SEWRPC Technical Report No. 63

TRENDS AND CONDITIONS FOR THE CHLORIDE IMPACT STUDY

Chapter 5

TRENDS AND CONDITIONS FOR CHLORIDE AND SPECIFIC CONDUCTANCE IN THE LAKES OF SOUTHEAST WISCONSIN

5.1 INTRODUCTION

This chapter examines the conditions and trends of chloride levels in the Region's lakes. Lakes of southeastern Wisconsin have historically had naturally low levels of chloride, typically 5 mg/l or less. Prior to 1910, five lakes in Southeastern Wisconsin contained mean chloride concentrations of 3.9 mg/l and mean maximum chloride concentrations of 5.1 mg/l. The highest chloride concentration reported prior to 1910 was 10 mg/l on North Lake on September 4, 1907.[1] Trend data on the few southeastern lakes where data exists only indicate a slight increase in chloride concentrations from the early 1900s to the 1960s.[2] However, since 1960, increasing chloride concentration trends, particularly in many of the Region's lakes, have been reported.[3] Hence, this chapter focuses on chloride concentration and specific conductivity data collected from the 1960s to 2022 in the Region's lakes.

[1] *E.A. Birge, C. Juday, "The Inland Lakes of Wisconsin", Wisconsin Geological and Natural History Survey, Scientific Series No. 7, 1911*

[2] *Lillie R A, and Mason J W, "Limnological Characteristics of Wisconsin Lakes", Wisconsin Department of Natural Resources Technical Bulletin No. 138. 1983.*

[3] *S.R. Corsi, L.A. De Cicco, M.A. Lutz, and R.M. Hirsch, "River Chloride Trends in Snow-Affected Urban Watersheds: Increasing Concentrations Outpace Urban Growth Rate and Are Common Among All Seasons," Science of the Total Environment, 508:488-497, 2015; and J.A. Thornton, T.M. Slawski, and H. Lin, "Salinization: The Ultimate Threat to Temperate Lakes, with Particular Reference to Southeastern Wisconsin (USA)," Chinese Journal of Oceanology and Limnology, 33:1-15, 2015.*

This chapter will provide background info on Region lakes and discuss importance of chloride for lakes and relationship with specific conductivity. A brief review is also provided regarding efforts by Commission staff to gather, aggregate, and evaluate chloride data on lakes. Evaluations of current conditions and historical trends are made insofar as possible based on these data sets and the limits of data available. The overarching goal of this chapter was to determine the extent to which waterbodies in the study area have been impacted by chloride pollution and to what degree chloride conditions in these waterways are improving, becoming worse, or remaining stable. This information combined with classification data such as watershed size, lake area, residence time, percent composition of urban and rural land uses, and land use changes over time were included in this analysis. Finally, several case studies amongst selected lakes of chloride trends, using the best data sets, are summarized.

5.2 REGIONAL LAKE BACKROUND INFORMATION

Southeastern Wisconsin contains hundreds of lakes that span a wide range of lake and watershed characteristics. Using the Wisconsin Department of Natural Resources (WDNR) 24K hydrogeodatabase, Commission staff identified 803 waterbodies within its chloride study area, which includes the Region as well as the portions of Dodge, Fond du Lac, Jefferson, and Sheboygan Counties. Most of these waterbodies are small (less than five acres) and many do not have a reported surface water acreage let alone any chemical or biological information. Of the 482 waterbodies with a reported acreage, the surface water area ranges from 0.17 acres (unnamed lake in Waukesha County) to 5,403.8 acres (Geneva Lake in Walworth County) with a median of 9 feet. Waukesha County contains the highest number of these waterbodies at 136 lakes, followed by Washington County at 63 lakes and Walworth County at 57 lakes. Only 370 waterbodies have a reported maximum depth, which ranges from 1 foot (Noyes Pond in Milwaukee County) to 135 feet (Geneva Lake) with a median of 11 feet. The watershed size for these waterbodies also varies widely, with the smallest watershed at 0.04 square miles for Hogan Lake in Waukesha County and the largest watershed at 282.3 miles for Echo Lake in Racine County.

Lake morphological and hydrological characteristics, such as lake depth, surface area, predominant water sources, watershed size, and residence time, can be important for influencing chloride dynamics. Residence time is the average time that water spends in a lake and is influenced by the lake volume and water flow. Concentrations of chloride, as a dissolved substance, may be influenced by residence time as lakes with longer residence times allow chloride to accumulate while shorter residence times reduce buildup, but make lakes more sensitive to rapid chloride changes (see Table5.ResidenceTime).[4] The WDNR has classified lakes within the chloride study area based on how water enters or exits the lake into four major types: seepage, spring, drainage and drained lakes. Seepage lakes have no inlet or outlet and rely on precipitation and groundwater; consequently, these tend to have lower pollutant levels. Spring lakes have an outlet, but no inlet and are typically found at the headwaters of streams. Drainage lakes have both an inlet and outlet where the main water sources is stream drainage. Consequently, streams and their associated tributaries have a major influence on water quality for these lakes. Lastly, drained lakes have no inlet, but like spring lakes, have a continuously flowing outlet. Drained lakes are not groundwater fed, so their primary source of water is from precipitation and direct runoff from their surroundings.[5] In addition to water source, the WDNR has further categorized lakes based on their physical characteristics such as surface area, stratification, hydrology and watershed size (headwater versus lowland drainage) into natural communities.[6] These features are identified as the primary influences on a lake and, to a large degree, these characteristics determine the natural biological communities each lake type supports.[7] Using this information, lakes and reservoirs fall into one of ten natural community types (Table5.NaturalCommunity). This detailed categorization considers the natural dynamics of each lake and forms the basis of water quality criteria thresholds and use attainment goals to protect both water quality and biodiversity. As shown on Map 5.ClStudyLakes_NatComms there are a total of 419 WDNR-designated natural community lakes in the chloride study area. Small lakes are the most common (218 lakes) followed by deep headwater lakes (44 lakes), deep seepage lakes (36 lakes), shallow seepage lakes (30 lakes), and deep lowland lakes (27 lakes). All other natural communities are represented by 16 lakes or fewer across the study area. Waukesha County contains three-quarters of the two-story lakes, half of the impounded waters, and nearly 40 percent of the deep seepage lakes within the study area while Walworth County contains 30 percent of the shallow seepage lakes. The other natural communities are spread across the chloride study area in relative proportion to the number of lakes in each County.

[4] *Sources and pathways of chloride to surface waters of the Region are discussed in detail in SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment, *April 2024.*

[5] *Wisconsin Department of Natural Resources Bureau of Fisheries and Habitat Management Publication No. PUB-FH-800, Wisconsin Lakes, 2009.*

[6] *For more information, see the WDNR description of Wisconsin's Riverine and Lake Natural Communities model at the following link: https://dnr.wisconsin.gov/topic/Rivers/NaturalCommunities.html*

[7] *WDNR, Wisconsin 2024 Consolidated Assessment and Listing Methodology (WisCALM) for CWA Section 303(d) and 305(b) Integrated Reporting, Assessment Guidance for 2023 – 2024.*

5.3 DATA COLLECTION AND ORGANIZATION

Data for analyzing chloride and specific conductance data to support trends in Southeastern Wisconsin was compiled from various agency databases to build a comprehensive dataset. It's important to note that this data was not collected as part of a single study but rather from multiple studies where water quality data was gathered. As a result, data was merged spatially (e.g., from different depths and sampling stations) and temporally (e.g., yearly, seasonally, and within decades) to create a cohesive dataset.

Data Sources

Both historical and more recently collected data was compiled for this evaluation. Historical lake data was sourced from lake use reports developed by the WDNR and commissioned by the Commission in the early 1960s.[8] This historical data was combined with more recent data from several additional sources, including the Environmental Protection Agency's Water Quality Portal (WQP), the U.S. Geological Survey National Water's Information System (NWIS), the EPA STOrage and RETrieval (STORET) database, and the WDNR's Surface Water Integrated Monitoring System (SWIMS) database, as well as data contributed by lake associations and other citizen science groups: Camp and Center Lake Rehabilitation District, City of Muskego, Middle Genesee Lake Management District, and the Phantom Lake Management District.[9,10] The majority of the chloride data for the Region's lakes was drawn from the SWIMS database (58 percent) followed by the NWIS (27.5 percent), SEWRPC (11 percent), and Lake associations (4.5 percent).

Data Formatting and Aggregation

Collecting and merging data from multiple datasets and various data sources into one cohesive database was a laborious process. To ensure that all lake chloride and specific conductance samples within the chloride study area were included, Commission staff queried the WQP, NWIS, and SWIMS databases and then removed samples that were represented in more than one database. Commission staff utilized the programming language R version 4.1.1 with the R package "dataRetrieval" version 2.7.14 to query for and download data from WQP. The characteristic names "chloride" and "specific conductance" were utilized with the "readWQPdata" function in the R package to programmatically query all chloride and specific conductance data across the following Wisconsin Counties: Kenosha, Racine, Milwaukee, Walworth,

[8] *For an example of one such report, see Lake Use Report No. FX-41,* Army Lake, Walworth County, Wisconsin*, Wisconsin Department of Natural Resources, 1969 at the following link: https://www.sewrpc.org/SEWRPCFiles/Publications/lkur/fx-41-army-lake-walworth-county-fox-river-watershed.pdf.*

[9] *To access the USGS NWIS database, use the following link: https://nwis.waterdata.usgs.gov/usa/nwis/qwdata.*

[10] *For more information on SWIMS, see the following link: https://dnr.wisconsin.gov/topic/SurfaceWater/SWIMS.*

Waukesha, Washington, Ozaukee, Sheboygan, Dodge, Jefferson, and Fond du Lac. The USGS NWIS database was queried using the "readNWISwq" function in the "dataRetrieval" package. For this function, the parameter codes 00940 and 99220 were used to query chloride data while 00095 was used to query specific conductance data. There is no equivalent R package for SWIMS, so Commission staff used the SWIMS interface to query parameter codes 940 and 941 for chloride data and 94, 95, and 402 for specific conductance across the same Counties as listed above for WQP. The Commission also received raw chloride and specific conductance data from lake organizations through spreadsheets and tables in reports.

Different agency databases code their data differently, therefore staff had to recognize align and reconcile these different data formats. All chloride data downloaded was reported in mg/l and all specific conductance data was reported in μS/cm @ 25ºC, so no unit conversion was necessary for this data. However, water depths were reported in both metric and imperial units and in both numeric and text formats. All water depths were formatted into a numeric column and converted into feet. Data collection timestamps were represented in various formats across the different datasets. All timestamps were converted into a "Year/Month/Day Hour:Minute:Second" format if that level of time specificity was provided; all timestamps with only a date were presumed to occur at noon (e.g., chloride samples from the 1960s lake use reports). Each chloride and specific conductance observation in WQP, NWIS, and SWIMS was reported with Global Position System (GPS) coordinates using the World Geodetic System 84 (WGS 84). Some chloride and specific conductance data was collected without a GPS coordinate listed, such as the 1960s lake use reports and data from individual lake organizations. In these instances, the SWIMS "deep hole" monitoring station, which are generally located in the middle of each lake, was used as a proxy coordinate unless another position in the lake (e.g., "lake outlet") was specified.

The collected data covered a broad geographic scope across the entire chloride study area and additional areas in surrounding Counties. Commission staff utilized the WDNR 24K hydrogeodatabase to create a spatial dataset of only the lakes within the chloride study area. The WDNR dataset was used because it provides a unique Water Body Identification Code for each lake that could be used to easily aggregate the data. The individual chloride and specific conductance observations were then spatially joined to these lakes using ArcGIS version 10.7.1. This process created a dataset with compiled data from each source with a corresponding WBIC to identify, filter, and aggregate the data by individual lakes.

Equally demanding was the process of data quality assurance and control. Staff conducted a thorough review to check each lake's data for outliers or anomalous features and flag them for potential removal if conditions were warranted. Commission staff developed plots of each lake's chloride and specific conductance data over time to assist with data review. One such example was seen in Lilly Lake in Kenosha County where chloride samples between 1978 and 1983 were extremely elevated potentially due to unnatural background interference from ongoing dredging. Obvious typos that altered the chloride concentration by an order of magnitude were also flagged and removed if warranted. Lastly, duplicate data was flagged and removed so only one unique entry remained. This data would sometimes arise because a single chloride sample would be reported in both SWIMS and NWIS and ultimately both would also appear in WQP. Observations with the same timestamp, measurement value, and water depth but different organizational sources (i.e., WDNR and USGS) were flagged and only the observation from the original source was kept in the database. These redundancies were eliminated from the final dataset to ensure the accuracy of downstream data analyses.

Additional formatting and spatial data operations were performed to support statistical analysis and visualization, creating columns for data collection year, month, decade, and season. Analyzing seasonality was expected to help in identifying times when chloride levels were likely elevated in regional lakes. A seasonal breakdown of the entire regional lake dataset (total of 3,218 individual chloride samples) over the 1960-2022 period of record revealed the following data distribution; Spring (March-May, 43.6%), Summer (June-August, 21.5%), Fall (September-November, 22.5%), and Winter (December-February, 12.4%). Winter sampling is both difficult and potentially hazardous, resulting in only 12.4% of the dataset. In addition, very few lakes had data collected across all four seasons in the same year. Consequently, the limited number and consistency of seasonal data collected either within the same lake and year or among lakes restricted the ability for any meaningful comparisons. For example, seasonal chloride concentrations over time for Little Cedar Lake (Figure5.LittleCedarSeasonality) shows some typical limitations regarding seasonal data amongst our regional lake dataset:

- most seasonal data only exists for dates prior to the 1990s;
- where seasonal data does exist within the same year;
    - winter seasons do not show a peak compared to other seasons (sometimes shows a decrease compared to other seasons)
    - the differences among seasons were negligible (less than +/- 5 mg/l) within the same year

However, the one exception to this lack of seasonality amongst chloride concentrations was found within Little Muskego Lake, which did exhibit elevated concentrations in winter samples compared to other seasons (see Chapter 3 of this report). The seasonal variation on Little Muskego Lake was

observed as part of the regional chloride study targeted seasonal sampling (one of six lakes) by Commission staff from 2018-2021 and is discussed in more detail in the Chloride Trends section below.

Given that lake residence is an important factor potentially influencing the concentration of chloride in a lake, it was included to be assessed amongst the lakes in this study. Therefore, Commission staff compiled a dataset of published residence times for each lake using a combination of Commission reports, WDNR modeled data, and reports from other organizations. Residence times reported in Commission or other reports were used in favor of the WDNR modeled data when both sets existed for the lake. These residence times were also joined to each observation using the lake WBIC. Additional lake characteristic information from the WDNR, such as the lake type, surface area, maximum depth, natural community, and watershed were joined to each observation using the lake WBIC.

The WDNR Water Explorer (WEx) tool was used to automatically delineate a watershed for as many lakes in the dataset as possible.[11] Year 2015 land use data was compiled by the Commission for the Chloride Impact Study and summarized for each lake watershed to examine, for example, the percent of urban land uses in the watershed contributing to each lake.[12] Similarly, for the lakes within the Region, the Commission's 1963, 1970, 1980, 1990, 2000, 2010, 2015, and 2020 land use data was summarized for each lake watershed. This summarized watershed information was joined to the chloride and specific conductance data using the lake WBIC.

Defining Recent Conditions and Trends Data

To assess the current chloride conditions in the Region's lakes, data from a recent ten-year period (2013 to 2022) was aggregated to represent the most recent levels (see Table5.ChlorideRecentCondition). A total of 45 lakes have been identified as having recent data, comprising 735 individual chloride samples. For lakes with multiple samples taken over the 10-year period, those data points were averaged to provide a single mean value for each lake. It is important to note that these "recent conditions" for lakes and their associated characteristics were compared to year 2015 land use conditions for subsequent analyses summarized below.

Among all the lakes in the region, 116 lakes have at least one chloride sample collected between 1960 and 2022. To further refine the data for trend analyses, it was required that an individual lake have at least two

[11] *For more information on WEx, see https://dnr.wisconsin.gov/topic/SurfaceWater/WEx.html. Commission staff were able to delineate watersheds for 215 lakes using the WEx tool; some lakes were too small for WEx to generate a watershed. The WEx tool aggregates pre-defined catchments created for the WDNR 24k hydrogeodatabase (see explanation of watershed delineation at M. Diebel, D. Menuz, and A. Ruesch,* 1:24K Hydrography Attribution Data, *Wisconsin Department of Natural Resources, 2013). These watershed extents were then used to summarize the land uses contributing to each lake, including tallying the percent of urban lands and percent of roads and parking lots.*

[12] *See SEWRPC Technical Report No. 61, Field Monitoring and Data Collection for the Chloride Impact Study, September 2023, for details of land uses established for the regional chloride study area.*

data points over a span of 10 years. There are 71 lakes with a total of 2,803 individual chemistry samples meeting the trend lake criteria for our period of data analysis from 1960 through 2022 (see Figure5.LakeTrendDistribution). In order to make comparisons of trends in lakes over time, Commission staff employed an approach used in Dugan et al. 2020[13]. In this approach, the chloride and specific conductance datasets were standardized to a distribution with a mean equal to 0 and a standard deviation equal to 1. Next, linear regression models were created for each trend lake to classify them into three groups of trends: decreasing where slope < 0 and $P < 0.01$, not statistically increasing or decreasing where slope $= 0$ and $P > 0.01$, or increasing where slope > 0 and $P < 0.01$.[14]

5.4 RECENT CHLORIDE CONDITIONS OF REGION LAKES

The study area includes twelve major watersheds, but lakes with recent data are primarily concentrated in the Fox River, Milwaukee River, and Rock River watersheds (see Map 5.ChlorideNumberSamplesLakes_Recent_RGB). There were 45 lakes with recent chloride data within the decade from 2013 to 2022 and the majority of these lakes or 29 (62 percent) contained between 1 to 10 water samples during this time period (see Map 5.ChlorideNumberSamplesLakes_Recent_RGB). Nine lakes (20 percent) contained between 11 to 20 water samples and eight of the lakes (18 percent) had between 21 to 100 samples.

The average chloride concentration across all lakes is 61.4 mg/l, although values range significantly from as low as 3.82 mg/l in Mueller Lake (Milwaukee River watershed) to 218.3 mg/l in Bass Bay Lake (Fox River watershed) (see Map5.ChlorideRecentCondition). Only four lakes had concentrations between 5 to 10 mg/l that would be expected of natural, baseline conditions as observed by Birge and Juday in the Region's lakes in the early 20th century.[15] These concentrations would represent lake conditions prior to widespread application of salts on roads and parking lots as well as more intensive application of salt-containing agricultural fertilizers. The four lakes with recent chloride concentrations within this range are Amy Belle and Mueller lakes in Washington County and Peters Lake and Lake Wandawega in Walworth County. These

[13] H.A Dugan, S.L. Bartlett, S.M. Burke, J.P. Doubek, F. E. Krivak-Tetley, N.K. Skaff, J. C. Summers, K. J. Farell, I. M. McCullough, A.M. Morales-Williams, D.C. Roberts, Z. Ouyang, F. Scordo, P. Hanson, and K.C. Weathers, "Salting Our Freshwater Lakes." Proceedings of the National Academy of Sciences of the United States of America, 114(17): 4453-4458, 2017.

[14] Ibid

[15] Birge and Juday, 1911, op. cit.

lakes share some similarities in that they are seepage or headwater lakes with generally somewhat lower percents of urban land uses in their contributing watersheds.

Forty-two of the 45 lakes within the Region had chloride concentrations that exceed expected natural conditions (see Map5.ChlorideRecentCondition). These concentrations range from barely exceeding natural conditions (e.g., 12.8 mg/l in Lulu Lake in Walworth County) to exceeding natural conditions by over 20 times (e.g., 218.3 mg/l in Bass Bay Lake in Waukesha County). There were no consistent patterns in lake type among this population of lakes, but many of these lakes, particularly those at the higher end of the chloride range, are located near population centers and often have highly urbanized watersheds. For example, although the regional study area subwatershed scales are much larger than each of the individual lake watershed sizes, an overlay of the existing percent of urban land uses and current mean chloride concentrations on Map 5.ChlorideRecentMean_PercentUrban_RGB generally demonstrates that the highest mean chloride concentrations are associated with the highest urban areas of the study area. More details on the association between land use and chloride concentrations are discussed further in the "Relationships with Chloride" section below.

In Wisconsin, the chloride toxicity standards for surface water are set at 395 mg/l for acute exposure and 757 mg/l for chronic exposure. While none of the lakes in the region surpass these state standards, many have elevated chloride levels that, according to laboratory studies, likely pose ecological risks (see Table5.ChlorideLakeThreshholds). Research shows that even modest increases above natural chloride background levels can cause biological impacts, with concentrations of 35 to 40 mg/l significantly altering diatom communities, impairing daphnia (*Daphnia* spp.) reproduction, and increasing daphnia mortality rates within lake ecosystems.[16,17] Currently, 32 lakes meet or exceed this concentration threshold. At a concentration of 54 mg/l,[18] changes to wetland species composition have been observed; 20 lakes meet or exceed this level. Additionally, eight lakes meet or exceed 108 mg/l,[19] a concentration associated with

[16] *SEWRPC Technical Report No. 62, Impacts of Chloride on the Natural and Built Environment, April 2024, provides a detailed summary of biological impacts caused by elevated chloride concentrations.*

[17] *Arnott et al., 2020, Environmental Science and Technology, 54: 9,398-9,407; and, Cochero et al., 2017, Science of the Total Environment, 579:1,496-1,503.*

[18] *Richburg et al., 2001, Wetlands, 21:247-255.*

[19] *Morgan et al., 2012, North American Journal of Fisheries Management, 32: 941-952.*

reduced fish diversity. At 185 mg/l[20] and above, mesocosm experiments suggest potential shifts in phytoplankton community composition, with three lakes reaching or surpassing this concentration.

Although we discuss chloride time series trends among the study area lakes in more detail in Section 5.5 below, Figure 5.YearlyAverageChlorideLevelsThresholds) shows a comprehensive look at all the chloride data collected as part of this study among lakes from 1960 to 2022. This highlights the irregularities and gaps in the chloride concentration dataset, but it does provide the most comprehensive areawide assessment of the study area overtime for lakes. Figure 5.YearlyAverageChlorideLevelsThresholds also identifies the current time period of 2013-2022 and demonstrates that the highest chloride concentrations in lakes have occurred in the most recent time period since 1960. There is a large variability in the rates of chloride concentration changes among individual lakes within this regional study area, but the one very consistent feature of these chloride trends is that nearly all of them are increasing in concentration with time. As noted above, some lakes like Wandawega Lake and also highlighted on Figure 5.YearlyAverageChlorideLevelsThresholds seems to remain unchanging over time and continues to be within or below the 10 mg/l threshold indicative of background level conditions. In contrast, Little Muskego Lake represents the opposite extreme of consistently maintaining the highest concentration and rate of change of chloride concentration amongst all the lakes in the study area (see Figure 5.YearlyAverageChlorideLevelsThresholds). However, Geneva Lake also featured on Figure 5.YearlyAverageChlorideLevelsThresholds is a good example of the intermediate and more consistent increase in chloride concentrations over time, which is representative of the majority of the lake trends.

However, Figure 5.YearlyAverageChlorideLevelsThresholds also shows that lakes within the study area have been consistently exceeding chloride concentration thresholds known to impact changes in biological communities since at least 1995, and the proportion of these exceedances have increased with time. Hence, as of 1975 four lakes (five percent) out of total number of 79 lakes exceeded the chloride concentration threshold of 35 mg/l and no lakes were recorded to exceed 54 mg/l. Between 1975 to 1995 23 lakes (28 percent) out of total of 82 lakes exceeded the threshold of 35 mg/l and 8 lakes (nine percent) were recorded to exceed 54 mg/l. Between 1995 to 2013 30 lakes (59 percent) out of total of 51 lakes exceeded the threshold of 35 mg/l and 14 lakes (28 percent) were recorded to exceed 54 mg/l. In contrast, the current time period shows that 32 lakes (70 percent) exceed thresholds of 35 mg/l and 20 (44 percent) exceed thresholds of 54 mg/l (Table5.ChlorideLakeThreshholds).

[20] *Astorg et al., 2023, Limnology and Oceanography Letters, 8: 38-47.*

Relationships With Chloride

Commission staff examined potential explanatory variables for chloride conditions in the Region's lakes using the average chloride concentrations in the 45 lakes comprising the recent conditions dataset (data collected between 2013 and 2022). This analysis included both lake morphological and hydrological variables as well as watershed characterization variables:

- Lake variables
  - Lake type (drainage, seepage, drained, spring, and not assigned)
  - Natural community (see Table 5.NaturalCommunity)
  - Surface area as delineated using WDNR spatial database
  - Maximum depth as reported by WDNR
  - Residence time (see Table 5.ResidenceTime)
- Watershed variables
  - Watershed size as delineated using WDNR WEx tool
  - Percent of urban lands in watershed using 2015 Commission land use
  - Percent of roads and parking lots in watershed using 2015 land use
  - Percent of urban lands within 1,000-feet of lake using 2015 land use
  - Percent of roads and parking lots within 1,000-feet of lake using 2015 land use
  - Percent of lands served by sanitary sewer within 1,000-feet of lake[21]
  - Change in watershed percent of urban lands between 1963 and 2015 land use
  - Change in watershed percent of roads and parking lots between 1963 and 2015 land use
  - Percent of agricultural lands in watershed using 2015 land use

The summarized information for each of the 45 lakes in the recent condition dataset are presented in Table 5.LakeCharRecentCl. As with the lakes across the Region, the lakes within this dataset are varied in their lake and watershed characteristics. Lakes had surface areas ranging from 9.1 to 5,403.8 acres, maximum reported depths ranging from 6 to 135 feet, and had watersheds ranging from 0.2 to 88.8 square miles. These lakes also varied in their hydrology and natural community, with shallow and deep seepage lakes, shallow and deep lowland lakes, deep headwater and two-story lakes, and impoundments and reservoirs represented. A broad range of watershed land uses was also represented by lakes with predominantly urban watersheds (e.g., Little Muskego and Silver Lakes in Waukesha County), predominantly agricultural watersheds (e.g.,

[21] *The Commission's sanitary sewer service dataset was most recently updated in 2010.*

Delavan and Peters Lakes in Walworth County), and lakes with a majority of their watershed in woodlands and wetlands (e.g., Auburn Lake in Fond du Lac County and Mueller Lake in Washington County). Although the shorelines of most lakes in southeastern Wisconsin are highly developed, the recent condition dataset still included a range of urban land uses within 1,000-feet of the shore between 3.9 percent (Lulu Lake in Walworth County) to 95.2 percent (Little Muskego Lake).

Commission staff created linear regression models for numerical variables and analysis of variable (ANOVA) models for the categorial variables to examine statistically significant relationships with the average chloride concentration across the 45 lakes for which there was corresponding lake and watershed information.[22] An alpha value of 0.05 was used for the models. The linear regression and ANOVA model results are presented in Table 5.RelationshipStats.

Several variables included in the analysis did not have statistically significant relationships with recent average lake chloride concentrations. These variables were lake type, natural community, surface area, maximum depth, residence time, watershed size, and the percent of agricultural lands within the watershed. Although these variables did not have a significant relationship with average lake chloride concentrations, some of these lake and watersheds characteristics may still have an important role in influencing lake chloride dynamics. For example, lakes with long residence times may have little interannual variability in chloride concentrations while more riverine lakes with shorter residence times may have substantial interannual variability that reflects seasonal patterns in chloride applications within their watersheds. Lake residence time is explored in more detail amongst select lakes in Section 5.5 of this report.

All the statistically significant variables were related to urban land use in some manner (see Figure 5.RecentClR2). The percentage of roads and parking lots and percent of urban land uses in the watershed had the highest R^2 values of any variable examined at 0.461 and 0.451, respectively (see Figure 5.ClRelationScatters). Several of the other variables with significant relationships to average lake chloride concentrations also had significant correlations to the percentages of roads and parking lots and urban lands within the watershed. For example, percent urban lands, percent roads and parking lots, and percent sewered lands within an area of 1,000-feet from a lake were each found to be significantly correlated with mean chloride concentrations. However, although these parameters within 1,000-feet from the lake were significant, the strength of these relationships was not as high compared to either percent urban land or percent roads and parking lots at the watershed scales. This seems to illustrate that the amounts of urban

[22] Some lakes in the recent condition dataset, such as an unnamed lake in Franklin, were too small for WEx to delineate a watershed and consequently this lake was not included in the watershed variable analyses.

land surrounding a lake is an important determinant of chloride concentrations, but it seems that accounting for the entire proportions of either urban land or roads and parking lots at the scale of the total watershed is a better (i.e., higher R^2 values) predictor of chloride conditions within lakes.

In addition, at the watershed scale both the percent change in urban land between 1963 and 2015 and percent change in roads and parking lots between 1963 and 2015 were found to be significantly correlated with mean chloride concentrations. In contrast, there was no significant relationship between chloride concentrations and percent agricultural land use, even though percent urban land is negatively significantly correlated with percent agricultural land use (R^2 value at 0.468) amongst these lake watersheds. These relationships indicate that watershed land use is an important determinant of lake chloride concentrations and suggest that salt sources stemming from urban land uses, such as salt application on roads, sidewalks, and parking lots as well as chloride generated from residential households (e.g., via septic systems) and commercial or industrial uses are good predictors of increased chloride concentrations within the Region's lakes.

While it is not surprising, it is important to note that amongst these lake watersheds percent urban land is highly correlated with percent roads and parking lots (R^2 value of 0.628). Although the percent urban land use ranged from less than 10 percent to a high of 69 percent and the percent roads and parking lots ranged from 2.3 percent in Peters Lake to a high of 24 percent in Silver Lake, Waukesha County (see Figure 5. Percent Urban Land Use and Percent Roads and Parking Lots Relationship). As discussed above, it seems that either of these variables are good predictors of chloride concentrations in lakes. However, Figure 5. Percent Urban Land Use and Percent Roads and Parking Lots Relationship also shows that the worst seven lakes (i.e., exceeding 108 mg/l chloride concentration threshold) generally contain at least 50 percent or greater percent urban land use and contain at least 10 percent roads and parking lots or greater.[23] One slight exception to this general pattern is Wind Lake which contains a watershed comprised of 33.5 percent urban land and 8.9 percent roads and parking lots. In addition, Figure 5. Percent Urban Land Use and Percent Roads and Parking Lots Relationship also shows that the best 13 lakes (i.e., less than 35 mg/l chloride concentration threshold) watersheds generally contain less than 40 percent urban lands and less than five percent roads and parking lots. A couple of exceptions to this trend are Amy Bell Lake and Mueller Lake. Amy Bell Lake slightly exceeds both these limits and contains 42.1 percent urban land and 5.8 percent roads and parking lots. Mueller Lake's watershed is less than 40 percent urban land, but it contains 15.1 percent

[23]Note that there are eight lakes that exceed the 108 mg/l threshold in chloride concentrations, but one lake was too small for the WDNR WEx tool to delineate a watershed, so there are no values for the watershed characteristics of this lake.

roads and parking lots, and this may just be an anomaly amongst this group of lakes with current chloride data. Nonetheless, although the data is a bit noisy, it seems like there may be a combination of both percent urban land and percent roads and parking lots as predictors of the best and worst chloride lakes. More specifically, lakes with less than 40 percent urban land use and less than 5 percent roads and parking lots are indicative of the least impacted chloride condition lakes versus lakes greater than 40 percent urban land use and 10 percent roads and parking lots are indicative of most degraded or highest impacted chloride condition lakes.

A comprehensive assessment of chloride conditions across the region's lakes remains challenging, as only a small fraction of lakes have recent chloride data available. Most of the lakes without recent data are small and lack public access, whereas many larger, accessible lakes often supported by organizations dedicated to their conservation have some monitoring efforts in place. The limited availability of recent chloride data restricts the capacity to assess the current conditions and biological impacts of chloride on these waterbodies comprehensively; however, these 45 lakes are well distributed throughout the study area and comprise a good diversity of lake types, watershed sizes, and land uses representative of most lakes throughout the study area. Hence, the current conditions data combined within the historical period of record is indicative that the overall water quality of the lakes in terms of chloride concentrations in the study area are much worse than conditions in 1960. More importantly, this analysis seems to demonstrate that this degradation is highly associated with the amounts of percent urban land and percent of roads and parking lots.

Specific Conductance Conditions

[To be completed.]

5.5 CHLORIDE TRENDS IN REGION LAKES

[To be completed.]

Technical Report No. 63

CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 5

TRENDS AND CONDITIONS FOR CHLORIDE AND SPECIFIC CONDUCTANCE IN THE LAKES OF SOUTHEAST WISCONSIN

TABLES

Table 5.LakeResidenceTimes
Residence Time Among Lakes within the Region

Lake	Residence Time (years)	Lake	Residence Time (years)
Ashippun Lake [a]	2.30	Little Cedar Lake	0.60
Auburn Lake	0.63	Little Muskego Lake	1.23
Bark Lake [a]	0.38	Long Lake (Fond du Lac)	0.99
Bass Bay Lake	1.32	Long Lake (Racine)	0.88
Beaver Lake [a]	2.60	Lower Nemahbin Lake	0.15
Benedict Lake [a]	5.50	Lower Phantom Lake	0.06
Benet Lake	1.00	Lucas Lake	0.22
Bernice Lake	0.01	Lulu Lake	0.38
Big Muskego Lake	1.73	Mauthe Lake	0.07
Bohner Lake	0.90	Merton Millpond	0.01
Brown Deer Park Pond	0.66	Middle Lake	4.11
Brown Lake	0.33	Mill Lake	3.29
Buena Lake	0.96	Mill Pond	<0.01
Camp Lake	0.74	Monterey Millpond	0.01
Cedar Grove Mill Pond	0.01	Mud Lake	0.33
Cedar Lake	8.22	Mud Lake	0.27
Center Lake	0.85	Nagawicka Lake [a]	0.8
Como Lake	1.12	North Lake [a]	0.8
Comus Lake	0.06	Oconomowoc Lake [a]	0.45
Cornell Lake	0.04	Okauchee Lake [a]	0.9
Cravath Lake [a]	0.25	Ottawa Lake	0.47
Crooked Lake [a]	0.01	Paradise Valley Lake	0.15
Crooked Lake	0.41	Pewaukee Lake	2.74
Cross Lake	9.01	Pickerel Lake	0.52
Delavan Lake [a]	2.00	Pike Lake [a]	1.10
Druid Lake	0.82	Pleasant Lake	0.30
Dyer Lake	0.55	Pretty Lake [a]	3.30
Eagle Lake	1.51	Random Lake	1.34
Eagle Spring Lake [a]	0.07	Rice Lake [a]	7.07
East Troy Pond (Trent)	0.01	School Section Lake [a]	0.14
Echo Lake	0.01	Scout Lake	0.44
Elizabeth Lake [a]	1.85	Silver Lake	3.84
Fowler Lake [a]	6.9	Silver Lake (Paradise Valley) [a]	3.20
Friess Lake [a]	0.3	Sinissippi Lake (Hustisford)	0.08
Geneva Lake [a]	13.9	Smith Lake	0.28
George Lake [a]	0.18	Spring Lake	0.44
Gilbert Lake	0.25	Tichigan Lake	0.05
Green Lake	1.53	Tombeau Lake [a]	0.14
Hasmer Lake	0.79	Tripp Lake [a]	0.06
Honey Lake (Vienna)	0.00	Upper Phantom Lake [a]	0.99
Hooker Lake	1.42	Upper Kelly Lake	0.23
La Grange Lake	0.11	Upper Nemahbin Lake [a]	0.55
Lac La Belle	0.33	Upper Oconomowoc Lake	0.01
Lake Beulah	4.38	Upper Phantom Lake	0.99
Lake Denoon	3.60	Voltz Lake [a]	2.2
Lake Ellen	1.30	Vern Wolf Lake	0.93
Lake Ivanhoe [a]	2.00	Waterville Lake	0.11
Lake Keesus	3.01	Waubeesee Lake	1.95
Lake Twelve	0.10	Wind Lake [a]	0.6
Lake Wandawega	2.00		

[a] *Source: SEWRPC, all other Residence times are from The Wisconsin Department of Natural Resources*

Table 5.NaturalCommunities
Natural Communities Among Lakes with Chloride Data and Recent (2013-2022) Data in the Region

Natural Community	No. Lakes with Data	No. Lakes with Recent Data	Lake Size	Stratification	Hydrology	Watershed Size (square miles)	Characteristics
Small Lakes	10	1	< 10 acres	Variable	Any	Any	Unique small lakes, limited monitoring data
Shallow Seepage	8	2	≥ 10 acres	Mixed	Seepage	N/A	No significant surface water inflow/outflow, shallow, mixed
Shallow Headwater	6	0	≥ 10 acres	Mixed	Headwater Drainage	< 4	Receives water from a small watershed, shallow, mixed.
Shallow Lowland	7	4	≥ 10 acres	Mixed	Lowland Drainage	≥ 4	Receives water from a large watershed, shallow, mixed.
Deep Seepage	20	9	≥ 10 acres	Stratified	Seepage	N/A	No significant surface water inflow/outflow, deep, stratified.
Deep Headwater	23	9	≥ 10 acres	Stratified	Headwater Drainage	< 4	Receives water from a small watershed, deep, stratified.
Deep Lowland	23	10	≥ 10 acres	Stratified	Lowland Drainage	≥ 4	Receives water from a large watershed, deep, stratified.
Spring Ponds	0	0	Any size	Variable	Spring Fed	N/A	Fed by constant cold groundwater, providing cool, clear water year-round.
Two-Story Lakes	13	8	Any size	Stratified	Any	Any	Supports both warm-water and cold-water fish species in stratified layers.
Impounded Flowing Waters	6	2	Any size	Variable	Headwater/Low land	Any	Artificial lakes formed by dams, may support cold-water species in some cases

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 5.ChlorideRegionRecentConditions
Chloride Concentrations and Data Characteristics of Lakes in Recent Conditions Dataset: 2013 – 2022

Official Name	WBIC	County	Watershed	Date Range	Lake Type	Natural Community	Mean (mg/L)	Samples (n)
Camp Lake	747100	Kenosha	Fox River	2013 to 2016	Drainage	Shallow Lowland	70.3	8
Center Lake	747300	Kenosha	Fox River	2013 to 2016	Drainage	Deep Lowland	74.9	8
Lake Mary	743000	Kenosha	Fox River	2018 to 2018	Drained	Deep Headwater	123.0	1
Powers Lake	744200	Kenosha	Fox River	2013 to 2021	Drainage	Deep Headwater	47.5	11
Voltz Lake	746300	Kenosha	Fox River	2018 to 2021	Drained	Deep Headwater	35.3	45
Unnamed	5588789	Milwaukee	Root River	2017 to 2017	Small	Small	191.0	1
Browns Lake	750300	Racine	Fox River	2018 to 2018	Drained	Deep Headwater	97.4	1
Eagle Lake	759800	Racine	Fox River	2017 to 2017	Drainage	Shallow Lowland	56.2	1
Wind Lake	761700	Racine	Fox River	2013 to 2022	Drainage	Deep Lowland	121.3	13
Booth Lake	740400	Walworth	Fox River	2013 to 2022	Seepage	Deep Seepage	16.6	14
Delavan Lake	793600	Walworth	Rock River	2013 to 2022	Drainage	Deep Lowland	56.7	26
Geneva Lake	758300	Walworth	Fox River	2013 to 2022	Spring	Two-Story	50.7	77
Honey Lake (Vienna)	752300	Walworth	Fox River	2021 to 2022	Drainage	Impounded Flowing Water	51.7	4
Lake Beulah	766600	Walworth	Fox River	2013 to 2022	Drainage	Two-Story	25.5	88
Lake Wandawega	740700	Walworth	Fox River	2013 to 2018	Seepage	Shallow Seepage	6.6	4
Lulu Lake	768800	Walworth	Fox River	2013 to 2019	Drainage	Deep Lowland	12.8	19
Peters Lake	741400	Walworth	Fox River	2017 to 2017	Seepage	Shallow Seepage	6.4	1
Potter Lake	753800	Walworth	Fox River	2016 to 2020	Seepage	Deep Seepage	65.3	6
Amy Bell Lake	774000	Washington	Rock River	2019 to 2022	Seepage	Deep Seepage	6.3	8
Cedar Lake	25300	Washington	Milwaukee River	2013 to 2022	Spring	Two-Story	58.8	70
Mueller Lake	778900	Washington	Milwaukee River	2017 to 2017	Spring	Deep Headwater	3.8	1
Silver Lake (Paradise Valley)	36200	Washington	Milwaukee River	2017 to 2021	Drainage	Deep Headwater	37.8	57
Bass Bay Lake	763200	Waukesha	Fox River	2013 to 2014	Drainage	Deep Headwater	218.3	3
Beaver Lake	774400	Waukesha	Rock River	2013 to 2022	Spring	Deep Headwater	73.3	19
Big Muskego Lake	762400	Waukesha	Fox River	2013 to 2014	Drainage	Shallow Lowland	110.3	3
Fowler Lake	849400	Waukesha	Rock River	2020 to 2020	Drainage	Two-Story	52.3	3
Golden Lake	775900	Waukesha	Rock River	2013 to 2022	Spring	Deep Headwater	37.6	19
Lake Denoon	761300	Waukesha	Fox River	2013 to 2014	Seepage	Deep Seepage	64.8	2
Lake Keesus	852400	Waukesha	Rock River	2018 to 2018	Spring	Deep Lowland	45.6	1
Little Muskego Lake	762700	Waukesha	Fox River	2014 to 2021	Drainage	Deep Lowland	185.7	69
Lower Phantom Lake	765800	Waukesha	Fox River	2013 to 2018	Seepage	Reservoir	34.2	7
Middle Genesee Lake	778300	Waukesha	Rock River	2013 to 2017	Seepage	Deep Seepage	57.0	9
Moose Lake	778400	Waukesha	Rock River	2018 to 2021	Seepage	Deep Seepage	61.9	58
Nagawicka Lake	828000	Waukesha	Rock River	2018 to 2018	Drainage	Two-Story	43.2	1
North Lake	850800	Waukesha	Rock River	2021 to 2022	Drainage	Two-Story	45.2	5

Official Name	WBIC	County	Watershed	Date Range	Lake Type	Natural Community	Mean (mg/L)	Samples (n)
Oconomowoc Lake	849600	Waukesha	Rock River	2013 to 2022	Drainage	Two-Story	55.0	13
Okauchee Lake	850300	Waukesha	Rock River	2014 to 2022	Drainage	Two-Story	47.5	6
Pewaukee Lake	772000	Waukesha	Fox River	2018 to 2018	Drainage	Deep Lowland	146.0	1
Pretty Lake	779300	Waukesha	Rock River	2022 to 2022	Seepage	Deep Seepage	21.8	1
School Section Lake	825000	Waukesha	Rock River	2013 to 2022	Drainage	Shallow Lowland	29.0	20
Silver Lake	779800	Waukesha	Rock River	2017 to 2022	Seepage	Deep Seepage	128.6	10
Upper Phantom Lake	766000	Waukesha	Fox River	2013 to 2017	Seepage	Deep Seepage	41.9	12
Auburn Lake	42400	Fond Du Lac	Milwaukee River	2019 to 2019	Drainage	Deep Lowland	17.5	1
Long Lake	38700	Fond Du Lac	Milwaukee River	2016 to 2022	Drainage	Deep Lowland	25.0	4
Mauthe Lake	38200	Fond Du Lac	Milwaukee River	2019 to 2019	Drainage	Deep Lowland	21.7	2

Notes: Mean (mg/L) is an average of all Chloride samples taken in the years defined as "Recent" 2013 to 2022

Table 5.ChlorideLakeThreshholds
Chloride Concentrations of Lakes in Recent Conditions Dataset: 2013 - 2022[a]

Recent Lakes			Chloride Concentrations				
OFFICIAL_NAME	**WBIC**	**COUNTY**	**35 mg/l: Diatoms**	**40 mg/l: Daphnia**	**54 mg/l: Wetland Plant Species**	**108 mg/l: Fish Diversity**	**185 mg/l: Plankton**
Camp Lake	747100	Kenosha	X	X	X		
Center Lake	747300	Kenosha	X	X	X		
Lake Mary	743000	Kenosha	X	X	X	X	
Powers Lake	744200	Kenosha	X	X			
Voltz Lake	746300	Kenosha	X				
Unnamed	5588789	Milwaukee	X	X	X	X	X
Browns Lake	750300	Racine	X	X	X		
Eagle Lake	759800	Racine	X	X	X		
Wind Lake	761700	Racine	X	X	X	X	
Delavan Lake	793600	Walworth	X	X	X		
Geneva Lake	758300	Walworth	X	X			
Honey Lake (Vienna)	752300	Walworth	X	X			
Potter Lake	753800	Walworth	X	X	X		
Cedar Lake	25300	Washington	X	X	X		
Silver Lake (Paradise Valley)	36200	Washington	X				
Bass Bay Lake	763200	Waukesha	X	X	X	X	X
Beaver Lake	774400	Waukesha	X	X	X		
Big Muskego Lake	762400	Waukesha	X	X	X	X	
Fowler Lake	849400	Waukesha	X	X			
Golden Lake	775900	Waukesha	X				
Lake Denoon	761300	Waukesha	X	X	X		
Lake Keesus	852400	Waukesha	X	X			
Little Muskego Lake	762700	Waukesha	X	X	X	X	X
Middle Genesee Lake	778300	Waukesha	X	X	X		
Moose Lake	778400	Waukesha	X	X	X		
Nagawicka Lake	828000	Waukesha	X	X			
North Lake	850800	Waukesha	X	X			
Oconomowoc Lake	849600	Waukesha	X	X	X		
Okauchee Lake	850300	Waukesha	X	X			
Pewaukee Lake	772000	Waukesha	X	X	X	X	
Silver Lake	779800	Waukesha	X	X	X	X	
Upper Phantom Lake	766000	Waukesha	X	X			

Note: Lakes not listed have no chloride data or have concentrations below the known effect concentrations

[a] SEWRPC Technical Report No. 62, Impacts of Chloride on the Natural and Built Environment, April 2024, Table 3.17

Table 5.LakeCharRecentCl
Characteristics of Lakes in Recent Conditions Dataset: 2013 - 2022

Lake							Watershed[a]						1,000-Foot Shoreline Buffer		
Lake Name	WBIC	County	Mean Chloride (mg/L)	Surface Area (Acres)	Residence Time (year)	Max. Depth (feet)	Total Area (Square Miles)	Urban Lands (%)	Roads and Parking Lots (%)	Agri-cultural Lands (%)	Change in Urban Lands (%)[b]	Change in Roads and Parking Lots (%)[b]	Urban Lands (%)	Roads and Parking Lots (%)	Urban Area Served by Sewer (%)
Auburn Lake	42400	Fond Du Lac	17.5	90.0	0.63	29	6.34	6.3	2.6	28.5	N/A	N/A	14.2	2.6	0
Long Lake	38700	Fond Du Lac	25.0	423.6	0.99	23	20.7	8.5	3.0	46.6	N/A	N/A	26.5	4.9	0
Mauthe Lake	38200	Fond Du Lac	21.7	70.2	0.07	47	34.4	6.6	2.6	38.3	N/A	N/A	16.7	0.9	0
Camp Lake	747100	Kenosha	70.3	439.5	0.74	19	8.96	26.9	6.5	34.4	9.0	1.8	51.3	12.6	52.6
Center Lake	747300	Kenosha	74.9	126.5	0.85	28	4.04	28.5	6.4	36.8	12.7	2.4	54.6	9.8	61.0
Lake Mary	743000	Kenosha	123.0	327.5	1.92	33	2.42	41.0	9.6	29.2	15.1	2.6	74.5	18.0	74.7
Powers Lake	744200	Kenosha	47.5	451.6	4.2	33	3.35	24.8	4.8	29.7	9.1	1.1	64.0	12.2	0
Voltz Lake	746300	Kenosha	35.3	61.3	2.2	24	0.54	15.7	3.5	39.9	-2.7	-0.4	31.4	7.9	25.4
Unnamed[c]	5588789	Milwaukee	191.0	9.1		6							52.8	24.2	63.2
Browns Lake	750300	Racine	97.4	397.4		44	1.33	40.8	7.0	3.4	4.5	-0.4	80.4	16.0	71.6
Eagle Lake	759800	Racine	56.2	529.5	1.51	11	6.82	16.6	3.8	53.4	6.0	0.4	49.3	9.5	50.5
Wind Lake	761700	Racine	121.3	919.5	0.52	47	41.2	33.5	8.9	23.5	19.7	5.9	57.3	11.9	58.8
Booth Lake	740400	Walworth	16.6	118.1		24	0.45	31.8	4.8	8.0	5.2	0.4	39.6	6.2	0
Delavan Lake	793600	Walworth	56.7	1,907.1	0.12	52	40.6	19.2	6.0	59.3	9.0	3.1	56.5	9.2	60.4
Geneva Lake	758300	Walworth	50.7	5,403.8	13.91	135	28.5	30.4	6.3	15.1	8.4	2.0	69.3	10.4	42.5
Honey Lake (Vienna)	752300	Walworth	51.7	40.0	0.01	6	71.7	12.3	4.5	58.5	7.5	2.2	47.0	12.0	0
Lake Beulah	766600	Walworth	25.5	812.3	4.38	58	10.1	21.0	4.1	25.9	8.0	0.8	44.3	6.6	0.1
Lake Wandawega	740700	Walworth	6.6	119.6	2	8	1.61	30.9	4.9	20.7	16.7	1.1	56.3	7.7	0
Lulu Lake	768800	Walworth	12.8	95.2	0.38	40	17.4	14.2	3.5	37.1	10.1	1.5	3.9		0
Peters Lake	741400	Walworth	6.4	57.8		8	5.08	7.9	2.3	62.6	4.9	0.5	35.9	0.6	0
Potter Lake	753800	Walworth	65.3	154.7		26	1.43	44.1	8.6	26.1	16.4	3.6	55.8	9.0	52.3
Amy Bell Lake	774000	Washington	6.3	30.1		37	0.36	42.1	5.8	5.7	17.4	1.9	56.9	7.9	0
Big Cedar Lake	25300	Washington	58.8	937.2	8.22	105	9.39	22.9	5.6	27.9	11.4	2.0	44.8	8.3	0
Mueller Lake	778900	Washington	3.8	12.4		33	0.62	31.2	15.1	7	17.9	8.0	39.1	6.6	0
Silver Lake	36200	Washington	37.8	122.4	4.25	47	1.06	41.3	7.5	8.61	23.3	1.8	49.4	7.9	31.3
Bass Bay Lake	763200	Waukesha	218.3	104.2	1.32	23	2.49	69.0	15.3	8.18	53.8	11.7	38.8	6.4	32.3
Beaver Lake	774400	Waukesha	73.3	313.5	5.21	46	2.44	45.2	5.8	15.2	22.4	2.1	57.5	6.1	0
Big Muskego Lake	762400	Waukesha	110.3	2,194.7	1.73	23	28.0	39.4	10.5	16.5	23.4	7.2	13.2	2.1	8.3
Fowler Lake	849400	Waukesha	52.3	96.6	0.05	50	88.8	25.2	5.4	31.0	15.3	2.3	81.5	22.0	82.1
Golden Lake	775900	Waukesha	37.6	199.7		44	1.26	15.1	3.4	24.5	3.6	0.5	28.2	6.1	0
Lake Denoon	761300	Waukesha	64.8	167.2	3.6	55	1.11	34.2	6.2	30.0	19.0	2.8	52.9	9.0	58.0

Lake Keesus	852400	Waukesha	45.6	235.3	3.01	42	4.01	41.9	5.8	28.8	30.9	2.9	56.2	7.2	0
Little Muskego Lake	762700	Waukesha	185.7	469.8	1.23	65	11.6	51.7	15.1	15.2	26.7	10.3	95.2	19.9	97.2
Lower Phantom Lake	765800	Waukesha	34.2	373.1	0.06	12	70.8	27.6	5.4	29.5	19.1	2.8	51.0	11.2	27.2
Middle Genesee Lake	778300	Waukesha	57.0	98.1		40	2.13	38.8	11.5	34.3	28.7	8.7	43.7	7.7	0
Moose Lake	778400	Waukesha	61.9	83.3		61	0.96	29.1	6.1	7.2	12.9	1.9	48.1	9.2	0
Nagawicka Lake	828000	Waukesha	43.2	981.2	1.75	90	46.4	44.8	9.3	19.8	34.1	6.1	68.8	9.9	74.2
North Lake	850800	Waukesha	45.2	440.6	0.44	78.4	69.9	21.8	4.5	34.8	14.8	1.9	40.0	5.5	0
Oconomowoc Lake	849600	Waukesha	55.0	795.5	0.74	60	86.8	24.3	5.1	31.7	15.2	2.1	58.7	9.1	8.1
Okauchee Lake	850300	Waukesha	47.5	1,210.6	1.12	90	80.2	23.4	4.9	33	15.1	2.0	68.9	11.6	25.0
Pewaukee Lake	772000	Waukesha	146.0	2,437.8	2.74	45	26.9	49.2	11.7	12.3	32.7	6.9	71.1	11.1	77.1
Phantom Lake	766000	Waukesha	41.9	110.3	0.99	29	0.91	40.2	6.0	20.1	17.1	2.3	60.8	7.3	0
Pretty Lake	779300	Waukesha	21.8	64.9	3.3	31	0.20	38.9	3.8	0.09	4.1	0.3	41.0	5.4	0
School Section Lake	825000	Waukesha	29.0	122.1	0.15	8	7.01	15.7	2.8	28.3	10.6	0.9	28.7	5.4	0
Silver Lake	779800	Waukesha	128.6	217.1		40	2.45	66.2	23.8	9.68	51.8	21.0	53.1	8.9	42.7

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

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

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

Source: SEWRPC

Table 5.RelationshipStats
Statistical Models and Results for Chloride Relationship Analysis of Recent Data: 2013 to 2022

Variable	Model Used	Slope	p-value	Significant?	R^2
Categorical Variables					
Lake Type	ANOVA	N/A	0.217	No	N/A
Natural Community	ANOVA	N/A	0.368	No	N/A
Numerical Variables					
Lake Surface Area	Linear Regression	0.007	0.339	No	0.017
Lake Maximum Depth	Linear Regression	-0.005	0.985	No	<0.001
Lake Residence Time	Linear Regression	-0.540	0.861	No	0.001
Watershed Size	Linear Regression	-0.047	0.862	No	0.001
Percent of Agricultural Lands in Watershed	Linear Regression	-0.794	0.089	No	0.067
Percent of Urban Lands in Watershed	Linear Regression	2.130	$6.1x10^{-7}$	Yes	0.451
Percent of Roads and Parking Lots in Watershed	Linear Regression	7.484	$4.0x10^{-7}$	Yes	0.461
Percent of Urban Lands 1,000-Feet from Lake	Linear Regression	1.014	0.010	Yes	0.144
Percent of Roads and Parking Lots 1,000-Feet from Lake	Linear Regression	5.371	$2.2x10^{-5}$	Yes	0.280
Percent of Sewered Lands 1,000-Feet from Lake	Linear Regression	0.996	$7.7x10^{-6}$	Yes	0.375
Change in Urban Land Percent Between 1963 and 2015	Linear Regression	2.438	$2.2x10^{-5}$	Yes	0.373
Change in Roads and Parking Lots Between 1963 and 2015	Linear Regression	7.284	$1.4x10^{-5}$	Yes	0.386

Source: SEWRPC

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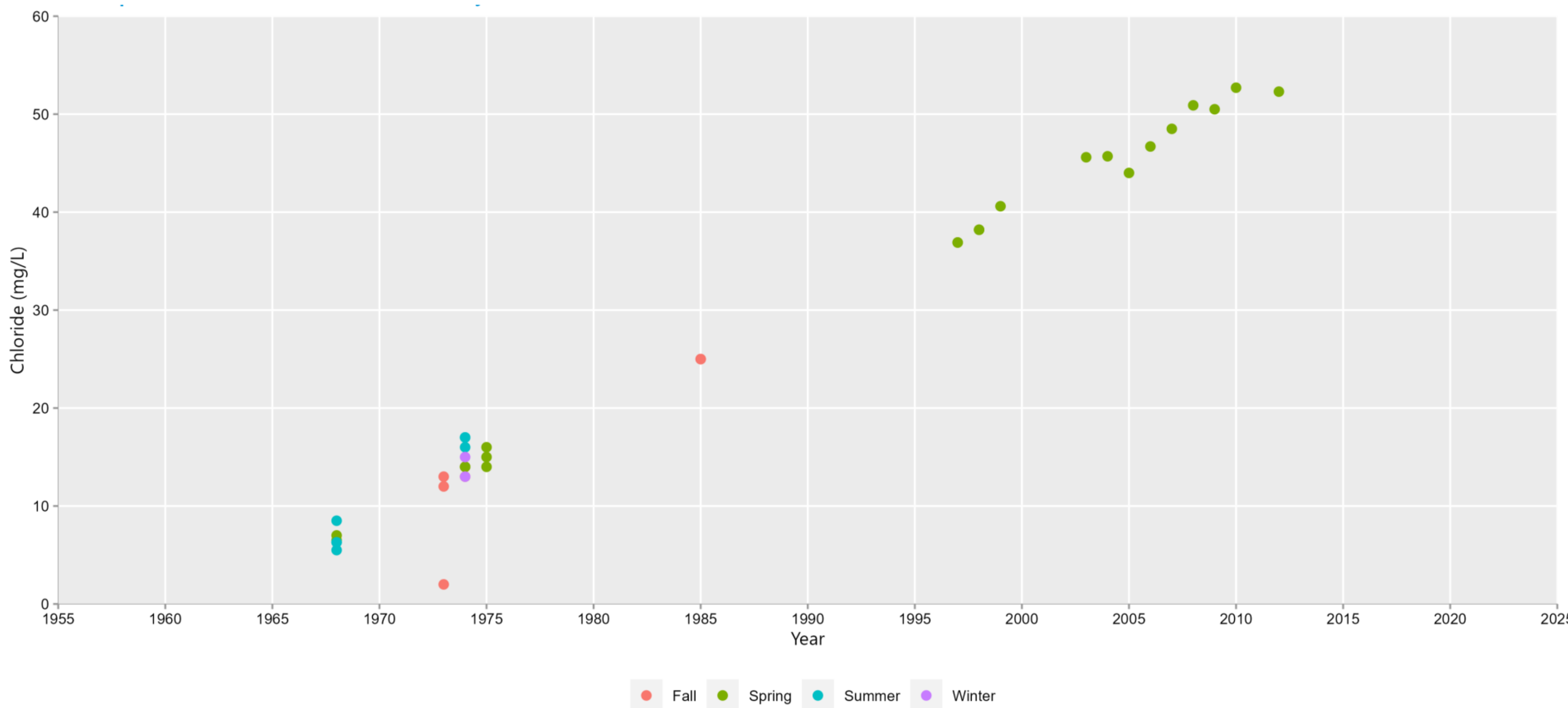
Chapter 5

TRENDS AND CONDITIONS FOR CHLORIDE AND SPECIFIC CONDUCTANCE IN THE LAKES OF SOUTHEAST WISCONSIN

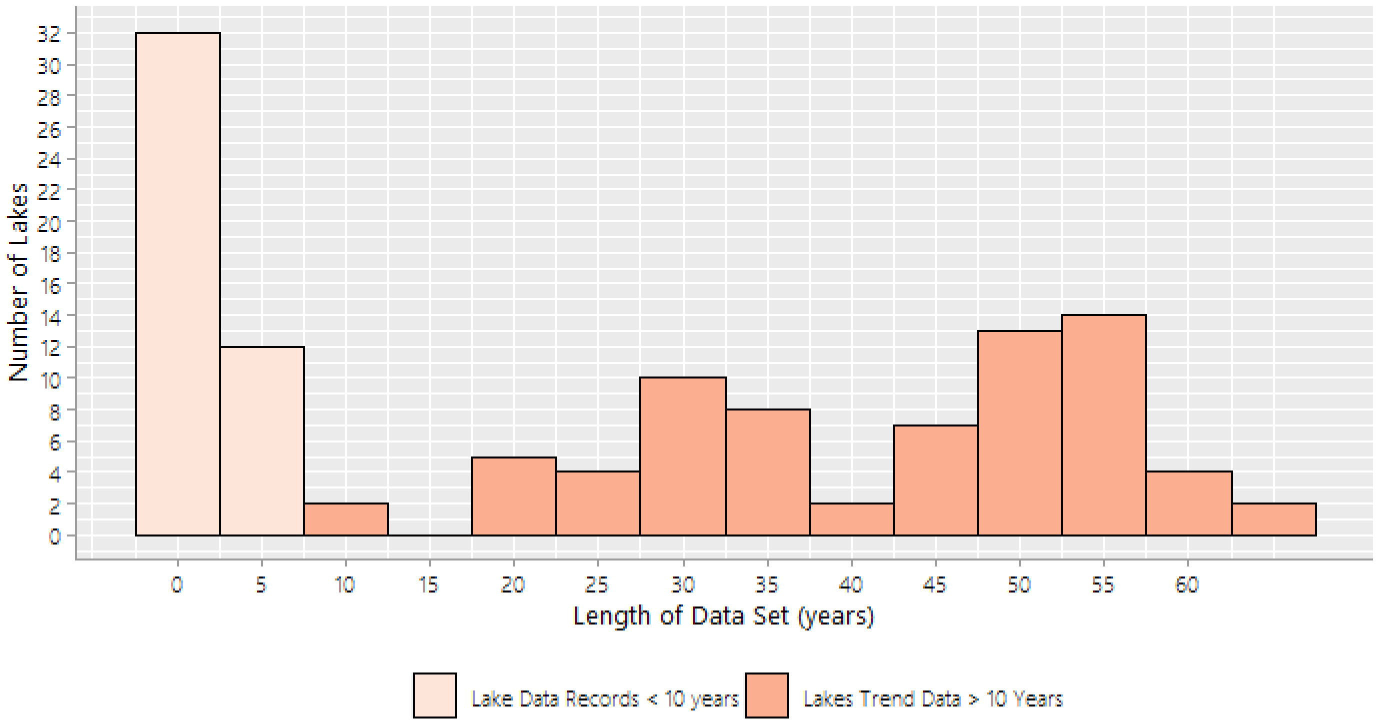
FIGURES

Figure 5.LittleCedarSeasonality
Little Cedar Chloride Data Color by Season : 1960 to 2022



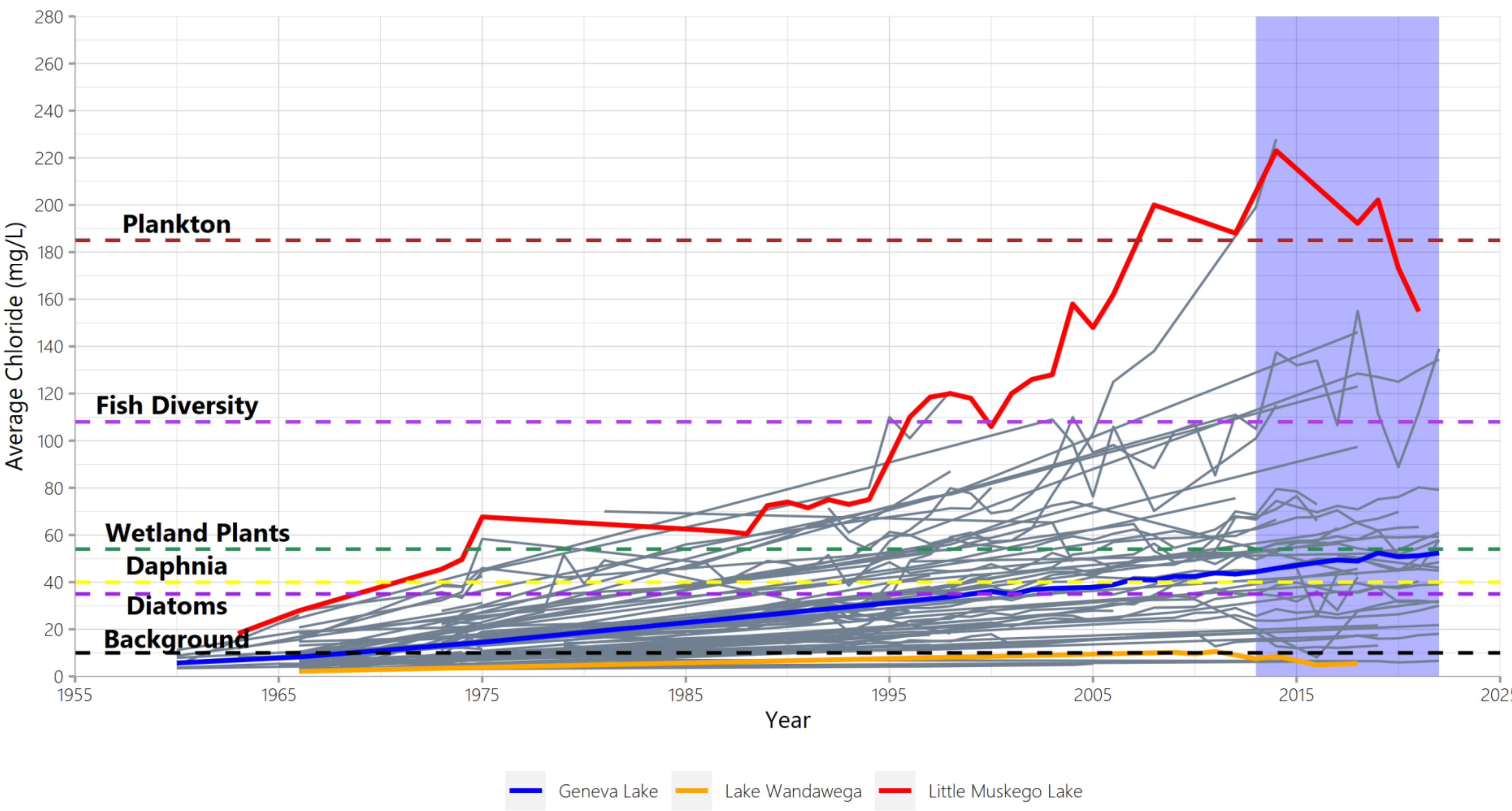
Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 5.LakeTrendDistribution
Distribution of Lakes Trend Data and Length of Datasets : 1960 to 2022



Source: Wisconsin Department of Natural Resources and SEWRPC

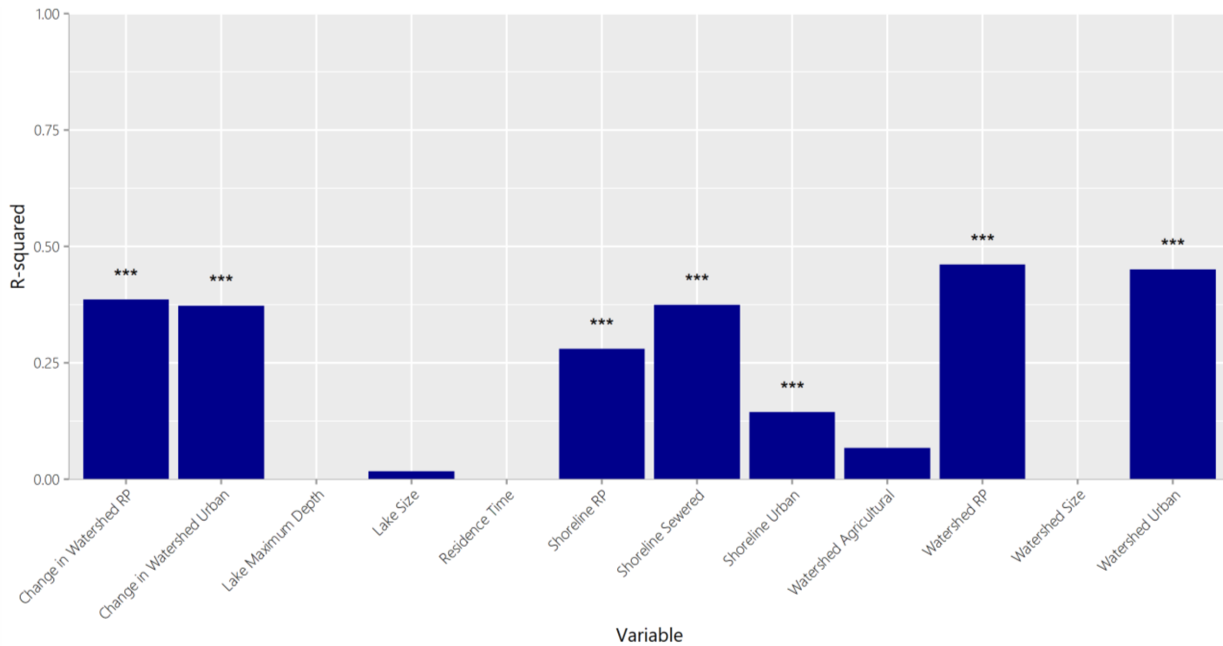
Figure 5.YearlyAverageChlorideLevelsThresholds
All Chloride Lake Data: 1960 to 2022



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

Source: SEWRPC

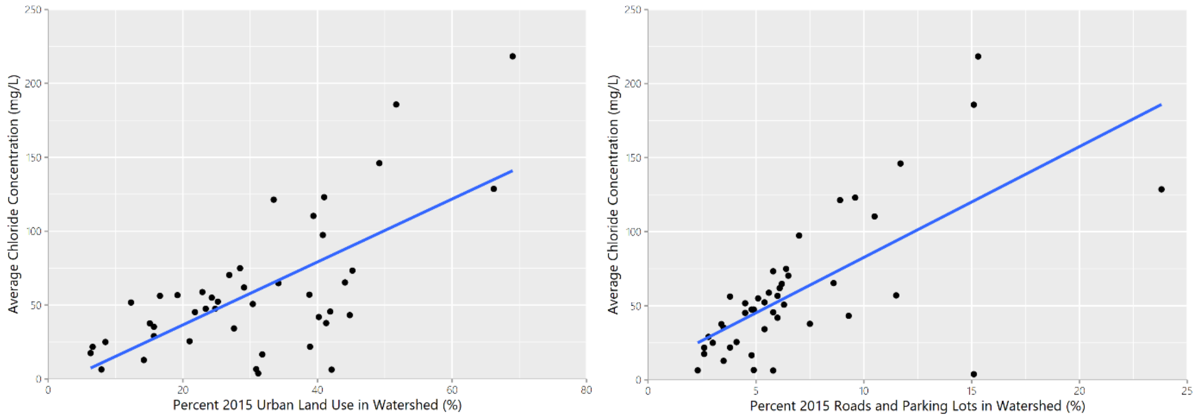
Figure 5.RecentClR2
R-squared Values of Explanatory Variables with Recent Average Lake Chloride : 2013 - 2022



Note: Explanatory variables with a statistically significant relationship to average lake chloride are indicated by the "***" symbols. "Watershed RP" is the percent of the watershed in roads and parking lots while "Watershed Urban" is the percent of the watershed in urban land uses. The "Change in Watershed RP" variable is the difference between the roads and parking lot percent of the watershed in 2015 compared to 1963. "Change in Watershed Urban" is the difference between the urban land use percent of the watershed in 2015 compared to 1963.

Source: SEWRPC

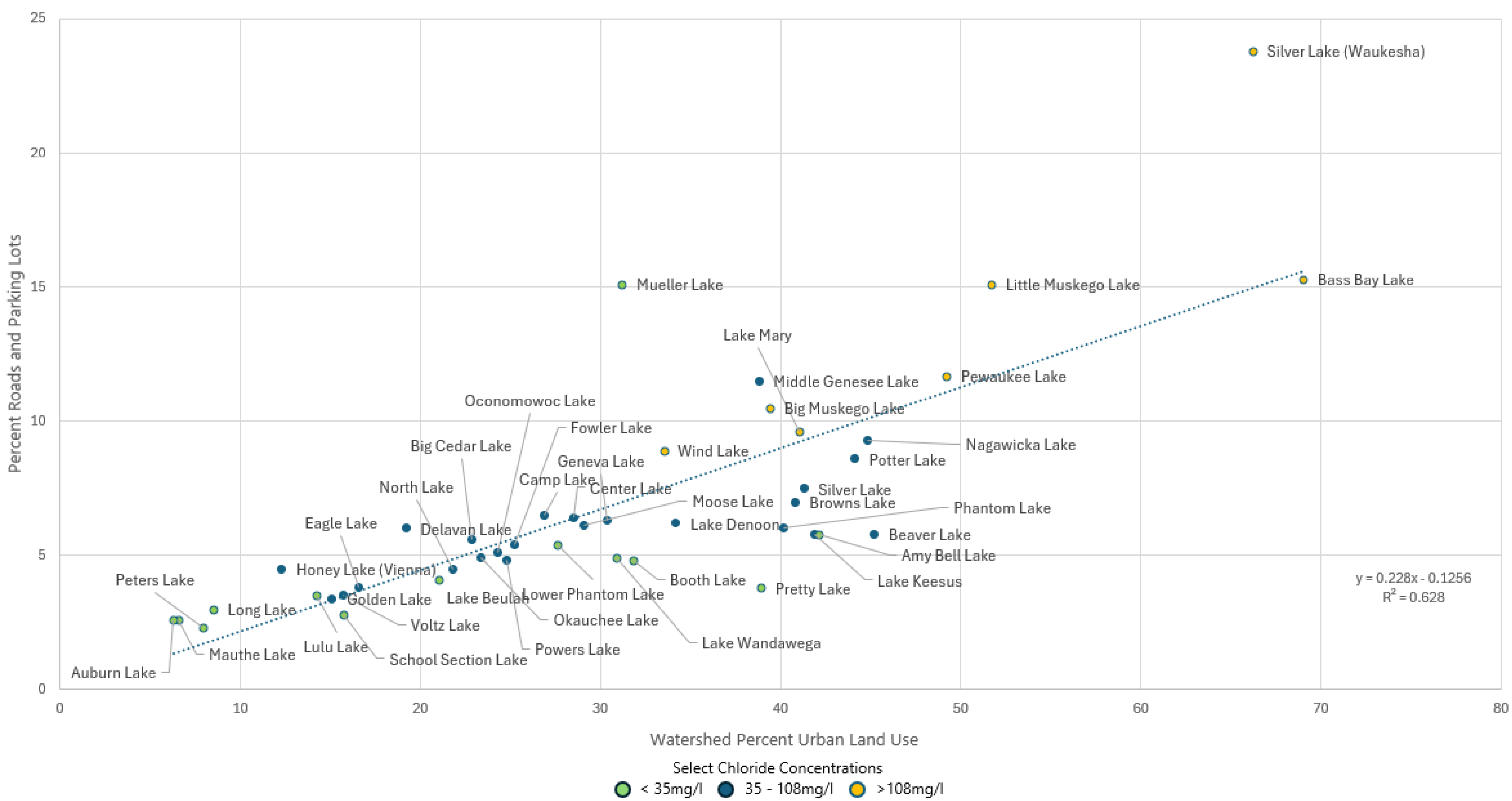
Figure 5.ClRelationScatters
Scatterplots of Percent Urban Land Use and Percent Roads and Parking Lots in Watershed by Recent Average Chloride Concentration: 2013-2022



Source: SEWRPC

Figure 5. Percent Urban Land Use and Percent Roads and Parking Lots Relationship

Relationship of Percent Urban Land use and Percent Roads and Parking Lots Among Select Lake Chloride Concentrations: 2013 -2022



Source: Wisconsin Department of Natural Resources and SEWRPC

Technical Report No. 63

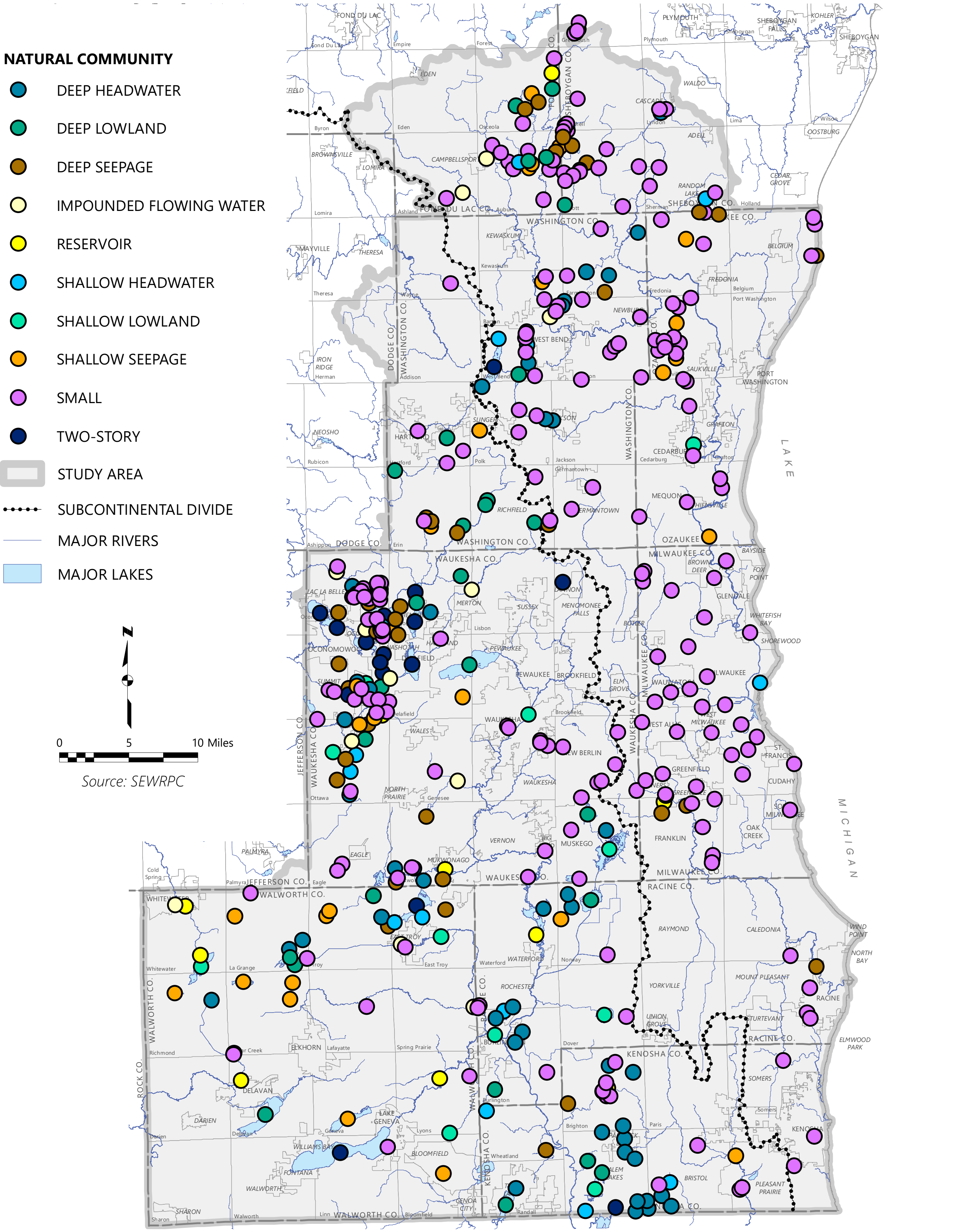
CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 5

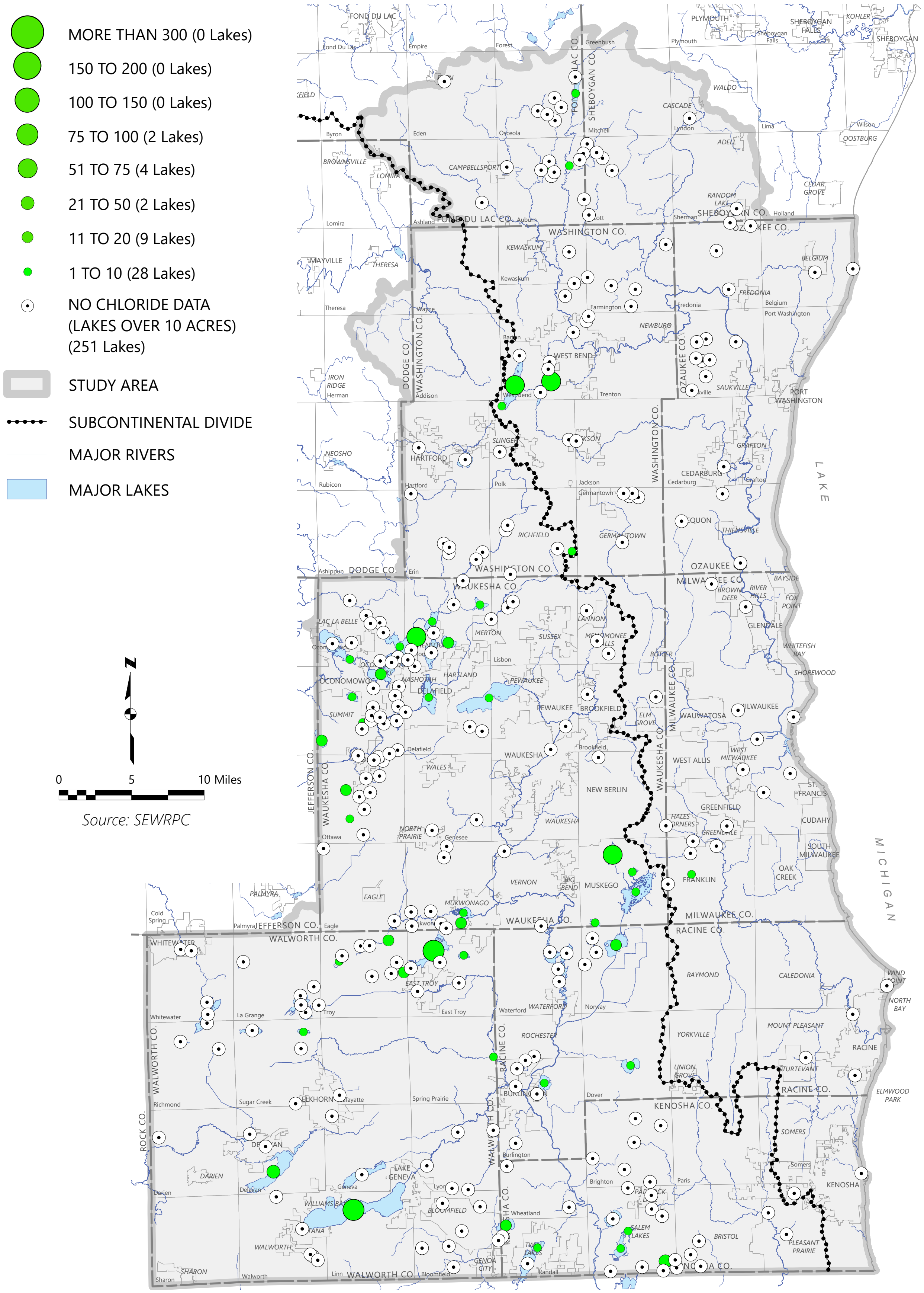
TRENDS AND CONDITIONS FOR CHLORIDE AND SPECIFIC CONDUCTANCE IN THE LAKES OF SOUTHEAST WISCONSIN

MAPS

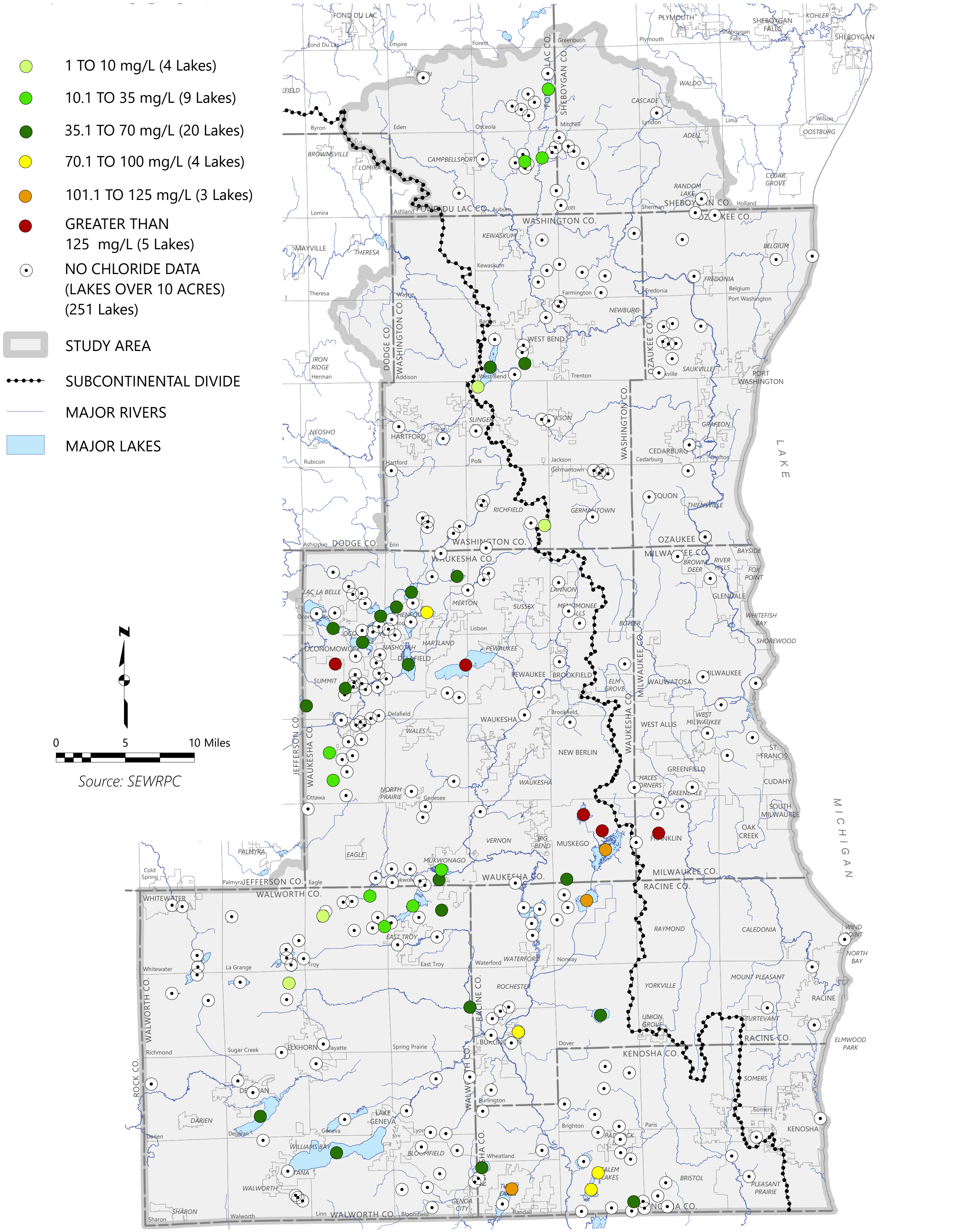
Map 5.ClStudyLakes_NatComms
WDNR-Designated Natural Communities of Lakes in Chloride Study Area



Map 5.ChlorideNumberSamplesLakes_Recent
Number of Recent Chloride Samples Among Lakes: 2013 to 2022



Map 5.ChorideMeanLakes_Recent
Recent Mean Chloride Concentration Among Lakes: 2013 through 2022



Map 5.ClorideRecentMean_PercentUrban
Recent Mean Chloride Concentrations in Lakes and Percent Urban Land Use by Subwatersheds Within the Study Area