Technical Report No. 63

CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 2

STUDY AREA BACKGROUND

2.4 SOURCES OF CHLORIDE

Chlorine is the 20th most abundant element found within the earth's crust. In nature it is found in the combined state only ("compounded"), chiefly with sodium (Na), potassium (K), magnesium (Mg), and calcium (Ca). Elevated levels of chloride in the environment, particularly in freshwater systems, can have significant impacts. Once in the water, chloride is a persistent pollutant that does not break down or settle out. Chloride levels in Wisconsin rivers have shown a steep increase, from around 600,000 tons annually in the early 2000s to nearly 800,000 tons per year by 2018, making some Wisconsin rivers, streams, and lakes designated as impaired due to high chloride concentrations.[1]

Natural Sources of Chloride to the Environment

Commonly occurring chloride salts are released into the environment from both natural and anthropogenic (human-induced) sources. Natural sources of chloride include the dissolution (weathering) of rocks and minerals, atmospheric deposition (primarily salt spray from oceans), and natural salt deposits found underground. [2]

[1] *H. Karnopp, "Are chloride levels increasing in Wisconsin waterways because of road salt use?" Wisconsin Watch, December 12, 2022, wisconsinwatch.org/2022/12/are-chloride-levels-increasing-in-wisconsin-waterways-because-of-road-salt-use, accessed May 2025.*

[2] *These are minor sources of chloride to the environment in southeastern Wisconsin because chloride is a minor component of the Region's underlying bedrock, the Region is located far from the nearest ocean, and salt is not actively mined in the Region.*

Weathering of Rock and Soil Minerals

Chloride is naturally present in rocks, soil, and water. Chemical weathering is a natural process that breaks down rock and soil minerals, releasing ions that can contribute chloride to groundwater and surface water. Natural sources include the dissolution of chloride-bearing rock, such as halite, when exposed to water or acidic solutions.

Chloride concentrations in inland freshwater bodies from natural sources are typically less than 20 mg/l.[3] Natural chloride concentrations in these surface waters reflect the composition of the underlying bedrock and soils as well as deposition from precipitation events. Waterbodies in southeastern Wisconsin typically have very low natural chloride concentrations due to the dolomite bedrock found in the Region. These rocks are rich in carbonates and contain little chloride. Because of this, rock weathering is a minor source of chloride in the environment in the study area.

Atmospheric Deposition

Atmospheric deposition is a natural process by which ions or particles in the atmosphere fall to the ground through either wet or dry deposition. Much of the chloride in the atmosphere comes from the oceans through the processes of wave action and sea spray.[4] Atmospheric chloride is also generated from anthropogenic sources such as fossil fuel combustion or large-scale incineration, which can release hydrochloric acid (HCl) and other compounds to the atmosphere.[5] Wet deposition occurs through precipitation sources including rain, snow, ice, and fog, which carry dissolved chloride from the atmosphere to the ground. During dry deposition, chloride particles in dust, gases, or aerosols settle directly on the Earth's surface.

In southeastern Wisconsin, the majority of the total atmospheric deposition of chloride falls in the form of wet deposition. Wetter years with higher than normal precipitation are correlated with greater quantities of atmospheric deposition compared to drier years, as shown in Figure 2.AtmosphericDeposition. The figure

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[3] *See references in Table 1 of W.D. Hintz and R.A. Relyea, "*A Review of the Species, Community, and Ecosystem Impacts of Road Salt Salinization in Freshwater,*"* Freshwater Biology, *64:1,081-1,097, 2019.*

[4] *T.E. Graedel, and W.C. Keene;* "The Budget and Cycle of Earth's Natural Chlorine," *Pure & Applied Chemistry, 68(9): 1,689-1,697, 1996.*

[5] *J.D. Haskins, L. Jaegle, and J.A. Thornton,* "Significant Decrease in Wet Deposition of Anthropogenic Chloride Across the Eastern United States, 1998-2018," *Geophysical Research Letters, 47: e2020GL090195, doi 10.1029/2020GL090195, 2020.*

also indicates the good correlation between annual rainfall totals and atmospheric deposition for chloride to the Region. For the mass balance analysis completed as part of the Study, atmospheric deposition was a minor source of chloride to the Region. [6]

Anthropogenic (Human-Derived) Sources of Chloride to the Environment

As discussed in Technical Report (TR) No. 62 there are multiple pathways for chlorides to move through the environment, ultimately ending up either in surface water or groundwater resources.[7] Figure 2.SourcesDiagram is a simplified diagram of the major human-derived sources of chloride to the environment and their main pathways to surface water and groundwater resources. Major sources of chloride include deicing salts, agricultural uses, and water softening salts.[8] In Figure 2.SourcesDiagram the major sources of chloride are also categorized by if they predominantly occur on urban or rural land uses. As indicated in the figure, deicing salts and water softening occur in both urban and rural land uses, but have a larger impact in urban areas due to more compact impervious areas and population. Agricultural uses on rural lands also contribute chlorides to the environment via fertilizers on crops and farm operations. Ultimately chlorides in the environment are transported to either surface waters (lakes and streams) or groundwater. It should be noted that groundwater and surface waters do interact, with chlorides potentially moving back and forth between them. The following sections describe common human-based sources of chloride and their relative contributions to the water resources of the study area.

Winter Maintenance (Deicing) Activities

Deicing salt ("road salt") is commonly used to reduce and/or prevent the formation and/or accumulation of snow or ice on impervious surfaces (i.e., roads, parking lots, driveways, and sidewalks).[9] When snow and ice from treated surfaces melt, these dissolved salts (predominantly sodium chloride) are washed off the impervious surfaces either directly into stormwater systems (sewers, ponds, channels) which discharge to

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[6] *SEWRPC Technical Report No. 65,* Mass Balance Analysis for Chloride in Southeastern Wisconsin*, in progress.*

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

[8] *SEWRPC TR-65,* op. cit.

[9] *Granto, DeSimone, Barbaro, and Jeznach, United States Geological Survey, and U.S. Department of Transportation Federal Highway Administration, "*Methods for Evaluating Potential Sources of Chloride in Surface Waters and Groundwaters of the Conterminous United States*," 2015.*

surface waters or chloride-laden runoff flows onto adjacent vegetated land surfaces and infiltrates to groundwater. As such, road salt can move through the environment via one of several pathways:[10]

- Dissolve and percolate into the soil with melting snow or ice
- Runoff with snowmelt into surface waters
- Splash, bounce, or get plowed into adjacent roadsides where it can be deposited onto vegetation or into the soil, or get sprayed into the air by moving vehicles
- Spill during storage, processing, or transport

The use of deicing salt was introduced in the 1930s for transportation and vehicle safety, with widespread use beginning in the 1950s after WWII and the expansion of the U.S. Interstate Highway System, and continued growing in the 1960s when people began commuting for both work and pleasure.[11] Figure 2.HistoricalSaltUse illustrates how the use of salt for deicing in the U.S. has increased from 1940 to 2022. It is important to note, that aside from the development of the U.S. Interstate Highway System beginning in the 1950s, several other factors including food preservation, refrigeration, the rise and closure of the synthetic soda ash industry have influenced salt usage throughout time.[12] Also, as indicated in the historical Regional land use information described above in Section 2.1, the largest expansion of urban development (i.e., increases in road density and impervious surfaces) within the study area occurred during the same period from 1950 through 1963.

Winter deicing activities are performed by both public entities and private ones. Public winter deicing is applied predominantly on roadways within a county or community. In Wisconsin, each county is also responsible for deicing activities on State trunk highways, U.S. highways, and U.S. interstates. Private deicing

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[10] *D.M. Ramakrishna and T. Viraraghavan, "Environmental Impact of Chemical Deicers—A Review,"* Water, Air, and Soil Pollution, *166:49-63, 2005.*

[11] *Northern Salt Incorporated, "What is Road Salt? Where does Road Salt come from? How does Road Salt work?" January 12, 2021, northernsalt.com/what-is-road-salt-where-does-road-salt-come-from-how-does-road-salt-work, accessed May 2025.*

[12] *D.S. Kostick,* The Material Flow of Salt*, U.S. Bureau of Mines Information Circular 9343, United States Department of the Interior, 1993.*

is completed by contractors or private citizens on commercial and residential parking lots, sidewalks, and driveways. For the TR-65 mass balance analysis, public deicing and private deicing were determined to be major sources of chloride to the Region.

Wastewater

Wastewater can contain chloride from a variety of private and public sources including residential, commercial, agricultural, and industrial land uses. Most of the wastewater from these sources are intended to undergo some level of treatment to improve water quality prior to being discharged back into the environment. Wastewater in the study area is managed through either treatment at a public wastewater treatment plant (WWTP), at a private onsite wastewater treatment system (POWTS or septic/mound system), or by a private WWTP serving smaller entities such as manufactured home parks, institutions, or an industry. Wastewater to a public WWTP can be conveyed through an underground sewer network or transported/hauled by truck to the facility. Pathways for wastewater chlorides into the environment are also reviewed in Technical Reports 62, 65, and 66 of this Study.

Wastewater Chloride Sources

Chlorides in wastewater can originate from a variety of sources including salt used to recharge water softeners, salts used in home food preparation, chlorides excreted by people, chloride-containing products used in homes, and chlorides used in commercial and industrial processes. Winter deicing products may also enter the sanitary sewers via infiltration and inflow. Water supply sources across the study area also contain varying levels of chloride, along with chemicals used for disinfection or other drinking water treatment processes. In addition, some WWTPs use chloride-containing chemical additives as part of the treatment process, such as aluminum chloride ($AlCl_3$) and ferric chloride ($FeCl_3$) which are used as coagulants to remove contaminants such as phosphorus during wastewater treatment.

Southeastern Wisconsin is considered to have hard groundwater (>120 mg/l as $CaCO_3$). Therefore, water softening, which removes calcium, magnesium, and certain other metal cations, is a common practice in many homes and businesses to remove the hardness from groundwater. These removal systems, as explained in greater detail in TR-66, are regenerated by flushing with a salt brine solution, typically sodium chloride. This chloride-rich brine is then discharged to a WWTP or POWTS.

Wastewater Treatment

Wastewater effluent from a public WWTP is typically discharged into a nearby waterway, or more rarely to infiltration ponds that allow the effluent to infiltrate into soils and eventually reach groundwater. There are currently 48 active public WWTPs in operation within the study area.

Because conventional wastewater treatment processes do not remove chloride ions from wastewater effluent, chloride is directly discharged back into the environment. For the study area, average study period discharge chloride concentrations for public WWTP were on the order of 200 mg/l to 500 mg/l. Also to note, 14 public WWTPs in the study area had discharge chloride variances as of January 2024.[13] This means that the WWTP is discharging higher chloride concentrations than is normally permitted based on the water quality standards for the receiving waterbody. The variance allows for a temporary increase in the allowable chloride effluent limit, but requires the WWTP to develop and implement a chloride reduction plan to achieve compliance with water quality standards. For the TR-65 mass balance analysis, public WWTP effluent was determined to be a major source of chloride to the study area.

There are three common types of private onsite wastewater treatment systems (POWTS): conventional septic systems, mound systems, and holding tanks. Conventional septic systems collect wastewater in a septic tank, which allows solids to settle out before discharging effluent to a subsurface drainfield where it infiltrates through the soil. Microorganisms in the soil further treat wastewater, removing coliform bacteria, viruses, and nutrients. Ultimately, the treated wastewater percolates through the ground and enters the groundwater. Mound systems function similar to conventional septic systems, but are located in areas of high groundwater, high bedrock, or poor soils. In a mound system the drainfield is raised in an above grade mound with gravel and sand layers underneath to encourage natural treatment processes. Holding tanks are used on properties where either conditions are not amenable to soil treatment or there is not enough room to build a drain field. Holding tanks provide temporary wastewater storage and then are pumped by a permitted waste hauler and transported to either a public WWTP or in some cases land spread. For the TR-65 mass balance analysis, the contribution of holding tanks was represented in the public WWTP effluent, which overall was determined to be a major source of chloride to the study area. Chloride contributions from septic/mound systems were determined to be a relatively minor chloride source to the Region.

[13] *SEWRPC Technical Report No. 66,* State of the Art for Chloride Management*, in progress.*

Industrial facilities may discharge wastewater directly to surface waters (i.e., point source) following treatment at the facility. Some industries have chloride in their discharge due to the products they produce or chemicals they use.[14] As a point source, the WDNR regulates industrial wastewater discharges via WPDES permits. While there are hundreds of industrial facilities located within the study area, as of 2020, only twelve were permitted to discharge wastewater directly into surface water and required to monitor chloride in the wastewater effluent. The results of the TR-65 analysis indicate that the chloride load discharged to the environment from these 12 industrial facilities is a minor source of chloride in the study area. However, it is important to note that because the available data represent only a small percentage of the industrial facilities in the study area the actual amount of chloride discharged from industrial sources into the environment is likely much higher.

Agricultural Sources

Agricultural fertilizer and/or manure spreading is another source of chloride to the environment. Major agricultural fertilizers that contain chloride include potassium chloride (KCl), calcium chloride ($CaCl_2$), ammonium chloride (NH_4Cl) and magnesium chloride ($MgCl_2$) with potassium chloride (or "muriate of potash") being the primary source as it the cheapest to produce and purchase and has the highest concentration of potassium.[15] It is estimated that about 95 percent of potash used in the U.S. is applied as KCl.[16] Potash (KCl) is about 47 percent chloride and 53 percent potassium by weight. Nutrient requirements vary by crop and in general, fruiting and flowering plants as well as potatoes require higher levels of potassium.[17] The most prevalent crops in the study area requiring potassium fertilizers included corn,

[14] *Minnesota Pollution Control Agency,* Minnesota Statewide Chloride Management Plan*, 2016.*

[15] *Potash is a catch-all term describing a range of potassium-containing fertilizers including potassium chloride (KCl) which is also called muriate of potash, potassium sulfate ($K2SO_4$), potassium-magnesium sulfate ($K2SO_4$-$MgSO_4$), potassium thiosulfate (K_2S2O_3), and potassium nitrate (KNO_3). Potash is produced mostly in the form of potassium chloride (KCl).*

[16] *D.L. Armstrong, and K.P. Griffin, "Production and Use of Potassium,"* Better Crops with Plant Food, *82(3):6-8, 1998; S.M. Jasinski, D.A. Kramer, J.A. Ober, and J.P. Searls,* Fertilizers—Sustaining Global Food Supplies, *U.S. Geological Survey Fact Sheet No. 99-155, 1999; J.P. Searls,* Potash, *U.S. Geological Survey Commodity Statistics and Information, 2000; California Fertilizer Foundation,* Plant Nutrients, *2011.*

[17] *C.A.M. Laboski and J.B. Peters,* Nutrient Allocation Guidelines for Field, Vegetable, and Fruit Crops in Wisconsin (A2809)*, University of Wisconsin-Extension, 2012.*

soybeans, and alfalfa crops. Potash application rates and loading for the study area are detailed in the chloride mass balance analysis in TR-65.[18]

As shown in Figure 2.HistoricalPotash, the amount of potash applied to agricultural fields within the U.S. became increasingly prevalent in the 1950s and continued to exponentially increase until the 1970s where the use leveled off. Based on county-level data as discussed in TR-62, about 20.3 million pounds of chloride are applied annually to agricultural fields as potash fertilizer in the seven-county Southeastern Wisconsin Region. [19,20]

The amount of chloride in livestock manure varies, depending on the type of livestock or whether the manure is in solid or liquid form. It has been estimated that most dairy and feed lot manures contain about 5-10 percent salt.[21] Since chloride constitutes about 60 percent of the weight of salt, this suggests that at least 3 to 6 percent of manure is chloride. Concentrations of chloride in various manures have been documented at 400 mg/l for horse manure,[22] a mean of 1,028 mg/l for hog manure,[23] 1,650 mg/l for dairy

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[18] *Technical Report No. 65,* op. cit.

[19] *Wisconsin Department of Agriculture, Trade and Consumer Protection, "Agricultural Chemical Use,"* Wisconsin Farm Reporter, *20(9):3-4, May 22, 2019; Wisconsin Department of Agriculture, Trade and Consumer Protection, "Agricultural Chemical Use: Barley,"* Wisconsin Farm Reporter, *20(9):4, May 12, 2020; Wisconsin Department of Agriculture, Trade and Consumer Protection, "Agricultural Chemical Use: Soybeans,"* Wisconsin Farm Reporter, *21(10):3-4, June 1, 2021; U.S. Department of Agriculture National Agricultural Statistics Service,* 2017 Census of Agriculture: Wisconsin State and County Data, *April 2019.*

[20] As detailed in TR-65, these data are limited to barley, corn, and soybeans, and information for the latter two were used to estimate the quantity of potash applied to these crops.

[21] *University of Arizona, "Manure Use and Management Fact Sheet – Animal Management (UA)," cals.arizona.edu/animalwaste/farmasyst/awface8.html, no date, accessed June 3, 2022.*

[22] *S.V. Panno, K.C. Hackley, H.H. Hwang, S.E. Greenberg, I.G. Krapac, S. Landberger, and D.J. O'Kelly,* Database for the Characterization and Identification of NaCl Sources in Natural Waters of Illinois, *Illinois State Geological Survey Open File Series 2005-1, 2005.*

[23] Ibid.

manure,[24] and 6,000 mg/l in poultry manure.[25] Chloride concentrations in manure are also highly dependent on the form of the manure (i.e., liquid or solid) and if concentrations are measured as excreted, or in a manure lagoon, where concentrations are diluted by mixing of other process wastewaters. In 2017, manure was applied to over 71,500 acres or about 11 percent of agricultural lands in southeastern Wisconsin.[26]

In Wisconsin, a livestock operation with 1,000 animal units or more is defined as a Concentrated Animal Feeding Operation (CAFO).[27] Under state and federal law, CAFOs must have a WDNR-issued WPDES permit. Because CAFOs present a major concern as a source of pollution runoff, the WPDES permit also requires CAFOs to maintain a nutrient management plan; a response plan for manure and non-manure spills; specified manure spreading limits and setbacks; and additional inspection, monitoring, and reporting requirements. As of 2020, there were 17 CAFOs located within the Region and larger study area.[28]

The results of the TR-65 analysis indicate that the chloride load discharged to the environment from all agricultural sources evaluated for the Study is a moderately significant source of chloride to the Region.

Other Minor Sources of Chloride

Two additional potential anthropogenic sources of chloride to the environment include landfill leachate and irrigation, which are discussed below.

Landfill Leachate

Landfill leachate is the liquid generated from landfill waste or from precipitation infiltrating through the landfill. Depending on the composition of the waste in a landfill, leachate may contain high levels of chloride. There are various types of landfills including those that accept solid municipal waste, industrial waste, or hazardous waste. There are six municipal solid waste landfills located within the Region and two additional landfills at power generation stations that are used to dispose of coal combustion residuals (CCRs).

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[24] *J.P. Zublena, J.C. Barker, and D.P. Wessen,* Soil Facts: Dairy Manure as a Fertilizer Source, *North Carolina State University Agricultural Extension Service Publication AG-439-28 WQWM-122, 2012.*

[25] *K.L. Wells,* The Agronomics of Manure Use for Crop Production, *University of Kentucky Cooperative Extension Service Report AGR-165, 2014.*

[26] *U.S. Department of Agriculture National Agricultural Statistics Service 2019,* op. cit.

[27] Wisconsin Administrative Code, *NR 243: Animal Feeding Operations, relates an animal unit to the impact of one beef steer or cow. Therefore, 1000 beef cattle are equivalent to 1000 animal units. Other animals have differing ratios.*

[28] *SEWRPC TR-65,* op. cit.

Assuming the landfill is operated, maintained, and monitored in accordance with State and Federal regulations and the lining and leachate system is well-designed and constructed, this should minimize the risk of landfill leachate entering groundwater resources. But for older closed landfills or ones with failing liners, landfill leachate could enter local groundwater. While landfills are recognized as a potential source of chloride to the environment, due to little available data, landfill chloride contributions to surface water and groundwater resources were not quantified for this Study.

<u>Irrigation</u>

Irrigation practices supplement soil moisture from groundwater or surface water sources to meet water requirements for crops and other vegetation, or to increase crop yields and improve crop quality. Irrigation practices vary year to year, and are influenced by weather conditions, crop type, and farming practices. The USGS estimated that in 2015 approximately 12,200 acres or almost two percent of the agricultural land in the study area were irrigated, with an average application of 9.5 million gallons per day (mgd).[29] Irrigation water will contain the amount of chlorides found in its source water, either groundwater or surface water. The results of the TR-65 analysis indicate that the chloride load discharged to the environment from irrigation is a minor source of chloride to the Region.

2.5 WATER QUALITY STANDARDS

Protectiveness of Existing Standards

Therefore, as part of this Study we established seven chloride thresholds ranging from 10 mg/l to 1400 mg/l (Table 2.Chloride Thresholds for Analysis) for assessment of surface waterbodies in the succeeding chapters of this report. The lower threshold of 10 mg/l is considered the historical background concentration for waterbodies within the study area and the State of Wisconsin as a whole.[30] Using this threshold will allow comparison of how much our waterbodies have changed or been impacted by chloride. The next threshold is 35 mg/l and represents the most conservative lower impact concentration to negatively affect multiple

[29] *U.S. Geological Survey,* USGS Water Use Data for Wisconsin: 1985-2015, *waterdata.usgs.gov/wi/nwis/wu, accessed April 10, 2025.*

[30] *SEWRPC Technical Report No. 4,* Water Quality and Flow of Streams in Southeastern Wisconsin Technical Report*, May 1967; SEWRPC Technical Report No. 17,* Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975*, 1978; E.A. Birge, C. Juday, "The Inland Lakes of Wisconsin", Wisconsin Geological and Natural History Survey,* Scientific Series *No. 7, 1911; and, Lillie R A, and Mason J W, "Limnological Characteristics of Wisconsin Lakes", Wisconsin Department of Natural Resources* Technical Bulletin *No. 138. 1983.*

species and trophic levels within freshwater communities (lethal and nonlethal impacts).[31] The next four chloride thresholds of 120 mg/l, 230 mg/l, 395 mg/l, and 757 mg/l represent the chronic Canadian water quality guideline for the protection of aquatic life, the chronic American ambient water quality criteria, the Wisconsin chronic toxicity criteria, and the Wisconsin acute toxicity criteria standards, respectively. The inclusion of these threshold concentrations will allow comparison of existing State of Wisconsin criteria and more restrictive National and International criteria thresholds to gauge multiple levels of water quality achievement in terms of chloride concentrations. Finally, the highest threshold concentration of 1,400 mg/l was chosen to represent an extreme impact level concentration for chlorides.[32] Exceedance of this threshold is associated with a severe level of impacts due to known 0.25-hour through 456-hour EC50 (concentration at which 50 percent of the test organisms showed a toxicity effect) and/or LC50 (concentration that is lethal to 50 percent of the text organisms) for multiple freshwater aquatic organisms. Concentrations exceeding this threshold are considered to also have negative impacts to the composition and structure of freshwater ecological communities, ecological processes such as competition and predation, and/or energy flow within aquatic ecosystems such as inhibition of denitrification, organic matter decomposition, nutrient cycling, and/or primary production. It was envisioned that any waterbodies exceeding this highest threshold to be identified as high priority areas for targeted or priority intervention.

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[31] *SEWRPC Technical Report No. 62,* Impacts of Chloride on the Natural and Built Environment*, April 2024; Canadian Council of Ministers of the Environment (CCME). Canadian water quality guidelines for the protection of aquatic life: chloride, 2011; Canadian Council of Ministers of the Environment (CCME). Scientific Criteria Document for the development of the Canadian water quality guidelines for the protection of aquatic life: chloride ion, 2011; and, Lauren Lawson and Donald A. Jackson, "Water quality patterns in at-risk fish habitat: Assessing frequency and cumulative duration of chloride guideline exceedance during early life stages of an endangered fish",* Ecological Indicators*, Volume 168, 2024, ISSN 1470-160X, doi.org/10.1016/j.ecolind.2024.112707.*

[32] *SEWRPC Technical Report No. 62, 2024,* op. cit.

Technical Report No. 63

CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 2

STUDY AREA BACKGROUND

TABLES

Table 2.Chloride Thresholds for Analysis
Surface Water Chloride Thresholds for Assessment of Lakes and Streams in the Chloride Impact Study

Threshold Chloride Concentration (mg/l)	Source	Description	Reference
10	Historical/Ambient Background Concentration	This concentration represents a surface water baseline level of chloride from observations in the early 1900s that represent a time period unimpacted by human influences in inland freshwater lakes and streams within the Southeastern Wisconsin regional area. Concentrations below this threshold are considered normal and concentrations above this threshold are considered to begin to have observed negative biological effects.	SEWRPC Technical Report No. 4, 1967; SEWRPC Technical Report No. 17, 1978; E.A. Birge, C. Juday, 1911; and Lillie and Mason 1983.
35	Conservative Lower Impact Concentration	Lowest concentration to negatively affect freshwater aquatic life (lethal and non-lethal impacts) among several trophic levels within aquatic ecosystems. Chloride levels exceeding this concentration have been linked to reduction in fish species diversity, decreased reproduction and increased mortality of several zooplankton (Daphnia) species, substantial changes in the composition of periphytic diatom assemblages, reduced bacteria density in biofilms, reduction in survival of the glochidia life stage of two mussel species (*Lampsilis fasciola* and *Epioblasma torulosa rangiana*), and acute toxicity to the Sida water flea (*Psuedosida ramosa*) and egg life stages of Rohu Carp (*Labeo rohita*). In addition, concentrations between 35 to 120 mg/l are also associated with acute toxicity to wood frog (*Lithobates sylvatica*) tadpoles and reduced photosynthetic production in common waterweed (*Elodea canadensis*), and reductions in wetland plant species richness.	SEWRPC Technical Report No. 62, 2024; Canadian Council of Ministers of the Environment (CCME) 2011; and, Lawson, and Jackson, Ecological Indicators, Volume 168, 2024.
120	Canadian Chronic Toxicity Threshold	Seven-day exposure to fish and invertebrates.	CCME 2011
230	USEPA Chronic Toxicity Threshold	The four-day average concentration of chloride is not to exceed this value more than once in three years on average.	USEPA 1988
395	Wisconsin Chronic Toxicity Threshold	The four-day average of the daily maximum concentrations of chloride taken over four consecutive days is not to exceed this value more than once in a three-year period.	NR 102, NR 103, NR 104, NR 105, and NR 207 of the Wisconsin Administrative Code
757	Wisconsin Acute Toxicity Threshold	The daily maximum concentration of chloride is not to exceed this value more than once in a three-year period.	NR 102, NR 103, NR 104, NR 105, and NR 207 of the Wisconsin Administrative Code
1400	Extreme Impact Level Concentration	This was chosen to represent a chloride concentration associated with a severe level of impacts due to known 0.25-hour through 456-hour EC50 (concentration at which 50 percent of the test organisms showed a toxicity effect) and/or LC50 (concentration that is lethal to 50 percent of the text organisms) for multiple freshwater aquatic organisms. Concentrations exceeding this threshold are considered to also have negative impacts to the composition and structure of freshwater ecological communities, ecological processes such as competition and predation, and/or energy flow within aquatic ecosystems such as inhibition of denitrification, organic matter decomposition, nutrient cycling, and/or primary production.	SEWRPC Technical Report No. 62, 2024

Source: SEWRPC

Technical Report No. 63

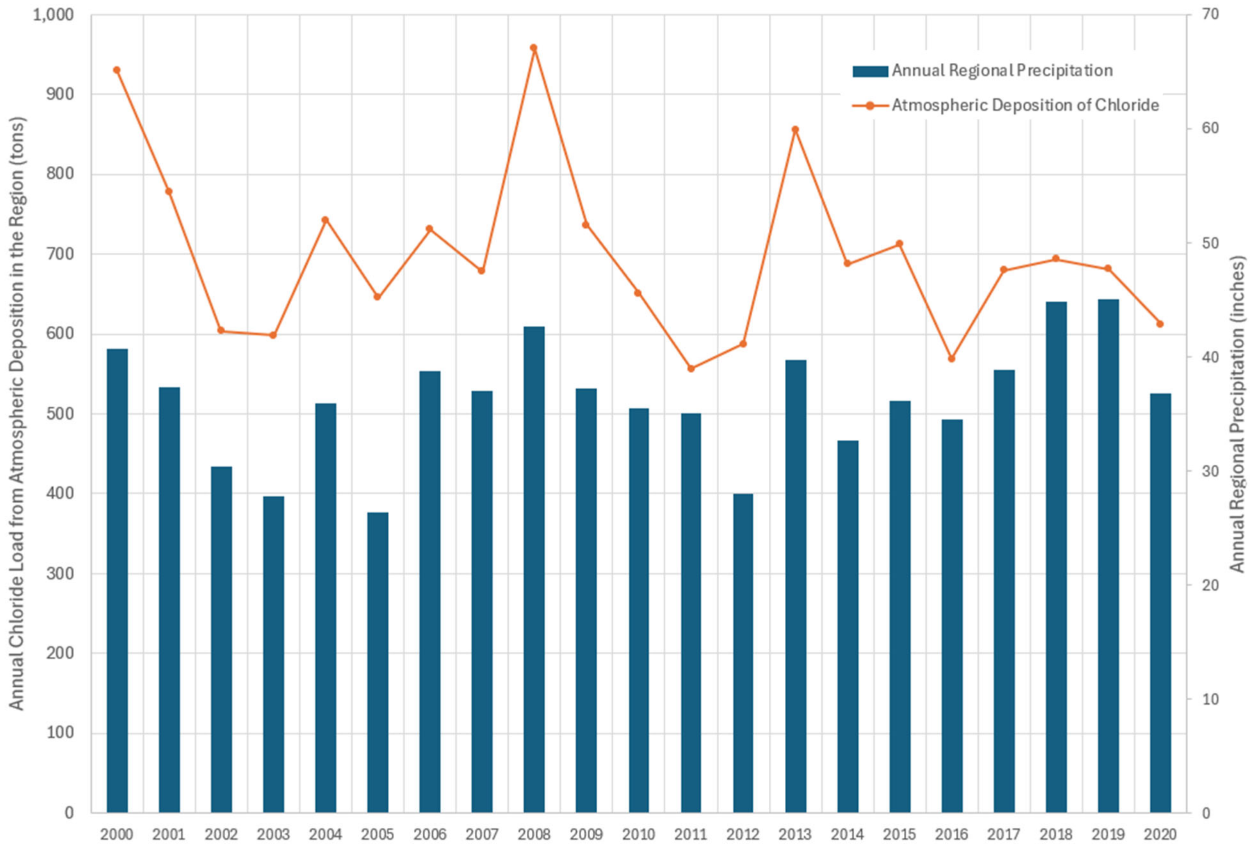
CHLORIDE CONDITIONS AND TRENDS IN SOUTHEASTERN WISCONSIN

Chapter 2

STUDY AREA BACKGROUND

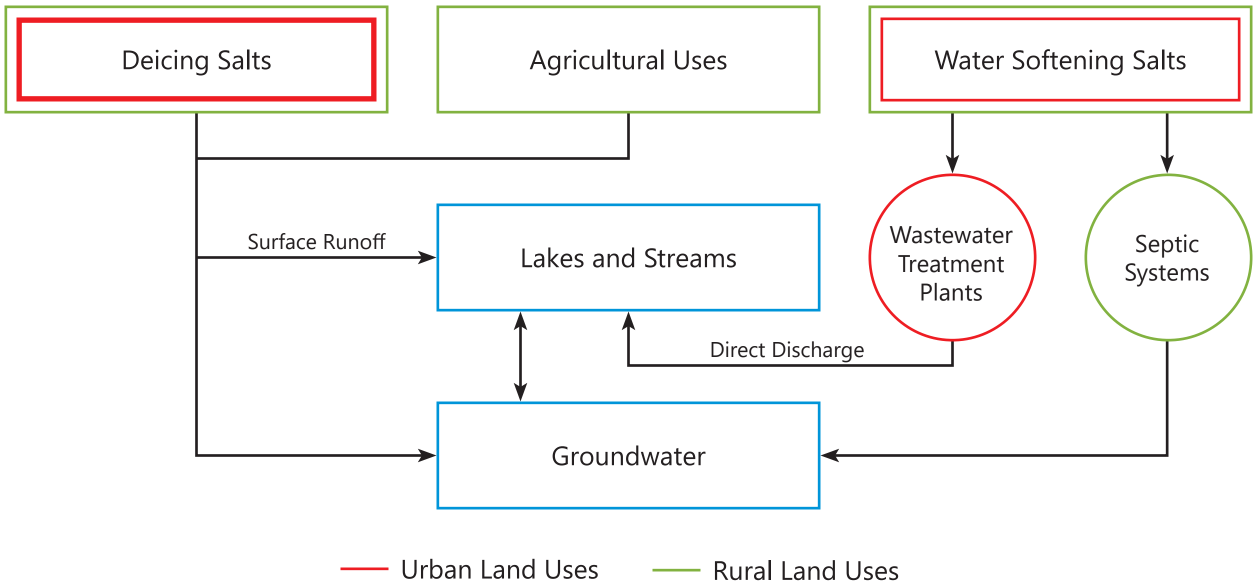
FIGURES

Figure 2.AtmosphericDeposition
Regional Annual Chloride Load from Atmospheric Deposition Compared to Annual Precipitation



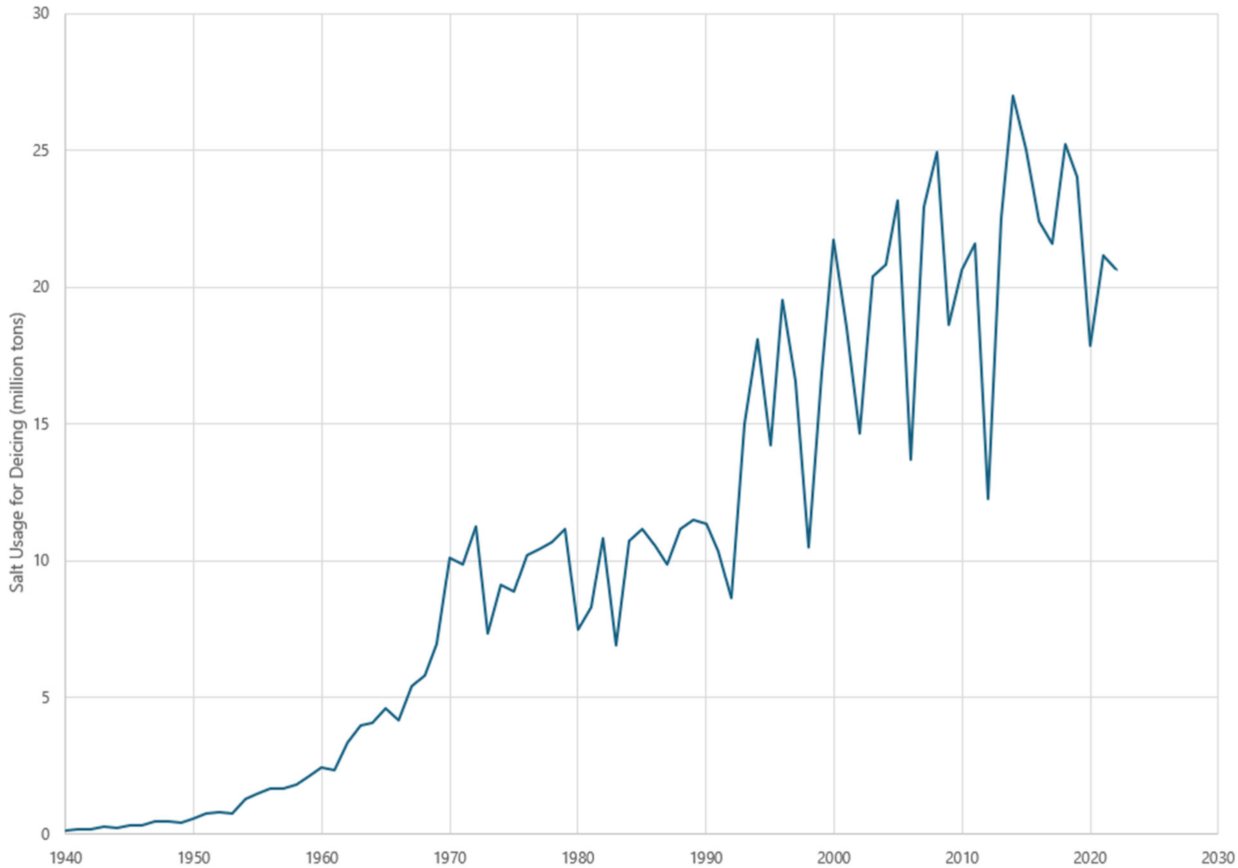
Source: National Atmospheric Deposition Program and NOAA National Centers for Environmental Information

Figure 2.SourcesDiagram
Major Human-Derived Sources of Chloride



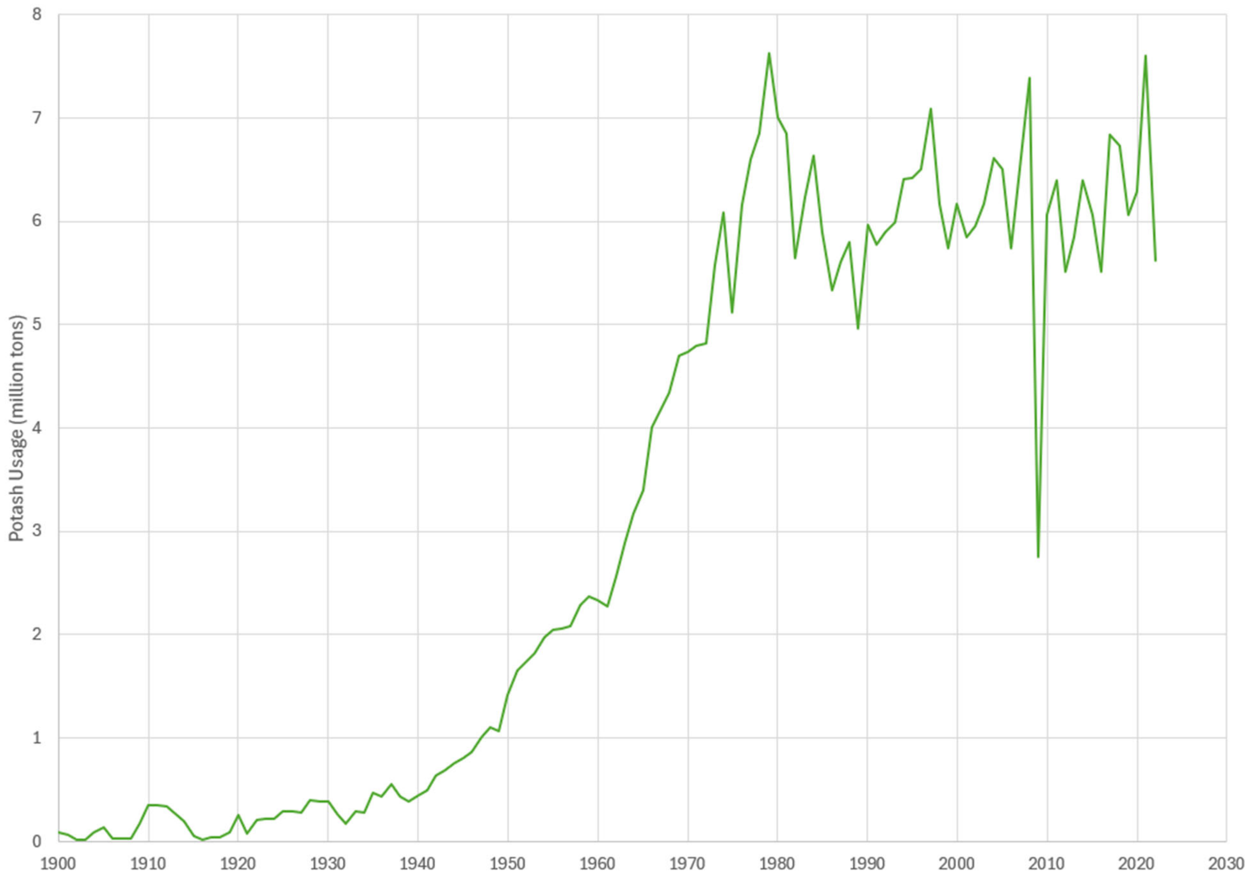
Source: Minnesota Pollution Control Agency and SEWRPC

Figure 2.HistoricalSaltUsage
Deicing Salt Usage in the United States: 1940 to 2022



Source: USGS, USBM, and SEWRPC

Figure 2.HistoricalPotash
Potash Usage in the United States: 1900 to 2022



Source: United States Geological Survey