Brown's Creek CHLORIDE

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KEY FINDINGS

Chloride concentrations in Brown's Creek showed little change from 2001 - 2006, then increased gradually from 2007 through 2019.

Annual and seasonal chloride loads appear to be highly driven by flow, possibly because of increased flushing of salt that had built up on the landscape and in groundwater during drier periods when pollutants are less likely to be mobilized.

INTRODUCTION

The Metropolitan Council Environmental Services (MCES) is committed to stewardship of Twin Cities streams and tributary rivers and works with its partners to maintain and improve waterbody health and function. These efforts are supported by the collection and analysis of high-quality, long-term data.

In 2014, *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams* described statistical water quality trends for streams and tributary rivers in the Twin Cities. At that time, data were insufficient to analyze chloride trends. By 2019, our monitoring work provided sufficient data for statistical trend analysis. Meanwhile, concern about chloride pollution has increased for watershed managers and the general public. This memo includes information about chloride sources and timing of chloride runoff and addresses the following questions:

- How has in-stream chloride changed over time?
- How have upland watershed activities impacted in-stream chloride over time?
- What can monitoring data tell us about chloride sources and pathways in the watershed?

During the analysis period, Brown's Creek Watershed District (BCWD), cities and townships within the Brown's Creek watershed (portions of the Cities of Grant, Hugo, and Stillwater, and May and Stillwater Townships), Washington County and Minnesota Department of Transportation have been actively addressing chloride pollution through winter de-icing equipment upgrades, salt application changes, pilot projects and outreach and education. Brown's Creek Watershed District is a member of the East Metro Water Resource Education Program (EMWREP), a partnership of 25 local units of government, hosted by the Washington Conservation District. Over the analysis period the program has sponsored or participated in many deicing salt training and education efforts.

This memo provides data and analyses from Brown's Creek with state and regional context about chloride pollution. This information has prompted questions from MCES staff and will likely prompt questions from readers. We hope to initiate a dialog about regional chloride dynamics and inspire action to alleviate chloride pollution. Please contact us to discuss potential future partnerships if you are interested in continuing this work.

CHLORIDE POLLUTION IN TWIN CITIES WATERS

Chloride concentrations have been rapidly rising in many Twin Cities waterbodies over the past two decades. In the Twin Cities, 40 lakes and streams are impaired for aquatic life due to chloride contamination and an additional 41 waterbodies are high risk for chloride impairment[1]. A recent study by MCES indicated an increasing trend for chloride concentrations in the Mississippi, Minnesota, and St. Croix Rivers during the recent 30 years[2]. Thirty percent of Twin Cities shallow aquifer monitoring wells have chloride concentrations that exceed the Minnesota state water quality standard.[3]

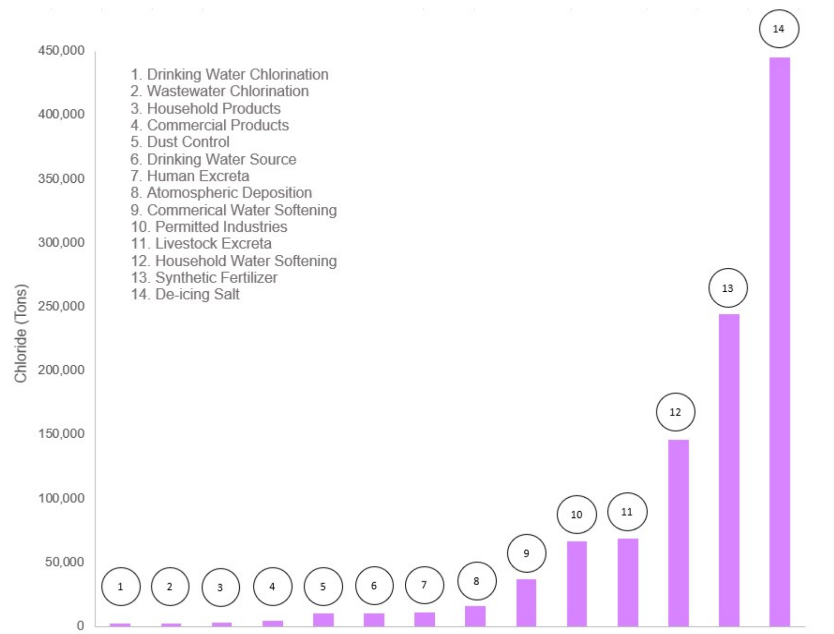

Figure 1: Major chloride sources and their annual chloride contributions to the environment in Minnesota.

Chloride is a permanent water pollutant, there is no easy way to remove it with existing technology. It is toxic to fish, aquatic bugs, and amphibians. Chronic toxicity is indicated by samples above 230 mg/L, acute toxicity by samples above 860 mg/L.[4]

Chloride pollution in Minnesota has multiple sources.[5] The four largest are livestock excreta, household water softening, synthetic fertilizer and de-icing salt (Figure 1).

Livestock Excreta: Research found elevated chloride in seepage from earthen-lined manure storage and high chloride levels in groundwater downgradient of manure storage,[6] but there is little research investigating effects of livestock feedlots or manure application practices on chloride levels in water.

Household water softening: More than 70% of the drinking water used in the Twin Cities comes from groundwater[7] and many groundwater users soften their water with chloride salts. The chloride waste from the water softening process enters surface and groundwater through wastewater treatment plants or residential subsurface sewage treatment systems.[8]

Synthetic fertilizer: Chloride is associated with macronutrients like potassium. The most common potassium source in Minnesota is potash fertilizer, potassium chloride.[9] Plants consume the potassium and release the chloride into surface and groundwater.

De-icing salt: Approximately 402,000 tons of de-icing salt is annually applied in the Twin Cities.[10] De-icing salt is carried by melting ice and snow into surface and groundwater.

Climate change is creating a warmer, wetter climate in Minnesota and the effects are most significant during the coldest months. An altered winter freeze-thaw cycle will have unpredictable effects on chloride use and pollution dynamics.

STREAM AND WATERSHED DESCRIPTION

Brown's Creek is 8.25-miles long and directly drains approximately 7.2 square miles of a mix of agricultural and developed urbanized land in Washington County. The stream has a groundwater component: the ratio of flow to precipitation is 0.46, while most metro streams are between 0.05 – 0.3.[11] Much of the watershed is isolated from the stream: landlocked, partially landlocked, and/or hydrologically diverted (Figure 2).

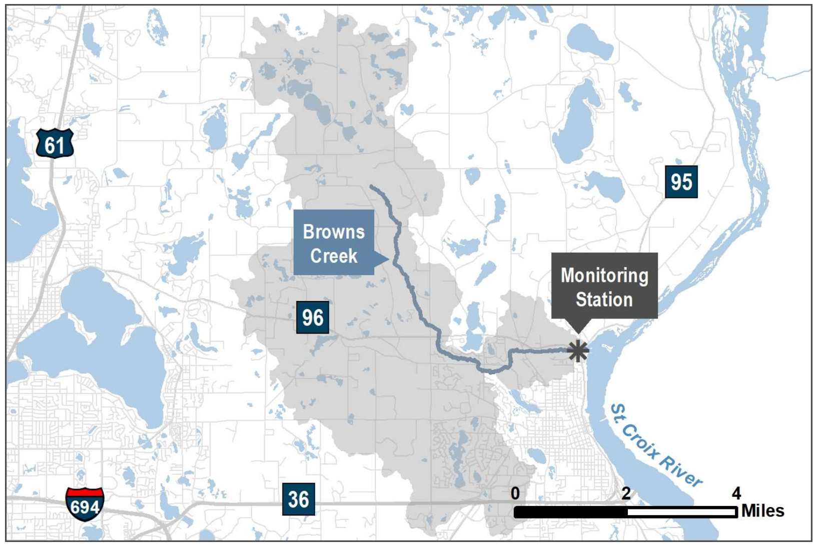

Figure 2: Map of Brown's Creek Watershed

Brown's Creek watershed is a total of 18,154 acres, 35.4% of the land use is developed/impervious surfaces and 14.8% is agricultural land.[12] Other primary land covers in the watershed are forest, grasses/herbaceous, and wetlands.

Approximately 7% of the Brown's Creek watershed is roadways, based on an analysis completed by the Minnesota Pollution Control Agency (MPCA). [13] The MPCA found that watersheds with 18% roadway density or higher are more likely to have chloride concentrations above water quality standards.[14] This roadway analysis does not include the most urbanized parts of the Brown's Creek watershed, as these areas are disconnected from the stream for most flow conditions.

No waterbodies in the Brown's Creek watershed are known to be impaired or at risk of being impaired for aquatic life use due to excess chloride (Figure 2).

Brown's Creek chloride pollution sources may include livestock excreta, household water softening, synthetic fertilizer, and de-icing salt.

Livestock Excreta: Brown's Creek watershed has eight registered feedlots in its monitored area with a total of 778 animal units.

Household Water Softening: Most residential developments are served by subsurface sewage treatment systems. Chloride waste from the water softening process enters surface and groundwater through wastewater treatment plants or residential subsurface sewage treatment systems.[15] Wastewater from the City of Stillwater is treated at the MCES St. Croix Valley Wastewater Treatment Plant and discharged to the St. Croix River.

Synthetic Fertilizer: Chloride may come from agricultural and urban application of potash fertilizer.[16] This source of chloride is not well understood in the watershed.

De-icing Salt: De-icing salt is primarily applied between December and March and would likely runoff during melt events from February through April. De-icing salt is unlikely to be the primary source of chloride due to the rural nature of the watershed.

FINDINGS

Annual Chloride Dynamics 2001-2019

Chloride Concentration

MCES and the Washington Conservation District collected 378 chloride samples between 2001 and 2019. The ambient concentrations are plotted with the annual median concentration (Figure 3). Ambient concentration describes the conditions experienced by aquatic organisms in the stream. These values are affected by precipitation, flow, and watershed factors, including those caused by human activity.

Annual median chloride generally increased from 2001 through 2019. Ambient chloride concentrations in Brown's Creek were generally very low despite some high individual values during the analysis period.

Ambient concentration: The mass of chloride divided by the total volume of water in a stream at a specific time. This value represents the instantaneous amount of chloride in the stream water.

Annual Median Concentration: This is the 'typical' concentration observed in the stream during the year. It is the center of our observed data and is not affected by extreme high or low concentrations.

Precipitation and Streamflow

Ambient concentrations are often closely tied to rainfall and resulting flow conditions in the stream. Figure 4 shows annual total precipitation and the 1981-2010 National Weather Service Climate Normal precipitation at Minneapolis-St. Paul airport[17] with Brown's Creek annual median flows. Flow is usually higher in years with greater rainfall. Flow in Brown's Creek varied dynamically during the assessment period. Flows generally increased from 2013 to 2019, corresponding with higher than normal annual precipitation amounts during that period.

Annual Mean Flow: The average of all daily flows for the year.

Streamflow and Chloride Concentration

Figure 5 shows annual median chloride concentration and annual median flow values, representing typical conditions for each year. Chloride concentration and flow are not well correlated in Brown's Creek. Chloride generally increases from 2001 – 2019, despite variability in flow. Factors other than flow impact chloride conditions in the stream.

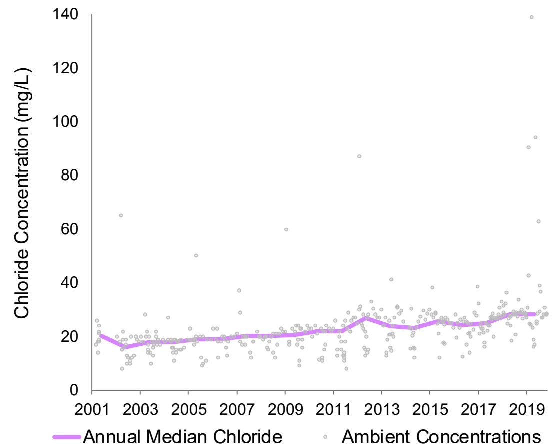

Figure 3: Annual Median and Ambient Chloride Concentrations of Brown's Creek

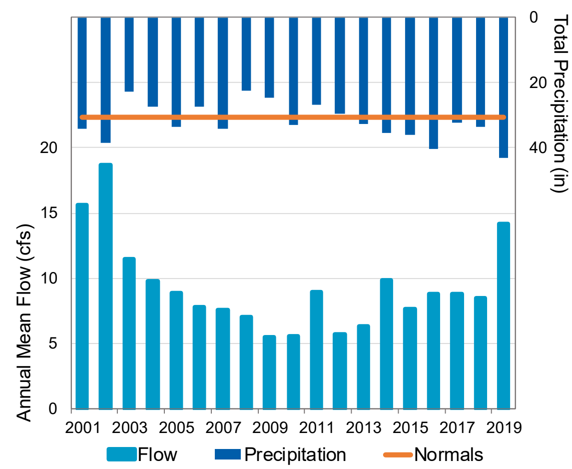

Figure 4: Annual Mean Flow and Precipitation for Brown's Creek

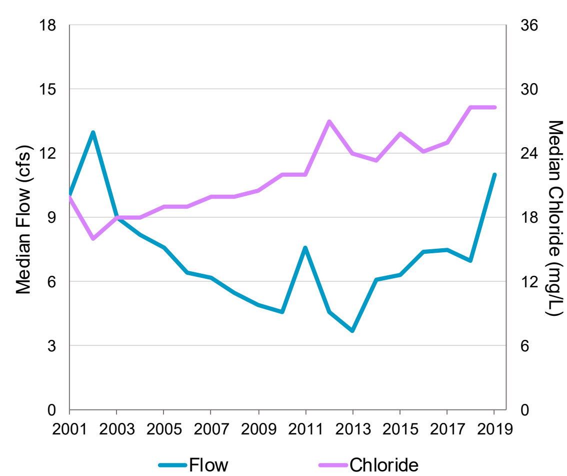

Figure 5: Annual Median Flow and Chloride Concentration in Brown's Creek

In order to see how non-flow factors, such as watershed practices, may have affected chloride concentrations, we used the R-QWTREND model.

Chloride Trends

R-QWTREND is a statistical model specifically designed to investigate pollutant trends, which tests potential trends (increase or decrease in concentration) against a no-trend model (no increase or decrease in concentrations). This model removes the variability of annual flow and seasonality from the statistical analysis. If the model does not show a statistically significant trend for a given time period, there is not sufficient evidence to claim that concentrations are increasing or decreasing. If increasing or decreasing concentrations cannot be described, then concentrations are assumed to be stable.

R-QWTREND analysis shows that changes of the flow-adjusted chloride concentration in Brown's Creek can be best represented by a statistically significant two-trend model ($p = 1.6 \times 10^{-15}$) over the assessment period from 2001 to 2019 (Table 1 and Figure 6). The model shows that the flow-adjusted chloride concentration stayed relatively constant during the 2001 to 2006 period and then increased gradually by about 53% from 2007 to 2019. From 2001-2006 there is not strong enough evidence that a trend exists. This period is reported as statistically non-significant (NS) and the modeled trend concentrations, changes in percentages, and rates are not provided (Table 1 and Figure 6).

Table 1: Statistical Trend for Chloride Concentration in Brown's Creek

Trend Period	Concentration range (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	*p*	Trend
2001 – 2006	-	-	-	0.87	NS
2007 – 2019	18.5 - 28.3	53%	0.75	0.0000	⬆

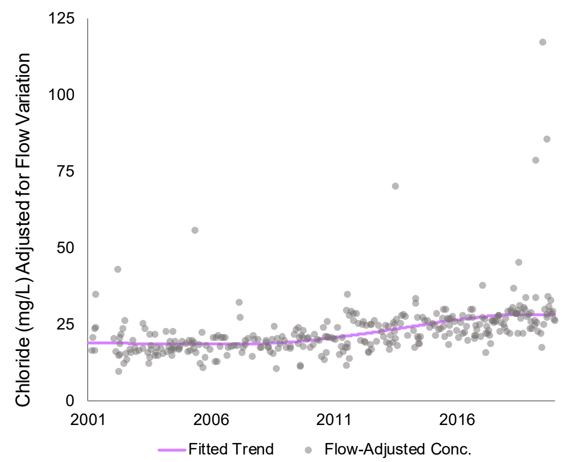

Figure 6: Flow-Adjusted Trends for Chloride Concentration in Brown's Creek

The exact drivers of the increase in flow-adjusted chloride concentrations in Brown's Creek over the 2007-2019 period are unknown but likely related to increased contributions from subsurface sewage treatment systems or increases in in de-icing salt and synthetic fertilizer runoff.

Additional data from 2020 and into the future has the potential to impact the significance and the direction of the recent trend period.

Pollutant trend: An analysis that shows the direction of change (improving vs. declining water quality) in a pollutant over time. This study examined changes in flow-adjusted chloride concentration from 2001 – 2019, allowing us to look at human-caused influences in chloride concentrations.

Flow-adjusted concentration: An adjustment to ambient concentration that removes variability of annual flow and seasonality mathematically, for use in statistical analysis.

Chloride Load

Figure 7 illustrates annual loads and annual mean flow. The annual loads for chloride exhibited significant year-to-year variation and align closely with flow, indicating the influence of precipitation and flow on the transport of pollutants within the watershed and the stream.

The increase in chloride loads in years of higher flow could be due to the increased flushing of salt that had built up on the landscape and in groundwater during drier years, when pollutants are less likely to be mobilized.

> **Pollutant Load:** The total mass of a pollutant exported from a stream over a period of time. MCES uses Flux32 software to estimate pollutant loads.

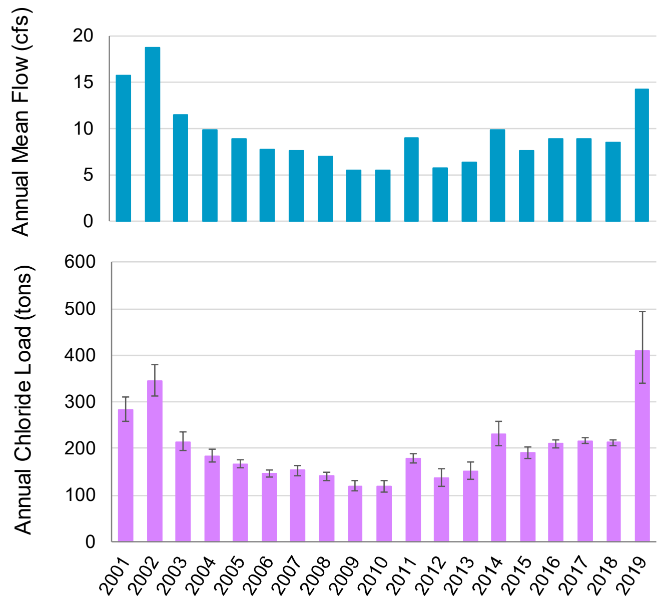

Figure 7: Mean Annual Flows and Annual Chloride Loads in Brown's Creek (Error bars = 95% Confidence Interval)

Seasonal Chloride Dynamics 2001 – 2019

Chloride Concentration and Streamflow

Seasonal changes can influence monthly median flow and monthly median chloride concentration. Peak flow was observed during the spring, while peak chloride concentration occurred in winter (Figure 8). Monthly median flows and chloride concentrations do not vary much during the year, likely due to groundwater contributions. There is no clear seasonal relationship between chloride and flow.

Chloride Load

Chloride loads calculated with Flux32 were compiled as monthly averages for 2001-2019. Figure 9 uses a bar to indicate maximum and minimum values for each month. The bottom of each box represents the first quartile, the top represents the third quartile, and the line in the middle of the box represents the median monthly chloride load. From 2001-2019, somewhat higher monthly loads occur in the spring and early summer, possibly due to de-icing salt and synthetic fertilizer runoff coupled with the higher flows occurring during that period.

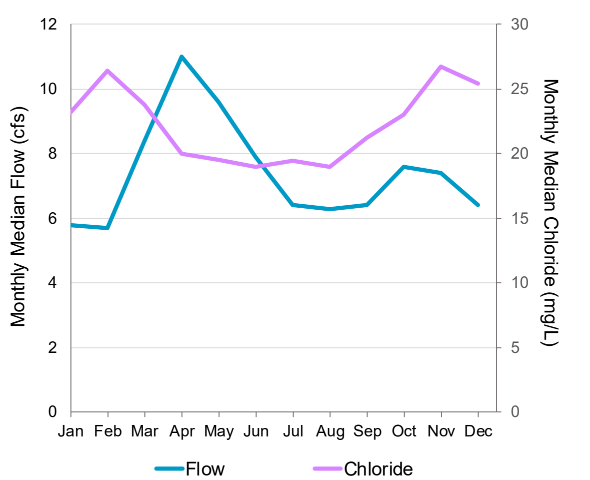

Figure 8: Monthly Median Flow and Median Ambient Chloride Concentrations in Brown's Creek

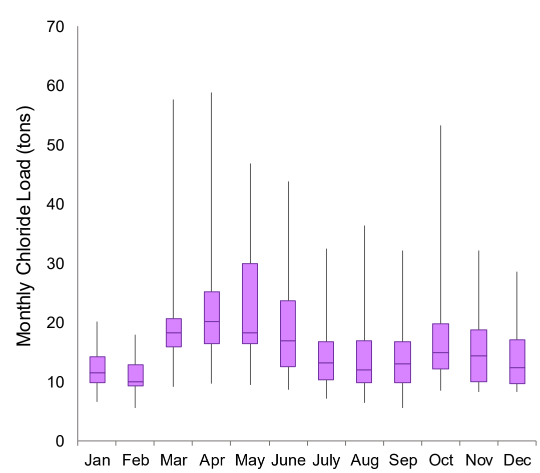

Figure 9: Monthly Chloride Loads in Brown's Creek

LIMITATIONS

The analyses described in this memo identify changes in chloride concentrations in the stream, but they do not identify the cause of those changes. MCES has suggested hypotheses about causes of changing chloride dynamics but additional information or research is needed to identify specific changes in watershed management, climactic changes, or any other factors which may have affected concentration in the stream.

During some winter months in from 2001 – 2019, hazardous ice conditions precluded sample collection. This data gap possibly biases our understanding of seasonal and annual chloride dynamics.

RECOMMENDATIONS & NEXT STEPS

Chloride pollution reduction projects and initiatives are most effective when guided by data collection and analysis. In order to support the Brown's Creek Watershed District and partners to prioritize resources to understand chloride dynamics and mitigate chloride pollution, MCES provides the following recommendations:

- Delineate the contributing groundwater watershed, groundwater sources, and their chloride concentrations to Brown's Creek.
- Calculate or compile the ground and surface watershed water and chloride budgets including but not limited to livestock excreta, fertilizer use, household water softening and de-icing salt application.
- Measure ambient groundwater chloride concentrations for the contributing groundwater watershed.
- Investigate baseflow separation and chloride concentration dynamics.
- Compile a timeline of land use changes, chloride best management practices and stormwater management installations in the watershed.
- Pursue a home water softener upgrade incentive program or centralized water softening.
- Continue to identify and implement chloride mitigation and management BMPs including trainings to minimize de-icing salt use.

We are aware that not all watershed organizations have the time, capacity, or resources to take these or other future next steps. MCES may have the ability to assist with future data collection, data analysis or other technical advice. Please contact us to discuss the potential of future partnerships if you are interested in continuing this work. Please contact us for additional technical information or information on field, laboratory and data analysis methods. Method documentation is also available as part of the *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams* report, *Introduction and Methodologies* section, available on the Council website at https://metrocouncil.org/streams.

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[1] Minnesota Pollution Control Agency. *Chloride 101.* <https://www.pca.state.mn.us/water/chloride-101>
[2] Metropolitan Council Environmental Services, 2018. Regional Assessment of River Quality in the Twin Cities Metropolitan Area. <https://metrocouncil.org/Wastewater-Water/Services/Water-Quality-Management/River-Monitoring-Analysis/Regional-Assessment-of-River-Quality-(2).aspx>
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[4] Minnesota Administrative Rules. *Minnesota Water Quality Standards for Protection of Waters of the State*. Minn. Rules 7050.0218 and Minn. Rules7050.0222. < https://www.revisor.mn.gov/rules/7050/>
[5] Overbo and Heger, n.d. *Estimating annual chloride use in Minnesota.* Water Resources Center. <wrc.umn.edu/chloride>
[6] Minnesota Pollution Control Agency. 2001. Effects of Liquid Manure Storage Systems on Groundwater Quality. <https://www.pca.state.mn.us/sites/default/files/rpt-liquidmanurestorage.pdf>
[7] Metropolitan Council, 2013. Municipal Water Use in the Seven-County Twin Cities Metro Area. <https://metrocouncil.org/Wastewater-Water/Planning/Water-Supply-Planning.aspx>
[8] Minnesota Pollution Control Agency. *Chloride 101.* <https://www.pca.state.mn.us/water/chloride-101>
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[10] Minnesota Pollution Control Agency. *Chloride 101.* <https://www.pca.state.mn.us/water/chloride-101>

[11] Metropolitan Council. 2014. Brown’s Creek. In Comprehensive water quality assessment of select metropolitan area streams. St. Paul: Metropolitan Council.

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[13] Minnesota Pollution Control Agency. 2020. Draft Statewide Chloride Management Plan <https://www.pca.state.mn.us/water/draft-statewide-chloride-management-plan>

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[16] USGS. 2015. Methods for Evaluation Potential Sources of Chloride in Surface Waters and Groundwaters of the Conterminous United States.

[17] Minnesota Department of Natural Resources. 2020. *Minneapolis/St. Paul Climate Data Normals and Averages.* *<https://www.dnr.state.mn.us/climate/twin_cities/normals.html>*