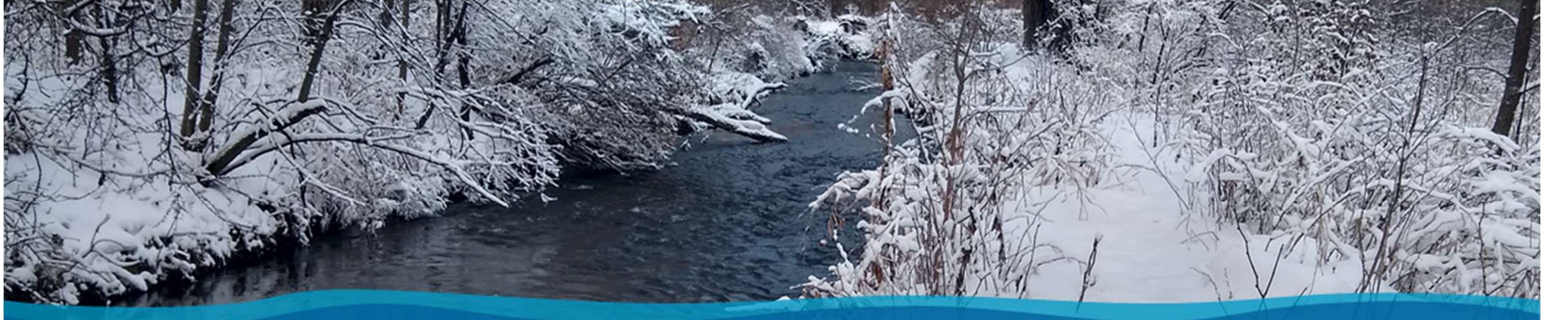

Battle Creek CHLORIDE

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KEY FINDINGS

Chloride increased in Battle Creek from 2002-2019, likely due to increased use and mobilization of winter de-icing salt in the watershed.

Most chloride is exported from Battle Creek between April and October, but chloride export is high year-round. Further investigation is needed to understand seasonal chloride dynamics in the watershed, including an examination of chloride cycling in lakes and transport of chloride in shallow groundwater

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 those analyses, 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, Ramsey Washington Metro Watershed District (RWMWD) and partners have been actively addressing chloride pollution through outreach and education efforts.

This memo provides data and analyses from Battle Creek with state and regional context about chloride pollution. This information has prompted questions from MCES staff and will likely prompt questions from readers. This memo is intended 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]

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]

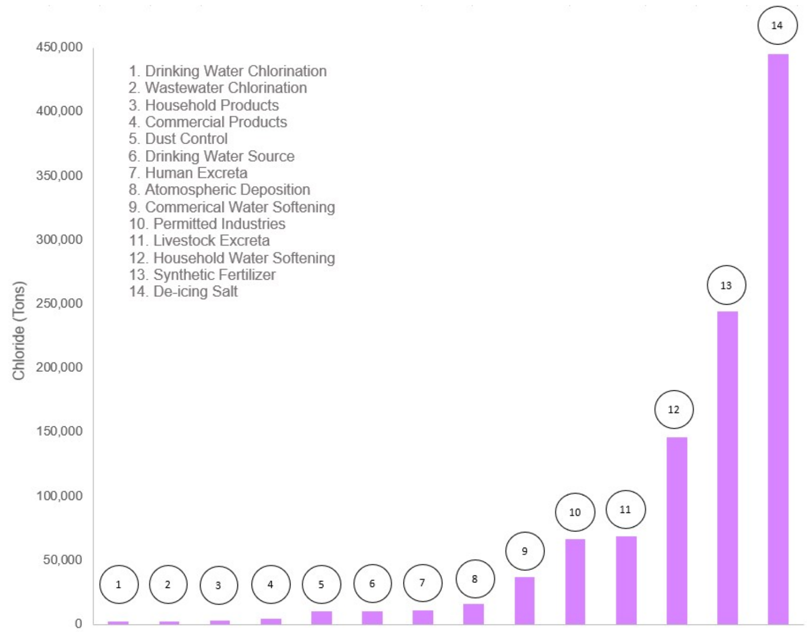

Figure 1: Major chloride sources and their annual chloride contributions to the environment in Minnesota.

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

Household water softening: More than 70% of the drinking water used in the Twin Cities comes from groundwater[6] 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.[7]

Synthetic fertilizer: Chloride is associated with macronutrients like potassium. The most common potassium source in Minnesota is potash fertilizer, potassium chloride.[8] 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.[9] 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

Battle Creek is 4-miles long and drains approximately 11.2 square miles of mostly urbanized land in Ramsey County. The headwaters are at Battle Creek Lake and it discharges to the Mississippi River at Pig's Eye Lake in St. Paul (Figure 2).

Battle Creek watershed is 7,134 acres, 62.7% of the land use is developed urban and there is 0.3% agricultural land use.[10] About 40% of the watershed drains directly to Battle Creek, 24% drains to Tanners Lake prior to discharge to Battle Creek Lake, 36% of the watershed drains directly to Battle Creek Lake.

Approximately 29% of the Battle Creek watershed is roadways, based on an analysis completed by the Minnesota Pollution Control Agency (MPCA).[11] The MPCA found that watersheds with 18% roadway density or higher are more likely to have chloride concentrations above water quality standards.[12]

Three waterbodies in the Battle Creek watershed are impaired for aquatic life use due to excess chloride (Figure 2). Battle Creek is impaired for chloride from Battle Creek Lake to Pig's Eye Lake. Battle Creek and Tanners Lakes are also impaired for chloride.[13]

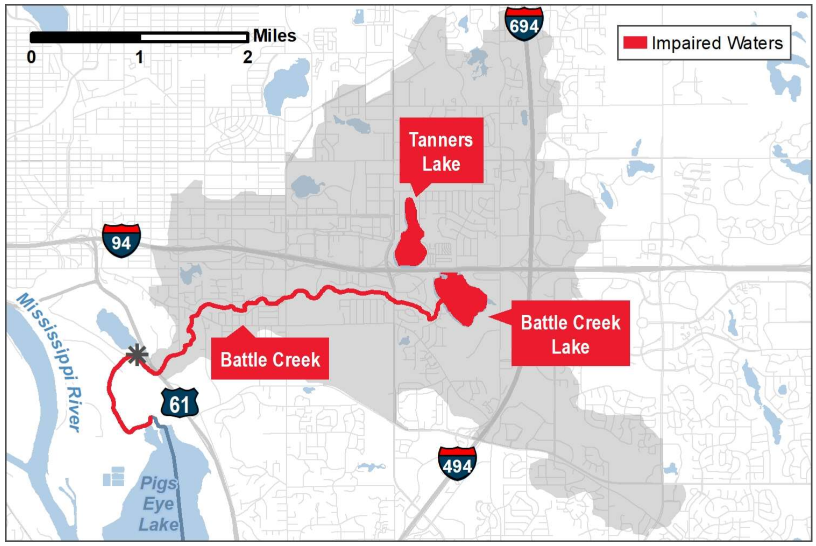

Figure 2: Map of Battle Creek Watershed

Household water softening is not likely to be a major chloride source in Battle Creek watershed. Chloride from household water softening enters surface and groundwater through wastewater treatment plants or residential subsurface sewage treatment systems. All wastewater from the Battle Creek watershed is treated through the MCES Metropolitan Wastewater Treatment Plant and discharged to the Mississippi River in St. Paul.

Synthetic fertilizer is a possible chloride source in the Battle Creek watershed. Chloride may come from residential and other urban and suburban turf management application of potash fertilizer.[14] This source of chloride is not well understood in the watershed.

De-icing salt is likely the primary source of chloride pollution in Battle Creek watershed. De-icing salt is primarily applied between December and March and would likely runoff during melt events from February through April.

FINDINGS

Annual Chloride Dynamics 2002-2019

Chloride Concentration

MCES and RWMWD collected 661 chloride samples between 2002 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.

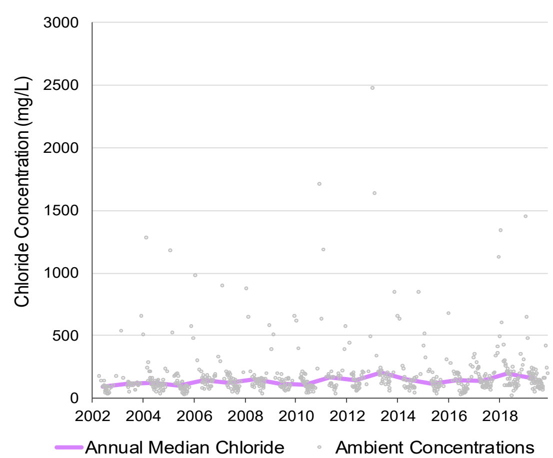

Figure 3: Annual Median and Ambient Chloride Concentrations of Battle Creek

Figure 3 shows that while there is significant variability in chloride concentration, annual median concentrations are high and have generally increased since 2002. There are a significant number of samples with concentrations above the chronic and acute toxicity levels for chloride.

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. Higher streamflow can lower pollutant levels through dilution, and lower streamflow can increase pollutant levels through concentration.

Figure 4 shows Battle Creek yearly precipitation, the 1981-2010 National Weather Service Climate Normal precipitation at Minneapolis-St. Paul airport, and annual mean flows. Flow is usually higher in years with greater rainfall. Flow in Battle Creek varied dynamically during the assessment period. Flows generally increased from 2012 to 2019, except in 2017 and 2018, corresponding with higher than normal annual precipitation amounts during that period.

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

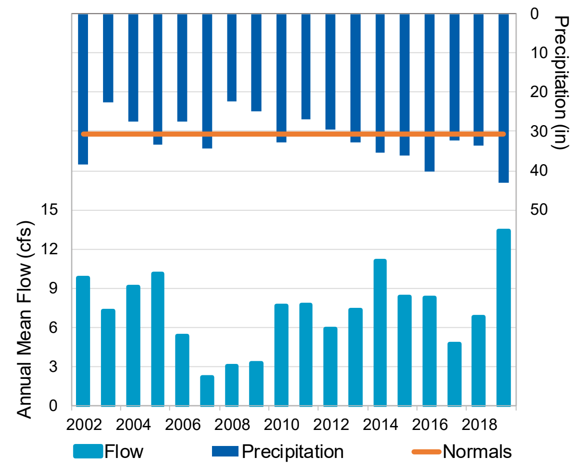

Figure 4: Annual Mean Flow and Precipitation for Battle Creek

Streamflow and Chloride Concentration

Figure 5 shows annual median chloride concentration and annual median flow values, representing typical conditions for each year.

There is a general relationship between flow and concentration: when flow has been high, concentration has generally been low due to dilution, and when flow has been low, concentration has increased. However, there is variability in concentration that does not vary perfectly with flow. This means that factors other than flow impact chloride conditions in the stream.

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

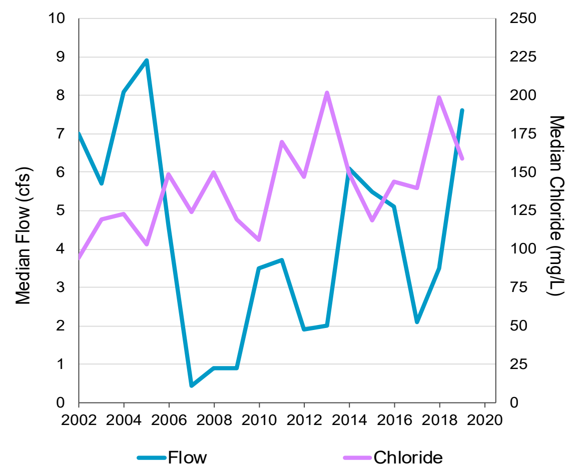

Figure 5: Annual Median Flow and Chloride Concentration in Battle Creek

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 in chloride concentration in Battle Creek can be best represented by a statistically significant one-trend model, $p = 0.0013$. Chloride concentration increased by 20% from 2002 to 2019 (Table 1 and Figure 6), likely due to behaviors in the watershed, including potentially an increase in use of de-icing salt and synthetic fertilizer.

Table 1: Statistical Trend for Chloride Concentration in Battle Creek

Trend Period	Concentration range (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	*p*	Trend
2002 – 2019	177.4 - 213.3	20%	1.99	0.0072	⬆

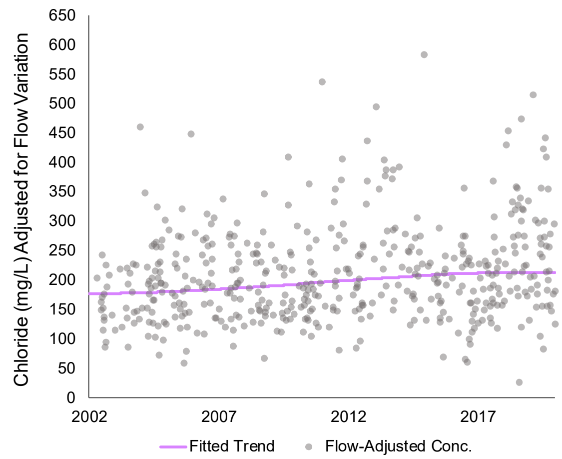

Figure 6: Flow-Adjusted Trends for Chloride Concentration in Battle Creek

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 2002 – 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.

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

Chloride Load

Figure 7 illustrates annual loads and annual mean flow. The annual chloride loads exhibited significant year-to-year variation 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 in watershed lakes and groundwater during drier years, when pollutants are less likely to be mobilized. Annual chloride load variability in Battle Creek is also likely due to quantity and timing of winter storm events and de-icing response to those storm events.

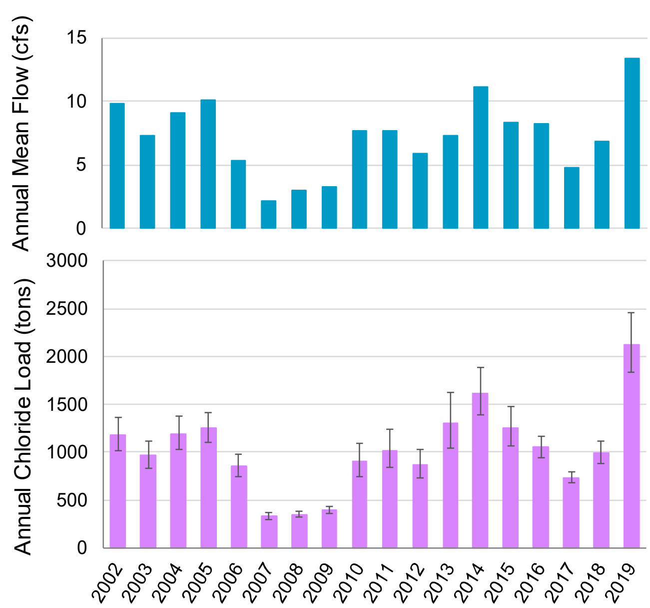

Figure 7: Mean Annual Flows and Annual Chloride Loads in Battle Creek (Error bars = 95% Confidence Interval)

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

Seasonal Chloride Dynamics 2002 – 2019

Chloride Concentration and Streamflow

Figure 8 shows monthly median chloride concentration and monthly median flow values, representing typical conditions in each month. Seasonal changes can influence monthly median flow and monthly median chloride concentration. De-icing salt is likely the primary source of chloride in the watershed. De-icing salt is primarily applied between December and March and mobilizes during the winter. Peak flow was observed during the spring, while peak chloride concentration occurred in winter.

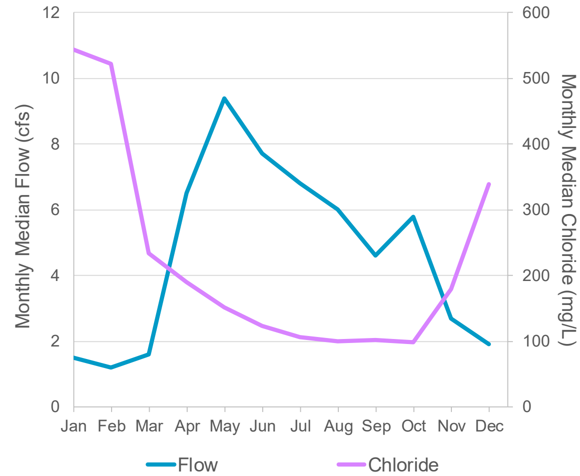

Figure 8: 2002 – 2019 Monthly Median Flow and Median Ambient Chloride Concentrations in Battle Creek

Chloride Load

Chloride load is seasonally dynamic. Chloride loads calculated with Flux32 were compiled as monthly averages for 2002-2019, Figure 9 uses a line 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 2002-2019, higher monthly loads occur from late spring until early fall. Chloride dynamics are likely affected by chloride cycling in Battle Creek and Tanners Lakes, shallow groundwater storage and additional, unknown factors.

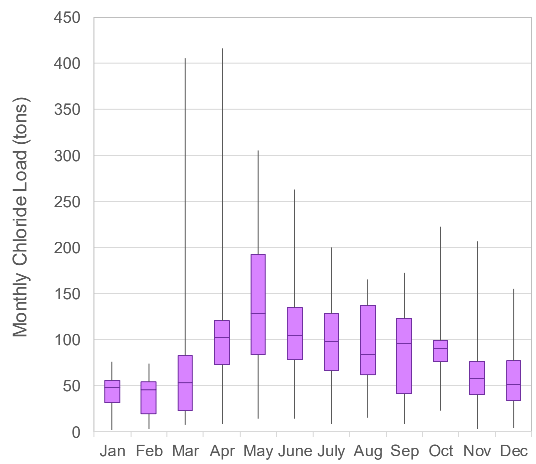

Figure 9: 2002-2019 Monthly Chloride Loads in Battle Creek

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 2002 – 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 RWMWD and partners to prioritize resources to understand chloride dynamics and mitigate chloride pollution, MCES provides the following recommendations:

- Calculate or compile the watershed water and chloride budgets including but not limited to synthetic fertilizer use and de-icing salt application.

- Investigate chloride concentrations and cycling in Tanners and Battle Creek lakes to understand how lakes affect in-stream chloride.
- Investigate the potential for stormwater runoff to enter shallow groundwater and how that affects chloride pollution timing and concentration.
- Compile a timeline of land use changes, chloride best management practices and stormwater management installations in the watershed.
- Update flow and load duration curves from 2014 *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams.* This analysis calculates the likelihood of a chloride standard exceedance for a particular flow.
- Investigate whether milder winters exacerbate seasonal chloride pollution by investigating winter chloride trends during thaw events, two or more days with air temperature lows above 32°F.
- Investigate relationship between continuous conductivity and chloride to understand chloride dynamics at a higher resolution at the MCES station and upstream locations.
- Continue to implement chloride mitigation and management BMPs including trainings to minimizing de-icing salt use on roads, parking lots, sidewalks and other impervious surfaces.

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>

[3] Minnesota Pollution Control Agency. *Chloride 101.* <https://www.pca.state.mn.us/water/chloride-101>

[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] Metropolitan Council, 2013. Municipal Water Use in the Seven-County Twin Cities Metro Area. <https://metrocouncil.org/Wastewater-Water/Planning/Water-Supply-Planning.aspx>

[7] Minnesota Pollution Control Agency. *Chloride 101.* <https://www.pca.state.mn.us/water/chloride-101>

[8] Rehm, G. and M. Schmitt. 1997. Potassium for crop production. Minnesota Extension Service. Minneapolis: University of Minnesota.

[9] Minnesota Pollution Control Agency. <https://www.pca.state.mn.us/water/chloride-101>

[10] Metropolitan Council Environmental Services. 2014. Comprehensive Water Quality Assessment of Select Metropolitan Area Streams. St. Paul: MCES.

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

[12] Minnesota Pollution Control Agency. 2016. Twin Cities Metropolitan Area Chloride Management Plan. <https://www.pca.state.mn.us/sites/default/files/wq-iw11-06ff.pdf>

[13] Minnesota Pollution Control Agency. *Minnesota's Impaired Waters List.* <https://www.pca.state.mn.us/water/minnesotas-impaired-waters-list>

[14] Granato, G.E., DeSimone, L.A., Barbaro, J.R., and Jeznach, L.C., 2015, Methods for evaluating potential sources of chloride in surface waters and groundwaters of the conterminous United States: U.S. Geological Survey Open-File Report 2015–1080, 89 p., http://dx.doi.org/10.3133/ofr20151080.