Southeastern Wisconsin

Regional Planning Commission

Chloride Impact Study for the Southeastern Wisconsin Region

TAC Meeting

January 31, 2024

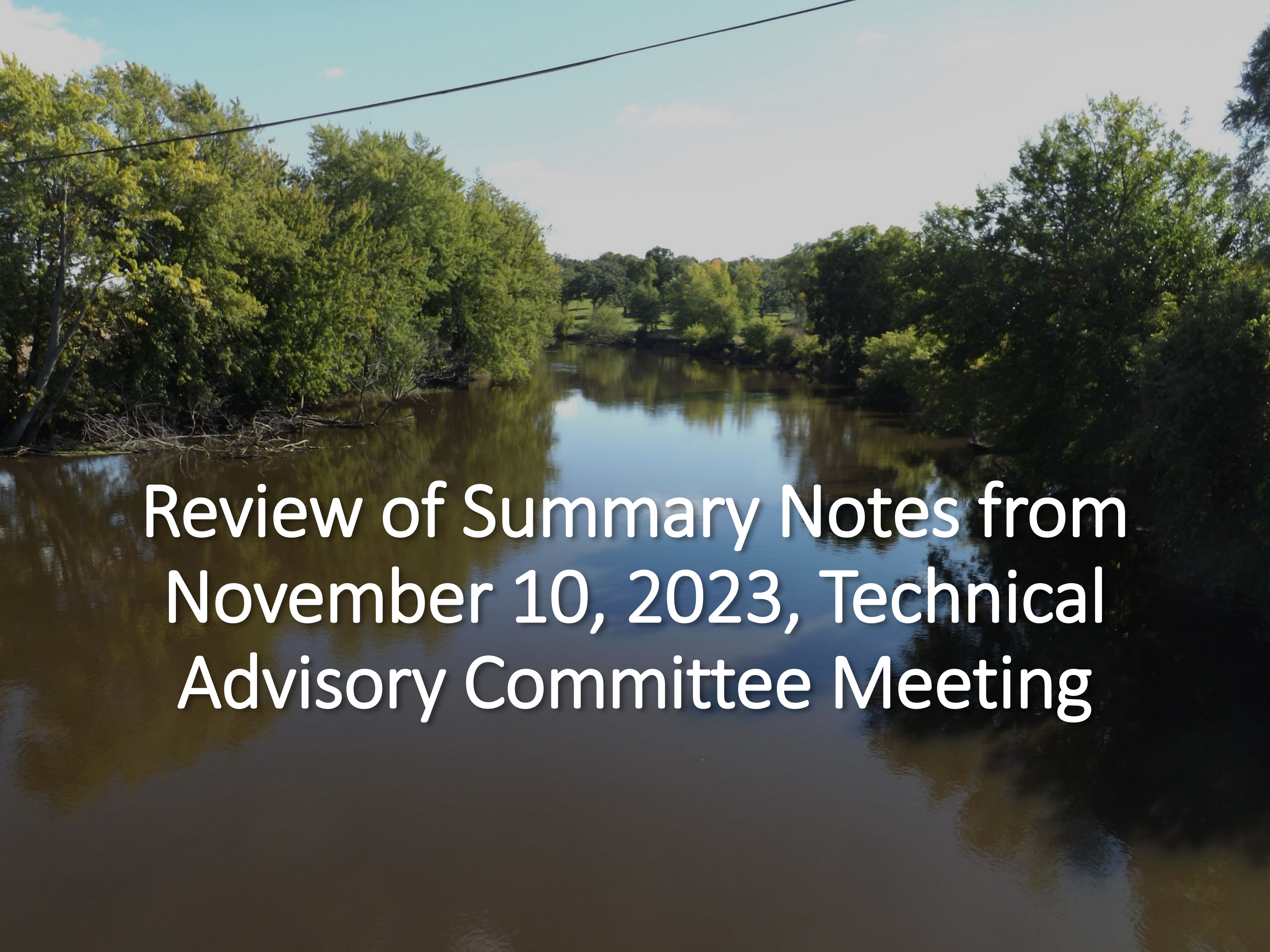
#270056

Speakers

- Laura Herrick, Chief Environmental Engineer
- Joseph Boxhorn, Principal Planner

Agenda

- Review of Summary Notes from November 10, 2023, TAC meeting
- Review of preliminary draft chapters of SEWRPC Technical Report No. 62, Impacts of Chloride on the Natural and Built Environment
  - Draft Chapter 3, Impacts of Chloride on Biological Systems
  - Draft Chapter 5, Impacts of Chlorides on Human Health and Human Activities
- Next Steps



Review of Summary Notes from November 10, 2023, Technical Advisory Committee Meeting

Technical Report No. 62
Impacts of Chloride on the Natural and Built Environment

Chloride Study Reports

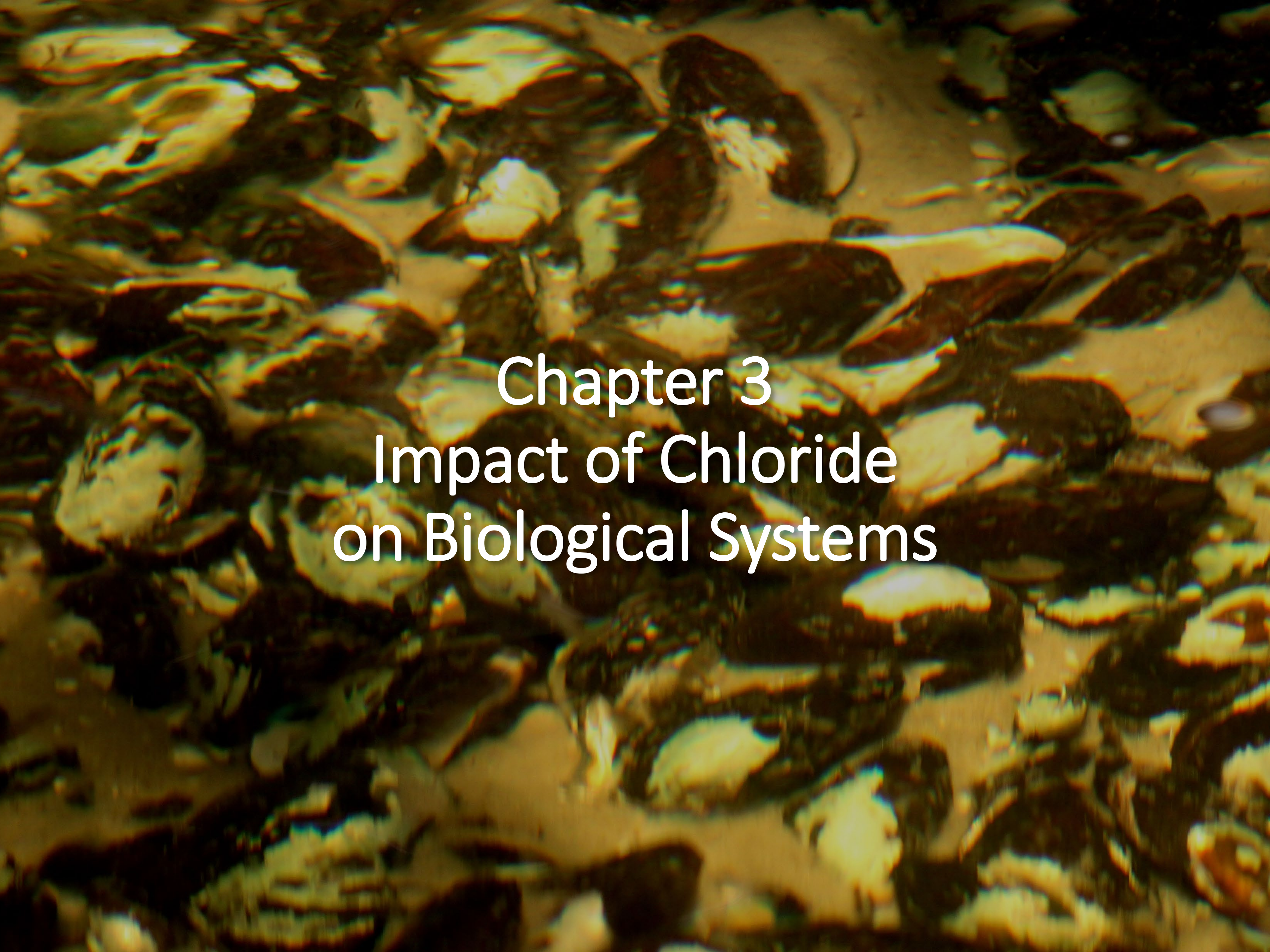
- *PR-57-A Chloride Impact Study for Southeastern Wisconsin*
- *TR-61-Field Monitoring and Data Collection for the Chloride Impact Study*
- **TR-62-Impacts of Chloride on the Natural and Built Environment**
- *TR-63-Chloride Conditions and Trends in Southeastern Wisconsin*
- *TR-64-Regression Analysis 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*

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**

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
- Appendix A presents definitions of acronyms and abbreviations used in this report



Chapter 3
Impact of Chloride on Biological Systems

Effects on Organisms

- Chapter reports results on about 200 species and other taxa
  - 57 percent found in Wisconsin
  - Another 27 percent belong to genera found in Wisconsin
  - This is a small sample of all species
    - 1.5 – 2.2 million named species
    - 3.0 – 11.0 million estimated species
    - Wisconsin has over 80,000 species

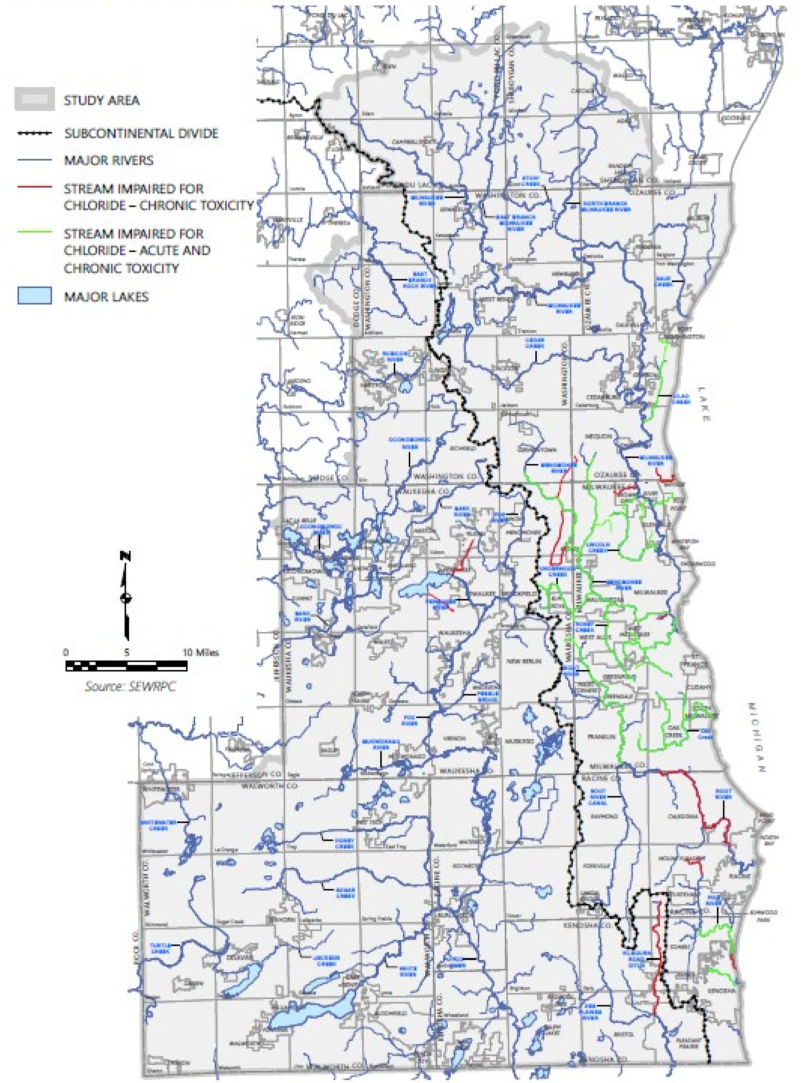
Toxicity – General Issues

- Toxicity is the ability of a substance to cause adverse effects
  - Effects can differ depending on the substance, organism exposed, level and manner of exposure
    - In aquatic systems level of exposure is often expressed as the concentration of the toxin
- Acute toxicity – Impacts from a single or small number of exposures over a short time period
- Chronic toxicity – Impacts from constant or repeated exposure over a longer time period
- Both can have lethal and sublethal effects

Toxicity Standards

- Wisconsin criteria for chloride toxicity for fish and aquatic life
  - Acute – 757 mg/l
  - Chronic – 395 mg/l
- As of 2022, 35 waterbodies in southeastern Wisconsin were listed as being impaired due to exceeding one or both of these standards
- USEPA recommended criteria
  - Acute – 860 mg/l
  - Chronic – 230 mg/l

Map 3.1
Waterbodies Impaired for Chloride: 2022



Acute Toxicity

- Often measured using death of test organisms
  - LC50 – the concentration of a toxin at which half the test organisms die over the test period
    - A lower LC50 indicates greater toxicity
    - This represents a substantial impact on a population
    - Appreciable impacts occur at concentrations below the LC50

Figure 3.1
Aquatic Organisms Used in Acute Toxicity Testing

Source: Wikimedia Commons

Acute Toxicity

- Tables 3.2 – 3.5 summarize chloride LC50s for four groups
- Appendix B lists LC50s for chloride salts from toxicity studies on aquatic organisms

Table B.1
Acute Toxicity of Chloride Compounds to Freshwater Aquatic Organisms

Species	Common Name	Cation[a]	Cation Concentration (mg/l)	Chloride Concentration (mg/l)	Exposure Time (hours)	Response[b]	Reference[c]
Salvelinus fontinalis	Brook trout	Na^+	19,670	**30,330**	0.25	LC50	Phillips, 1944
Daphnia magna	Water flea	K^+	721	**654**	2.00	LC50	Densmore *et al.*, 2018
Daphnia magna	Water flea	K^+	271	**246**	4.00	LC50	Densmore *et al.*, 2018
Lepomis macrochirus	Bluegill	Na^+	7,868	**12,132**	6.00	LC47	Waller, *et al.*, 1996
Oncorhynchus mykiss	Rainbow trout	Na^+	7,868	**12,132**	6.00	LC40	Waller, *et al.*, 1996
Labeo rohita	Rohu carp (fingerlings)	Ca^{2+}	4,425	**7,830**	6.00	LC50	Mallick, *et al.*, 2014
Chironomus attenuatus	Midge	Na^+	3,932	**6,063**	6.00	LC50	Thornton and Sauer, 1972
Labeo rohita	Rohu carp (spawn)	Ca^{2+}	2,613	**4,624**	6.00	LC50	Mallick, *et al.*, 2014
Labeo rohita	Rohu carp (eggs)	Ca^{2+}	1,349	**2,388**	6.00	LC50	Mallick, *et al.*, 2014
Labeo rohita	Rohu carp (fingerlings)	Ca^{2+}	4,112	**7,275**	12.00	LC50	Mallick, *et al.*, 2014
Labeo rohita	Rohu carp (fry)	Ca^{2+}	3,559	**6,296**	12.00	LC50	Mallick, *et al.*, 2014
Labeo rohita	Rohu carp (spawn)	Ca^{2+}	1,985	**3,513**	12.00	LC50	Mallick, *et al.*, 2014
Labeo rohita	Rohu carp (eggs)	Ca^{2+}	838	**1,484**	12.00	LC50	Mallick, *et al.*, 2014
Labeo rohita	Rohu carp (eggs)	Ca^{2+}	387	**686**	18.00	LC50	Mallick, *et al.*, 2014
Caenorhabditis elegans	Round worm	Ca_{2+}	16,033	**28,367**	24.00	LC50	Tartara *et al.*, 1997
Gambusia affins	Mosquito fish	Mg^{2+}	4,776	**13,932**	24.00	LC50	Wallen *et al.*, 1957
Gambusia affins	Mosquito fish	Na^+	7,105	**10,955**	24.00	LC50	Wallen *et al.*, 1957
Lepomis macrochirus	Bluegill	Na^+	5,557	**8,568**	24.00	LC50	Dowden and Bennett, 1965

Chronic Toxicity

- Can lead to death of organism
- Can also have sublethal effects on
    - Growth and development
    - Reproduction
    - Behavior
    - Physiology
- Many different effect end points are used to examine chronic toxicity

Factors That Affect Chloride Toxicity

- Exposure
  - Level of exposure/dose
  - Length of exposure
  - Manner of exposure
- Biological factors
  - Developmental/life history stage
    - Younger stages are often more sensitive to chloride toxicity
  - Genetic variation
    - Some strains of a species may be more sensitive than others

Factors That Affect Chloride Toxicity

- Environmental Factors
  - Temperature
    - Greater impacts at warmer temperatures
  - Water hardness
    - Greater impacts in softer water
  - Other chemicals
    - Sulfate can make chloride more toxic
  - Food availability
    - Greater impacts when food is less available

Factors That Affect Chloride Toxicity

- Other salt ingredients
  - Cation associated with chloride
    - For some effects it may be the cation that causes the toxicity
    - $KCl > MgCl_2 > CaCl_2 > NaCl$
    - Cations may interact in complex ways
  - Anticaking additives
    - Ferrocyanides can release cyanide
  - Anticorrosion additives
    - Can add biochemical oxygen demand and ammonia to water
  - Impurities
    - Toxic/heavy metals

How Organisms are Exposed to Chloride

- Dwelling in water
  - How much of life is spent in water
    - Whole life (fish, aquatic plants, plankton)
    - Part of life (amphibians, aquatic insects)
  - There may be higher exposure at the bottom due to density effects (turtles, macroinvertebrates)

Credit: Flickr User Fred Salamin

Credit: Wikimedia Commons User Peter Paplanus

How Organisms are Exposed to Chloride

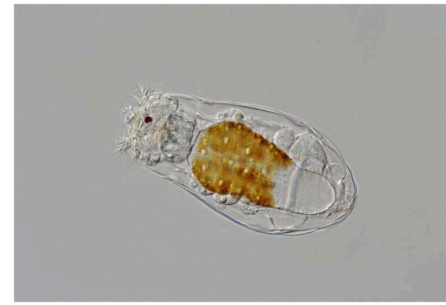
- Dwelling in soil contaminated with salts
  - For plants, this leads to uptake through roots
  - For others, exposure through body surface
- Direct deposition of salts
  - Spray, splash, aerosols, rainfall
    - More exposure near roads
  - Plowing/depositing of contaminated snow onto plants

How Organisms are Exposed to Chloride

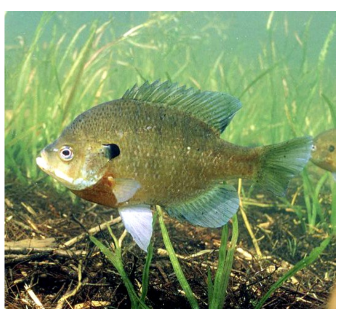
- Ingestion of salts
  - Road salt is the same size, shape, and color as grit ingested by some birds
  - Many mammals require sodium and seek it out
    - This can attract them to roads where deicing salts have been applied
    - Larger mammals can pose a hazard

Organism Sensitivity to Chloride

- Organisms vary in their sensitivity to chloride
  - 96-hour LC50 examples (mg/l)
    - Zooplankton – 1,000-1,600
    - Aquatic insects – 400-8,100
      - Mayflies – 425-2,800
      - Caddisflies – 2,100 – 8,100
    - Freshwater fish – 3,000-13,000



Credit: Flickr User Bob Henricks



Organism Sensitivity to Chloride

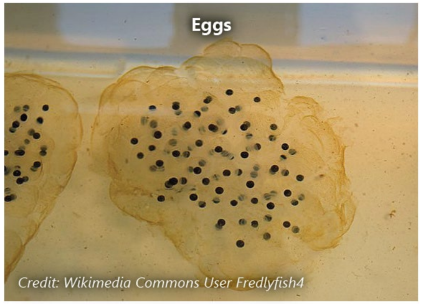
- Appendix C summarizes information on sensitivity of terrestrial plants to chloride

Table C.1
Relative Salt (NaCl) Tolerance of Selected Plants

Common Name	Scientific Name	Tolerance
	Deciduous Trees	
Alder, European black	*Alnus glutinosa*	L-M
Alder, speckled	*Alnus rugosa*	L-M
Alder, white	*Alnus incana*	L
Apricot	*Prunus armeniaca*	H
Ash, blue	*Fraxinus quadrangulata*	M
Ash, European	*Fraxinus excelsior*	H
Ash, green	*Fraxinus pennsylvanica*	M-H
Ash, white	*Fraxinus americana*	L-H
Aspen, bigtooth	*Populus grandidentata*	M-H
Aspen, upright European	*Populus tremula*	H
Aspen, quaking	*Populus tremuloides*	L-H
Beech, American	*Fagus grandifolia*	L-M
Beech, European	*Fagus sylvatica*	L
Birch, Cherry	*Betula, lenta*	H
Birch, Dahurian	*Betula davurica*	L
Birch, European white	*Betula pendula*	M
Birch, gray	*Betula populifolia*	M-H
Birch, Japanese whitespire	*Betula platyphylla*	L-M
Birch, paper	*Betula papyrifera*	L-H
Birch, river	*Betula nigra*	M

Factors Affecting Chloride Sensitivity

- Developmental stage
  - Earlier/younger stages are often more sensitive
    - Eggs, larvae, fry
  - Younger tissues can be more sensitive
    - Plant meristems, buds
- Preferred habitat
  - Stream and lake beds
  - Ephemeral ponds
  - Time spent terrestrial



Credit: Wikimedia Commons User Fredlyfish4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Factors Affecting Chloride Sensitivity

- Inability to escape saline water or soil
    - Sessile lifestyle
        - Mussels
    - Being rooted
        - Plants
        - Having perennial above-ground parts
    - Short dispersal distances
        - Some amphibians and macroinvertebrates

Factors Affecting Chloride Sensitivity

- Physiology and Life Cycle
  - Permeability of skin
  - Ability to retain and excrete ions
  - Ability to moderate osmotic effects by synthesizing solutes that adjust the internal concentration of their cells
  - Gas exchange through body wall rather than gills
  - Brooding eggs internally versus depositing them in the environment
  - Amount of time needed to develop
  - Timing of reproduction

Types of Sublethal Chloride Impacts

- Physical Damage
  - Terrestrial Plants – Burning of tissues, loss of leaves, damage to buds
- Reduced Growth
  - Reduced size of adults
  - May only affect a portion of the organisms (e.g., reduced leaf size)
  - Seen in many groups
    - Zooplankton, macroinvertebrates, fish, amphibians, plants
  - May be from diversion of energy to dealing with osmotic stress

Types of Sublethal Chloride Impacts

- Effects on Reproduction
  - Reduced egg hatching/seed germination (many groups)
  - Smaller broods
  - Increased time between broods
  - Increased age when reproduction starts
  - Inhibited fertilization
  - Reduced flower production
- Reduced population growth rates

Types of Sublethal Chloride Impacts

- Developmental delays
  - Seen in several groups
  - Can lengthen development time
  - Can result in smaller size at adulthood
- Developmental abnormalities
  - Deformities
    - Fish, amphibians, macroinvertebrates
  - Altered sex ratios
    - Macroinvertebrates
    - Masculinization of frogs

Types of Sublethal Chloride Impacts

- Altered behavior
  - Reduced activity levels
    - Less movement
    - Slower swimming
    - Less feeding
  - Disrupted response to light
  - Reduced anti-parasite behavior
  - Reduced fear
    - Birds and mammals
- Reduced photosynthetic activity

Underlying Mechanisms of Impacts

- Freshwater organisms are adapted to keep ions in and water out. High chloride salt concentration can disrupt this
- Osmotic stress
  - Can reduce ability to take up water and nutrients
  - Requires energy to compensate for
  - Can inhibit egg swelling
- Inhibition of enzymes
  - Photosynthesis
  - Denitrification
- Changes in internal cation balance

Biological Communities

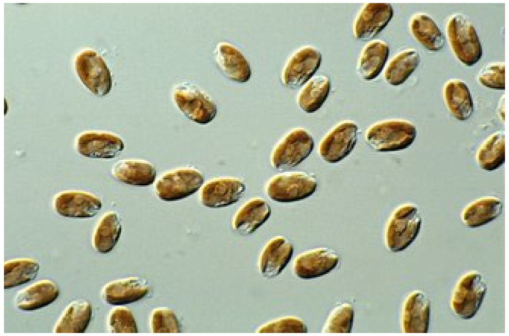
- Some ways communities are measured
    - What species are present
    - Species Richness – The number of species at a site
    - Evenness – How the relative abundances of species at a site compare to one another
    - Diversity – Measures that combine richness and evenness
    - Biomass – The mass or weight of organisms in a community

Impacts of Chloride on Communities

- Tolerance differences among species can lead to increased abundance of tolerant species and reduced abundance of intolerant species as chloride concentrations increase
  - Sensitive species can be lost from communities
- Increased chloride concentrations may also change the intensity of ecological processes among species in communities
  - Competition, predation, parasitism
- In some instances, this could allow other tolerant species to invade and establish in communities
  - e.g., invasive cattails in wetlands

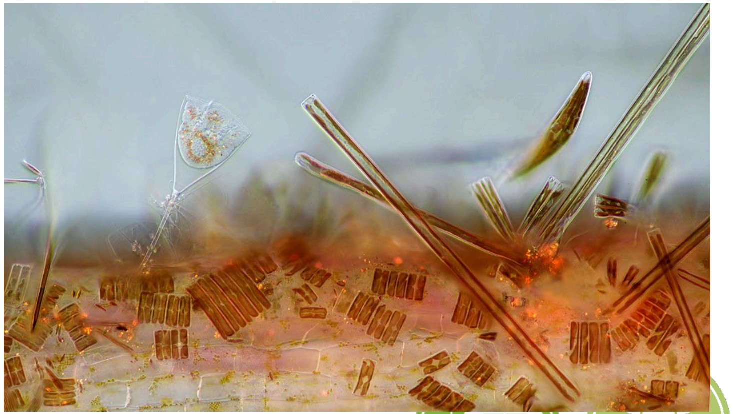
Impacts on Community Composition

- Mesocosm study shows the presence of different plankton communities at different specific conductance levels
  - Green algae and cryptomonads at low specific conductance
  - Chrysophyte flagellates at higher specific conductance
  - Zooplankton and ciliates also declined as specific conductance increased



Impacts on Community Composition

- Taxonomic analysis study of 41 streams with chloride concentration ranging between 5 and 502 mg/l reported changes in diatom periphyton species composition as chloride increased
  - The greatest changes occurred at 15-35 mg/l
  - Sensitive species were replaced by tolerant ones
  - Diversity measures did not correlate with chloride concentration

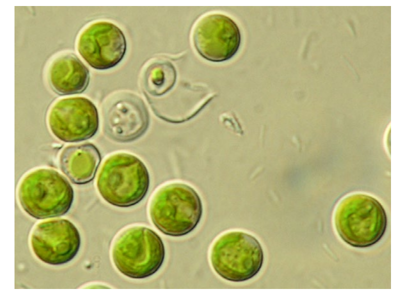


Impacts on Community Composition

- Field study sampling 107 river sites found that as salinity and specific conductance increased the macroinvertebrate community changed
  - Percentages of mayflies, stoneflies, and caddisflies decreased
  - Percentages of beetles, true bugs, dragonflies, and true flies increased

Impacts on Ecological Interactions

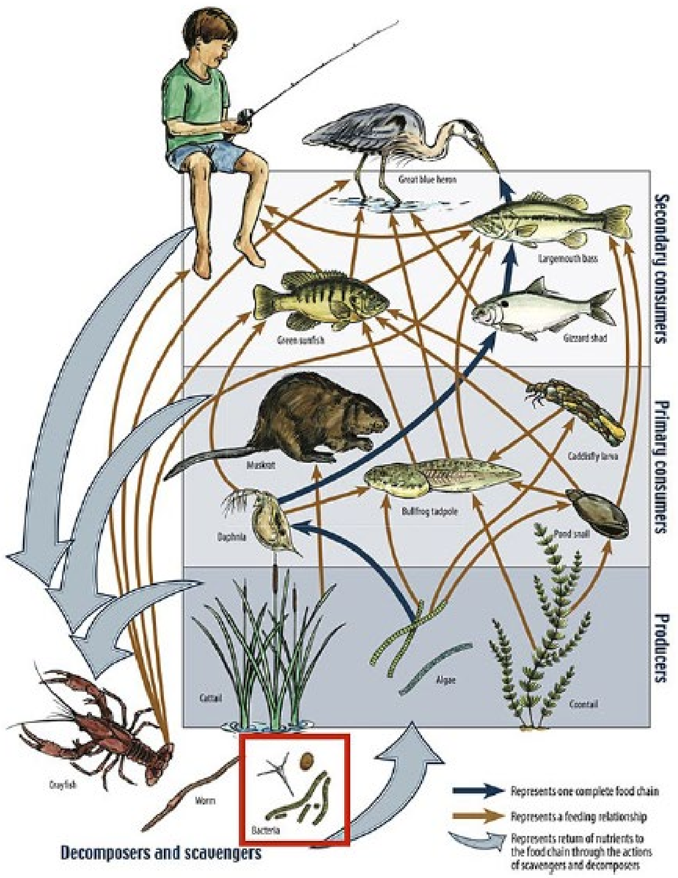
- Increased chloride can change competitive interactions by favoring the more tolerant species
  - Seen in algae and zooplankton



Impacts on Ecological Interactions

- Food web interactions
  - Several studies have attributed increases in algae in lakes, ponds, or mesocosms to salinity reducing the abundance of zooplankton grazers
  - This has the potential to impact other organisms in the food web

Figure: 3.17
A Simplified Aquatic Food Web



Source: Missouri Department of Conservation

Are Current Chloride Standards Protective?

- Several thresholds from the literature at which impacts have been reported are below 395 mg/l and 757 mg/l

Table 3.17
Some Chloride Concentration Thresholds for Changes in Biological Communities

Chloride Concentration (mg/l)	Reported Impact	References
5-40	Decreased reproduction and increased mortality in six *Daphnia* Species	Arnott et al., 2020, *Environmental Science and Technology*, 54:9,398-9,407.
16	Reduced bacteria density in biofilms	Cochero et al., 2017, *Science of the Total Environment*, 579:1,496-1,503.
33-108	Reductions in fish diversity	Morgan et al., 2012, *North American Journal of Fisheries Management*, 32:941-952.
35	Substantial changes in composition of periphytic diatom assemblages	Porter-Goff et al., 2013, *Ecological Indicators*, 32:97-106
54	Reductions in wetland plant species richness	Richburg et al., 2001, *Wetlands*, 21:247-255.
100	Decrease in photosynthetic production in common waterweed	Zimmerman-Timm, 2007, In: Lozar, et al., *Water Uses and Human Impacts on the Water Budget*
185	Substantial shift in phytoplankton community composition and reduction in ciliates	Astorg et al., 2023, *Limnology and Oceanography Letters*, 8:38-47.
250	Reductions in zooplankton abundance and diversity	Sinclair and Arnott, 2018, *Freshwater Biology* 63:1,273-1,286.
250-260	Wood frogs and spring peepers stop using ponds for breeding	Sadowski, 2002, *Prairie Perspectives*, 5:144-162; Gallagher et al., 2014, *Wetlands Ecology and Management*, 22:551-564
2,000	Inhibition of denitrification in forested wetlands	Lancaster et al., 2016, *Environmental Pollution*

Source: SEWRPC

Are Current Chloride Standards Protective?

- Zooplankton mesocosm study replicated at 16 sites
  - Exposed zooplankton communities from lakes to chloride ranging from 2 – 1,500 mg/l
  - Assessed the number of sites at which four zooplankton groups had 50 percent reductions in abundance at chloride concentrations less than 230 mg/l, USEPA's recommended chronic toxicity criterion

Table 3.18
Reductions in Zooplankton Abundance Relative to the USEPA Recommended Criterion Continuous Maximum Concentration

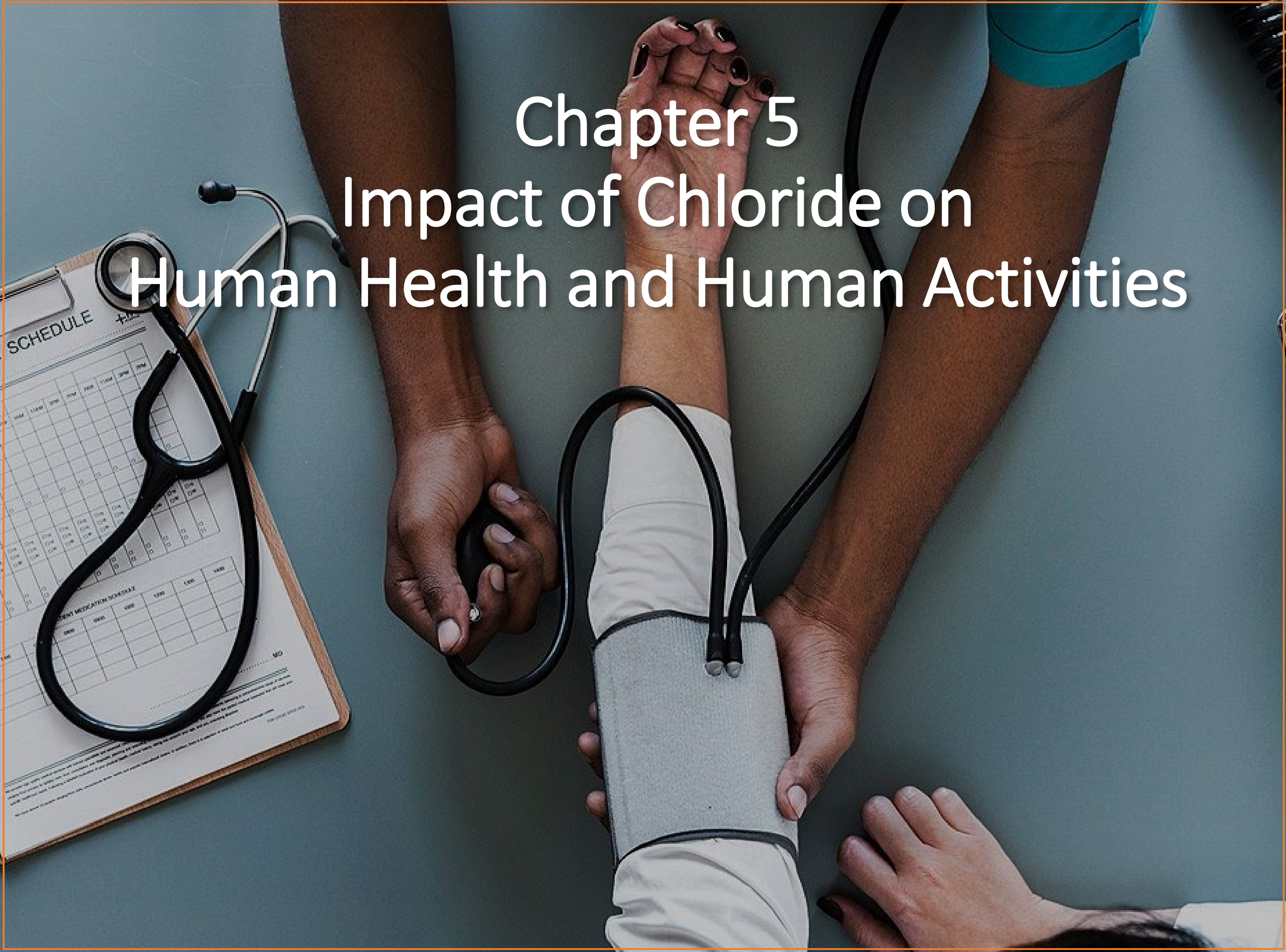
Zooplankton Group	Percent of Sites Showing 50 Percent Reductions at Chloride Concentrations Below 230 mg/l	Range of Reductions Observed at a Chloride Concentration of 230 mg/l (percent)
Cladocera	86	22-83
Calanoid copepods	90	15-96
Cyclopoid copepods	60	13-96
Rotifers	82	10-100

Source: W.D. Hintz et al., "Current Water Quality Guidelines Across North America Do Not Protect Lakes from Salinization," Proceedings of the National Academy of Sciences,*" 119:e2115033119, 2022*

Impacts of Chloride on Ecosystem Functions

- Organic matter decomposition in streams decreases with increasing salinity and chloride concentration
  - Less energy availability to those organisms that depend on organic matter
  - Can result is less biomass in the system and accumulation of organic litter on stream beds
- Some studies also show reductions in primary production, though others did not observe this
- Chloride salts can also interfere with some nutrient cycling processes (see Chapter 2)
- This could affect the amount and quality of ecosystem services.

Chapter 5
Impact of Chloride on Human Health and Human Activities



Health Effects of Sodium – Blood Pressure

- About 116 million Americans have or are treated for high blood pressure
  - Sodium ingestion is linked to high blood pressure
- Human sodium requirements
  - Typical requirement is 500-1,500 mg/day
  - U.S. Institute of Medicine places upper limit at 2,300 mg/day
  - Average intake is 3,400 mg/day
- USEPA recommends 20 mg/l as upper limit in drinking water for health purposes
  - 34 water utilities in Southeastern Wisconsin report sodium concentrations higher than this

Health Effects of Salt – Lung Diseases

- High concentrations of airborne particles smaller than 2.5 micrometers ($PM_{2.5}$) can cause asthma, respiratory inflammation, and lung cancer
  - Deicing salts constitute about 2-8 percent of $PM_{2.5}$
  - One study concluded that road salt applications may be associated with about 1 percent of lung cancer deaths due to $PM_{2.5}$ or about 190 deaths from lung cancer per year

Health Effects-Lead Release from Plumbing

- Increases in chloride concentration in drinking water can promote corrosion of plumbing which can release metals such as lead
  - Discussed in Chapter 4
  - In 2022, there were over 115,000 utility-owned and 119,000 customer-owned lead water service lines in Southeastern Wisconsin
  - 2016-2020 an annual average of 2,600 children under 6 in the Region diagnosed with lead blood levels indicative of lead poisoning
  - USEPA estimates that about 20 percent of exposure to lead comes from drinking water

Other Health Effects

- High sodium intake may affect the severity of osteoporosis in post-menopausal women
- High sodium intake may increase severity of kidney disease
- Physical contact with salt can irritate skin, eyes, mucous membranes

Other Drinking Water Impacts

- Chloride concentration above 250 mg/l or sodium concentration above 200 mg/l impart a salty taste to water
  - Wisconsin drinking water secondary maximum contaminant limit for chloride = 250 mg/l
  - USEPA aesthetic advisory for sodium 30-60 mg/l

Other Drinking Water Impacts

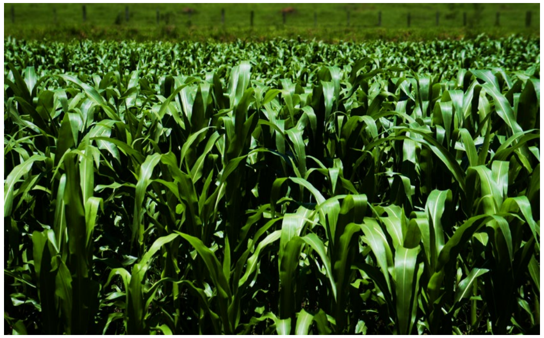
- There are reports of wells contaminated with deicing salts
  - New York State – estimated 26 percent of private wells impacted by road salt from applications or storage sites
  - Twin Cities Metropolitan Area – about 30 percent of wells exceed Minnesota chloride standards
  - Southeastern Wisconsin Utilities
    - 1 reports chloride over 250 mg/l
    - 6 report chloride over 200 mg/l
    - 34 report sodium over 20 mg/l

Other Drinking Water Impacts

- Wells in two types of locations appear to be most sensitive to contamination from road salt
  - Wells down gradient of salt storage facilities
  - Wells near and down gradient of roads

Impacts to Agriculture

- Increased salinity of soil can reduce crop yields
  - In general, vegetable crops are more sensitive to soil salinity than field crops or forage crops
- Increased salinity of irrigation water can reduce crop yields
  - Impacts increase linearly with water salinity



Aesthetic Impacts of Road Salts

- A few attempts have been made to quantify these
  - Damage to roadside trees (Adirondack Mountains, NY): $157 per ton road salt applied
  - Cost to replant and re-establish natural roadside vegetation damaged by salt (Adirondack Mountains, NY): $13,700 per mile
  - Reduction of environmental value due to road salt application (Adirondack Mountains, NY): $3,140 per lane mile per year
    - Applied to TCMA: $230-$310 per ton salt applied
  - Building cleaning – Dalhousie University, Nova Scotia, Canada: $19,200 – $20,400 per year

Next Steps

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

Comments on TR 62 Chapters 3 and 5 are due by **March 1, 2024**

Direct email→ jboxhorn@sewrpc.org

Anticipate the next TAC meeting to be April 2024 and include review of Technical Report No. 64, *Regression Analysis of Specific Conductance and Chloride Concentrations*

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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PARTNERS FOR A CLEANER ENVIRONMENT

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

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Thank You

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