Southeastern Wisconsin
Regional Planning Commission

Chloride Impact Study for the Southeastern Wisconsin Region

TAC Meeting
April 26, 2023

#267633

1

Speakers

2

- Laura Herrick, Chief Environmental Engineer
- Joe Boxhorn, Principal Planner
- Zijia Li, Engineer

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Agenda

- Review of Summary Notes from November 9, 2022, TAC meeting
- Review of preliminary draft chapters of SEWRPC Technical Report No. 62, Impacts of Chloride on the Natural and Built Environment
  - Draft Chapter 1, Introduction
  - Draft Chapter 2, Physical and Chemical Impacts of Chloride on the Natural Environment
  - Draft Chapter 4, Impacts of Chloride on Infrastructure and the Built Environment
- Next Steps

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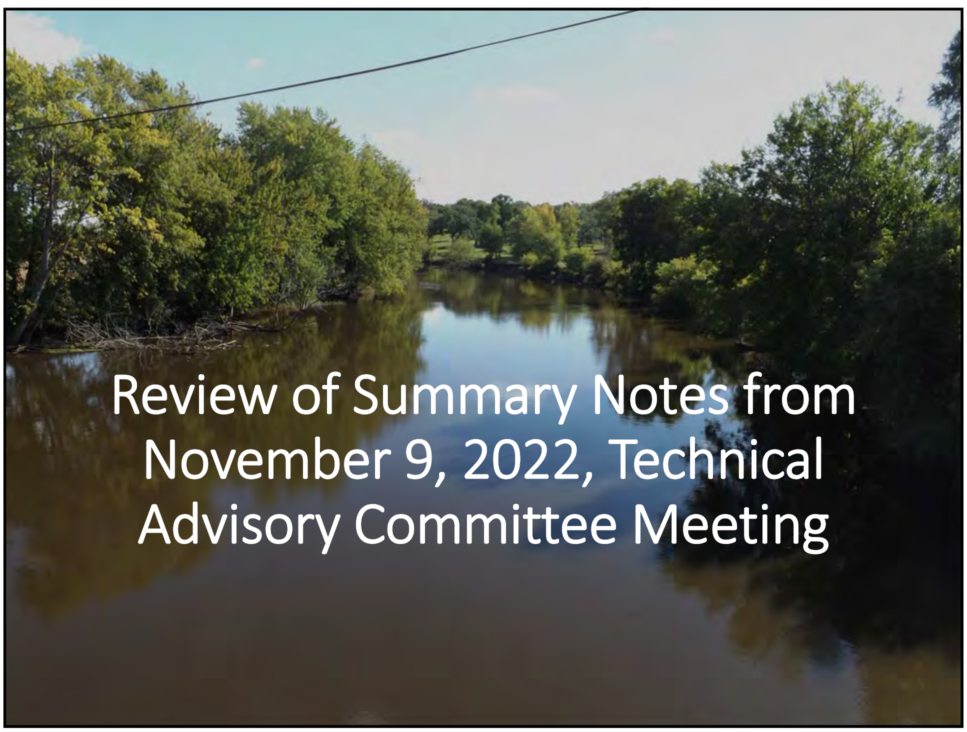

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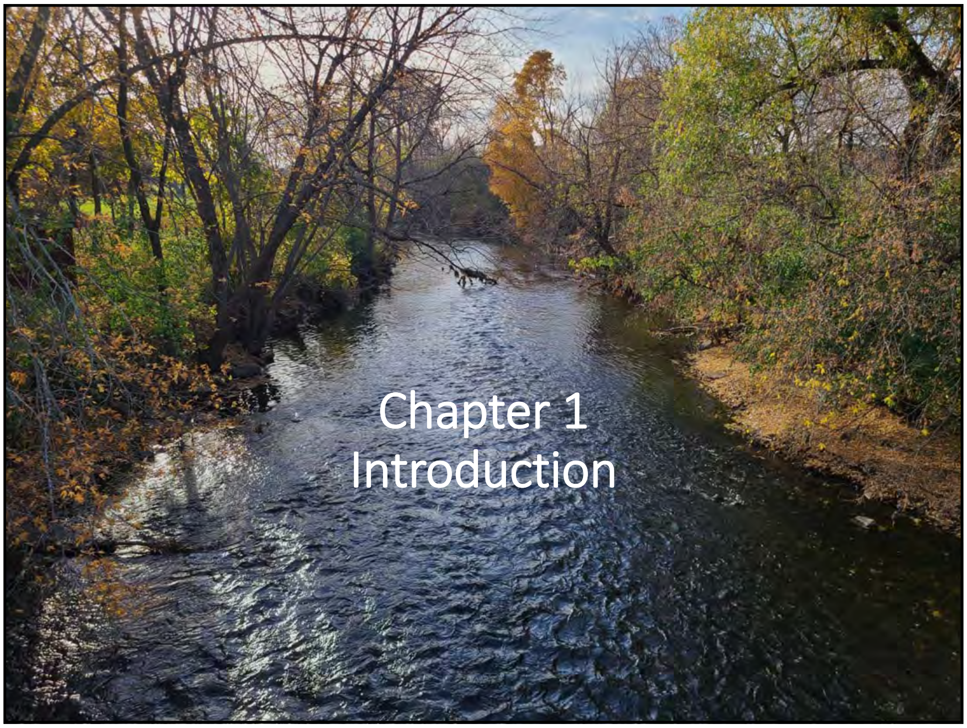

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Chapter 1

6

- Introductory chapter
- Places the report in the context of the objectives of the Chloride Study
- Presents the organization of the report

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Chloride Study Reports

- *PR-57-A Chloride Impact Study for Southeastern Wisconsin*
- *TR-61-Field Monitoring and Data Collection for the Chloride Impact Study*
- **TR-62-Impacts of Chloride on the Natural and Built Environment**
- *TR-63-Chloride Conditions and Trends in Southeastern Wisconsin*
- *TR-64-Regression Analysis of Specific Conductance and Chloride Concentrations*
- *TR-65-Mass Balance Analysis for Chloride in Southeastern Wisconsin*
- *TR-66-State of the Art for Chloride Management*
- *TR-67-Legal and Policy Considerations for the Management of Chloride*

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General Notes on this Report

- This report reviews the scientific and technical literature on impacts of chloride and chloride salts
- Impacts differ as to whether they are caused by chloride, the cation associated with chloride, or salinity in general
- Measurement of chloride differs among studies with chloride being expressed as concentration (or mass) of chloride or specific chloride salts, salinity, or specific conductance
- The current state of knowledge on the relationship of chloride to impacts varies. We have a fair understanding of some and a much poorer understanding of others

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TR-62 Chapters

- **Chapter 1 – Introduction**
- **Chapter 2 – Physical and Chemical Impacts of Chloride on the Natural Environment**
- *Chapter 3 – Impacts of Chloride on Biological Systems*
- **Chapter 4 – Impacts of Chloride on Infrastructure and the Built Environment**
- *Chapter 5 – Impacts of Chlorides on Humans and Human Activities*

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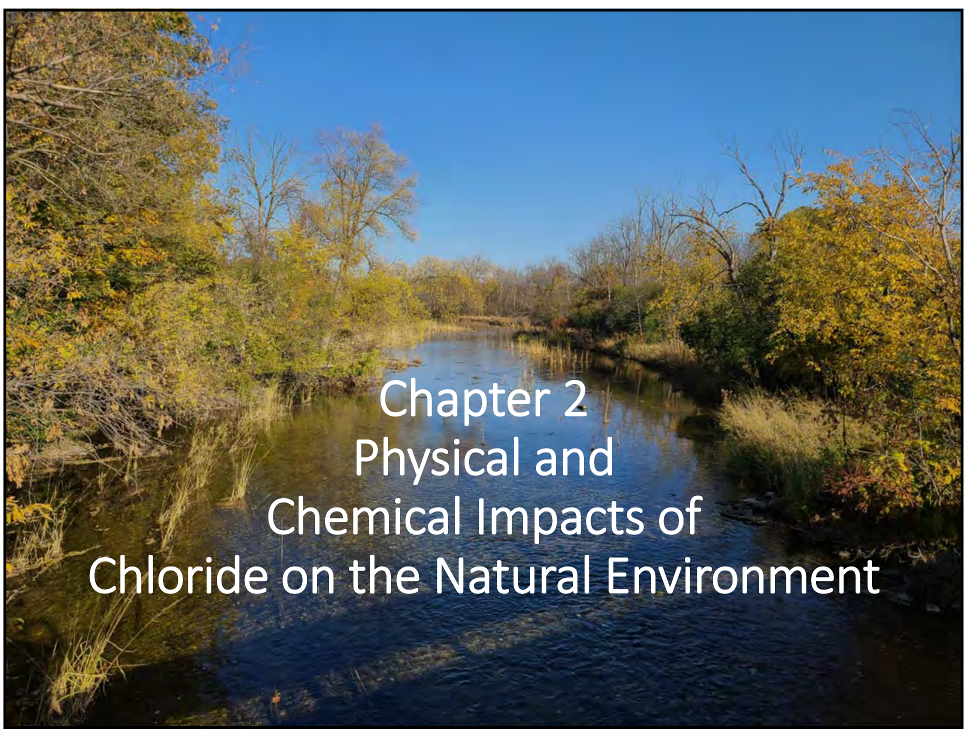

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Hydrologic Cycle

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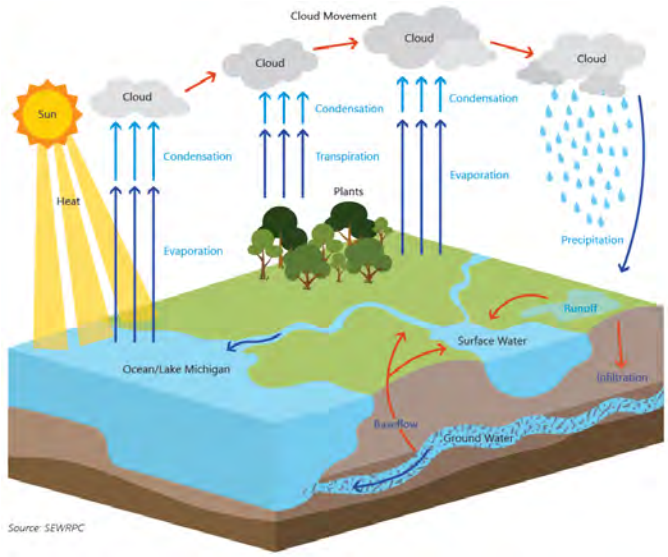

Source: SEWRPC

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Chloride Pathways

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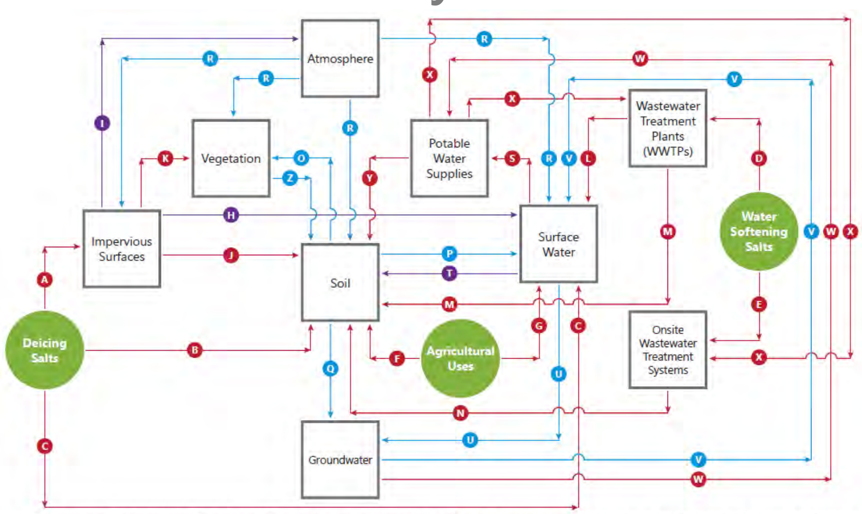

Note: Blue arrows indicate natural processes. Red arrows indicate human activities. Purple arrows indicate paths that are a combination of natural processes and human activities. The paths are described in Table 2.Pathways.

Source: SEWRPC

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Chloride Transport

13

- Factors influencing how chloride percolates through soil into groundwater
  - Types of soil, sediment, and rock present
  - Texture and drainage characteristics of soil
  - Level of soil saturation
  - Ion exchange capacity of soil
  - Permeability of aquifer material
  - Direction and velocity of groundwater flow
  - Evaporative conditions in soil pores
  - Amount of rainfall

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Chloride Pathways

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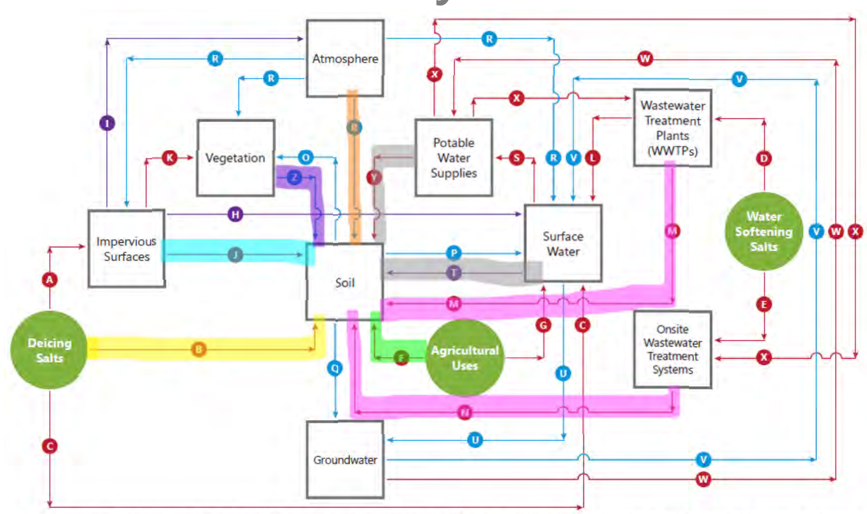

Note: Blue arrows indicate natural processes. Red arrows indicate human activities. Purple arrows indicate paths that are a combination of natural processes and human activities. The paths are described in Table 2.Pathways.

Source: SEWRPC

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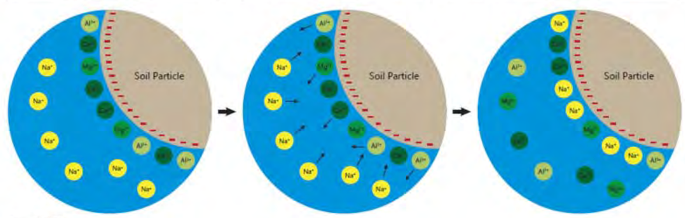
Cation Interactions

15

Figure 2.Cation Displacement
Displacement of Cations by Sodium in Soil and Sediment

When sodium ions (Na^{+}) are common in soil water, they can displace other cations such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and aluminum (Al^{3+}) that are bound to clay and humus particles.



Source: SEWRPC

- Clay and humus particles in soil are negatively charged
- Positively-charged cations are electrically bound to these
- Sodium in soil from salt can displace these cations

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Soil Structure Breakdown

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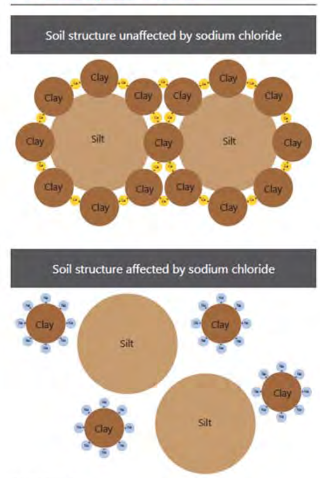
- Divalent and multivalent cations such as calcium or magnesium form bridges between clay particles
- This holds them together, forming soil aggregates
- Replacement of these cations by sodium breaks these bridges
- Clay and silt particles are released clogging soil pores
- Soil aggregates get smaller, leading to soil compaction

Figure 2.Soil Structure
Basic Units of Soil Structure Unaffected and Affected by Sodium Chloride



Source: SEWRPC

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Breakdown Impacts

17

- Impacts include
  - Reduced infiltration
  - Reduced water retention
  - Reduced water and nutrient availability
  - Reduced root penetration
  - Reduced seedling emergence
  - Formation of crusts on soil

Figure 2.Soil Comparison
A Comparison of Good and Poor Soil Structure

Source: Wikimedia Commons

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Heavy Metal Release

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- Chloride salts in the environment can promote the release of heavy metals and metalloids from soils and sediment
  - A few are essential nutrients to some organisms in small amounts
    - For example, iron, cobalt, zinc
  - Others have no biological function
    - For example, arsenic, cadmium, lead, mercury
  - At high enough concentrations, all are toxic to organisms
- Heavy metals and metalloids will accumulate in soils and sediment, especially those with high organic content

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Sources of Heavy Metals

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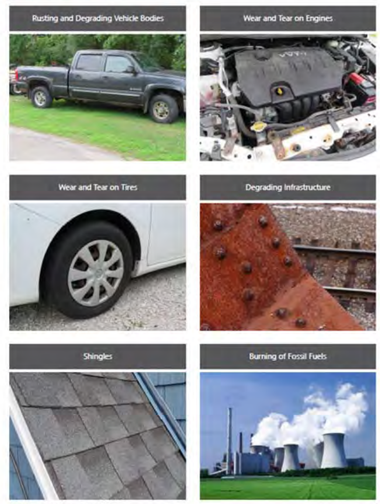
- Heavy metals are commonly found in roadside soils
- Automobile traffic is a major source
  - Corrosion
  - Wear and tear of parts
- Burning of fossil fuels
- Siding and shingles
- Industrial activities
- Infrastructure corrosion

Figure 2.Metal Sources
Examples of Sources of Heavy Metals to the Environment



Source: Wikimedia Commons and SEWRPC

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Release Mechanisms and Impacts

20

- Release mechanisms related to chloride salts include
  - Breakdown of soil structure
  - Cation displacement/ion exchange
  - Acidification of soil and sediment
- Impacts of metal mobilization
  - Release makes them more bioavailable
  - Toxicity to organisms
  - Inhibition of some microbial activity (e.g., litter breakdown)
  - Release of nickel can promote wetland methane generation

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Groundwater Flow Systems

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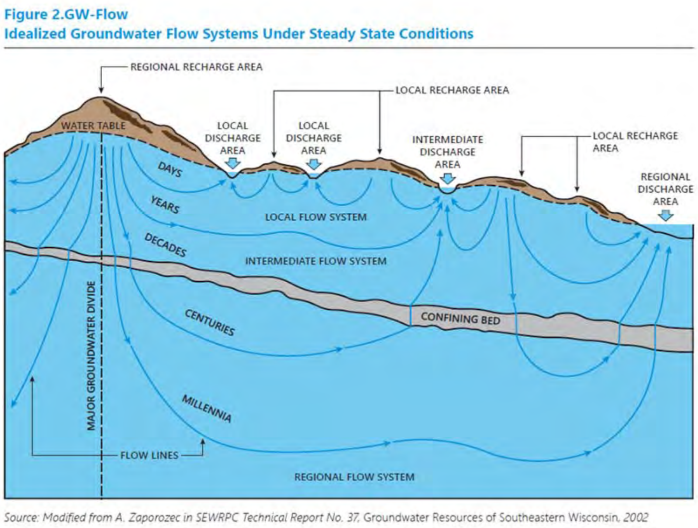

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Chloride Pathways

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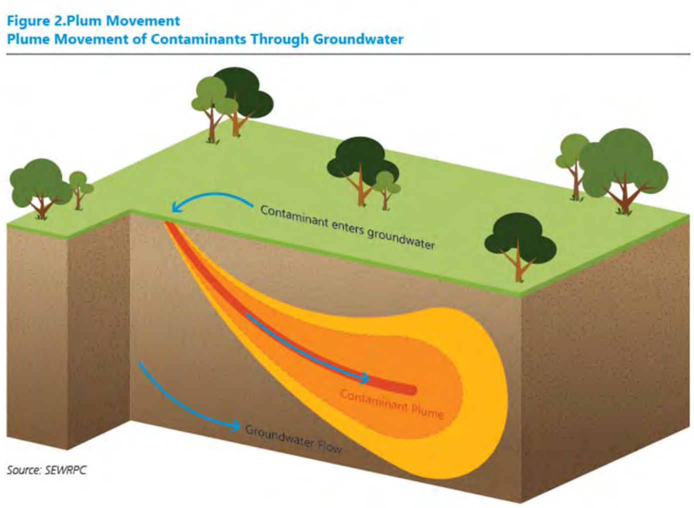

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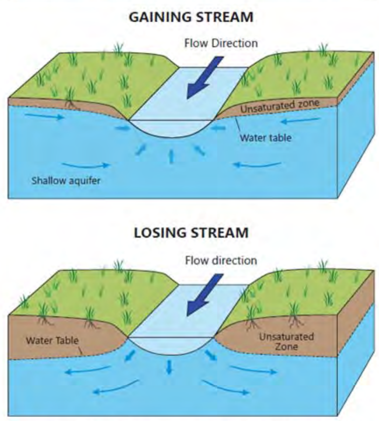
Interactions with Surface Water

23

- Chloride salts can persist in groundwater for a long time
- Shallow groundwater and surface waterbodies are often hydrologically connected
- Water flowing from groundwater to surface water can carry chloride into surface water
- Water flowing from surface water to groundwater can carry chloride into groundwater

Figure 2.SW/GW Interaction
Interactions of Surface Water and Groundwater



Source: Modified from T.C. Winter, J.W. Harvey, O.L. Franke, and W.M. Alley, Ground Water and Surface Water: A Single Resource, U.S. Geological Survey Circular 1139, p. 9, 1998, and SEWRPC

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Chemical Effects on Groundwater

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- Increases oxidation-reduction potential
  - Influences chemical reactions
  - Alters solubility of some substances (e.g., metals)
- Acidifies groundwater
- Promotes release of heavy metals
  - Similar mechanisms as previously discussed
  - Can lead to release of radium
    - Greater release related to groundwater salinity
  - Can lead to release of radon

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Impacts on Streams and Rivers

25

- Historical concentrations of chloride in streams were on the order of 8-20 mg/l
- Recent planning efforts show much higher mean concentrations
  - Root River (2005-2012) 202 mg/l
  - Oak Creek (2007-2016) 293 mg/l
- Expect delays in responses of stream concentrations to reduced chloride loadings
  - Storage in groundwater, soils
- Storage can also keep levels elevated during summer months

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Effects in Streams and Rivers

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- Dissolved salts increase water density
  - Salt-laden water may sink to the bottom of a stream leading to a dense saline layer just above the bed
  - Stratification of deeper impoundments with longer residence times
- Acidify water
- Promote release of cations, heavy metals
- Promote release of some nutrients and dissolved organic carbon
- Reduce rates of denitrification (conversion of nitrate to nitrogen gas)

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Impacts on Lakes

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- Residence time of water in a lake is an important factor influencing chloride concentration
  - Longer residence time means concentrations will change more slowly, but chloride will build up
  - Shorter residence time means greater sensitivity to sudden fluctuations
- Lakes can also show seasonal changes in chloride concentration and salinity due to exclusion of ions from ice as water freezes
  - Shallow lakes and wetlands are most sensitive to this
- Density effects from chloride salt inputs can alter patterns of lake mixing and stratification

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Lake Mixing Patterns

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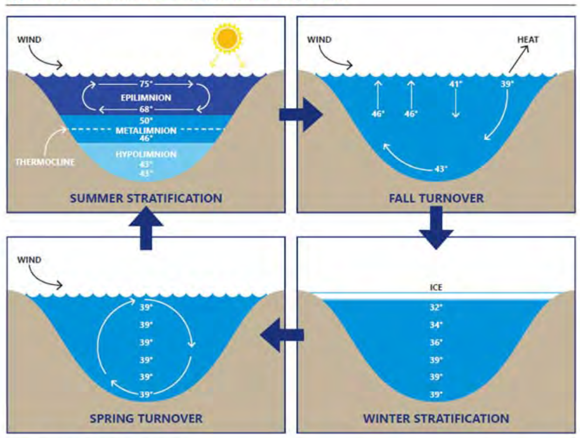
Figure 2.Stratification
Typical Seasonal Thermal Stratification Within Deeper Lakes



Note: Temperatures are in degrees Fahrenheit.

Source: Modified from B. Shaw, C. Mechenich, and L. Klessig, Understanding Lake Data, *University of Wisconsin-Extension, p. 3, 2004 and SEWRPC*

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Inhibition of Mixing by Chloride

29

- Chemical conditions in a lake can alter its density structure and affect mixing and stratification
- Salt-laden water will sink to the bottom of the lake increasing the density difference between upper and lower waters. This can affect mixing in various ways
    - It can delay mixing
    - It can reduce mixing depth
    - It can prevent mixing from occurring during spring or fall of some years
    - It can permanently prevent mixing from occurring

29

Effects of Prolonged Stratification

30

- Deeper waters are cut off from the atmosphere
    - Oxygen is only restored during turnover
    - If oxygen demands are high enough, oxygen will be exhausted in deeper water
- Anoxia causes a major change in the chemistry and biology of deep waters
    - Bacteria will shift to anaerobic respiration using other materials as a substitute for oxygen, leading to release of metals, sulfide, and methane
    - Oxidation-reduction conditions change, making some substances more soluble and leading to release of metals and nutrients from sediment

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Example of Anoxia Effects

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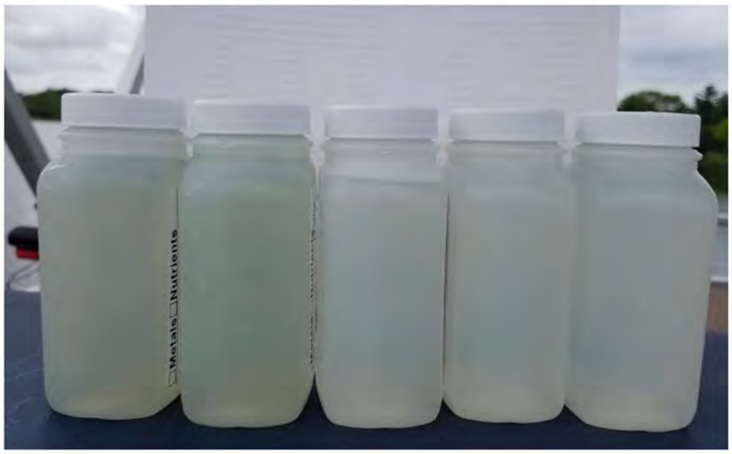
Figure 2.Lake Sample
Water Samples from Different Depths in Voltz Lake, Kenosha County, Wisconsin – August 14, 2019



Source: SEWRPC

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Background on Wetlands

32

- Natural concentrations of chloride in inland, freshwater wetlands are on the order of 0-12mg/l
- A recent review cited reports of chloride-contaminated wetlands having concentrations as high as 13,500 mg/l
- Many biogeochemical transformations of elements occur in wetlands
  - These are important in nutrient cycling and carbon cycling
  - They occur through a combination of chemical reactions and biological activity
  - Contamination of wetlands by chloride salts can affect both the chemistry and biology involved in these transformations

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Impacts on Wetlands

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- Release of heavy metals
  - Wetland soils and sediment may accumulate large amounts of metals due to their high organic content and the tendency of metals to bind to organic matter
- Reduced solubility of gases in water
  - Reduces the depth of oxygen penetration in wetland soils
  - Increased release of nitrous oxide and methane
- Impacts on nutrient cycling
  - Increased anoxia may lead to release of hydrogen sulfide and phosphorus and increased iron sulfide minerals in soils through altering iron and sulfur cycling

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Nitrogen Cycle

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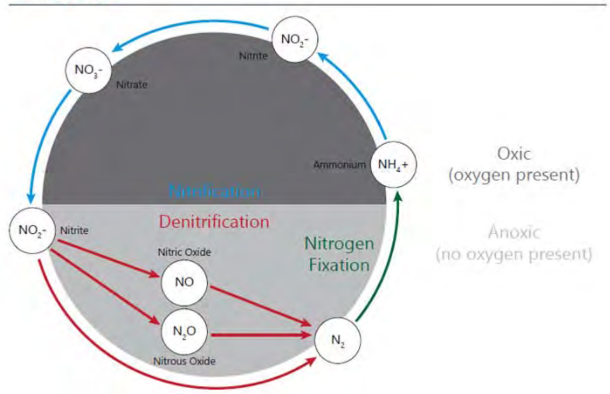
Figure 2.N-cycle
The Nitrogen Cycle



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Impacts on Carbon Cycling

35

- Wetland are major sinks for carbon
  - 45-75 percent of terrestrial carbon is in wetland soils
- Impacts of chloride salts on carbon cycling in wetlands are not well understood
- By making metals more available, salinization may increase anaerobic breakdown of organic matter leading to increased carbon dioxide release
- Evidence is equivocal on impacts on methane production
  - May spur increased release due to increased nickel availability and growth of microbial mats on sediment surface
  - May decrease release through decrease in soil microbes

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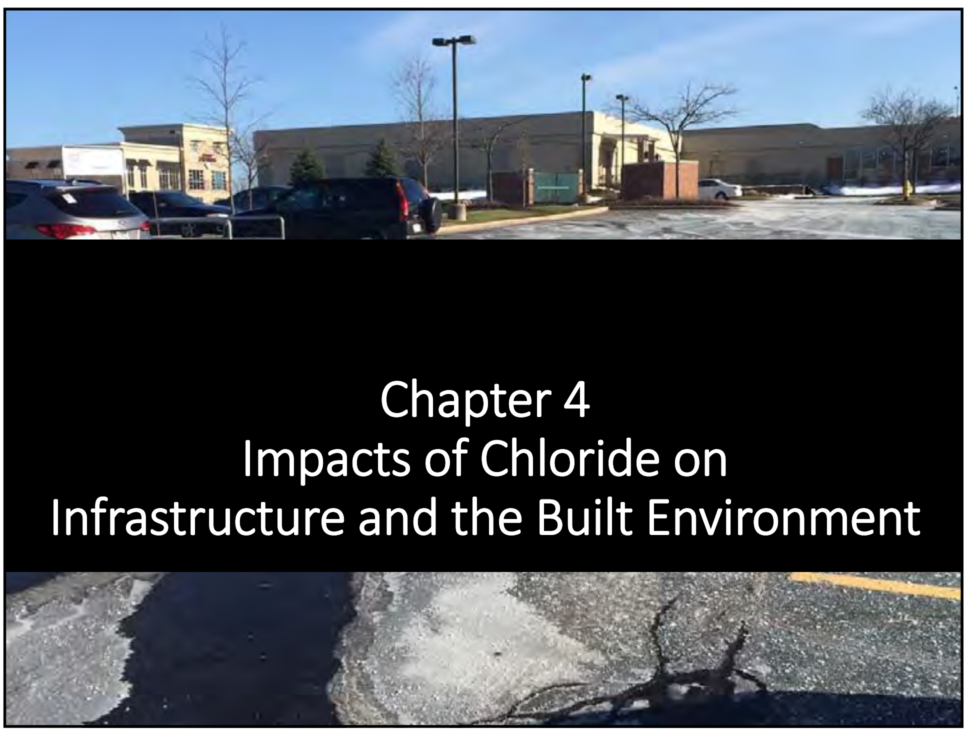

Chapter 4
Impacts of Chloride on Infrastructure and the Built Environment

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Major Sections

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- Chloride-Induced Metal Corrosion Mechanisms
- Deicer-Induced Concrete Deterioration Mechanisms
- Chloride Impacts to Motor Vehicles and Infrastructure

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Metal Corrosion Mechanisms

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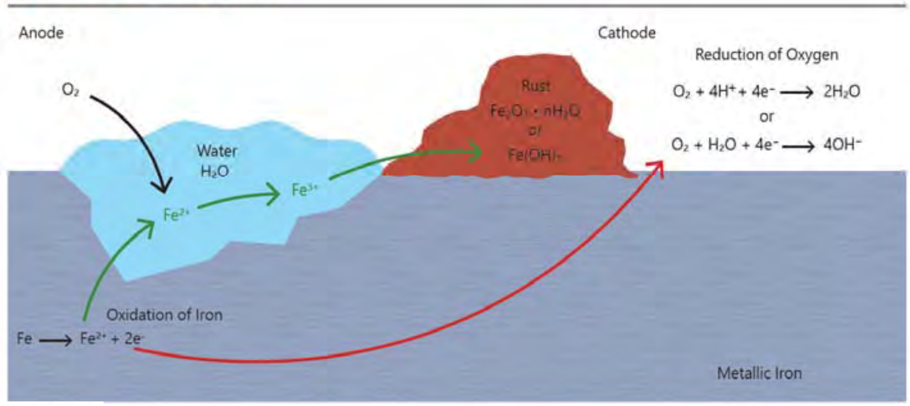
Figure 4.2
Typical Iron Corrosion Process



Source: SEWRPC

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Chloride Increases Corrosion Rate

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- Strong electrolyte
  - Increases speed of electron transfer
- Decreases freezing point
  - Increases contact time between liquid water and metal

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Corrosion Susceptibility

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- Iron, steel, and magnesium alloys are most susceptible
  - $CaCl_2$ is more corrosive to steel compared to NaCl and $MgCl_2$
- Aluminum and copper alloys are less susceptible

40

Corrosion Inhibitors

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- WisDOT uses corrosion inhibitors in 10-50% of road salt applications
- Anodic Inhibitors – Phosphates, carbonates, silicates
  - Very effective but may increase corrosion in very low concentrations
- Cathodic Inhibitors – $CaCO_3$, Zinc, polyphosphates
  - Less effective but safer
- Agricultural Biproducts – generally physical protection
  - Other environmental impacts

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Concrete Deterioration Mechanisms

42

- Salt Scaling
  - Multiple mechanism
- Cement Paste Reactions
  - $MgCl_2$ most damaging
  - NaCl least damaging
- Alkali-Aggregate Reactions
  - NaCl increases pH, promotes Alkali-Silica Reactions
  - $CaCl_2$ and $MgCl_2$ promotes Alkali-Carbonate Reactions

Figure 4.3
Concrete Scaling Damage

Source: SEWRPC

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Improving Concrete Durability

43

- Reduce permeability: fly ash and silica fume additives
- Increase strength: reduce water-to-cement ratio to below 0.4
- Increase resistance to frost damage: increase air entrainment to >3%
- Washing programs

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Effects on Steel Reinforcement

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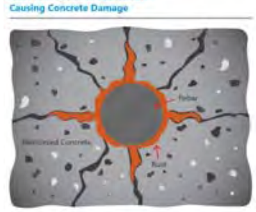
- Normally protected by concrete cover and high pH
- Compromised by concrete deterioration, rebar corrosion can commence
- Expansive rust cracks concrete
- Most report $MgCl_2$ being most damaging, but inconclusive

Figure 4.5
Reinforced Concrete BeamDamaged by Rebar Corrosion

Source: WisDOT

Figure 4.6
Steel Reinforcement Corrosion Causing Concrete Damage



Source: SEWRPC

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Chloride Impacts

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- Present damage estimates from literature
- Analyze for comparison of costs
- Apply cost estimates to our region
- Use cost estimates with care
  - Difficult to estimate damages
  - Most studies are between 20 to 50 years old

Figure 4.1
Metallic Corrosion on a Bridge, Culvert, and Motor Vehicle

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Impacts to Motor Vehicles

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Table 4.2
Annual Cost Estimates of Vehicle Corrosion from All Sources

	Annual Cost Per Vehicle (dollars)					
	1978 BCL Study		1991 TRB Study		2002 FHWA Study	
	1975 dollars	2021 dollars[a]	1989 dollars	2021 dollars[a]	1999 dollars	2021 dollars[a]
New Vehicle Corrosion Protection	140 to 210	710 to 1,064	250 to 800	547 to 1,751	150	245
Used Vehicle Corrosion Repairs and Maintenance	46	236	--	--	32	53

[a] *Adjusted for inflation using the U.S. Bureau of Labor Statistics Consumer Price Index for June of each year*

Source: Battelle Columbus Laboratories, Economic Effects of Metallic Corrosion in the United States, 1978; Transportation Research Board, Comparing Salt and Calcium Magnesium Acetate, 1991; Federal Highway Administration, Corrosion Cost and Preventative Strategies in the United States, 2002

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Impacts to Motor Vehicles

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- Total Annual Corrosion Cost from Road Salt
  - Based on 2002 FHWA study and 1992 Jones and Jeffery estimate
    - $120 per vehicle (2021 dollars)
    - $180M in SE WI Region (2021 dollars)

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Impacts to Motor Vehicles

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Table 4.3
Annual Cost Estimates of Vehicle Deprecation Due to Corrosion by Road Salt

	Annual Cost Per Vehicle (dollars)					
	1976 EPA Study		1991 Menzies Study		2002 FHWA Study	
	1973 dollars	2021 dollars[a]	1991 dollars	2021 dollars[a]	1999 dollars	2021 dollars[a]
Depreciation Due to Corrosion by Road Salt	14	86	17	34	32	52

[a] *Adjusted for inflation using the U.S. Bureau of Labor Statistics Consumer Price Index for June of each year*

Source: *Environmental Protection Agency, An Economic Analysis of the Environmental Impact of Highway Deicing, 1976; Menzies T.R., National Cost of Motor Vehicle Corrosion from Deicing Salts, 1991; Federal Highway Administration, Corrosion Cost and Preventative Strategies in the United States, 2002*

- Cost of new vehicle corrosion protection as response to road salt: $274 to $547 per new vehicle (2021 dollars) based on 1991 TRB study

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Impacts to Motor Vehicles

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- Conclusion
  - Costs noticeably decreased in the automotive industry due to anticorrosion technology and management
  - Corrosion due to road salt still carries appreciable cost
  - Latest study from 20 years ago. Need new studies.

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Impacts to Bridges

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- 2022 National Bridge Inventory (NBI)
  - Primary bridge damage are due to metal and metal reinforcement corrosion
  - Nationally
    - 620,000 highway bridges
    - 69% concrete, 28% metal
    - 11% rated poor (18% in 2000)
    - Median age: 44 years (35 years in 2000)
  - Regionally
    - 2000 highway bridges
    - 6% rated poor
    - Median age: 40 years

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Impacts to Bridges

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- 2002 FHWA Study
  - Total nationwide annual direct cost of corrosion to highway bridges **from all sources**: $6.4B to $10.2B (1999 dollars)
- 1991 TRB Study
  - Total nationwide annual direct costs of corrosion to highway bridges **from road salt**: $250M to $650M (1991 dollars)
  - Applied to SE WI Region: $2.4M to $6.3M (2021 dollars)

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Impacts to Bridges

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- Conclusion
  - No cost trends can be determined from previous studies
  - 2 Competing Factors
    - Better concrete construction, anticorrosion technologies, and washing programs are reducing road salt impact to bridges
    - Increasing age of bridges adds risk of increasing damage from road salt
  - Latest study from 20 years ago. Need new studies.

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Impacts to Other Highway Components

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- Roadway Pavement
  - Improved concrete construction and practices have produced more durable pavement
  - No longer a serious concern for road salt damage
- Highway Drainage Systems, Fixtures, Accessories, and Sidewalks and Driveways
  - Road salt is not significant factor affecting durability

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Impacts to Buildings

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- Base of buildings along roads
  - Deicing vehicles splash water and salt onto building walls
  - Affecting only some densely developed city centers
  - Costs unknown but likely small
- Parking Structures
  - Annual nationwide repair cost (1991 TRB Study): $50M to $150M (1991 dollars)
    - Cost may be lower today due to corrosion protection

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Impacts to Water Supply Systems

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- Corrode Drinking Water Distribution Systems
  - 2014 Flint water crisis linked high lead levels with elevated chloride concentrations in finished water
  - 2018 study identified correlation between chloride concentrations and lead ALEs
  - Another 2018 study linked high chloride concentrations with well and home plumbing corrosion
- Not to be confused with chlorine used in drinking water treatment

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Anecdotal Impacts

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- Power Distribution Systems
  - Salt degrade insulators to electrical equipment
  - Electric pole fires
  - Power outages
- Railway Traffic Control Signaling
  - Ionic salt solutions on railroad tracks affect train detection
  - Train crashes

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Cost-Benefit of Road Salting

57

- Benefit
  - 1992 Marquette Study
  - Cost of accident reduced by 10% to 30% after road salt was applied
  - Every $1 spent on direct winter maintenance operation provides $7 in direct economic benefits for 2-lane highways, and $4 for freeway
- Cost
  - 1976 USEPA study and 1992 Vitaliano Study
  - Every $1 spent on direct winter maintenance operation can cause between $7 and $15 of damages
- Does not factor in commerce, human life, and transportation safety. Benefits of road salting likely outweigh costs

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Next Steps

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- Continue research and report writing
- Continue regression analysis
- Continue loading analysis
- Continue state-of-the-art information gathering

Comments on TR 62 Chapters 1, 2, 4 are due by May 19, 2023

Anticipate the next TAC meeting to be summer 2023 and include review of the entire draft TR 61 (field monitoring)

Meeting agendas, presentations, and minutes along with draft text will all be posted on the project website

www.sewrpc.org/chloridestudy

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Project Funding Provided By

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U.S. Department of Transportation
Federal Highway Administration

MMSD
PARTNERS FOR A CLEANER ENVIRONMENT

SEWRPC
Serving the counties of Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha

Fund for Lake Michigan

WISCONSIN
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Thank You

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