Southeastern Wisconsin
Regional Planning Commission

Chloride Impact Study for the Southeastern Wisconsin Region

TAC Meeting
April 17, 2024

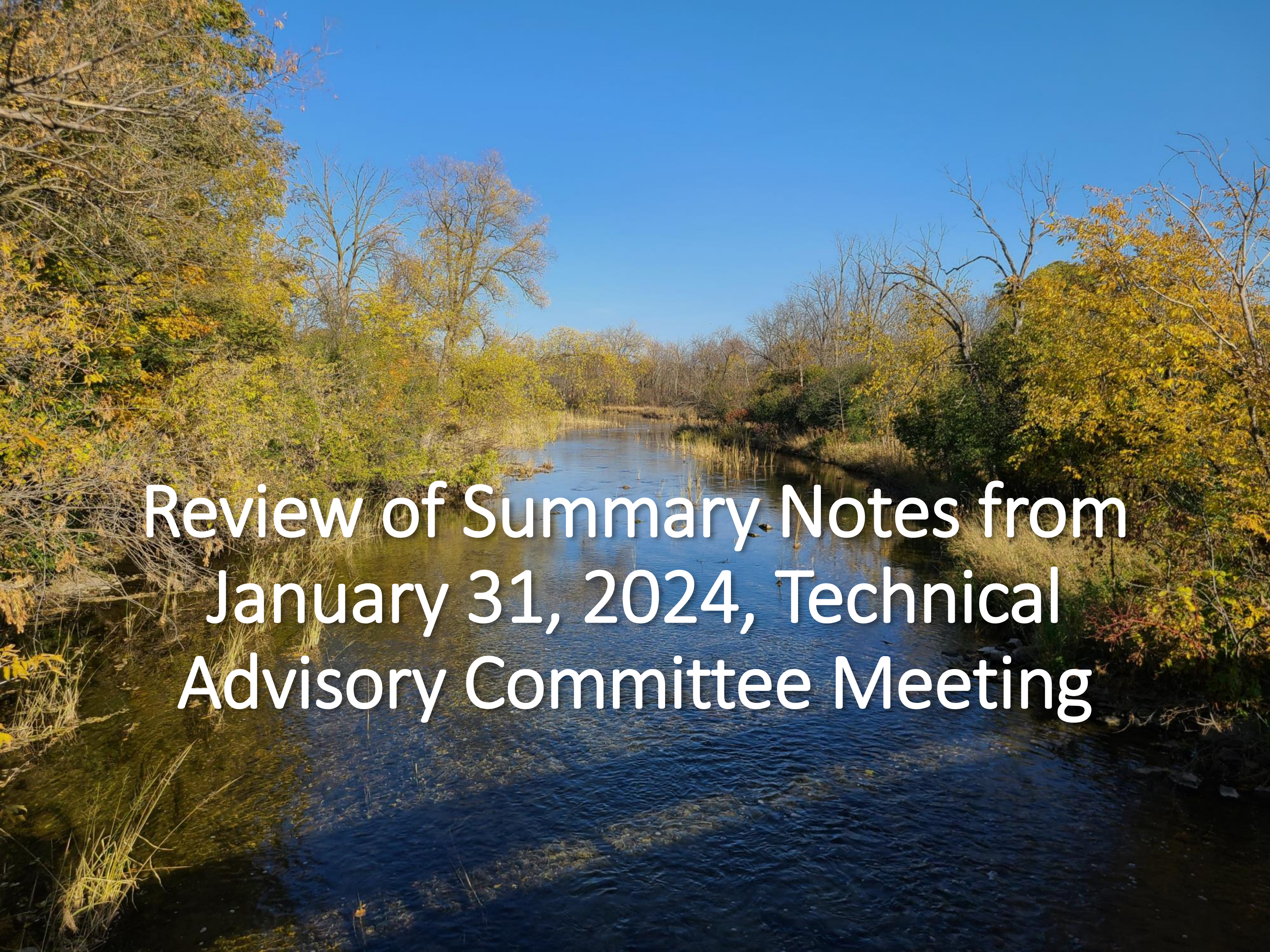
#272138

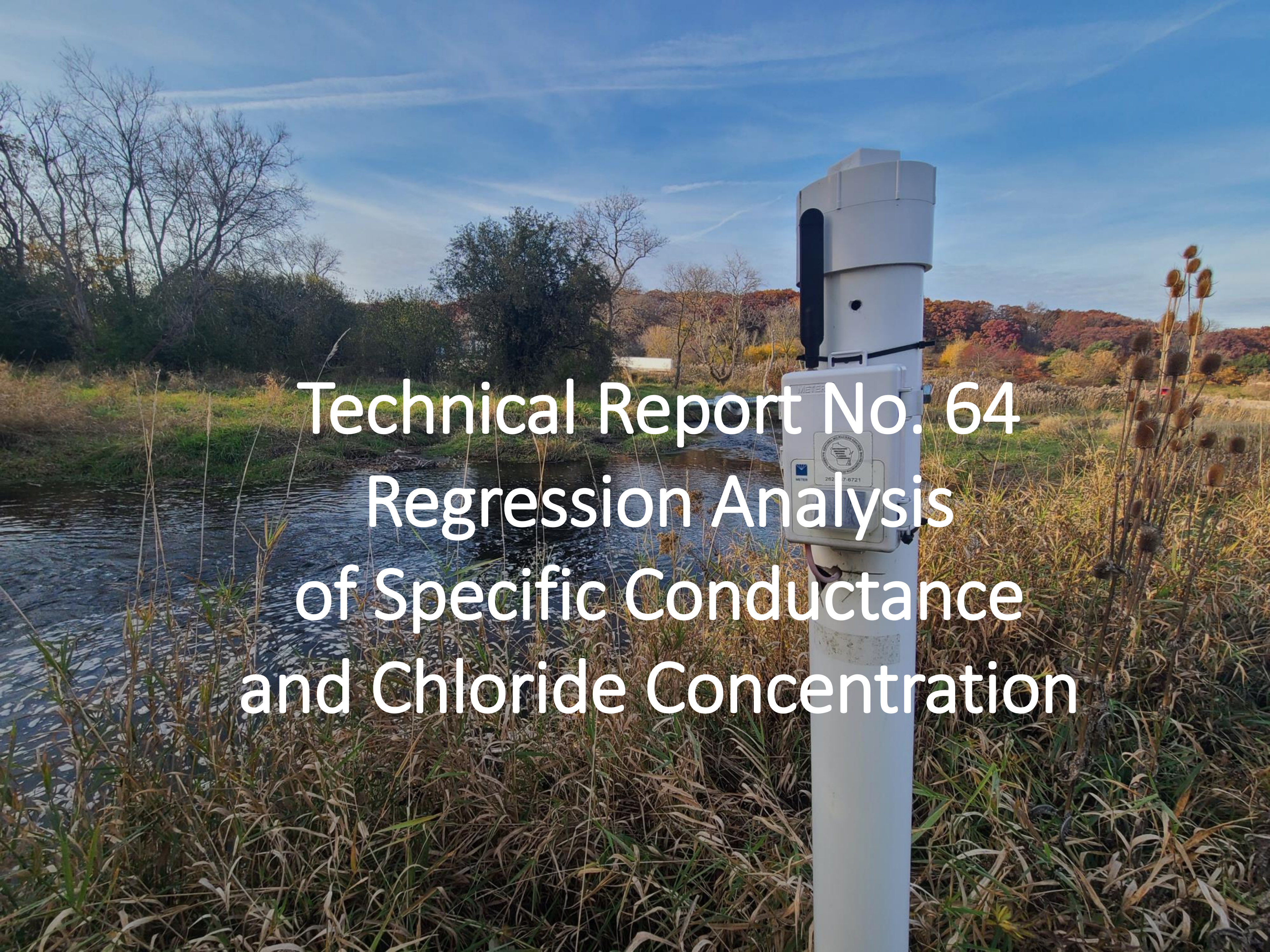
Speakers

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

Agenda

- Review of Summary Notes from January 31, 2024, TAC meeting
- Review of preliminary draft chapters of SEWRPC Technical Report No. 64, *Regression Analysis of Specific Conductance and Chloride Concentrations*
    - Draft Chapter 1, Introduction
    - Draft Chapter 2, Methods
    - Draft Chapter 3, Results
    - Draft Appendix B, Lake-Specific Regression for Lakes Sampled as part of the Chloride Impact Study
- Next Steps


Review of Summary Notes from
January 31, 2024, Technical
Advisory Committee Meeting



Technical Report No. 64
Regression Analysis of Specific Conductance and Chloride Concentration

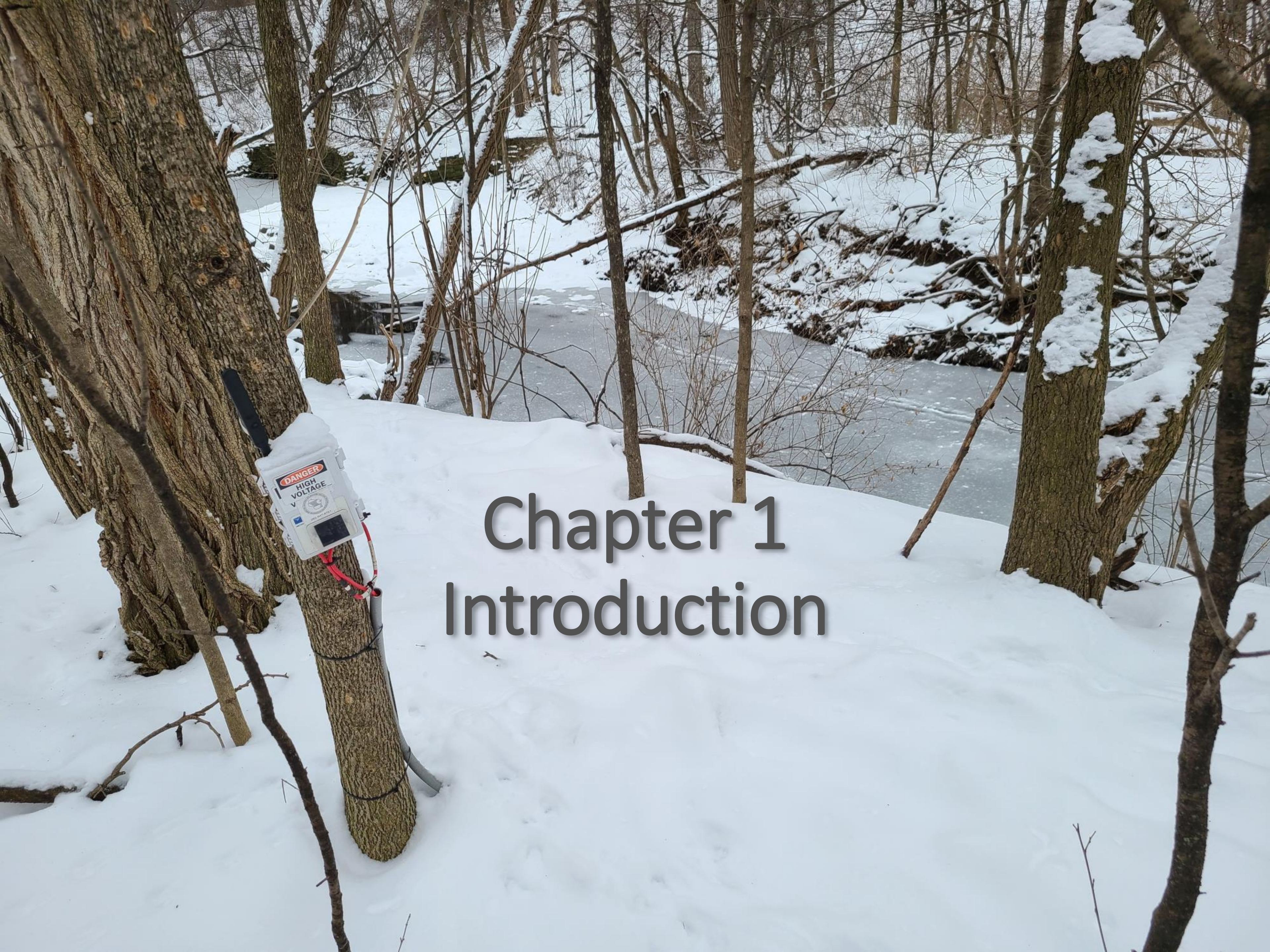
Chloride Study Reports

- *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-64 Chapters

- Chapter 1 – Introduction
- Chapter 2 – Methods
- Chapter 3 – Results
- Appendix A – Acronyms and Abbreviations
- Appendix B – Lake-Specific Regression for Lakes Sampled as Part of the Chloride Study

Chapter 1
Introduction



General Notes on this Report

- This report presents models that we developed to estimate chloride concentrations in southeastern Wisconsin streams from levels of specific conductance
    - Statistical background
    - Data used to develop the models
    - Methods used to develop the models
    - Presentation and evaluation of the models
    - Discussion of applying the models

Why Use a Surrogate for Chloride?

- Sampling can be expensive
  - About $25 to process a sample plus the costs of staff time and fuel to get to the site
- Staff resources and laboratory capacity limit how many samples you can collect and process
  - Use of specific conductance allowed us to take a measurement every five minutes at 41 sites
- Sampling during inclement weather can be dangerous
  - Ice, high stream discharge, traffic can pose hazards to field staff

What is Specific Conductance?

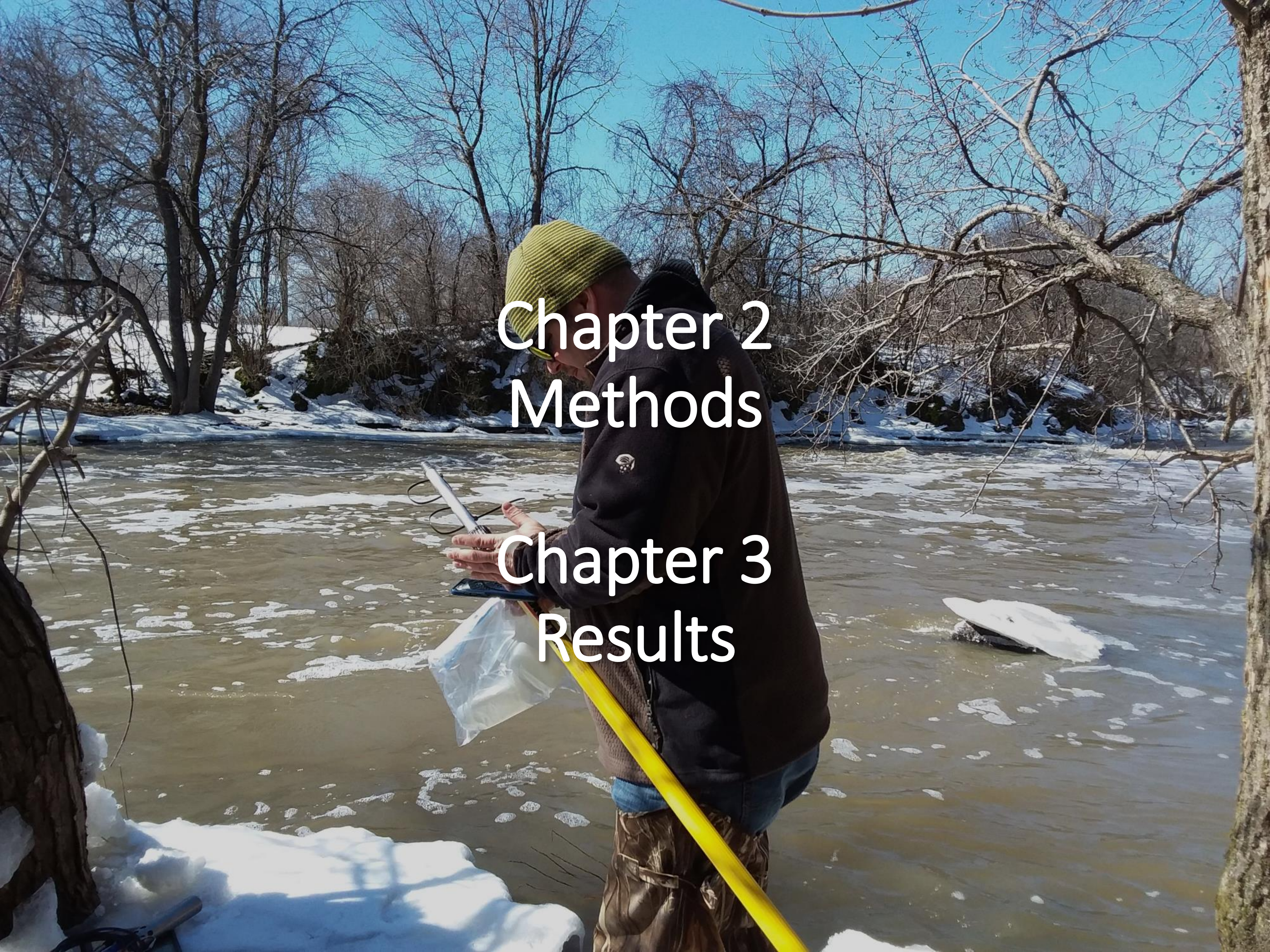
- Conductance is the ability of water to conduct an electric current
  - Measured in microSiemens per centimeter (µS/cm)
- Conductance depends on how many ions are in water
  - Distilled water conducts poorly (0.5 – 3.0 µS/cm)
  - More salts in water give it a greater ability to conduct electricity and higher conductance
  - The identity of the salts/ions also affect conductance

What is Specific Conductance?

- Water temperature also affects conductance
  - Standardize conductance measurements based on temperature
  - Specific conductance is the equivalent conductance at 77°F (25°C)

Why Not Use a Chloride Probe?

- Staff tested chloride-specific probes in 2017-2018
  - Slow response time
  - Fragile, not suitable for field deployment
  - Short life
    - Would require replacement two or three times during a two-year study


Chapter 2
Methods
Chapter 3
Results

What Is Regression Analysis?

- A set of statistical techniques for assessing and estimating the relationship between a dependent variable and one or more independent variables.
- Regression analysis can
  - Determine whether a relationship exists
  - Provide an equation describing the relationship
  - Assess the accuracy of the descriptions and predictions made by the equation

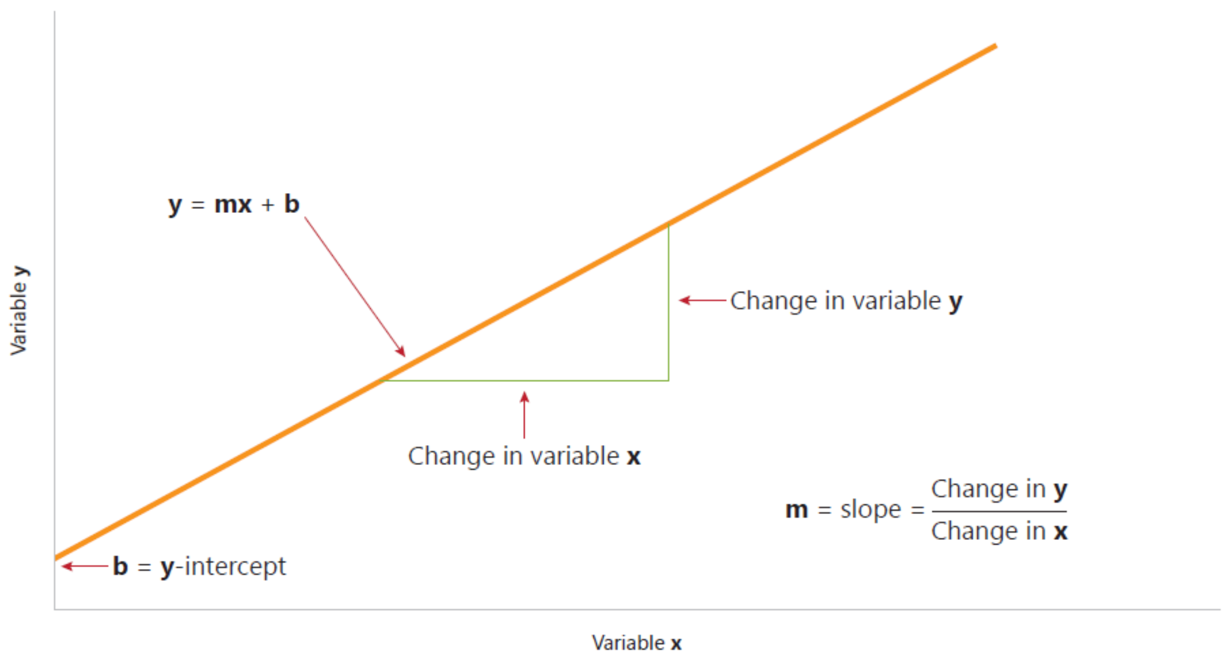
Uses of Regression Analysis

- Two major uses
  - Estimate the average value of the dependent variable for a given value of the independent variable
  - Infer causal relationships in an experimental context
- Our work is only for the first use

Simple Linear Equations

- Simple linear regression estimates the slope (m) and the y-intercept (b) of data that fit a simple linear equation

Figure 2.1
Characteristics of a Linear Equation



Source: SEWRPC

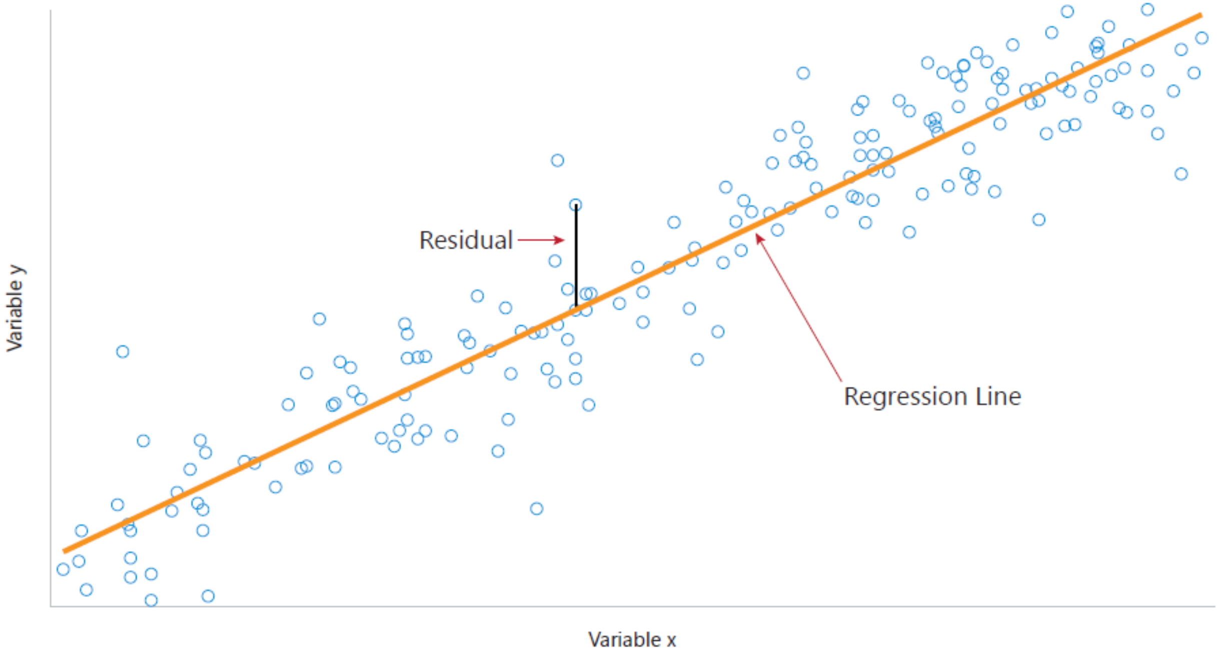
Assumptions of Linear Regression Analysis

- Data are representative of the population of interest
- The relationship between the variables is linear
  - If not either transform the data or use another method
- Independent variable has fixed values
  - In a practical sense, measure it with high precision
- Residuals are independent of one another

Assumptions of Linear Regression Analysis

- The residuals are normally distributed along the line

Figure 2.2
Residuals in a Linear Equation

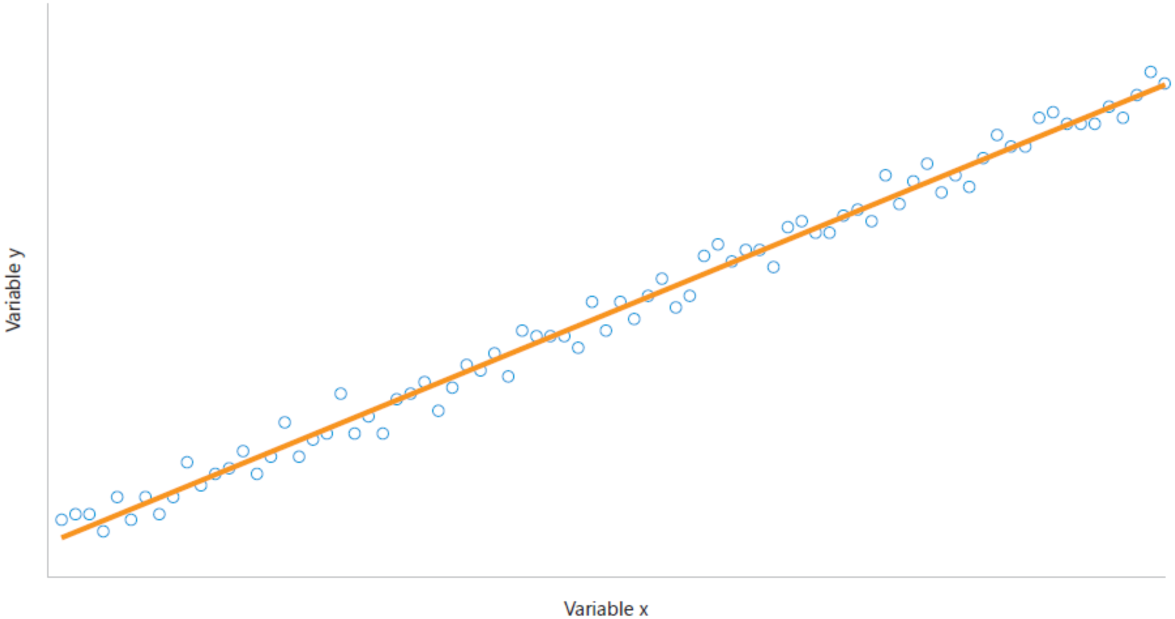


Source: SEWRPC

Assumptions of Linear Regression Analysis

- The variance of the residuals along the line is constant (homoscedasticity)

Figure 2.3
Homoscedastic Data

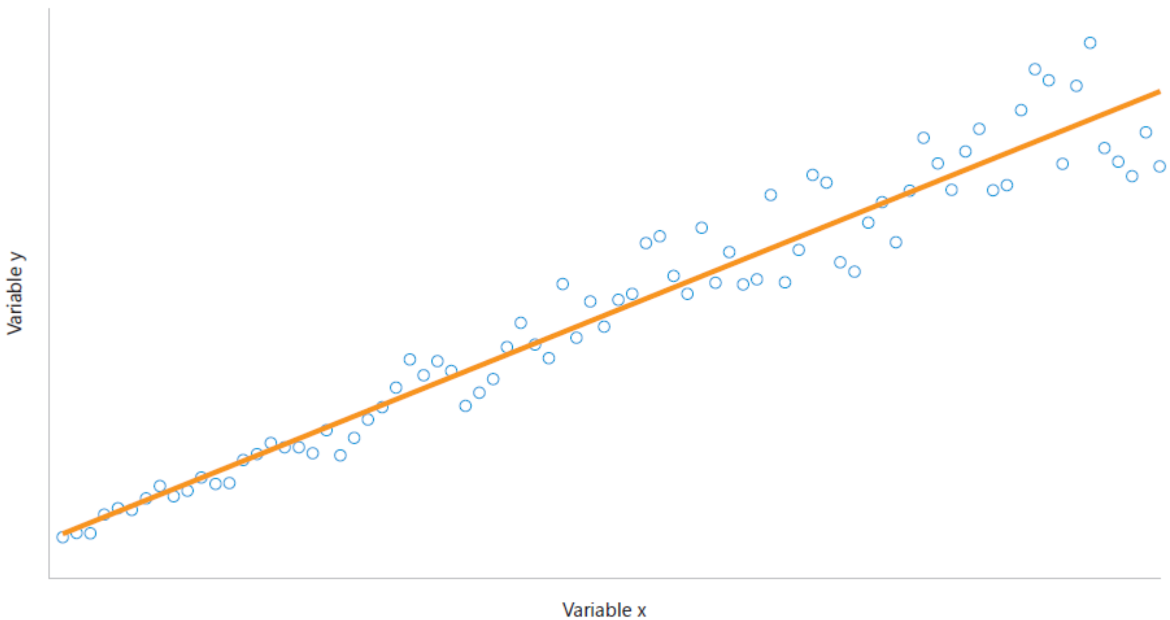


Source: SEWRPC

Assumptions of Linear Regression Analysis

- The variance of the residuals along the line is constant (homoscedasticity)

Figure 2.4
Heteroscedastic Data



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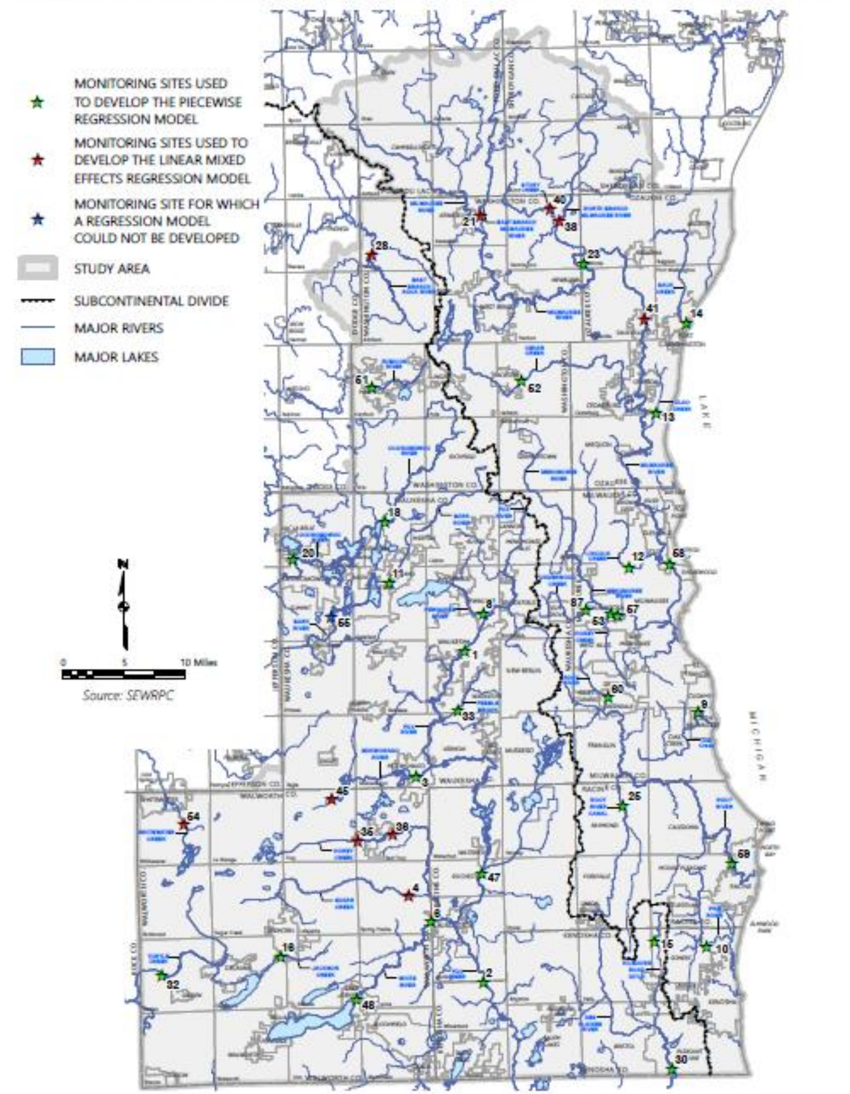
Assumptions of Linear Regression Analysis

- The number of assumptions that need to be met depends on the intended use of the regression
  - Developing valid confidence or prediction intervals requires that all the assumptions be met
  - Estimating values of the dependent variable only requires meeting two assumptions
    - Representativeness of the data
    - Linear relationship between the variables
    - Note that meeting additional assumptions may result in better estimates

Regression Development Data

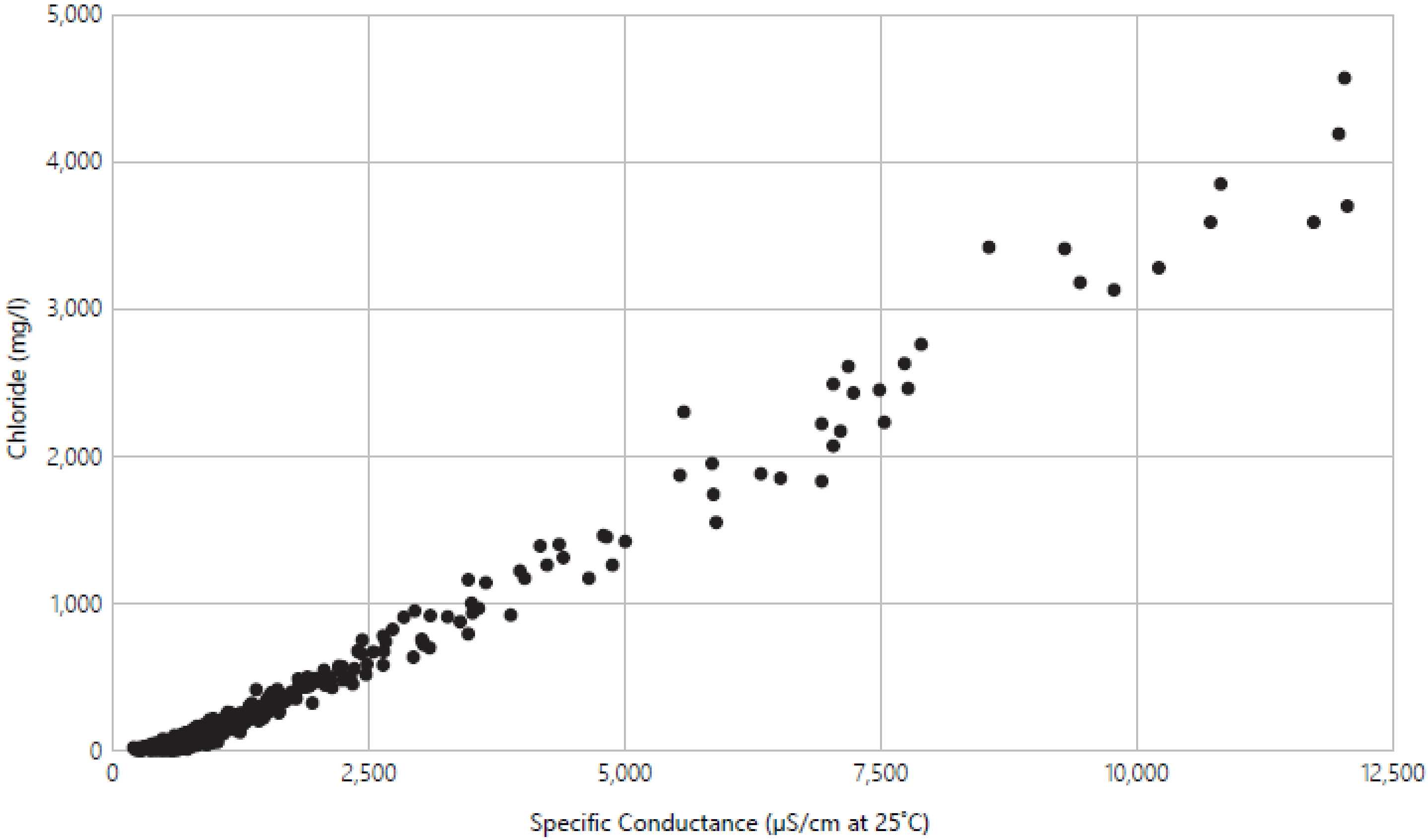
- 41 sampling sites
- 1,104 samples
  - 998 monthly samples collected October 2018 through October 2020
  - 106 event samples collected through study period and winter of 2020-2021

Map 2.1
SEWRPC Stream Monitoring Sites Used for Developing Regression Models for the Chloride Impact Study



Regression Development Data

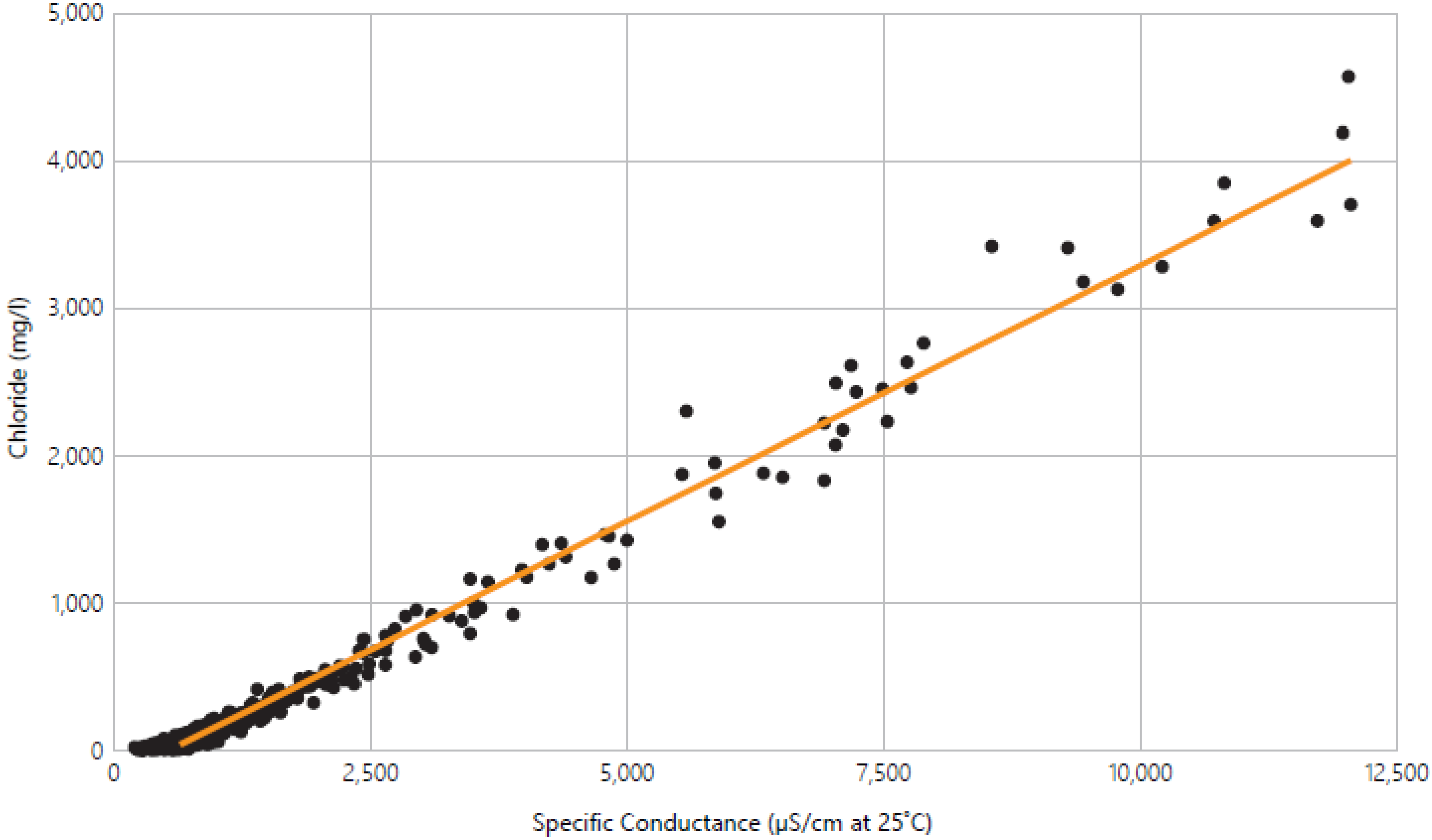
Figure 2.6
Paired Specific Conductance and Chloride for Chloride Study Sites



Source: SEWRPC

Preliminary Model-Simple Linear Regression

Figure 2.7
Preliminary Simple Linear Regresssion of Chloride Versus Specific Conductance



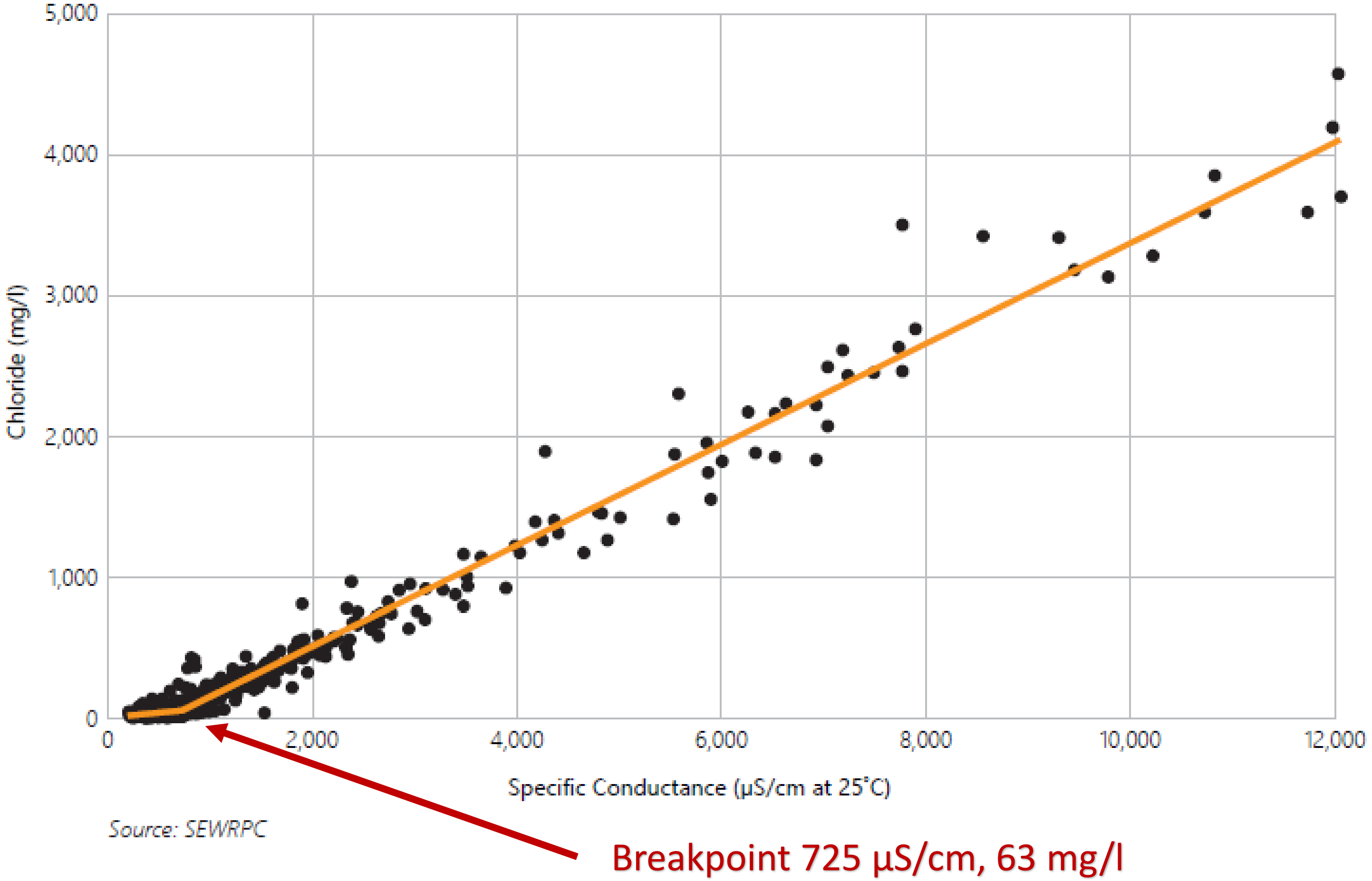
Source: SEWRPC

Piecewise Regression

- Simple linear regression model gave a poor fit to the data
  - Transforming the data made the problems worse
- Piecewise regression
  - Useful when the data have some departures from linearity
  - Divides the independent variable into intervals
  - Develops separate linear regression models for each interval
  - Important considerations
    - As few segments as possible
    - Iterative determination of breakpoints
    - Continuity at breakpoints

Preliminary Piecewise Regression Model

Figure 2.8
Preliminary Piecewise Regression of Chloride Versus Specific Conductance



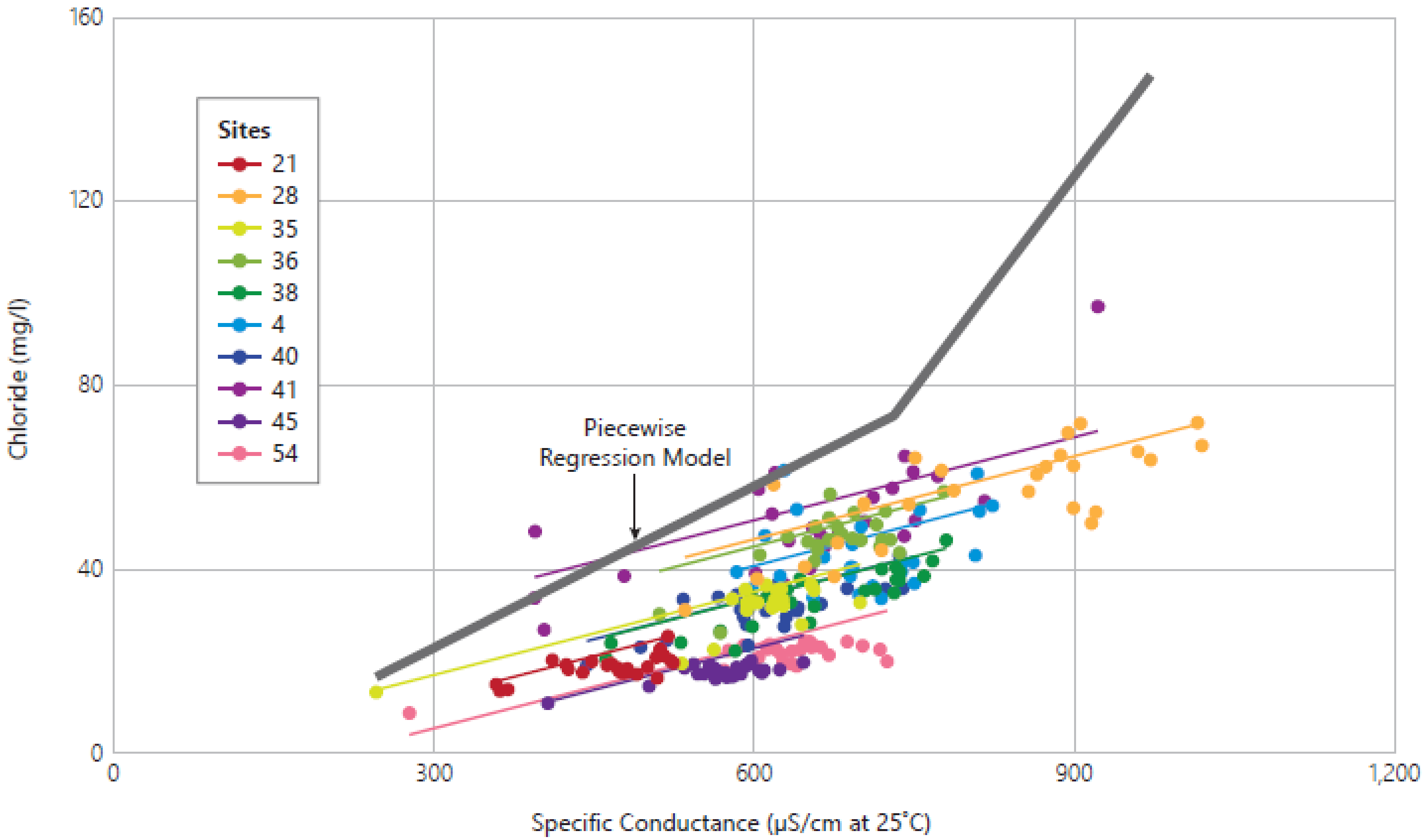
Source: SEWRPC

Preliminary Piecewise Regression Model

- Two-segment piecewise regression model gave a poor fit to the data
- Examination of results
  - Developed separate simple linear regression models for each sampling site
  - Examined where they were located relative to the preliminary piecewise regression model
  - At one site, we did not get a significant regression model
  - At 10 sites the site-specific regression lines fell below the two-segment piecewise regression

Site-specific Linear Regression for 10 Sites

Figure 2.9
Site-Specific Regressions of Chloride Versus Specific Conductance for Sites with Overpredictions of Chloride by the Preliminary Piecewise Regression



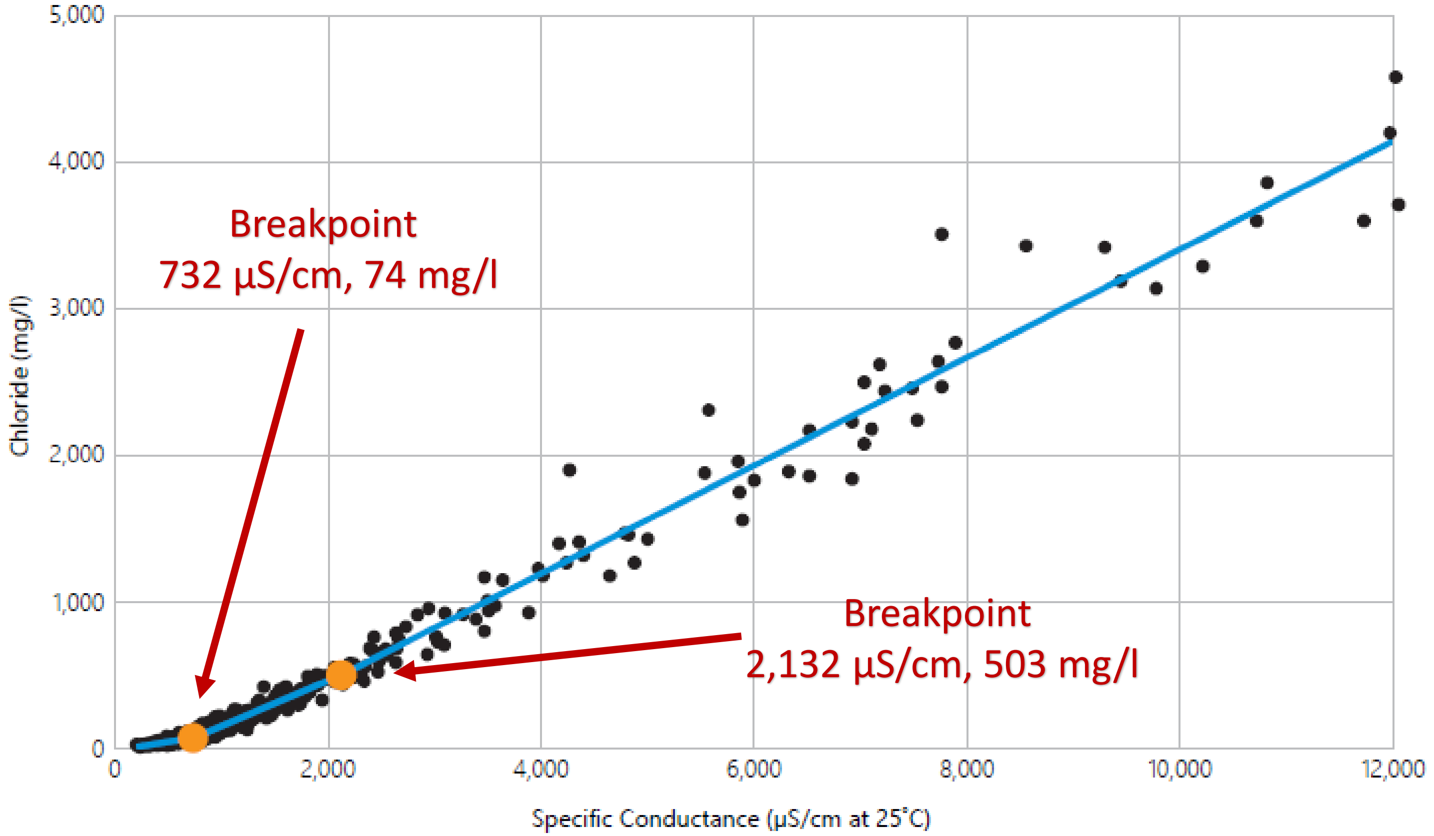
Source: SEWRPC

Groups for Analysis

- Divided the data set into three groups for analysis
  - A “high” group of 30 sites (818 samples)
    - Modeled using piecewise regression
  - A “low” group of 10 sites (253 samples)
    - Modeled using a linear mixed effects regression model
  - A “non-significant” group of 1 site (25 samples)
    - Not modeled

Three-segment Piecewise Regression

Figure 3.1
Piecewise Regression Model for Estimating Chloride from Specific Conductance in Southeastern Wisconsin Streams



Note: Black dots indicate the data used to develop the model. Orange dots indicated the breakpoints in the model.

Source: SEWRPC

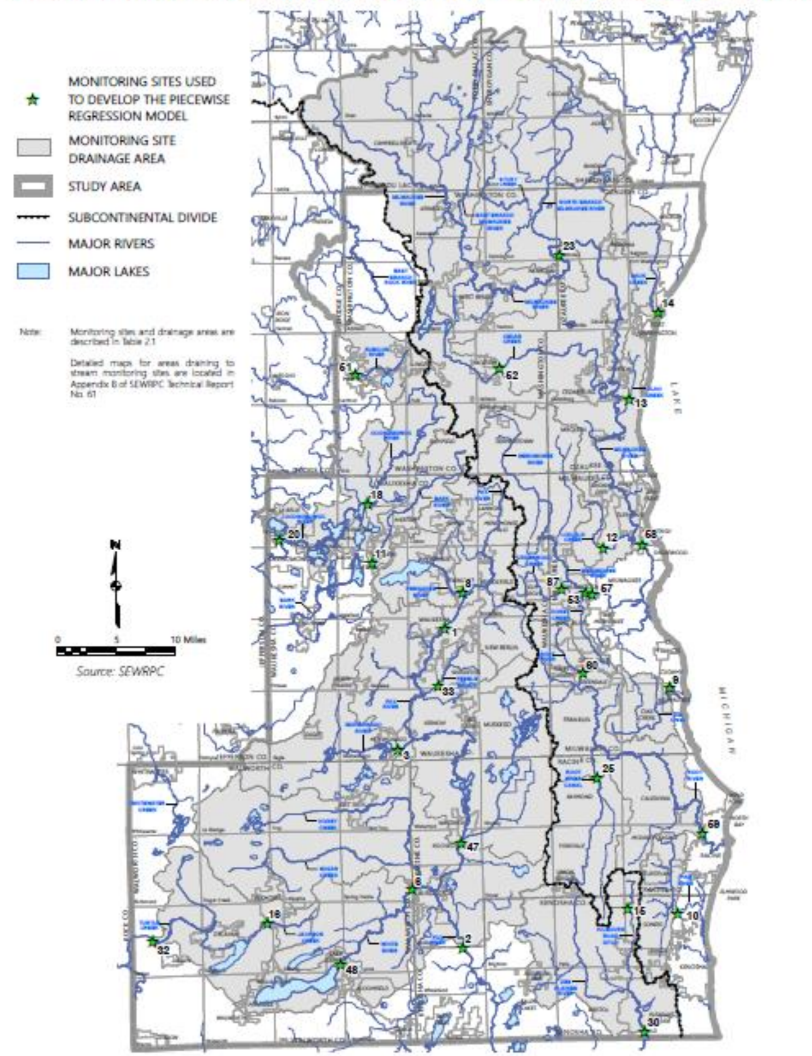
Three-segment Piecewise Regression

Table 3.1
Piecewise Regression Model for Estimating Chloride Concentration from Specific Conductance

Specific Conductance Range (µS/cm at 25°C)[a]	Equation to Estimate Chloride Concentration (mg/l)
SC ≤ 103	$[Cl^-] = 0$
103 < SC ≤ 732	$[Cl^-] = 0.1171 \times SC - 12.0$
732 < SC ≤ 2,123	$[Cl^-] = 0.3084 \times SC - 151.9$
SC > 2,123	$[Cl^-] = 0.3687 \times SC - 280.0$
Range of Values[b]	
Specific Conductance (µS/cm at 25°C)	Chloride (mg/l)
200 – 12,050	11 – 4,163

Note: SC indicates specific conductance. [Cl-] indicates chloride concentration.

Map 2.2
Stream Monitoring Sites and Associated Drainage Areas Used to Develop the Piecewise Regression Model



- Regression line crosses the x-axis at 103 µS/cm
- At and below this chloride concentration is set to 0 mg/l
- $R^2 = 0.9833$ (model accounts for over 98 percent of variation)

Evaluation of Piecewise Regression Model

- High R^2 value – specific conductance accounts for most of the variability in chloride
- Residual analysis showed heteroscedasticity – should not preclude using the model for estimating chloride concentration
- Discrepancies in estimated chloride concentrations between segments at breakpoints were about 0.1 mg/l – acceptable

Evaluation of Piecewise Regression Model

- Cross-validation of model
  - Tests the model for overfitting of data
  - Looks to see how sensitive the model is to removal of some of the data
  - Procedure
    - Randomly divide the data into 10 groups of equal size
    - Remove one group, rerun the regression with the other nine
    - Check to see how well the model estimates values in the removed group
    - Repeat for all 10 groups
    - Examine parameters and metrics

Cross-Validation Results-Piecewise Model

Examination of cross-validation iterations

- Slopes of the model segments were not sensitive to removal of data
  - Highest stability in 732 µS/cm – 2,132 µS/cm range
- Small variations in y-intercepts for the three segments
  - 1st segment within 9 mg/l of piecewise, most within 2 mg/l
  - 2nd segment within 12 mg/l of piecewise, most within 5 mg/l
  - 3rd segment with 20 mg/l of piecewise, most within 15 mg/l
- x-intercepts of 1st segment varied between 27 µS/cm and 130 µS/cm, but these values were rare in our samples

Cross-Validation Results-Piecewise Model

Examination of cross-validation iterations

- Breakpoints
  - 1st breakpoint – all within 6 percent of piecewise, most within 1 percent
  - 2nd breakpoint – all within 43 percent of piecewise, most within 1 percent
- R^2 of iterations all greater than 0.98 and within 1 percent of piecewise
- Mean squared error – a goodness of fit measure
  - All iterations within 16 percent of piecewise, most within 10 percent

Comparison to Measured Values

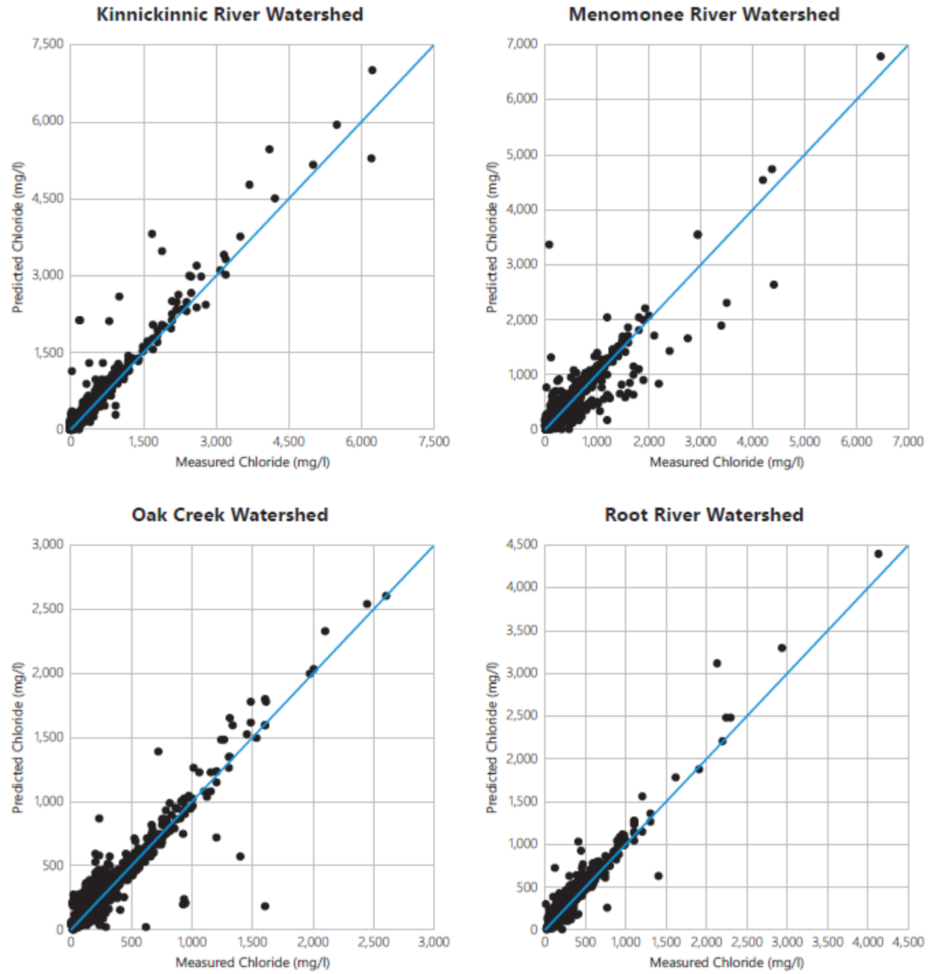
- Examined estimates made with the piecewise regression to measured chloride concentrations in four watersheds
  - Kinnickinnic River, Menomonee River, Oak Creek, and Root River
  - 23,307 paired samples collected between 1964 and 2022
  - All have moderate to high amounts of urban land use, but no good large data sets with paired specific conductance-chloride data were available in more rural watersheds
  - Looked at both ability to estimate concentrations and the ability to correctly estimate exceedances of regulatory thresholds

Comparison of Piecewise to Measured Data

<u>1964 - 2022</u>

- The piecewise regression tends to overestimate chloride concentration more than it underestimates it
- It also underestimates a substantial portion of samples in the Menomonee River watershed

Figure 3.2
Comparison of Chloride Concentrations Estimated by the Piecewise Regression Model to Measured Chloride Concentrations: 1964-2022

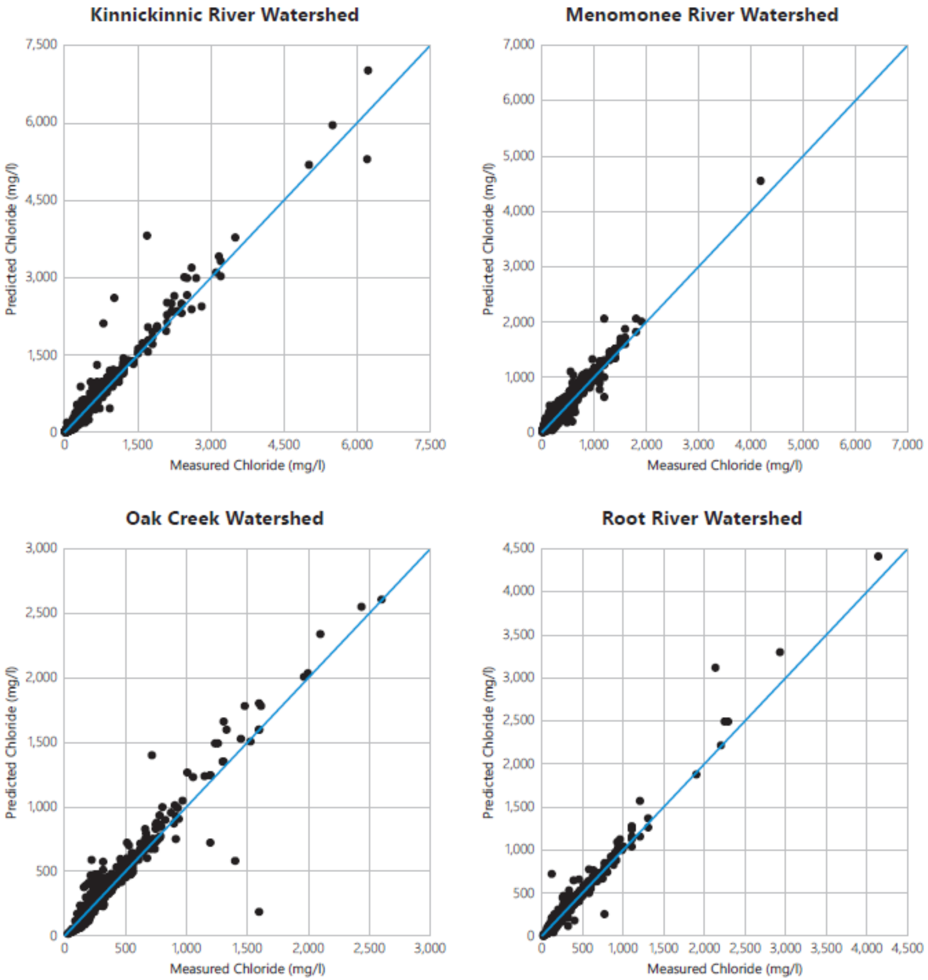


Comparison of Piecewise to Measured Data

2011 - 2022

- Better performance, but still tends to overestimate more than it underestimates
- Changes in monitoring technology over time?
- Changes in other water quality constituents over time?

Figure 3.3
Comparison of Chloride Concentrations Estimated by the Piecewise Regression Model to Measured Chloride Concentrations: 2011-2022



Comparison of Piecewise to Regulatory Thresholds

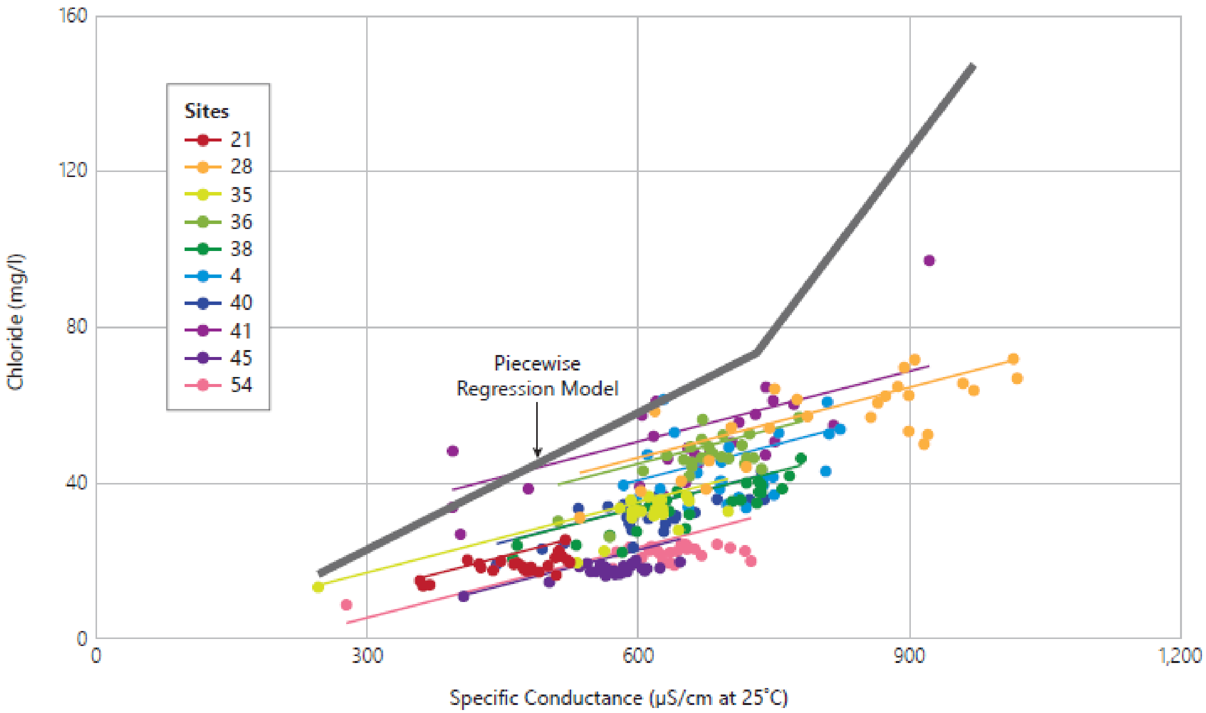
Examined the ability of the piecewise regression model to correctly estimate concentrations that exceeded water quality standards

	Acute Toxicity (757 mg/l)	Chronic Toxicity (395 mg/l)	Drinking Water Maximum Contaminant Limit (250 mg/l)
Correct prediction (percent)	99.5	97.5	92.5
False positives (percent)	0.3	2.1	7.6
False Negatives (percent)	14.1	8.4	7.8

What About the "Low" Group?

- Developed a linear mixed effects regression (LME) model

Figure 2.9
Site-Specific Regressions of Chloride Versus Specific Conductance for Sites with Overpredictions of Chloride by the Preliminary Piecewise Regression



Source: SEWRPC

Linear Mixed Effects Regression

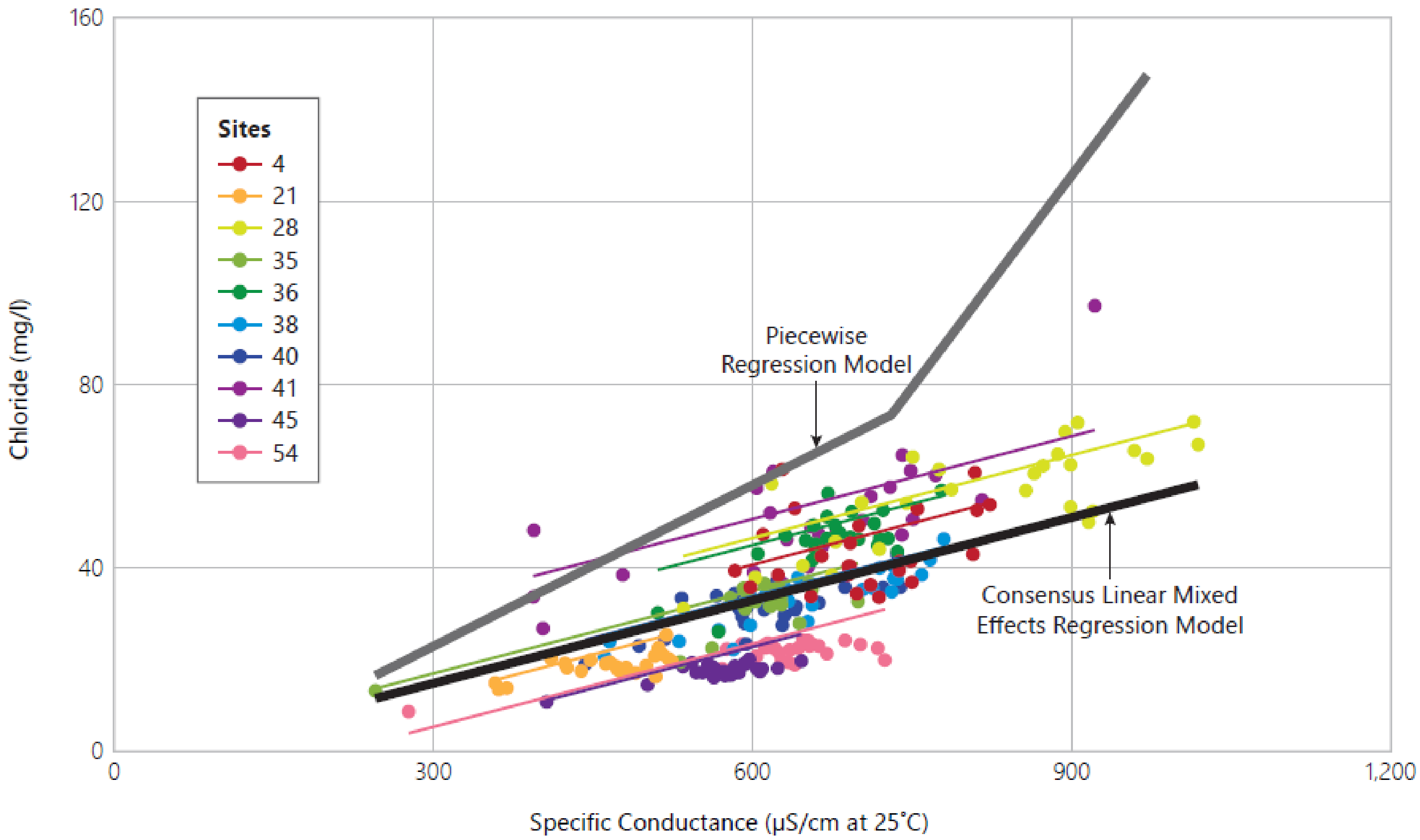
- Extension of linear regression which looks at the effects of both fixed and random factors
- Structures the data into levels
  - Within group level – variation among samples collected at a single site
  - Between group level – variation among sites
- By using all the data, we can get better estimates of the relationship at each site

Linear Mixed Effects Regression

- We assumed that the underlying relationship between specific conductance and chloride concentration was the same at all these sites
  - This is equivalent to saying that the slope of the relationship should be the same at each site
  - Treating as a fixed factor
- We assumed that the differences between the sites reflected differences in local water chemistry (i.e., other ions)
  - This is equivalent to saying that we could potentially see different y-intercepts at sites
  - Treating as a random factor

Linear Mixed Effects Regression Model

Figure 3.4
Linear Mixed Effects Model for Estimating Chloride from Specific Conductance in Southeastern Wisconsin Streams



Linear Mixed Effects Regression Model

Table 3.6
Linear Mixed Model for Estimating Chloride Concentration from Specific Conductance

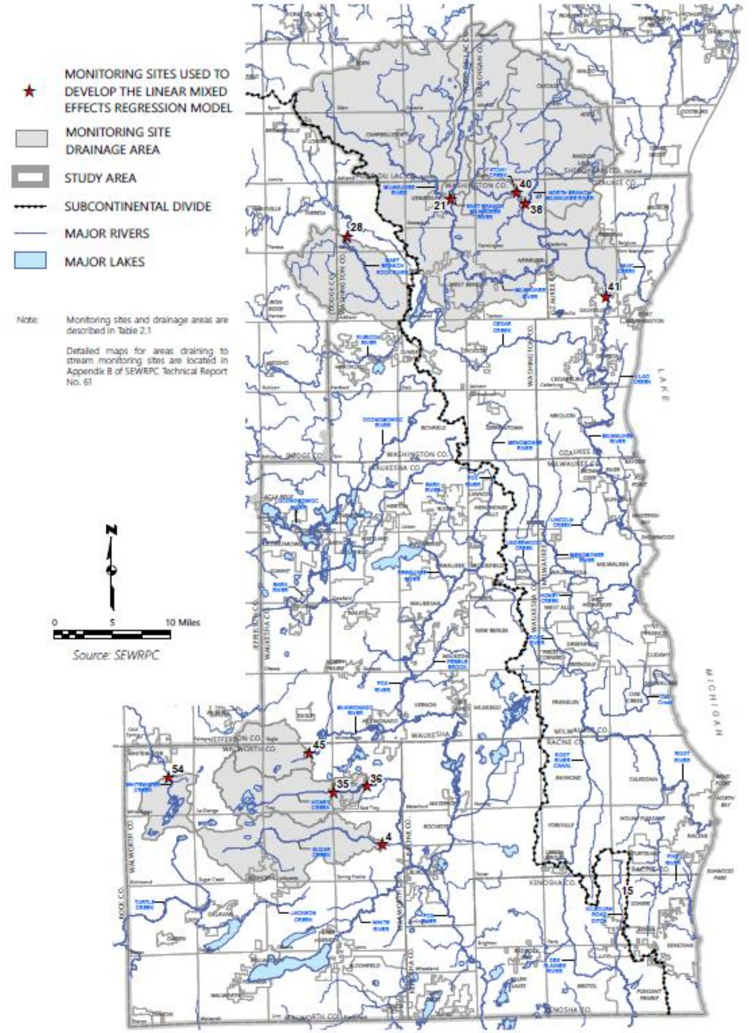
Site Number	Site	Specific Conductance Range (µS/cm at 25°C)[a]	Equation to Estimate Chloride Concentration (mg/l)
4	Sugar Creek	SC > 0	$[Cl^-] = 0.0603 \times SC + 4.5$
21	East Branch Milwaukee River	SC ≤ 100	$[Cl^-] = 0$
		SC > 100	$[Cl^-] = 0.0603 \times SC - 6.0$
28	East Branch Rock River	SC > 0	$[Cl^-] = 0.0603 \times SC + 10.3$
35	Honey Creek Upstream of East Troy	SC ≤ 19	$[Cl^-] = 0$
		SC > 19	$[Cl^-] = 0.0603 \times SC - 1.1$
36	Honey Creek Downstream of East Troy	SC > 0	$[Cl^-] = 0.0603 \times SC + 8.8$
38	North Branch Milwaukee River	SC ≤ 42	$[Cl^-] = 0$
		SC > 42	$[Cl^-] = 0.0603 \times SC - 2.5$
40	Stony Creek	SC ≤ 40	$[Cl^-] = 0$
		SC > 40	$[Cl^-] = 0.0603 \times SC - 2.4$
41	Milwaukee River near Saukville	SC > 0	$[Cl^-] = 0.0603 \times SC + 14.5$
45	Mukwonago River at Nature Road	SC ≤ 223	$[Cl^-] = 0$
		SC > 223	$[Cl^-] = 0.0603 \times SC - 13.4$
54	Whitewater Creek	SC ≤ 211	$[Cl^-] = 0$
		SC > 211	$[Cl^-] = 0.0603 \times SC - 12.7$
--	Consensus Model[b]	SC ≤ 55	$[Cl^-] = 0$
		SC > 55	$[Cl^-] = 0.0603 \times SC - 3.3$

Range of Values	
Specific Conductance (µS/cm at 25°C)	Chloride (mg/l)
245 – 1,020	11.5 – 97.2

Linear Mixed Effects Regression Model

- 11 sets of equations
  - 10 for individual sites
  - 1 consensus equation
- Set chloride concentrations to 0 at and below where the regression line crosses the x-axis

Map 2.3
Stream Monitoring Sites and Associated Drainage Areas Used to Develop the Linear Mixed Effects Regression Model



Evaluation of Linear Mixed Effects Model

- R^2
  - Conditional $R^2 = 0.306$
    - This describes the amount of variation that is accounted for by both specific conductance and between site differences
  - Marginal $R^2 = 0.838$
    - This describes the amount of the variation that is accounted for by specific conductance alone
    - values are not surprising – since specific conductance and chloride concentration values in the range this model examines are low, other ions have more influence

Cross-Validation Results-LME Model

Examination of cross-validation iterations

- Slope of the model was not sensitive to removal of data
  - Slopes were all very low
- Small variations in y-intercepts
  - Iteration y-intercepts for the consensus equation were within 3 mg/l of the LME consensus equation y-intercept
  - Iteration y-intercepts for the site-specific equations were all within 1-2 mg/l of the LME site specific equation y-intercepts
- x-intercepts varied

Cross-Validation Results-LME Model

Examination of cross-validation iterations

- R^2 of iterations for the consensus equation
  - Marginal R^2 values were within 16 percent of the LME
  - Conditional R^2 values were within 2 percent of the LME
- Mean squared error – a goodness of fit measure
  - All iterations within 7 percent of LME, most within 3 percent
- Overall, the model was reasonably stable, but could be affected by removal of higher chloride concentration samples
- No good independent data set was available to test this model against

Applications of These Models

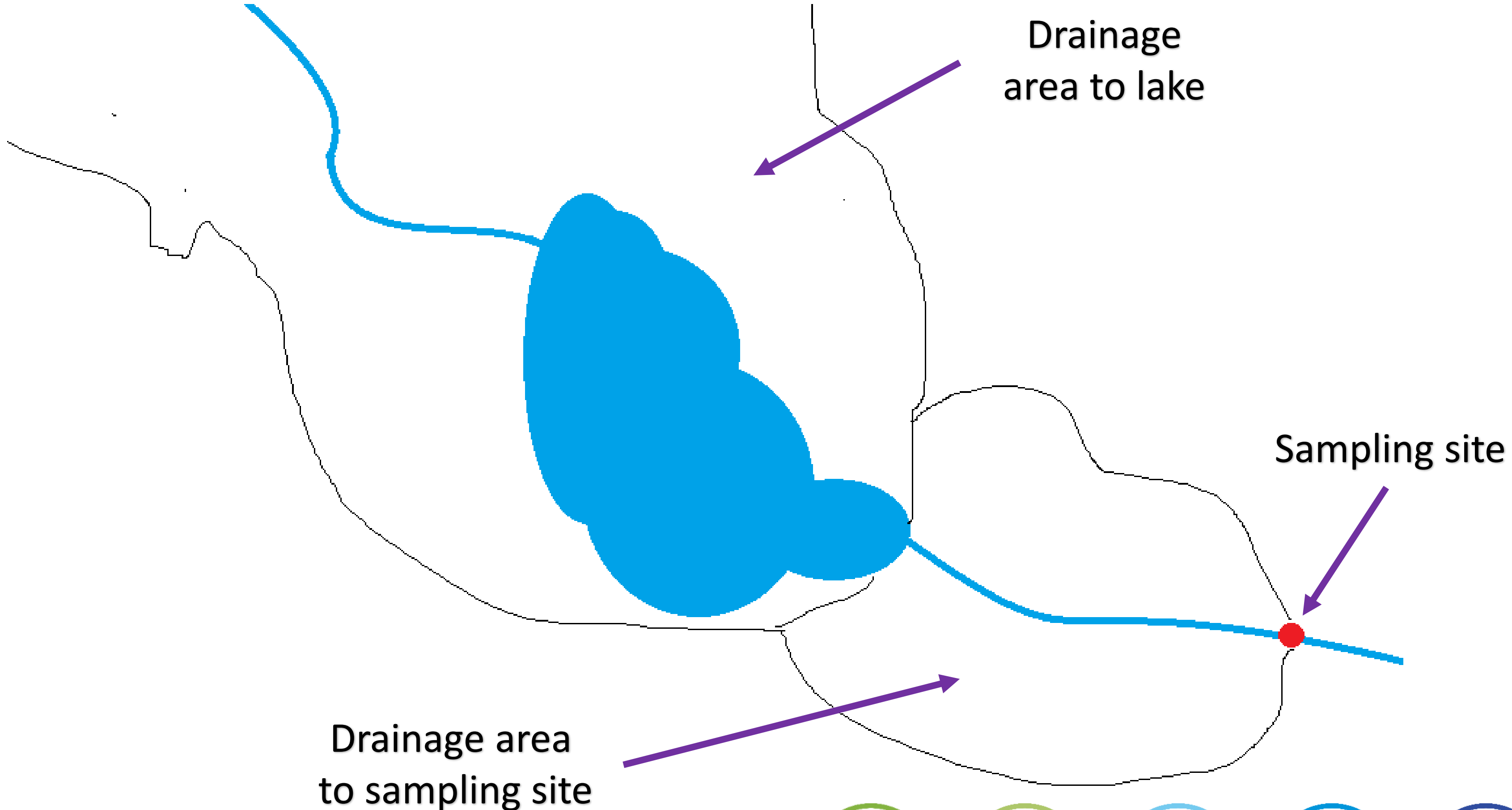
- Each model is useable for the sites used for their development
- For many sites in the Southeastern Wisconsin Region, the piecewise regression model is preferred.
  - The linear mixed effects regression model was developed using sites with low values of specific conductance and chloride concentration over narrow ranges
  - The linear mixed effects regression model will not give estimates of chloride concentrations that approach regulatory criteria because those criteria are beyond the data ranges for which it was developed

Considerations in Using the Piecewise Model

1. Remember that the model gives the average expected value of chloride concentration for a given value of specific conductance.
2. In the watersheds that we examined the piecewise regression tends to overestimate chloride concentration more often than it underestimate it
   - The low rate of false positives suggests that this may not be too big a problem for assessing whether regulatory criteria are exceeded
3. There is a lot of variability at low levels of specific conductance and chloride concentration due to the effects of other ions on specific conductance

Considerations in Using the Piecewise Model

4. The model may not perform well immediately downstream of lakes



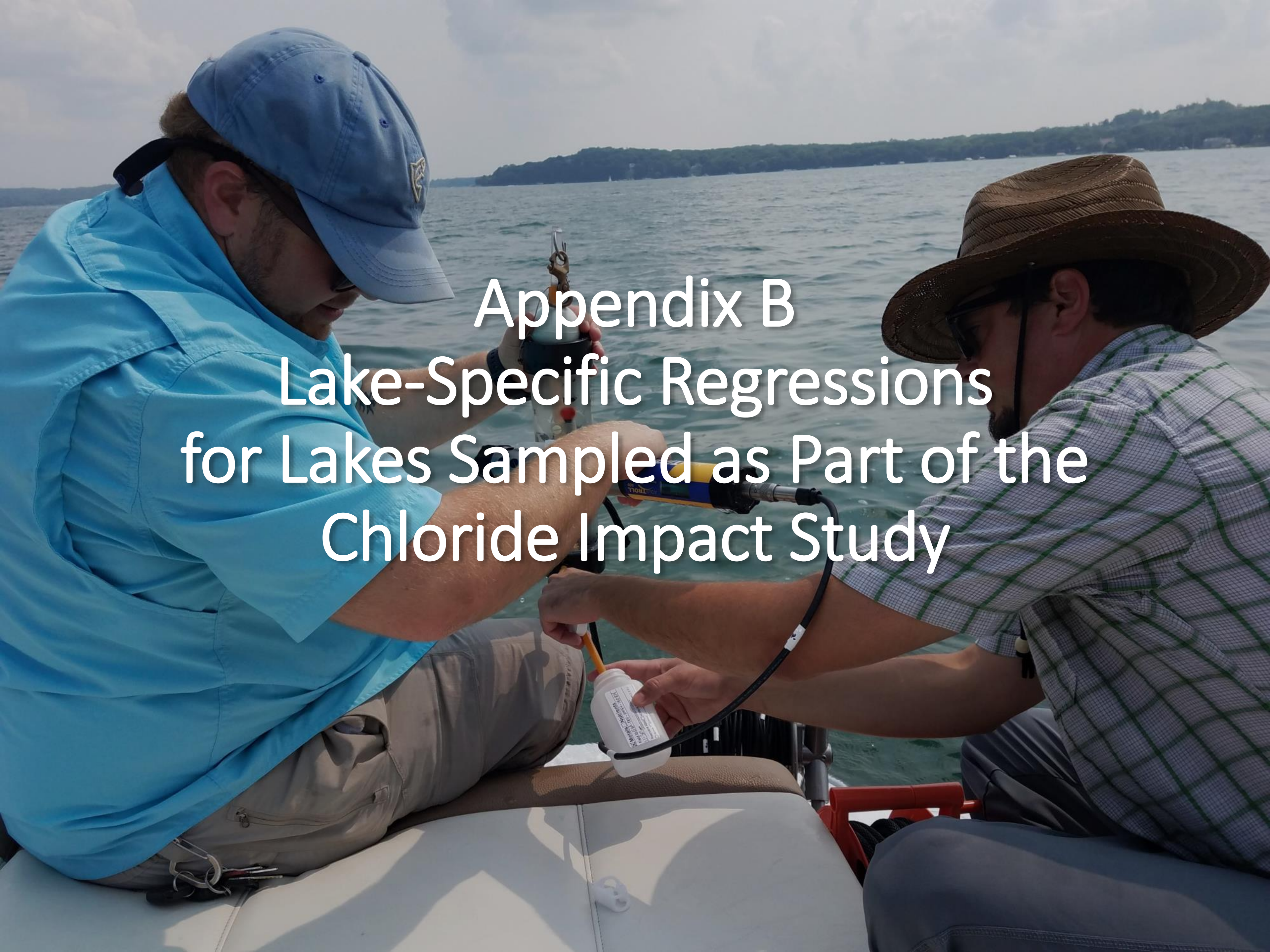
Considerations in Using the Piecewise Model

- When using this model on a stream not used in its development, it would be prudent to compare the estimates to any available recent paired specific conductance-chloride samples
- If recent paired samples are not available, it would be prudent to take some
- If the estimates are not reasonable, it might be better to develop a site-specific regression model

Considerations in Using the LME Model

- In some limited instances, the consensus equation from the linear mixed effects model might be used to estimate chloride concentrations
  - Piecewise regression systematically overestimates chloride concentrations
  - Sampling at the site shows that specific conductance never exceeds 1,000 µS/cm
  - Percentage of urban land use in the contributing area is less than 20 percent
  - Site is not immediately downstream of a lake
  - The linear mixed effects models is never suitable for determining whether water quality criteria are exceeded

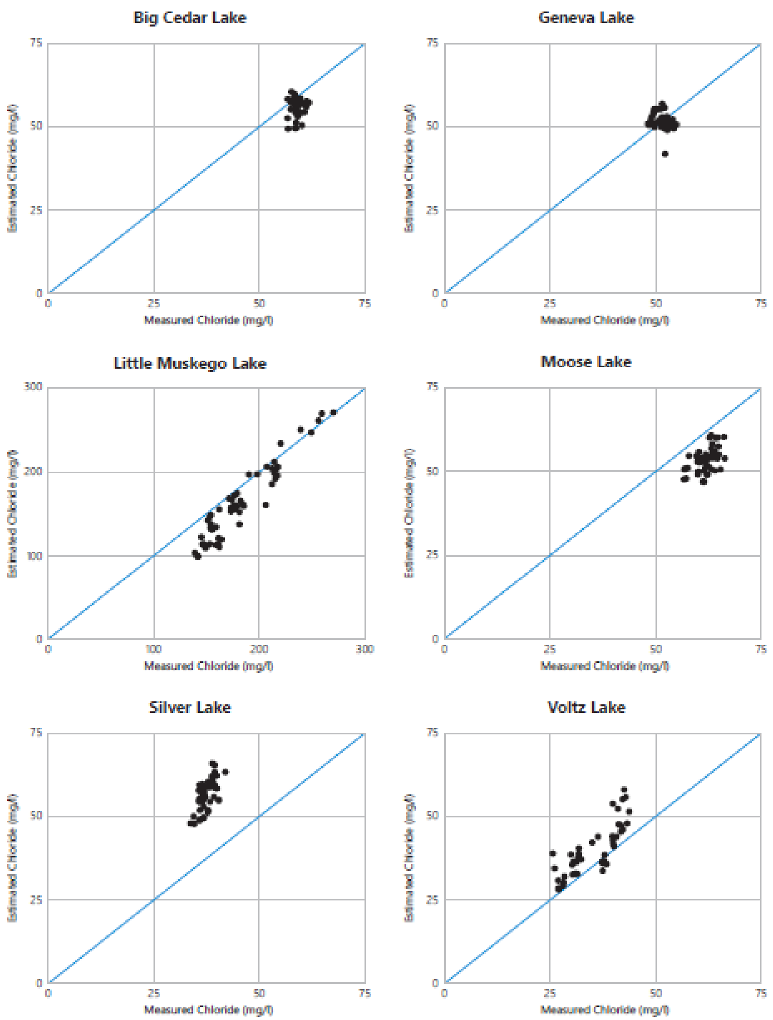
Appendix B
Lake-Specific Regressions for Lakes Sampled as Part of the Chloride Impact Study



Applicability of Regression Models to Lakes

- The regression models are not usable for samples collected from lakes
  - No lake data was used in their development
  - Running water and standing water systems can be different physically and chemically
  - The models performed poorly when compared to paired samples from lakes

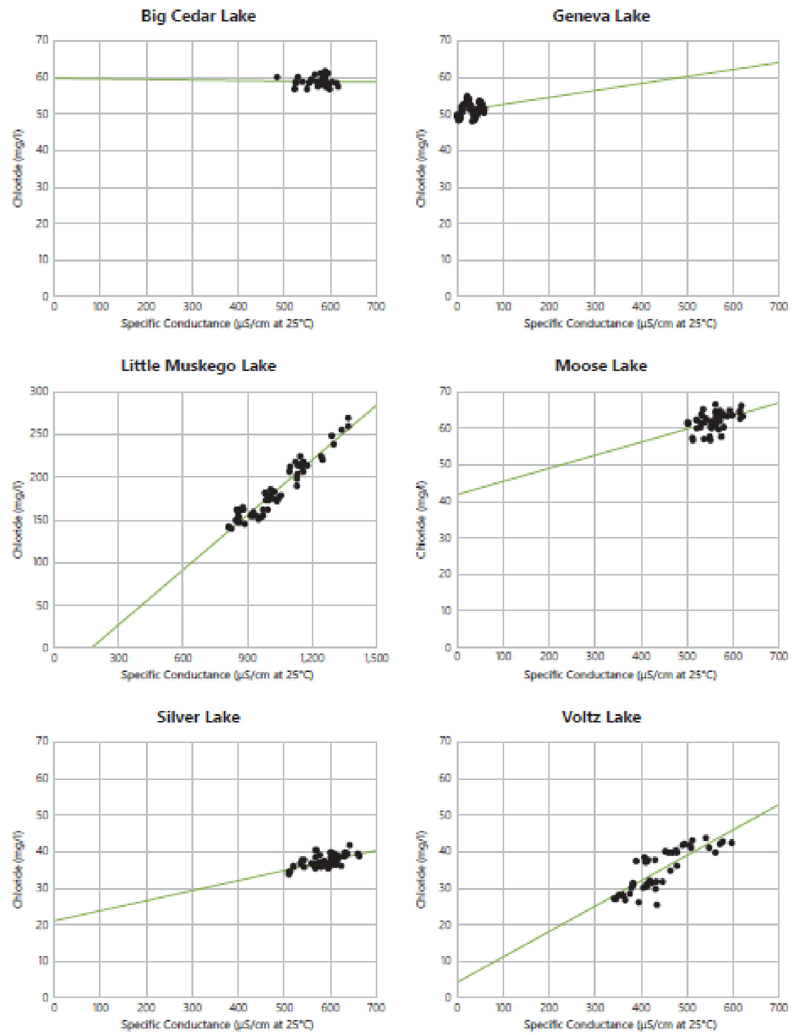
Figure B.1
Comparison of Chloride Concentrations Estimated from Specific Conductance to Measured Values in Six Lakes



Lake-Specific Regression Models

- Conducted simple linear regression analysis on the six lakes sampled as part of the Chloride Impact Study
  - Used only the samples collected as part of the study
  - Could not get significant regression for Big Cedar Lake and Geneva Lake
    - These lakes have long residence times and little variation in chloride or specific conductance

Figure B.2
Relationship Between Chloride Concentration and Specific Conductance in Six Lakes



Lake-Specific Regression Models

Table B.1
Site-Specific Regression Results for Lakes Sampled as a Part of the Chloride Impact Study[a]

Lake	Samples	Slope	y-Intercept	P-value[b]	Adjusted R^2
Big Cedar Lake	43	-0.001	59.8	0.839	0.000
Geneva Lake	55	-0.022	63.1	0.073	0.042
Little Muskego Lake	62	0.215	-37.9	<0.001	0.924
Moose Lake	52	0.036	41.7	<0.001	0.195
Silver Lake (Washington County)	56	0.028	21.1	<0.001	0.360
Voltz Lake	45	0.070	4.4	<0.001	0.647

- For Little Muskego and Voltz Lakes, specific conductance accounts for most of the variation in chloride concentration → Short residence times
- For Moose and Silver Lakes, specific conductance accounts for less than half the variation in chloride concentration → Intermediate residence times

What to Do About Other Lakes?

1. If historical and recent paired sample data are available, perform a lake-specific linear regression
   - This will require sufficient variability in specific conductance and chloride concentration → several years of data
   - Best to have samples from several locations in the water column
2. For lakes with longer residence times, sample chloride for a year to establish an average concentration
   - This average should be good for a few years
   - Sample annually to check to see that concentrations are still within the range used to establish the average

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 64 due by **May 17, 2024**

Direct email→ jboxhorn@sewrpc.org

Anticipate the next TAC meeting to be fall 2024 and include review of chapters from Technical Report No. 63, *Chloride Conditions and Trends in Southeastern Wisconsin* and/or Technical Report No. 66, *State of the Art of Chloride Management*

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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Thank You

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