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Technical Report No. 65

MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

Chapter 4

CHLORIDE LOADING AND MASS BALANCE ANALYSIS RESULTS

4.1 INTRODUCTION

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

4.2 REGIONAL CHLORIDE SOURCE LOADS: REGIONAL CHLORIDE BUDGET

The Regional chloride budget quantifies the annual chloride contributions from a variety of point and nonpoint sources throughout the Southeastern Wisconsin Region (Region). The average annual chloride load was estimated for sources in the Region during the 25-month study period from October 2018 through October 2020, and the results of the Regional chloride budget are presented in Figure 4.1. The total average annual chloride load to the environment from the eight Regional sources considered in the analysis was approximately 461,540 tons per year, as shown in Table 4.1. The table groups the chloride sources evaluated for the Regional chloride budget into four general categories: natural sources represent atmospheric deposition, winter maintenance (deicing salt) sources include public and private deicing activities; wastewater sources include treated effluent discharged from public wastewater treatment facilities (WWTFs), industrial facilities, and residential septic systems; and agricultural sources represent potash fertilizer, livestock waste, and irrigation.[1] Evaluating the general chloride source categories, winter maintenance had the highest chloride contribution at approximately 59 percent, followed by wastewater at about 36 percent, agricultural sources at 5 percent, and natural sources of chloride had the lowest estimated contribution at slightly more than 0.1 percent.

Winter Maintenance Operations

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

The total chloride load from deicing and anti-icing activities on public roadways in the Region showed a decreasing trend through the three winter seasons examined for the Study. This trend was generally consistent with the Winter Severity Index (WSI) trend over the same period, which indicated that the 2018-19 winter season was the most severe of the study period. During the study period, a majority of the estimated chloride load from deicing and anti-icing activities on public roadways in the Region came from solid rock salt applications (approximately 96 to 99 percent each year). While over 2 million gallons of liquid salt brine were applied to public roads in the Region during each winter season of the study period, the chloride content in liquid brines is much lower than the chloride content in rock salt, and thus the chloride load from salt brine comprised only a small proportion of the total winter maintenance chloride load. In general, the

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

use of salt brine for winter maintenance operations reduced the amount of chloride contributed to the environment compared to rock salt.

Wastewater

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

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

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

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

Agricultural Sources

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

Atmospheric Deposition

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

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

Regional Chloride Budget Compared with the Minnesota Statewide Chloride Budget

A similar study and chloride budget was developed for the entire state of Minnesota.[2] The Minnesota study covered over 79,600 square miles, an area much larger than Southeastern Wisconsin with vastly different land use and demographic characteristics. For example, the population density of the Region is over 10 times the population density of the State of Minnesota. Despite these differences, both studies identified road salt used for winter maintenance operations as the predominant source of chloride to the environment. The next two largest chloride sources identified by the Minnesota statewide chloride budget were potash fertilizer and WWTF effluent. The Regional chloride budget also had those two sources in the top three chloride contributors, but the chloride load computed from WWTF effluent was higher than the chloride load from potash fertilizers. Despite the differences between the study area scale, land use, and some of the calculation methodologies and assumptions, the top three chloride sources to the environment were consistent between the Southeastern Wisconsin Regional chloride budget and the Minnesota statewide chloride budget.

4.3 CHLORIDE SOURCE LOADS FOR STREAM MONITORING SITES

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

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[2] *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.*

in operation for the entire study period, but the chloride source loads were computed for the entire 25-month study period for all sites regardless of the monitoring site Study deployment dates.

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

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

Winter Maintenance Operations

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

River at Rochester. While Site 1 and Site 47 received a significant amount of chloride from deicing salt (72.1 percent and 68.8 percent, respectively), the next highest chloride source contributions at these two sites were from WWTF effluent (27.1 percent and 28.8 percent, respectively).

Wastewater

There were 16 stream monitoring sites that had active public WWTFs discharging treated effluent within their upstream drainage areas during the study period, as shown in Table 3.3. Several stream monitoring sites had only one public WWTF located upstream, while Site 58 Milwaukee River at Estabrook Park had the most WWTFs upstream with 11 active facilities, followed by Site 2 Fox River at New Munster with 10 WWTFs located upstream. The monitoring sites with the largest chloride loads from WWTF effluent calculated over the full 25-month study period were Site 2 Fox River at New Munster (46,269 tons), Site 47 Fox River at Rochester (39,638 tons), and Site 58 Milwaukee River at Estabrook Park (20,175 tons).[3] The monitoring sites with the lowest chloride loads from WWTF effluent over study period were Site 6 White River near Burlington (135 tons), Site 28 East Branch Rock River (175 tons), and Site 36 Honey Creek Downstream of East Troy (596 tons). Evaluating the WWTF chloride load normalized by drainage area, the monitoring sites with the highest chloride loads from WWTF effluent over the full 25-month study period were on the Fox River and included Site 1 Fox River at Waukesha, with a total load of 151.5 tons per square mile, followed by Site 47 Fox River at Rochester and Site 2 Fox River at New Munster with 87.0 and 57.3 tons per square mile, respectively.

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

The results of the Regional chloride budget presented in Table 4.1 showed that chloride contributions from industrial wastewater dischargers was the smallest source of chloride in the Region during the study period, slightly less than the chloride load from atmospheric deposition. During the study period there were 10

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

stream monitoring sites with at least one industrial facility located upstream that monitored chloride in its surface water discharge. Of those 10 monitoring sites, the sites with smallest estimated chloride loads from industrial wastewater over the full study period were on the Bark River (Site 11 Bark River Upstream and Site 55 Bark River Downstream both had 0.36 tons) and the largest estimated industrial wastewater chloride load was at Site 58 Milwaukee River at Estabrook Park (880 tons). Similar to the Regional chloride budget, chloride from industrial wastewater discharged to surface waters made up a small portion of the total chloride source load at individual stream monitoring sites. Table 4.2 shows that of the monitoring sites with at least one industrial facility discharging wastewater upstream, the chloride load from industrial wastewater was less than 1 or 2 percent at all sites except one. The lone exception was at Site 38 North Branch Milwaukee River, where the chloride load from three industrial wastewater dischargers located upstream was nearly 7 percent of the total chloride source load for the site. While the industrial wastewater contribution at Site 38 is still relatively low, it demonstrates how relatively minor sources of chloride can have a more significant impact locally.

Agricultural Sources

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

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

Site 21 East Branch Milwaukee River, where potash fertilizer made up 52 percent of the total chloride source load estimated for the study period, was the only monitoring site in the Study for which deicing salts used for winter maintenance were not the largest estimated source of chloride. The drainage area upstream of Site 21 is over 55 percent natural lands, which is the highest proportion of natural lands of all the stream monitoring sites in the Study.[4] Site 21 ranks the lowest of all stream monitoring sites in percent urban lands and percent roads and parking lots in the upstream drainage area (6.0 percent and 2.6 percent, respectively). With nearly 37 percent agricultural land, Site 21 ranks 24 out of 41 for the Study monitoring sites in that land use category and ranks 26 out of 41 for the total chloride load from potash fertilizer normalized by drainage area. While potash fertilizer was the largest source of chloride estimated for Site 21 during the study period, its higher percentage was more likely due to the absence of other chloride sources in the predominantly natural watershed. The relationships between land use and monitoring site chloride source loads are investigated further later in this Chapter.

Atmospheric Deposition

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

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

source load at these two sites, which can be attributed to the absence of other chloride sources in the largely natural watershed upstream.

Chloride Source Load Correlations and Relationships

This section investigates potential relationships or associations between the normalized total chloride source loads for the Study monitoring sites versus land use, waterbodies designated as impaired for chloride, and estimated in-stream chloride concentrations. The total chloride source loads presented in this section are normalized by drainage area to allow for direct comparison between monitoring sites, as described in the previous section. Spearman's rank correlation coefficient (Spearman's ρ) was used to assess potential associations. Spearman's ρ is a unitless coefficient that indicates the relative strength and monotonic direction of the relationship between two variables.[5] Spearman's ρ provides insight into potential associations and correlations but does not provide evidence of causation between two variables.

Land Use

Land use can have a significant influence on the water quality of a stream or lake. Land use can also dictate the types of chloride sources that are present within a watershed. Winter deicing and anti-icing activities are a major source of chloride in the Region, particularly in areas with more urban land use, whereas treated wastewater effluent and agricultural fertilizers may have a greater impact in more rural areas. Table 4.4 summarizes the normalized total chloride source load and relative ranking for each monitoring site along with various land use category breakouts and their related rankings among all sites.[6] The land use category breakouts include percent urban lands, roads and parking lots, agricultural lands, and natural lands.[7] These ranked datasets were used to evaluate correlations between the total chloride source load and the land use categories, and the resulting Spearman's ρ for each category is shown at the bottom of the table. Figure 4.3 illustrates the relationships between the total chloride source load estimated for each monitoring site and

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

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

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

the four land use categories listed in Table 4.4. These plots include linear regressions that provide insight into the strength of the relationship between the two variables.[8]

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

Chloride-Impaired Waterbodies

Associations between the total chloride source loads and chloride-impaired waterbodies in the study area were also investigated for monitoring sites that were located on a chloride-impaired waterbody or had a chloride-impaired body within the monitoring site drainage area. During the study period, there were nine monitoring sites that were located on a chloride-impaired stream segment as identified in Table 4.3, with total chloride source loads ranging from 286.3 to 971.9 tons per square mile. The table shows that the six monitoring sites with the highest total chloride source loads, all of which were greater than or equal to 600 tons per square mile (Site 12 Lincoln Creek, Site 53 Honey Creek at Wauwatosa, Site 60 Root River at Grange Avenue, Site 87 Underwood Creek, Site 9 Oak Creek, and Site 57 Menomonee River at Wauwatosa), were located on stream segments that are impaired for chloride. The nine monitoring sites located on chloride-impaired stream segments were among the 14 stream monitoring sites with the highest total chloride source loads shown in Table 4.3, and the remaining five sites had chloride-impaired waterbodies within their upstream drainage areas. A closer examination of those five monitoring sites revealed that one site (Site 59

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[8] For linear regression, R-squared (R^2) values measure the percentage of the variance in the dependent variable that can be attributed to or explained by the independent variable. R-squared values range from 0 to 1, where 1 indicates a perfect fit and higher values generally represent a stronger relationship between the variables.

Root River near Horlick Dam) was located a few hundred feet downstream of a chloride-impaired stream segment; one (Site 8 Pewaukee River) was located on a stream that was previously listed as impaired for chloride in 2018 but was delisted in 2020; two sites (Site 1 Fox River at Waukesha and Site 30 Des Plaines River) were on stream segments not listed but recommended for potential chloride impairment listing in Technical Report No. 63 (TR-63); and one site (Site 47 Fox River at Rochester) had two of the other monitoring sites (Site 1 and Site 8) nested within its upstream drainage area as shown in Table 2.4.[9] Furthermore, the 16 Study monitoring sites with chloride-impaired waterbodies located in their upstream contributing drainage areas were among the top 20 sites with the highest total chloride source loads in Table 4.3. It was not possible to quantify a correlation coefficient for chloride impairments; however, it is evident that the stream monitoring sites that were either located on a chloride-impaired waterbody or had chloride impairments upstream within the site drainage area also had the highest estimated total chloride source loads for the study period.

Estimated In-Stream Chloride Concentration

Commission staff also examined the relationship between the total chloride source loads and the estimated in-stream chloride concentrations for Study monitoring sites computed using the regression equations develop for the Study as described in Technical Report No. 64 (TR-64).[10] The estimated chloride concentration statistics used in the comparison included the mean, median and maximum chloride concentrations computed for each monitoring site. These statistics were computed for the 25-month study period except for the four monitoring sites that were installed during the project and utilized an extended period of record stretching into 2021.[11] The strongest correlation was observed between chloride source loads and the mean estimated chloride concentration for each monitoring site, with a computed Spearman's ρ of 0.943. The Spearman's correlation coefficients comparing the total chloride source loads with the median and maximum estimated chloride concentrations for each site were also very strong, 0.898 and 0.917, respectively. Figure 4.4 illustrates the relationship between the estimated mean chloride concentration and the total chloride source load computed for each monitoring site. A linear regression

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

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

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

performed for these two variables also indicated a strong correlation with a R^2 of 0.8934. These strong correlations highlight how in-stream chloride concentrations increase with the increasing amount of chloride applied within the upstream drainage area from a variety of sources. The relationships between chloride sources and in-stream chloride loads are further examined using the results of the chloride mass balance analysis discussed in the next section.

4.4 CHLORIDE MASS BALANCE ANALYSIS RESULTS

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

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

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

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

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

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

Potential Factors Influencing the Chloride Mass Balance Results

The differences observed over the study period between the computed chloride source loads and estimated in-stream chloride loads could be attributed to a variety of factors depending on the stream monitoring

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

site. As with any analysis, the results were only as good as the input data. Both the chloride source loads and in-stream chloride loads estimated for each site may be affected by issues with the underlying datasets. In other cases, drainage area characteristics may influence the way chloride moves through the environment and could affect the chloride loads estimated for a stream monitoring site. These factors are described in the following sections.

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

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

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

Another issue with the specific conductance data collected for the Study that could influence the estimated in-stream chloride loads was fouling of the in-stream sensor. Sensor fouling was observed at some stream monitoring sites and caused dampened or lower specific conductance readings. In some cases, Commission staff adjusted portions of the specific conductance dataset that were dampened, but in extreme cases the data were considered too dampened to adjust. For example, the specific conductance dataset for Site 9 Oak

Creek had two such periods of severe dampening: from October 1 through October 24, 2018 and from May 19 to June 17, 2020. Additionally, the in-stream continuous specific conductance sensors were factory-calibrated and could not be calibrated by the user. Most of the monitoring sites had lower in-stream specific conductance observations when compared to the specific conductance readings taken monthly with a separate handheld sonde that was regularly calibrated before use.[13] For example, the 25 monthly handheld sonde specific conductance field measurements collected during the study period at Site 10 Pike River were over 21 percent higher on average than the simultaneous specific conductance measurements recorded by the in-stream sensor. Periods of dampened specific conductance data translate directly to lower estimated chloride concentrations and reduced monthly in-stream chloride loads.

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

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

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

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

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

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

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

At some Study monitoring sites, the way that chloride is transported through the environment may be responsible for some of the differences observed between the computed chloride source loads and the estimated in-stream chloride loads. It is possible that some of the chloride applied within a site drainage area may not be measured or accounted for at the stream monitoring site. Complex flow interactions between surface water and groundwater may explain some of the chloride mass balance differences. Two examples are at Site 10 Pike River and Site 59 Root River near Horlick Dam, where the chloride source loads computed for the study period were much greater than the estimated in-stream chloride loads. Both of these monitoring sites were located on streams within the eastern portion of the Region near Lake Michigan. The general direction of shallow groundwater flow, based on the hydraulic gradient established by the water table elevations, within both site drainage areas is easterly toward the lake.[15] Based on the configuration of

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

the two upstream drainage areas, it would possible that chloride entering the environment within each of these watersheds could be transported through groundwater or subsurface pathways directly to Lake Michigan without being measured at the stream monitoring site.

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

Additional Chloride Relationships and Influencing Factors

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

Seasonal Patterns

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

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

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

The graphs shown in Appendix C Figure (b) for each stream monitoring site present the monthly differences between the estimated in-stream chloride loads and the calculated chloride source loads. A similar pattern emerges across all of the monitoring sites, showing excess chloride source loads during the winter followed by excess in-stream chloride loads during the subsequent non-winter months. Other studies have noted this phenomenon, suggesting that chloride applied to roadways during the winter season may be stored or retained in surficial soil layers and potentially in shallow groundwater, with slow release to surface water during the subsequent seasons.[16,17,18] The mass balance results for each monitoring site presented in Appendix C include an accounting of the winter season excess chloride source loads and the excess in-stream chloride loads over the following non-winter months throughout the study period. At some monitoring sites, the excess chloride source loads estimated for the 2018-19 winter season were largely accounted for by the excess in-stream loads over the subsequent or following non-winter months in 2019. At Site 9 Oak Creek, for example, the excess in-stream chloride load from March 2019 through October 2019 (3,971 tons) accounted for 99.8 percent of the excess chloride source estimated for the previous winter from November 2018 through February 2019 (3,979 tons). Three other monitoring sites exhibited similar chloride load results between November 2018 and October 2019: Site 30 Des Plaines River, Site 2 Fox River at New Munster, and Site 1 Fox River at Waukesha all had excess in-stream chloride loads that accounted for greater than 95 percent of the excess chloride source loads from the previous winter season. Appendix C shows that the difference between the excess chloride loads at those same monitoring sites were not as balanced over the second year of the Study when compared to the first year. For example, at Site 9 Oak Creek the excess in-stream chloride load from March 2020 through October 2020 (2,493 tons) accounted for 63.5 percent of the excess chloride source load estimated for the previous winter from November 2019 through February 2020 (3,979 tons).

It is important to note that 2018 and 2019 had particularly high annual precipitation totals, and rank as the top two wettest years on record for the Region as discussed in Chapter 2. It is likely that the excess rainfall and soil moisture would help flush chloride through shallow soil layers. The total precipitation between November 2018 and October 2019 was 45 inches, which is ranked the wettest November to October period on record in the Region dating back to 1894, whereas the total precipitation between November 2019 and October 2020 was 37 inches and ranked as the 27th wettest November to October period on record.[19] The mass balance results presented in Appendix C demonstrate that the balance of the seasonal chloride load excesses for many of the Study monitoring sites was generally better for the first winter and subsequent

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

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

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

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

non-winter months than for the second winter, which appears to be correlated with higher precipitation totals over the relatively short 25-month study period.

Land Use

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

Streamflow Discharge and Flow-Weighted Mean Chloride Concentrations

Chapter 3 of TR-63 explored the relationship between streamflow discharge and in-stream chloride, and examined in-stream chloride dynamics along with the response to various types of meteorological events.[20] In general, an inverse relationship was observed between streamflow discharge and chloride concentrations, by which high streamflow tended to lower in-stream chloride concentrations through dilution while low-flow conditions were associated with elevated chloride concentrations. Additionally, during winter and early spring chloride-laden runoff can cause short-term chloride concentration spikes in streams and rivers, as the "first flush" of pollutants carries excess chloride that had accumulated on surfaces and within the watershed throughout the winter season.

To account for the influence of streamflow discharge rates on chloride concentrations, in-stream chloride conditions were further evaluated using flow-weighted mean chloride concentrations (FWMCC). The FWMCC provide a more accurate representation of the chloride conditions in a stream from a pollutant

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

load perspective. The FWMCC were computed for each monitoring site by dividing the total mass of chloride by the total volume of streamflow discharge over a specific period of time. For this evaluation, the FWMCC were computed for the full study period as well as for each month of the study period. Appendix C presents the FWMCC for each monitoring site over the entire study period as well as the monthly minimum and maximum FWMCC. The monitoring sites with the highest overall FWMCC for the study period were Site 53 Honey Creek at Wauwatosa (221.6 mg/l), Site 12 Lincoln Creek (196.3 mg/l), and Site 1 Fox River at Waukesha (180.1 mg/l). The monitoring sites with the lowest overall FWMCC for the study period were Site 16 Jackson Creek (49.5 mg/l), Site 25 Root River Canal (50.1 mg/l), Site 3 Mukwonago River at Mukwonago (50.5 mg/l), and Site 10 Pike River (51.5 mg/l).

In addition to the overall study period and monthly FWMCC, the daily FWMCC were computed for Site 1 Fox River at Waukesha over the study period, as presented in Figure 4.6. The grey dots on this figure represent the daily FWMCC plotted against the mean daily streamflow discharge and illustrate the inverse relationship between chloride concentrations and streamflow discharge, as represented by the dashed trendline in red. This plot also shows outliers that don't follow the typical inverse relationship between chloride concentrations and streamflow discharge. These outliers, plotted above the rest of the datapoints, occurred when both chloride concentrations and streamflow rates were high. This typically was observed during the months of February and March when runoff and snowmelt can carry large amounts of chloride from the deicing and anti-icing activities throughout the winter months. The monthly FWMCC for Site 1 are represented by the blue dots plotted on the figure and ranged from 90.1 mg/l to 403.8 mg/l over the study period. The monthly data exhibited less variability than the daily data but followed the typical inverse relationship between chloride concentrations and streamflow discharge. The lone exception was an outlier in February 2019, which was also the maximum monthly FWMCC at that site for the study period. These outliers highlight how the months of February and March are critical for in-stream chloride conditions and potential chloride toxicity impacts to organisms. The impacts of chloride are discussed in detail in Technical Report No. 62 (TR-62).[21]

The monitoring sites with the largest monthly maximum FWMCC also had the largest range of monthly FWMCC and included Site 53, Site 12, Site 9, Site 57 and Site 1. Furthermore, these five monitoring sites had the highest percentages of urban land use and the lowest percentages of agricultural land use of all 14 sites considered in the chloride mass balance analysis. Site 12, Site 53 and Site 9 were also located on the most-flashy streams considered for the analysis, exhibiting large and rapid fluctuations in streamflow following a

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

meteorological event. Of the 14 sites considered in the mass balance analysis, Site 3 Mukwonago River at Mukwonago had the smallest range of monthly FWMCC, from 42.3 mg/l to 57.8 mg/l. Site 3 is located less than 1,000 feet downstream of the dam that releases water from Lower Phantom Lake. The relatively steady nature of the monthly FWMCC and the estimated in-stream chloride loads at Site 3 demonstrate the buffering effect of the upstream lake on chloride concentrations in the water flowing out of the lake. The influence of lakes on in-stream chloride concentrations has been observed in other studies and are discussed further in a separate technical report.[22,23]

Wastewater Treatment Facility Effluent

WWTF effluent can influence chloride concentrations in surface water, especially when streamflow discharge is low, as described in detail in TR-63 Chapter 3.[24] During drought or low flow conditions, the effluent discharged by treatment facilities can make up a substantial portion of the flow in the stream. Additionally, TR-63 demonstrated the influence of WWTF effluent by comparing chloride concentrations at monitoring sites located upstream and downstream of a small public WWTF plant. The influence of upstream WWTF effluent on the amount of in-stream chloride is further examined at the six mass balance monitoring sites with WWTFs located upstream (Site 1, Site 2, Site 25, Site 30, Site 58, and Site 59). The total in-stream chloride load was compared with the WWTF effluent chloride load for each month of the study period to estimate the proportion of chloride in the stream that originated from the upstream WWTFs. This evaluation assumed that all flow and chloride discharged from the WWTF was conveyed downstream to the monitoring site, neglecting interactions with groundwater. Figure 4.7 shows the total percent of in-stream chloride by month for the study period that is attributed to the WWTF effluent chloride load for each of the six mass balance monitoring sites with WWTFs located upstream.

Site 1 Fox River at Waukesha is considered the most critical monitoring site from a WWTF perspective, with the largest percentage of in-stream chloride load from WWTF effluent chloride load on average. Over the 25-month study period, the proportion of monthly in-stream chloride from WWTFs at Site 1 ranged from approximately 16 percent to 52 percent, and the chloride load from WWTF effluent made up slightly less than 30 percent on average of the in-stream chloride load. When the percent of in-stream chloride from WWTFs was compared to the average monthly USGS streamflow for all six sites over the study period, the

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

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

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

highest proportions of in-stream chloride from WWTFs corresponded to periods of low streamflow. In general, the highest proportions of chloride from WWTFs occurred during the summer months, peaking in August at most sites as shown in Figure 4.7.

4.5 CONCLUSIONS

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

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

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

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

- The chloride source load results demonstrate that the use of liquids for winter road maintenance, either through pre-wetting or direct liquid application, reduces chloride contributions to the environment when compared to operations that rely solely on rock salt applications to treat roadways.

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

- Overall, the computed chloride source loads and estimated in-stream chloride loads matched well for the 14 stream monitoring sites evaluated for the chloride mass balance. There were six monitoring sites that had an overall difference between chloride source loads and in-stream chloride loads within

12 percent over the full study period. There were nine monitoring sites where the chloride source loads and in-stream chloride loads were within 30 percent, and only one site had chloride mass balance results greater than 50 percent.

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

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

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

- Monitoring sites with smaller drainage areas are more sensitive to differences between chloride sources and in-stream loads and the factors influencing the chloride mass balance results than sites with larger drainage areas.

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

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

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

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

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

Technical Report No. 65

MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

Chapter 4

CHLORIDE LOADING AND MASS BALANCE ANALYSIS RESULTS

TABLES

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Table 4.1
Regional Chloride Budget: Estimated Average Annual Chloride Contributions

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

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

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

Source: SEWRPC

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

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

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

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

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

Source: SEWRPC

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

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

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

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

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

Source: SEWRPC

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

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

Table continued on next page.

Table 4.4 (Continued)

Site No.[a]	Total Chloride Source Load (tons/sq mi)	(rank)	Drainage Area Size (sq mi)	(rank)	Urban Lands (percent)	(rank)	Roads and Parking Lots (percent)	(rank)	Natural Lands (percent)	(rank)	Agricultural Lands (percent)	(rank)
51	247.5	16	27.5	29	25.8	20	7.2	17	26.8	19	42.6	20
52	178.3	23	53.6	18	23.3	21	8.0	16	23.2	23	43.4	19
53	909.1	2	10.7	38	98.5	1	30.4	1	1.5	41	0.0	41
54	47.3	39	18.8	33	11.2	35	3.4	37	38.5	4	45.5	17
55	223.2	18	53.2	19	43.3	10	9.3	13	27.3	17	19.7	31
57	599.7	6	124.5	8	67.3	6	19.5	6	13.5	32	14.4	34
58	186.7	20	684.7	2	21.7	23	6.6	21	27.8	16	44.4	18
59	288.5	13	189.7	6	35.0	14	9.4	12	13.6	31	46.3	16
60	796.9	3	15.0	36	91.9	3	26.4	3	7.5	37	0.3	39
87	759.2	4	19.0	32	88.4	4	25.5	4	10.6	34	0.5	38
Spearman's rank correlation coefficient[b]			ρ = -0.120		ρ = 0.806		ρ = 0.885		ρ = -0.690		ρ = -0.502	

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

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

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

Source: SEWRPC

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

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

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

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

Source: SEWRPC

Technical Report No. 65

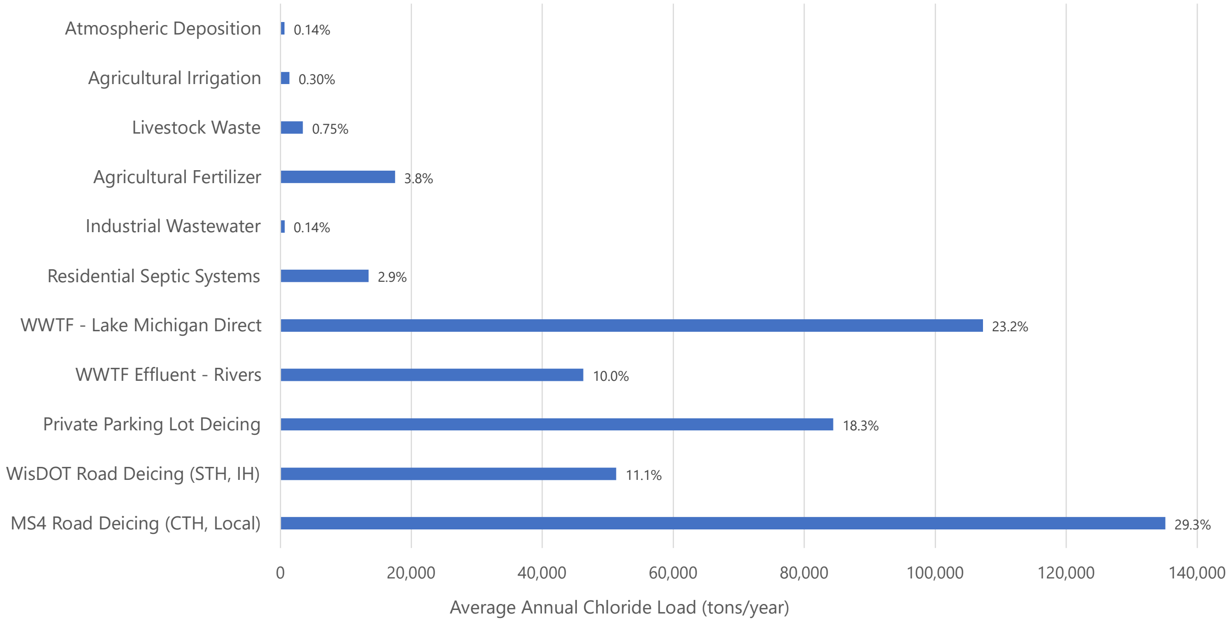
MASS BALANCE ANALYSIS FOR CHLORIDE IN SOUTHEASTERN WISCONSIN

Chapter 4

CHLORIDE LOADING AND MASS BALANCE ANALYSIS RESULTS

FIGURES

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



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

Source: SEWRPC

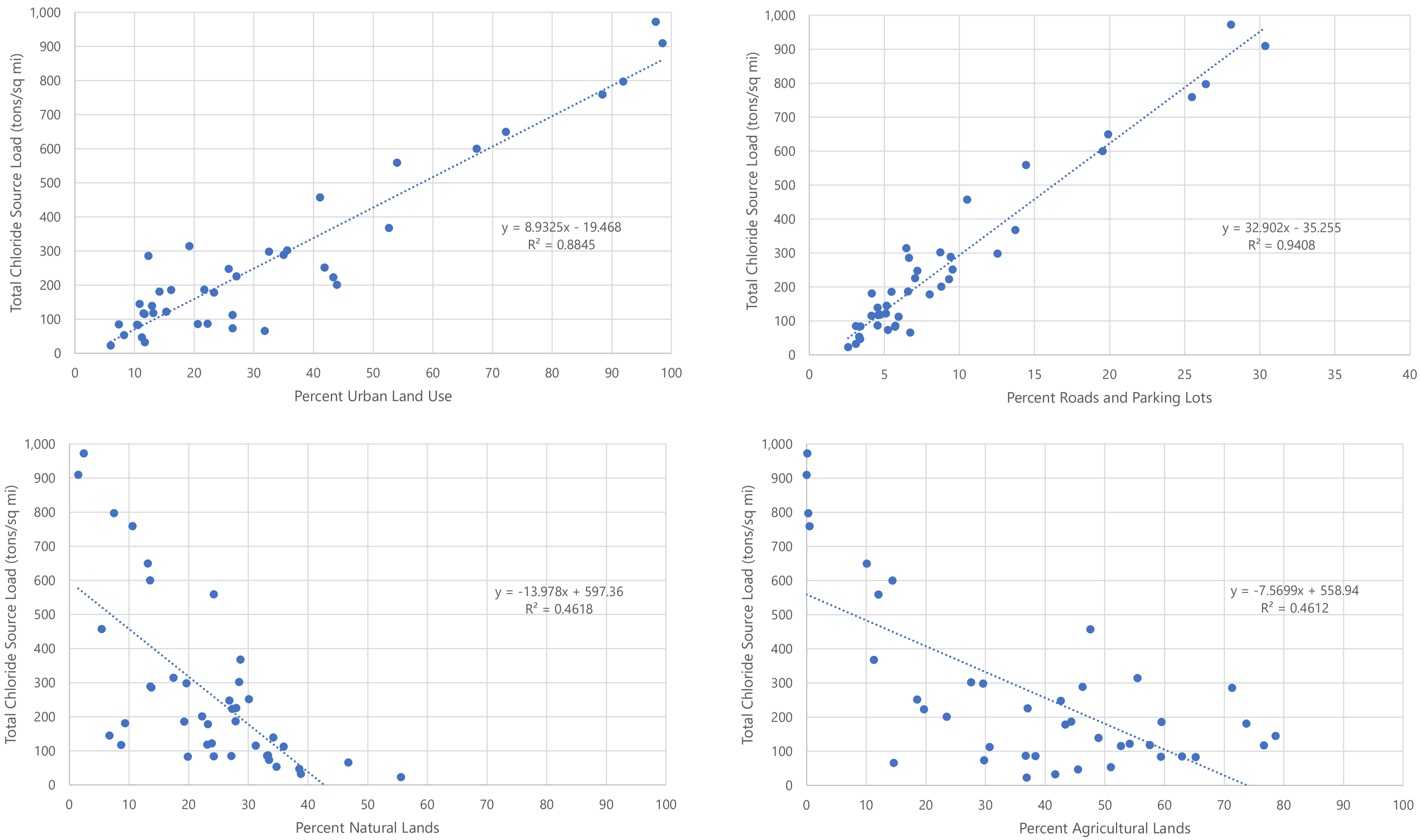
Figure 4.2
General Chloride Source Loads Estimated for Stream Monitoring Sites: October 2018 – October 2020

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

Source: SEWRPC

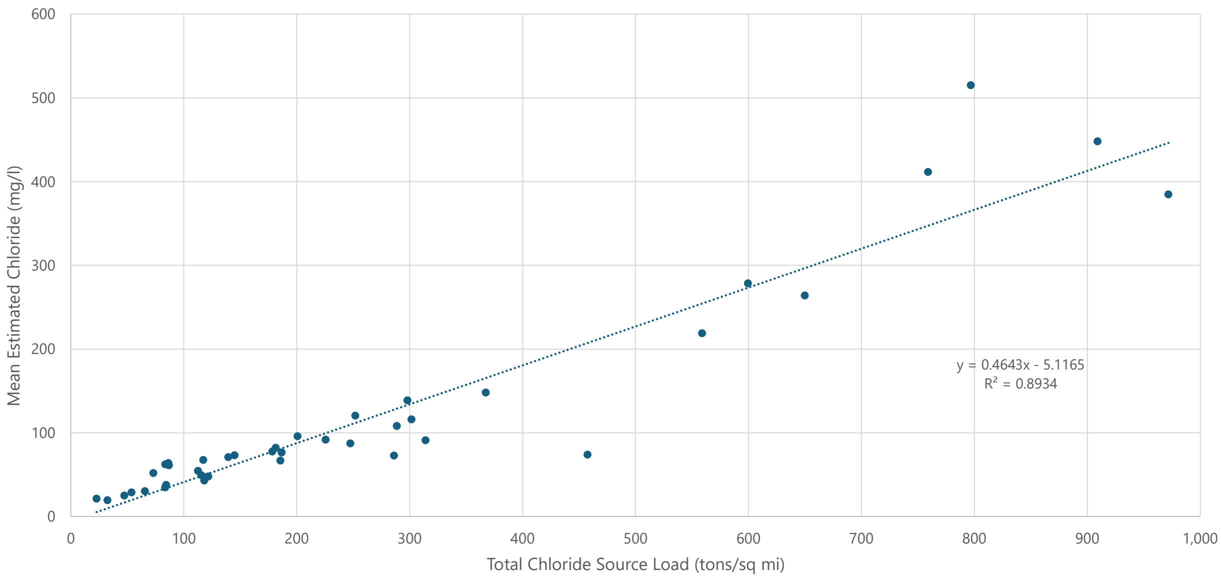
Figure 4.3

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



Source: SEWRPC

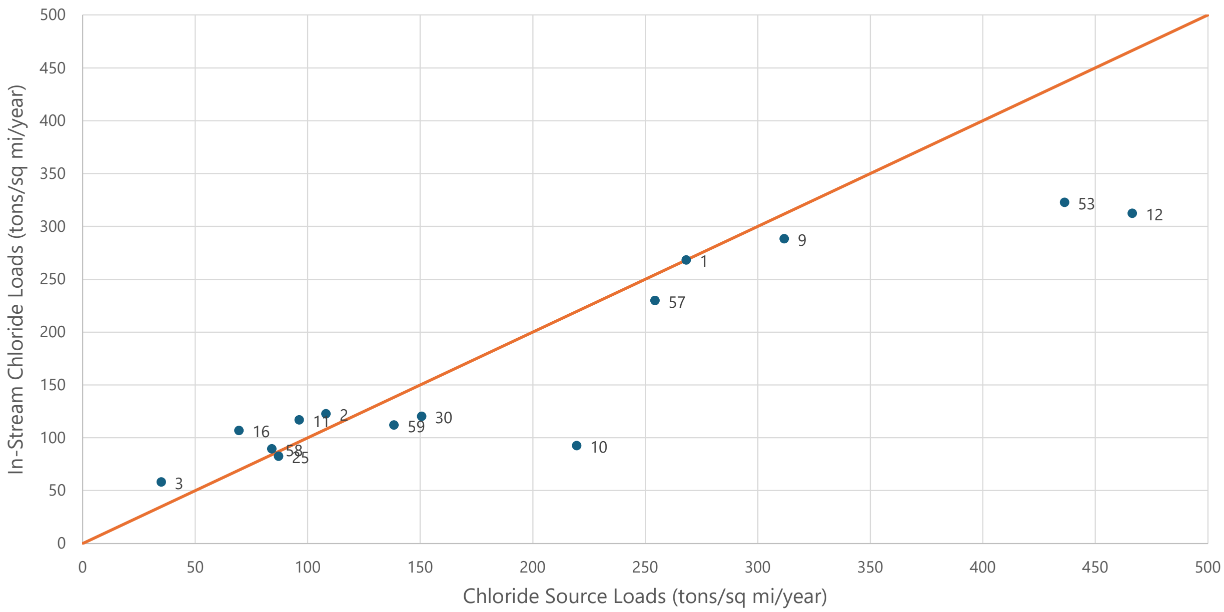
Figure 4.4
Chloride Source Loads Versus Mean Estimated Chloride Concentrations for each Monitoring Site



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

Source: SEWRPC

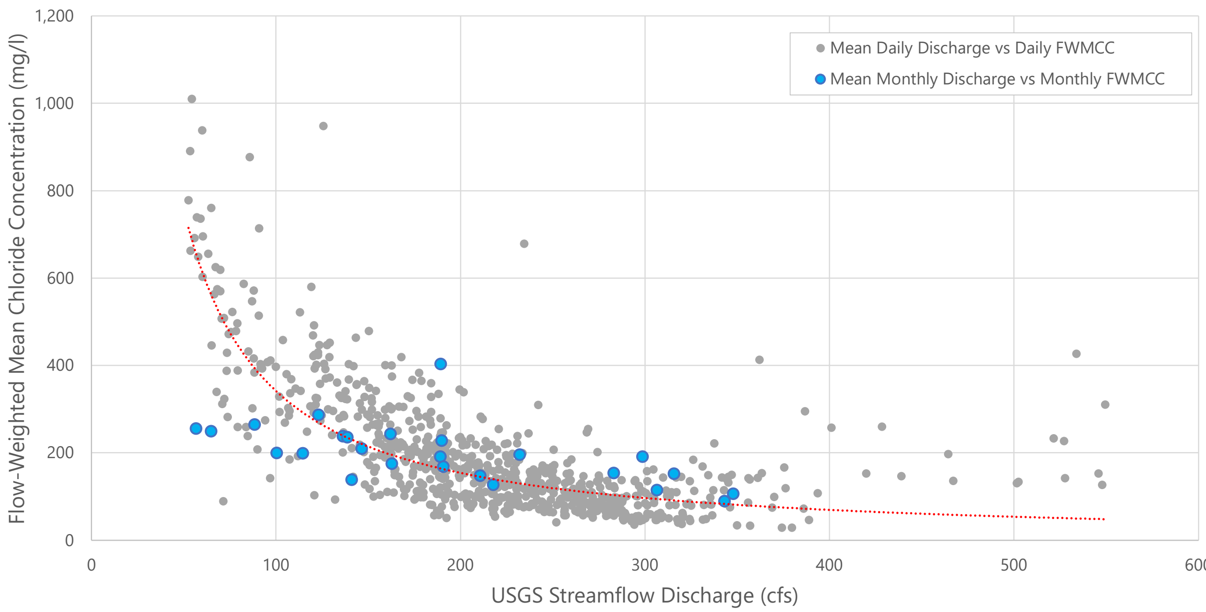
Figure 4.5
Comparison of Chloride Source Loads with In-Stream Chloride Loads During the Study Period



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

Source: SEWRPC

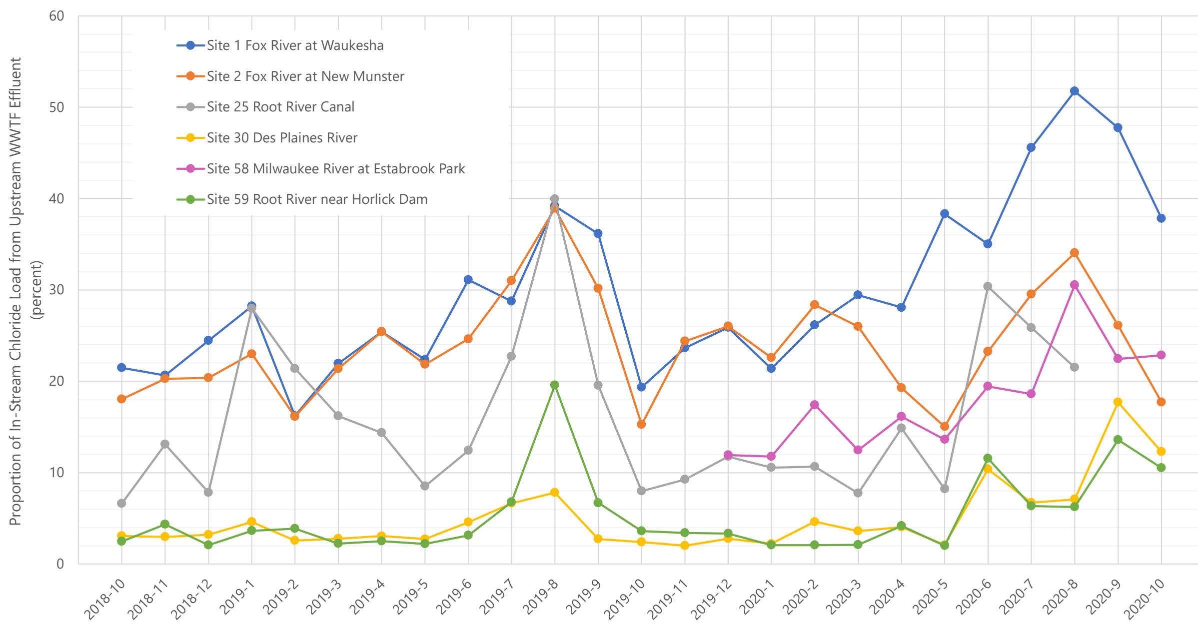
Figure 4.6
Flow-Weighted Mean Chloride Concentrations Versus USGS Streamflow Discharge: Daily and Monthly Comparisons for Site 1 Fox River at Waukesha



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

Source: USGS and SEWRPC

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



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

Source: WDNR, USGS, and SEWRPC