Southeastern Wisconsin
Regional Planning Commission

Chloride Impact Study for the Southeastern Wisconsin Region

TAC Meeting
August 27, 2025

#278196

Speakers

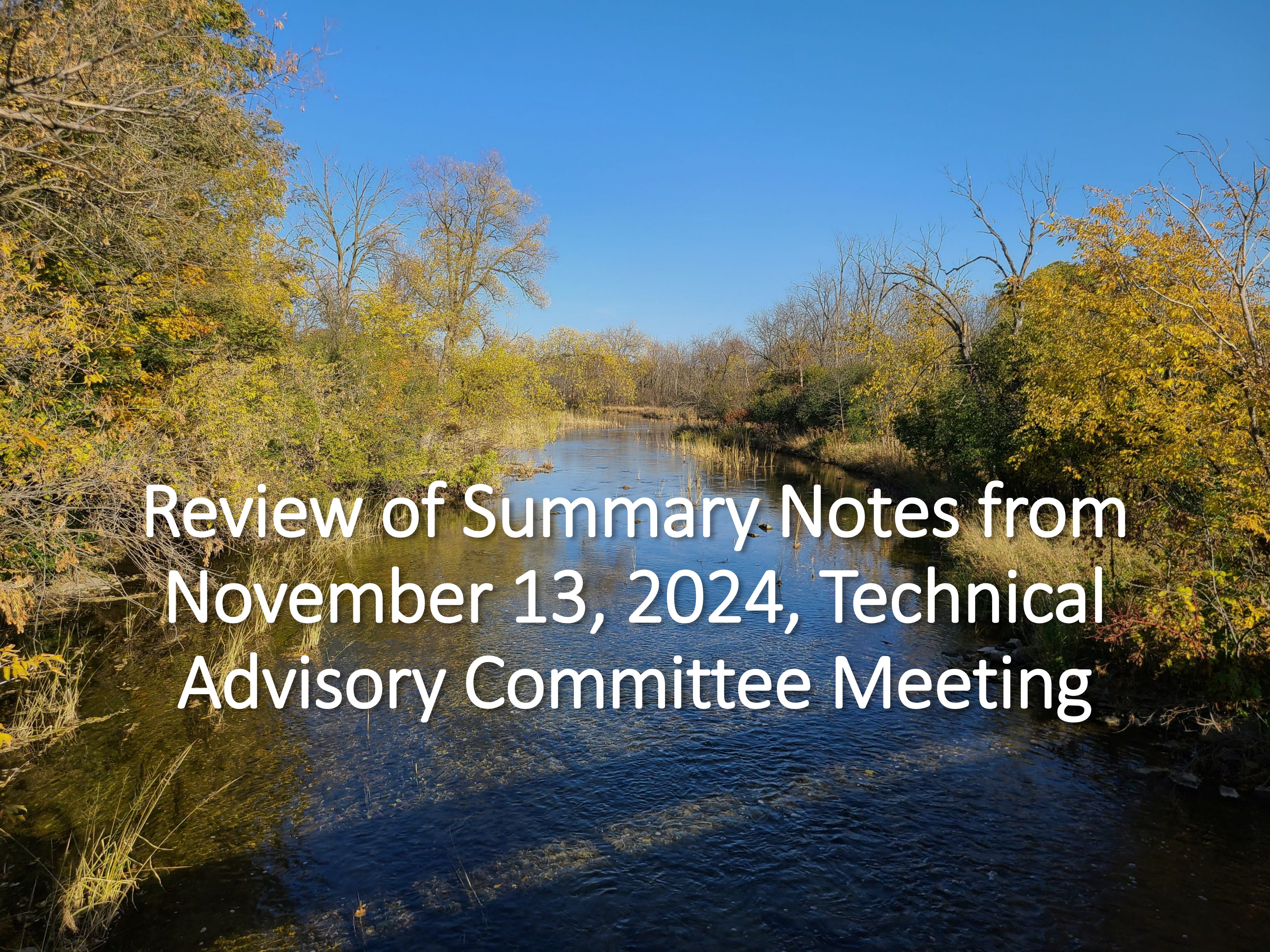
- Laura Herrick, Chief Environmental Engineer
- Tom Slawski, Chief Biologist
- Aaron Owens, Principal Planner
- Justin Poinsatte, Principal Specialist-Biologist

Agenda

- Review of Summary Notes from November 13, 2024 TAC meeting
- Review of preliminary draft chapters of SEWRPC Technical Report No. 63, *Chloride Conditions and Trends in SE WI*
  - *Chapter 2 – Study Area Background (Sources, Thresholds)*
  - *Chapter 3 – Analysis of Monitoring Data Collected for the Study: 2018-2021*
  - *Chapter 4 – Chloride Conditions and Trends: Rivers and Streams*
  - *Chapter 6 - Chloride Conditions and Trends: Groundwater*
- Next Steps

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*



Review of Summary Notes from November 13, 2024, Technical Advisory Committee Meeting

Technical Report No. 63
Chloride Conditions and Trends in SE WI

TR-63 Chapters

- **Chapter 1 – Introduction**
- **Chapter 2 – Study Area Background (part)**
- **Chapter 3 – Analysis of Chloride Impact Study Monitoring Data: 2018-2021**
- **Chapter 4 – Conditions and Trends: Rivers**
- **Chapter 5 – Conditions and Trends: Lakes**
- **Chapter 6 – Conditions and Trends: Groundwater**

TR-63 Chapters

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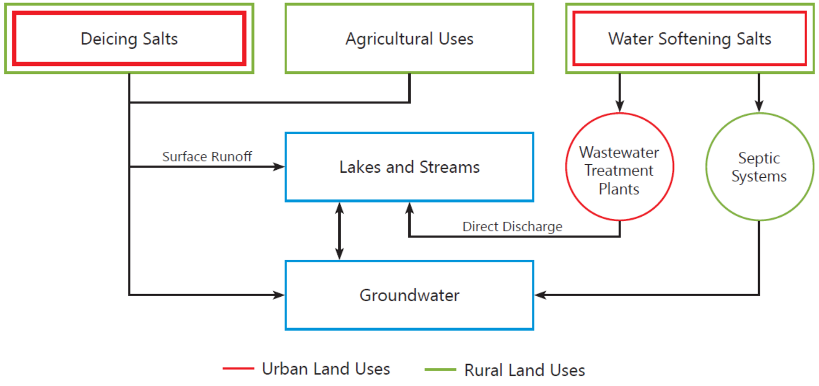
Sources of Chloride

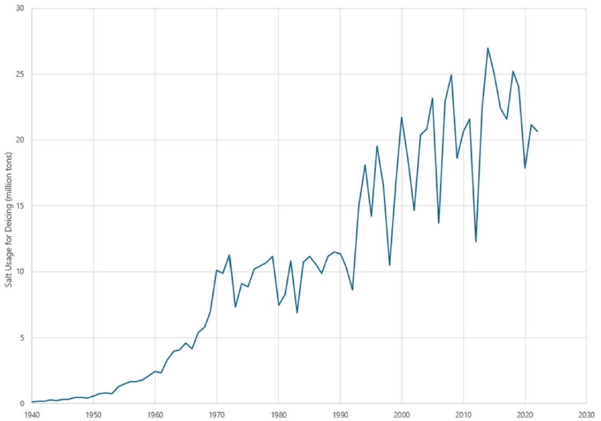
- Natural Sources
  - Rock Weathering - minor
  - Atmospheric Deposition - minor
- Human Sources
  - Winter Deicing – major
  - Wastewater – major WWTP, minor septic systems
  - Agricultural – moderately significant
  - Other Minor Sources – landfill leachate, irrigation

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

Thresholds

Problem-Chloride Thresholds for Biological Effects Exist at Much Lower Concentrations than the Acute or Chronic Concentration Standards.

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

Thresholds

Table 2.Chloride Thresholds for Analysis

Threshold Chloride Concentration (mg/l)	Source
10	Historical/Ambient Background Concentration
35	Conservative Lower Impact Concentration
120	Canadian Chronic Toxicity Threshold
230	USEPA Chronic Toxicity Threshold
395	Wisconsin Chronic Toxicity Threshold
757	Wisconsin Acute Toxicity Threshold
1400	Extreme Impact Level Concentration

Percentage breakdown among thresholds –for Assessment of Lakes and Streams

- ≤10 mg/l
- >10 - ≤35 mg/l
- >35 - ≤120 mg/l
- >120 - ≤230 mg/l
- >230 - ≤395 mg/l
- >395 - ≤757 mg/l
- >757 - ≤1,400 mg/l
- >1,400 mg/l

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Chapter 3 Overview

- Stream monitoring site and data collection description
- Chloride conditions in monitored streams
  - Data summary and site groupings
  - Other ions
  - Chloride dynamics and influencing factors
    - Responses to meteorological events
    - Seasons, land use, wastewater treatment
  - Comparisons against chloride thresholds
- Chloride conditions in monitored lakes
  - Lake monitoring site and data collection description
  - Chloride profiles with water depth
  - Correlations with watershed characteristics

Climate Conditions During Study

Thirty-Year Climate Normals for Southeastern Wisconsin: 1991-2020

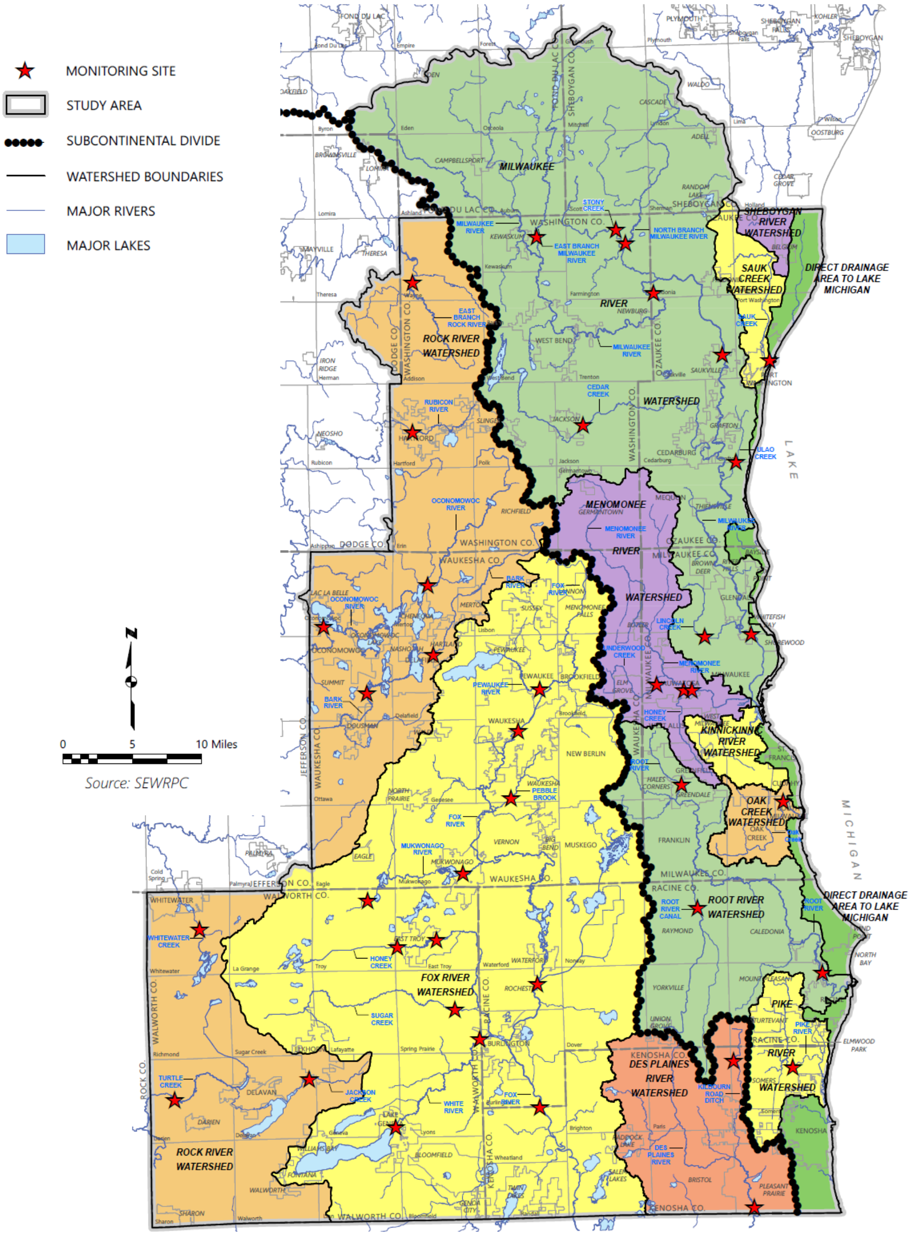
Month	Mean Temperature (°F)	Precipitation (inches)	Snowfall (inches)
January	20.7	1.64	12.6
February	24.2	1.56	10.7
March	34.3	2.05	5.3
April	45.4	3.67	1.7
May	56.7	3.96	0.1
June	66.7	4.60	0.0
July	71.3	3.67	0.0
August	69.6	3.80	0.0
September	62.3	3.33	0.0
October	50.2	2.91	0.2
November	37.5	2.22	2.1
December	26.3	1.87	9.8
Total	--	35.28	42.3

Source: Wisconsin State Climatology Office and National Oceanic and Atmospheric Administration

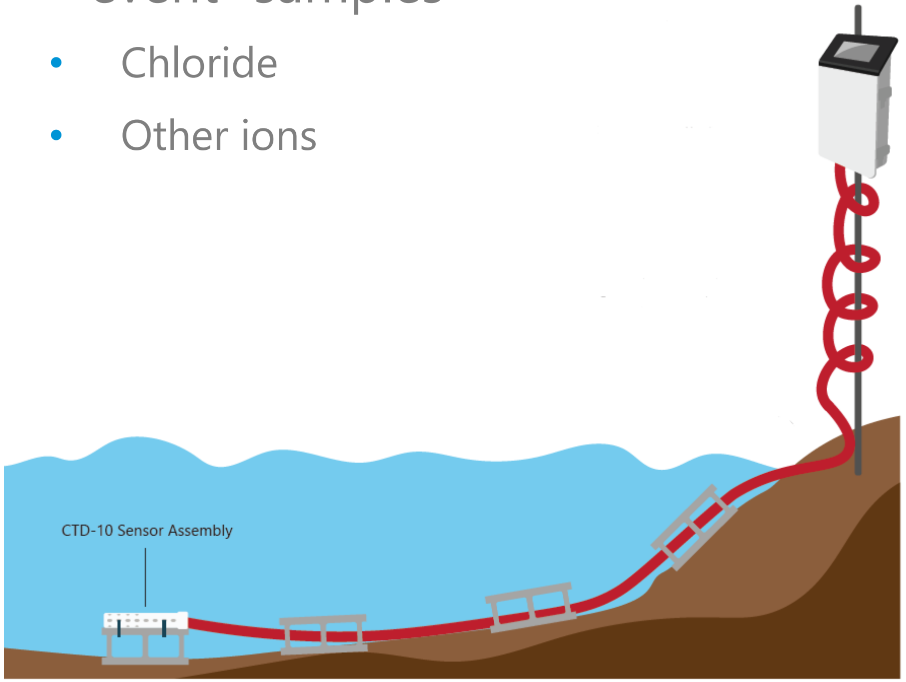
- Compared 2018-2021 weather conditions to climate normals
- Air temperature fairly normal with a few extreme events
  - Polar vortex in Feb. 2019 and 2021
- Precipitation
  - 2018-2019 especially wet years
  - 2020 normal
  - 2021 drough

Water Quality Monitoring – Streams

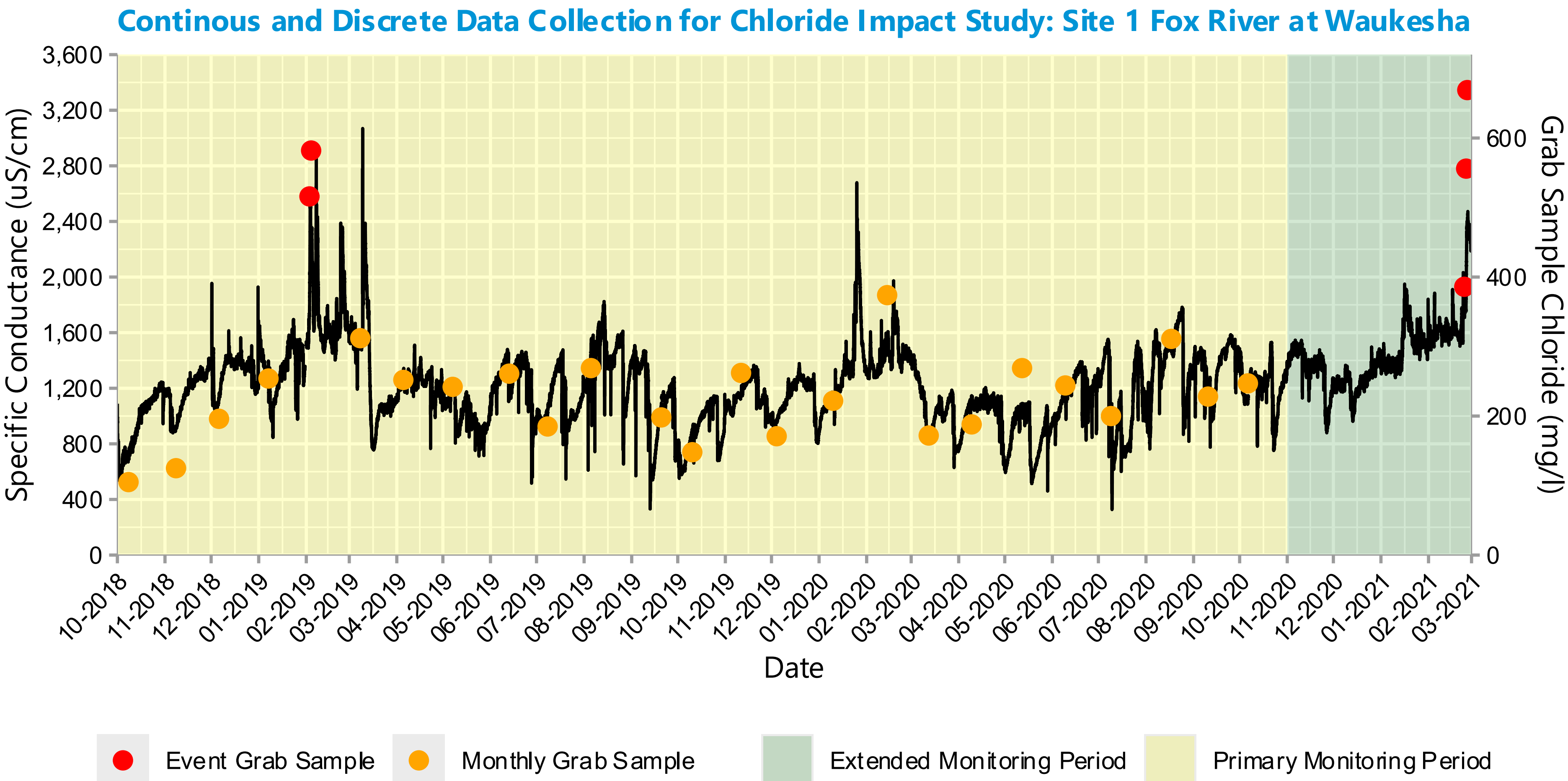
Major Watersheds, Surface Waters, and Stream Monitoring Sites Within the Study Area



- 41 stream sites across Region
- Data collected from October 2018 through 2021
- Specific conductance continuous monitoring (5-min)
- Monthly grab samples and "event" samples
  - Chloride
  - Other ions



Data Collection Example: Site 1



- Converted specific conductance to estimated chloride using regression models (TR-64)
  - Could not develop model for Site 55 Bark River Downstream
- Extended monitoring period in winter 2020-2021 to capture spike events

Data Summary

Specific Conductance and Chloride Concentration at Chloride Impact Study Sampling Sites: 2018-2021

Statistic	Specific Conductance Observations (µS/cm)	Estimated Chloride[a] (mg/l)	Measured Chloride[b] (all samples) (mg/l)	Measured Chloride[b] (event samples removed) (mg/l)
Observations and Samples	8,960,021	8,756,461	1,141	1,030
Minimum	42	0.0	8.7	10.8
Mean	833	118.0	232.0	121.9
Median	702	66.8	77.1	67.3
Maximum	14,689	5,135.8	6,630.0	1,890.0
Standard Deviation	579.9	192.2	533.8	171.6

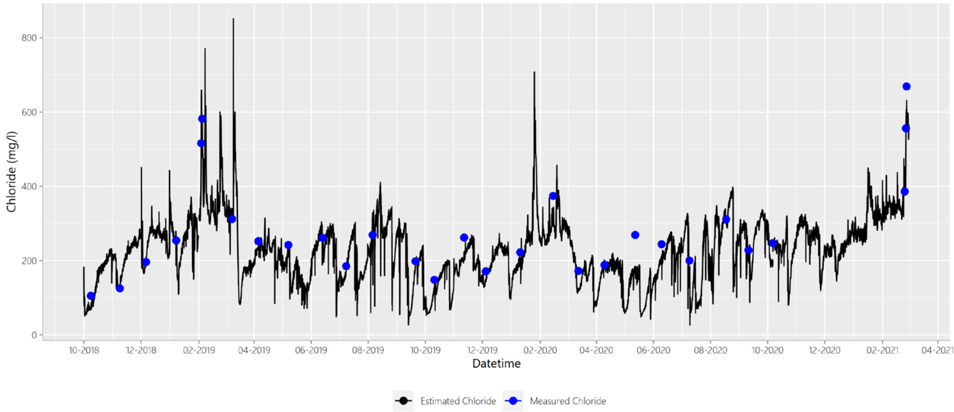
[a] *Chloride concentration was estimated from specific conductance using regression models developed as part of the Chloride Impact Study.*

[b] *Chloride concentration was determined by chemical analysis of water samples.*

Source: SEWRPC

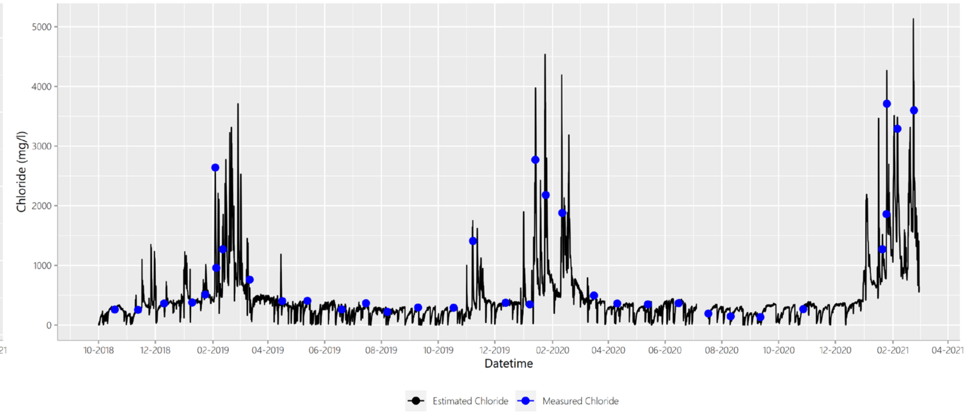
Estimated Chloride Time Series

Figure A.Site01ClEstClTimeSeries
Time Series of Estimated and Measured Chloride Concentrations at Site 01 Fox River at Waukesha: 2018-10 to 2021-02



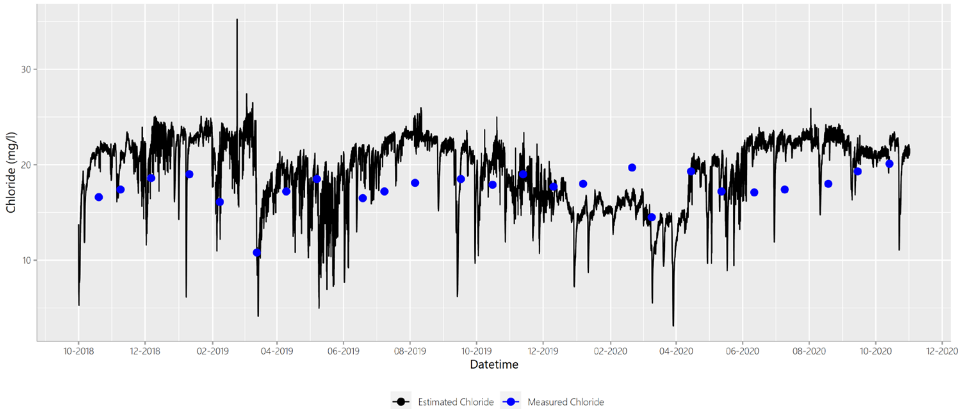
Source: SEWRPC

Figure A.Site12ClEstClTimeSeries
Time Series of Estimated and Measured Chloride Concentrations at Site 12 Lincoln Creek: 2018-10 to 2021-02



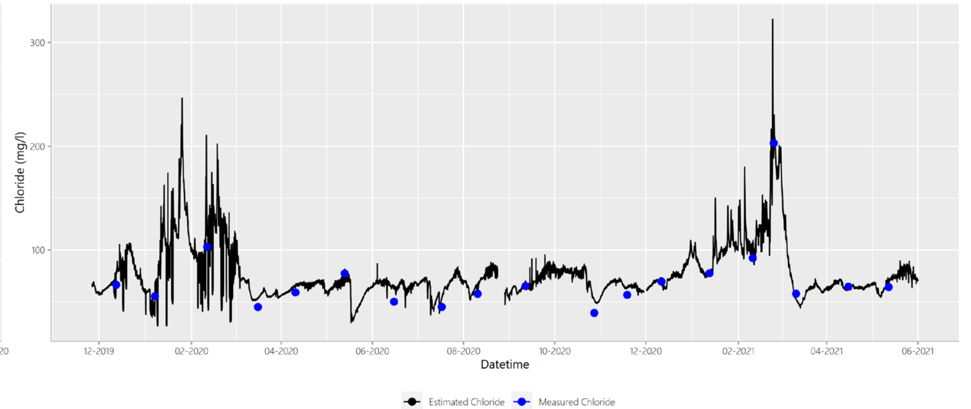
Source: SEWRPC

Figure A.Site45ClEstClTimeSeries
Time Series of Estimated and Measured Chloride Concentrations at Site 45 Mukwonago River at Nature Road: 2018-10 to 2020-10



Source: SEWRPC

Figure A.Site58ClEstClTimeSeries
Time Series of Estimated and Measured Chloride Concentrations at Site 58 Milwaukee River at Estabrook Park: 2019-12 to 2021-05



Source: SEWRPC

Site Groupings

Table 3.StreamSiteGroups
Groups of Stream Monitoring Sites with Similar Chloride Characteristics

Group Number	Group Description	Monitoring Sites in Group
1	Small stream, urban watershed, large winter spikes, and high to very high chloride	9, 12, 53, 57, 60, 87
2	Small stream, mixed urban and rural watershed, moderate winter spikes, and high chloride	1, 8, 10, 11, 13, 33
3	Small stream, rural watershed, moderate winter spikes, and moderate to high chloride	6, 14, 15, 16, 25, 30, 51, 52, 59
4	Small stream, rural watershed, no winter spikes, and moderate chloride	3, 4, 18, 20, 28, 32, 35, 36, 40, 48
5	Small stream, rural watershed, no winter spikes, and low chloride	21, 38, 45, 54
6	Large river, rural watershed, no winter spikes, and low chloride	2, 41
7	Large river, rural watershed, winter spikes, and moderate chloride	23, 47, 58

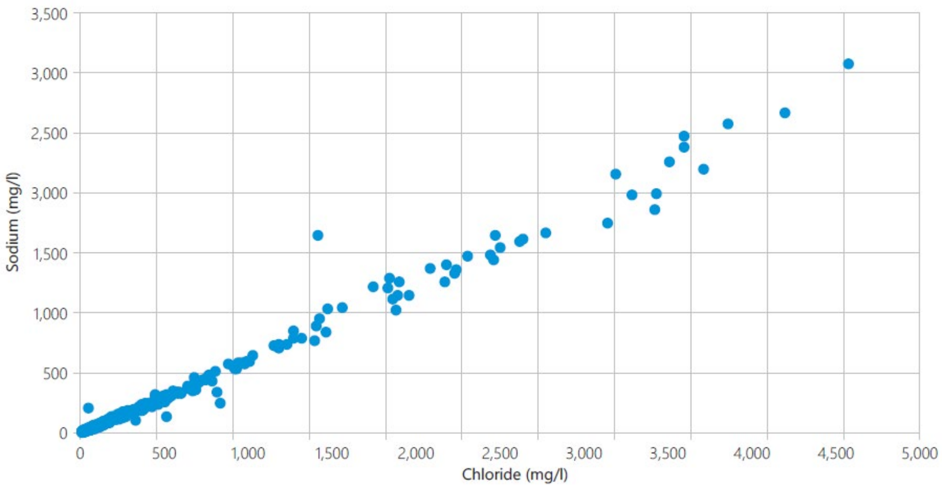
.Note: Site 55 Bark River Downstream is not included in this table as chloride could not be reliably estimated from specific conductance measurements at this site.

Source: SEWRPC

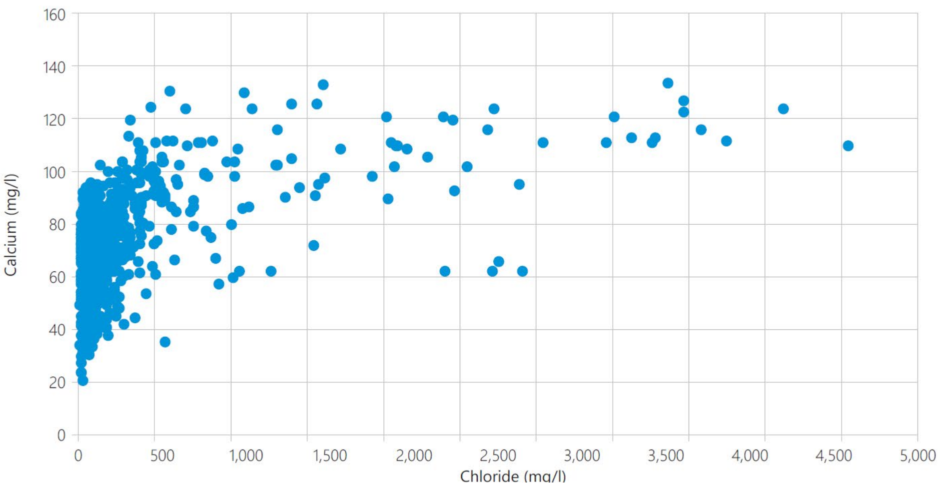
- Grouped sites based on similar chloride dynamics and influencing factors
  - Responses to precipitation events
  - Predominant land use and relative size of stream
- Small streams in urban watersheds characterized by flashy chloride levels
- Small streams in rural watersheds have low chloride and no/few spikes

Other Ions

Relationship Between Concentrations of Sodium and Chloride at Chloride Impact Study Stream Monitoring Sites

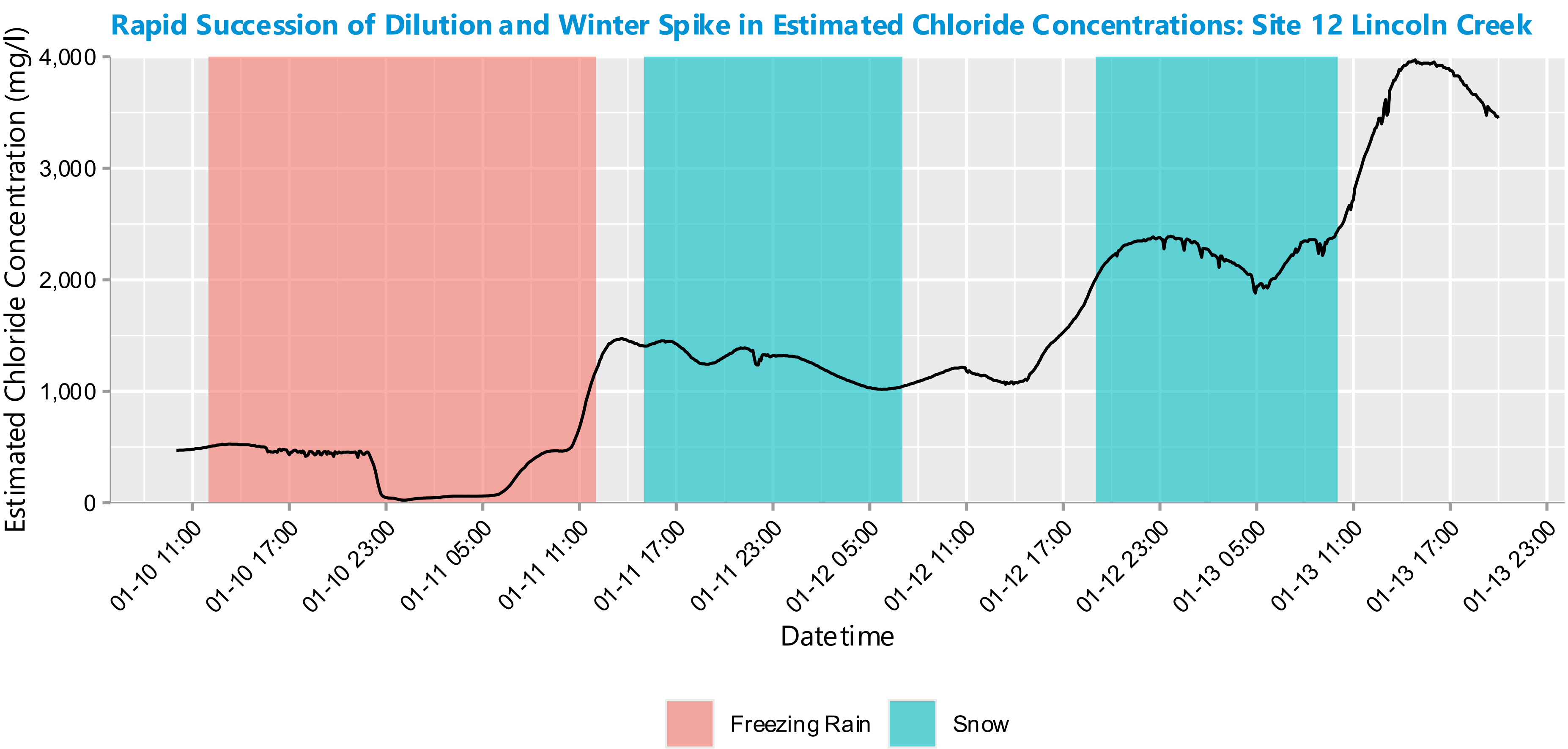


Relationship Between Concentrations of Calcium and Chloride at Chloride Impact Study Stream Monitoring Sites



- Tight correlation between chloride and sodium concentrations and not a strong relationship between chloride and calcium
  - Indicator that most chloride entering streams as sodium chloride
- Strong correlations between urban land use and both chloride and sodium

Winter Spike Events

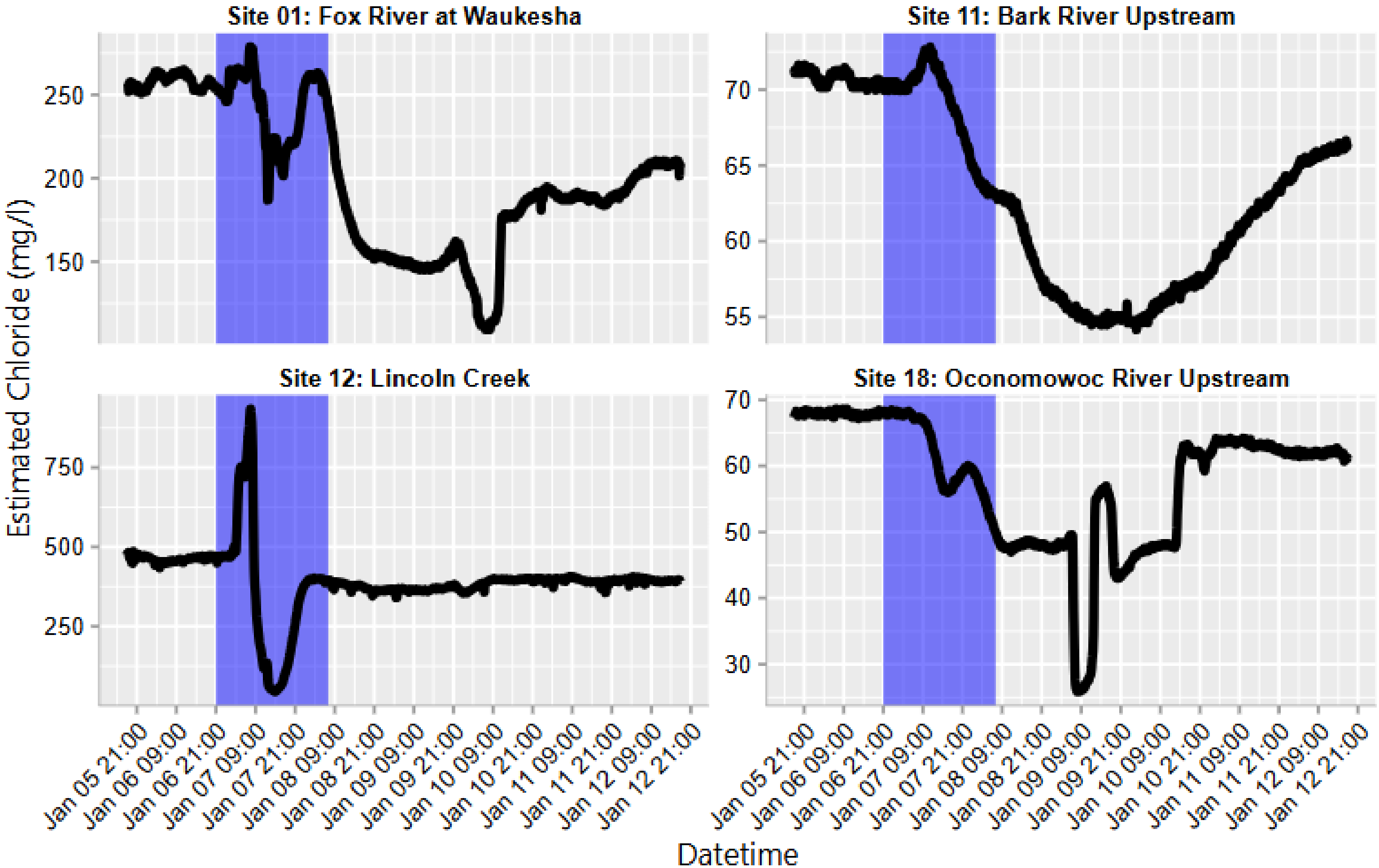


- Chloride concentrations are highly dynamic in streams
  - Rise from 40 mg/l to nearly 4,000 mg/l within two days
  - Especially during winter in streams with urban watersheds

Response to Winter Rain

Figure 3.EarlyWinterRain

Estimated Chloride Concentrations at Sites 1, 11, 12, and 18 Following Early Winter Rain



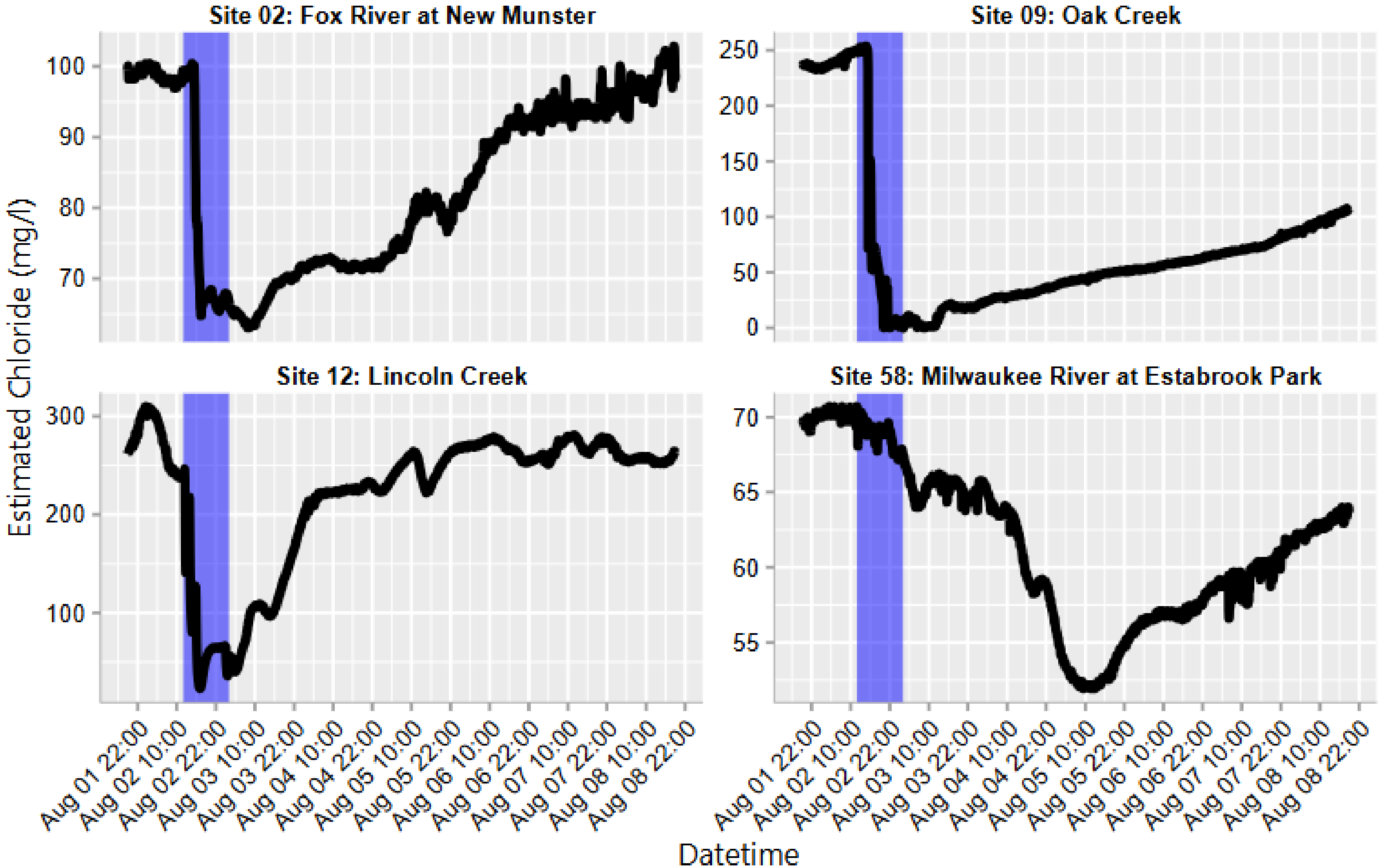
Note: Blue shading indicates early winter rain event.

Source: SEWRPC

Response to Summer Rain

Figure 3.HeavySummerRain

Estimated Chloride Concentrations at Sites 2, 9, 12, and 58 Following Heavy Summer Rain



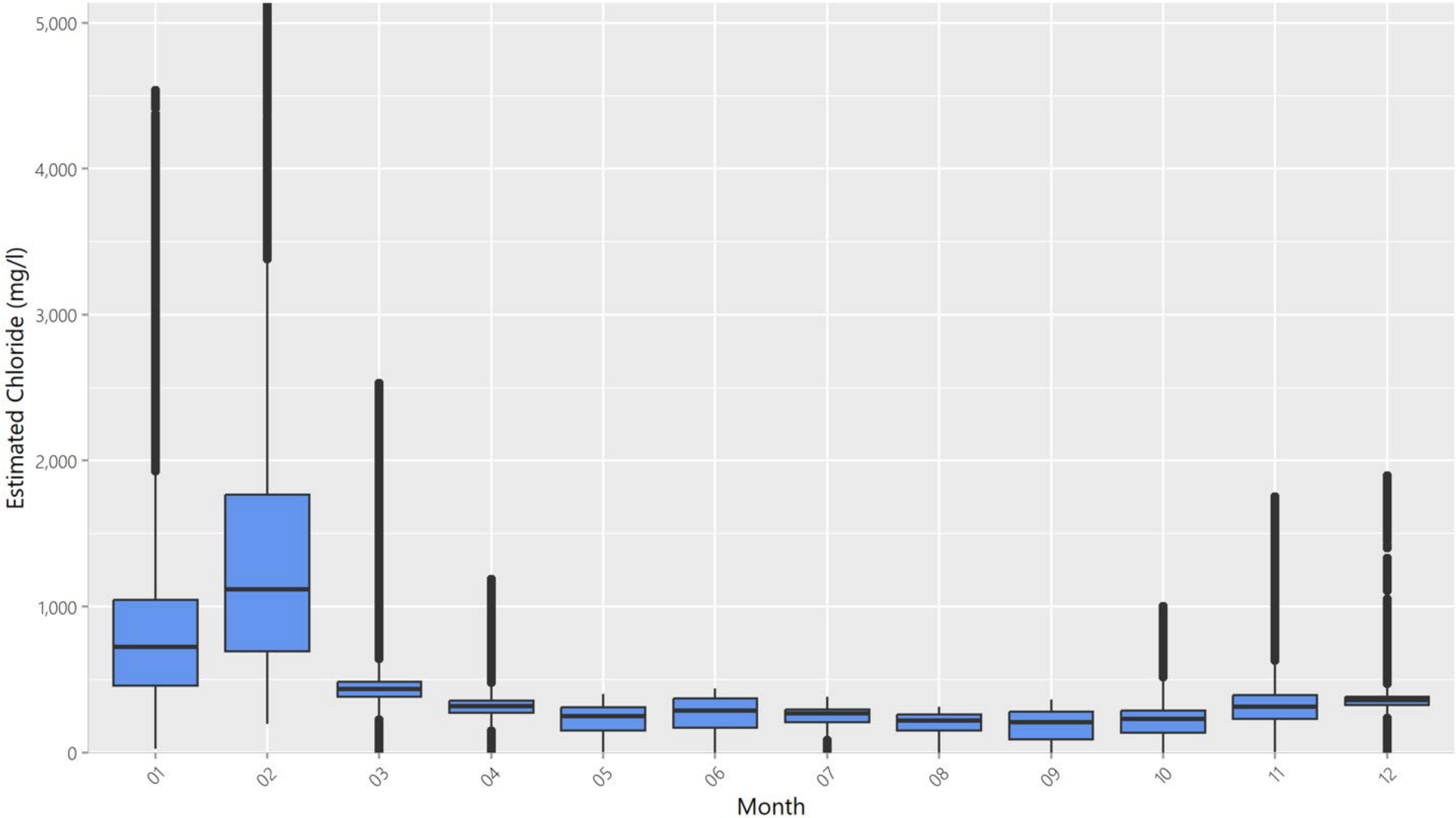
Note: Blue shading indicates general timing of rain event.

Source: SEWRPC

Seasonal Trends

Figure A.Site12EstClBoxMonth

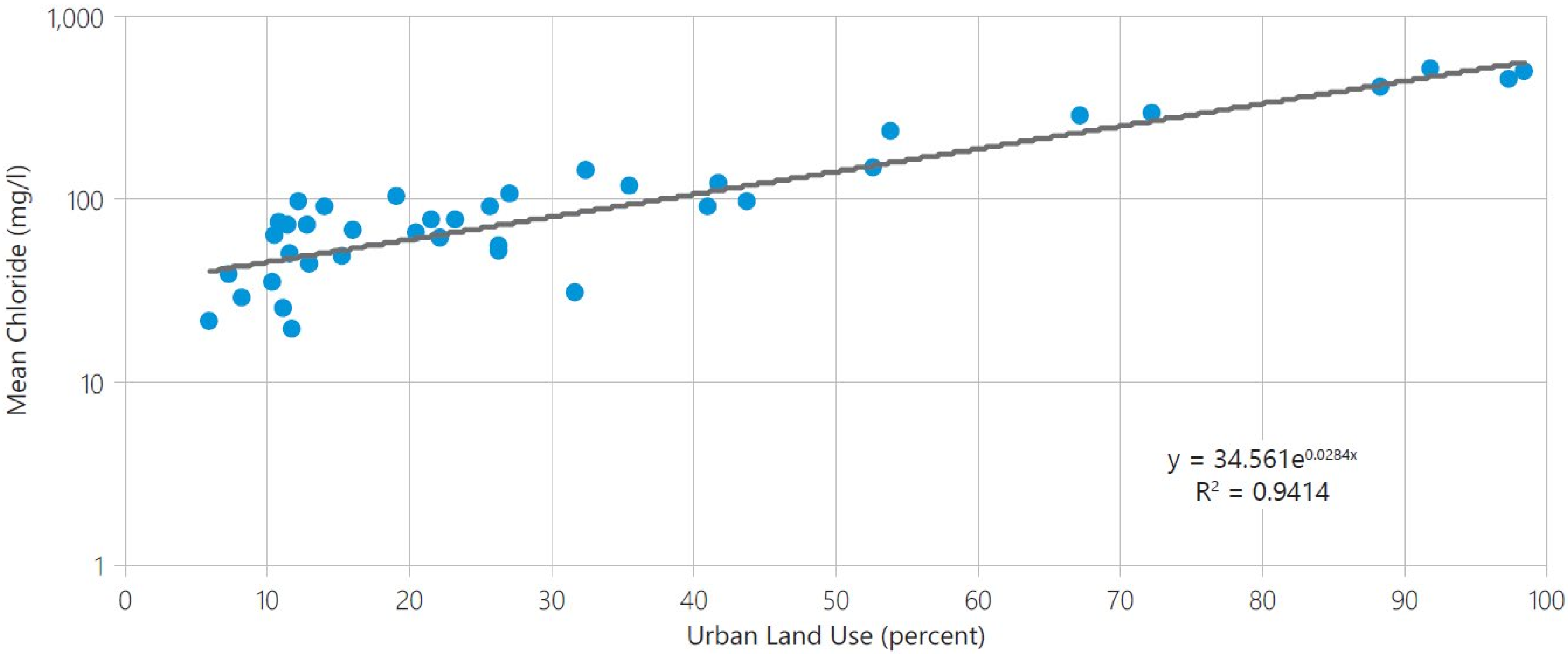
Monthly Boxplots of Estimated Chloride at Site 12 Lincoln Creek: 2018-10 to 2021-02



- Many sites, but particularly those with urban watersheds, exhibited higher chloride concentrations during winter
  - Winter spikes and higher baselines between spikes

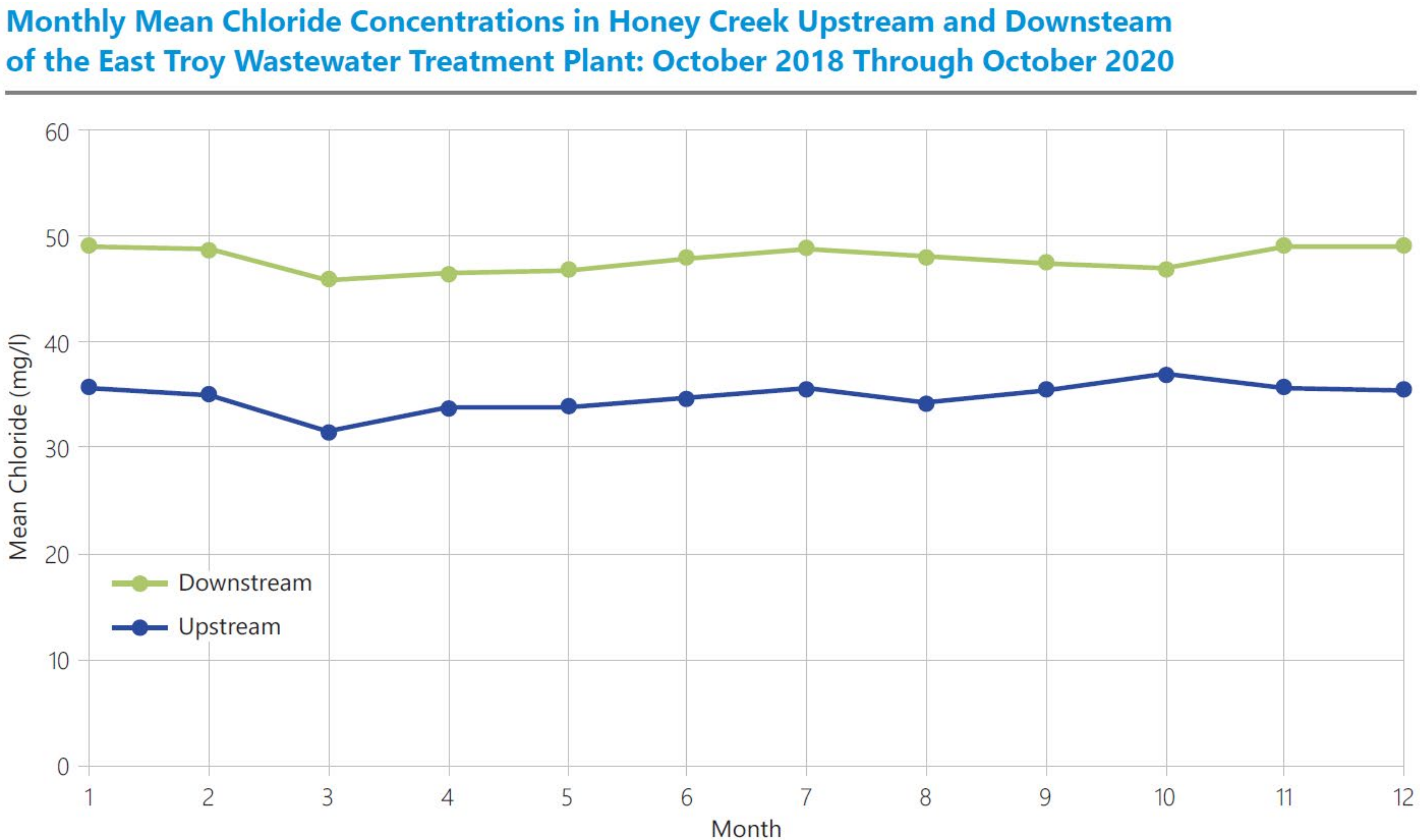
Land Use Correlations

Relationships Between Drainage Area Land Use and Mean Chloride Concentration at Chloride Impact Study Stream Monitoring Sites



- Utilized 2015 land use in delineated drainage areas for each site
- Significant, positive correlations between chloride concentrations with urban land use and roads and parking lots

Wastewater Effluent



- Analyzed impact of WWTF effluent on Fox River at Waukesha and Honey Creek in Walworth County
- Effluent can raise chloride concentrations in streams, particularly during dry periods in summer and early fall

Chloride Thresholds

Threshold Chloride Concentration (mg/l)	Source
10	Historical/Ambient Background Concentration
35	Conservative Lower Impact Concentration
120	Canadian Chronic Toxicity Threshold
230	USEPA Chronic Toxicity Threshold
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Percentage breakdown among thresholds –for Assessment of Lakes and Streams

- ≤10 mg/l
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- >395 - ≤757 mg/l
- >757 - ≤1,400 mg/l
- >1,400 mg/l

Threshold Exceedances

Percentage Estimated Chloride Concentrations Exceeded Various Thresholds

SEWRPC Site ID	Monitoring Site Name	Estimated Chloride Measurements Exceeding Concentration Threshold (percent)						
		10 mg/l	35 mg/l	120 mg/l	230 mg/l	395 mg/l	757 mg/l	1,400 mg/l
1	Fox River at Waukesha	99.9	99.9	91.0	49.0	2.7	<0.1	0.0
2	Fox River at New Munster	99.9	99.7	29.6	1.5	0.0	0.0	0.0
3	Mukwonago River at Mukwonago	99.2	99.0	0.0	0.0	0.0	0.0	0.0
4	Sugar Creek	100.0[a]	89.1	0.0	0.0	0.0	0.0	0.0
6	White River near Burlington	99.5	95.0	0.0	0.0	0.0	0.0	0.0
8	Pewaukee River	99.4	99.4	71.3	3.9	0.3	0.0	0.0
9	Oak Creek	99.4	95.7	82.8	57.2	16.9	5.2	0.8
10	Pike River	99.1	90.6	16.0	7.0	1.4	0.0	0.0
11	Bark River Upstream	100.0[a]	100.0	19.0	0.0	0.0	0.0	0.0
12	Lincoln Creek	98.1	96.0	87.4	72.9	29.2	12.8	5.5
13	Ulao Creek	99.9	98.1	54.1	12.4	2.0	0.3	0.0
14	Sauk Creek	99.1	91.2	5.5	0.3	<0.1	0.0	0.0
15	Kilbourn Road Ditch	99.9	93.7	18.2	7.5	1.8	0.5	0.2

- Each site evaluated for exceedance of thresholds by percent of measurements, total duration, and maximum contiguous duration

Threshold Exceedances

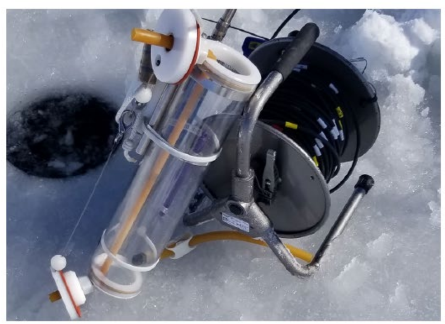
Maximum Length of Time that Chloride Concentration Exceeded Various Thresholds

Site ID	Monitoring Site Name	Length of Record (days)	Maximum Duration that Chloride Concentration Was Above the Threshold (days)						
			10 mg/l	35 mg/l	120 mg/l	230 mg/l	395 mg/l	757 mg/l	1,400 mg/l
1	Fox River at Waukesha	883	758.9	300.7	94.2	67.9	3.5	<0.1	D
2	Fox River at New Munster	883	494.2	387.6	169.0	6.8	D	D	D
3	Mukwonago River at Mukwonago	763	250.6	192.1	D	D	D	D	D
4	Sugar Creek	763	762.0	155.1	D	D	D	D	D
6	White River near Burlington	763	393.5	214.5	0.2	D	D	D	D
8	Pewaukee River	763	698.4	584.3	61.9	6.9	0.8	D	D
9	Oak Creek	883	281.9	268.8	97.3	65.8	36.5	11.1	3.7
10	Pike River	883	304.0	94.9	59.6	27.9	5.6	D	D
11	Bark River Upstream	763	762.0	613.2	27.9	D	D	D	D
12	Lincoln Creek	883	190.2	131.0	65.2	56.8	46.6	26.2	8.6
13	Ulao Creek	975	594.7	319.4	67.7	22.1	4.9	1.2	D
14	Sauk Creek	883	182.3	43.9	7.3	0.6	0.3	D	D
15	Kilbourn Road Ditch	883	673.0	190.6	58.0	21.6	6.6	4.3	1.1

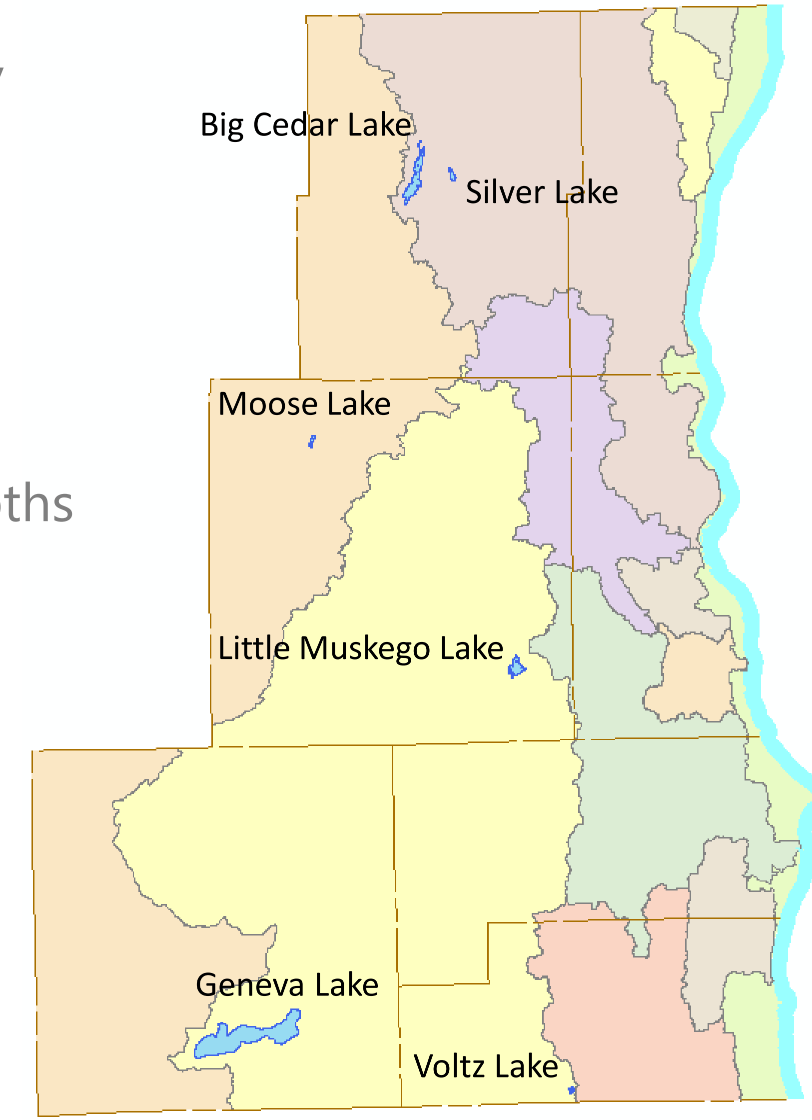
- Longest contiguous period that each site exceeded each threshold
- Most helpful for assessing potential chloride impairments
  - Acute toxicity: Site 1 Fox at Waukesha and Site 15 Kilbourn Road Ditch
  - Chronic toxicity: Site 30 Des Plaines

Water Quality Monitoring – Lakes

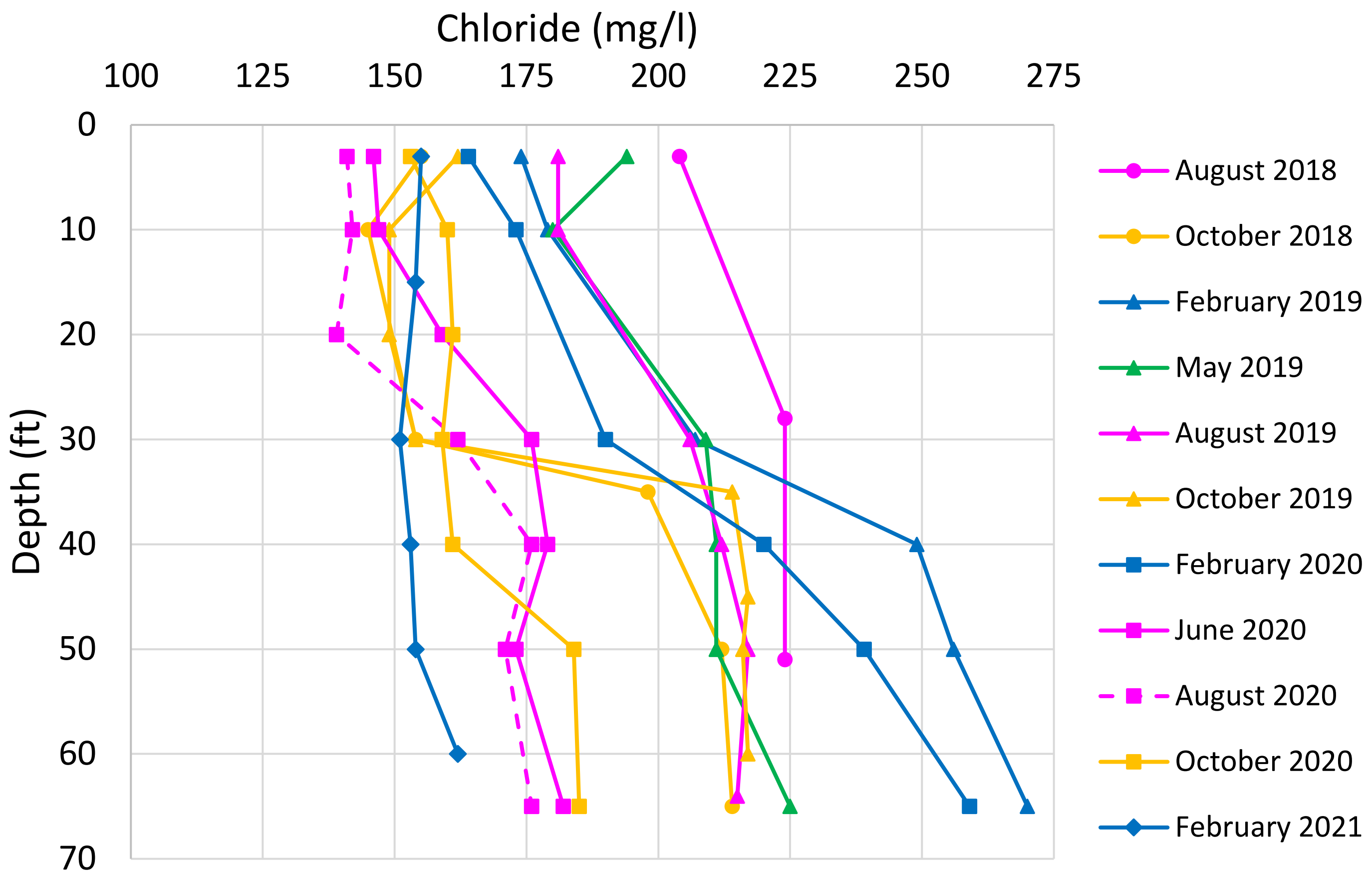
- 6 lakes sampled quarterly/seasonally
- Summer 2018 to Winter 2021
- Profile data collected
  - Specific Conductance
  - Temperature
- Chloride Grab Samples at various depths



Source: SEWRPC



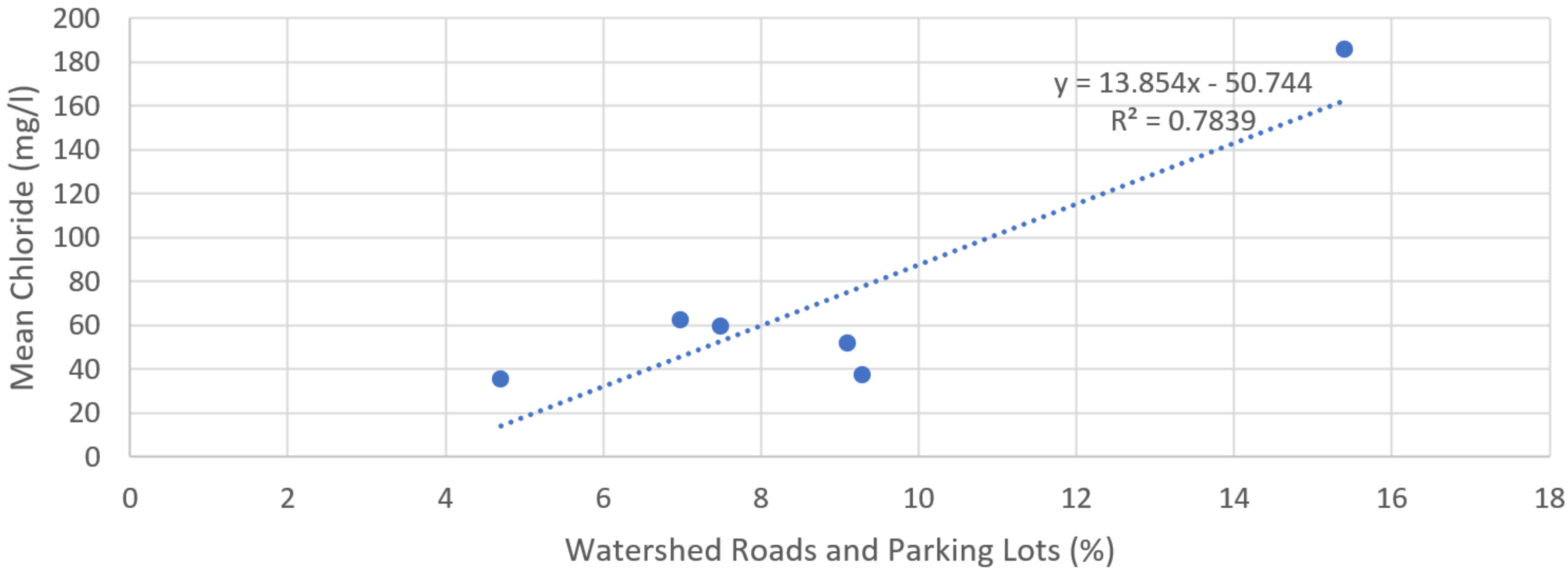
Lake Chloride Profiles



- Most lakes showed little variation with depth
- Little Muskego exhibited increased concentrations in deeper water

Land Use Correlations

Correlations of Lake Mean Shallow Chloride Concentrations with Watershed Land Uses



- Significant correlation with percent of roads and parking lots in watershed
- Limitations based on low number of lakes in Study
  - Substantially influenced by Little Muskego

Chapter 3 Summary

- Nearly all monitored streams and all monitored lakes had chloride above baseline and at potentially harmful concentrations
- Chloride is highly dynamic in streams and can fluctuate significant during and following precipitation events
    - Direction and magnitude of fluctuation depends on
        - Upstream land uses
        - Season in which precipitation event occurs
        - Size of stream
- Continuous monitoring can be helpful for assessing waterbodies, particularly for capturing spike events for which collecting a grab sample is not feasible
- Chloride does not vary with water depth in most lakes
- As for streams, watershed land use can impact lake chloride concentrations

Questions?

TR-63 Chapters

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Chapter 4 Overview

- 4.1 Introduction
- 4.2 Stream Background Information and Details
- 4.3 Data Compilation and Organization
  - **Data Sources and Retrieval**
  - Data Formatting and Aggregation
  - Database Quality Assurance and Control
  - **Developing Assessment Reaches for Analysis of Water Quality Conditions**
    - **Full Record Assessment Reach Dataset (1961-2022)**
    - **Recent Record Assessment Reach Dataset (2013-2022)**
  - **Assessing Robustness and Balance of Assessment Reach Datasets**

Chapter 4 Overview

- **4.4 Overview of Chloride Conditions and Trends in Streams (Full Study Area)**
  - **Historical Conditions and General Trends (1961-2022)**
    - **Temporal Trends; Seasonal Trends; Stream Size**
  - **Recent Conditions (2013-2022)**
    - **Land Use; Temporal Trends; Seasonal Trends**
- **4.5 Chloride Conditions and Trends Within Major Watersheds (12 watersheds)**
  - **Menomonee River Watershed**
    - **Historical Conditions and Trends (1961-2022)**
      - **Temporal Trends; Seasonal Trends**
    - **Recent Conditions (2013-2022)**
      - **Land Use; Temporal Trends; Seasonal Trends**
- 4.6 Summary of Chloride Conditions and Trends in the Streams and Rivers of the Study Area

Data Compilation and Organization

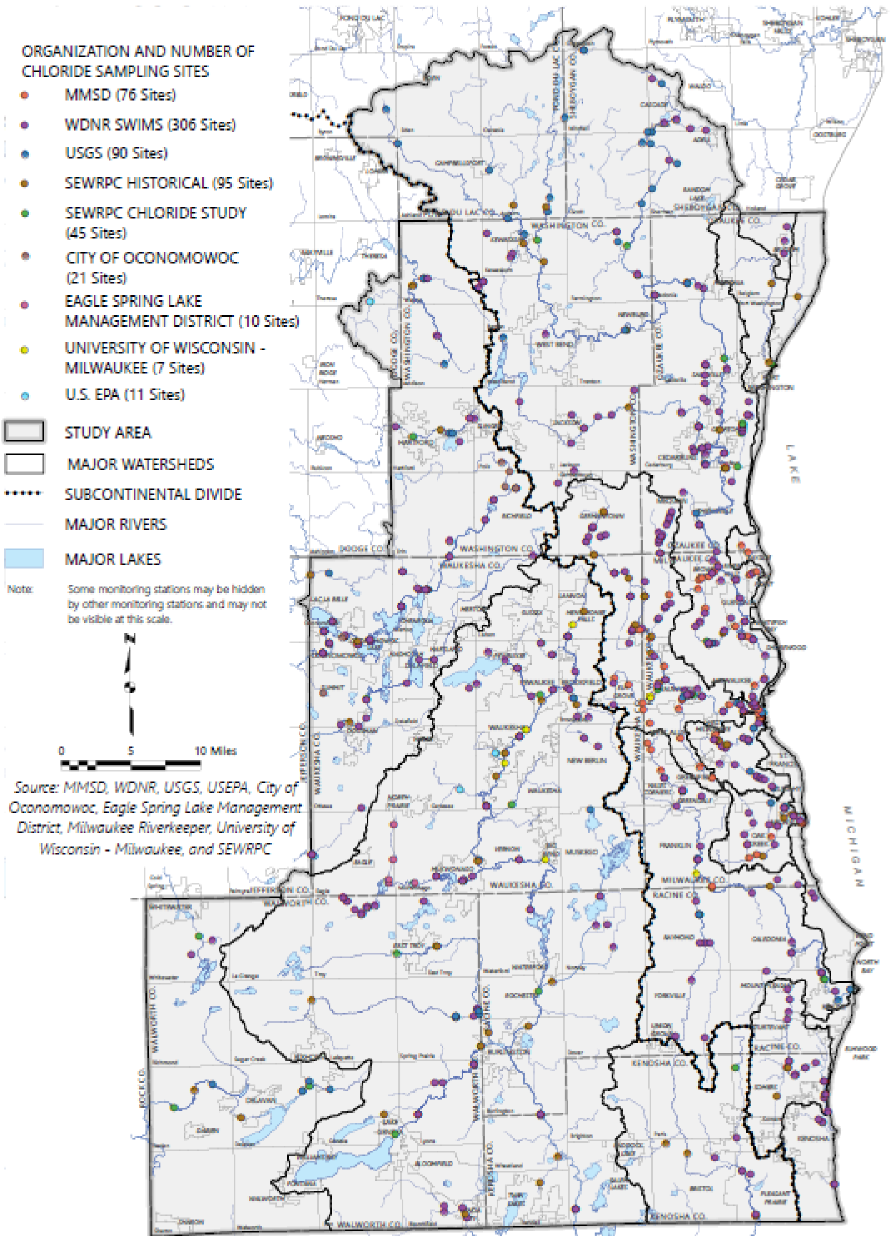
- Data Sources: MMSD, WDNR, SEWRPC, USGS, USEPA, Milwaukee Riverkeeper, City of Racine Pub Health Department, City of Oconomowoc, Eagle Spring Lake Management District, UWM

- Data from these sources were accessed through several databases:
  - USEPA National Water Quality Portal (WQP)
  - USGS National Water Information System (NWIS)
  - USEPA Storage and Retrieval Database (STORET)
  - WDNR Surface Water Integration Monitoring System (SWIMS)

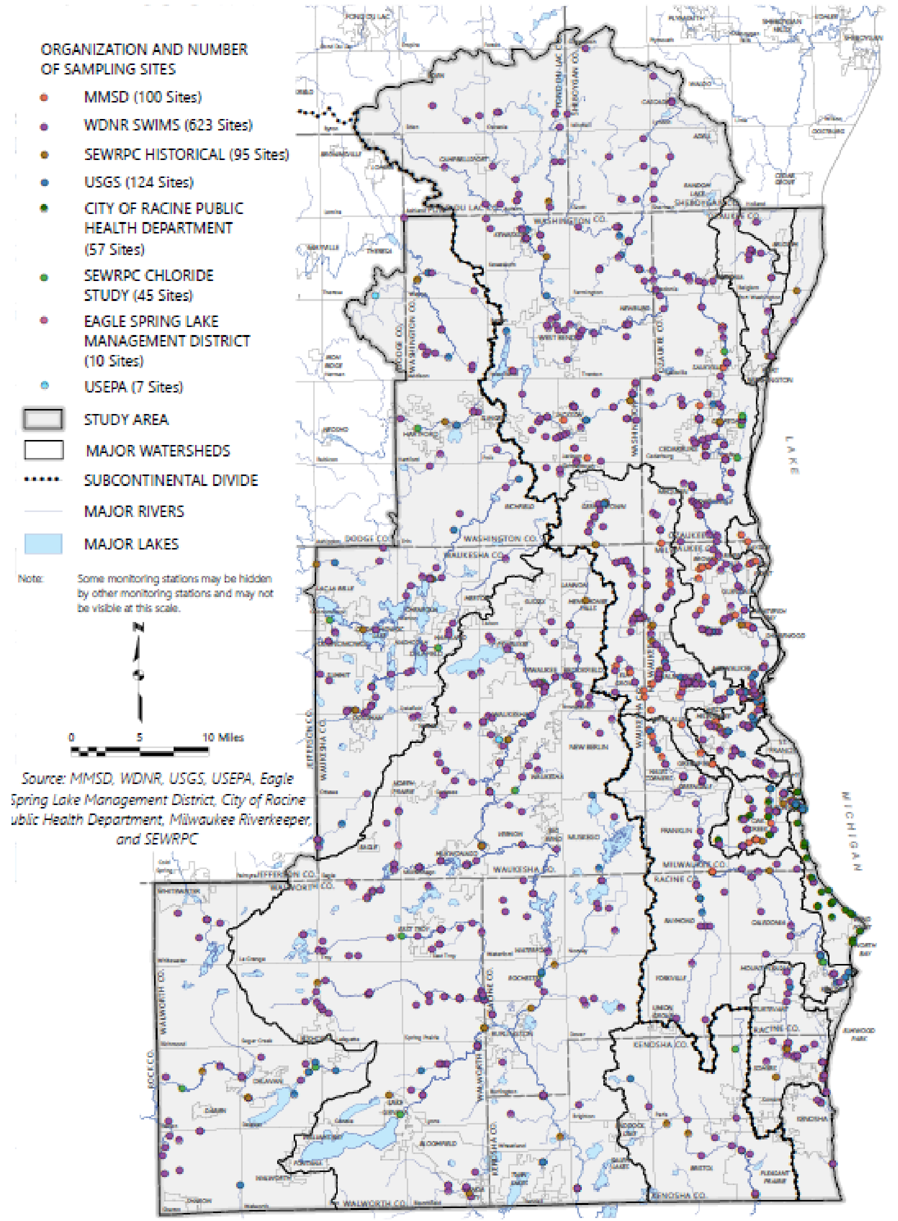
- Final database included:
  - Nearly 48,000 chloride measurements and over 50,000 specific conductance measurements
  - From 1,152 monitoring stations
  - Within 230 distinct streams

Data Compilation and Organization

Map 4.1
Stream Monitoring Stations with Chloride Samples



Map 4.2
Stream Monitoring Stations with Specific Conductance Samples

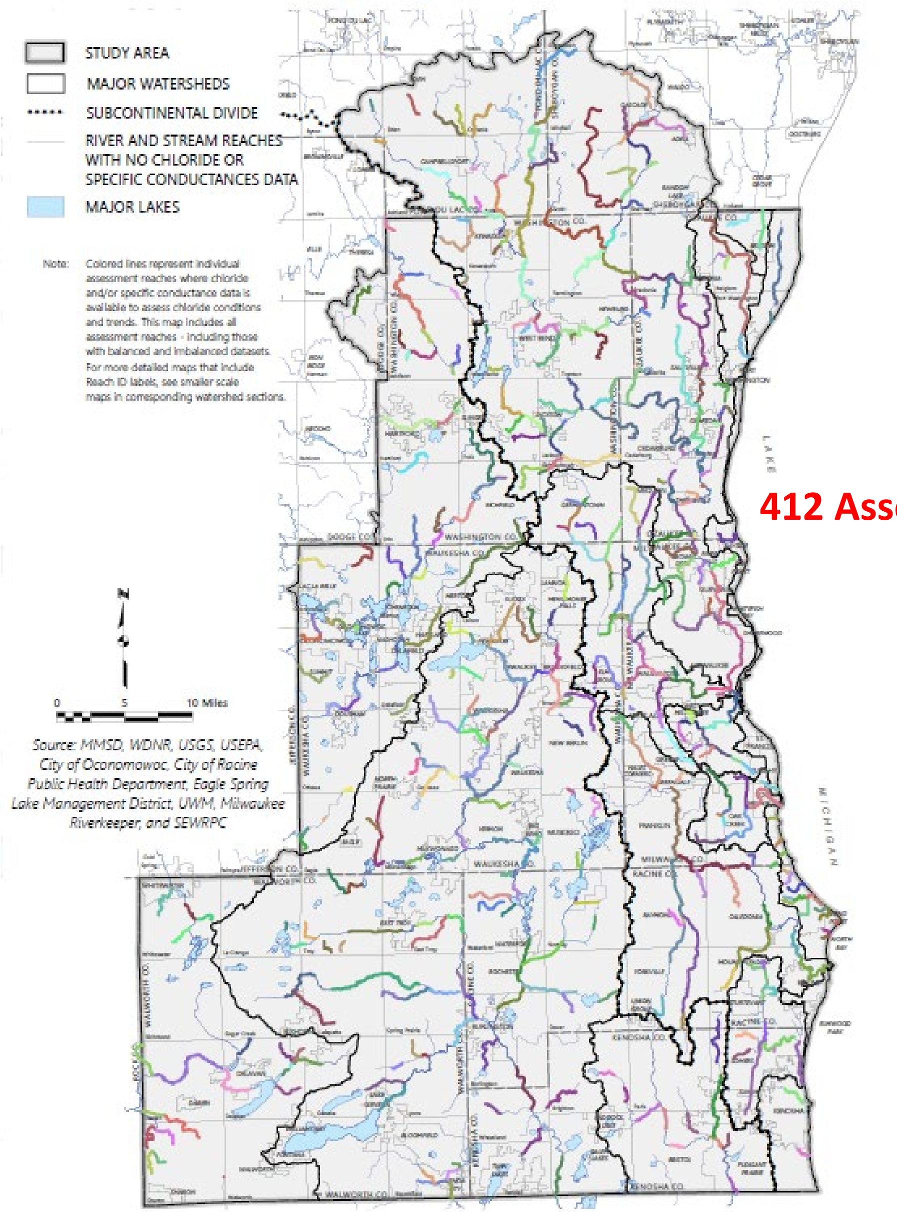


Developing Assessment Reaches for Analysis

- Identified stream segments that had at least one monitoring station where chloride and/or specific conductance had been collected
- Stream segments with similar hydrologic characteristics were then grouped together to form “assessment reaches”
  - WBIC
  - Reach Code – USGS Developed
  - Stream order
  - WWTP discharge locations
  - Best professional judgement (hydrologic features or land use patterns)

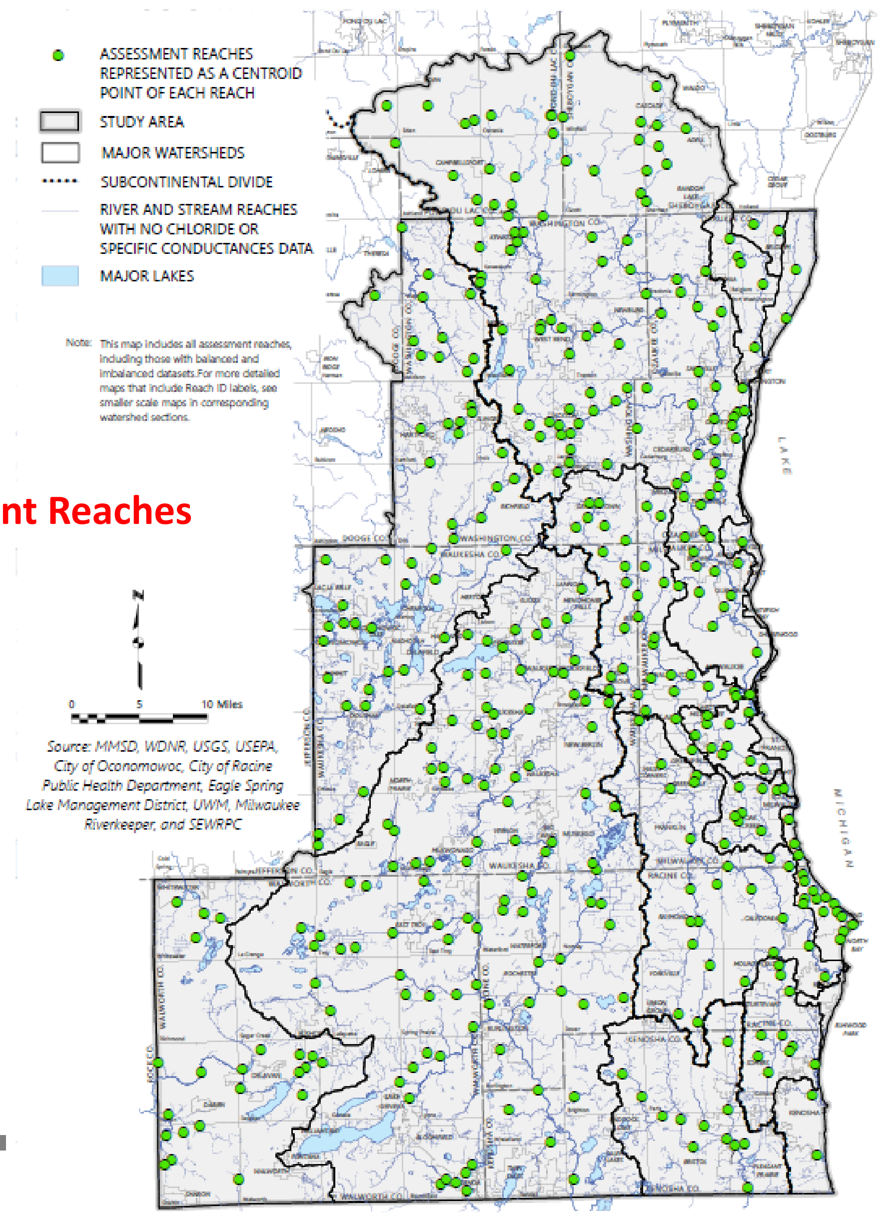
Developing Assessment Reaches for Analysis

Map 4.3
Assessment Reaches for the Chloride Impact Study



412 Assessment Reaches

Map 4.4
Assessment Reaches Represented as the Midway Point of Each Assessment Reach Length



Full Record Assessment Reach Dataset (1961-2022)

- Available chloride and/or specific conductance data varied significantly across the 412 assessment reaches (see Table 4.2)
    - Chloride samples per reach ranged from 0 to 4,186
    - 154 reaches had no chloride measurements
    - 72 reaches only had between 1-10 samples
    - Average of 115 samples per reach

- For reaches with no chloride data, specific conductance measurements could be used as a general indicator of chloride conditions and trends
    - Conductance samples per reach ranged from 0 to 3,879
    - Average of 123 samples per reach

Full Record Assessment Reach Dataset (1961-2022)

- Assessment Reaches Per Watershed:
  - Milwaukee: 115
  - Fox: 102
  - Rock: 71
  - Menomonee: 33
  - Root: 23
  - Direct Drainage to Lake Michigan: 23
  - Des Plaines: 12
  - Kinnickinnic: 10
  - Pike: 10
  - Oak Creek: 8
  - Sauk Creek: 5
  - Sheboygan: 2

Watershed	**Number of Samples**
Des Plaines River	404
Fox River	2,558
Kinnickinnic River	7,279
Menomonee River	16,964
Milwaukee River	11,562
Oak Creek	3,243
Pike River	1,114
Rock River	1,791
Root River	2,232
Sauk Creek	95
Sheboygan River	6
Direct Drainage Area to Lake Michigan	411

Recent Period Assessment Reach Dataset (2013-2022)

- 312 assessment reaches had chloride and/or conductance data in recent period of record
  - 15,565 recent chloride samples
  - 21,332 recent conductance samples
- Assessment Reaches Per Watershed with Recent Period Data :
  - Milwaukee: 104
  - Fox: 71
  - Rock: 41
  - Menomonee: 29
  - Root: 12
  - Direct Drainage Area to Lake Michigan: 10
  - Kinnickinnic: 10
  - Pike: 8
  - Oak Creek: 8
  - Sauk Creek: 5
  - Des Plaines: 4
  - Sheboygan: 0

Watershed	Number of Samples
Des Plaines River	63
Fox River	577
Kinnickinnic River	2,571
Menomonee River	4,379
Milwaukee River	4,856
Oak Creek	730
Pike River	743
Rock River	844
Root River	626
Sauk Creek	36
Sheboygan River	--
Direct Drainage Area to Lake Michigan	196

Assessing Balance of Assessment Reach Datasets

Balanced Dataset Criteria

Full Period of Record (1961-2022):

- At least 20 total samples
- Samples collected over a span of at least 15 years
- At least one sample collected in year 2000 or later
- At least 5 total samples -or- 10% of samples collected in winter
- At least 20% of samples collected in either summer or fall

Recent Period of Record (2013-2022):

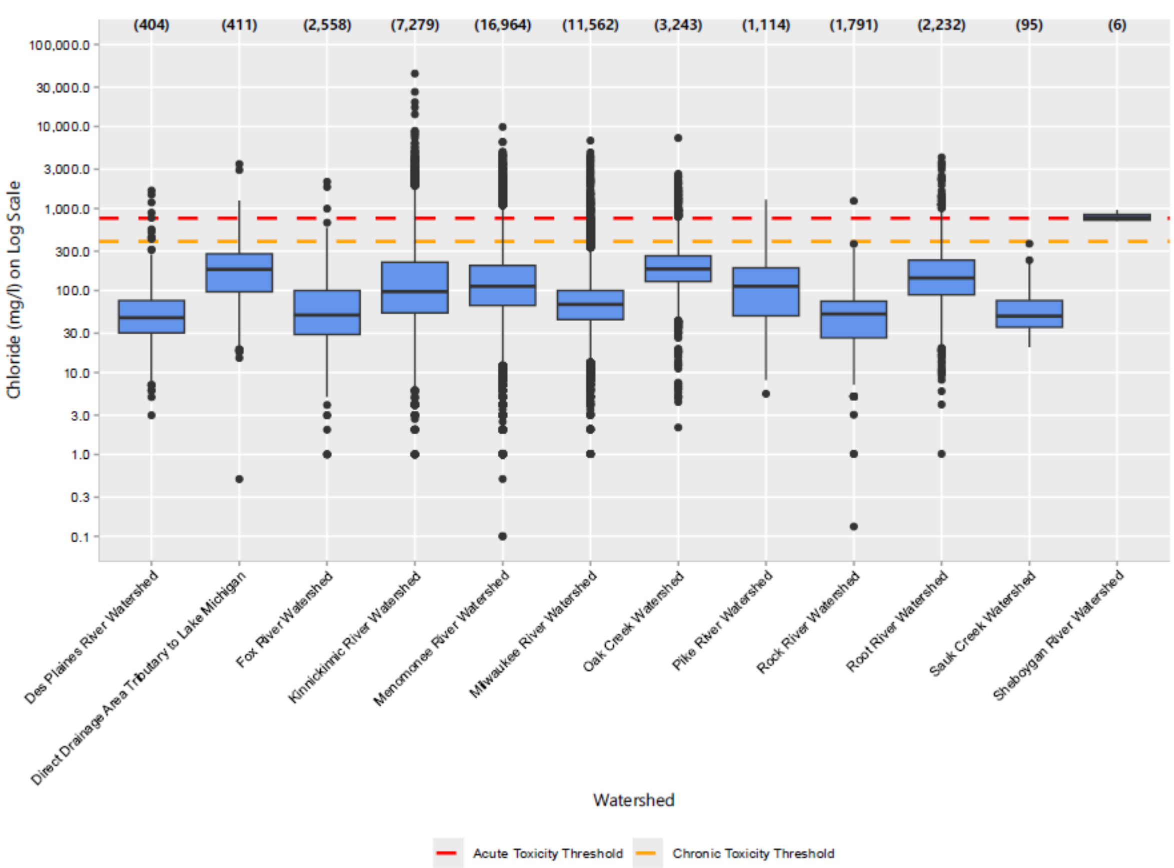
- At least 10 total samples
- At least 4 total samples -or- 10% of samples collected in winter
- At least 20% of samples collected in either summer or fall

Questions?

Chloride Conditions and Trends in Streams (Overview of Full Study Area)

Full Period of Record (1961-2022)

Figure 4.4
Distribution of Chloride Concentrations Among All Samples by Watershed: 1961-2022

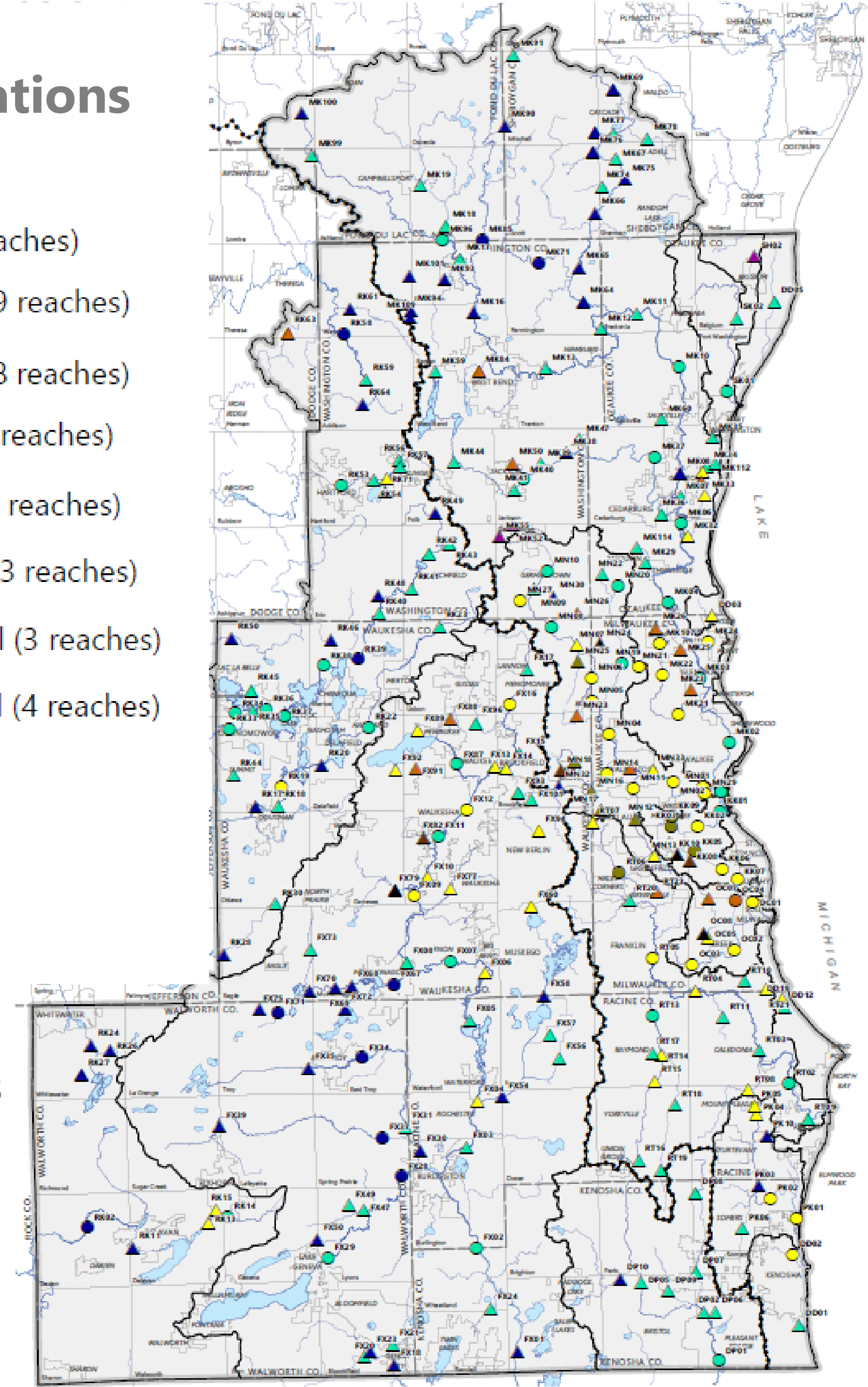


- Median chloride concentrations ranged from 46 mg/l (Des Plaines) to 180 mg/l (Oak Creek)
- All watersheds except Sauk Creek had samples exceeding the Wisconsin chronic and acute toxicity thresholds
- Most watersheds had a very large range of chloride concentrations

Map 4.9
Median Chloride Concentrations (1961-2022)

BALANCED IMBALANCED

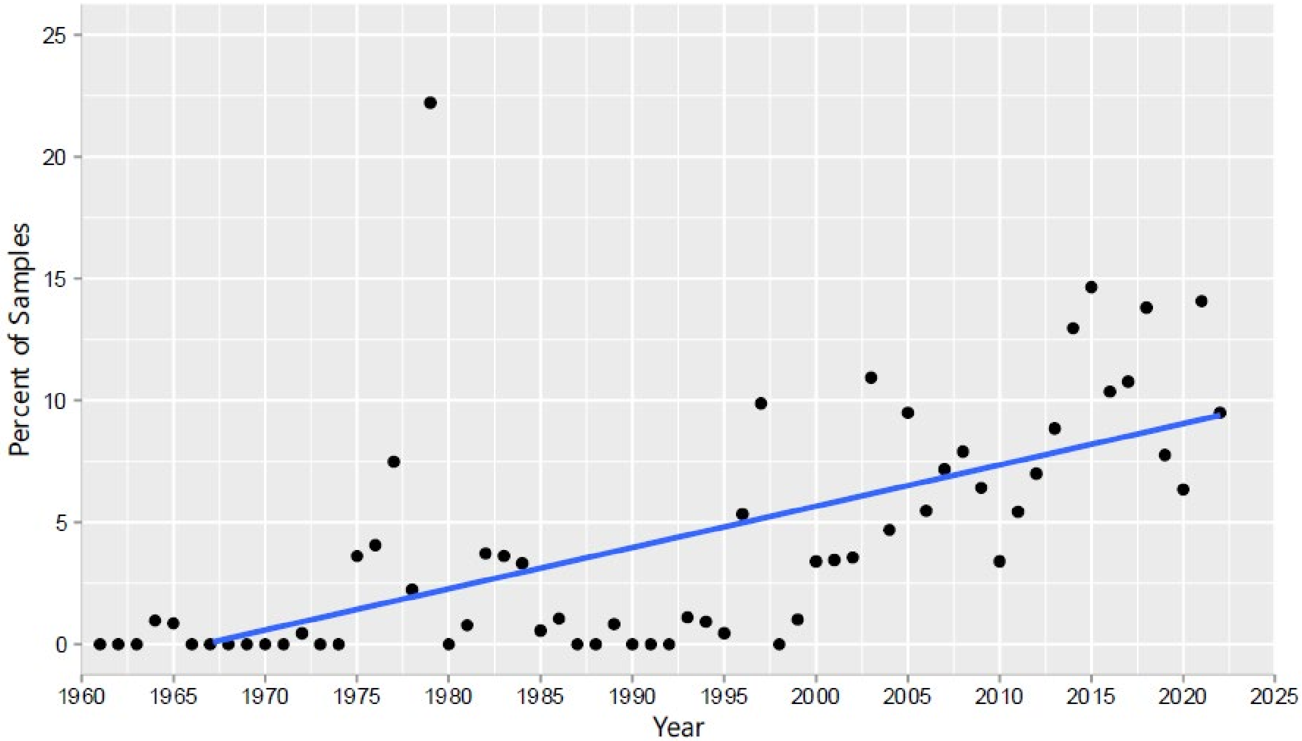
- 1 TO 35 mg/l (59 reaches)
- 36 TO 100 mg/l (109 reaches)
- 101 TO 249 mg/l (58 reaches)
- 250 TO 394 mg/l (9 reaches)
- 395 to 756 mg/l (15 reaches)
- 757 TO 1,000 mg/l (3 reaches)
- 1,001 TO 1,500 mg/l (3 reaches)
- 1,501 TO 2,400 mg/l (4 reaches)



- For reaches with balanced datasets, median chloride concentrations ranged from 14 mg/l (Mukwonago River FX71) to 663 mg/l (Mitchell Field Drainage Ditch, OC04)

- Maximum chloride concentrations for all reaches (balanced and imbalanced) ranged from 8 mg/l (Lower Pine River RK71) to 44,000 mg/l (Wilson Park Creek KK06)

Figure 4.5
Percent of Chloride Samples Exceeding Chronic Toxicity Threshold (1961-2022)



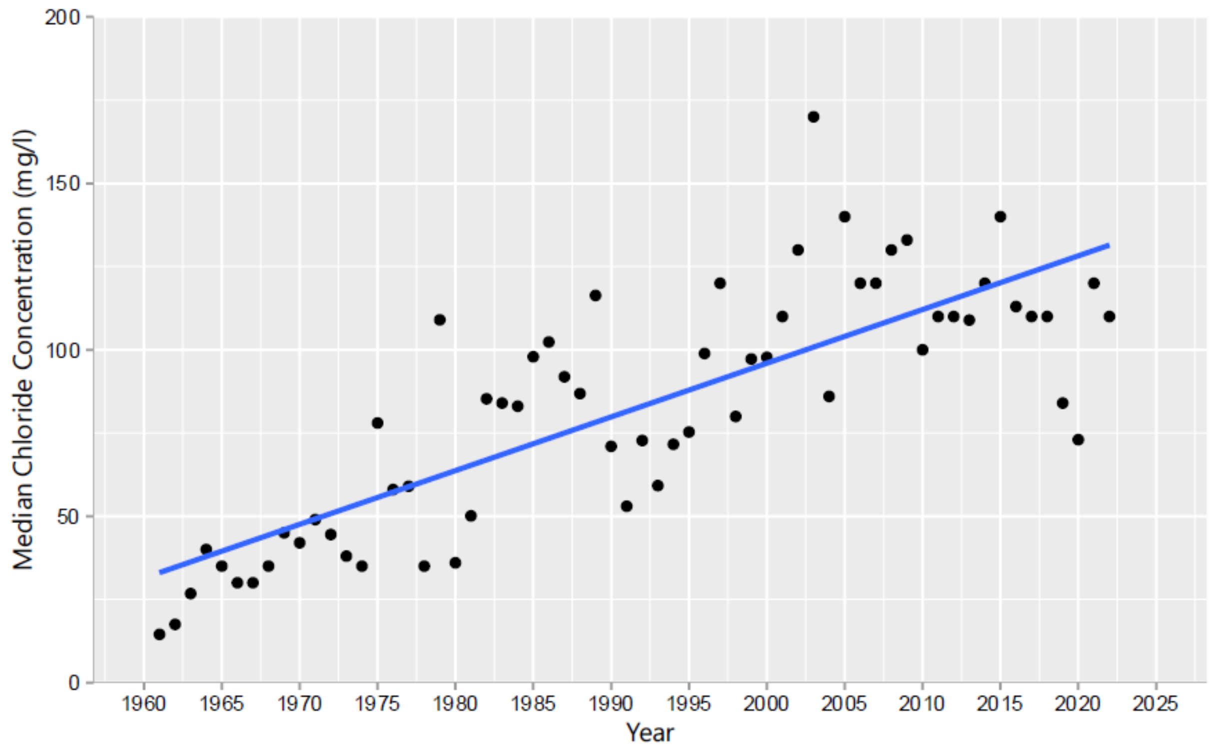
- 2,964 samples (6.2% of all samples) exceeded Wisconsin's chronic toxicity threshold (395 mg/l)
- 935 samples (2% of all samples) exceeded the acute toxicity threshold (757 mg/l)
- Percentage of chronic exceedances per year generally increased over time beginning in the mid-1970s
- Large variability from year to year

Exceedances of Various Water Quality & Biological Thresholds

- **Historical Background Concentration (10 mg/l)**
  - 99% of all samples exceeded
  - All but 2 assessment reaches had at least one sample exceeding
- **Conservative Lower Impact Concentration (35 mg/l)**
  - 87% of all samples exceeded
  - 92% of all assessment reaches had at least one sample exceeding
- **Canadian Chronic Toxicity Threshold (120 mg/l)**
  - 37% of samples exceeded
  - 58% of all assessment reaches had at least one sample exceeding
- **USEPA Chronic Toxicity Threshold (230 mg/l)**
  - 16% samples exceeded
  - 44% of all assessment reaches had at least one sample exceeding
- **Wisconsin Chronic Toxicity Threshold (395 mg/l)**
  - 6% of samples exceeded
  - 34% of all assessment reaches had at least one sample exceeding
- **Wisconsin Acute Toxicity Threshold (757 mg/l)**
  - 2% of samples exceeded
  - 26% of all assessment reaches had at least one sample exceeding
- **Extreme Impact Level Concentration (1,400 mg/l)**
  - 0.7% of samples exceeded
  - 16% of assessment reaches had at least one sample exceeding

Temporal Trends (1961-2022)

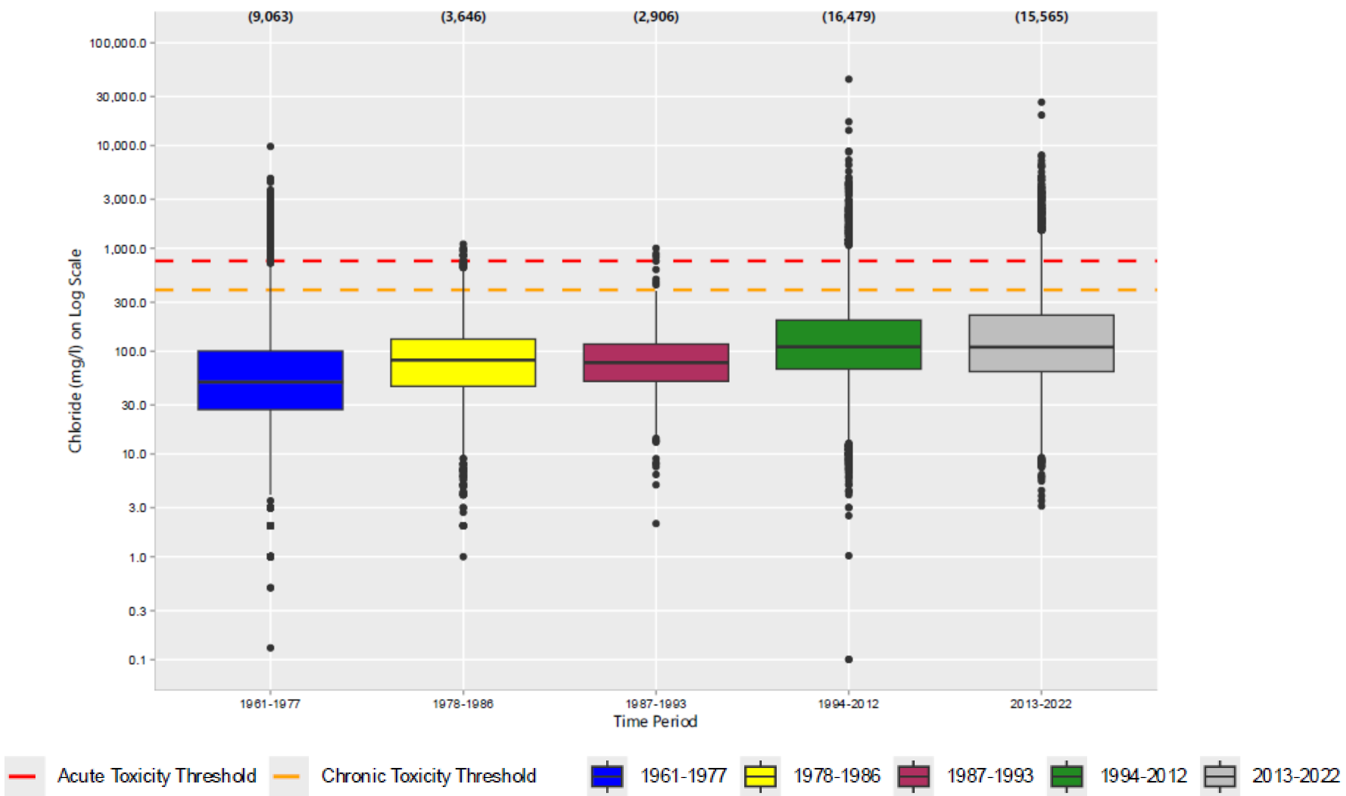
Figure 4.6
Trend in Yearly Median Chloride Concentrations in the Study Area for the Full Period of Record: 1961-2022



- Yearly medians increased about 1.6 mg/l per water year
- Lowest median: 14 mg/l in 1961
- Highest median: 170 mg/l in 2003
- Plateau or even slight decrease in median concentrations in most recent years

Temporal Trends (1961-2022)

Figure 4.7
Distribution of All Chloride Samples by Time Period for the Study Area: 1961-2022



- Full dataset divided into five time periods: 1961-1977, 1978-1986, 1987-1993, 1994-2012, and 2013-2022
- Statistically significant general increasing trend from 1961 through 2022
- Highest median and maximum concentrations occurred in the two most recent periods
- Similar median concentrations for 1994-2012 and 2013-2022 may indicate a possible stabilization in chloride conditions in recent years in the study area

Map 4.11
Trends in Chloride and Conductance (1961-2022)

- Increasing chloride trends:
  - 60 reaches
  - 80% of reaches with balanced datasets
- Decreasing chloride trends:
  - 2 reaches
  - Little Menomonee River & Root River Canal
- Increasing conductance trends:
  - 55 reaches
- Decreasing conductance trends:
  - 2 reaches
- Table 4.4 provides slope of trends (mg/l/year), R^2 values, sampling span
- Some trends have low R^2 values indicating reaches likely influenced by other factors than just time (seasonal variation, precipitation patterns, changes in land use, flow variations, etc

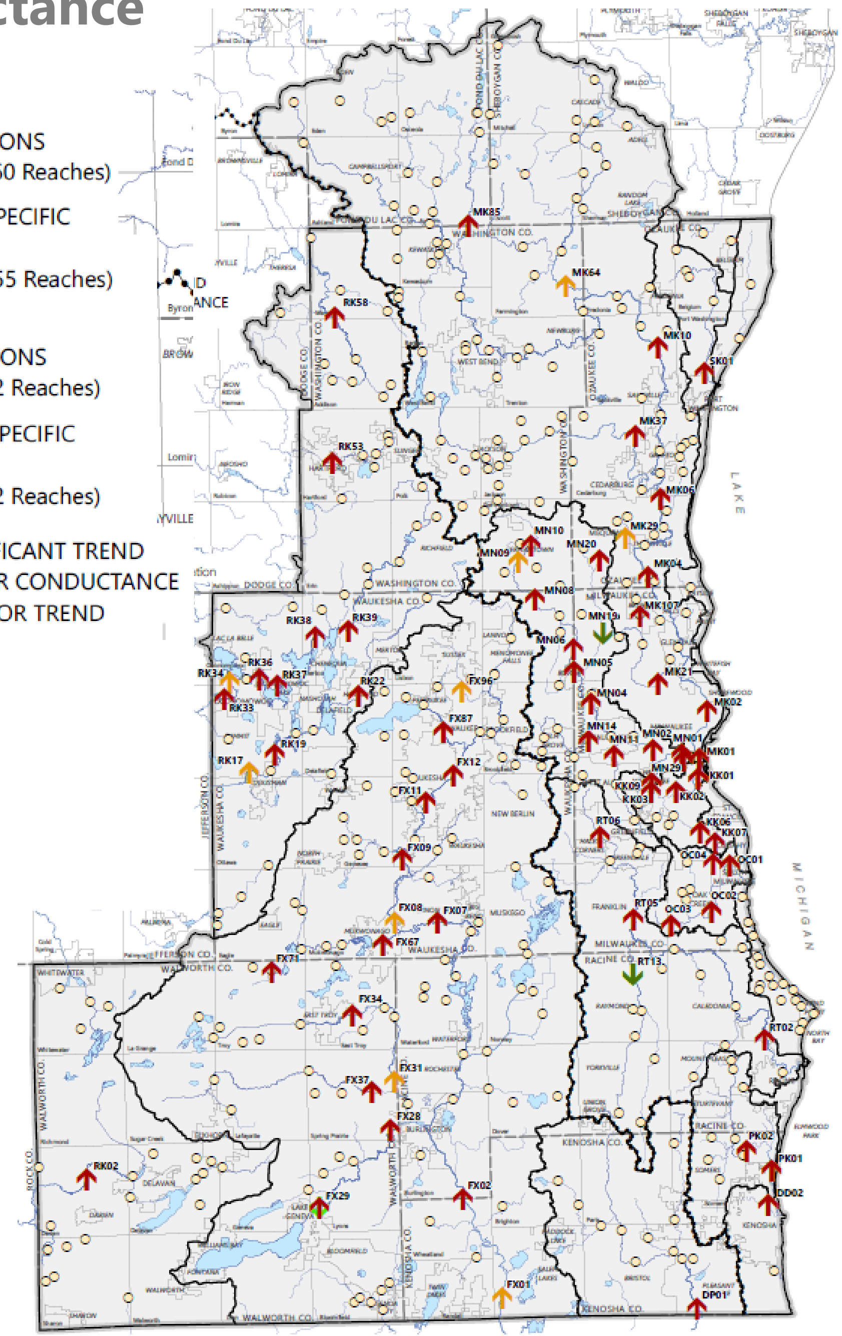
INCREASING TREND IN CHLORIDE CONCENTRATIONS (Statistically Significant - 60 Reaches)

INCREASING TREND IN SPECIFIC CONDUCTANCE LEVELS (Statistically Significant - 55 Reaches)

DECREASING TREND IN CHLORIDE CONCENTRATIONS (Statistically Significant - 2 Reaches)

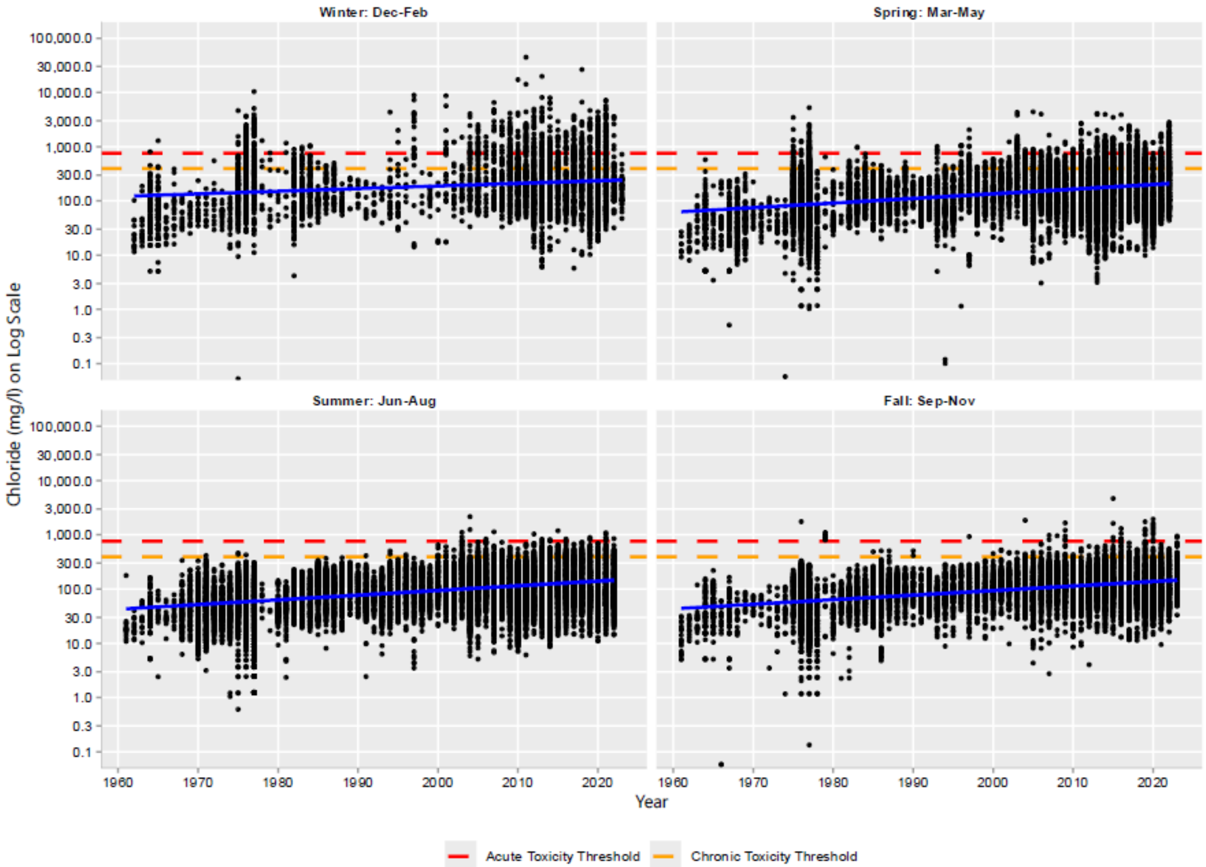
DECREASING TREND IN SPECIFIC CONDUCTANCE LEVELS (Statistically Significant - 2 Reaches)

NO STATISTICALLY SIGNIFICANT TREND FOR EITHER CHLORIDE OR CONDUCTANCE OR INSUFFICIENT DATA FOR TREND



Seasonal Trends (1961-2022)

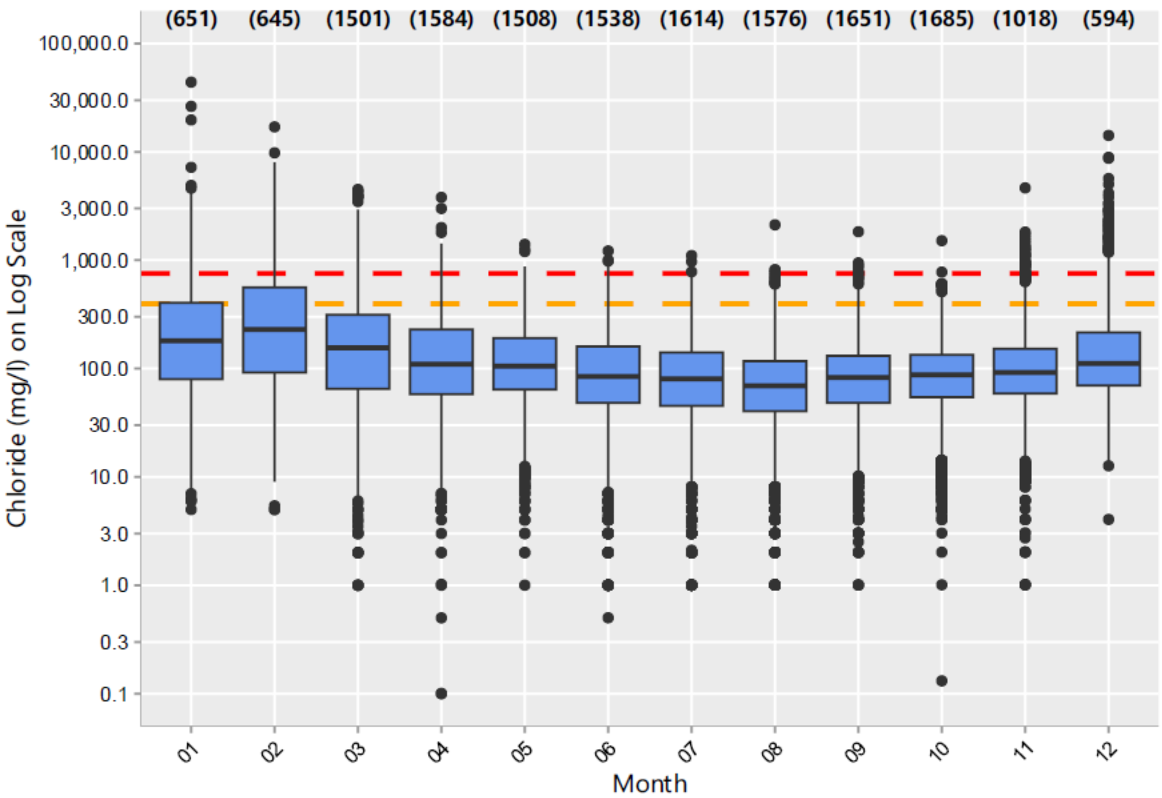
Figure 4.8
Trends in Chloride Concentration by Season Among All Samples Collected During the Full Period of Record: 1961-2022



- Chloride has increased across all 4 seasons over time
  - Winter: 4.3 mg/l/yr
  - Spring: 2.9 mg/l/yr
  - Summer: 1.7 mg/l/yr
  - Fall: 1.7 mg/l/yr
- Increasing exceedances of WI toxicity thresholds

Monthly Trends (1961-2022)

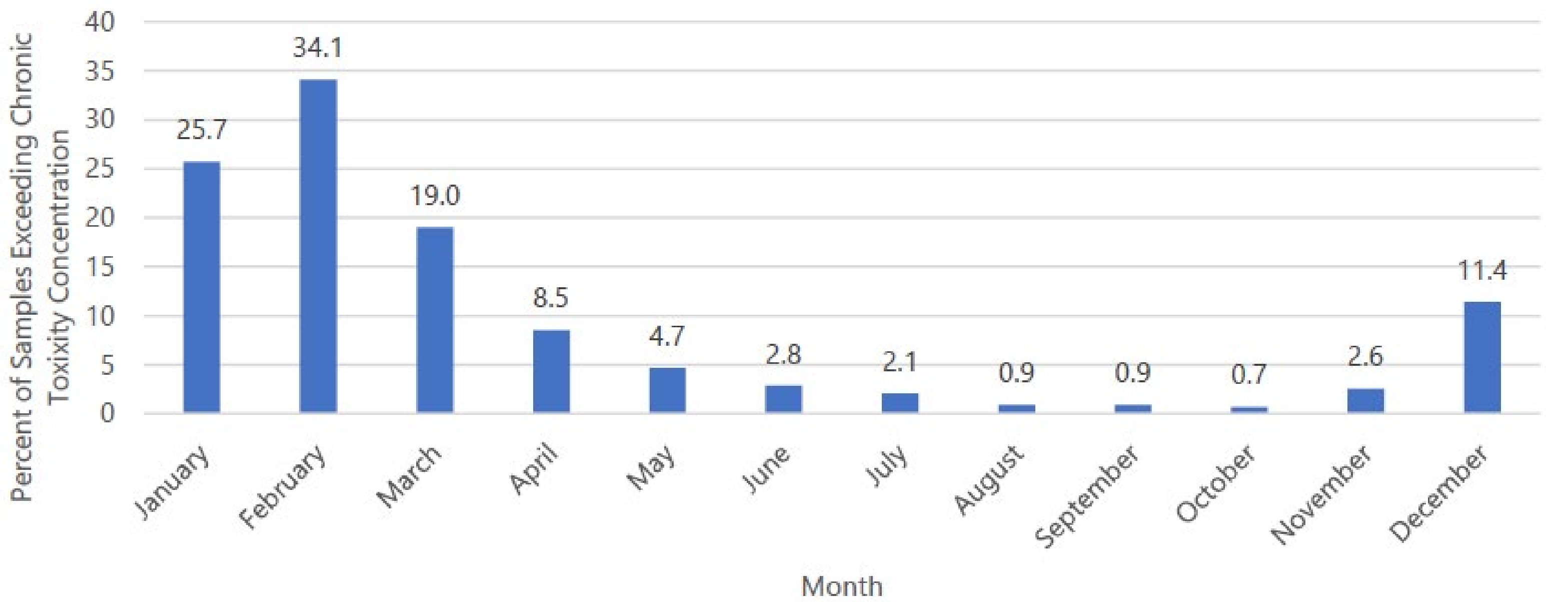
Figure 4.9
Distribution of Chloride Concentrations by Month for All Samples Collected During the Full Period of Record: 1961-2022



- In January and February, more than 25% of samples surpassed WI chronic toxicity threshold
- Chloride exceeded both WI chronic and acute toxicity thresholds in every month
- Often substantially above levels known to cause biological harm

Monthly Exceedance Trends (1961-2022)

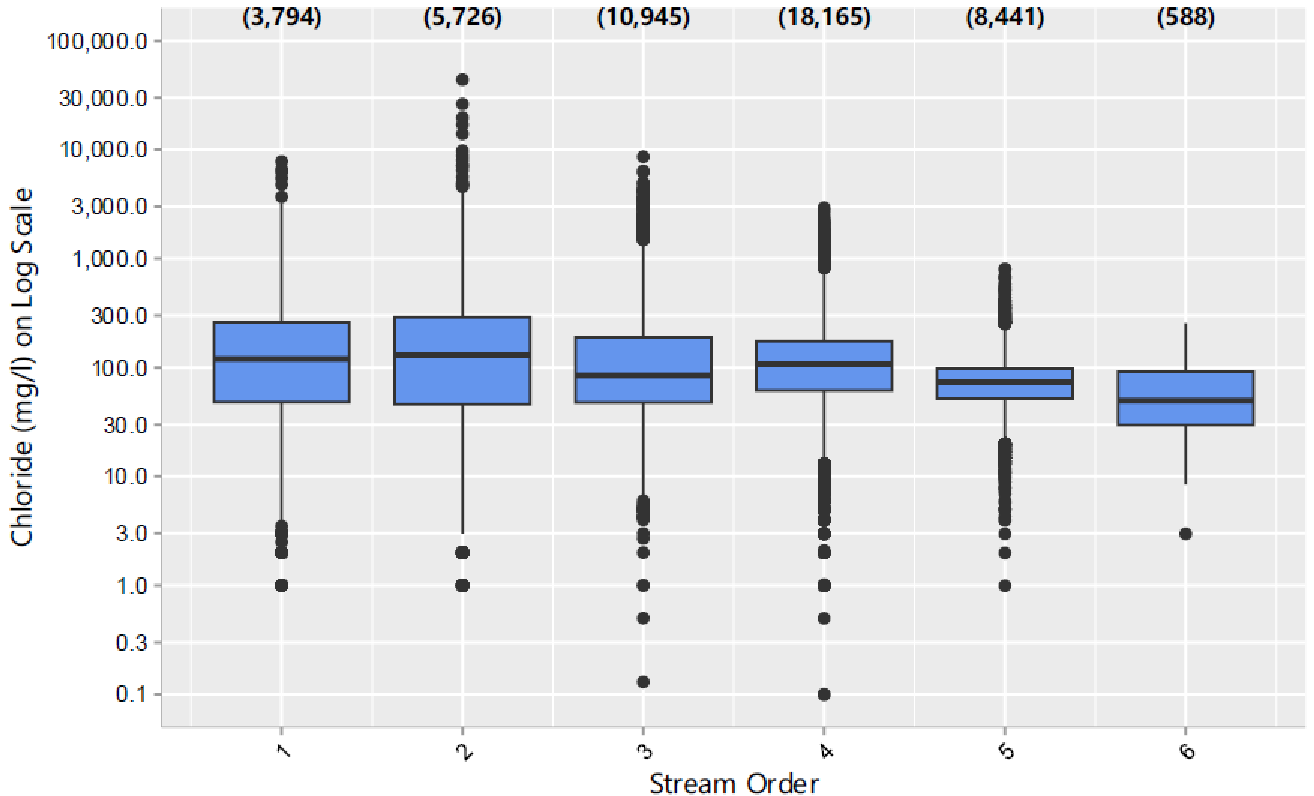
Figure 4.10
Percent of Chloride Samples Exceeding Chronic Toxicity Concentration Among All Samples Collected During the Full Period of Record: 1961-2022



- Most chronic toxicity exceedances occur in colder months, highlighting significant impact of winter deicing practices
- Exceedances decreased significantly May through November; Lowest in August through October
- Nonetheless, 387 chronic toxicity concentration exceedances June through November

Stream Size

Figure 4.11
Distribution of Chloride Concentration by Stream Order for All Samples Collected During the Full Period of Record: 1961-2022



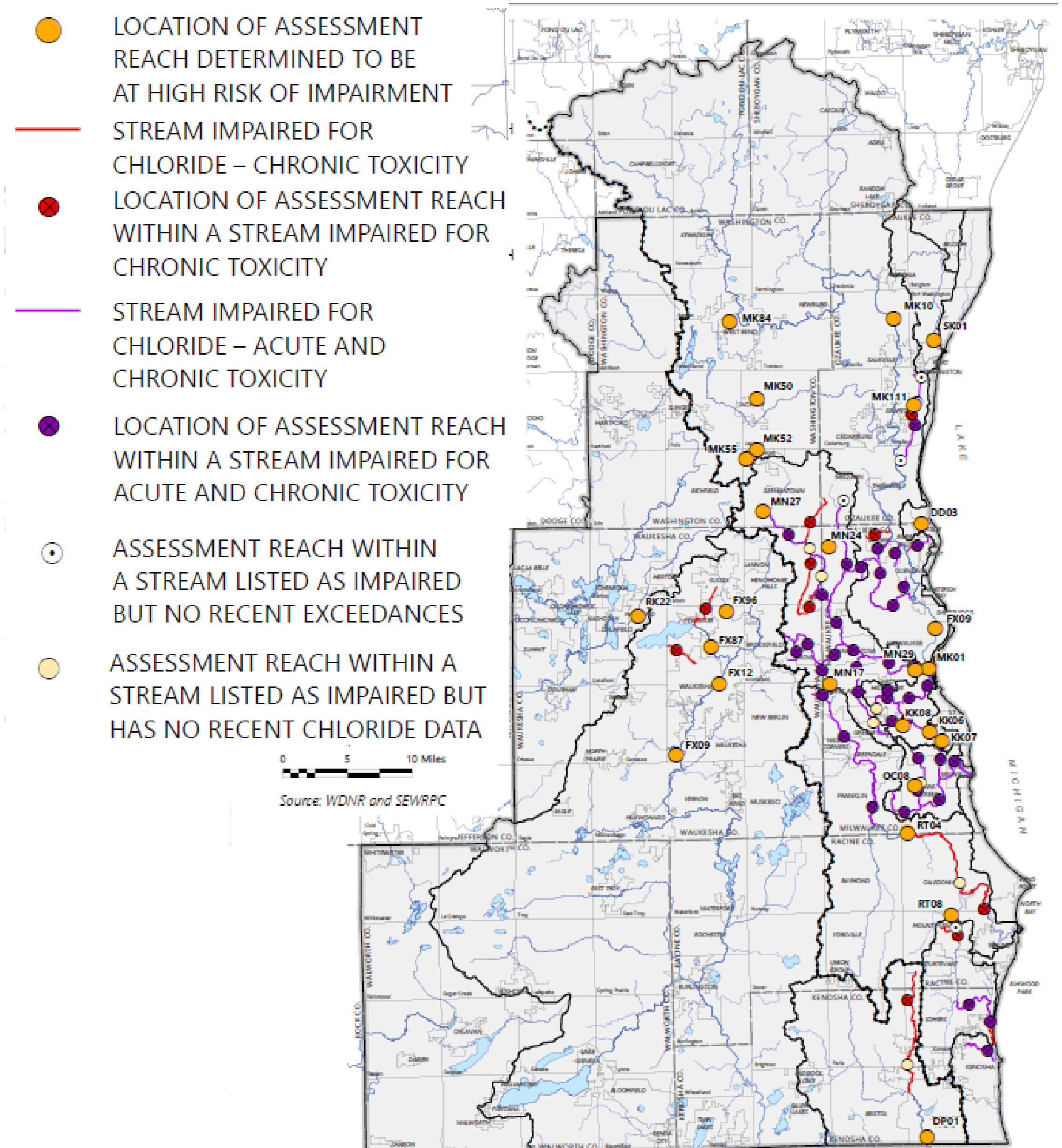
- Median chloride generally decreases from smaller to larger stream order
    - 64 mg/l (6th order rivers) to 284 mg/l (2nd order streams)

- Peaks in chloride evident in all stream sizes, especially in smaller streams (orders 1 – 3)

Streams at High Risk for Chronic Toxicity Impairment

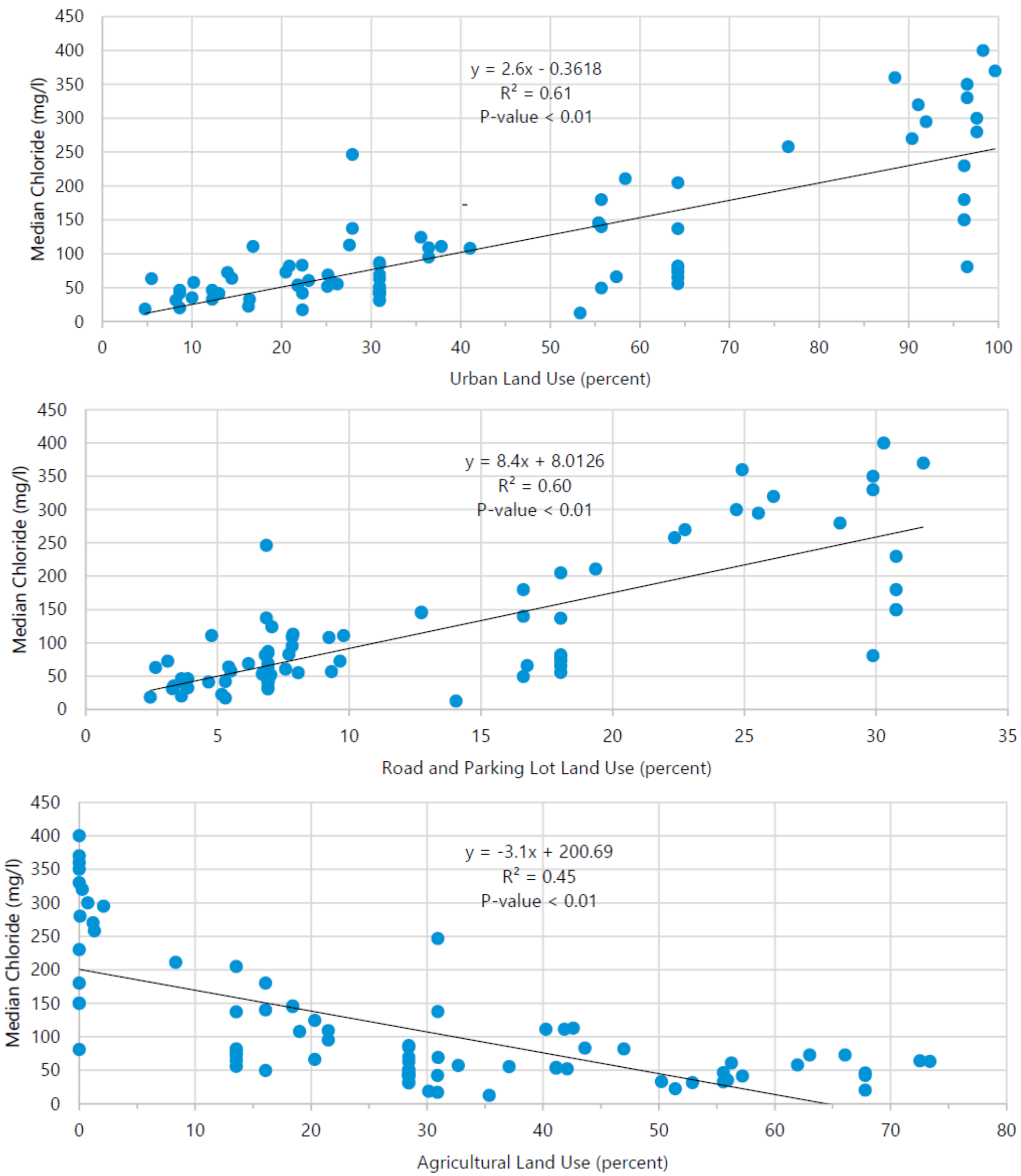
- "High Risk" streams for future impairment:
  - Not currently listed on 303(d) list
  - At least 1 recent-period sample within 10% of WI chronic threshold (>355 mg/l)
- 26 streams determined to be high risk for impairment (orange circles)
-

Map 4.14
Stream Assessment Reaches Determined to be High Risk for Impairment and Assessment Reaches Within Streams that are Impaired for Chloride Toxicity (Recent Period of Record)



Land Use and Median Chloride Relationships

Figure 4.15
Relationships Between Subwatershed Land Use and Median Chloride Concentration at Balanced Assessment Reaches During the Recent Period of Record: 2013-2022

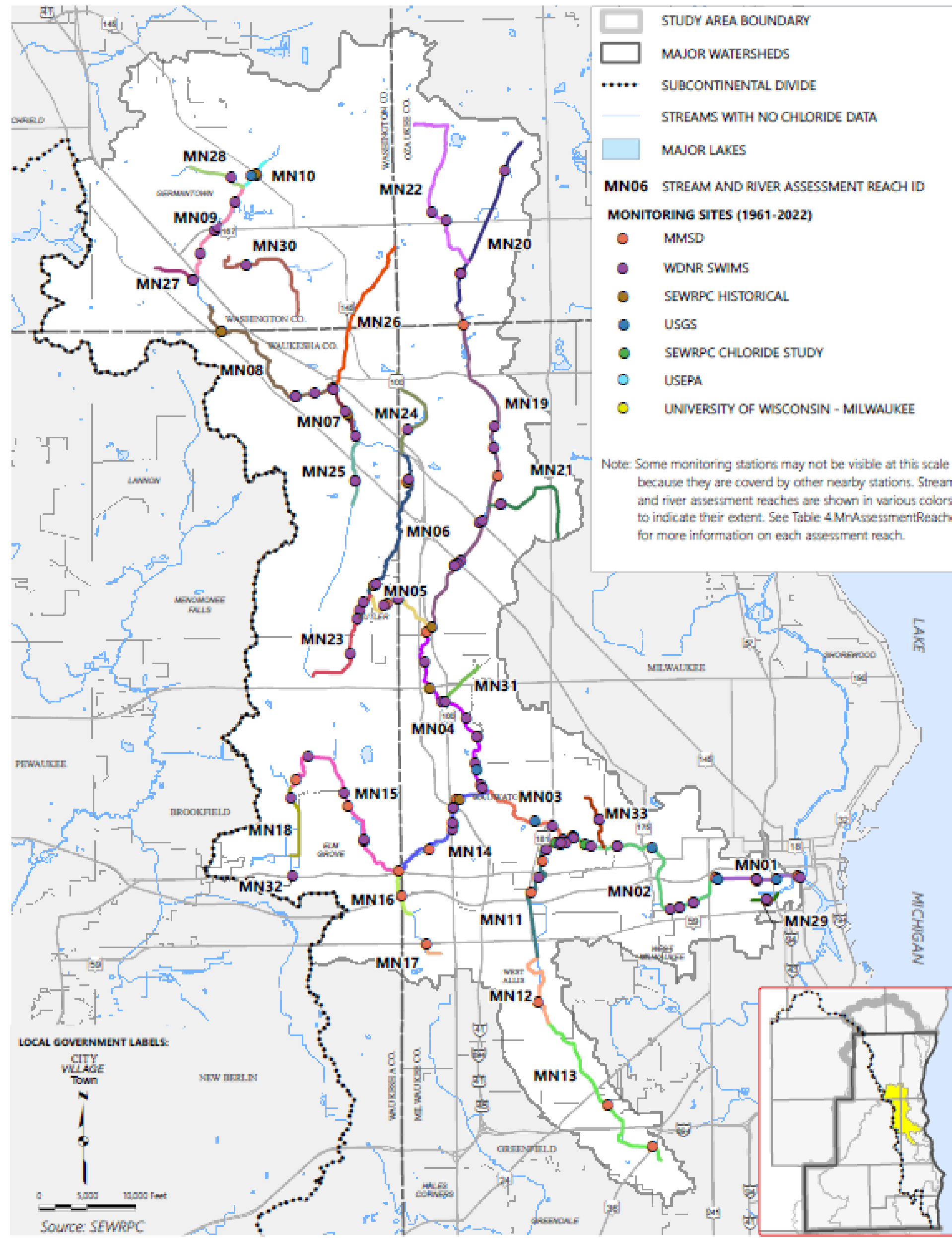


Menomonee River Watershed – Closer Look

Full Period of Record (1961-2022):

- Most comprehensive chloride and conductance dataset in study area
- 149 monitoring sites
- 33 assessment reaches
    - 16,964 chloride samples
    - 14,206 specific conductance measurements
- Availability of data varied greatly among assessment reaches
    - 0 to 4,186 chloride samples
    - 1 to 3,879 conductance measurements
- 14 reaches with balanced chloride datasets
- 16 reaches with balanced conductance datasets

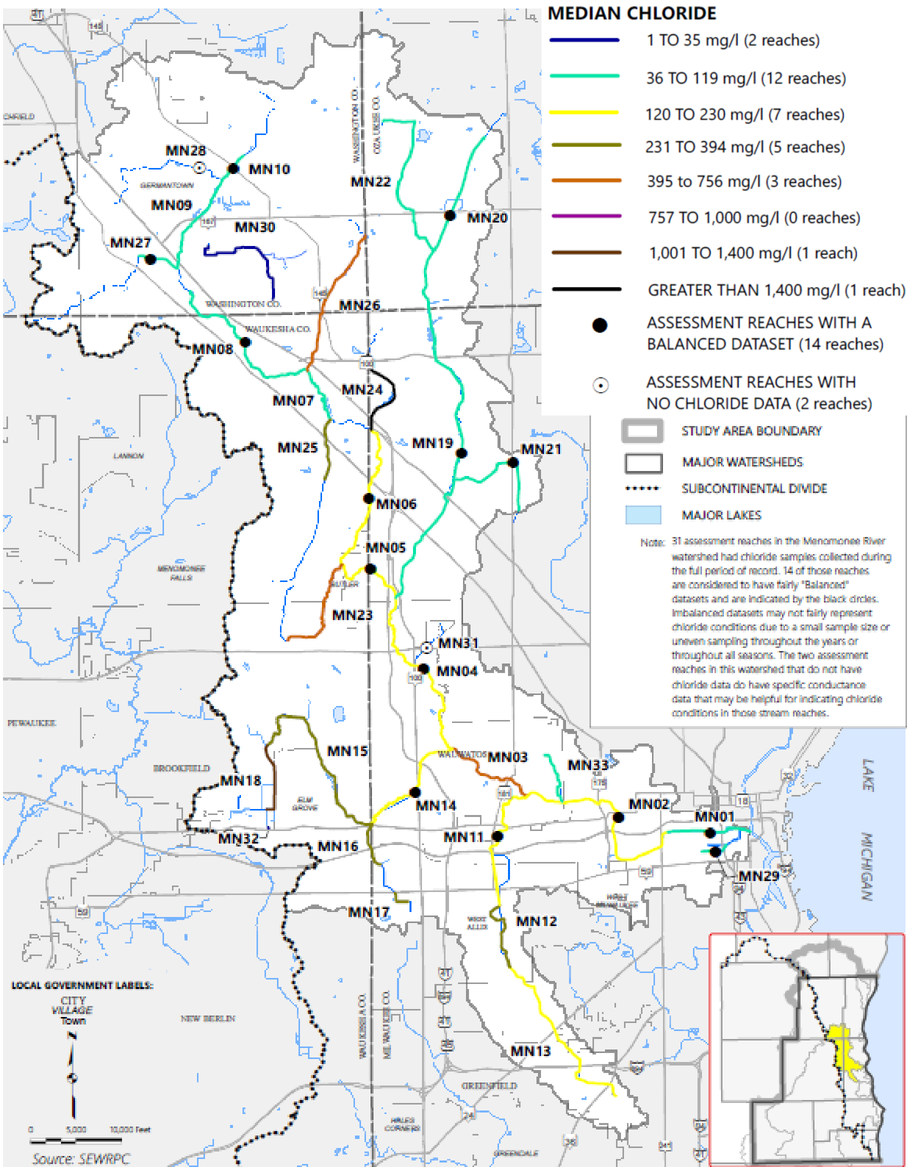
Map 4.58
Monitoring Sites and Assessment Reaches for Streams Within the Menomonee River Watershed



Median Chloride and Conductance Levels (2013-2022)

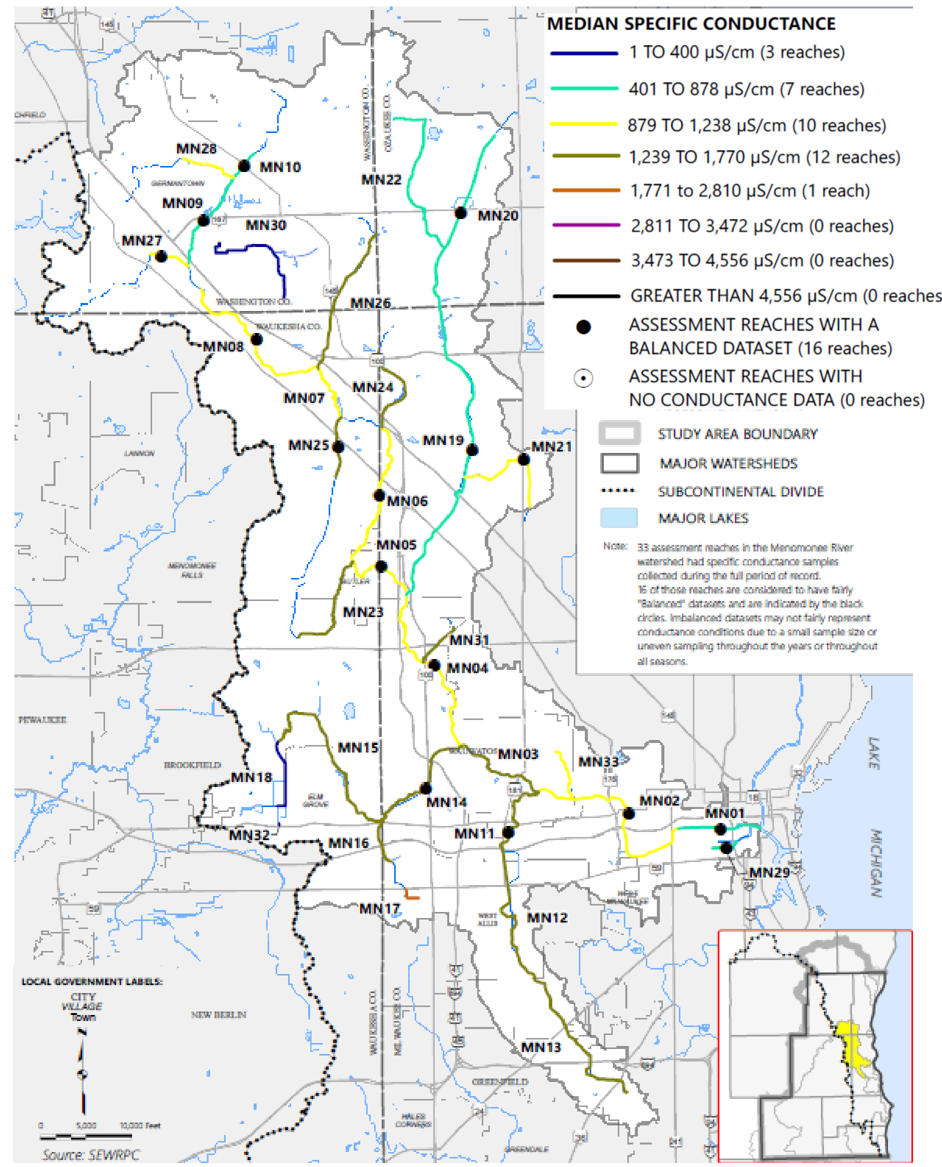
Median Chloride:

Map 4.59
Median Chloride Concentrations Within the Menomonee River Watershed for the Full Period of Record: 1961-2022



Median Conductance:

Map 4.60
Median Specific Conductance Within the Menomonee River Watershed for the Full Period of Record: 1961-2022



Menomonee River Watershed – Exceedances of Various WQ & Biological Thresholds (1961-2022)

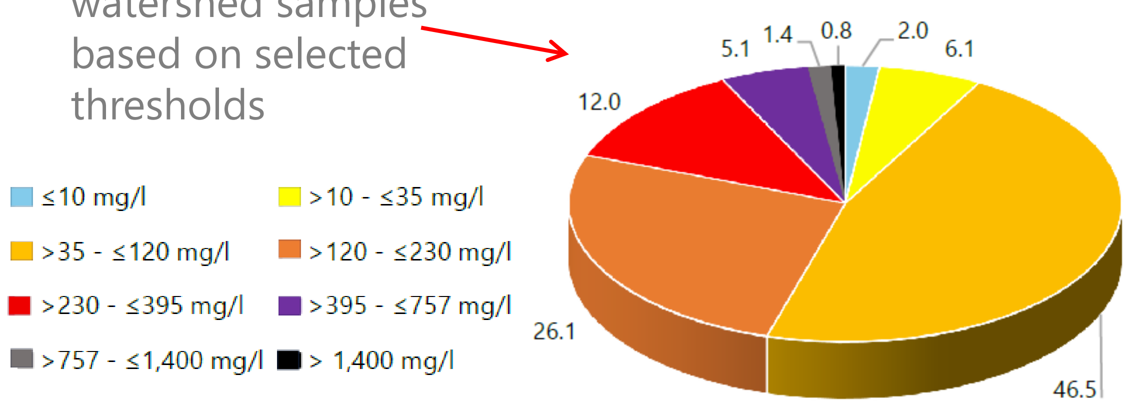
Table 4.31
Percentage of Measurements in Which Chloride Concentrations Exceeded Various Water Quality Thresholds in the Menomonee River Watershed Full Record: 1961-2022

Reach ID	Assessment Reach	Total Chloride Samples	Chloride Measurements Exceeding Concentration Thresholds (percent)						
			10 mg/l	35 mg/l	120 mg/l	230 mg/l	395 mg/l	757 mg/l	1,400 mg/l
MN01	Menomonee River: 0 to 1.8 miles	1,396	100	99.3	62.8	23.5	6.2	1.4	0.0
MN02	Menomonee River: 1.8 to 6.3 miles	231	100	100	87.9	47.2	15.6	6.1	1.3
MN03	Menomonee River: 6.3 to 8.4 miles	5	100	100	100	100	100	20.0	0.0
MN04	Menomonee River: 8.4 to 12.6 miles	359	100	99.4	84.1	25.1	5.8	1.4	0.3
MN05	Menomonee River: 12.6 to 14.5 miles	191	100	99.5	85.3	26.2	5.2	1.0	0.0
MN06	Menomonee River: 14.5 to 18.0 miles	--	--	--	--	--	--	--	--
MN07	Menomonee River: 19.0 to 20.4 miles	--	--	--	--	--	--	--	--
MN08	Menomonee River: 20.4 to 24.2 miles	204	100	100	67.2	3.4	1.0	0.5	0.0
MN09	Menomonee River: 24.8 to 27.1 miles	--	--	--	--	--	--	--	--
MN10	Menomonee River: 27.1 to 27.8 miles	184	100	89.1	0.0	0.0	0.0	0.0	0.0
MN11	Honey Creek: 0 to 3.1 miles	233	100	97	91.0	80.7	51.5	21.0	9.9
MN12	Honey Creek: 3.1 to 4.9 miles	86	100	97.7	84.9	80.2	57.0	15.1	3.5
MN13	Honey Creek: 4.9 to 9.0 miles	--	--	--	--	--	--	--	--
MN14	Underwood Creek: 0 to 2.8 miles	202	100	99.5	93.6	81.2	40.6	9.4	3.0

- Each assessment reach was evaluated for percentage of samples surpassing selected thresholds

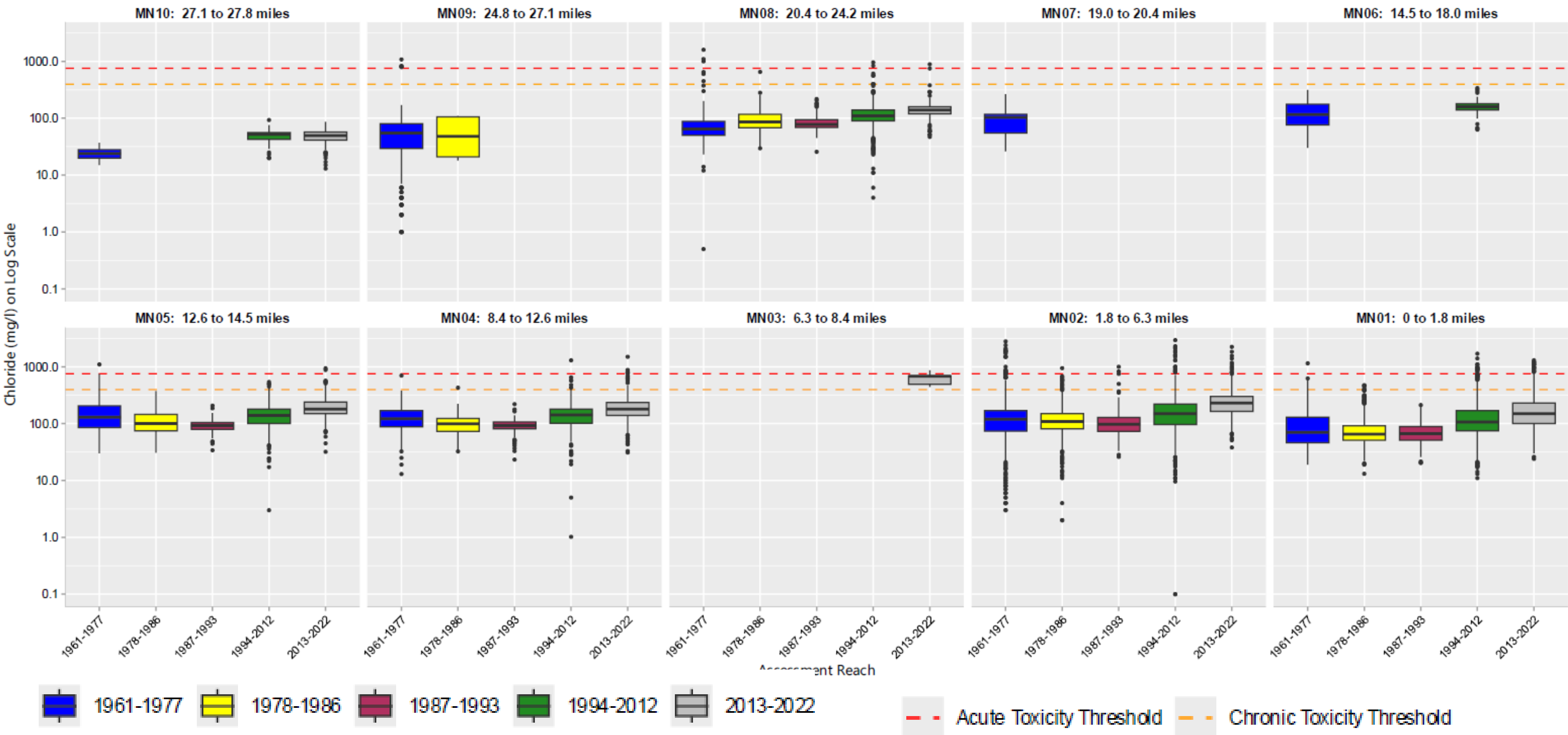
- Distribution of watershed samples based on selected thresholds

Figure 4.41
Percent of Chloride Samples Collected in the Menomonee River Watershed Within Various Thresholds of Water Quality: 1961-2022



Chloride by Time Period (1961-2022)

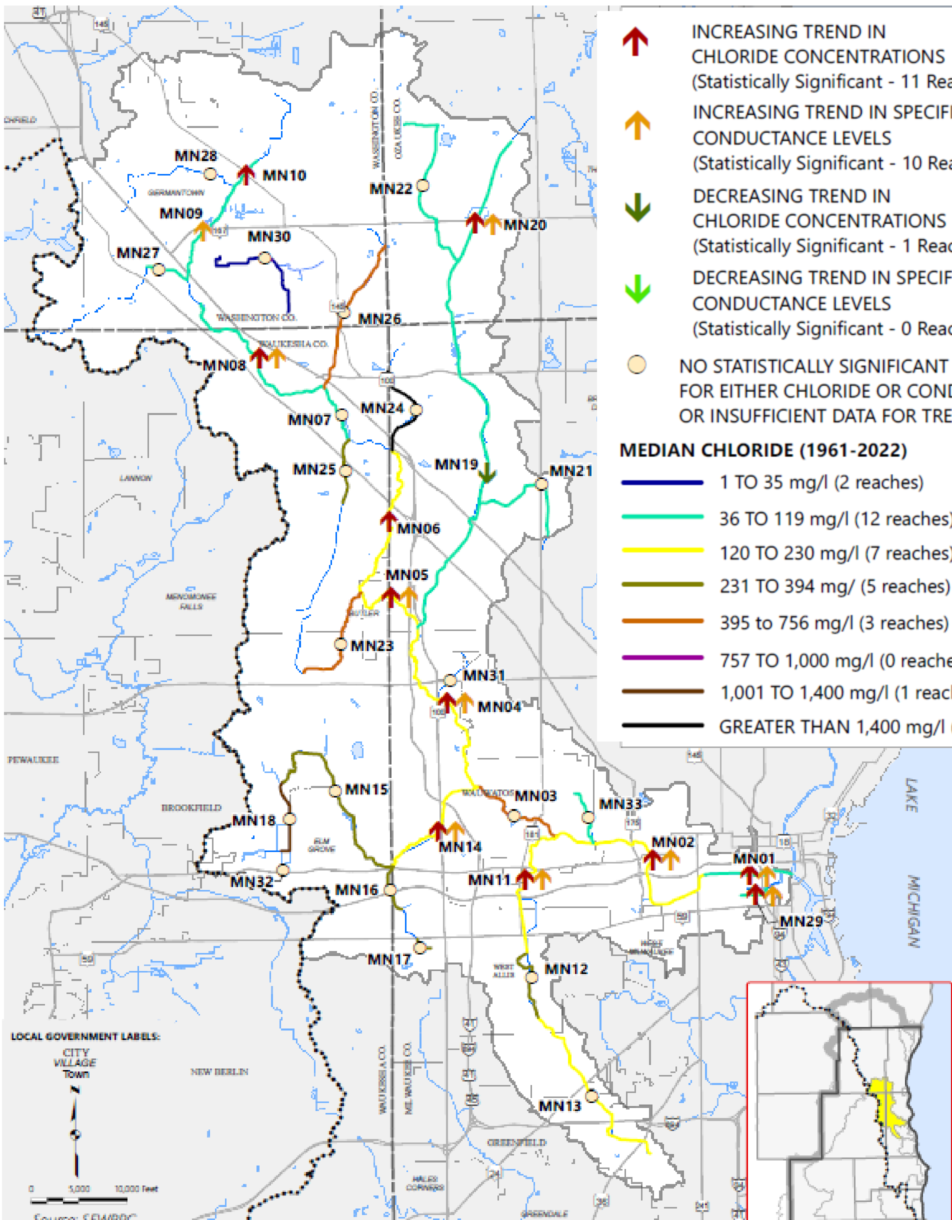
Figure 4.42
Distribution of Chloride Concentrations for All Samples Collected at Assessment Reaches Along the Mainstem of the Menomonee River: 1961-2022



- Distribution of chloride concentrations for all samples collected across the 10 assessment reaches of the Menomonee River mainstem. Analyzed across five time periods.

Trends in Chloride and Conductance (1961-2022)

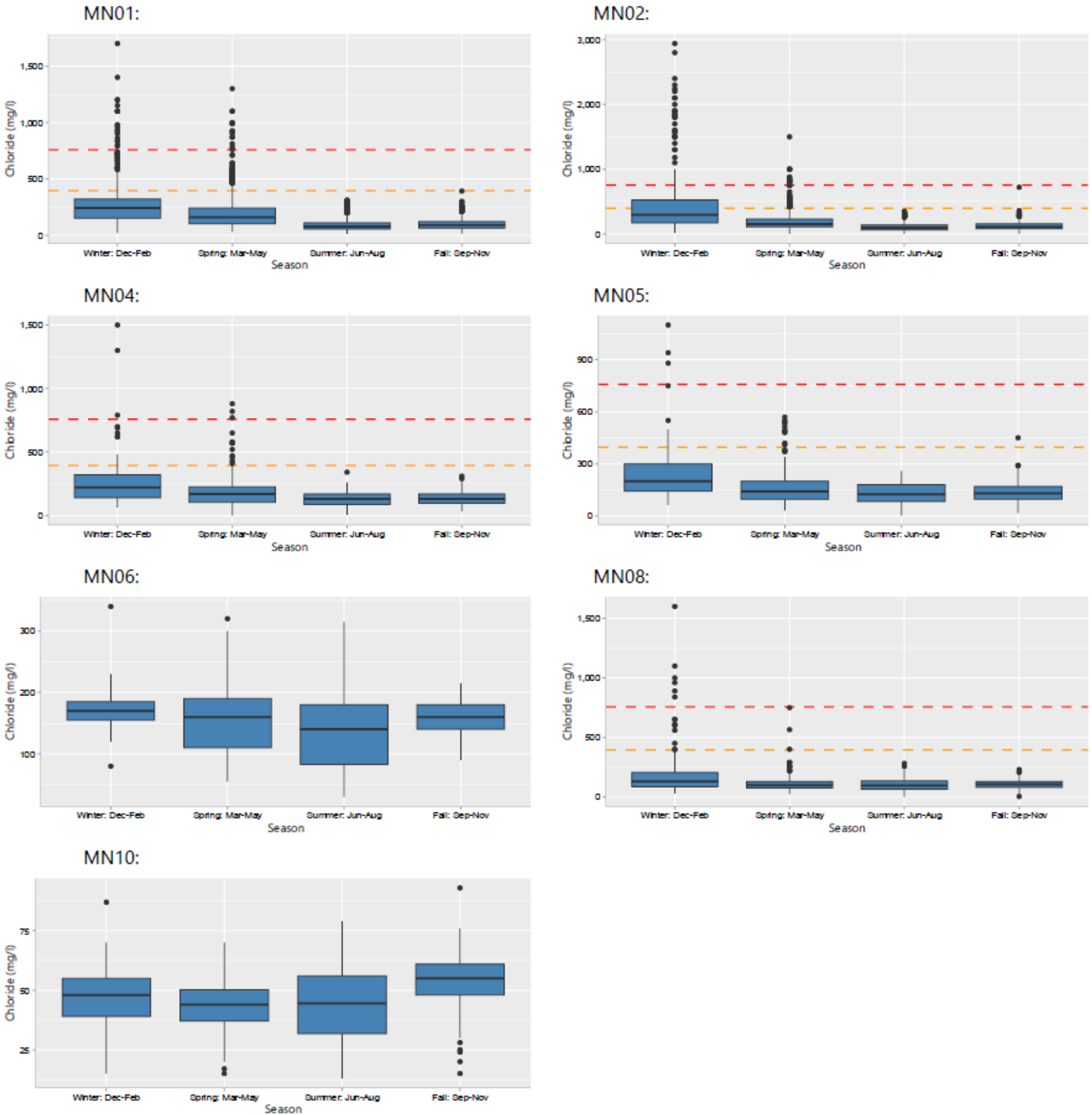
Map 4.61
Trends in Chloride and Specific Conductance Among Assessment Reaches Within the Menomonee River Watershed over the Full Period of Record: 1961-2022



- Increasing chloride trends:
  - 11 assessment reaches
  - 79% of reaches with balanced datasets
- Decreasing chloride trends:
  - 1 reach
  - Little Menomonee River (MN19)
- Increasing conductance trends:
  - 10 reaches
- Decreasing conductance trends:
  - None
- 9 reaches with increasing trends in both chloride and specific conductance
- Table 4.4 provides slope (mg/l/year) and other linear regression stats for these trends

Chloride by Season

Figure 4.44
Chloride Concentrations by Season for Balanced Menomonee River Mainstem Assessment Reaches: 1961-2022



- Show distribution of chloride levels across winter, spring, summer, fall (balanced assessment reaches only) for Menomonee River mainstem

- Downstream reaches:
  - Winter shows highest median and peak chloride; Slightly less elevated levels persisting into spring
  - Summer and fall exhibit lowest levels

- Upstream reaches:
  - Less variation between snow impacted seasons (winter/spring) and warmer seasons (summer/fall)
  - MN10 observed highest levels in fall

Menomonee River Watershed – Recent Conditions: 2013-2022

Dataset for Recent Period of Record (2013-2022):

- 29 assessment reaches with recent period data:
  - 4,379 chloride samples
  - 4,388 specific conductance measurements
- Availability of data varied greatly among assessment reaches
  - 0 to 1,396 chloride samples
  - 0 to 1,386 conductance measurements
- 10 reaches with balanced recent period chloride datasets
- 18 reaches with balanced recent period conductance datasets

Menomonee River Watershed – Recent Exceedances of Various WQ & Biological Thresholds (2013-2022)

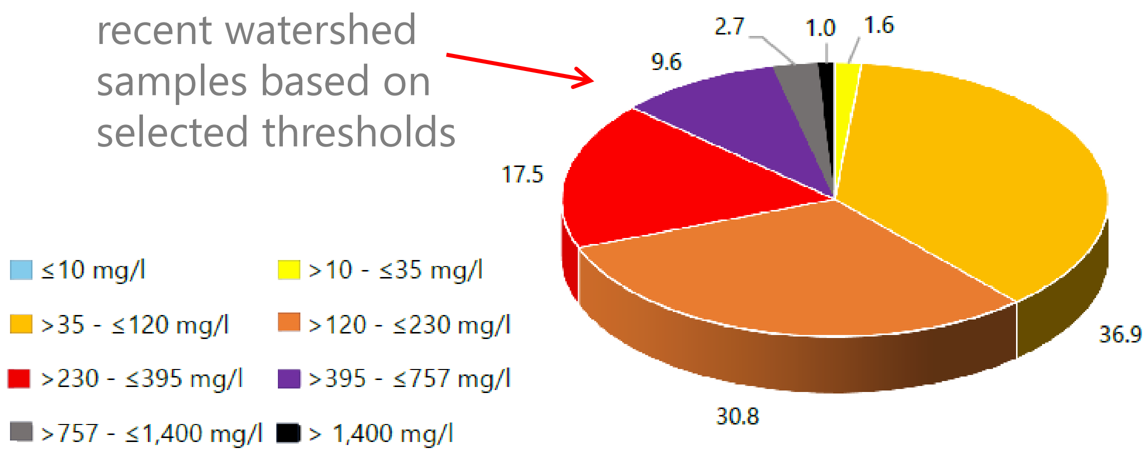
Table 4.33
Percentage of Recent Measurements in Which Chloride Concentration Exceeded Various Water Quality Thresholds in the Menomonee River Watershed Recent Record: 2013-2022

Reach ID	Assessment Reach	Total Chloride Samples	Chloride Measurements Exceeding Concentration Thresholds (percent)						
			10 mg/l	35 mg/l	120 mg/l	230 mg/l	395 mg/l	757 mg/l	1,400 mg/l
MN01	Menomonee River: 0 to 1.8 miles	1,396	100	99.3	62.8	23.5	6.2	1.4	0.0
MN02	Menomonee River: 1.8 to 6.3 miles	231	100	100	87.9	47.2	15.6	6.1	1.3
MN03	Menomonee River: 6.3 to 8.4 miles	5	100	100	100	100	100	20.0	0.0
MN04	Menomonee River: 8.4 to 12.6 miles	359	100	99.4	84.1	25.1	5.8	1.4	0.3
MN05	Menomonee River: 12.6 to 14.5 miles	191	100	99.5	85.3	26.2	5.2	1.0	0.0
MN06	Menomonee River: 14.5 to 18.0 miles	--	--	--	--	--	--	--	--
MN07	Menomonee River: 19.0 to 20.4 miles	--	--	--	--	--	--	--	--
MN08	Menomonee River: 20.4 to 24.2 miles	204	100	100	67.2	3.4	1.0	0.5	0.0
MN09	Menomonee River: 24.8 to 27.1 miles	--	--	--	--	--	--	--	--
MN10	Menomonee River: 27.1 to 27.8 miles	184	100	89.1	0.0	0.0	0.0	0.0	0.0
MN11	Honey Creek: 0 to 3.1 miles	233	100	97	91.0	80.7	51.5	21.0	9.9
MN12	Honey Creek: 3.1 to 4.9 miles	86	100	97.7	84.9	80.2	57.0	15.1	3.5
MN13	Honey Creek: 4.9 to 9.0 miles	--	--	--	--	--	--	--	--
MN14	Underwood Creek: 0 to 2.8 miles	202	100	99.5	93.6	81.2	40.6	9.4	3.0

- Each assessment reach was evaluated for percentage of recent samples surpassing selected thresholds

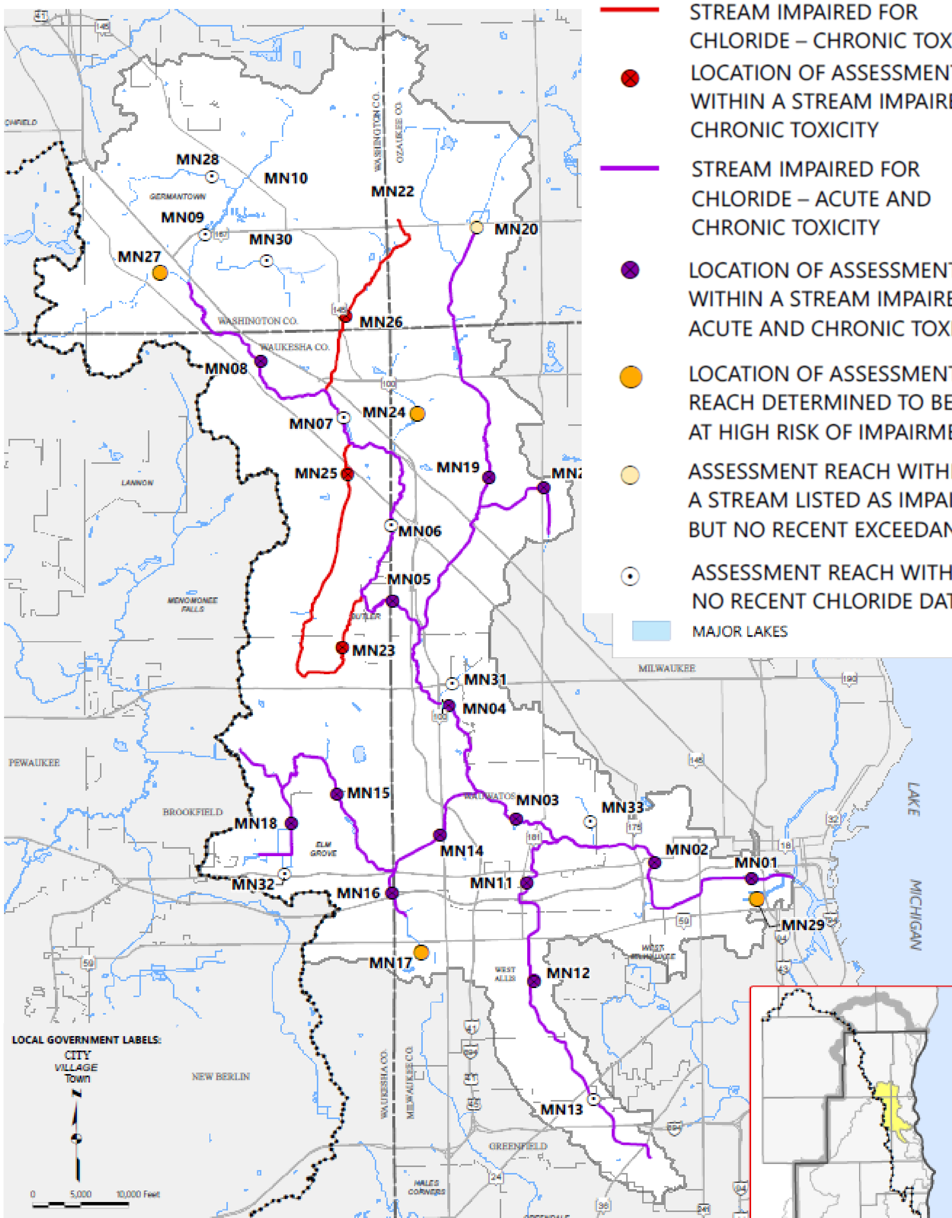
- Distribution of recent watershed samples based on selected thresholds

Figure 4.46
Percent of Recent Chloride Samples Collected in the Menomonee River Watershed Within Various Thresholds of Water Quality: 2013-2022



Streams Impaired for Chloride – Menomonee River Watershed

Map 4.64
Streams Impaired for Chloride Within the Menomonee River Watershed: 2024

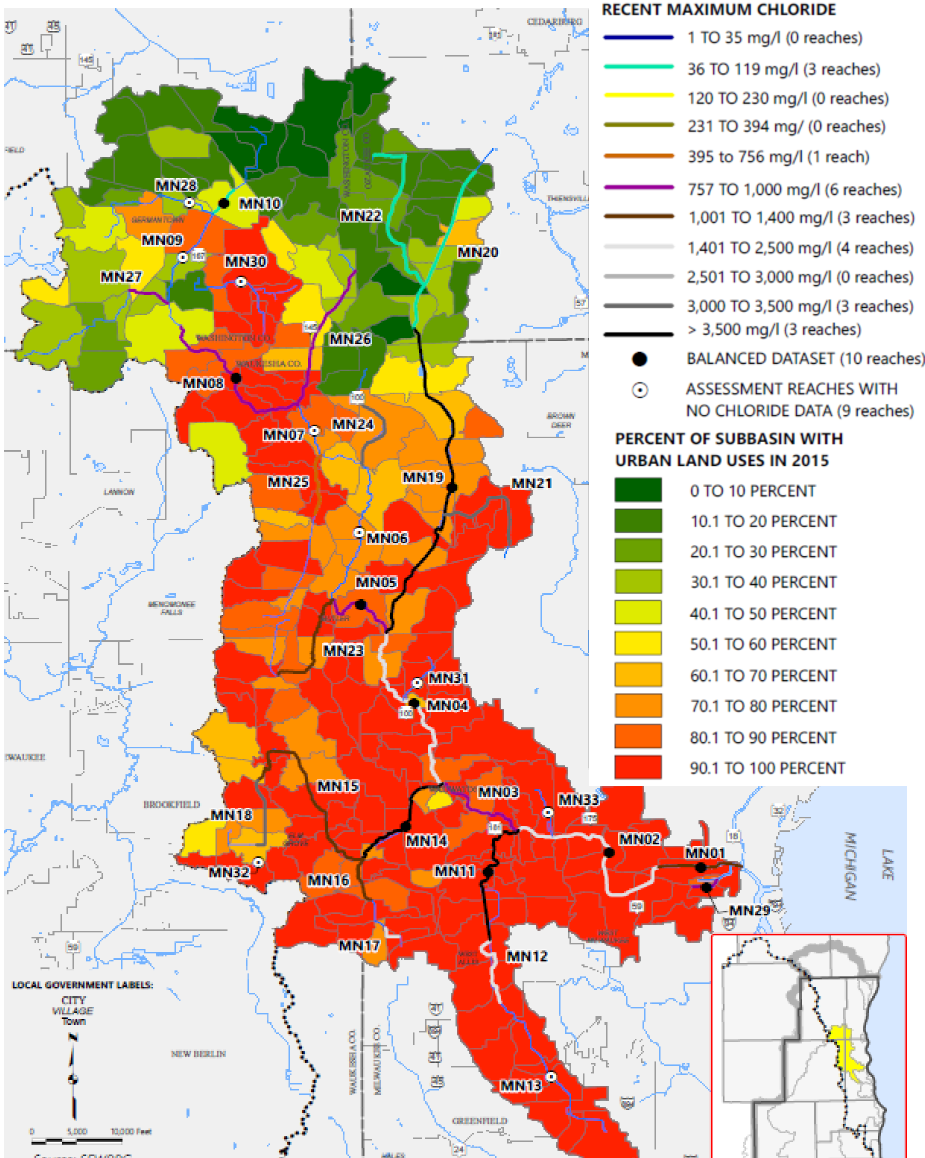


- 10 streams in watershed listed on 303(d) list for chloride impairment (see Table 4.34)
- Includes 21 of 33 assessment reaches (64% of watershed reaches)
  - 18 reaches within streams with acute impairments (purple circles)
  - 3 reaches within streams with chronic impairments (red circles)
- 4 additional stream reaches had observed maximum chloride concentrations above the chronic and acute toxicity thresholds but were not listed as impaired – likely due to limited datasets.
  - Shown as "high risk" stream reaches (orange circles)

Land Use and Maximum Chloride Levels (2013-2022)

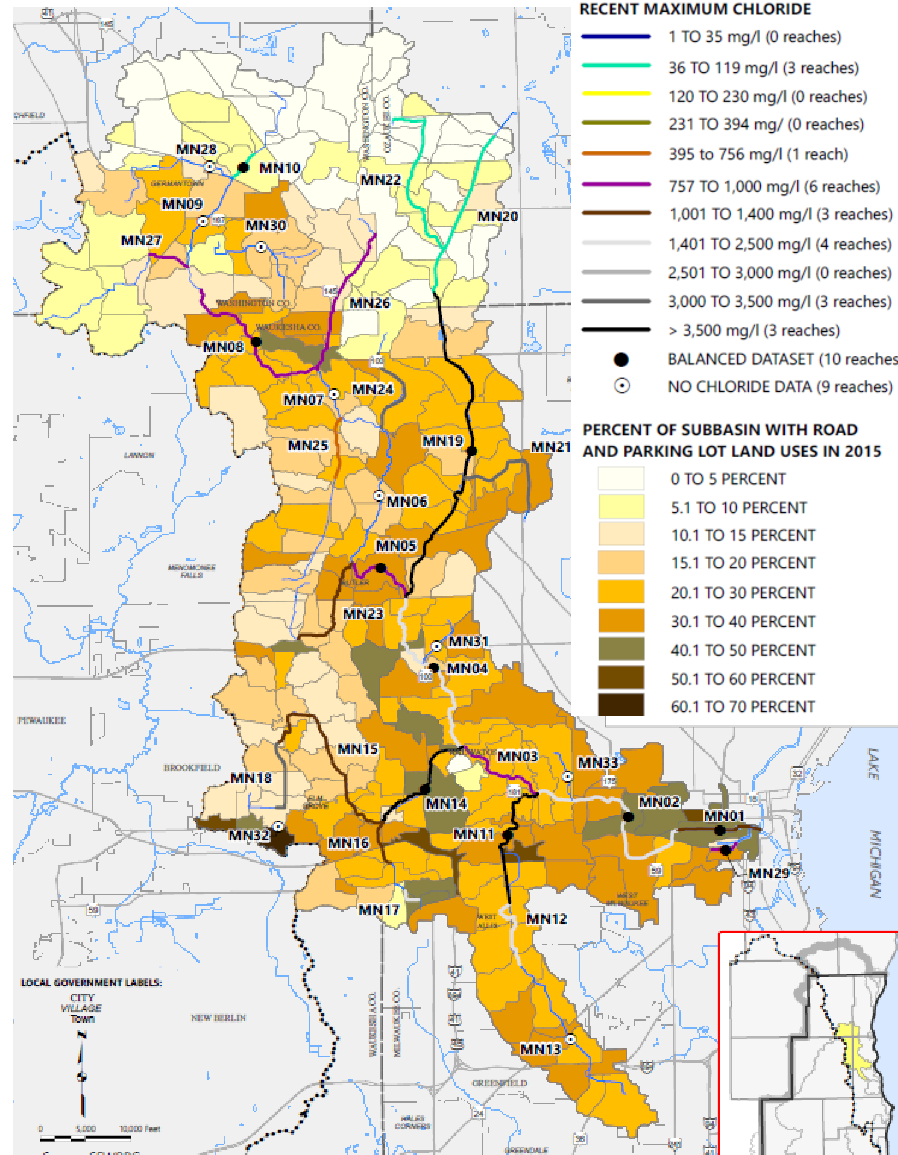
Percent Urban:

Map 4.67
Recent Maximum Chloride Concentrations in Stream Assessment Reaches Within the Menomonee River Watershed and Percent Urban Land Use by Subbasin



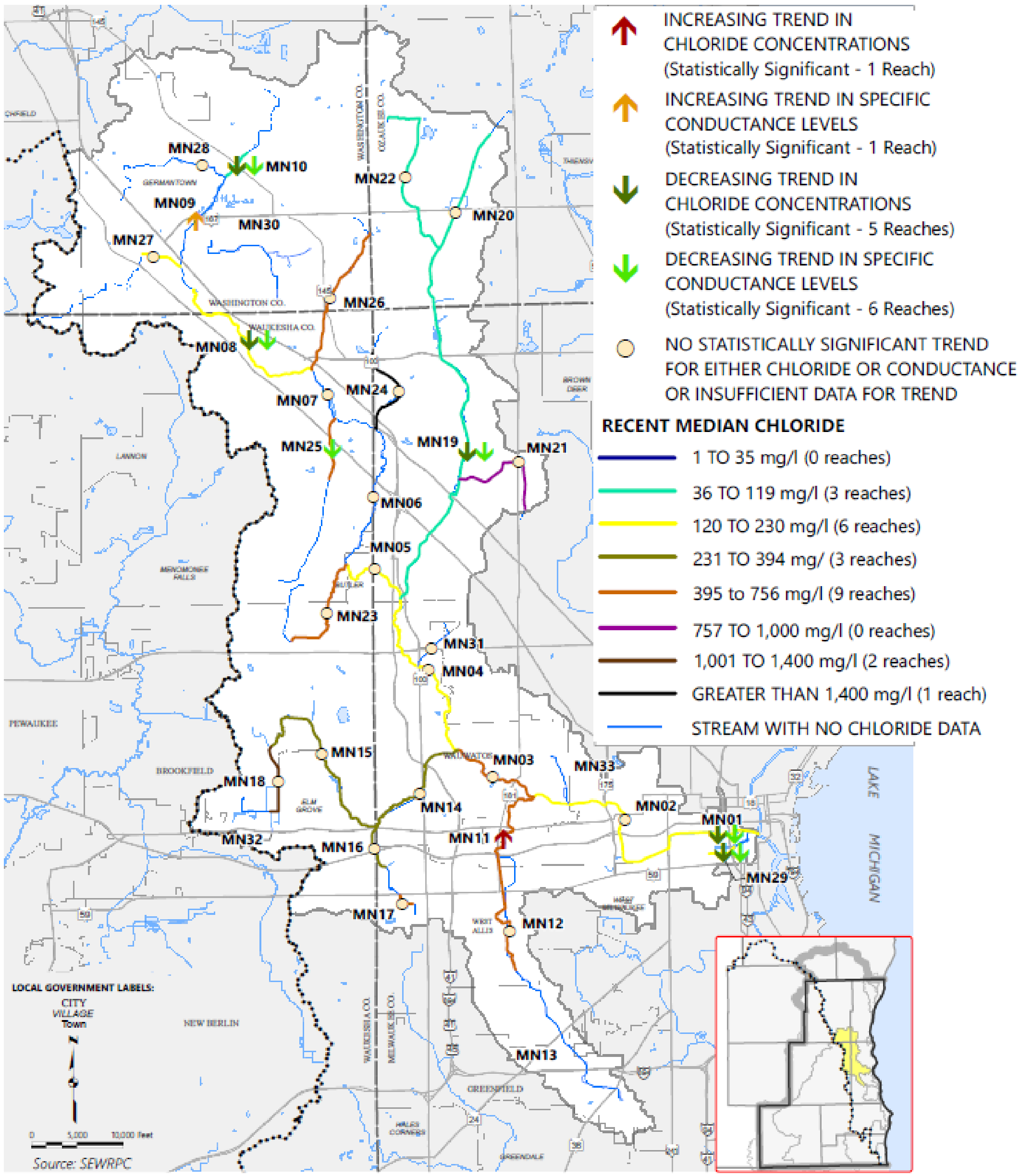
Road and Parking Lot Density:

Map 4.68
Recent Maximum Chloride Concentrations in Stream Assessment Reaches Within the Menomonee River Watershed and Road and Parking Lot Density in Subbasins



Trends in Chloride and Conductance (2013-2022)

Map 4.69
Trends in Chloride and Specific Conductance Among Balanced Assessment Reaches Within the Menomonee River Watershed over the Recent Period of Record: 2013-2022



- Increasing chloride trends:
  - 1 assessment reach (Honey Creek MN11)
- Decreasing chloride trends:
  - 5 reaches
- Increasing conductance trends:
  - 1 assessment reach (Menomonee River MN09)
- Decreasing conductance trends:
  - 6 assessment reaches
- 5 reaches with decreasing trends in both chloride and specific conductance
- Table 4.7 provides slope (mg/l/year) and other linear regression stats for these trends

Questions?

TR-63 Chapters

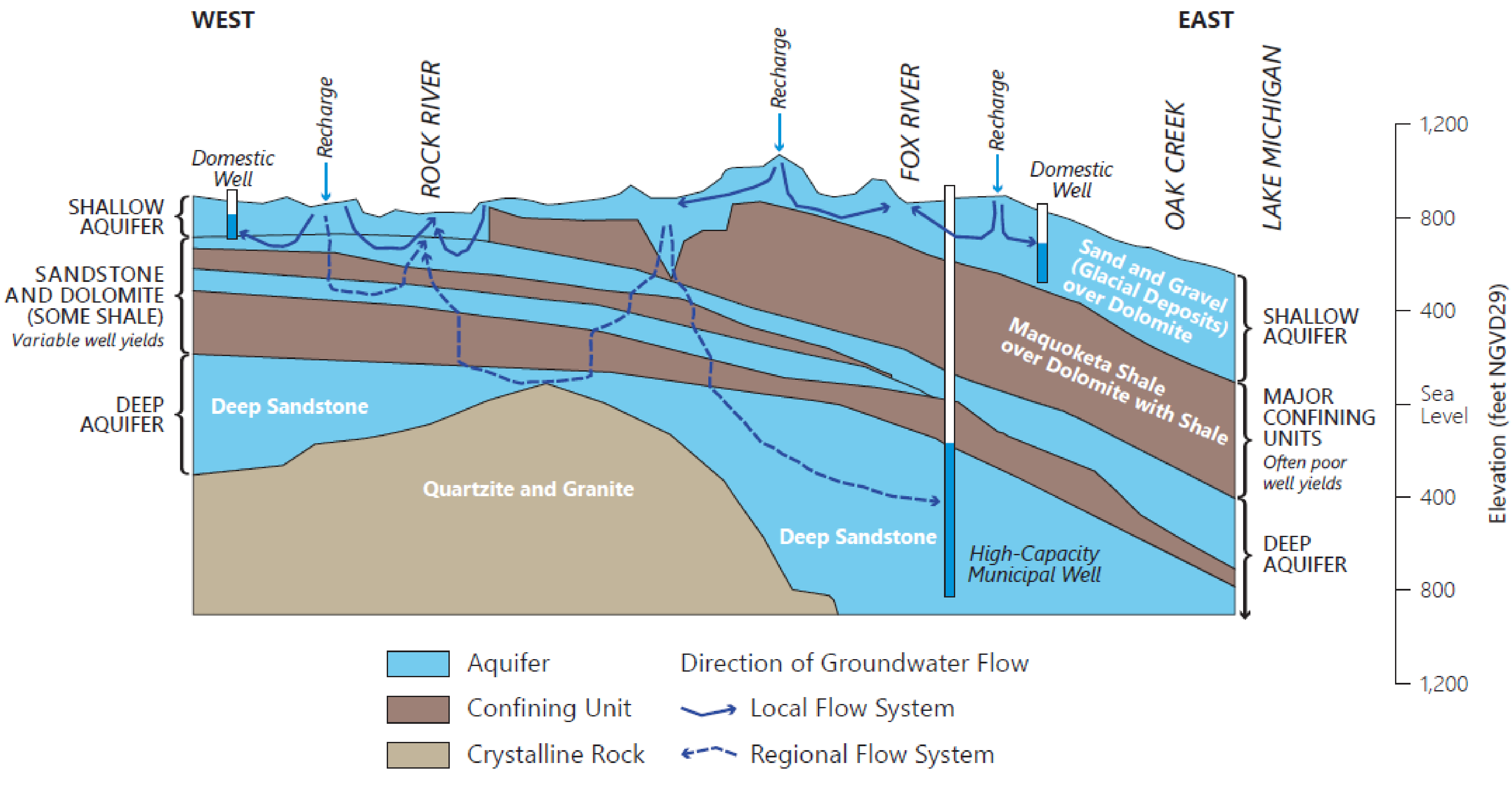
- **Chapter 1 – Introduction**
- **Chapter 2 – Study Area Background (part)**
- **Chapter 3 – Analysis of Chloride Impact Study Monitoring Data: 2018-2021**
- **Chapter 4 – Conditions and Trends: Rivers**
- **Chapter 5 – Conditions and Trends: Lakes**
- **Chapter 6 – Conditions and Trends: Groundwater**

Groundwater Chapter Outline

- Groundwater background
  - What is groundwater?
  - How does chloride move in groundwater?
  - What are sources of chloride to groundwater?
  - Groundwater chloride standards
- Data compilation and organization
- Chloride in shallow groundwater (<= 300 feet)
  - Conditions and trends
- Chloride in public drinking water
  - Conditions and trends

Groundwater background

Figure 6.1
Aquifer Systems in Southeastern Wisconsin



Source: U.S. Geological Survey, University of Wisconsin—Extension, and SEWRPC

Groundwater background

- Sources and movement of chloride
  - Natural sources
    - Predominantly from extraction of minerals in bedrock
    - Low in SE WI with natural concentrations 0 to 20 mg/l
      - Kammerer, 1981
  - Anthropogenic sources
    - Largely the same as for surface waters
      - Landfill leachate can be important additional source
  - Groundwater can be chloride source or sink for surface water and vice versa

Groundwater background

- Groundwater chloride standards
  - WDNR standards
    - 125 mg/l: Preventive Action Limit
    - 250 mg/l: Enforcement Standard
    - Apply to all regulated facilities, practices, and activities that affect groundwater quality
  - EPA standards
    - 250 mg/l: Secondary Maximum Contaminant Level
    - Aesthetic guideline
- Used 20, 125, and 250 mg/l as groundwater thresholds

Data Compilation and Organization

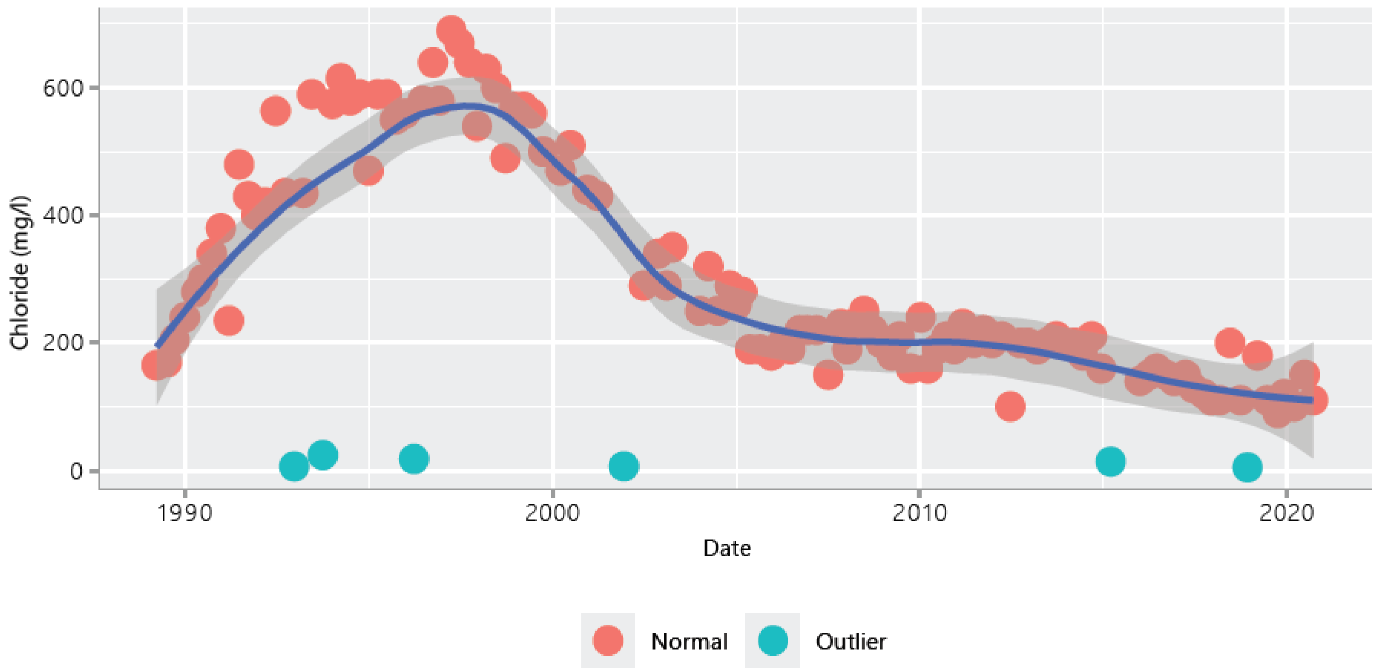
- Data sources
  - WDNR
    - Groundwater Retrieval Network (GRN)
    - System for Wastewater Application, Monitoring, and Permits (SWAMP)
  - United States Geological Survey (USGS)
  - Milwaukee Metropolitan Sewerage District (MMSD)
  - University of Wisconsin-Stevens Point
- Data extends through 2022, except for SWAMP (2020)

Data Compilation and Organization

- Data formatting
  - Concentrations converted to mg/l
  - Well depths converted to feet (when recorded)
  - Wells given unique IDs based on source and number
    - GRN-BR491
- "Shallow" wells considered <= 300 feet
- Identified and removed outliers and duplicates
- Aggregated data to Public Land Survey System (PLSS) Section
  - Finest spatial scale due to GRN limitations

Data Compilation and Organization

Figure 6.6
Example of Outlier Identification Process



Note: Blue line shows estimated mean chloride concentration determined using local polynomial regression of chloride across the time series.

- Compare each sample to regression average for sample date and preceding sample to determine major difference
- Removed 360 outliers (0.5% of dataset) using this approach

Data Summary

- Summarized total and recent (2013-2022) data across all observations, by well, and by PLSS Section
  - Overall, data very limited in much of study area

- 73,690 shallow groundwater chloride observations
  - 75% from GRN dataset
  - Ranging from 1945 – 2022
  - 5,983 unique wells across 1,397 PLSS Sections (44.5% SA)
    - Over half of wells only have one observation
  - Concentrations range from 0 – 6,310 mg/l
    - Median of 28.0 mg/l

Comparison Against Groundwater Standards

Table 6.2 GWThresholds
Comparison of Chloride Samples, Wells, and Sections to Existing Groundwater Thresholds: 1945 - 2022

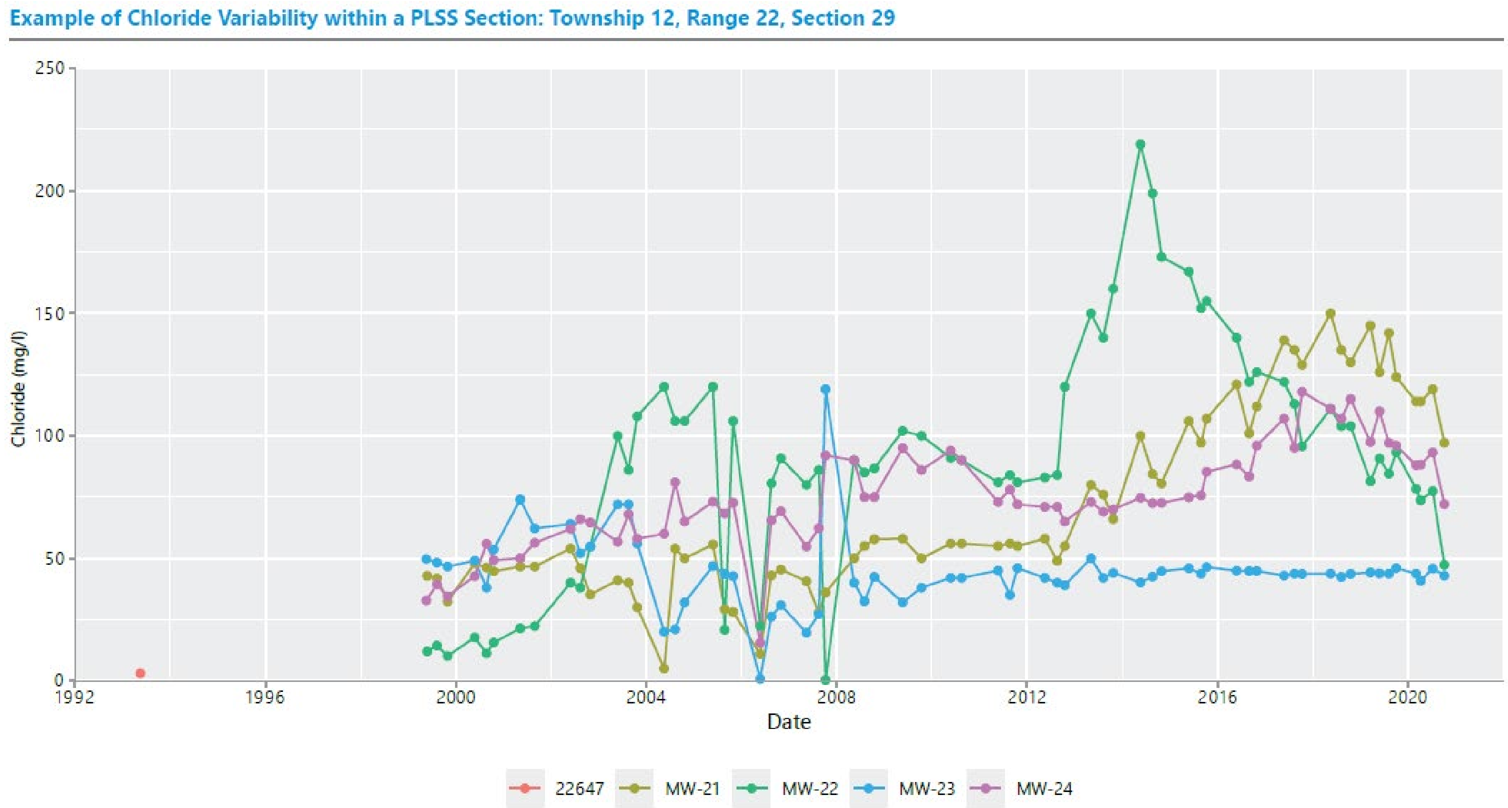
	Observation Exceeds Threshold		Median Concentration Exceeds Threshold			
Threshold	**Number of Observations**	**Percent of Observations**	**Number of Wells**	**Percent of Wells (of those with chloride data)**	**Number of Sections**	**Percent of Sections (of those with chloride data)[a]**
Highest Natural Levels (20 mg/)	43,407	58.9	2,890	48.7	593	42.4
Preventative Action Limit (125 mg/l)	14,123	19.1	702	11.8	82	5.9
Enforcement Standard (250 mg/l)	6,384	8.7	294	5.0	37	2.6

[a] *Of the 3,133 PLSS Sections in the study area, only 1,397 Sections had groundwater chloride data.*

Source: MMSD, WDNR, UWSP, and SEWRPC

- Nearly half of wells had median concentrations that exceeded natural threshold of 20 mg/l
- <12 % exceeded 125 mg/l and 5 % exceeded 250 mg/l
    - No consistent spatial correlation in these exceedances

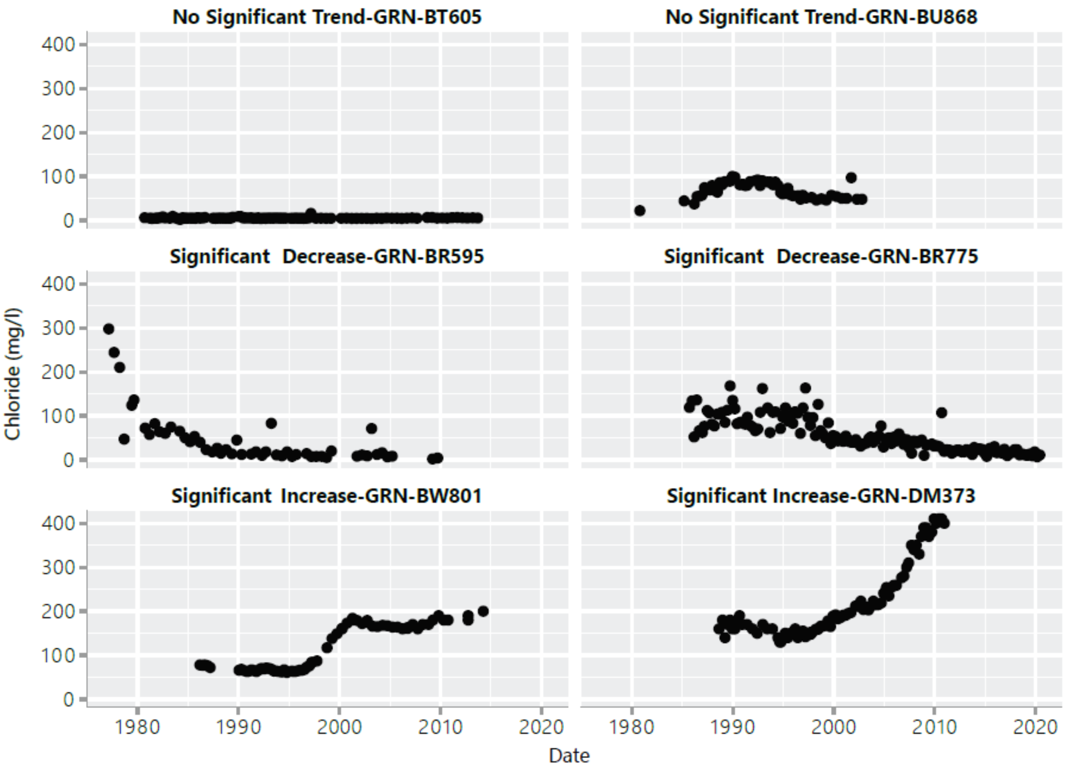
Variability



- Groundwater chloride highly variable, with differences:
  - Within wells over time
  - Between wells in same PLSS Section
  - Between PLSS Sections

Shallow Groundwater Chloride Trends

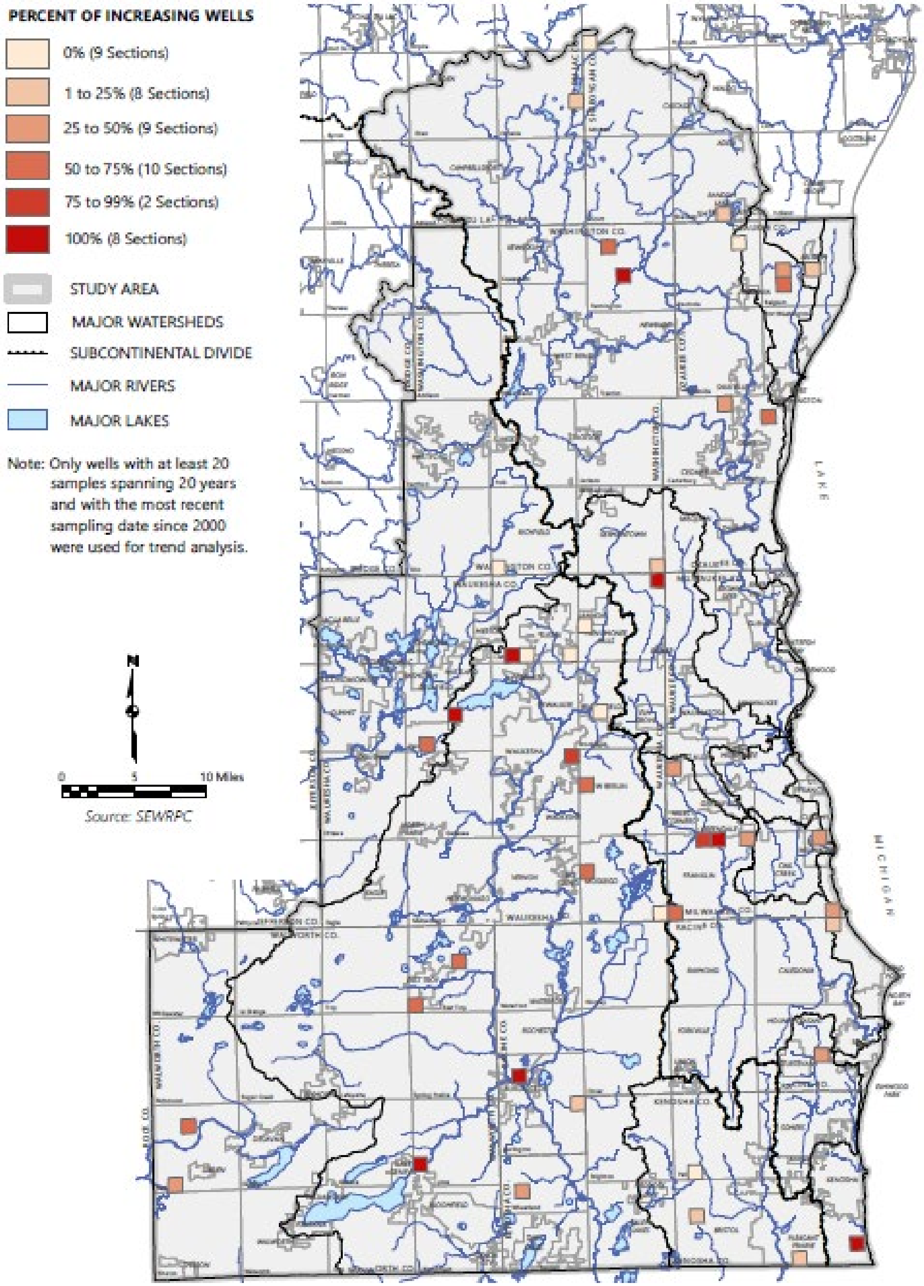
Figure 6.9
Chloride Concentrations Over Time for Example Trend Wells



Source: WDNR, MMSD, USGS, UWSP, and SEWRPC

- Trend dataset criteria:
  - At least 20 samples
  - Most recent sample since 2000
  - At least 20-year period
- 338 wells
  - 22,088 samples
  - 46 PLSS Sections

Shallow Groundwater Chloride Trends

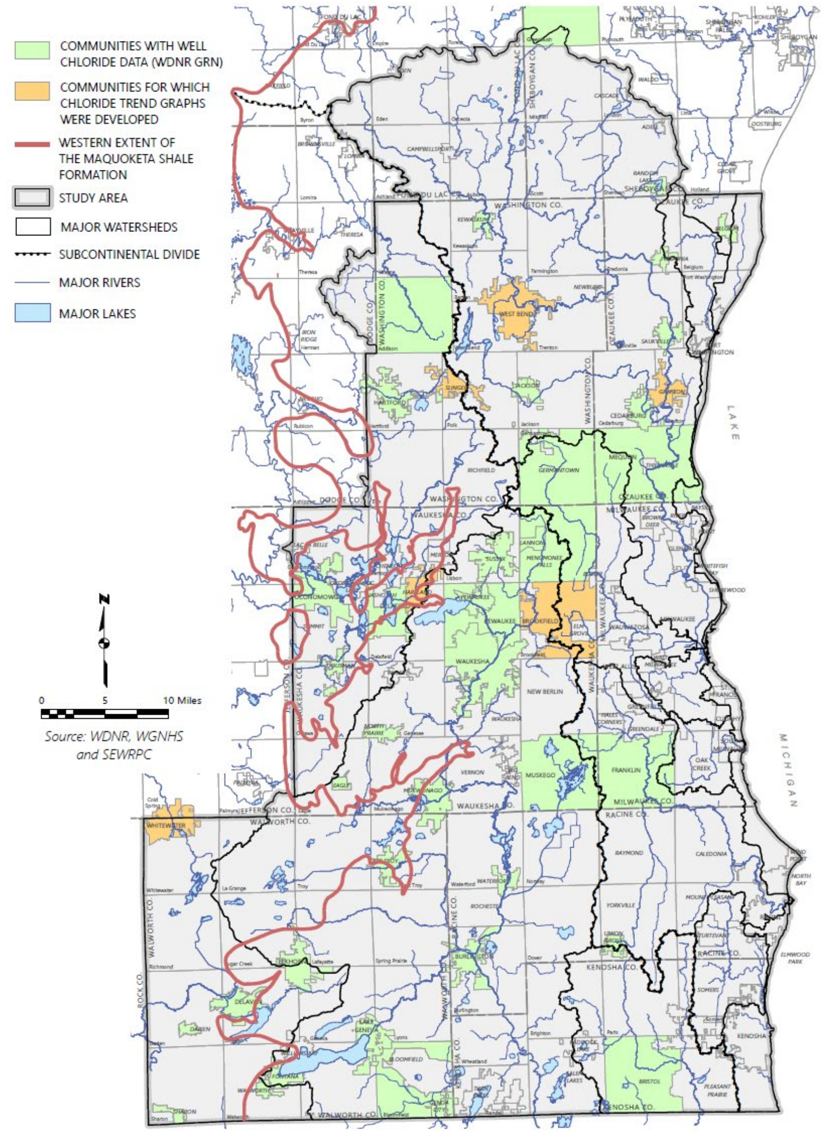


- Linear regression of chloride over time for each well
  - Tested for statistical significance ($\alpha = 0.05$)
- 46.2 % wells increasing
- 27.5 % wells decreasing
- 26.3 % no significant trend
- No statistical examination of land use influence
  - Little information on well contributing area

Municipal Wells

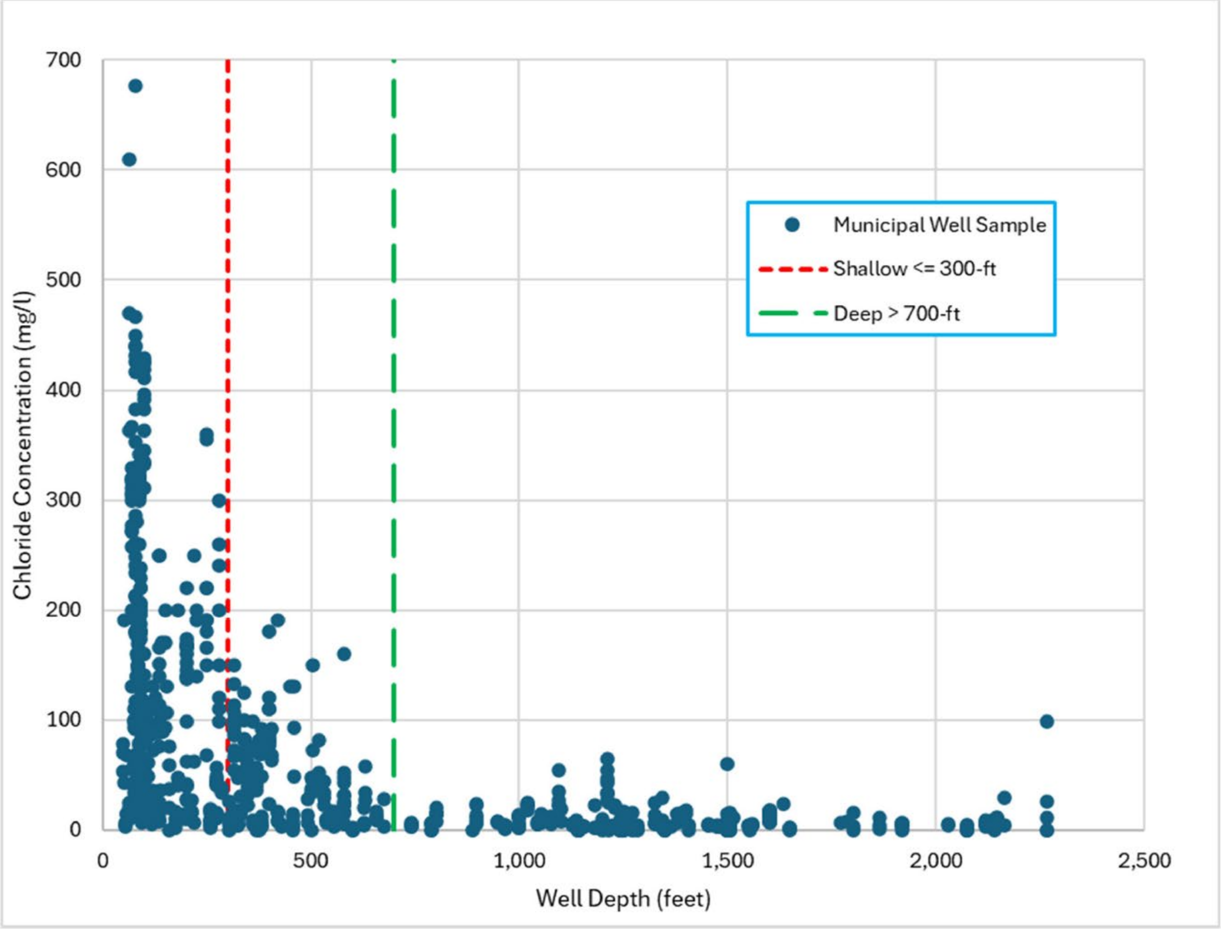
- 46 Municipalities
- 1977-2025
- Most munis only had 1-2 chloride datapts for record
- Those with more typically had a chloride value about every 10 years

Map 6.6
Communities with Municipal Well Data



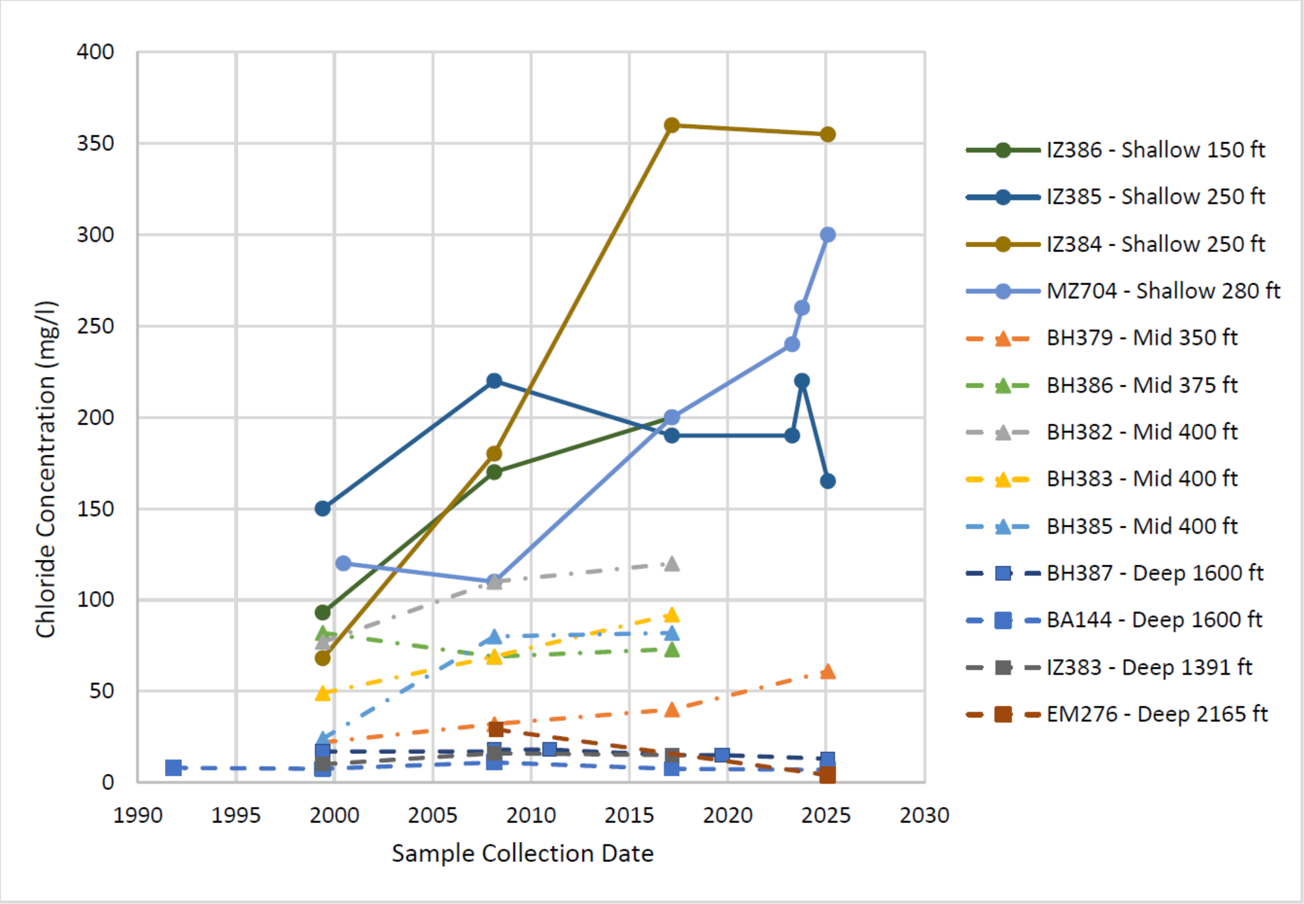
Municipal Wells

Figure 6.11
All Active Municipal Well Data: 1977-2025



Source: WDNR, SEWRPC, City of Brookfield, Village of Slinger, and City of West Bend

Figure 6.12
Municipal Well Chloride Trend – City of Brookfield: 1991-2025



Source: WDNR, SEWRPC, City of Brookfield

Questions?

Chloride Impact Study – Next Steps

- Comments on TR-63 Draft Chapters can be sent to Laura (lherrick@sewrpc.org)

- Comments are due by September 19, 2025

Chloride Impact Study – Next Steps

- Anticipate TAC meetings this fall to review the last chapter of TR-63 (Lakes) and all the draft chapters from TR-65 (Mass Balance Analysis for Chloride)
- Meeting agendas, presentations, and summary notes along with draft text are posted on project website

  www.sewrpc.org/chloride-study

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U.S. Department of Transportation
Federal Highway Administration

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Thank You

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