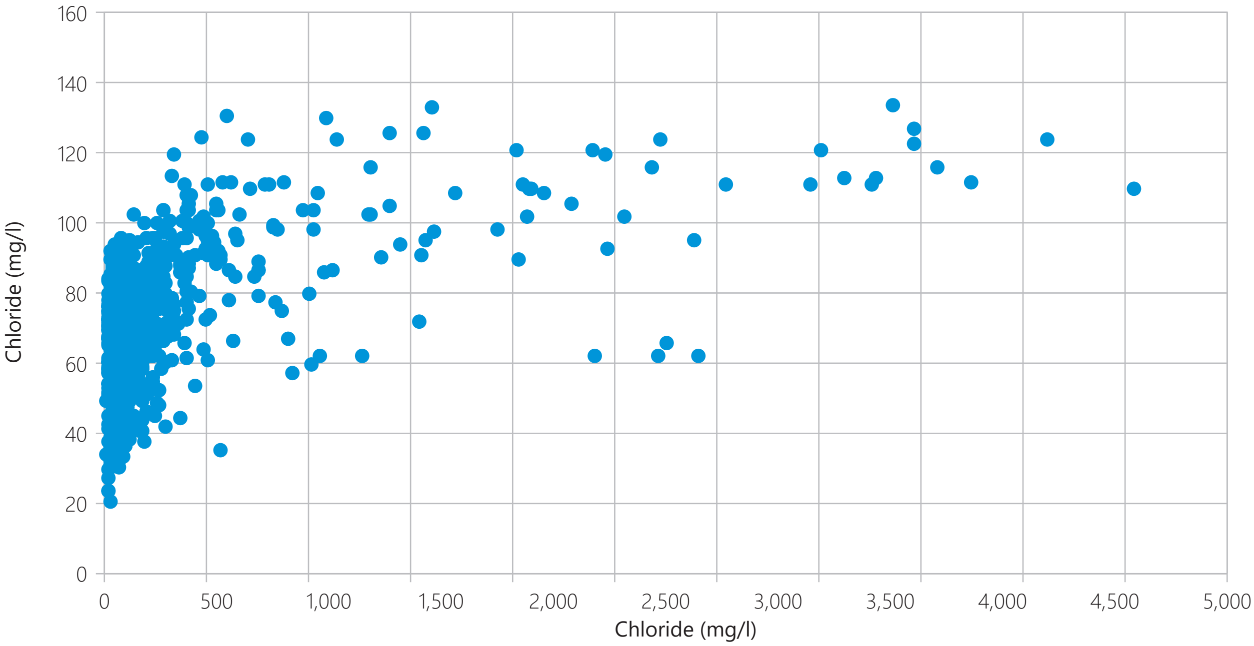
Source: SEWRPC

Figure 3.4
Relationship Between Concentrations of Sodium and Chloride at Chloride Impact Study Stream Monitoring Sites



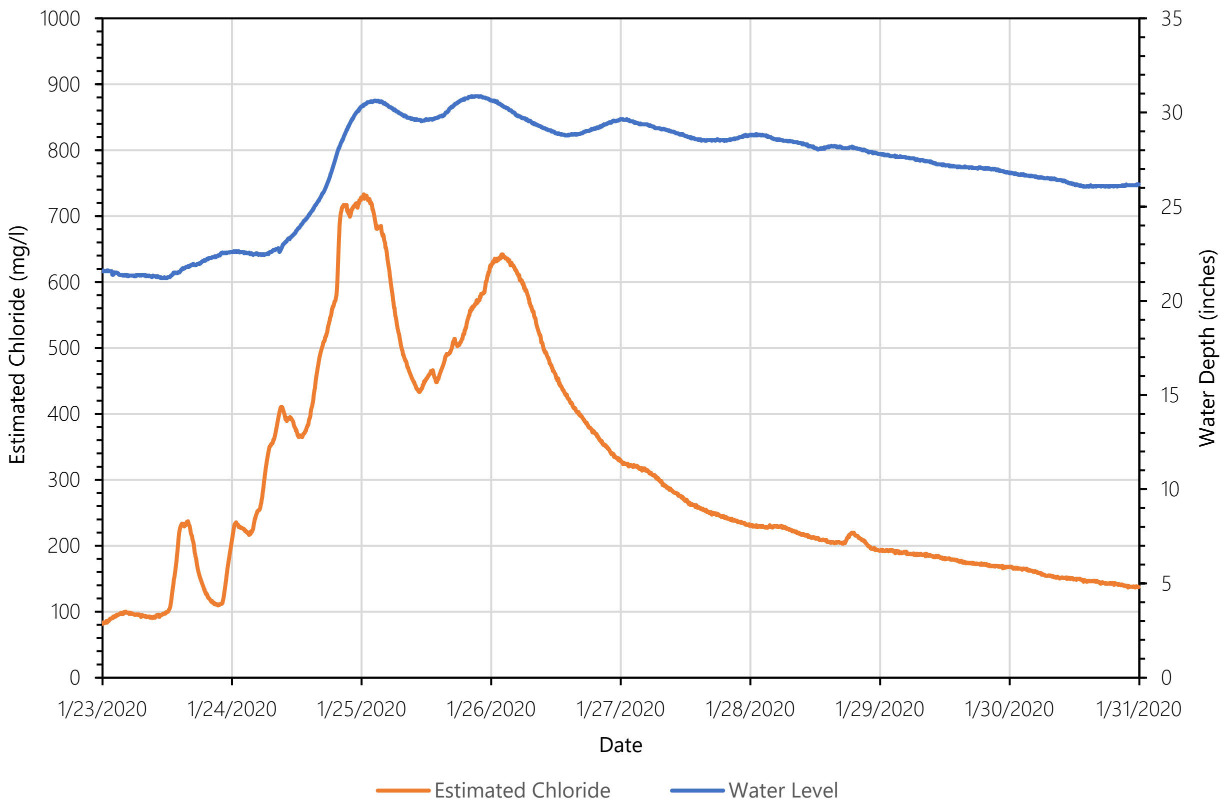
Source: SEWRPC

Figure 3.5
Relationship Between Concentrations of Calcium and Chloride at Chloride Impact Study Stream Monitoring Sites



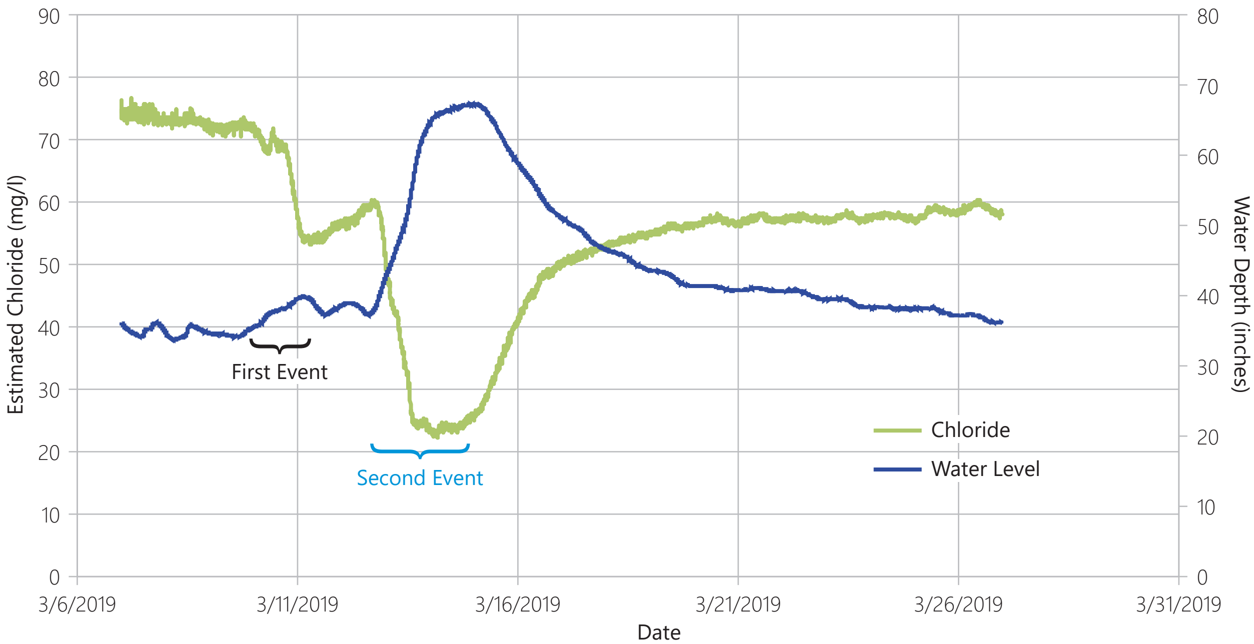
Source: SEWRPC

Figure 3.6
Estimated Continuous Chloride and Water Level Data: Site 15 Kilbourn Road Ditch



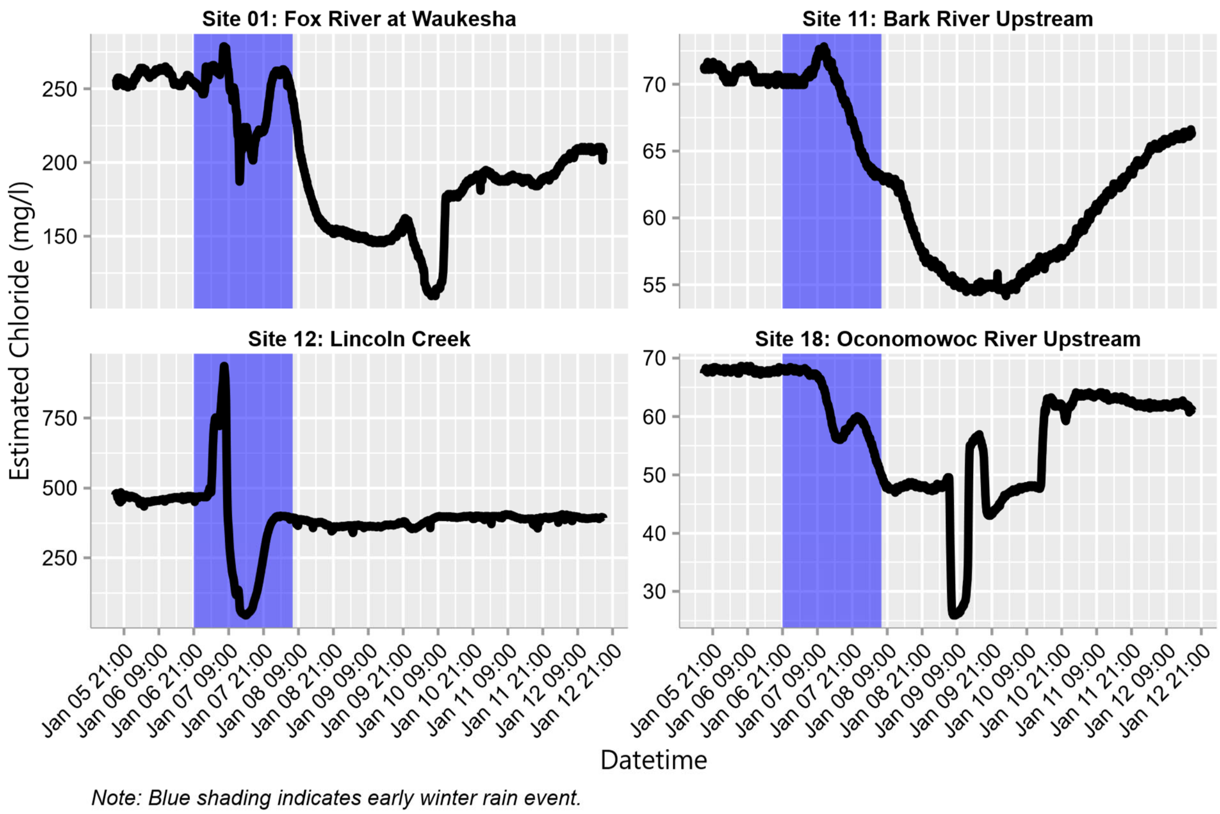
Source: SEWRPC

Figure 3.7
Water Depth and Chloride Concentration at Site 6 White River near Burlington: March 2019



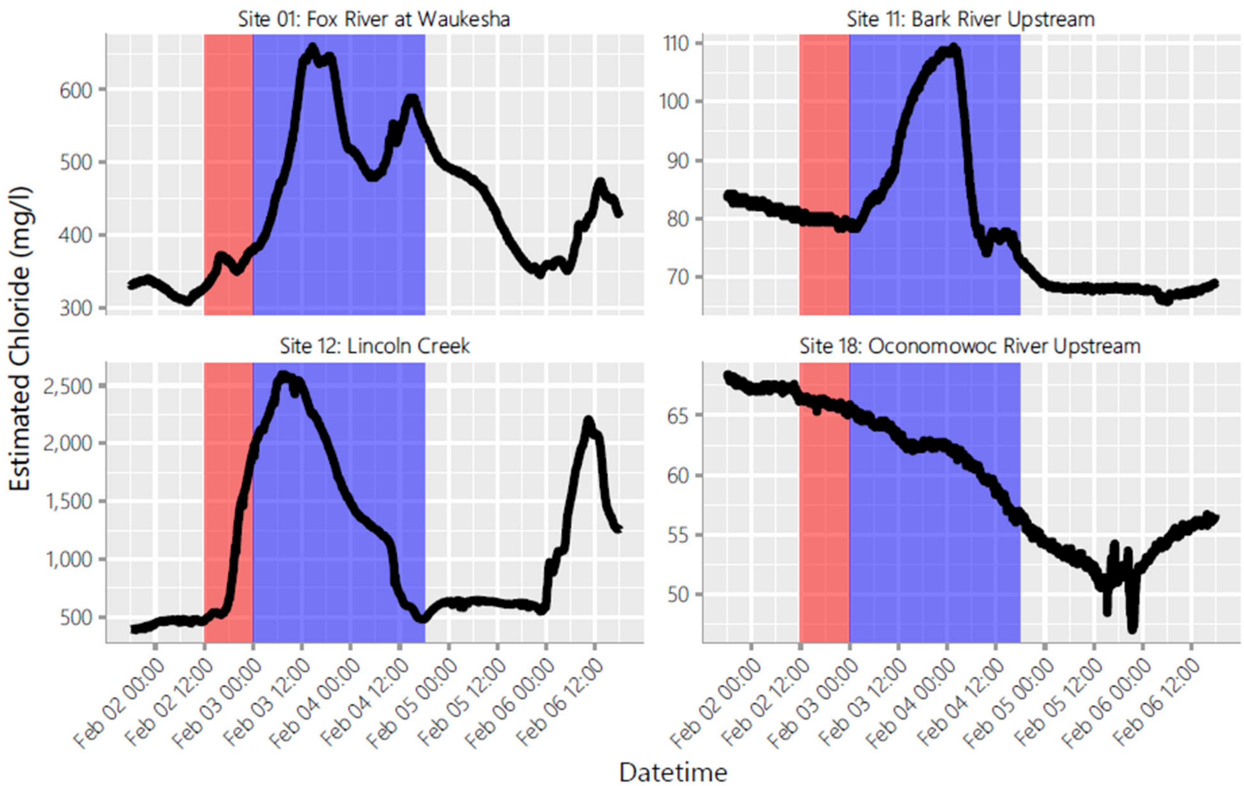
Source: SEWRPC

Figure 3.8
Estimated Chloride Concentrations at Sites 1, 11, 12, and 18 Following Early Winter Rain



Source: SEWRPC

Figure 3.9
Estimated Chloride Concentrations at Sites 1, 11, 12, and 18 Following Mid-Winter Rain

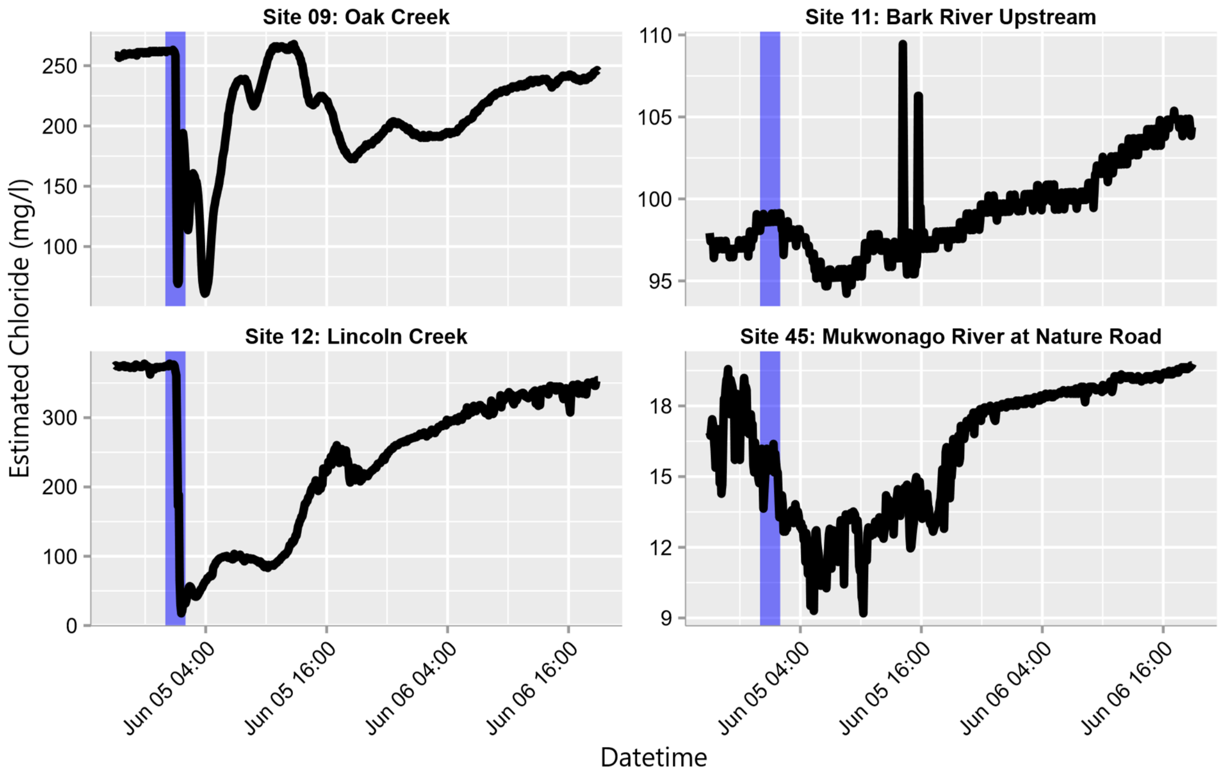


Note: Red shading indicates above freezing temperatures prior to onset of precipitation.

Blue shading indicates mid-winter rain event.

Source: SEWRPC

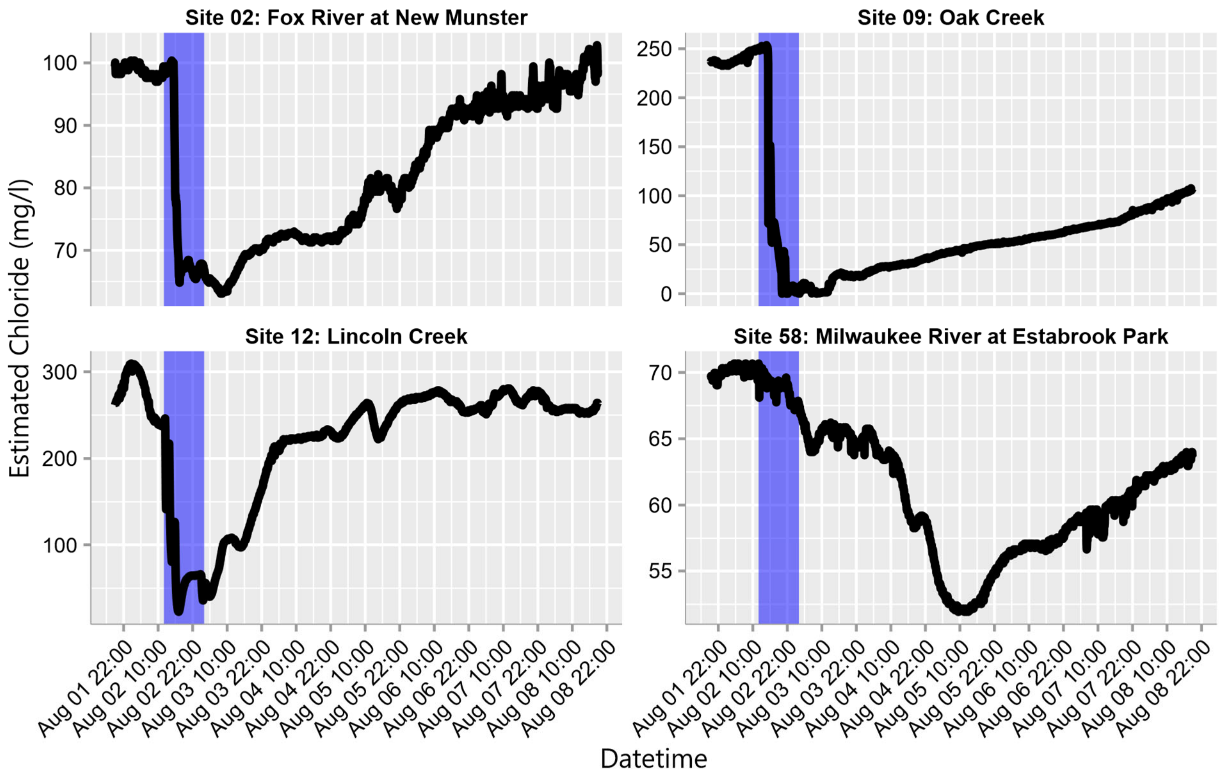
Figure 3.10
Estimated Chloride Concentrations at Sites 9, 11, 12, and 45 Following Light Summer Rain



Note: Blue shading indicates general timing of rain event.

Source: SEWRPC

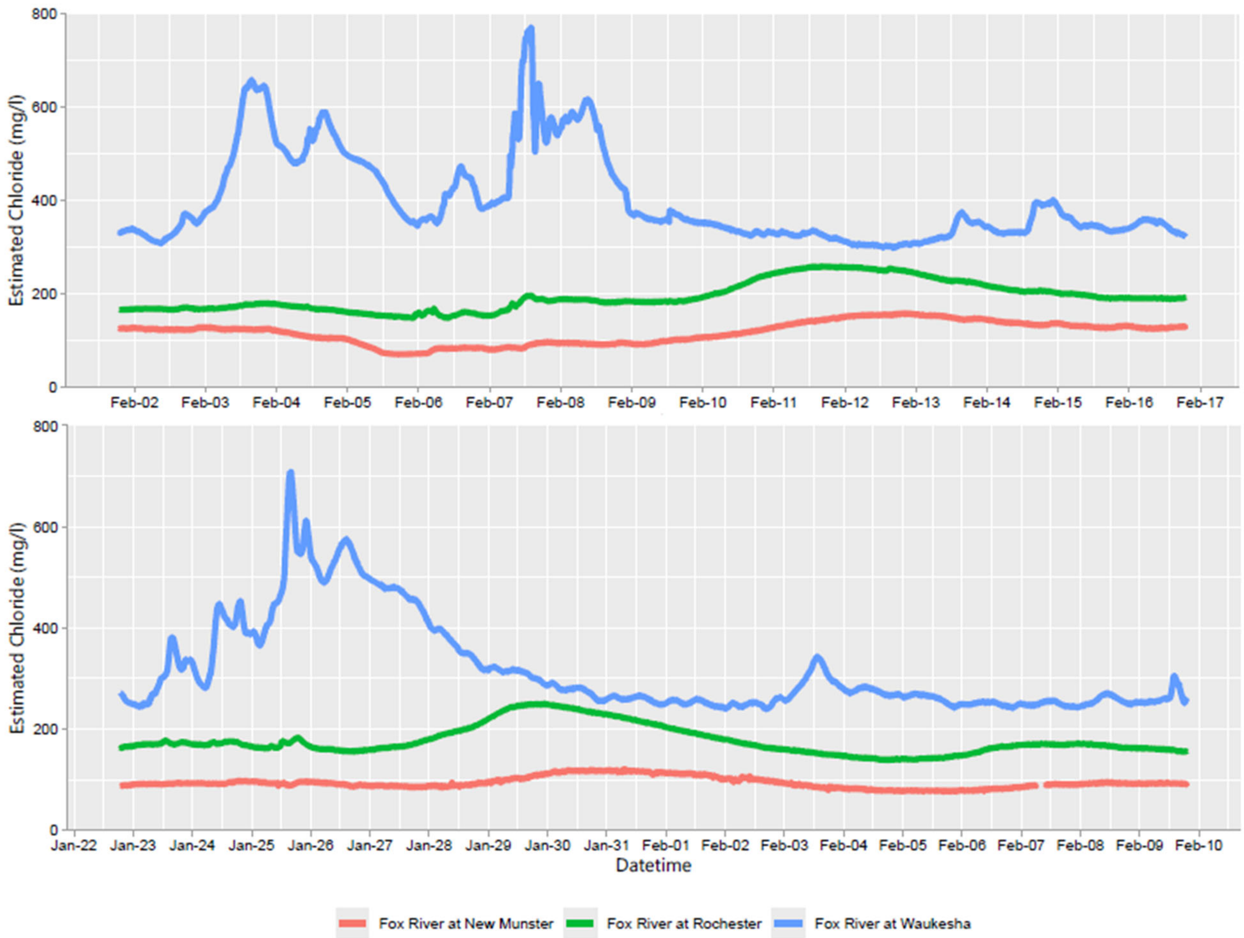
Figure 3.11
Estimated Chloride Concentrations at Sites 2, 9, 12, and 58 Following Heavy Summer Rain



Note: Blue shading indicates general timing of rain event.

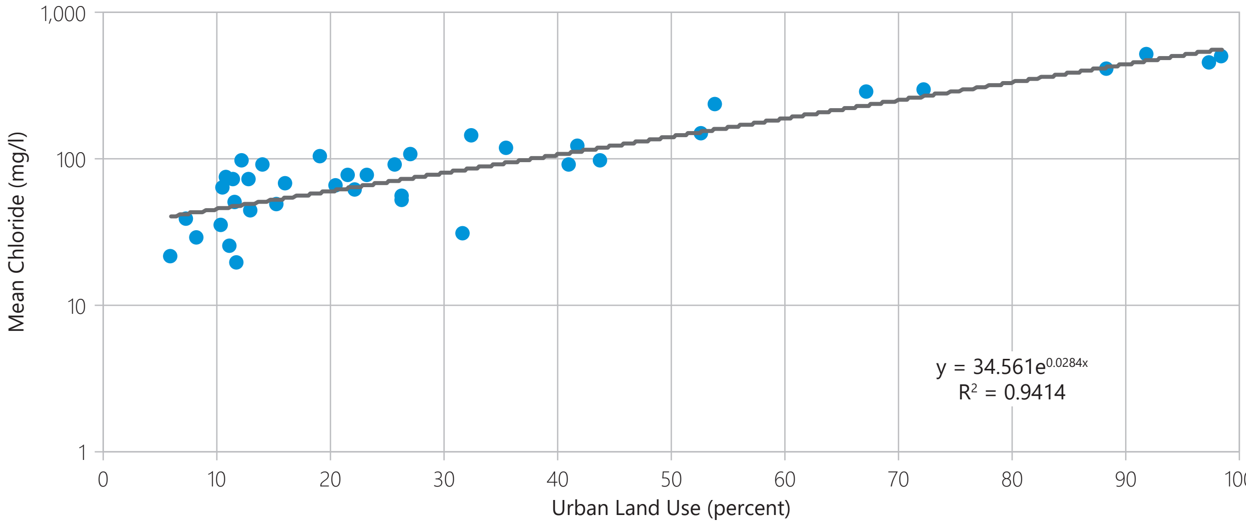
Source: SEWRPC

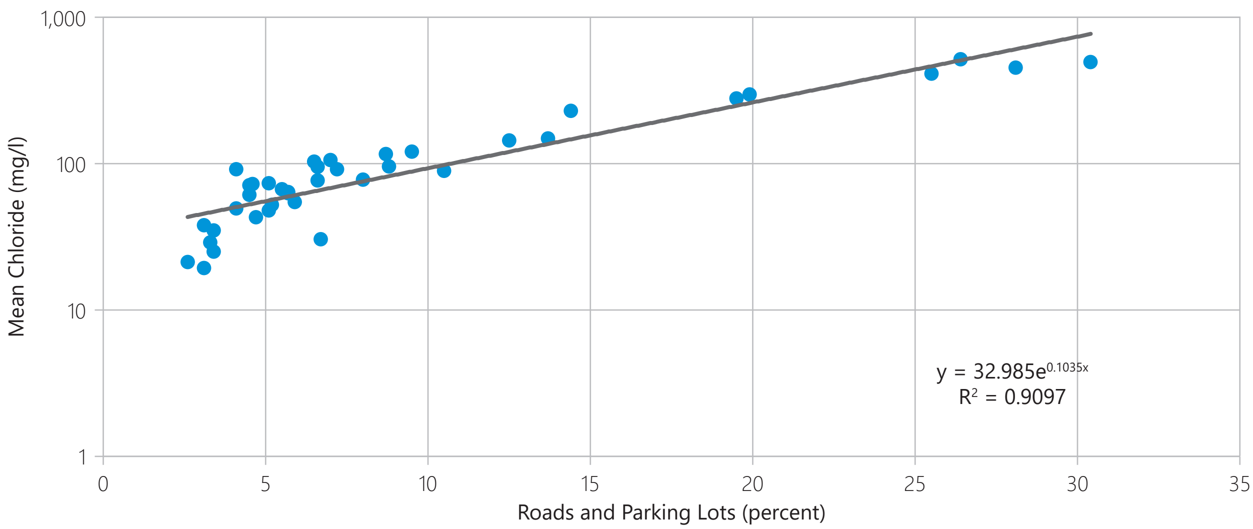
Figure 3.12
Propagation of Chloride-Rich Water Downstream on Fox River: February 2019 and January 2020

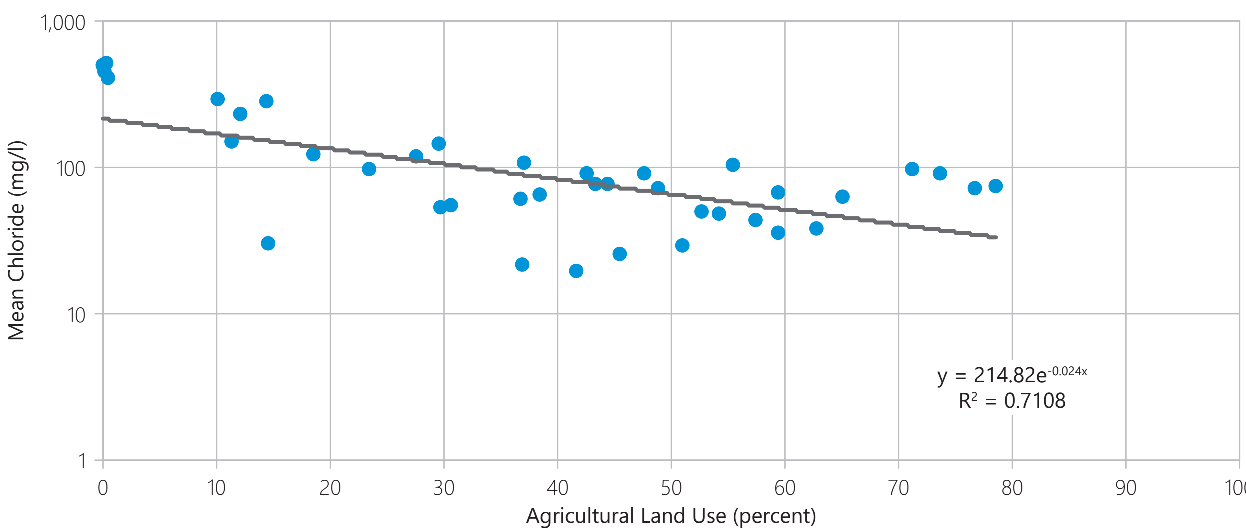


Source: SEWRPC

Figure 3.13
Relationships Between Drainage Area Land Use and Mean Chloride Concentration at Chloride Impact Study Stream Monitoring Sites

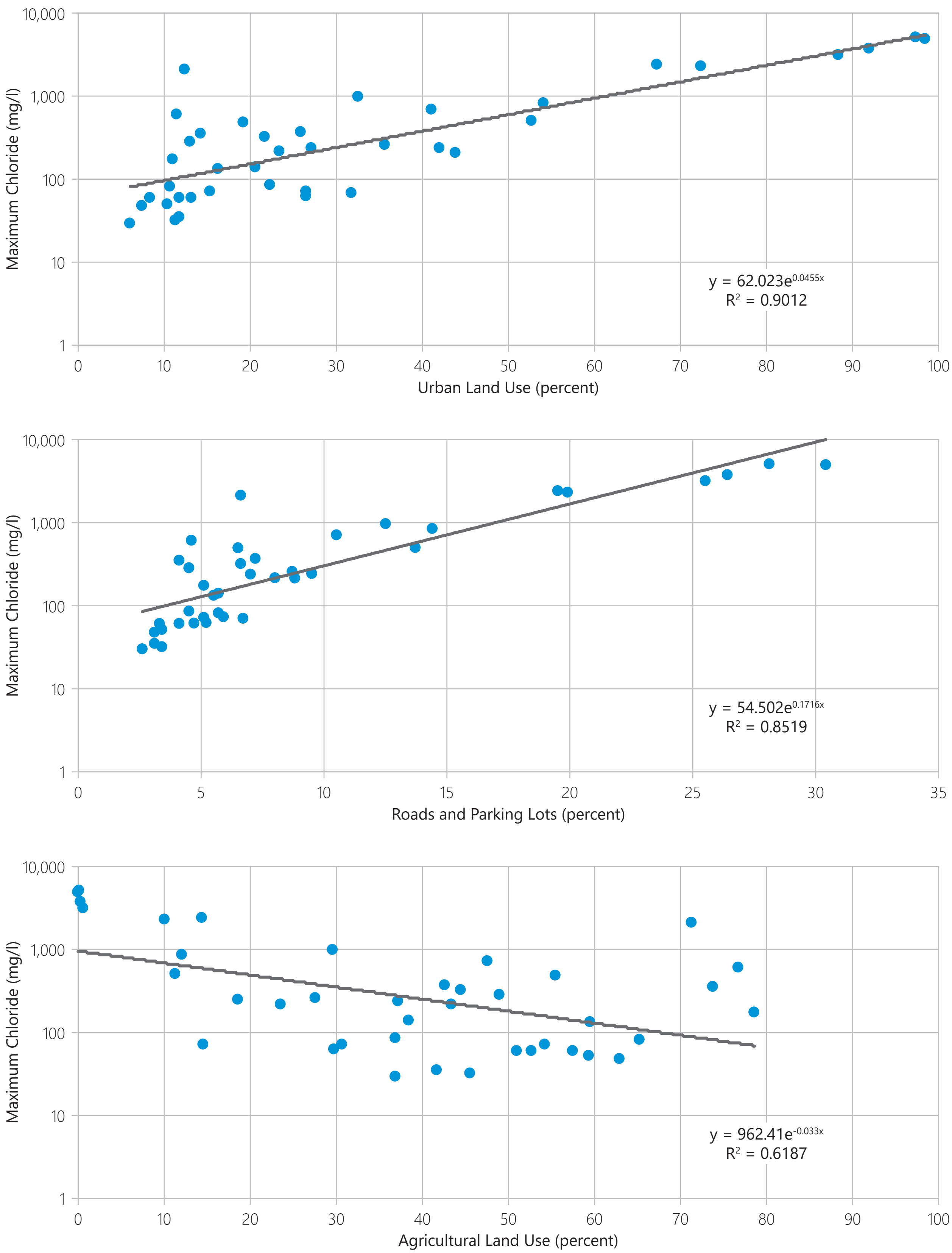






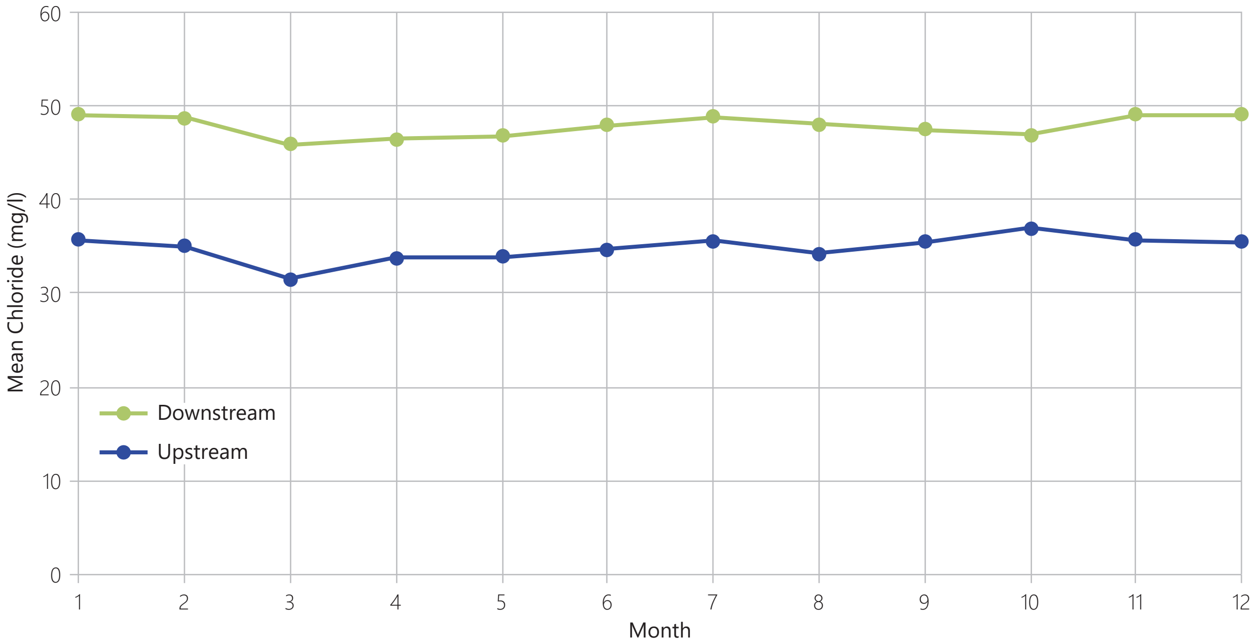
Source: SEWRPC

Figure 3.14
Relationships Between Drainage Area Land Use and Maximum Chloride Concentration at Chloride Impact Study Stream Monitoring Sites



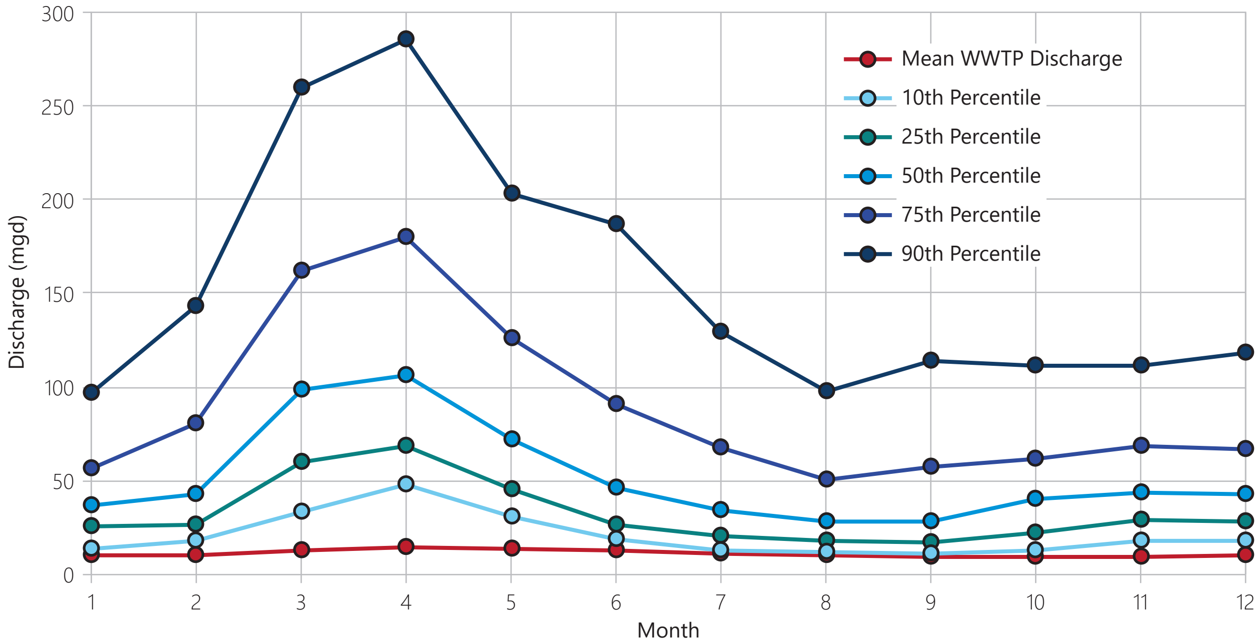
Source: SEWRPC

Figure 3.15
Monthly Mean Chloride Concentrations in Honey Creek Upstream and Downsteam of the East Troy Wastewater Treatment Plant: October 2018 Through October 2020



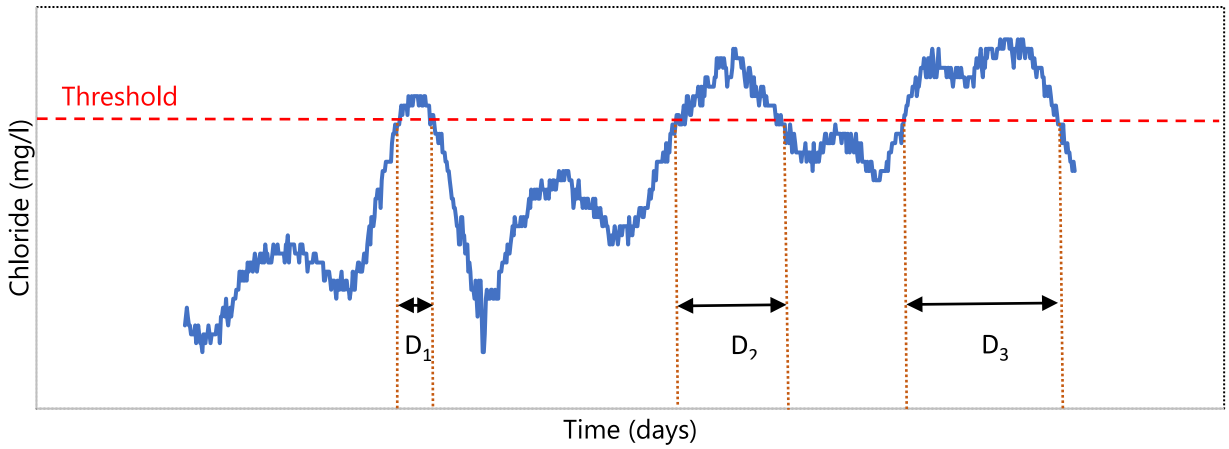
Source: SEWRPC

Figure 3.16
Comparison of Discharge in the Fox River at Waukesha to Discharge from Upstream Wastewater Treatment Plants



Source: SEWRPC

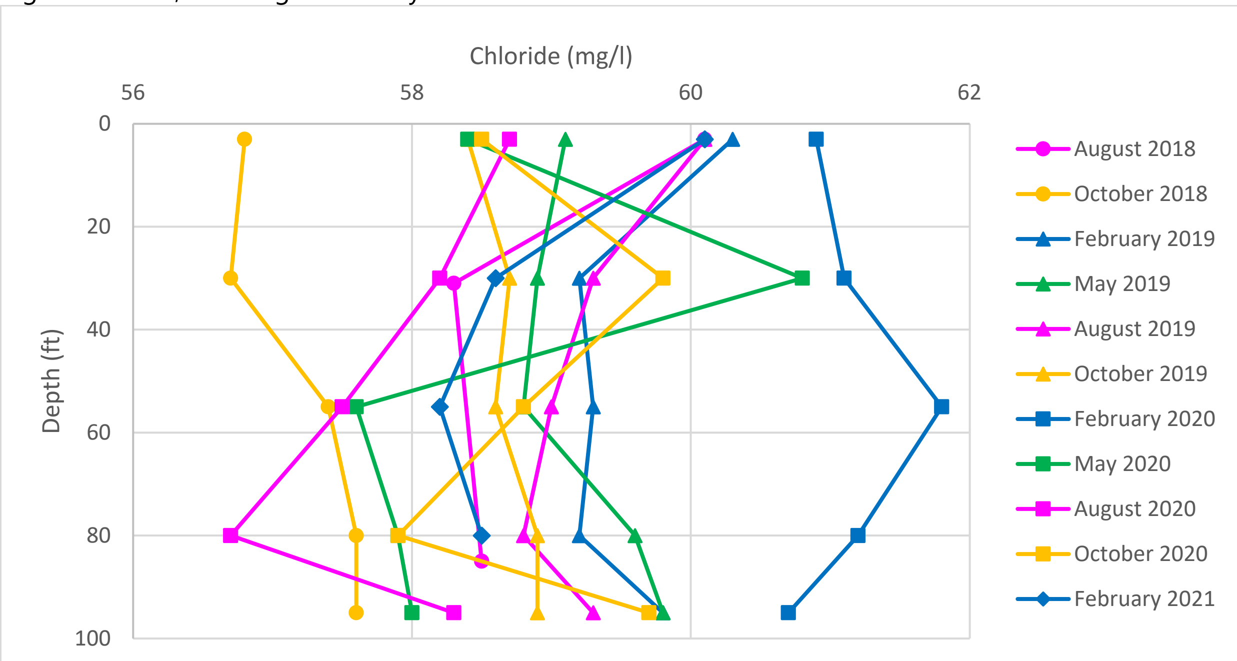
Figure 3.17
Example of Continuous Time Series Data Showing Events Exceeding Threshold



Source: SEWRPC

Figure 3.18
Profiles of Chloride Concentration with Depth on Study Lakes: 2018-2021

Big Cedar Lake, Washington County



Geneva Lake, Walworth County

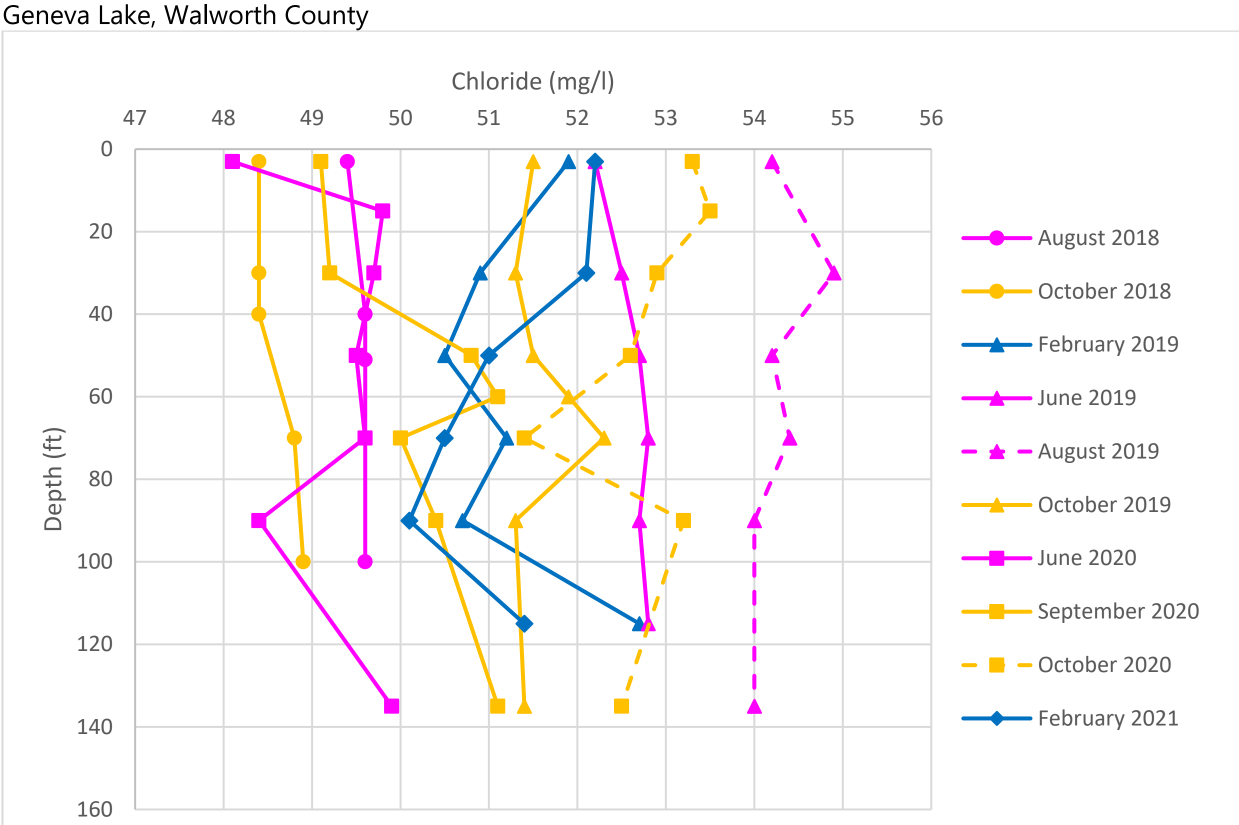
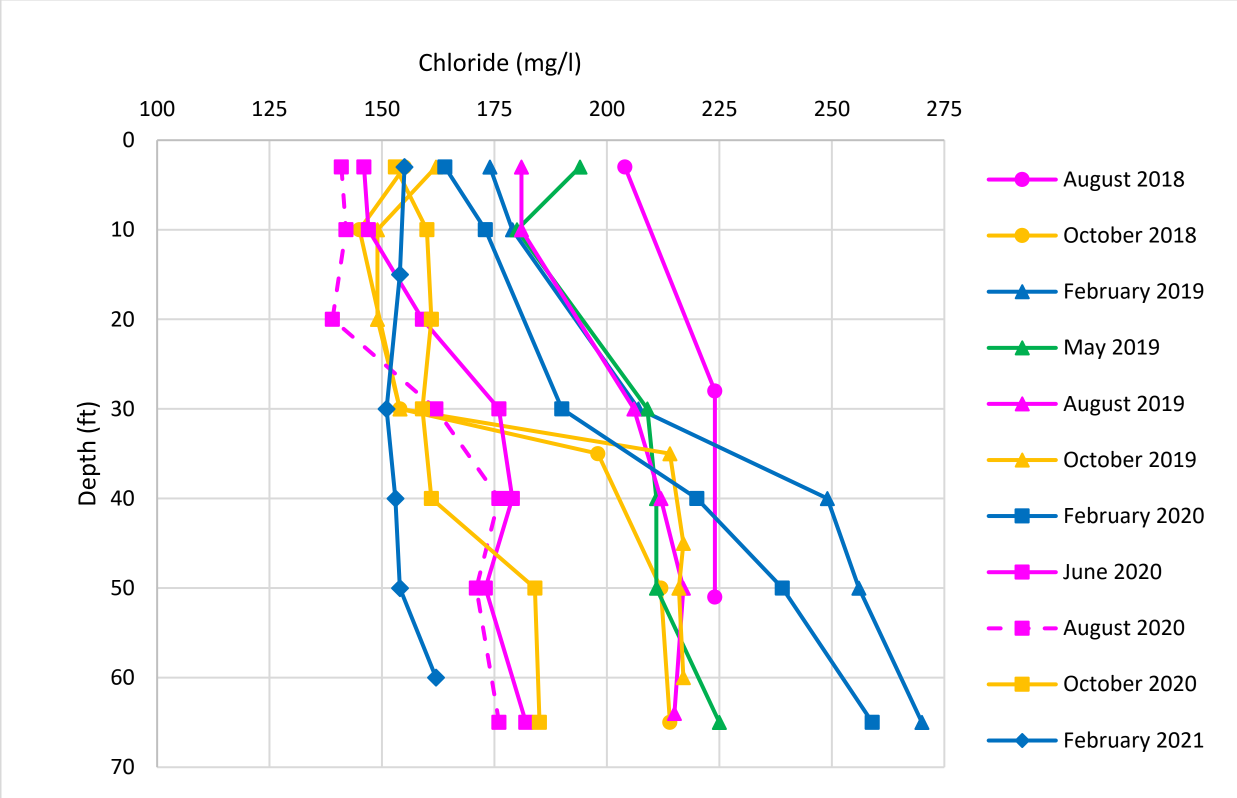


Figure 3.18 (Continued)

Little Muskego Lake, Waukesha County



Moose Lake, Waukesha County

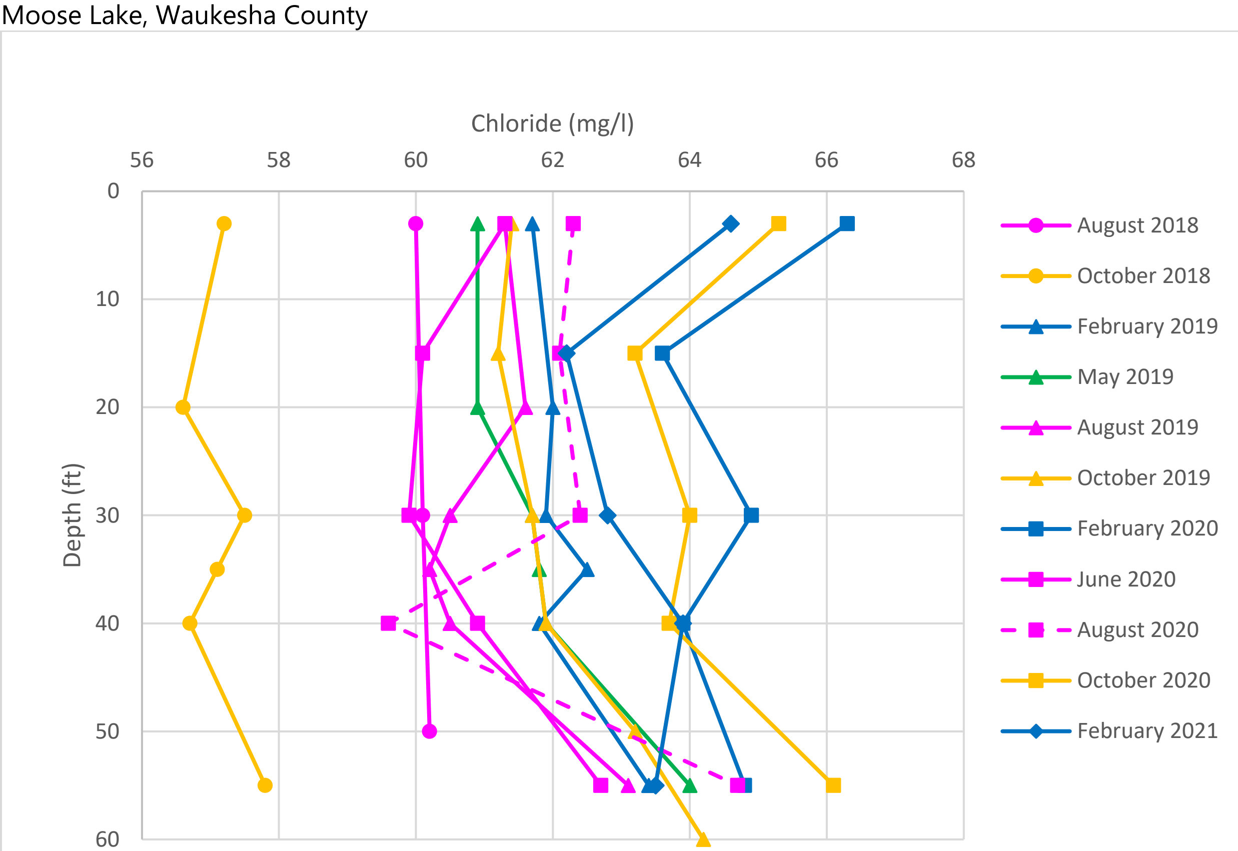
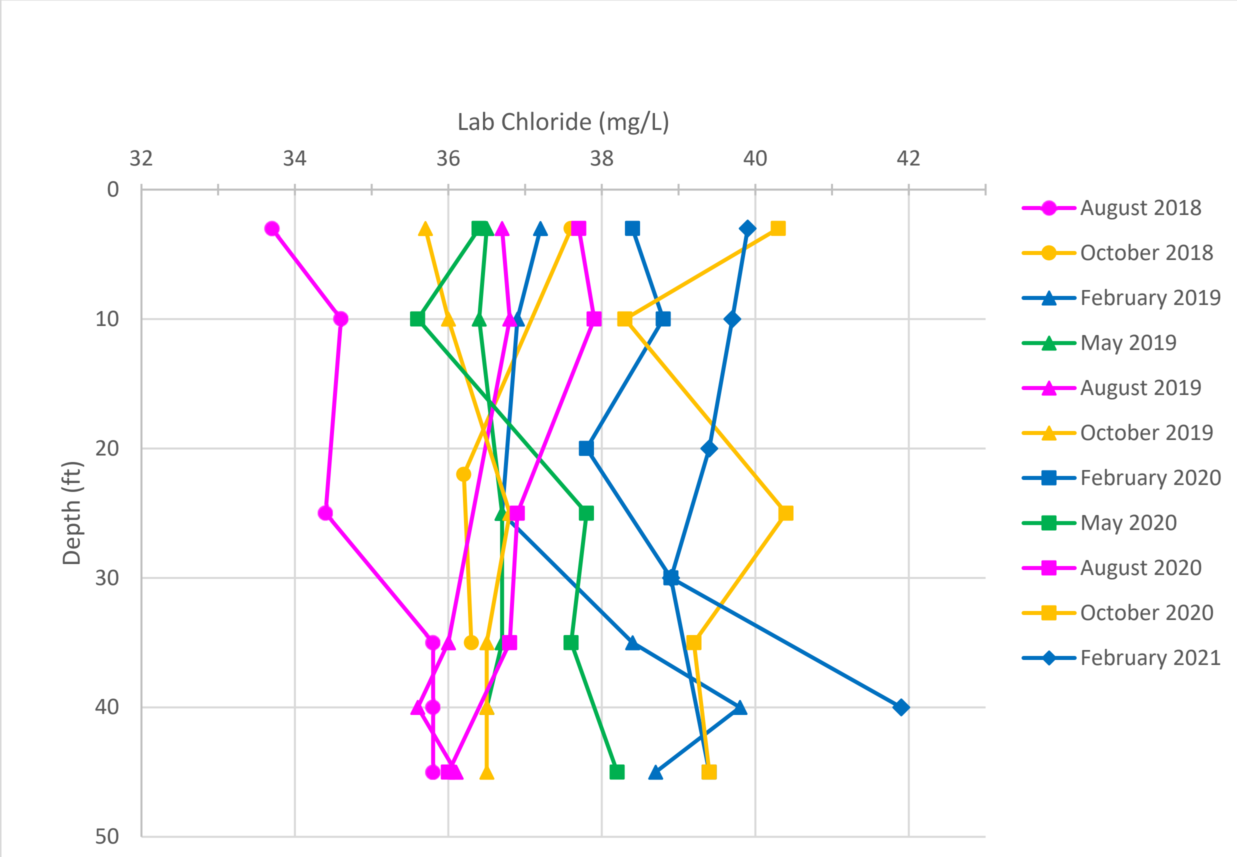
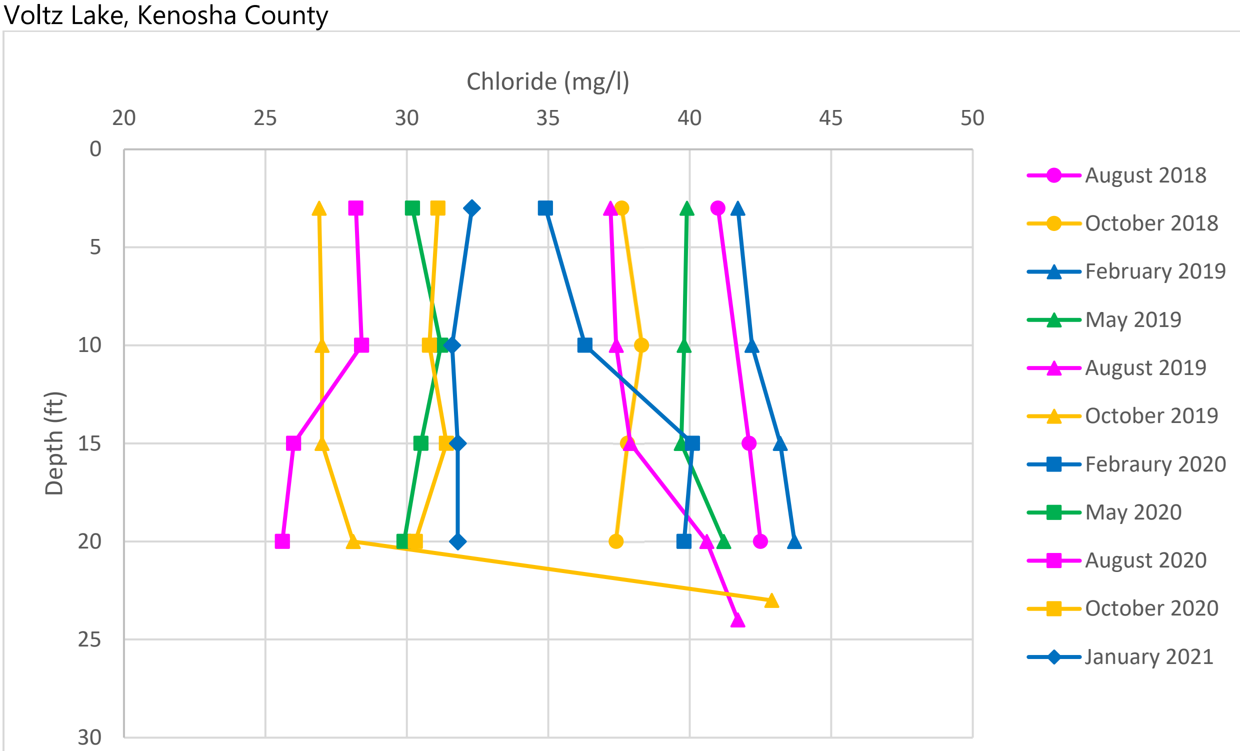


Figure 3.18 (Continued)

Silver Lake, Washington County

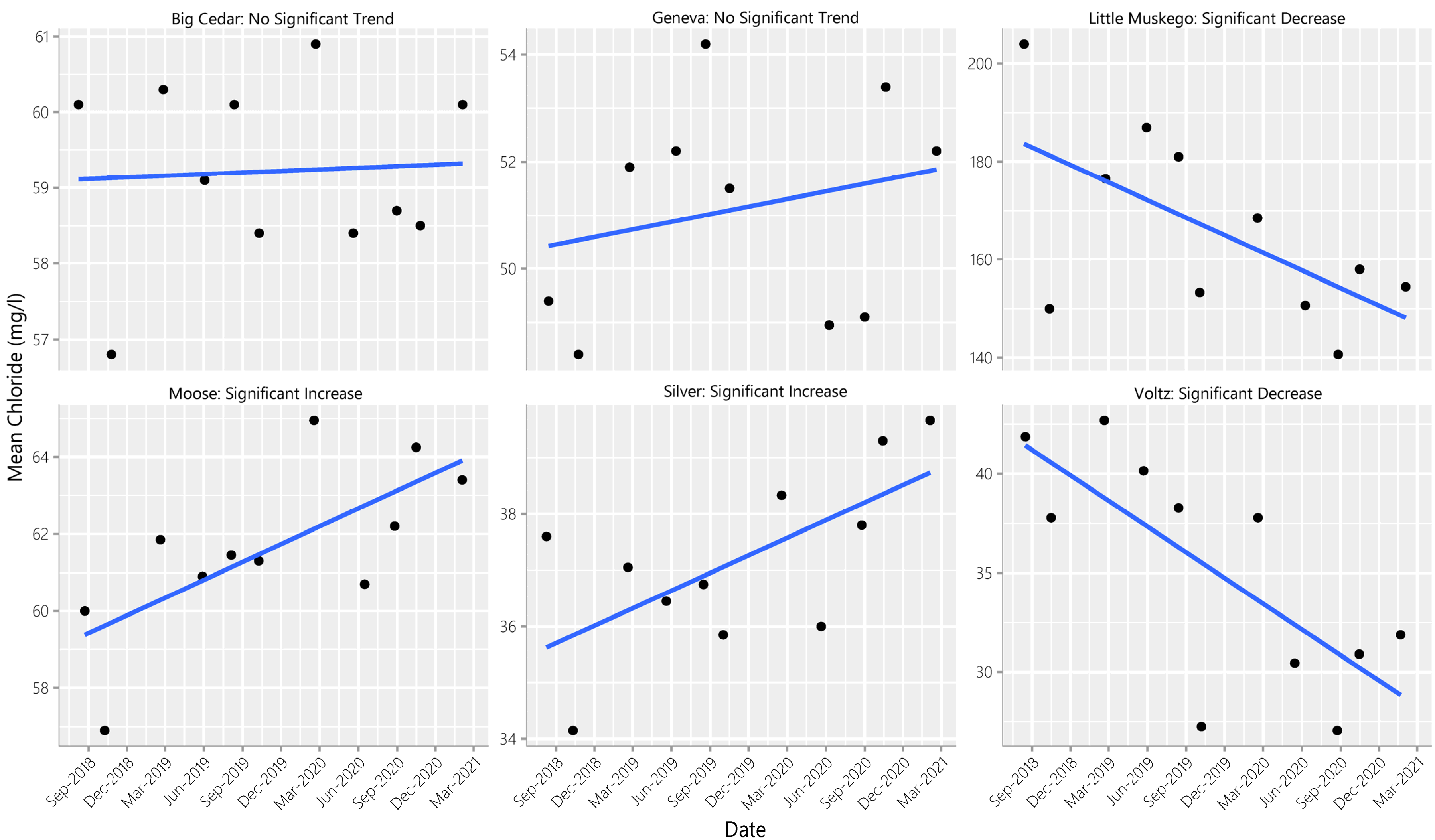


Voltz Lake, Kenosha County



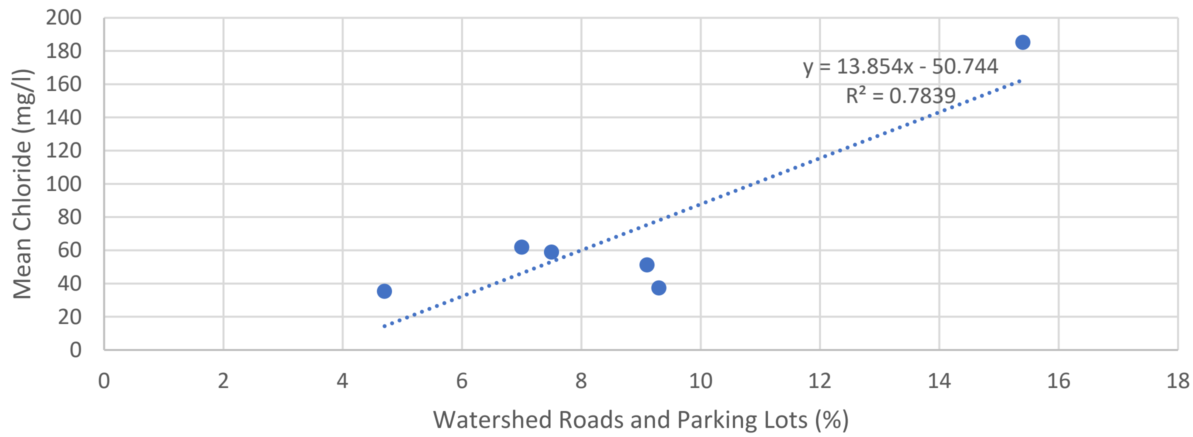
Source: SEWRPC

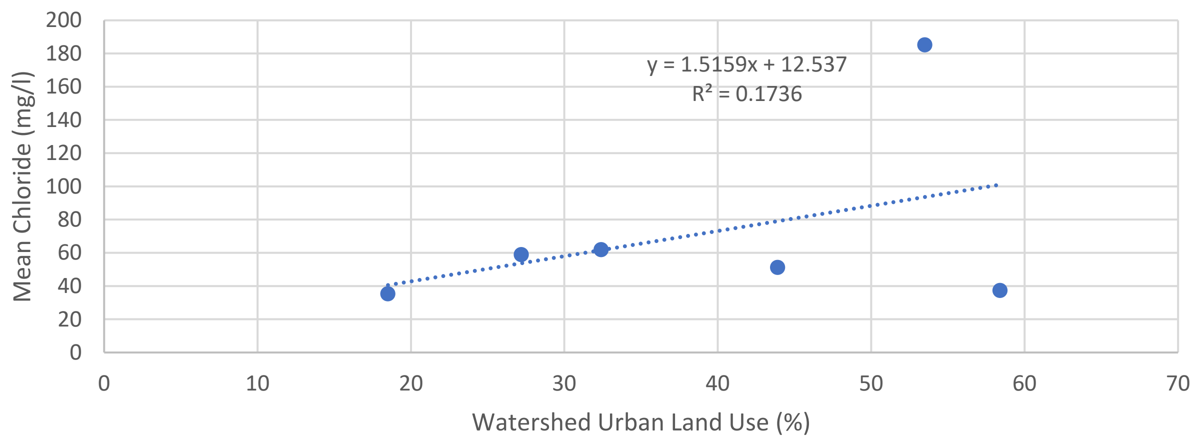
Figure 3.19
Mean Chloride Concentration Over Time for Shallow Samples in Chloride Impact Study Lakes: 2018-2021

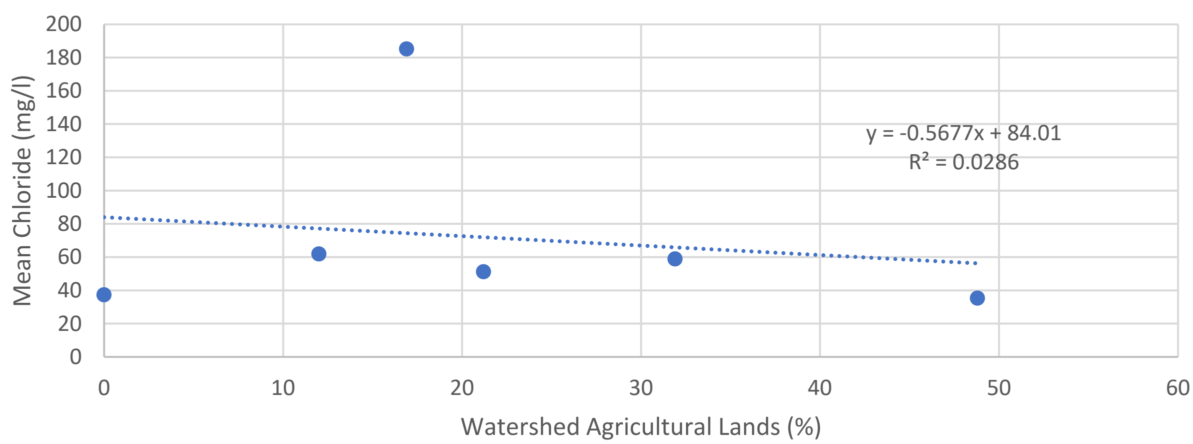


Source: SEWRPC

Figure 3.20
Correlations of Lake Mean Shallow Chloride Concentrations with Watershed Land Uses







Source: SEWRPC

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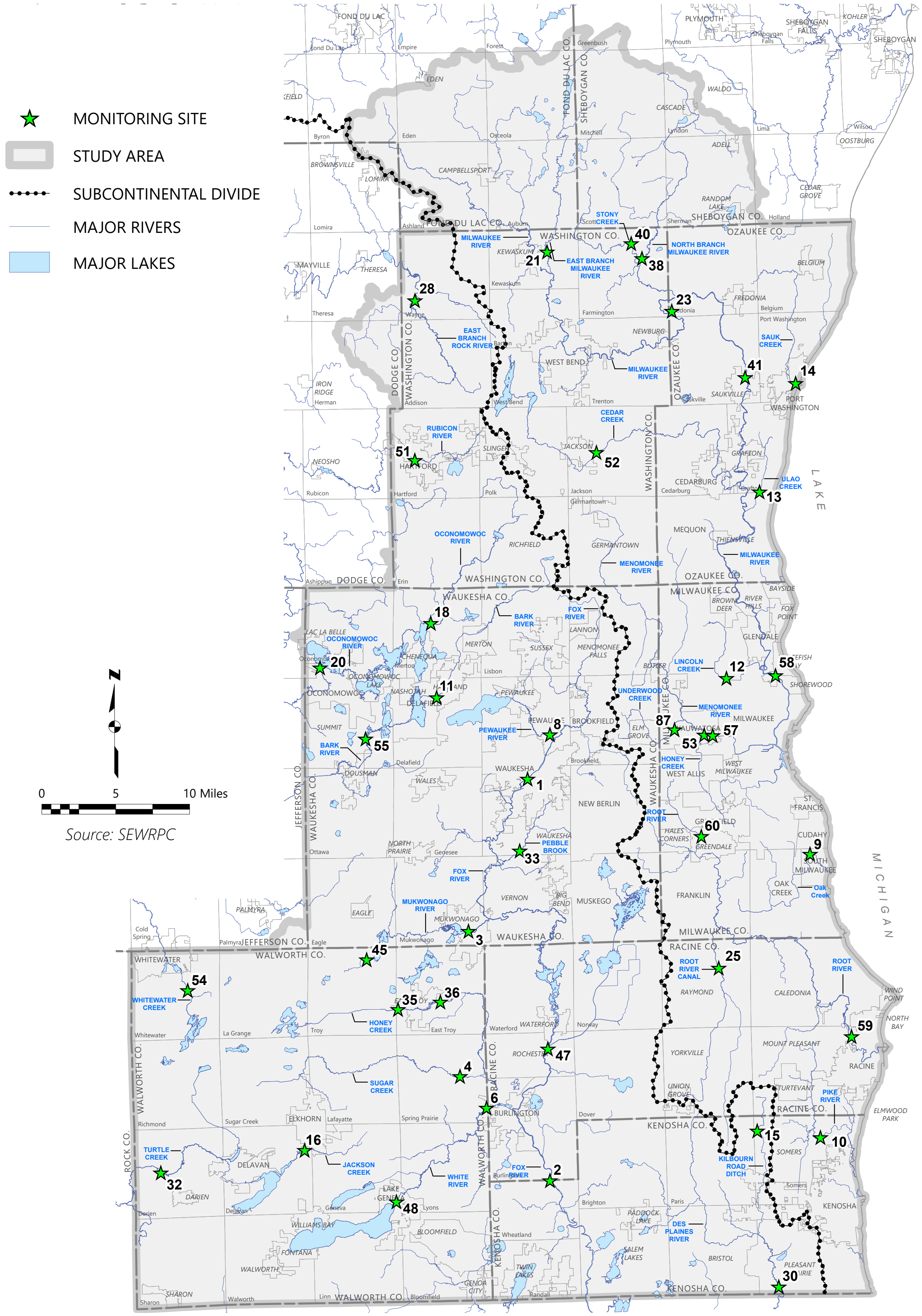
CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 3

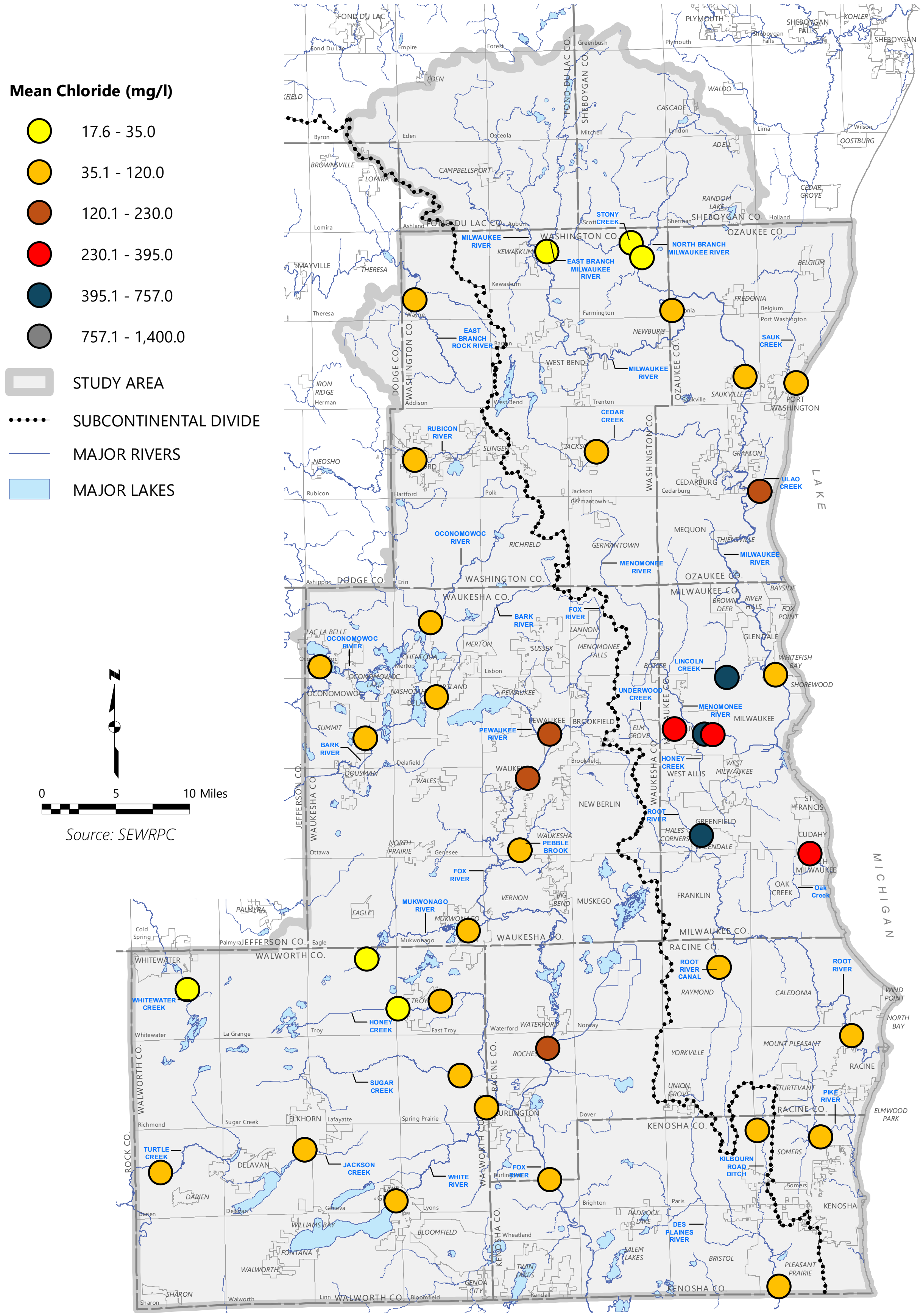
ANALYSIS OF MONITORING DATA COLLECTED FOR THE CHLORIDE IMPACT STUDY: 2018-2021

MAPS

Map 3.1
Stream Monitoring Sites for the Chloride Impact Study

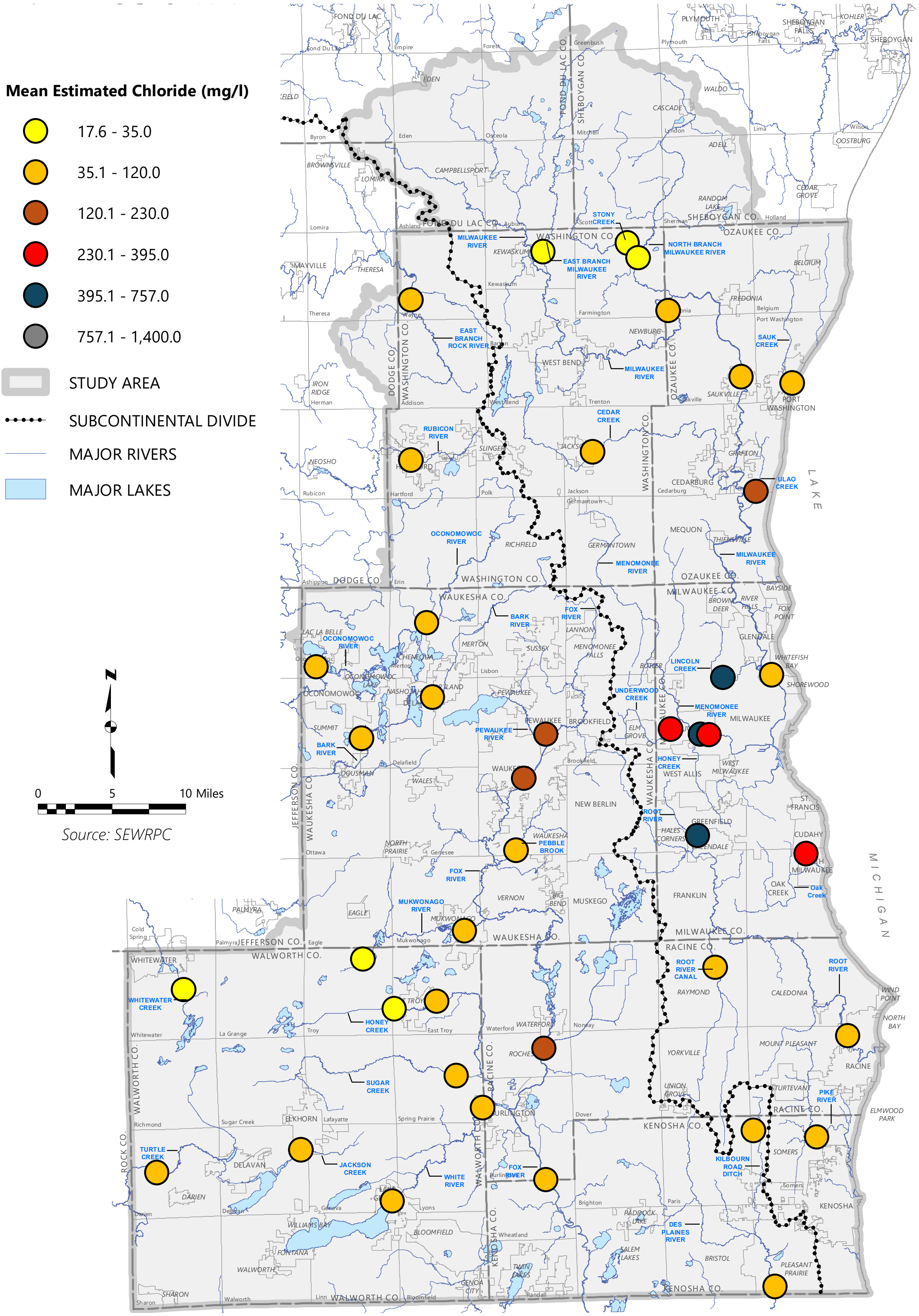


Map 3.2
Mean Chloride Concentrations at Chloride Impact Study Stream Monitoring Sites: 2018 - 2021

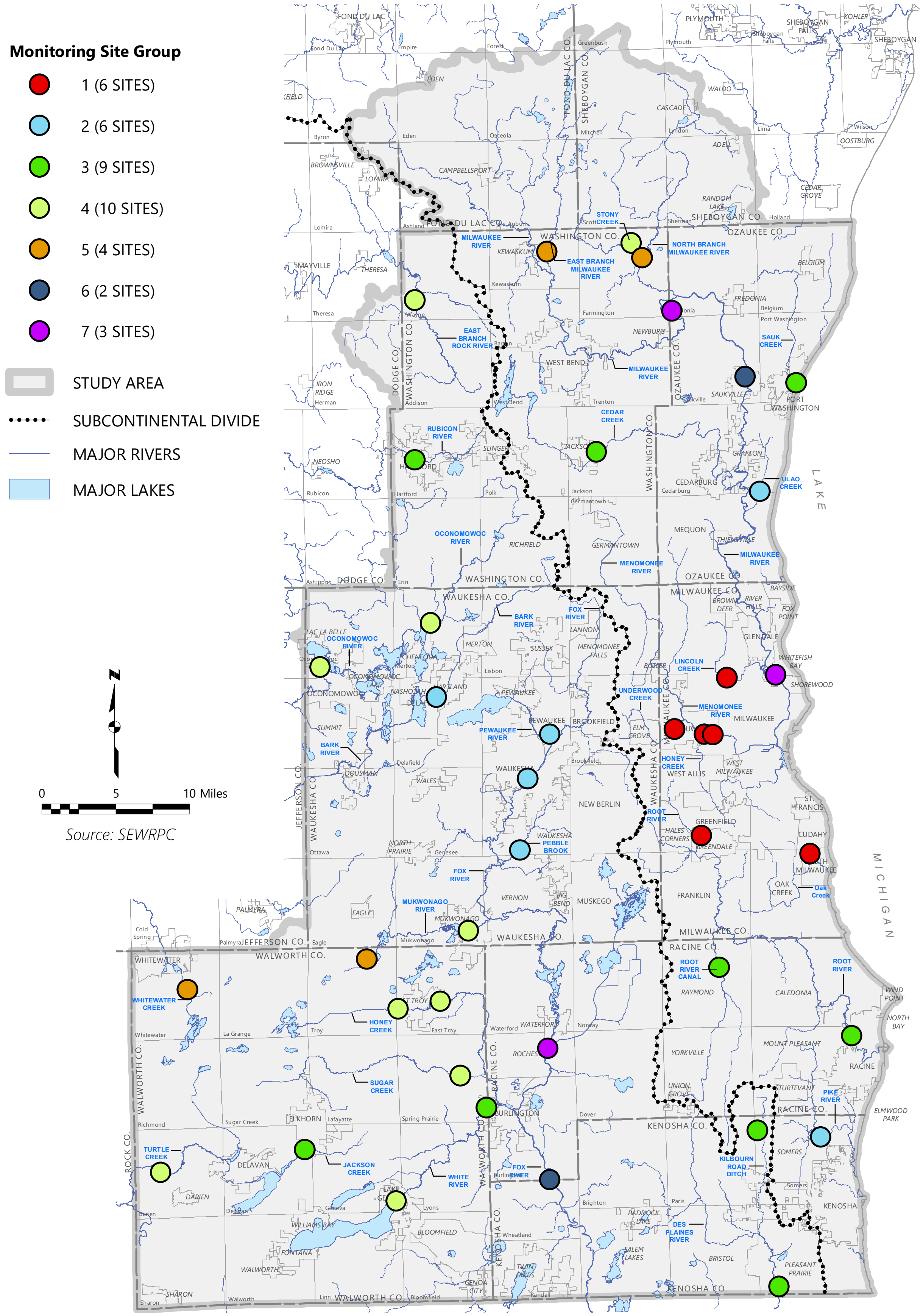


Source: SEWRPC

Map 3.3
Mean Estimated Chloride Concentrations at Chloride Impact Study Stream Monitoring Sites: 2018 - 2021

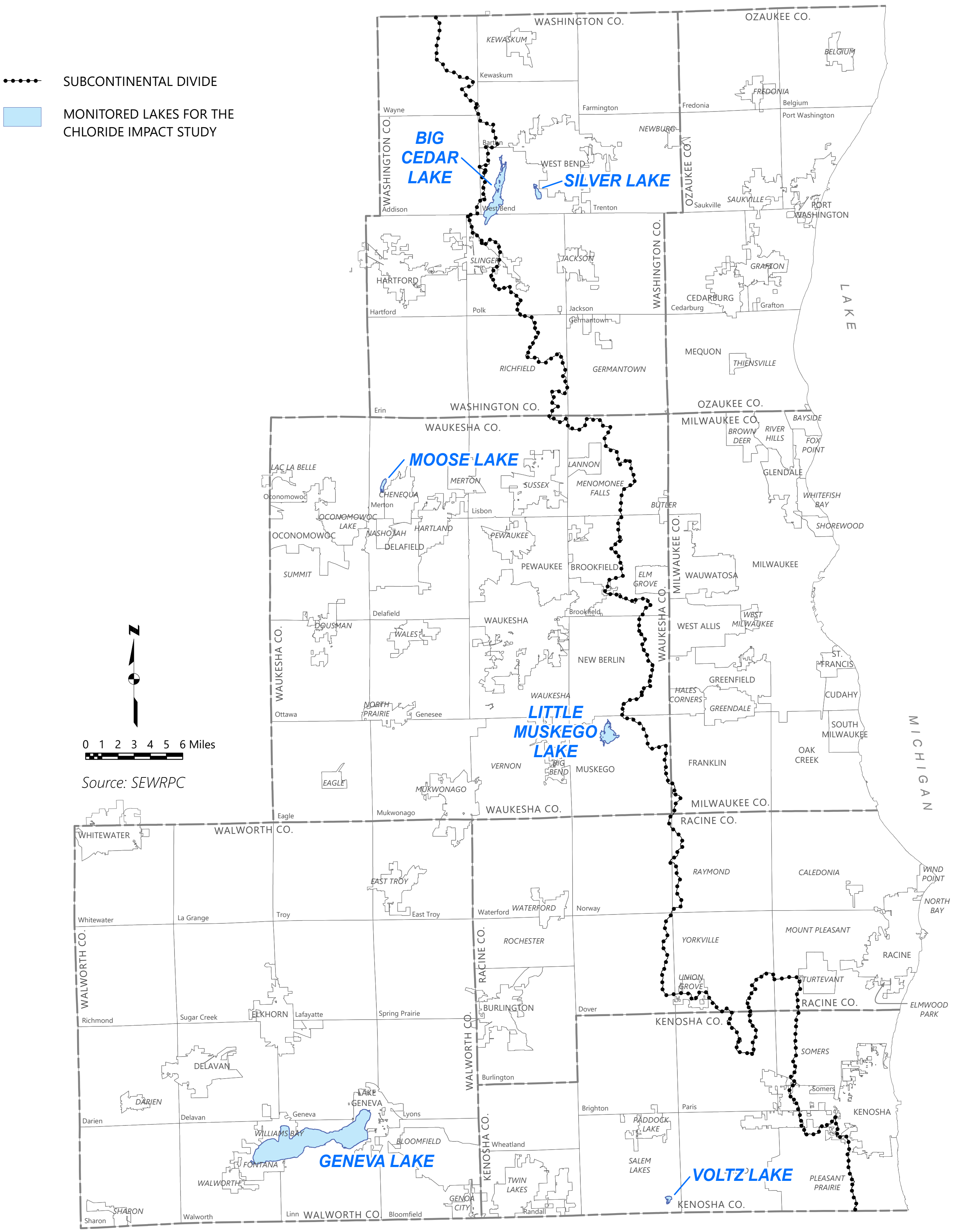


Map 3.4
Groups of Stream Monitoring Sites with Similar Characteristics



Source: SEWRPC

Map 3.5
Lakes Monitored for the Chloride Impact Study



Source: SEWRPC