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Technical Report No. 65

MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

Chapter 3

CHLORIDE LOADING AND MASS BALANCE ANALYSIS METHODOLOGY

3.1 INTRODUCTION

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

Chloride Mass Balance Approach

The Study mass balance analysis approach for individual stream monitoring sites used a simplified model based on conservation of mass principles to demonstrate the movement of chloride through the environment. The law of conservation of mass dictates that the mass of chloride entering a system should be equal to the mass of chloride leaving a system. Since chloride is a highly mobile pollutant in water, watershed boundaries naturally define the mass balance "system" with a focus on surface water.[1] Figure 3.1 presents a simplified schematic of the chloride mass balance system for a stream monitoring site. This figure shows the sources of chloride analyzed for the mass balance and the input data used to compute chloride loads. It was assumed that chloride contributions within the drainage area upstream of a monitoring site would be transported along with water to the watershed outlet (i.e. stream monitoring site) and out of the system. The mass balance model used the following equation to compare chloride source inputs with the in-stream chloride output at individual stream monitoring sites; the terms of the equation are defined below.

Σ Chloride Inputs – Chloride Output = Δ Chloride Retained in the System

- **Σ Chloride Inputs:** The sum of chloride inputs term in the equation encompasses a variety of chloride sources that are shown in Figure 3.1. The chloride mass load from various sources of chloride within the monitoring site upstream drainage area were estimated on a monthly basis over the study period from October 2018 through October 2020.[2] Chloride point source loading was computed from the best-available monitoring data. In general, the chloride mass load for point sources is estimated by multiplying the chloride concentration in water by the discharge or flow rate. Chloride from nonpoint sources was included in the analysis for datasets with detailed geospatial data readily available and for chloride sources that were likely to be transported to the stream within the relative timeline of the study period. For nonpoint sources, the mass load of chloride is estimated by multiplying a chloride application rate by the area over which the chloride is applied. The general equations used to estimate chloride mass loads may also include unit conversion factors or scaling factors.

- **Chloride Output:** The chloride output term in the equation is represented by the estimated in-stream chloride load that was computed for the stream monitoring sites on a monthly basis for the study period from October 2018 through October 2020. Similar to the computation for point source inputs, the in-stream chloride mass load is estimated by multiplying the chloride concentration in the stream by the streamflow discharge. Only those Study monitoring sites that were located near U.S.

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

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

Geological Survey (USGS) stream gage stations with reliable streamflow data were used in the mass balance analysis.

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

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

In contrast, subsurface pathways and travel times can be significantly longer. Figure 3.2 illustrates idealized groundwater flow systems under steady state conditions, following subsurface flow paths from where water enters the system in groundwater recharge areas to discharge areas where groundwater leaves the system and flows into surface water bodies. The figure is discussed in further detail in the Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) Technical Report No. 62 (TR-62), and shows that the time it takes groundwater to move from a recharge area to a discharge area may range from a few days to thousands of years, depending on subsurface geology and aquifer system characteristics.[3] Chloride sources that are expected to infiltrate into groundwater aquifers were not included in the mass balance analysis; however, some of those sources were evaluated on a Regional basis to develop a Regional chloride budget.

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

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

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

3.2 CHLORIDE SOURCE LOADING COMPUTATIONS

Chloride source loads for the Study were computed for point and nonpoint sources with reliable datasets from which a chloride mass load could be estimated. The sources of chloride evaluated for the Regional chloride budget include atmospheric deposition, winter maintenance operations such as deicing salts applied to public roads and private parking lots, wastewater from public treatment facilities and residential septic systems, industrial wastewater discharge, potash fertilizer, livestock, and agricultural irrigation.[4] This evaluation captured many, but not all, of the sources of chloride within Southeastern Wisconsin. The total chloride source load within individual stream monitoring site drainage areas were computed for chloride sources that had datasets with geospatial distribution information. These chloride sources, shown in Figure 3.1, include the sources listed above with the exception of residential septic systems and irrigation. The methodology and assumptions used to estimate chloride source loads for the entire Region and for individual stream monitoring sites are discussed in the following sections.

Atmospheric Deposition

Atmospheric deposition is the only natural source of chloride that was evaluated in the analysis. The total chloride atmospheric deposition gridded geospatial raster data for years 2018 to 2020 were obtained from the National Atmospheric Deposition Program (NADP) as described in Chapter 2. The source raster data cover the entire continental United States, with a 4 kilometer (km) by 4 km raster grid size and deposition

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

rates reported in kilograms per hectare (kg/ha).[5] The geospatial coordinate system used in the source dataset was converted to match the spatial reference of the Study geographic information system (GIS) datasets. The gridded raster dataset was overlain onto southeastern Wisconsin and clipped to the study area to include the upstream extend of the Milwaukee River watershed north of the Region. Figure 3.4 presents the total annual chloride deposition rates for the Region from 2018 through 2020.

Statistical data were extracted from the total chloride deposition gridded raster data for each county and each stream monitoring site drainage area for each year between 2000 and 2020. The statistical data included minimum, maximum, mean, and median total chloride deposition in kg/ha. During the study period, the mean chloride deposition rates ranged from approximately 0.75 to 1.0 kg/ha (0.67 to 0.89 pounds per acre) for the seven counties in southeastern Wisconsin. Using the mean chloride deposition rate applied over the corresponding area of deposition, the total chloride loads were calculated for each county in the Region and for the individual monitoring site drainage areas. The average annual chloride load from atmospheric deposition in the Region was approximately 662 tons per year during the study period from 2018 to 2020. The total annual chloride loading from atmospheric deposition for each County and the entire Region during the study period is shown in Table 3.1.

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

Winter Maintenance Operations

Chloride used for winter road maintenance operations is typically reported on a winter seasonal basis rather than an annual basis. While the winter season includes months that straddle more than one calendar year,

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[5] *1 kg/ha = 0.89 pounds per acre (lb/ac)*

the winter season totals may be referred to herein as the annual totals.[6] The methodology to geographically distribute road salt and other deicing/anti-icing material usage varies by road type and data source, utilizing the best available data as described in the following sections. These analyses assume that road salt and deicing materials are applied evenly throughout a particular jurisdictional area, without consideration of the level of service that may be assigned to different roadways. For example, the total amount of road salt applied to County roadways during a particular month was assumed to be distributed equally on all of the County highway lane miles within that county. While it is recognized that not all roads are treated equally under practical winter maintenance applications, and some areas such as hills and bridge decks may require targeted and repeated applications during a single storm event, data reporting did not supply this level of detail. Therefore, the uniform application assumption was deemed acceptable for this Regional-scale study.

State and Federal Highways and Interstates: WisDOT Chloride Load

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

The quantities of different materials used for deicing and anti-icing operations were converted to an equivalent chloride mass using deicing chemical property data provided by the Federal Highway Administration (FHWA).[7] Sodium chloride (NaCl) is slightly more than 60 percent chloride by mass, and that ratio was used to estimate the amount of chloride in rock salt. The ratio is slightly conservative as it does not account for salt impurities, which occur naturally in mined salt; rock salt has been estimated to contain 1 to 5 percent impurities depending on where it was mined.[8] Liquid salt brine used for pre-wetting and deicing/anti-icing was assumed to be an optimized 23.3 percent NaCl in solution. Similarly, the calcium

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

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

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

chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) liquids used for deicing and pre-wetting were assumed to be approximately 30 percent and 22 percent in solution, respectively.[9] The only reported proprietary deicer applied to state and federal highways during the study period was Beet Heet, which is a liquid product comprised of several carbohydrate sugars and chloride compounds.[10] Beet Heet was assumed to be approximately 30 percent chloride based on limited ingredient lists and bounding ranges provided by the manufacturer.

The total chloride mass load from deicing was summed for each County for every month of the study period. The average annual chloride mass load applied to state and federal highways in the Region during the study period was 51,300 tons per winter season, approximately 77 times the average annual amount of chloride in the Region from atmospheric deposition.[11] Figure 3.5 shows the monthly chloride loads resulting from deicing and anti-icing activities for the state and federal highways located within the Region over three winter seasons.

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

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

Where:

S_{DA} = WisDOT deicing salt applied within a monitoring site drainage area

S_{Xi} = total amount of WisDOT deicing salt applied within a given County X

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

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

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

LMR_{Xi} = site-specific WisDOT lane mile ratio for County X = (LM_{DAX} / LM_X), where:

LM_{DAX} = state and federal highway lane miles in the site drainage area within County X

LM_X = total state and federal highway lane miles in County X

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

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

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

The chloride mass loads computed for county and local roadways included a combination of data from municipal separate storm sewer system (MS4) permittees and data reported separately to the Commission. MS4 annual report data for winter road management includes the total quantities of materials used each month throughout the winter season covering the six-month period from October through March of the following year. The materials that were reported on the MS4 permit forms were limited to those available within the form drop-down menu, with the earliest versions of the form specifying only the use of solids and liquids in general. The MS4 form used during the study period included an expanded but still largely general list of deicing and anti-icing materials. Solid materials included on the permit form were rock salt, sand, and a salt/sand mixture. The sand/salt mixture was assumed to be 5 percent salt by weight based on typical practices in Wisconsin, with salt considered to be approximately 60 percent chloride by mass.[12] Liquid materials included on the permit form were salt brine, beet juice, and general categories for pre-wetting compounds and chem-melt. During the study period, liquid salt brine represented approximately 90 percent of the liquids reportedly used for winter road maintenance by MS4 permittees in the Region. Therefore, salt brine was the only liquid included in the loading analysis and was assumed to have a 23.3 percent chloride concentration in solution.

The MS4 report data were obtained from the Wisconsin Department of Natural Resources (WDNR), and the winter maintenance material usage totals were converted to chloride content and summed to estimate the total chloride mass load for the entire Region and for each county. Additional local roadway and community salt usage data that was submitted directly to the Commission was combined with the MS4 report data and incorporated into the analysis. Map 2.4 shows where winter maintenance data were available within the study area. Some portions of the study area were not well represented for local road deicing and the dataset may underestimate the chloride load in those areas. Furthermore, the data reported separately to the Commission was typically limited to the 2018-19 winter season, the first winter of the study period. The average annual chloride mass load from winter maintenance operations on county highways and local roadways in the Region during the study period was 135,141 tons per winter season, approximately 204 times the average annual chloride load in the Region from atmospheric deposition.[13] The monthly chloride loads resulting from deicing and anti-icing activities for the MS4 communities located within the Region over the three winter seasons are presented in Figure 3.6.

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

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

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

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

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

Private Winter Maintenance: Parking Lot Chloride Load

Unlike public road winter maintenance, material usage data were not available for private deicing and anti-icing operations. These operations would include winter maintenance for parking lots, sidewalks, and driveways. For private winter maintenance, the Study analysis focused on deicing of parking lots. Geospatial land use data with detailed land use codes for the existing 2015 land use dataset were examined in GIS to identify all the individual designated parking lot areas within the Region. The off-street parking areas in the existing land use dataset total over 25,500 acres and include parking related to residential, commercial, industrial, transportation, government and institutional, and recreational land uses. It is not practical to assume that every square foot of parking lot in the Region would receive the same level of winter maintenance and salt treatment. Some parking lots may not be in use year-round, and furthermore, many parking lots utilize a portion of the parking surface area for snow storage during winter. To account for this, a reduction factor may be applied for the parking lot area that would receive road salt and these salt application rate assumptions are discussed in the next paragraph.

While actual salt application rates vary based on pavement temperature and weather conditions, data from a literature review and previous studies were taken into consideration to estimate a salt application rate for parking lots. Rock salt was the only deicing material considered in the chloride loading analysis for private parking lots. Salt brine was not estimated because of the relatively low chloride content and smaller contribution to the overall chloride load. The industry standard salt application rate for parking lots was examined as a starting point. As described in Chapter 2, the industry standard for parking lots was estimated at approximately 600 pounds of salt per acre per application or storm event. There were approximately 25 storms per winter season on average from 2018-19 through 2020-21 based on the WisDOT winter storm reports for counties in the study area, which was equivalent to the average applications considered in a 2006 study for the City of Madison.[14] Assuming the industry standard salt application was applied to parking lots 25 times per winter season yields an annual rate of 0.34 pounds per square foot. It was further assumed that 75 percent of the parking lot acreage in the Region would receive salt and that reduction factor was applied to the salt application rate, resulting in an approximate annual rate of 0.26 pounds per square foot per winter season.[15] Therefore, the estimated annual salt application rate assumed for the Study analysis was 0.25 pounds per square foot of parking lot per winter season.[16] Similarly, if the average application rate

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

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

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

for parking lots from the City of Madison study is annualized based on 25 events per winter season, the resulting average annual salt application rate for parking lots would be 0.25 pounds per square foot per winter season, further supporting the assumed application rate used in this analysis.

The total annual chloride load estimated for private parking lot salting in the Region is approximately 84,430 tons per winter season on average, equivalent to approximately 127 times the average annual amount of chloride the Region received through atmospheric deposition during the study period. This analysis does not include the study areas outside of the Region because the detailed land use dataset with parking areas delineated does not extend beyond the Regional boundaries. However, since it is the best available data, the Regional detailed land use dataset was used for the individual site load analysis described in the following paragraph. It should be noted that the total parking lot area and the subsequent chloride load from private parking lot salt applications may be underestimated for monitoring sites with drainage areas extending outside the Region (Sites 21, 23, 28, 38, 40, 41, and 58). This was considered acceptable for the analysis because the areas outside of the Region in the upper Milwaukee River watershed are dominated by largely rural and natural lands, with fewer parking lots than in areas with more urban land uses.

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

Wastewater Treatment Facility Effluent Chloride Load

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

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

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

The average annual chloride load from public WWTFs that discharge into streams and rivers in the study area was approximately 46,276 tons per year during the study period, equivalent to about 70 times the average annual amount of chloride from atmospheric deposition across the Region. The average annual chloride load from public WWTF effluent discharged directly to Lake Michigan during the study period was estimated to be 107,261 tons per year, which is approximately 2.3 times the amount of chloride discharged to streams from the other public WWTFs in the study area and 162 times the average annual amount of chloride from atmospheric deposition across the Region. To estimate the chloride load from WWTF effluent for individual monitoring sites, the chloride load for each facility located in the upstream drainage area of the monitoring site were summed. Table 3.3 identifies the WWTFs that were located within the contributing drainage area and discharge treated wastewater effluent upstream of each stream monitoring site. The results of the chloride loading analysis for public WWTF effluent for the entire study area and upstream of individual stream monitoring sites are presented in Chapter 4.

Private Onsite Wastewater Treatment (Septic) Systems

As detailed in Chapter 2, the Commission's Vision 2050 project provided an accounting of the sewered and unsewered populations and households in the Region on a quarter-section scale based on 2010 census data. In 2010 there were approximately 81,909 unsewered households in the Region with an estimated population of 222,942. This equates to approximately 10 percent of the Regional population which were not served by a public sanitary sewer system. The 2010 unsewered household and population data was further broken out to estimate the percentage of septic systems versus holding tanks. Data provided by Walworth, Washington, and Waukesha County indicated that less than five percent of the unsewered households use holding tanks in those counties combined.[17] The unsewered households in those counties represent about 75 percent of the unsewered households in the Region as a whole. Conservatively, it was assumed that all of the unsewered households are on septic systems, neglecting the small percentage that have holding tanks. While some areas have locally higher concentrations of holding tanks, such as residential properties adjacent to some of the Regional lakes, in general the Counties prohibit holding tanks for new residential construction. This assumption provides a conservative yet reasonable representation of private septic systems across the Region.

The following data was used to estimate the potential chloride loading from different domestic sources of chloride. However, this Study did not explicitly include background chloride concentrations in the water supply. The chloride from domestic waste sources such as human excreta and household products was estimated from literature values as a combined 34,000 milligrams (mg) of chloride per person per day, which

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

is approximately equivalent to 27.3 pounds of chloride per person per year.[18] The chloride mass load for the Region was estimated by multiplying the Regional unsewered population by the per capita chloride estimates, resulting in 3,043 tons of chloride per year across the Region.

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

The 420 pounds per household per year annual water softener salt usage assumption was checked using an alternate methodology from a Minnesota study, which estimated water softener salt usage based on per capita water usage, water hardness to be removed, and water softener efficiency using the following equation.[19]

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

= Water softener salt usage in pounds (lb NaCl)

The 2015 USGS domestic water use data for each County in the Region were used to estimate per capita water use; the Regional average of 57.8 gallons per day (gpd) per capita was rounded up to 60 gpd for use in the equation.[20] The average Regional hardness of the assumed groundwater supply was estimated using shallow sand and gravel aquifer hardness data from a 1981 USGS study.[21] The average of the mean hardness

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

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

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

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

for the Region was 359 milligrams per liter (mg/l).[22] Similar to the Minnesota study, it was conservatively assumed that water is softened to zero grains per gallon (gpg), for a total hardness removed of 21 gpg.[23] The Minnesota study assumed water softener efficiencies of 2,000 and 4,000 grains per pound of salt for timer and demand-based water softeners, respectively. An average water softener efficiency of 3,000 grains per pound of salt was assumed for this analysis. Using the above parameters along with the total unsewered population in the Region results in an estimated 10,364 tons of chloride per year from water softener salt usage. This calculated chloride load is less than one percent different than the chloride load computed using the assumed 420 pounds of water softener salt per household per year; the similar results provide further support for the assumed water softener salt usage per household.

The estimated chloride from domestic waste sources were added to the chloride estimates for water softener salt usage to determine the Regional chloride load from private septic systems. Based on the estimates of chloride loading for the unsewered households and population in the Region, the total chloride load estimated for private septic systems in the Region is approximately 13,478 tons per year, which is equivalent to the average annual amount of chloride the Region receives through atmospheric deposition. The chloride load from private septic systems was not estimated for individual monitoring site drainage areas for the mass balance analysis because this source is designed to discharge wastewater to subsurface soils for treatment and ultimately to groundwater. While there may be subsurface pathways that transport the treated wastewater to a surface waterbody over longer periods of time, it is not possible to determine the timing nor the amount of chloride from septic systems that end up in streams versus the deeper groundwater aquifer. Thus, chloride contributions from septic systems were included in the Regional chloride budget but were not calculated for individual monitoring sites or included in the mass balance analysis.

Industrial Wastewater Effluent Chloride Load

While there are hundreds of industrial operations located within the Region, this Study focused on those facilities that were permitted to discharge wastewater to surface waters and were also required by permit

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

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

to monitor chloride in the wastewater effluent. The locations of these facilities are shown on Map 2.7. The WDNR provided water quality monitoring data for each facility that included chloride concentrations and flow rates. The flow rate data available for each facility ranged from daily measurements to monthly observations. The frequency of effluent chloride sampling was monthly at best; however, most of the industrial wastewater permittees had a more sporadic sampling frequency that varied by facility. Table 3.4 summarizes details related to the flow rate and chloride dataset available for each facility during the study period. Of the 12 industrial wastewater dischargers considered in this analysis, the table shows that two facilities had chloride data for every month of the 25-month study period, four were missing data for 3 months or less, and six facilities were missing data for 20 months or more, including four facilities had no chloride sample data collected during study period. An average monthly chloride load was estimated for each month of the study period, either using chloride sample data or when sample data were not available, estimated chloride concentrations were developed using chloride data collected outside of the October 2018 to October 2020 study period. The average monthly chloride concentration and flow data were multiplied to estimate the monthly chloride mass load for each industrial facility. The total chloride loads computed for each industrial facility over the 25-month study period are presented in Table 3.4.

The resulting average annual chloride load estimated for industrial wastewater point source discharge in the study area was 636 tons per year, which is slightly less than but on the order of the average annual amount of chloride contributed to the Region through atmospheric deposition. It is important to reiterate that these industrial discharge chloride loads do not represent the full extent of chloride contributed to the environment by industrial facilities, but only those that discharge directly to surface water and are required to provide chloride monitoring data to the WDNR. These estimates do not include chloride from industrial wastewater discharge sent to municipal wastewater treatment facilities or disposed of through land spreading. The results of the chloride loading analysis for industrial wastewater effluent for the entire study area and upstream of individual stream monitoring sites are presented in Chapter 4.

Agricultural Sources of Chloride

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

Chloride Load from Agricultural Fertilizer

While the types of crops planted and fertilizing practices can vary year to year, the first step in determining how much chloride was applied to the Region through agricultural fertilizers during the study period was to determine which crops were grown between 2018 and 2020. The cropland raster data were downloaded from the Cropscape website, and ArcMap was used to convert the spatial raster data into shapefiles and reproject the data into the proper coordinate system.[24] The annual cropland datasets were geospatially intersected with County and stream monitoring site drainage area shapefiles to estimate the total acreage of different crops grown each year throughout the Region. Based on this geo-spatial analysis, selected crops grown within the Region are summarized in Table 3.5. Of the crops grown most prevalently in the Region, corn, soybeans, and alfalfa utilize the greatest amount of potassium. Potatoes, barley, and winter wheat require potassium as well, but these crops are grown in much smaller quantities within the Region. As such, the only crops that were considered for the potash fertilizer chloride loading analysis were corn, soybeans, and alfalfa. Table 3.6 summarizes the total acreage of these three crops within each County for the 2018 through 2020 growing seasons. Additionally, pastureland is rarely fertilized aside from incidental manure applications during livestock grazing and was not considered in the analysis. This assumption is supported by Table 40 of the 2017 Census of Agriculture, which shows that the acres of pastureland that are fertilized are a fraction of a percent of the total cropland acres in the Region that are fertilized.[25]

After determining the types of crops that are grown within the study area, the amount of potash fertilizer applied to relevant crops was estimated. The U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) agricultural chemical use reports for corn and soybeans were used to estimate potash usage on these crops in Wisconsin.[26,27] The statewide 2018 data for corn indicates that approximately 79 percent of the acres planted with corn received potash with an average application rate of 76 pounds per acre per year. Similar information was obtained from the 2020 soybean data showing that approximately 77 percent of the acres planted with soybeans received potash with an average application rate of 92 pounds per acre per year. These rates were applied to the cropland acres planted each year with corn and soybeans, respectively, to estimate the amount of potash applied to those crops annually during the study period.

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

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

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

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

The amount of potash fertilizers applied annually to alfalfa fields within the study area was estimated using the fertilizer application rate guidelines presented in Table 7.4 of the Nutrient Allocation Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin, along with assumptions for soil conditions and target crop yields.[28] Potassium soil conditions were estimated using the results from soil testing data for all farmer field samples analyzed between 2005 and 2019 to estimate a mean potassium soil concentration for each County. Overall, the soils in the Region range between optimum levels and high levels for potassium, with a majority falling within the optimum range.[29] The crop yield data for alfalfa in the state of Wisconsin compiled by the USDA NASS was 2.35 tons per acre in 2018, 2.4 tons per acre in 2019, and 3.2 tons per acre in 2020. The target crop yield goal range was set to the next higher yield category. Based on the fertilizer application guidelines for alfalfa, considering optimum potassium soil conditions and a target crop yield of 3.6 to 4.5 tons per acre, the recommended potash application rate of 240 pounds per acre per year was used to estimate the total potash applied to alfalfa during the study period.

As mentioned in Chapter 2, potassium chloride (KCl) is the most prevalent form of potash fertilizer used in the United States. Regardless of what form of potash is applied, it is often reported as a mass of potassium oxide (K_2O), which was converted to an equivalent amount of KCl required to deliver an equal mass of potassium to the soil. Using chemical stoichiometry, the mass quantity of K_2O was multiplied by 1.583 to determine the mass of KCl with an equivalent amount of potassium. Since KCl is 47.6 percent chloride by weight, the mass quantity of KCl was multiplied by 0.476 to get mass quantity of chloride. The resulting ratio of K_2O to KCl is approximately 0.754, which is aligned with literature values ranging from 0.76 to 0.78.[30] These chloride load estimates are conservative, representing the maximum amount of chloride applied as potash, assuming all potash is applied as KCl. This is a reasonable assumption as historical fertilizer usage data compiled by the USDA show that approximately 90 percent of the potash applied in the United States between 1960 and 2015 is applied as KCl.[31,32] Other references have estimated this value could be as high as 95 percent as discussed in Chapter 2. However, it is likely that the amount of chloride applied may be smaller, because potash can be applied as KCl or a variety of other compound forms. These estimates also

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

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

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

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

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

do not account for any crop uptake of chloride, which is an appropriate assumption for the types of crops considered in the analysis, considering that chloride is a micronutrient and is applied in much larger amounts than is utilized by plants.

The timing of fertilizer applications across the Region is complex and varies by crop, by location, and by year. Fertilizer application timing guidelines for row crops like corn or soybeans recommend fertilizer applications either in spring or in fall, or split applications based on different considerations including crop type and toxicity risk, as well as weather and soil conditions. In southeastern Wisconsin, potash is typically applied to alfalfa fields several times during the growing season following each cutting, with the first cutting typically in June and the last cutting in the fall.[33] For the mass balance analysis the monthly chloride load from fertilizer was estimated by distributing the total annual load equally across the warmer season months from April to October. This assumption was considered reasonable given the temporal uncertainty in the dataset and variability of fertilizer application timing, and the relatively long chloride transport times through soil. It is likely that chloride from fertilizer applications slowly move through the soil over the growing season, year after year.

The average annual chloride load from agricultural fertilizer applied to the Region during the study period was approximately 17,508 tons. This average was computed for three growing seasons over the period from 2018 to 2020 and is equivalent to approximately 26 times the average annual amount of chloride from atmospheric deposition over the Region during the study period. The total annual chloride load from potash by crop type for each County in the Region is presented in Figure 3.7. Additional results and details for chloride loading from agricultural fertilizer are discussed in Chapter 4.

Chloride Load from Livestock Operations

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

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

Total Regional Chloride Load from Livestock Manure

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

A 2003 American Society of Agricultural Engineers (ASAE) standard provides manure characteristics for different types of livestock as well as the typical live animal mass per animal.[34] The chloride content for manure generated by dairy cattle, swine, sheep and layers (chicken) is reported in pounds of chloride per 1,000 pounds of live animal mass (equivalent to one animal unit (AU) per day. To determine the chloride generated daily by these livestock populations, the total number of animals were multiplied by the typical live animal mass converted to animal units and the chloride content using the data shown in Table 3.7. For the purposes of estimating a Regional chloride load from livestock, the chloride content for layers was applied to the other types of chickens represented in the inventory under the broilers and pullets categories.

A different approach was taken to determine the chloride load from livestock manure for horses, beef cows, and turkeys. The daily manure production per animal was obtained from the USDA/Natural Resources Conservation Service (NRCS) 2016 technical note and multiplied by the total number of animals to estimate total waste generated daily.[35] Chloride concentration data for different types of animal manure were obtained from various sources as shown in Table 3.7. These estimated chloride concentrations were applied to the total waste generated by the livestock populations to estimate the total chloride mass load.

The 2017 livestock inventory for the Region includes a breakout of the cattle and calves category into three subgroups: dairy cows, beef cows and other cattle. The "other cattle" subgroup is defined as heifers that had not calved, steers, bulls, and calves. The "other cattle" subgroup makes up approximately 60 percent of the total Regional inventory of cattle and calves, so it was important to include an estimate of the potential chloride load generated from such a large proportion of livestock in the Region. The AU calculation worksheets submitted by each dairy concentrated animal feeding operation (CAFO) in the Region provided

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

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

a breakout of the livestock populations by type and size.[36] The CAFO inventories were summed for the Region to estimate a distribution of animal type and size to apply to the "other cattle" subgroup. The distribution was applied to the "other cattle" inventory, and the individual AU equivalent factors were applied to each type of animal to determine the total AU represented by the heifers and calves in the "other cattle" subgroup. The chloride content for dairy cows was applied to the "other cattle" AU to estimate a chloride load. The chloride load for the steers was computed using the same methodology and data that was used for beef cows.

The annual chloride load from livestock manure estimated for the Region was 3,439 tons per year, with over 95 percent of the chloride load generated by cattle, cows, and calves. The annual chloride load from livestock manure was approximately five times the average annual amount of chloride from atmospheric deposition over the Region during the study period. Figure 3.8 presents the annual chloride load from livestock manure for the seven Counties in the Region. The countywide inventories used to estimate the chloride load for the Region could not be used to estimate the chloride load for individual monitoring sites due to a lack of detailed geospatial data. Instead, manure generated from livestock that are housed on CAFO farms was used to estimate the livestock chloride load for monitoring sites as described in the next section.

Chloride Load from CAFOs within the Study Area

The livestock animals housed at CAFO farms are a subset of the total livestock population within the Region and larger study area. The estimated chloride load from CAFOs located within the study area was computed for use in the mass balance analysis for individual stream monitoring sites. During the study period, a majority of the CAFOs in the study area were dairy operations, along with three "layer" (chicken) CAFOs and one duck CAFO (see Map 2.8). According to the CAFO permit documents, the CAFO operations with layers did not land-spread any chicken manure. All chicken manure generated on the farms was composted and sold as consumer fertilizer off-farm; therefore, the layer CAFOs were not included in the Study analysis. Similarly, the duck CAFO was not included in the chloride loading analysis since the process wash water generated on-farm was sent to a permitted municipal WWTF. While the duck operation was permitted to spread up to 5000 tons of manure per year, a chloride load was not estimated due to a lack of chloride

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

content data.[37] Hence, the only CAFOs for which a chloride load was estimated for individual monitoring sites were dairy operations, using the methodology described in the following paragraphs.

The animal counts for each dairy CAFO farm from the years 2018 through 2020 were obtained from the AU calculation worksheets downloaded from the WDNR e-permitting website referenced in Chapter 2. The AU calculation worksheets are updated annually and submitted to the WDNR to satisfy CAFO permit requirements. The annual chloride load produced by each CAFO was estimated from the animal counts, along with daily chloride production numbers and manure chloride concentrations from literature. The methodology was similar to the approach used to estimate the Regional chloride load from the County livestock inventories, only with more detailed input data. The AU for milk cows, heifers, and calves were computed and summed, and the dairy manure content from ASAE 2003 was applied to the summed AU to determine the chloride load. The chloride load for steers was computed using the data for beef cows as explained in the previous section and was added the dairy chloride load to estimate the total annual chloride load generated at each dairy CAFO for every year during the study period.

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

The timing of this chloride source was harder to estimate. The spreading logs that were submitted to the WDNR as part of the required permit reporting indicated that the timing of land spreading was variable from year to year and farm to farm. Wisconsin enforces regulations to limit land spreading practices in order to protect water quality; consequently, land spreading is typically performed when conditions are favorable and as needed to free-up additional manure storage on the farm. Because a temporal component is required for the individual site mass balance analyses, it was assumed that the majority of CAFO land

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

spreading occurred during the growing season when the ground is not frozen, thus the annual load was distributed evenly across the months from April to November. Results for the CAFO chloride loading analysis for each monitoring site are presented in Chapter 4.

Irrigation Chloride Load

Based on USGS estimates for 2015, water used for irrigation within the seven counties in southeastern Wisconsin was approximately 9.5 mgd. The study estimates that 95 percent of the water used for irrigation was pumped from groundwater. Data presented in Technical Report No. 63 (TR-63) related to chloride conditions and trends in groundwater were used to estimate the chloride concentration of irrigation water used in the Region.[38] Considering recent conditions covering the period from 2013 to 2022, the mean chloride concentration in shallow groundwater within the Region was 96.7 mg/l. By multiplying the total water used for irrigation by the average chloride concentration in shallow groundwater, the resulting annual chloride load estimated for the Region was 1399 tons per year, which is equivalent to approximately twice the average annual amount of chloride resulting from atmospheric deposition over the Region during the study period. An annual chloride load is estimated for this source based on USGS data, but there is no geospatial or temporary component to the dataset, so this source is not included in the individual site mass balance analyses presented in Chapter 4.

3.3 IN-STREAM CHLORIDE LOAD COMPUTATIONS

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

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

Where:

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

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

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

Streamflow Discharge

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

Previous studies have shown that chloride levels in streams are highly dependent on streamflow discharge.[39] Sensitivity testing for the chloride loading analysis confirmed that in-stream chloride loading results are highly sensitive to discharge, particularly in streams with a wide range of discharges and rapid changes in streamflow. Additionally, the sensitivity testing evaluated various chloride load computation intervals ranging from 15-minute to monthly data averaging intervals. The total monthly chloride load was compared for each computation interval and results indicated that smaller computational intervals provided more accurate estimates of chloride loads in streams. The smaller computation interval better represented variations in discharge and in-stream chloride concentrations that were not captured when data were averaged over longer intervals. Chloride load differences were greater for "flashier" sites with greater variability in streamflow discharge and observed specific conductance. Typically, the monthly chloride load computed using the average monthly discharge and average chloride concentration was much higher than the monthly chloride load computed from the sum of the daily, hourly, or sub-hourly averaged parameters.

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[39] *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.*

This is partially because averages tend to skew upward with outliers, resulting in overestimates. While it was noted that the smaller computation intervals were more sensitive to missing data, ultimately the 15-minute computational interval was chosen to estimate in-stream chloride loads.

In most cases, the Study stream monitoring site was close to the USGS stream gage station, and the upstream contributing drainage areas were similar enough to use the streamflow discharge dataset directly. One exception was Site 16 Jackson Creek, which was located nearly a mile upstream of the USGS stream gage station. The predominantly rural 9.8 square mile upstream drainage area for Site 16 is approximately 58 percent of the upstream contributing drainage area to the Jackson Creek USGS stream gage. The portion of the drainage upstream of the USGS that is outside of the Site 16 drainage area includes the southern half of the City of Elkhorn and has more developed urban land use. Since the difference in drainage areas is less than 50 percent, the stream gage data transfer methodology recommended in the *Wisconsin Administrative Code*, Chapter NR 116 was used to determine the proportion of streamflow at the gage to be applied to Site 16.[40] Based on the drainage area ratio and regional coefficient provided for Southeastern Wisconsin, the streamflow data at the gage was reduced by a factor of 0.71 to estimate the streamflow at Site 16.

In-Stream Chloride Concentrations

As discussed in Chapter 2, the specific conductance data collected for the Study was used to estimate in-stream chloride concentrations at 14 stream monitoring sites. The 5-minute specific conductance data was averaged over 15-minute intervals and then converted to estimated chloride concentrations using the piecewise regression equations. This created the 15-minute estimated chloride dataset used to compute in-stream chloride loads. The development of the regression relationship between chloride and specific conductance is detailed in Technical Report No. 64 (TR-64).[41]

There are many factors that can influence in-stream chloride concentration estimates, such as the performance of the in-stream sensor and the quality of the specific conductance data collected during the study period. Sensor fouling was observed at several monitoring sites during the study and resulted in dampened or lower specific conductance readings. In some cases the specific conductance data were adjusted, and in rare cases, the specific conductance data were deemed too severely dampened to apply

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

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

the adjustment. The periods of dampened specific conductance data translate to underestimated chloride concentrations and lower monthly in-stream chloride loads. Monitoring site maintenance procedures along with specific conductance data post-processing and adjustment procedures are discussed in further detail Technical Report No. 61 (TR-61).[42]

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

In-Stream Chloride Loads

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

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

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

from the second location was utilized from December 2019 through October 2020. The results of the in-stream chloride loading calculations and the mass balance analysis are presented in Chapter 4.

Technical Report No. 65

MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

Chapter 3

CHLORIDE LOADING AND MASS BALANCE ANALYSIS METHODOLOGY

TABLES

#278297
200-1100
KMH/mid
7/3/25

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

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

Source: NADP and SEWRPC

#278298
200-1100
KMH/LKH/mid
4/9/2025, 9/3/25

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

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

Table continued on next page.

Table 3.2 (Continued)

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

Table continued on next page.

Table 3.2 (Continued)

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

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

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

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

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

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

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

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

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

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

Source: WDNR and SEWRPC

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

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

Table continued on next page.

Table 3.3 (Continued)

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

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

Source: WDNR and SEWRPC

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

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

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

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

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

Source: WDNR and SEWRPC

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

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

Source: USDA NASS

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

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

Source: USDA NASS

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

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

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

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

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

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

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

Source: SEWRPC

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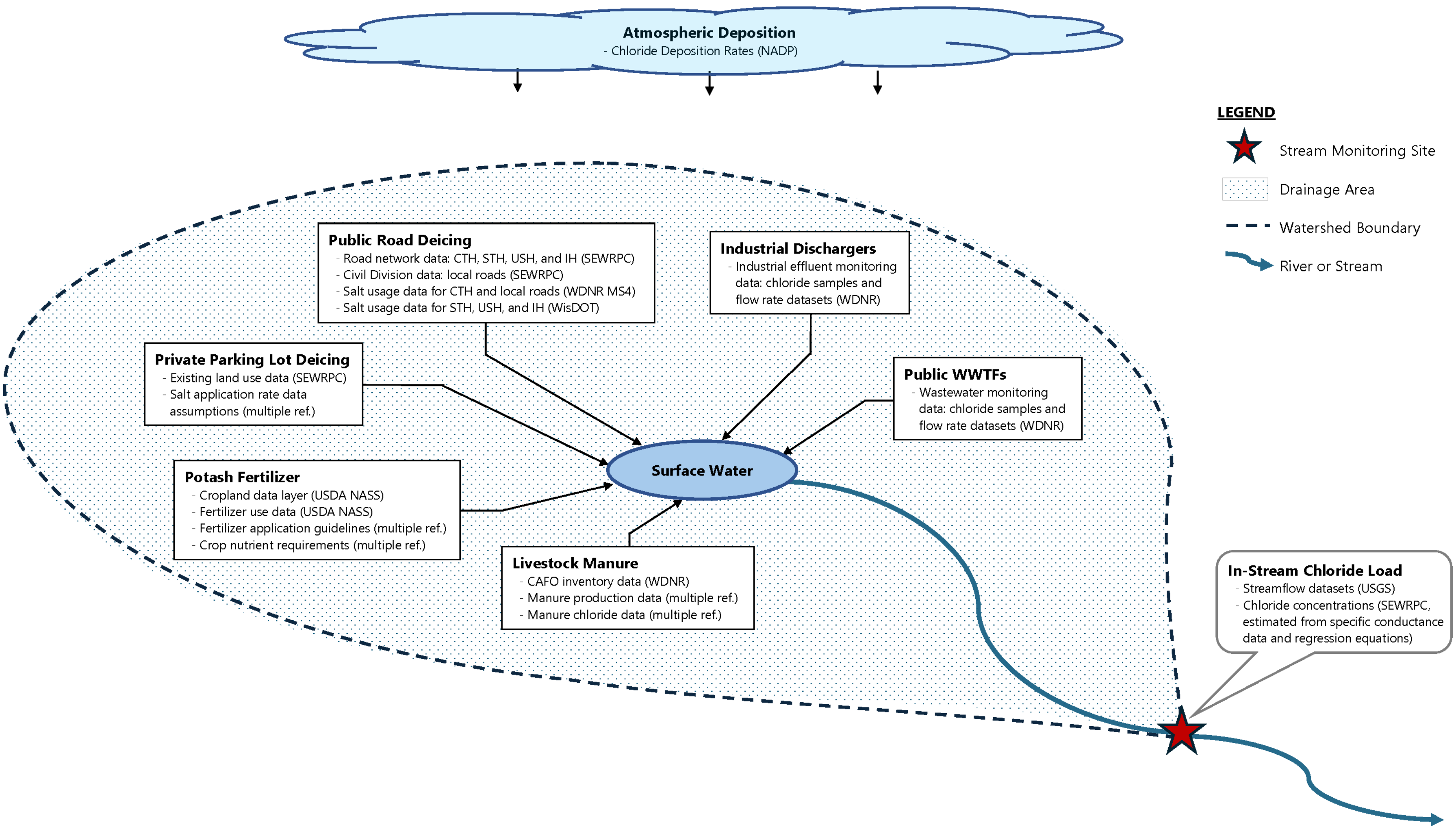
MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

Chapter 3

CHLORIDE LOADING AND MASS BALANCE ANALYSIS METHODOLOGY

FIGURES

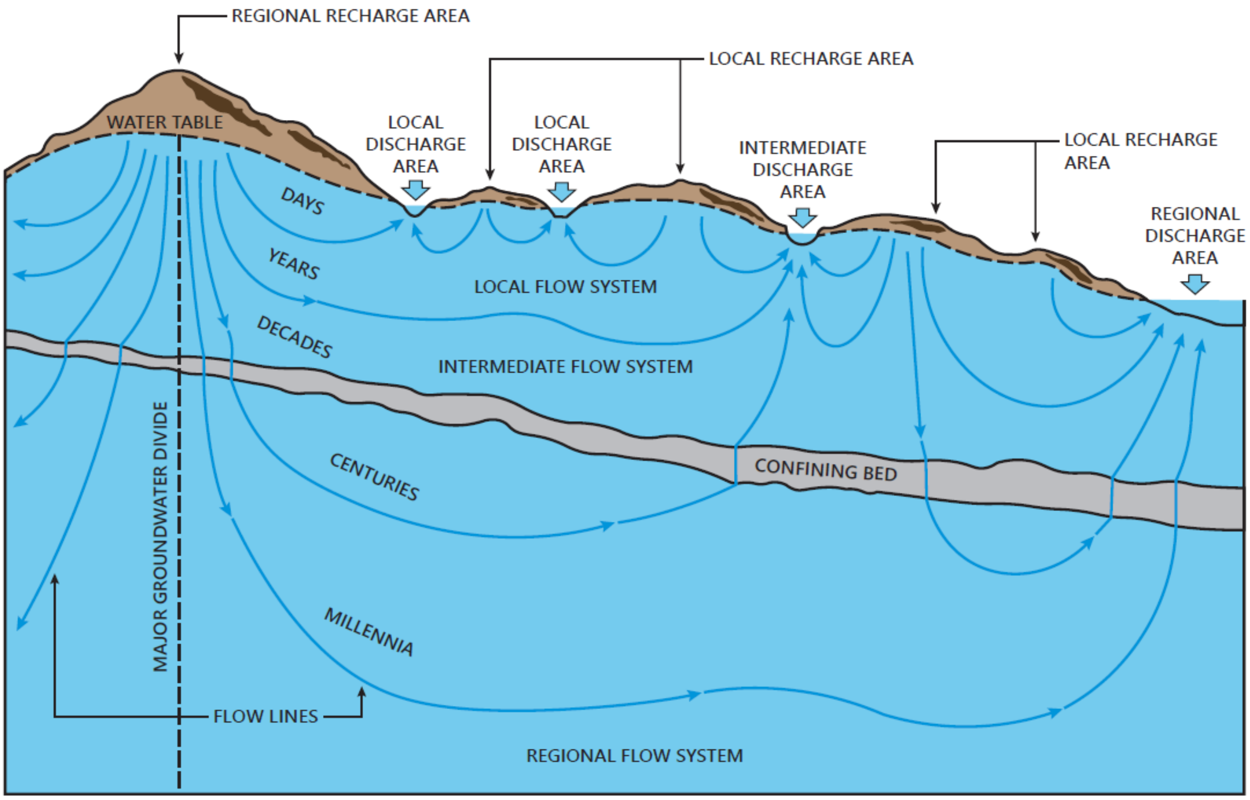
Figure 3.1
Chloride Mass Balance Schematic for Stream Monitoring Sites



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

Source: SEWRPC

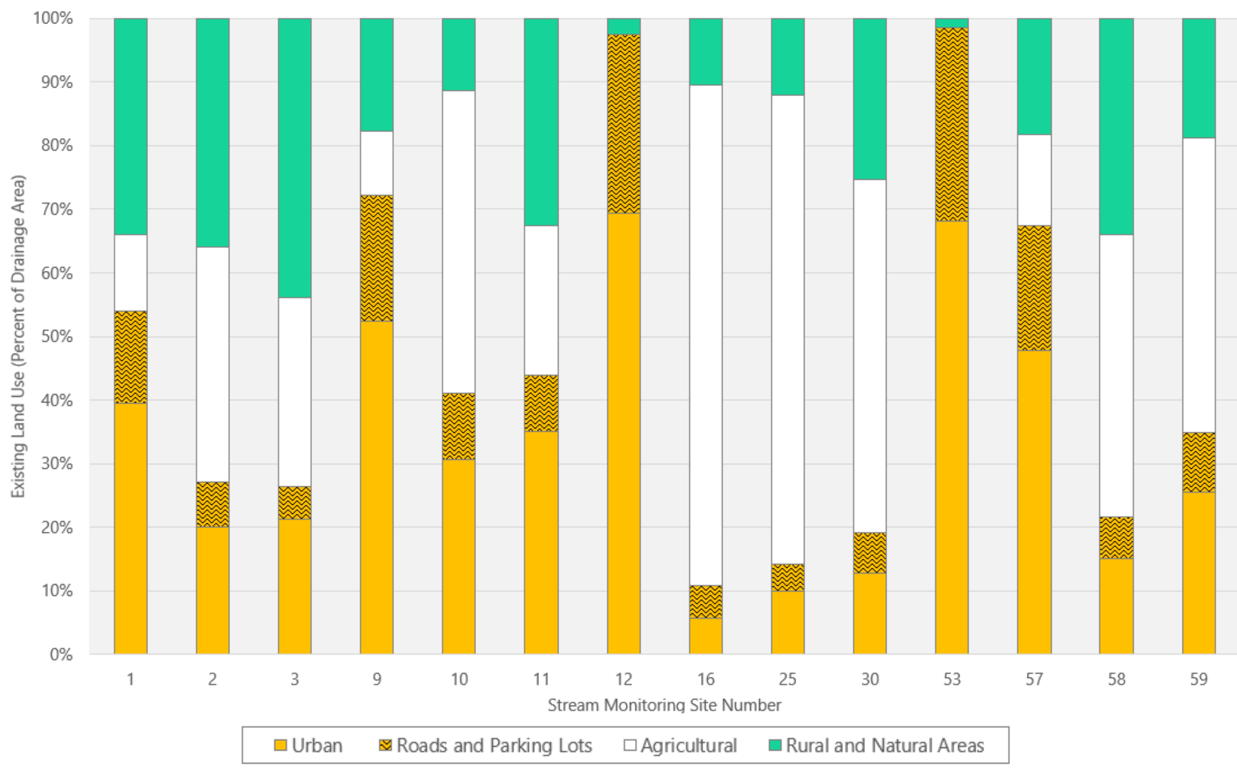
Figure 3.2
Idealized Groundwater Flow Systems Under Steady State Conditions



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

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

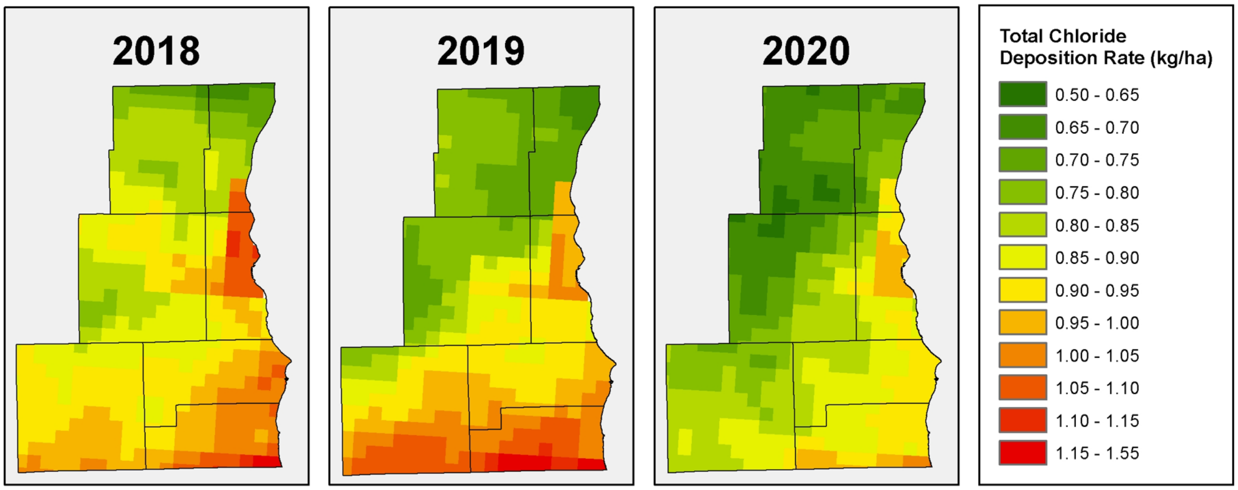
Figure 3.3
Existing Generalized Land Use Percentages for Monitoring Sites in the Mass Balance Analysis



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

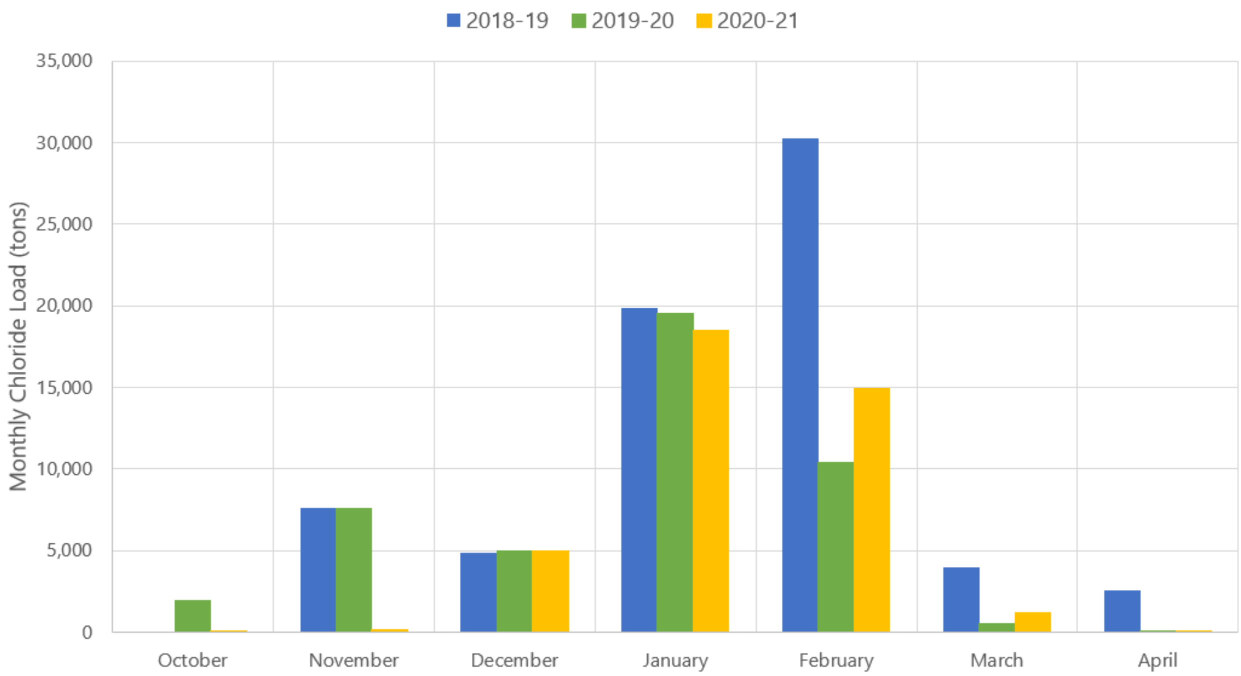
Source: SEWRPC

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



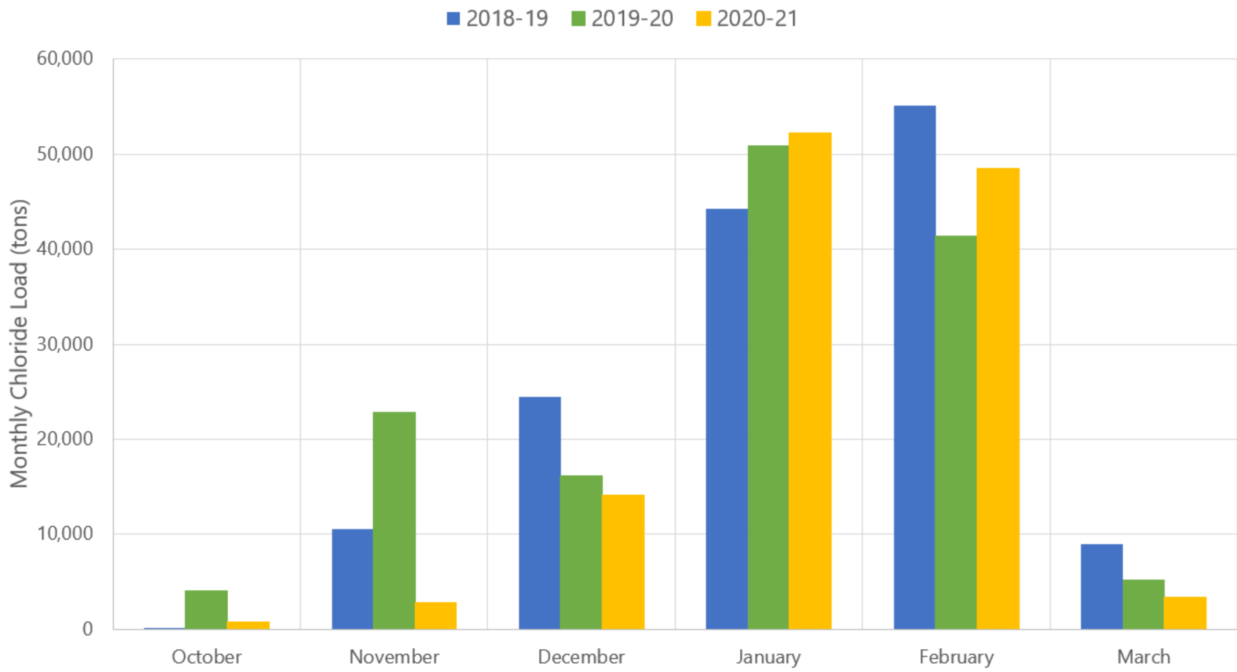
Source: NADP and SEWPRC

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



Source: WisDOT and SEWRPC

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

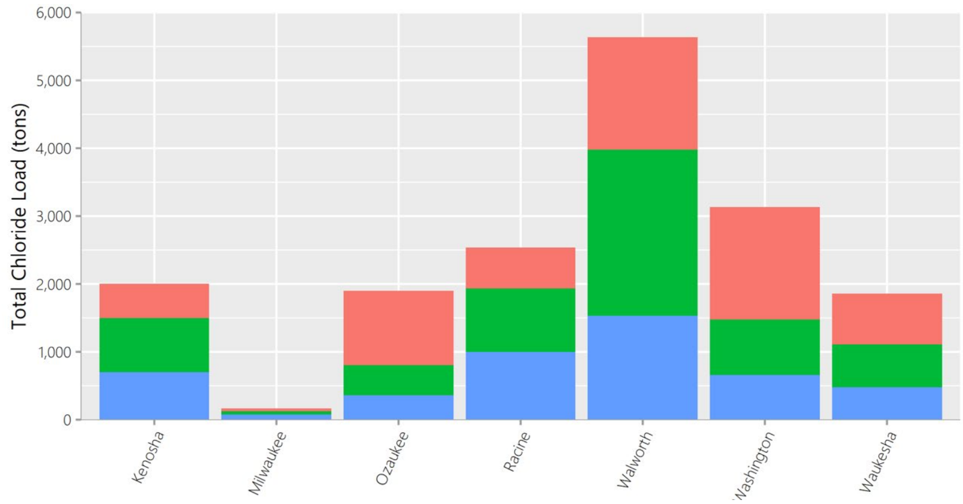


Note: Data reported separately for communities without MS4 permits were not included in the totals above. Also, approximately 99 percent of the chloride comes from rock salt, the rest is from salt brine and a sand/salt mixture.

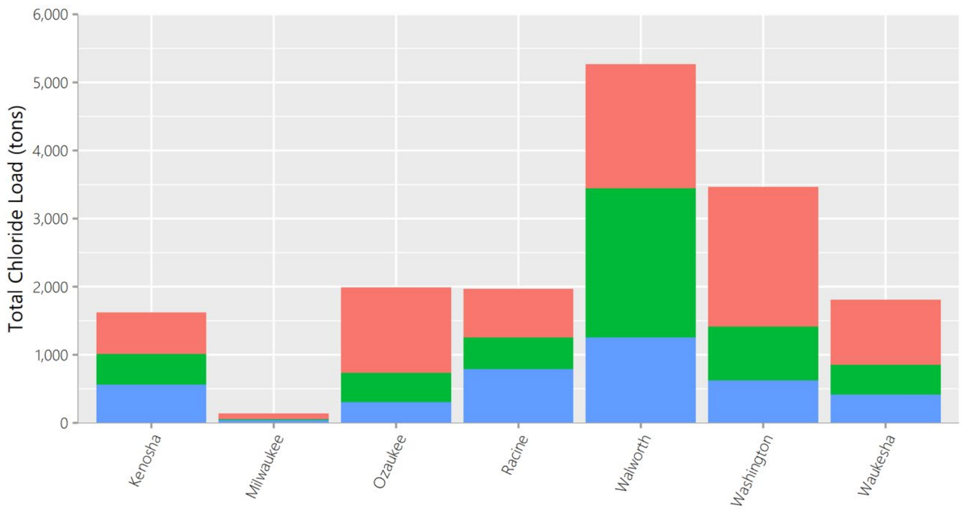
Source: WDNR and SEWRPC

Figure 3.7
Annual Estimated Chloride Load from Potash Fertilizer by County: 2018–2020

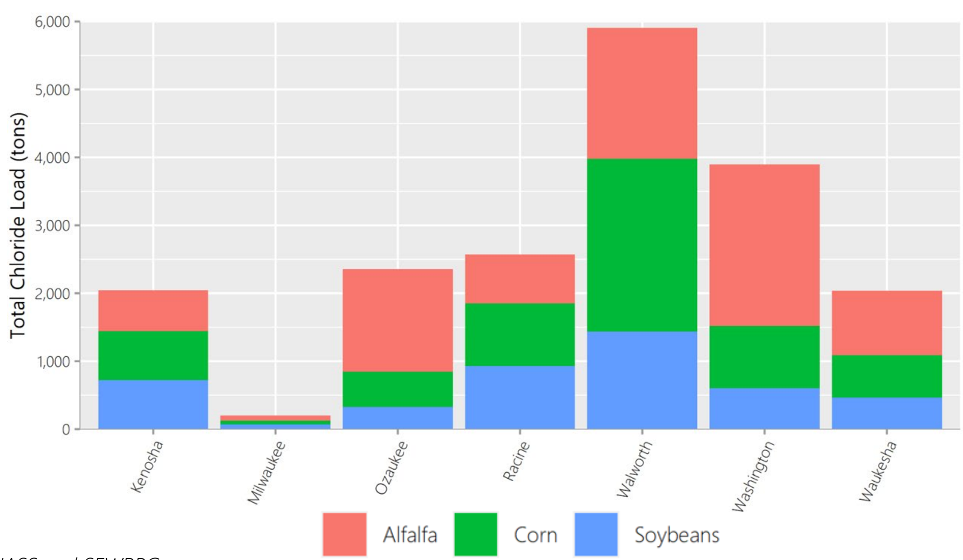
2018:



2019:

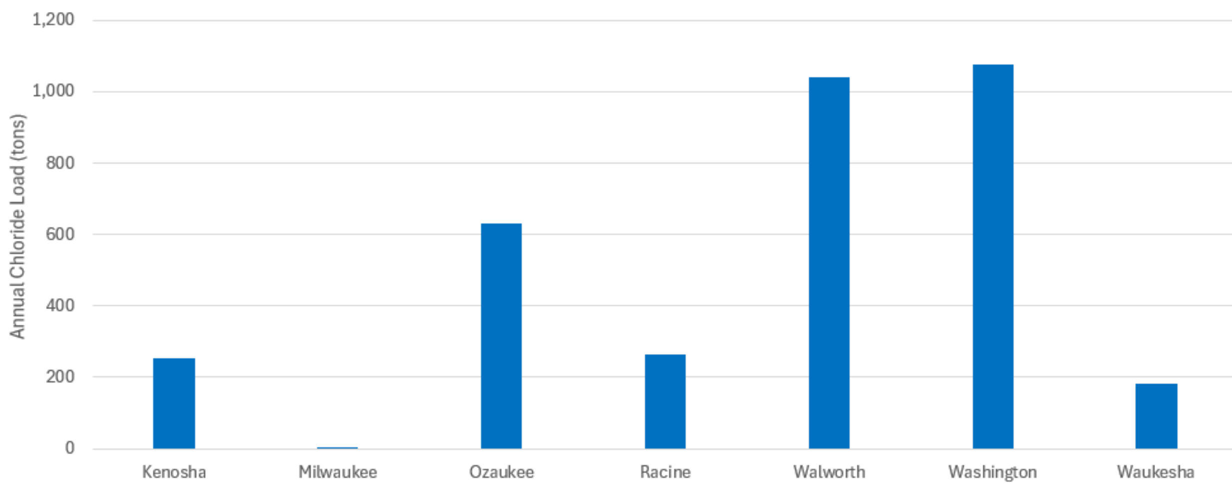


2020:



Source: USDA NASS and SEWRPC

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



Source: USDA NASS and SEWRPC

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CHLORIDE LOADING AND MASS BALANCE ANALYSIS METHODOLOGY

MAPS

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