

Planning Report No. 57

A CHLORIDE IMPACT STUDY FOR SOUTHEASTERN WISCONSIN

Chapter 7

CHLORIDE MONITORING OPTIONS

This Chapter utilizes information and data from a series of Technical Reports developed by the Southeastern Wisconsin Regional Planning Commission (Commission or SEWRPC) for the Chloride Impact Study (Study). These reports include SEWRPC Technical Report No. 61, *Field Monitoring and Data Collection for the Chloride Impact Study*, September 2024 (TR-61); SEWRPC Technical Report No. 62, *Impacts of Chloride on the Natural and Built Environment*, April 2024 (TR-62); SEWRPC Technical Report No. 63, *Chloride Conditions and Trends in Southeastern Wisconsin*, **Month** 2026 (TR-63); SEWRPC Technical Report No. 64, *Regression Analysis of Specific Conductance and Chloride on Concentrations*, May 2024 (TR-64); and SEWRPC Technical Report No. 65, *Mass Balance Analysis for Chloride in Southeastern Wisconsin*, December 2025 (TR-65). Refer to these reports for additional details.

7.1 INTRODUCTION

Effective chloride management requires a robust monitoring framework to accurately quantify chloride pollution and evaluate the efficacy of chloride reduction strategies. Because chloride is a persistent pollutant that dissolves easily in water and does not naturally degrade, capturing the true impact on surface and groundwater resources presents logistical challenges, particularly in the winter season when chloride impacts are greatest. Traditional, infrequent sampling often misses chloride spikes associated with winter storms, snowmelt events, and localized runoff.

To overcome these data gaps and establish a more reliable baseline of environmental impact and policy decisions, it will likely be necessary to employ strategies with multiple monitoring options. A comprehensive approach to monitoring chloride-related water quality ensures that data collection extends beyond isolated

point-in-time snapshots, providing a fuller picture of chloride conditions in surface waters and groundwater to guide sustainable reduction strategies.

7.2 STREAM AND RIVER MONITORING

Because instream chloride concentrations are highly dynamic, relying on a single monitoring method can often provide an incomplete picture of conditions. Additionally, some monitoring methods are less accessible to volunteer citizen scientists who are critical for expanding the extent of waterbodies monitored. A successful stream monitoring framework integrates multiple strategies to quantify chloride conditions and long-term trends throughout an extensive study area.

Discrete Grab Sampling

Discrete grab sampling provides the most accurate, point-in-time assessment of instream chloride concentrations. This approach involves physically collecting a stream water sample in the field. Samples are subsequently sent for analysis at a controlled laboratory environment, such as the Wisconsin State Laboratory of Hygiene (WSLH), utilizing highly precise methods like Standard Method SM 4500-CL-R-E.¹

When collecting samples during periods of low streamflow and safe conditions, the collector can enter the water downstream of an identified sampling location and walk upstream to that site. The sample should be collected facing upstream to avoid capturing any sediment or debris that may have been disturbed while walking through the stream. Sampling bottles should be submerged approximately six inches below the water surface, filled and rinsed three times, before submerging for a final time to collect the sample. Occasionally, site conditions such as high streamflow, instream ice cover, or hazardous conditions along the streambanks require grab samples to be collected from the streambank or a nearby bridge crossing using an extendable assisted sampler (see **Figure 6.2** in Chapter 6 of this report).

At a minimum, grab sampling should be conducted at a chloride stream monitoring location twice yearly, once in the winter and once in the summer. However, a more frequent and routine sampling schedule is preferred. For example, to develop a water quality dataset that captured a variety of conditions representative of each stream monitoring site for the Chloride Impact Study, Commission field staff

¹ *Standard Methods Committee of the American Public Health Association, American Water Works Association, and Water Environmental Federation. Method 4500-Cl⁻ Chloride In: Standard Methods for the Examination of Water and Wastewater, 21st Edition, Washington DC: APHA Press, 2005.*

collected monthly grab samples during the middle two weeks of each month, regardless of weather conditions. Ideally, routine sampling should be supplemented with targeted grab samples during winter weather events to capture conditions representative of peak chloride concentrations.

While discrete grab sampling is the gold standard for accuracy at the exact moment of collection, it does have significant drawbacks for watershed or Region-wide monitoring. Because grab samples represent isolated snapshots, they inherently fail to capture the highly dynamic nature of stream chloride conditions. This method frequently misses rapid chloride spikes driven by active deicing operations and snowmelt events, as well as dilution events during heavy rains, ultimately providing an incomplete picture of the total chloride loading and exposure durations for the stream.

Automated Continuous Specific Conductance Monitoring

To overcome the missing data between discrete grab sampling and achieve a high-resolution picture of surface water conditions, monitoring programs can utilize specific conductance as a reliable proxy for chloride. Numerous studies show that specific conductance can be converted to estimates of chloride concentrations through a proven conversion equation based on statistical correlation. By pairing continuous specific conductance measurements with targeted discrete chloride grab samples, predictive formulas can be developed that can provide fairly accurate estimates of continuous stream chloride concentrations.

As detailed in SEWRPC TR-61, TR-63, and TR-64, this paired data methodology was utilized to establish a high-resolution estimation of baseline chloride conditions at monitoring sites representative of the diverse characteristics of the Southeastern Wisconsin Region (Region). Developing robust specific conductance-chloride regression models requires a carefully designed monitoring program that integrates reliable and durable field equipment, strategic sampling, and appropriate statistical frameworks. Some methodologies, strategies, and other considerations that are critical to implementing a successful continuous specific conductance monitoring program are provided in the following subsections.

Equipment Deployment and Protection

- Continuous monitoring requires reliable and durable specific conductance sensors that can withstand the underwater elements within streams and rivers and collect accurate data down to near-freezing water temperatures.²
- Continuous monitoring sensors for specific conductance also often collect data for water temperature and relative water depth above the sensor. While water depth is not a required element to develop specific conductance-chloride regression models, the information is helpful for interpretation of the data collected as well as for monitoring field conditions and maintenance needs of the sensors.
- Continuous sensors will need to collect data at relatively frequent intervals to capture pulses of chloride within the streams. For the Chloride Impact Study, sensors were programmed to collect specific conductance, water temperature, and relative depth above sensor every five minutes; however, data capture at 15-minute intervals is likely sufficient for most stream monitoring sites.
- Once target stream reaches are identified, exact equipment installation sites should be selected based on several criteria including safe and easy access for field staff, a minimum baseflow depth of three feet to prevent the sensors from winter freezing, stable channel bottom substrates to securely support the sensor, and concealment from public view to minimize tampering. For more detailed information on site selection for the Chloride Impact Study, see Chapter 2 of SEWRPC TR-61.
- To protect the instream sensors from the elements and wildlife, the sensors should be deployed within a protective housing. Commission staff assembled protective housings from two-inch diameter PVC pipes that were 12 inches in length and had multiple half-inch diameter holes drilled along the entire length of the pipe to allow water to freely flow towards the sensor. A two-inch PVC cap with a half-inch hole drilled through the top was placed at one end of the housing to provide access for the sensor cable and the opposite end of the housing was left uncapped to promote flow through the housing and flushing of sediments and other debris. Once secured within the protective housing, the entire assembly was attached to a concrete cinder block using plastic cable ties (see **Figure 7.1**).

² See SEWRPC TR-61 for detailed information regarding the sensors that were used by Commission staff during the over two-year monitoring program for the Chloride Impact Study.

- Most continuous instream sensors will require a connection to an onshore data logger. Cables connecting the sensor to the onshore data logger need to be protected from the elements. Commission staff utilized flexible PVC conduit to enclose the entire length of cable to protect it from damage. Cables should be weighed down to secure them to the channel bottom and bank to minimize ice and debris impacts. Onshore data loggers should be mounted to a pole, tree, or other structure at an elevation that will keep the data logger above any potential flood flows (see Figure 6.1 in Chapter 6 of this report for a schematic of stream monitoring site equipment installation for the Study).
- Data loggers with telemetry capabilities allow data to be transmitted to servers via cellular signal. This allows practitioners to remotely monitor and visualize the data in near-real time, download data, modify equipment operational settings, and troubleshoot equipment issues. For Commission staff, the ability to view data in near-real time allowed crews to be dispatched to collect weather event-based chloride grab samples when spikes in specific conductance were being observed.

Maintenance and Quality Assurance

- Routine site visits (monthly at minimum) are required to visually inspect the monitoring site and the equipment. These inspections should confirm that the sensor has not shifted far distances along the streambed and that the sensor is not buried in debris or sediment. For the Chloride Impact Study, these routine inspections occurred in conjunction with scheduled monthly grab sampling. If in-office data monitoring is possible, site visits should also be conducted when specific conductance readings are unexpectedly low or dampened, which can indicate sensor fouling, sedimentation, or burial.
- In addition to routine inspections, more extensive cleanings of the sensor equipment are necessary to remove sediment, algae, macroinvertebrates, and biofilm from the sensor electrodes. At least twice a year (and more often when required), Commission staff pulled the sensor assemblies to the surface of the water for thorough inspection and cleaning (see Figure 7.2). It is important to note that sensors with pressure transducers used to monitor water depth can be very sensitive to cold air temperatures and drastic temperature changes. Therefore, Commission staff performed sensor cleanings in the spring and fall when air temperatures were above 45°F.

- Continuous sensor accuracy should be routinely verified by collecting specific conductance measurements using a secondary, calibrated handheld meter during each monthly visit. Continuous specific conductance sensors that can be calibrated while in the field are ideal.

Sampling Strategies for Data Pairing

- To overcome the limitations of routine monthly sampling – which often misses peak chloride concentrations resulting from winter road treatments – targeted weather event sampling should be used to capture extreme spikes and ensure the data range is robust enough for regression modeling.
- For accurate regression model development, laboratory analyzed chloride concentrations should be precisely paired with the specific conductance level recorded by the automated sensor at the exact time of discrete grab sample collection.

Statistical Modeling Considerations

- Simple linear regression is often inadequate for modeling the specific conductance-chloride relationship due to increasing variability at higher chloride concentrations and non-linear chloride trends at low specific conductance levels.
- A piecewise linear regression model, which partitions the data into intervals with separate linear equations, often provides a better fit for streams with wide ranges of specific conductance.
- For sampling sites characterized by consistently low specific conductance (e.g., below 1,000 $\mu\text{S}/\text{cm}$) and low chloride concentrations, Commission staff found that individual regression models developed for specific streams (referred to as linear mixed effects models in TR-64) may be more appropriate.
- Because non-chloride ions can significantly influence specific conductance at low levels, regression models should establish a minimum specific conductance threshold below which chloride estimates default to zero.

Site Limitations and Long-Term Validity

- Regression models designed for streams may perform poorly in lakes or in stream reaches immediately downstream of lakes because the large water volumes of the lake will buffer and temper chloride concentrations.
- Because ambient concentrations of other background ions can change over time, the relationship between specific conductance and chloride may drift, requiring periodic model re-evaluation using new paired chloride-specific conductance samples.

Applying Chloride Impact Study Regression Models to New Stream Monitoring Sites

SEWRPC TR-64 presents the development of the Chloride Impact Study regression relationship between chloride and specific conductance. These regression models may offer a potentially cost-effective method for estimating chloride concentrations based on specific conductance measurements at new stream sites in the Southeastern Wisconsin Region. Several important factors should be considered when applying these regression models developed for the Study. First, an estimate generated by the model represents the average chloride concentration that is expected to be observed at a particular level of specific conductance. There will be variation around this average, so some deviation of estimated concentrations from measured values in paired specific conductance-chloride samples should be expected. Additionally, transferring these models to other stream locations requires strict validation protocols to ensure local accuracy. When applying the regression models that were developed for the Study to new stream locations, the following validation guidelines should be adhered to (see SEWRPC TR-64 for comprehensive details related to the regression models):

- **Piecewise Regression Model Application:** For most newly monitored streams, the piecewise regression model is the preferred predictive tool because it encompasses a broader range of specific conductance levels and chloride concentrations (see **Table 7.1**). Before relying on the model, practitioners must collect a set of recent paired specific conductance and chloride grab samples at the new site. The chloride estimates generated by the piecewise model should be directly compared against the actual laboratory-measured chloride concentrations from the paired samples. If the comparison demonstrates that the piecewise model produces reasonable estimates for the new site, it can be adopted for continuous estimation of chloride concentrations. If the estimates are consistently inaccurate or unreasonable, an alternative model or a uniquely developed site-specific regression will be necessary.

- Linear Mixed Effects Regression Model Application: The consensus equation derived from the Study's linear mixed effects model was highly specialized and is generally not preferred over the piecewise model for new stream locations (see Table 7.2 for linear mixed consensus equation). Its application should be strictly limited to sites that meet all of the following conditions:
 - Initial field sampling demonstrates that the piecewise model consistently overestimates chloride concentrations at the site.
 - Continuous or historical monitoring shows that specific conductance at the site never exceeds 1,000 $\mu\text{S}/\text{cm}$.
 - A spatial analysis of the contributing drainage area confirms that urban land accounts for less than 20 percent of the total area.
 - There are no major highways or significant transportation networks draining directly into the waterbody immediately upstream of the monitoring location.

Even when a prospective new site meets all the criteria for a linear mixed effects model, the application of the model still requires the same rigorous field validation using recent paired samples to confirm predictive accuracy before broad implementation.

Ion-Selective Electrodes (ISE)

Ion Selective Electrodes (ISE) offer a method for the direct, on-site measurement of chloride ion levels in surface waters without needing complex laboratory analysis. Submersible ISE probes utilize a chloride-sensitive membrane that generates an electrical potential proportional to the concentration of chloride ions in a water body. Like conductance sensors, ISE sensors can connect to data loggers to provide continuous data logging. However, due to a variety of reasons, the application of ISEs for chloride monitoring may be most viable for on-site, point-in-time chloride readings in the field. This method could allow practitioners to conduct rapid screening and localized hotspot identification without waiting for laboratory analysis turnaround times.

While ISE sensors are capable of direct measurement of chloride concentrations, deploying these probes for continuous stream monitoring presents several major challenges. First, ISE probes are generally considered to be less robust equipment than specific conductance sensors. These devices are highly

susceptible to signal drift over time and to maintain accuracy they require rigorous and regular field calibrations which can increase labor and maintenance demands for monitoring programs. Second, the chloride-sensitive membranes on ISEs are highly prone to physical and biological fouling from sediment, algae, and biofilm which can dramatically skew and dampen instream chloride measurements. Lastly, chloride ISE sensors can be affected by competing ions in surface waters, such as bromide and sulfide, which can further alter the direct chloride readings.

Chloride Test Strips

Chloride test strips can provide a highly accessible and cost-effective option for discrete monitoring of waterbodies, groundwater, or drinking water. The most commonly utilized chloride test strips are Quantab strips manufactured by Hatch. Test strips operate by dipping the strips into a water sample and allowing fluid to rise up the strip by capillary action. The strip contains silver ions, which combine with chloride in the sample, triggering a silver chloride chemical reaction. The chemical reaction forms a white column on the test strip and after the appropriate amount of time, the length of the white column on the strip is then compared to a conversion chart to estimate chloride concentration. Depending on the anticipated pollution levels, monitoring programs can utilize low-range test strips (measuring 30 to 600 mg/l) or high-range test strips (measuring 300 to 6,000 mg/l).

The low cost and simplicity of chloride test strips make them an obtainable tool for citizen science and volunteer monitoring networks. By crowdsourcing data collection, monitoring programs can gather baseline chloride data across a significantly larger number of waterbodies than would be financially possible to monitor using expensive and labor-intensive automated sensors or laboratory testing. Additionally, chloride test strips may be a good tool to help identify chloride hotspots and chloride sources by testing various tributaries and/or stormwater outlet pipes. Volunteer monitoring programs have successfully utilized test strips to expand spatial data coverage. For example, the Izaak Walton League of America has implemented the “Salt Watch” program that distributes free chloride test strip kits nationwide, allowing citizen scientists to quickly identify general chloride conditions within local streams and lakes. The volunteers can then enter their data into an online database that will be shared and visualized via maps on the project website. The goals of the Salt Watch program are to raise awareness in the general public about the connection between road salt and public health, to identify waterways with high levels of road salt pollution, and to advocate for smarter road salting practices by sharing Salt Watch results with private landowners and local and state agencies.

The most significant drawback of test strips is the potential subjectivity involved in reading the results. Visually assessing exactly where the color change stops against a printed scale can introduce human error, reducing the overall precision and repeatability of the measurement compared to high-tech sensors or controlled laboratory analysis. Additionally, because the strips rely on a silver chloride reaction to measure concentrations, other anions that react with silver can interfere with the results, including bromide, iodide, sulfide, cyanide, and strong acids. Chloride test strip results should be considered estimates of chloride conditions in a waterbody at one moment in time and are not admissible to be included in water quality databases such as WDNR's SWIMS or the USEPA's Water Quality Portal.

Flow Integration and Load Calculations

Chloride concentrations in streams are driven by the relationship between the total mass of chloride entering the stream (chloride load) and the volume of water available to dilute the chloride. Because of this, chloride concentrations in a stream are highly dependent on its streamflow. For example, chloride concentrations might spike during a low-flow winter period or become heavily diluted during an intense rainstorm. If a monitoring period happens to have several wet years in a row, it could appear that chloride concentrations are dropping, when in reality there is just more water diluting the same amount of chloride entering the stream.

This same idea of dilution determines how chloride behaves spatially across different sized waterbodies. Large chloride loads entering a major river can often result in fairly low chloride concentrations because the large volume of water heavily dilutes the chloride salts. Conversely, a small headwater stream receiving a much smaller load of chloride can lead to severe localized concentration spikes because the small stream lacks the baseflow volume to dilute the runoff. For these reasons, large rivers are often better monitored to track total pollutant loading moving through a watershed, while small urban streams should be prioritized to identify acute concentration spikes that are toxic to local aquatic life.

While continuous specific conductance sensors and discrete grab samples provide important data regarding chloride concentrations, concentration metrics alone offer an incomplete picture of overall chloride conditions. To fully characterize chloride pollution, monitoring programs should ideally collect simultaneous streamflow data. Integrating streamflow with concentration data is critical for calculating the total mass load of chloride being transported to downstream waterbodies and isolating true pollution trends from random weather-driven flow variations.

Co-Locating Monitoring Sites with Established USGS Gages

When designing a continuous monitoring network, the most efficient method for integrating flow data is to leverage existing flow monitoring stations. Whenever feasible, new continuous specific conductance monitoring should be sited at or near established U.S. Geological Survey (USGS) streamflow gaging stations. As of 2018, the USGS maintained 34 stream gage stations within the Region as part of their greater USGS national streamgaging network (see locations of gaging stations on Map 2.9 in SEWRPC TR-61). While the stream gage stations are primarily operated and maintained by the USGS, they are funded in partnership with one or more federal, state, and local agencies or organizations.³ These stations continuously monitor streamflow throughout the year by measuring stream water levels and computing streamflow discharge from those measurements using a rating curve. Rating curves are developed for individual stream gage stations to provide relationships between water levels and streamflow discharge and are periodically refined over time. Co-location of water quality monitoring sites with USGS streamflow gaging stations can provide a monitoring program with access to continuous, rigorously quality-assured discharge data that can align temporally with continuous specific conductance readings.

For the Study, Commission staff prioritized establishing continuous and discrete stream monitoring at locations that were adjacent to USGS stream gages, establishing 14 Study monitoring sites co-located with gages. Using the regression equations that were developed for the Study, the 5-minute continuous specific conductance data observed at stream monitoring sites were converted to estimated chloride concentrations. These estimated concentrations were then combined with the USGS streamflow data to calculate monthly instream chloride loads for each site. Detailed methodologies for the instream chloride loading analysis can be found in SEWRPC TR-65.

Flow Estimation for Ungaged Streams

The vast majority of streams do not have USGS streamflow gaging stations; therefore, alternative methodologies would be required to integrate flow data. A potential option for estimating flow is to deploy continuous specific conductance sensors that are also equipped with pressure transducers to measure water depth or deploy stand-alone water level loggers at the same locations. To convert this depth data into total volume of water flowing through the stream, field staff must take manual streamflow measurements using a wading rod (to measure depth) and velocity meter (to measure water speed) across a full spectrum of flow regimes, with seasonal stream conditions ranging from winter baseflow to high spring water levels.

³ USGS National Streamgaging Network website: www.usgs.gov/mission-areas/water-resources/science/usgs-national-streamgaging-network.

These paired stage and discharge measurements can then be used to develop a continuous site-specific rating curve, or a mathematical model that converts measured water depth and velocity directly into flow volume.

Commission staff investigated the feasibility of developing streamflow datasets for the Chloride Impact Study stream monitoring sites that were not located near USGS stations. However, the range of flow measurements collected during the Study's three year monitoring period were relatively limited, covering only the wadable range of water levels. Additionally, the water depth data collected by the instream sensors at the monitoring sites was determined to not be reliable enough to use for flow estimates, as the depth sensors were subject to malfunction. Furthermore, because the instream sensors were not fully secured in position on the stream bed, they could be moved during high flow events or by human intervention, and occasionally the sensors were found buried in the streambed substrates. These challenging conditions limited the development of a reliable streamflow record at ungaged stream monitoring sites for the Study.

7.3 LAKE MONITORING

Existing lake chloride data is often inconsistent or lacking, with significant gaps in spatial coverage, time, and season, and the most complete datasets have a bias towards large lakes with public access. Furthermore, there is limited data collected during the winter months, with sampling being difficult and potentially hazardous.

For the Chloride Impact Study, Commission staff successfully conducted a two-year monitoring program for six lakes in the Region. The monitoring program consisted of discrete grab sampling at various depths as well as conducting vertical specific conductance and temperature profiles. Lake monitoring during the spring, summer, and fall was conducted from a boat anchored at the lake's deepest hole, while monitoring during winter was conducted through the ice when conditions allowed. Based on this experience, several options for monitoring chloride conditions in the lakes of the Southeastern Wisconsin Region are described in the following sections. Further details on the equipment and methodology used for monitoring chloride conditions in lakes for the Chloride Impact Study can be found in SEWRPC TR-61.

Discrete Grab Sampling

Lake Surface Sampling

For most lakes, collecting a surface chloride sample at the lake's deep hole once or twice a year is sufficient (further guidance on sampling frequency and timing is provided later in this chapter). When collecting a

surface sample, the sampling bottle should be submerged to a depth of approximately three feet and triple-rinsed with the lake water to remove any potential contaminants before capturing the final sample. Samples should then be sent for analysis at a controlled laboratory environment, such as the WSLH.

In addition to sampling lake surface water, collecting grab samples from tributary streams flowing into the lake can provide valuable supplementary chloride data. Tributary stream sampling locations should be established at the nearest upstream road crossing where apparent stream current is visible, and the stream is no longer influenced by backwater impacts from the lake. To ensure consistency and comparability, these tributary stream samples should be collected as close to the time of the lake surface sampling as possible.

Similar to discussion of stream monitoring (see “Chloride Test Strips” in Section 7.2), chloride test strips are a cost-effective option for assessing general baseline conditions for lakes in the Region and for identifying lakes that require more comprehensive monitoring. Utilizing volunteers to crowdsource data collection enables monitoring programs to expand their baseline chloride tracking to a much larger number of lakes that otherwise would be cost-prohibitive to monitor via laboratory analysis of discrete grab samples. It should be noted that chloride test strip results should be considered general estimates of chloride conditions at a single point in time and are not admissible to major water quality databases as measured chloride concentrations. Chloride test strips can be requested at no cost through the Izaak Walton League of America “Salt Watch” program.

Sampling at Discrete Depths

Surface water impacted by chloride increases in density, meaning that chloride-laden water can settle to the deepest part of a waterbody under the right conditions. If lake water contains excessive chloride, chemical stratification can potentially interfere with seasonal lake mixing in the fall and spring. This chemical stratification can delay or prevent the mixing of oxygen into the benthic zone at the lake bottom, negatively impacting aquatic life. Therefore, for lakes that are highly impacted by chloride pollution (surface water samples greater than 230 mg/l), it may be prudent to sample chloride concentrations at several discrete depths in addition to surface water sampling, to monitor for potential chemical stratification.

To conduct chloride sampling at discrete depths, a vertical sampling device can be utilized. Lake monitoring for the Chloride Impact Study used a 3-liter Niskin-style vertical water sampler (see [Figure 7.3](#)). The device consists of a 35-inch long by 5-inch diameter clear plastic cylinder equipped with spring-loaded hinged doors at each end. The sampler is attached to a measured leader line and slowly lowered to the desired sampling depth with both doors in the open position. Once at the targeted depth, a brass messenger weight

is fed onto the leader line and released. The weight travels down the line to strike the sampler release pin, snapping the doors closed to trap water from that specific depth. After retrieving the sampler to the surface, the sampler's air vent is opened to allow water to flow through the bottom drain hose, letting a small volume of water run freely to flush the hose. A labeled 250 ml sample bottle is then triple rinsed using the drain hose to remove any residual contaminants before filling it a final time for laboratory analysis of chloride concentration (see **Figure 7.4**).⁴

Lake Specific Conductance and Temperature Profiling

Collecting specific conductance and water temperature vertical profiles at a lake's deep hole can provide a cost-effective method for characterizing general chloride conditions across different depths by using specific conductance as a proxy for chloride. The exact location of the lake's deep hole can be confirmed by using a portable sonar or fish finder.⁵ To perform vertical lake profiles for the Chloride Impact Study, Commission field staff utilized a multiparameter sonde equipped with depth, water temperature, and specific conductance sensors, which was attached to a long communication cable (200 feet) on a reel for steady deployment. This cable connected to a wireless device that transmitted real-time data visualization to software installed on a mobile device. Once deployed just below the surface (typically three feet), the sonde should be left in place for an initial five minutes to allow the sensors to fully equilibrate. Following this equilibration, the device is slowly lowered along the vertical profile at an approximate rate of two feet every 10 seconds. The descent is paused at pre-determined depths – strategically selected based on thermal stratification to capture the surface, layers directly above and below the thermocline, and near the lake bottom – to allow the sensors to adjust and record accurate readings.⁶ While the sonde data is continuously recorded by the software, discrete temperature and specific conductance readings should also be

⁴ For the Chloride Impact Study, Commission staff also had several other constituents from lake grab samples measured by the lab to gain a more comprehensive understanding of overall water quality conditions. These constituents included metals (calcium, magnesium, potassium, and sodium), sulfate, and hardness. These additional constituents are not required to be measured for a typical lake monitoring program.

⁵ The WDNR often has established water quality monitoring sites at the deep hole of lakes within the Region. The coordinates of these deep hole sites can be helpful in navigating to the correct location.

⁶ A thermocline is a transition layer of water within a lake that separates the warmer surface water from the cooler, denser, deep water below. Typically, the depth of the thermocline can range from less than 10 feet to greater than 20 feet below the surface for lakes in southeastern Wisconsin, with depth varying by lake, month, and year. The thermocline is generally characterized by a temperature change of approximately 0.5°F per foot of water depth.

documented manually in a field book at each target depth. Additionally, monitoring the real-time data for rapid temperature drops allows identification of the thermocline depth.

Guidance for Lake Monitoring Programs

Residence time of a lake is the amount of time required for natural water sources under typical conditions to fill the lake one time, or essentially the average time that water spends in a lake. Changes in concentrations of chloride in a lake can be strongly influenced by residence time. For example, lakes with long residence times may have little variability in chloride concentrations throughout the year while more riverine-like lakes with very short residence times may have substantial interannual variability that reflects seasonal patterns in road salt applications within their watersheds. Because winter deicing materials are a primary source of chloride in lakes, lakes with highly urbanized watersheds or dense shoreline development are at the greatest risk for elevated chloride loads and should be the highest priority for monitoring efforts. The following guidance presents a tiered approach to future lake monitoring – ranging from minimum to advanced levels of effort – designed to effectively track seasonal and annual chloride trends over time.

Lakes with a very short residence time (< 1 month):

- Minimum Monitoring: Collect a surface grab sample for laboratory chloride measurement at the lake's deep hole at least bi-annually (during winter and summer).
- Advanced Monitoring: In addition to the minimum monitoring regimen described above, collect additional weather event-based chloride grab samples to capture conditions after heavy deicing salt applications or large snowmelt events in the watershed. Additionally, collect a specific conductance and temperature profile at the lake's deep hole monthly during the summer and at least once during the winter when ice cover is thick enough to provide safe access. Consider collecting additional chloride grab samples from inflowing tributary streams as closely timed to the lake surface sampling as possible.

Lakes with a short residence time (between 1 month and 1 year):

- Minimum Monitoring: Collect a surface grab sample for laboratory chloride measurement at the lake's deep hole at least once per year in the summer. Additionally, collect a specific conductance and temperature profile at the lake's deep hole at least once per year in summer.

- Advanced Monitoring: Collect a surface grab sample for laboratory chloride measurement at the lake's deep hole at least bi-annually (during winter and summer). Additionally, collect a specific conductance and temperature profile at the lake's deep hole monthly during the summer and once during the winter when ice cover is thick enough to provide safe access. Consider collecting additional chloride grab samples from inflowing tributary streams as closely timed to the lake surface sampling as possible.
- Consider additional discrete chloride sampling for lakes that are heavily impacted by chloride pollution – such as lakes where specific conductance vertical profiles show substantial increase with depth or where surface chloride grab samples exceed 230 mg/l. Additional grab samples should be collected at the lake surface (3-feet), mid-depth, and near lake bottom.

Lakes with a long residence time (> 1 year):

- Minimum Monitoring: Collect a surface grab sample for laboratory chloride measurement at the lake's deep hole at least every other year in the summer. Additionally, collect a specific conductance and temperature profile at the deep hole at least annually during the summer.
- Advanced Monitoring: Collect a surface grab sample for laboratory chloride measurement at the lake's deep hole at least annually in the summer. Additionally, if the annual profile for specific conductance show chlorides accumulating at depth, collect a specific conductance and temperature profile at the deep hole monthly during the summer. Consider collecting additional chloride grab samples from inflowing tributary streams as closely timed to the lake surface sampling as possible.
- Consider additional discrete chloride sampling for lakes that are heavily impacted by chloride pollution – such as lakes where specific conductance vertical profiles show substantial increase with depth or where surface chloride grab samples exceed 230 mg/l. Additional grab samples should be collected at the lake surface (3-feet), mid-depth, and near lake bottom.

7.4 BIOLOGICAL INDICATOR ASSESSMENTS

While specific conductance and discrete chloride grab samples can measure the physical presence of chloride, integrating biological assessments into a stream and/or lake monitoring program can provide

evidence of how the pollutant impacts local aquatic life. Monitoring programs can consider employing several approaches to evaluate these ecological impacts.

- **Benthic Macroinvertebrate Investigations:** Sampling macroinvertebrate communities using standard kick-net protocols or artificial substrate samplers can provide an indication of long-term chloride impacts. Because the sensitivity to chloride salts can vary significantly across species, community composition can serve as a natural salinity gauge. For example, highly sensitive taxa such as mayflies (order Ephemeroptera) and stoneflies (order Plecoptera), and pulmonate snails rapidly decline in diversity and abundance as chloride concentrations rise. Conversely, communities in highly chloride impacted waters often shift toward salt-tolerant macroinvertebrate groups, including larval beetles (order Coleoptera), dragonflies and damselflies (order Odonata), certain crustaceans, and specific true flies (order Diptera) such as mosquitoes and biting midges (see SEWRPC TR-62).
- **Algal Assessments:** Algae respond rapidly to environmental stressors. Periphytic diatoms can be sampled from rocks and submerged surfaces for assessment. The disappearance of diatom species with low chloride tolerance and the dominance of salt tolerant species can provide an indication of salinization.
- **Fish Population Assessments:** Surveys evaluating fish populations with a specific focus on the survival rates and presence of highly sensitive early life stages, such as larvae and fry may be informative. Because these young fish lack fully developed osmoregulatory structures that control internal water and electrolyte balance, such as mature gills and kidneys, they are significantly more vulnerable to osmotic stress than adult fish (see TR-62). Tracking these populations during high salinity weather events can be particularly telling, as chloride-induced stunted growth can prolong the time fish spend in these small, vulnerable life stages, thereby increasing their risk of predation.
- **Aquatic Plant Surveys:** Assessments should evaluate the overall health of aquatic plant communities to identify potential chloride induced stress. Because elevated salinity can disrupt the cellular water absorption required for plant growth, field surveys could target sublethal physical indicators of salt stress, including stunted growth, reduced biomass, wilting, leaf discoloration, and leaf burn. Additionally, monitoring can track reproductive impacts, as high chloride concentrations can significantly reduce both flower production and seed germination (see TR-62).

7.5 GROUNDWATER MONITORING

Groundwater monitoring is critical for tracking long-term chloride accumulation within aquifer systems. When the amount of chloride coming from deicing, wastewater treatment plants, and private onsite wastewater treatment systems (septic systems) within a basin exceeds the amount exiting through surface flow, the remainder is likely stored in the groundwater, causing aquifer concentrations to rise over time. Because of this dynamic, groundwater can act as both a sink and a continuous source of chloride resulting in complex seasonal interactions with surface waters. During winter and spring, shallow groundwater discharge can dilute acute chloride spikes in streams caused by salty surface runoff from impervious surfaces. Conversely, during the summer and fall baseflow periods, chloride stored in the groundwater is slowly released, which can elevate stream concentrations even in the absence of active road salt applications. This effect is often amplified during extended droughts.

Due to the long residence time of water in many aquifers, chloride flushing can take decades or longer. Even if winter maintenance programs drastically reduce deicer applications, historical chloride stored in the groundwater will continue to discharge into surface water, creating a potentially substantial time lag in ecological improvements. Utilizing existing municipal and private well networks, along with new dedicated observation wells, can provide the critical data needed to track these subsurface chloride transport dynamics, estimate baseflow contributions, and monitor drinking water quality over these extended time periods.

Municipal Well Monitoring

Municipal high-capacity wells can provide established infrastructure for assessing groundwater trends across the Region, however, monitoring protocols could be improved to address existing data gaps.

- **Increasing Sampling Frequency:** Analysis of municipal well data for the Chloride Impact Study found that historical water sampling for chloride in municipal wells was frequently sparse, sometimes occurring only once every 10 years. Monitoring programs should increase this frequency for all wells to at least once annually. Chloride data for shallow municipal wells (less than 300 feet deep) showed much more dynamic conditions than mid-depth and deep wells and were often found to exceed the preventative action limit of 125 mg/l and occasionally exceed the drinking water enforcement standard of 250 mg/l. Therefore, shallow municipal wells should be sampled more frequently and should include sampling during both winter/spring and summer/fall periods to identify seasonal fluctuations.

- **Addressing Coarse Location Data:** A challenge in assessing municipal well data is the lack of precise spatial data. State databases often only identify municipal well locations down the Public Land Survey System (PLSS) section level (roughly one square mile or 640 acres) due to security concerns. Monitoring programs should consider recording finer-scale spatial locations of their wells – even down to the quarter section – to enable accurate spatial and trend analysis.

Private Well Monitoring Networks

Private domestic wells typically draw from shallower, unconfined aquifers, making them more vulnerable to localized chloride inputs than municipal wells. However, because of their vast numbers across the Region, they offer the best opportunity to expand monitoring and map groundwater chloride impacts. Implementing the following actions will significantly improve the quality and accessibility of private well data.

- **Addressing Depth Data Gaps:** A critical limitation in assessing private well monitoring data is missing construction details, particularly well depth. Commission staff analysis found that over 55 percent of shallow well chloride observations lacked a reported well depth. Municipalities and health departments who collect and/or collate well sampling data from private well owners should prioritize consistently identifying and recording well depths to ensure data can be properly correlated with specific aquifers and contamination pathways.
- **Targeted Sampling:** Agencies or organizations can implement discrete grab sampling campaigns targeting high-risk areas prone to elevated chloride, such as shallow aquifers beneath urban areas and near chloride-discharging facilities like wastewater treatment facilities and landfills.
- **Consistent Long-Term Tracking:** Study analysis found that 75 percent of shallow wells in historical databases possess less than ten years of data, and often only a single observation. Monitoring programs should aim to integrate standardized chloride testing into annual private well testing initiatives to build more robust, long-term datasets.
- **Addressing Coarse Location Data:** Similar to municipal wells, private well location data is often missing or generalized due to privacy restrictions. To enable accurate spatial and trend analysis, monitoring programs should prioritize recording finer-scale spatial locations for willing well owners.

- **Data Aggregation and Public Outreach Platforms:** Support and improve centralized data-sharing tools, such as the Wisconsin Well Water Quality Viewer, created and maintained by the Center for Watershed Science and Education at the University of Wisconsin-Stevens Point. This platform provides a single location to assemble and aggregate statewide groundwater chloride data. Additionally, expanding public outreach and educational campaigns encourages homeowners to voluntarily test and submit private well monitoring results, filling data gaps regarding shallow aquifer conditions in many locations of the Region.

Dedicated Observation Well Network

While robust surface water monitoring has provided a picture of chloride conditions in streams and lakes, much remains unknown regarding the conditions, trends, and transport dynamics of chloride within groundwatersheds.⁷ To better characterize the subsurface dynamics, agencies will need to look beyond existing municipal and private well information.

- **Long-Term Monitoring Partnerships:** Scientific agencies, such as the USGS and/or Wisconsin Geological and Natural History Survey (WGNHS), could develop and maintain dedicated long-term groundwater monitoring networks utilizing strategically located observation wells.
- **Routine Sampling:** This monitoring program should implement routine groundwater sampling schedules designed with the specific intent of tracking chloride conditions, rather than relying solely on secondary data collected for drinking water compliance.
- **Groundwatershed Dynamics:** Monitoring should utilize observation well networks to establish chloride depth profiles and quantify estimations of chloride moving through the groundwatersheds and into receiving surface waters.

⁷ A groundwatershed is the subsurface catchment area where all water within the soil and rock flows towards the same destination. Surface watershed boundaries and groundwatershed boundaries often do not match. While surface watersheds are defined by elevations of land, groundwatersheds are defined by underground rock layers and pressure zones that dictate which way the water flows beneath the land surface.

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CHLORIDE MONITORING OPTIONS

TABLES

Table 7.1
Piecewise Regression Model for Estimating Chloride Concentration from Specific Conductance

Specific Conductance Range ($\mu\text{S}/\text{cm}$ at 25°C) ^a	Equation to Estimate Chloride Concentration (mg/l)
$\text{SC} \leq 103$	$[\text{Cl}^{-}] = 0$
$103 < \text{SC} \leq 732$	$[\text{Cl}^{-}] = 0.1171 \times \text{SC} - 12.0$
$732 < \text{SC} \leq 2,123$	$[\text{Cl}^{-}] = 0.3084 \times \text{SC} - 151.9$
$\text{SC} > 2,123$	$[\text{Cl}^{-}] = 0.3687 \times \text{SC} - 280.0$

Range of Values ^b	
Specific Conductance ($\mu\text{S}/\text{cm}$ at 25°C)	Chloride (mg/l)
200 – 12,050	11 – 4,163

Note: SC indicates specific conductance. $[\text{Cl}^{-}]$ indicates chloride concentration.

^a The standard temperature used for adjusting conductivity to calculate specific conductance is 25°C , which is equivalent to 77°F .

^b Estimates outside the range of data used to develop the regression model should be treated as less reliable due to extrapolating beyond the range of values used to develop the model.

Source: SEWRPC

Table 7.2
Consensus Linear Mixed 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 ≤ 55	[Cl ⁻] = 0
SC > 55	[Cl ⁻] = 0.0603 × SC – 3.3
Range of Values^b	
Specific Conductance (µS/cm at 25°C)	Chloride (mg/l)
245 – 1,021	11.5 – 97.2

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

^a The standard temperature used for adjusting conductivity to calculate specific conductance is 25°C, which is equivalent to 77°F.

^b Estimates outside the range of data used to develop the regression model should be treated as less reliable due to extrapolating beyond the range of values used to develop the model.

Source: SEWRPC

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FIGURES

Figure 7.1
Continuous Sensor and Housing Assembly



Source: SEWRPC

Figure 7.2
Sensor Cleaning and Maintenance



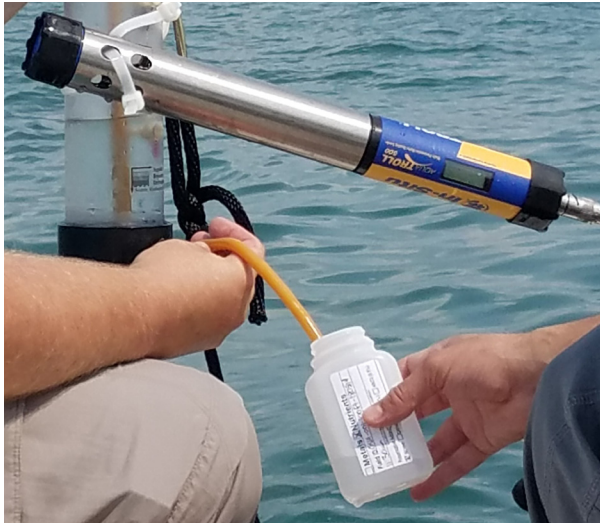
Source: SEWRPC

Figure 7.3
Niskin-Style Vertical Water Sampler and Aqua
TROLL 500 Multiparameter Sonde Assembly



Source: SEWRPC

Figure 7.4
Lake Water Quality Sample Collection



Source: SEWRPC