



Silver Creek CHLORIDE

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ENVIRONMENTAL SERVICES

KEY FINDINGS

Chloride concentrations in Silver Creek increased over the study period of 2002 – 2019 but remained far below water quality standards for impairment.

There is little monthly variation in flow or chloride export from Silver Creek, likely because there is a significant groundwater contribution to the stream. More investigation is needed on chloride transport in groundwater to further understand chloride dynamics in the Silver Creek watershed.

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?

Although Silver Creek is not currently impaired for chloride or considered at risk for impairment by Minnesota Pollution Control Agency (MPCA), chloride in surface water is a growing concern throughout the metro area. Outreach efforts concerning chloride sources and use are focused on restoration and protection of area waters. Carnelian Marine 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 Silver 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 impairment¹. A recent study by MCES indicated an increasing trend for chloride concentrations in the Mississippi, Minnesota, and St. Croix Rivers during the recent 30 years². 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

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 groundwater⁷ 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.

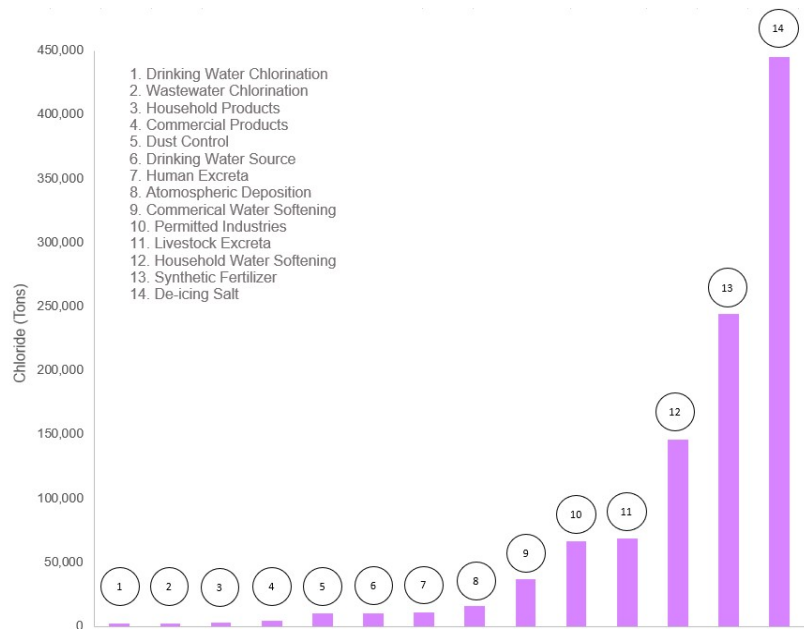


Figure 1: Major chloride sources and their annual chloride contributions to the environment in Minnesota.

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

Silver Creek is 2.5-miles long and drains approximately 8.6 square miles in Washington County. Silver Creek flows through portions of the cities of Stillwater and Grant and May and Stillwater townships. Silver Creek originates at a series of lakes – Silver Lake, Loon Lake, South and North Twin Lakes, and Carol Lake – in the southwest part of Stillwater Township before discharges to the St. Croix River north of Stillwater (Figure 2).

Sources of flow to Silver Creek are not well understood. Portions of Silver Creek watershed are believed to be landlocked and do not contribute flow during most years. There is also evidence that Silver Creek flow has a significant groundwater component due to the groundwater seeps and springs located near the outlet of Silver Creek to the St. Croix River. The groundwater watershed and groundwater contribution are not well documented.¹¹

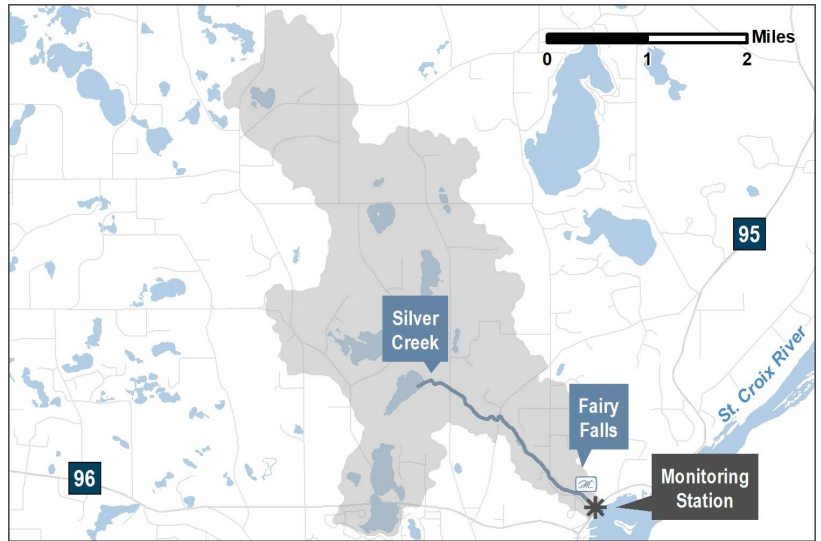


Figure 2: Map of Silver Creek Watershed

Silver Creek surface watershed is 5,559 acres; 25.4% of the land use is agricultural and 17.4% is developed urban land.¹² Other primary landcovers are forest, open water, grasses/herbaceous and wetlands.

Approximately 6% of the Silver 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

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

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

Livestock Excreta: Silver Creek watershed has three registered feedlots in its monitored area with a total of 140 animal units (AUs), and an additional two feedlots in the unmonitored area with 209 AUs.

Household Water Softening: The Silver Creek watershed contains one class D domestic discharge facility. Household wastewater collection is not centralized in the watershed. Residential developments are mostly 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

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.

FINDINGS

Annual Chloride Dynamics 2002-2019

Chloride Concentration

MCES and Carnelian Marine Watershed District partner to monitor Silver Creek, and Washington Conservation District (WCD) collects the samples. The partners collected 325 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.

Annual median chloride concentration generally increased from 2002 to 2019. Sampled concentrations are all still far below water quality standards for impairment (Figure 3).

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 airport¹⁷ with Silver Creek annual mean flows. In most years, precipitation appears to have a minimal effect on flow in what is believed to be a groundwater-dominated stream.

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 Silver Creek. Chloride generally increases from

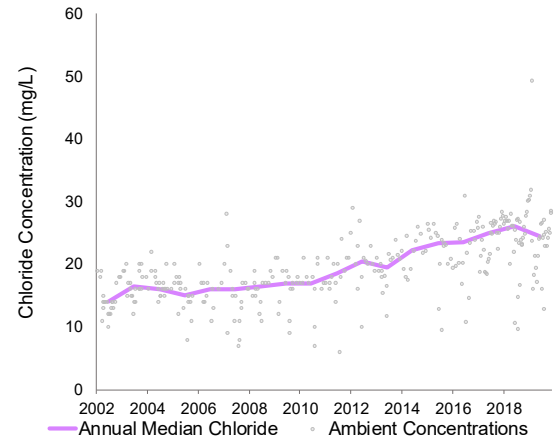


Figure 3: Annual Median and Ambient Chloride Concentrations of Silver Creek

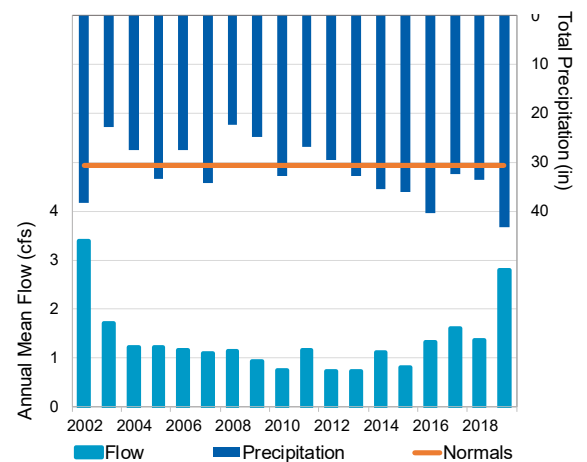


Figure 4: Annual Mean Flow and Precipitation for Silver Creek

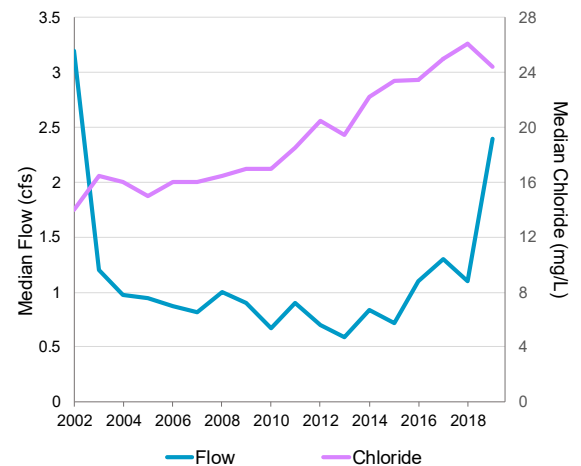


Figure 5: Annual Median Flow and Chloride Concentration in Silver Creek

2002 – 2019, despite variability in flow. 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.

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 Silver Creek can be best represented by a statistically significant two-trend model, $p = 1.1 \times 10^{-16}$. This model has only one significant period, from 2009-2019, which shows an increase in flow-adjusted concentration. From 2002-2008 the trend is statistically non-significant (NS) which means there is not strong enough evidence that a trend exists. Modeled trend concentrations, changes in percentages and rates are not provided for this period (Table 1 and Figure 6).

Table 1: Statistical Trend for Chloride Concentration in Silver Creek

Trend Period	Concentration range (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	p	Trend
2002-2008	---	---	---	0.39	NS
2009-2019	15.8 - 25.1	58%	0.84	0	↑

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.

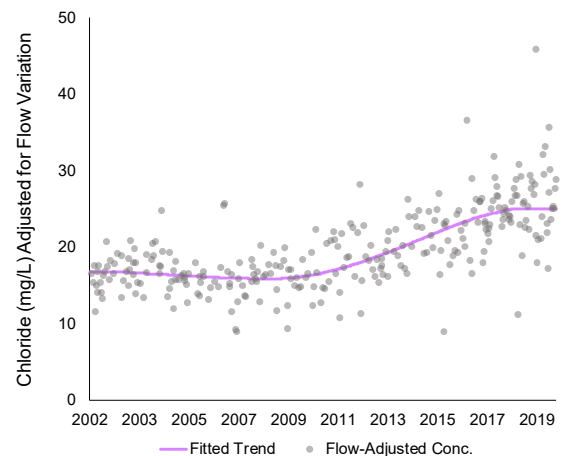


Figure 6: Flow-Adjusted Trends for Chloride Concentration in Silver Creek

The exact drivers of the increase in flow-adjusted chloride concentrations in Silver Creek over the 2009-2019 period are unknown but likely related to increased contributions from subsurface sewage treatment systems or increases 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.

Chloride Loads

Figure 7 illustrates annual loads and annual mean flow. The annual loads for chloride vary 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.

Seasonal Chloride Dynamics 2002 – 2019

Chloride Concentration and Streamflow

Often, seasonal changes such as snowmelt and spring rain influence monthly median flow and monthly median chloride concentration. However, both monthly median flows and median chloride concentrations show minimal seasonal variation in Silver Creek (Figure 8). This is possibly due to groundwater contributions or chloride cycling in lakes which maintain more consistent flow and concentration throughout the year.

Chloride Load

Chloride loads calculated with Flux32 were compiled as monthly averages for 2002-2019. 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.

Similar to monthly concentration, monthly chloride loads in Silver Creek show little variation or seasonal pattern.

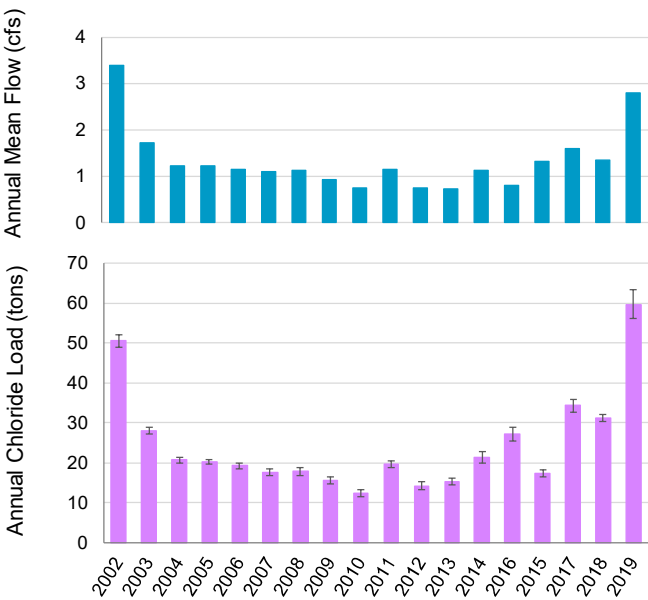


Figure 7: Annual Chloride Loads in Silver Creek (Error bars = 95% Confidence Interval)

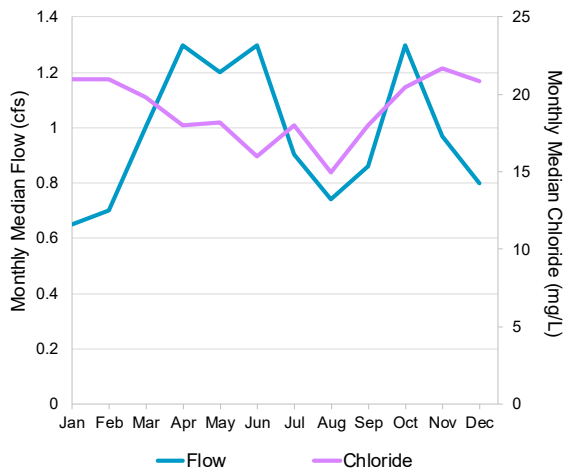


Figure 8: Monthly Median Flow and Median Ambient Chloride Concentrations in Silver Creek

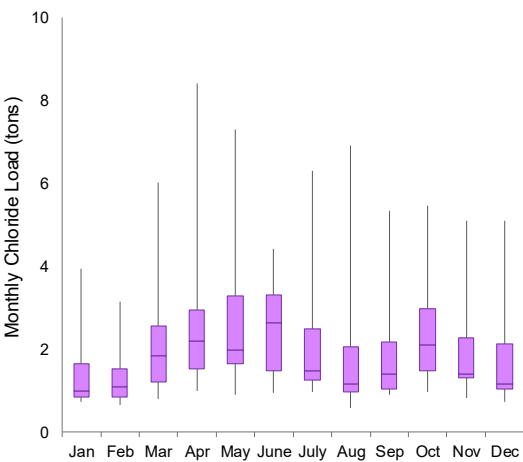


Figure 9: Monthly Chloride Loads in Silver Creek

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 and spring months in from 2002 – 2019, hazardous conditions and St. Croix River backwater 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 Carnelian Marine 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 Silver 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.
- Investigate chloride concentrations and cycling in lakes to understand how lakes affect in-stream chloride.
- 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://metro council.org/streams>.

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://metro council.org/Wastewater-Water/Services/Water-Quality-Management/River-Monitoring-Analysis/Regional-Assessment-of-River-Quality-\(2\).aspx](https://metro council.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. Rules 7050.0222. <<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://metro council.org/Wastewater-Water/Planning/Water-Supply-Planning.aspx>>

⁸ Minnesota Pollution Control Agency. *Chloride 101*. <<https://www.pca.state.mn.us/water/chloride-101>>

⁹ Rehm, G. and M. Schmitt. 1997. Potassium for crop production. Minnesota Extension Service. Minneapolis: University of Minnesota.

¹⁰ Minnesota Pollution Control Agency. *Chloride 101*. <<https://www.pca.state.mn.us/water/chloride-101>>

¹¹ Metropolitan Council. 2014. Silver Creek. In *Comprehensive water quality assessment of select metropolitan area streams*. St. Paul: Metropolitan Council.

¹² Metropolitan Council Environmental Services. 2014. *Comprehensive Water Quality Assessment of Select Metropolitan Area Streams*. St. Paul: MCES.

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

¹⁴ 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>>

¹⁵ Minnesota Pollution Control Agency. *Chloride 101*. <<https://www.pca.state.mn.us/water/chloride-101>>

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>