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Jacquelyn Molloseau
Grand Valley State University

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Assessing the Role of Groundwater in Road Salt Pollution of Urban Lakes

Jacquelyn Molloseau

Grand Valley State University

Annis Water Resources Institute

Advisor: Dr. Alan Steinman

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Introduction

As urbanization continues in locations that experience freezing temperatures, road salt pollution in freshwater ecosystems is increasingly becoming a concern. Unnaturally high salinity levels due to anthropogenic sources of salt, primarily from the salting of roadways to prevent ice-related accidents, produce negative effects on the chemical and biological composition of these systems. Past studies indicate that salt pollution in lakes can prevent seasonal turnover (mixing), keeping dissolved oxygen and nutrients from being distributed evenly throughout the water column (Foley & Steinman, 2023; Wiltse et al., 2019; Wyman & Koretsky, 2017). Additionally, biodiversity decreases in these areas as a result of anoxia and a lack of nutrients in the epilimnion (surface layer) in parts of the lake and the negative impact high chloride levels can have on some organisms (Lawson & Jackson, 2020). To make matters worse, these lakes can have inflows of chloride throughout the year because sediments in the area may be able to retain chloride during the winter and release it in the summer (Molloseau & Steinman, 2023). What results is a meromictic (non-mixing) lake that is constantly under stress and cannot sustain life in its benthic region.

A string of three urban lakes on the eastern side of Grand Rapids are currently experiencing such issues with road salt pollution and high chloride levels (Figure 1). However, only the lake furthest to the east, Church Lake, is known to have a significant inflow of salt from a tributary that runs under a major road (Foley and Steinman, 2023). While there is a small surface inflow from Church Lake into the second of the three lakes (Middleboro Lake), it is unlikely that surface flow can account for its high salinity issues given 1) the relatively low surface discharge and 2) salt entering Church Lake should sink to the hypolimnion given its higher density than water and not be present in surface flows. The lake furthest to the west, Westboro Lake, also has elevated salinity levels but no major surface inflow that could account for a source of salt. Groundwater, however, may be playing a role in contaminating these two downstream lakes. Past research indicates that road salt can seep into groundwater, causing issues with drinking water supply and creating another pathway for the contamination of lakes (Steinman et al., 2022; Williams et al., 1999). As contaminated groundwater flows into lake systems, areas that are not directly exposed to road salt via runoff can become polluted (Mackie et al., 2022; Meriano et al., 2009).

To assess whether groundwater is playing a role in the salt contamination of the three lakes, we conducted a study that 1) assessed the presence of groundwater seepage in these systems, and 2) sampled shallow groundwater for contamination.

Methods

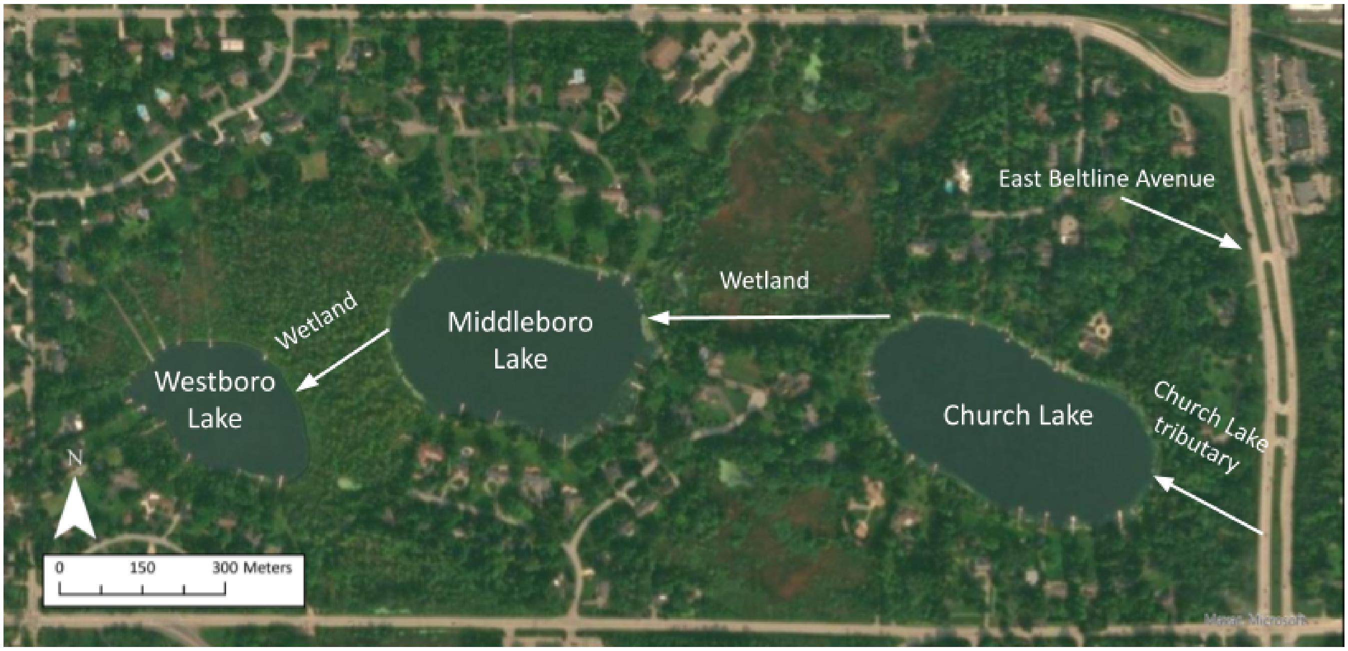

Figure 1: Map of the three lakes sampled. Church Lake is known to have severe road salt pollution, which originates from East Beltline Avenue and flows into the lake through the Church Lake tributary. Wetlands connect the three lakes, but there is limited surface flow between them otherwise.

Study Site:

Church, Middleboro, and Westboro Lakes are residential lakes located on the eastern side of Grand Rapids, MI next to East Beltline Avenue, a major roadway in the area (Figure 1). Past limnological surveys on Church Lake indicated that the lake contains high levels of chloride and, as a result, no longer undergoes seasonal lake turnover in its deeper sections (Foley & Steinman, 2023). The Church Lake tributary flowing underneath East Beltline Avenue has been identified as the main source of road salt pollution. Additionally, a sediment flume study revealed that sediments within the Church Lake tributary can retain chloride during winter months and release it during the summer, generating a constant inflow of chloride into the lake (Molloseau & Steinman, 2023). Sampling during Summer 2022 indicated that Middleboro and Westboro Lakes also have high specific conductivity, an indicator for salt pollution, despite no clear source of direct runoff (A. Passejna, unpubl. data). Because of the lack of major inflows aside from the tributary into Church Lake, I hypothesized that groundwater hydrologically connected these three lakes. Therefore, if the groundwater is polluted with road salt, it may be the source of contamination to Middleboro and Westboro Lakes. Sediments in the area may worsen this issue since they keep the area saturated with road salt, making it more likely to infiltrate groundwater.

Data collection and mapping:

Initial data collection involved measuring temperature and specific conductivity throughout the three lakes using a YSI EXO. An emphasis was placed on collecting data points within the littoral zone since these areas are the most accessible for groundwater sampling. These measurements were taken 0.5 - 1 m above the lake bottom depending on water depth at location, and a depth finder was used to establish depth before taking the measurements. Groundwater tends to be colder and have higher concentrations of ions than lake water, making temperature and conductivity a convenient method for identifying areas of seepage (Driscoll, 1986). Since all three lakes have high specific conductivity, particularly in the benthic zone, specific conductivity was a less useful indicator than temperature. However, it provided more insight into the distribution of conductivity throughout the lakes, which up to this point had been sampled only at a few select sites. It was also difficult to differentiate between groundwater and lake water in the deeper sections of Church Lake due to the lake's low temperatures and high specific conductivity from lack of seasonal mixing. However, given that the deeper locations were inaccessible for our groundwater sampling methods, the lack of temperature and specific conductivity differentials were of less concern for the goals of this study. The data from all three lakes were analyzed using coKriging in ArcGIS(3.1) to make two maps per lake, one mapping temperature and the other specific conductivity.

Groundwater sampling:

Piezometers were constructed from 1" PVC pipe, flexible plastic tubing, and a PVC drive point piezometer (Solinst) (Figure 2). Each piezometer was approximately 3.5 m in length, which allowed about 1 m of PVC to protrude from the surface of the water after being installed. Since sediments in the littoral zones were very soft, piezometers were pushed into the sediment until submerged ~1.5 m. Tubing was then inserted into the piezometer and any water that had entered the system was purged with a hand pump. A PVC cap was secured on top of the piezometer to prevent external contamination. A hole was drilled into the top of each cap so that a length of tubing could protrude from the top of the piezometer, making it easier to access when sampling. The cap and tubing hole were sealed with silicone to prevent leakage. Tubing was bent and secured to the piezometer to prevent unnecessary movement and contamination. Piezometers were purged after installation and marked with flagging tape to increase visibility during the incubation period.

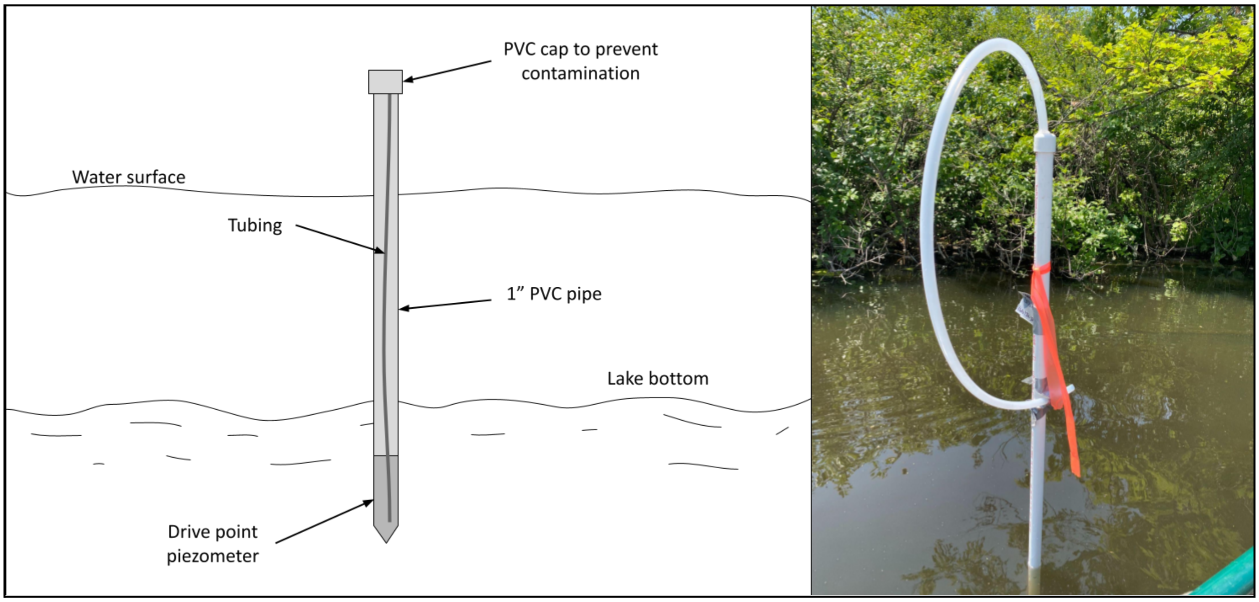

Figure 2: Basic diagram of a drive point piezometer that was used to sample groundwater with an image of the piezometer in situ.

Because there were no clear areas of groundwater seepage based on the specific conductivity and temperature maps, piezometers were installed on the east and west ends of the lakes since surface flow runs from east to west (Figure 3) (see results). Piezometers were incubated within the lakes for eight days. After this period of time, piezometers were sampled for chloride and soluble reactive phosphorus (SRP) analysis. Before samples were collected, piezometers were purged and allowed to refill for 15 minutes. This allowed the tubing to be rinsed before sampling and also ensured that fresh groundwater samples were collected. Additionally, surface water samples were collected at each piezometer site for comparison. All samples were collected in 250 mL acid washed bottles and stored on ice during transport.

Figure 3: Locations of piezometers installed throughout the tri-lakes system.

After returning to the lab, chloride and SRP samples were prepared for analysis by filtering 20 mL of sample water into scintillation vials. Chloride samples were kept in a freezer until they could be analyzed, while SRP samples were stored in a refrigerator. Concentrations for both parameters were determined using a SEAL Analytical AQ400 Discrete Analyzer.

Data Analysis

Survey data taken throughout the three lakes were converted into heat maps using coKriging in ArcGIS (3.1). Surface and groundwater samples collected during the piezometer experiment were compared using t-tests where appropriate. Similar tests were also performed across lakes and locations of piezometers (east vs. west end of lake). Significance was determined at an alpha level of 0.05 and data was analyzed using SAS Studio.

Results

Specific Conductivity and Temperature Maps:

Both temperature and specific conductivity maps were generated using Cokriging in ArcGIS (3.1) with depth as the other variable incorporated into the calculations. Both temperature and conductivity varied by depth because of the effects of salt-driven chemical stratification, making it necessary to include depth in the models.

Specific conductivity maps for all three lakes did not reveal any obvious areas of groundwater seepage in the littoral zones. However, both Middleboro and Church Lakes exhibited similar patterns of high specific conductivity in their deepest sections (Figures 4 & 5). This pattern may be indicative of groundwater seepage, but more likely this reveals that Middleboro Lake has similar road salt pollution issues as Church Lake. The Westboro Lake specific conductivity map appears to indicate that there are spots of lower conductivity in deeper portions of the lake, but conductivity varied by only about 20 µS/cm throughout the lake (Figure 6). Therefore, if the lake is experiencing road salt pollution, it is evenly distributed throughout the system.

Temperature maps also were not indicative of distinct groundwater seepage in shallower portions of the lakes (Figures 7-9). Similar to the specific conductivity maps, the cold spots in the deeper portions of the Church and Middleboro Lakes may indicate either groundwater seepage or the lack of seasonal turnover.

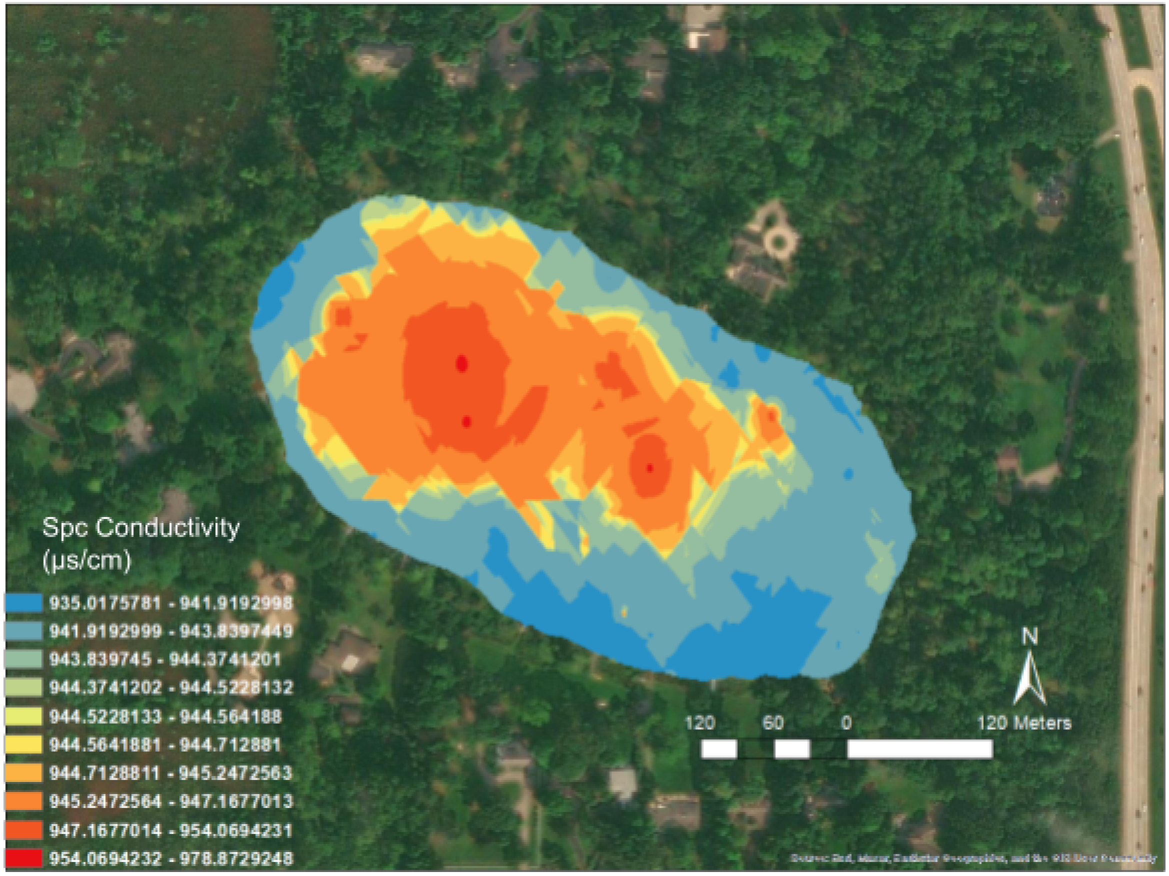

Figure 4: CoKriging map of specific conductivity along the bottom of Church Lake. Note that specific conductivity values listed are calculated using depth as another variable and therefore do not represent absolute values.

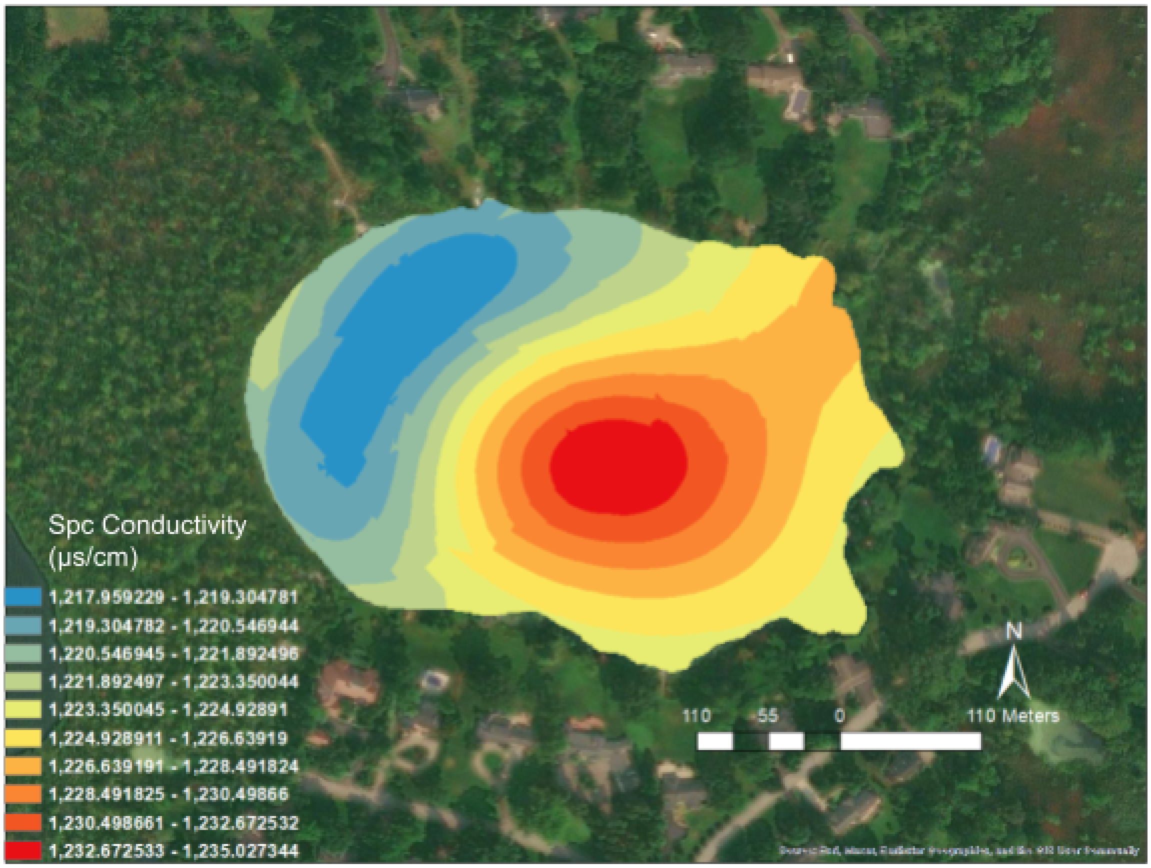

Figure 5: CoKriging map of specific conductivity along the bottom of Middleboro Lake. Note that specific conductivity values listed are calculated using depth as another variable and therefore do not represent absolute values.

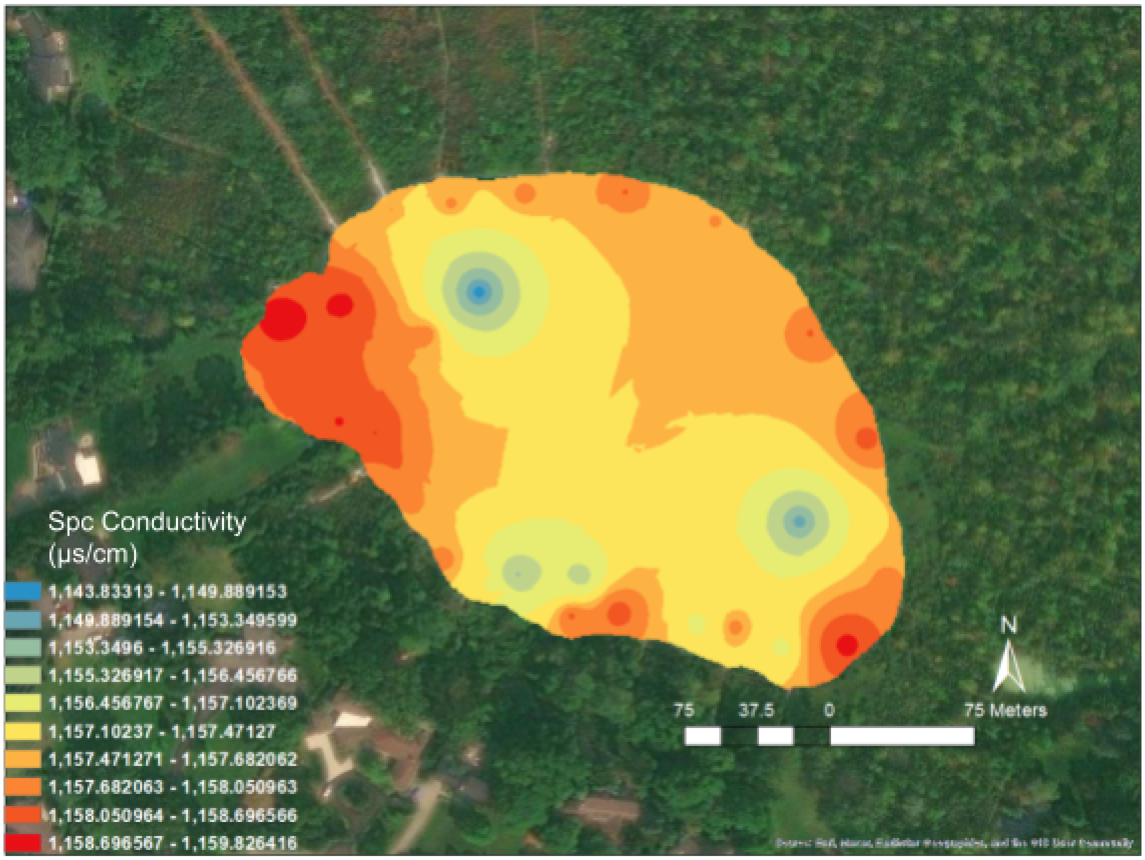

Figure 6: CoKriging map of specific conductivity along the bottom of Westboro Lake. Note that specific conductivity values listed are calculated using depth as another variable and therefore do not represent absolute values.

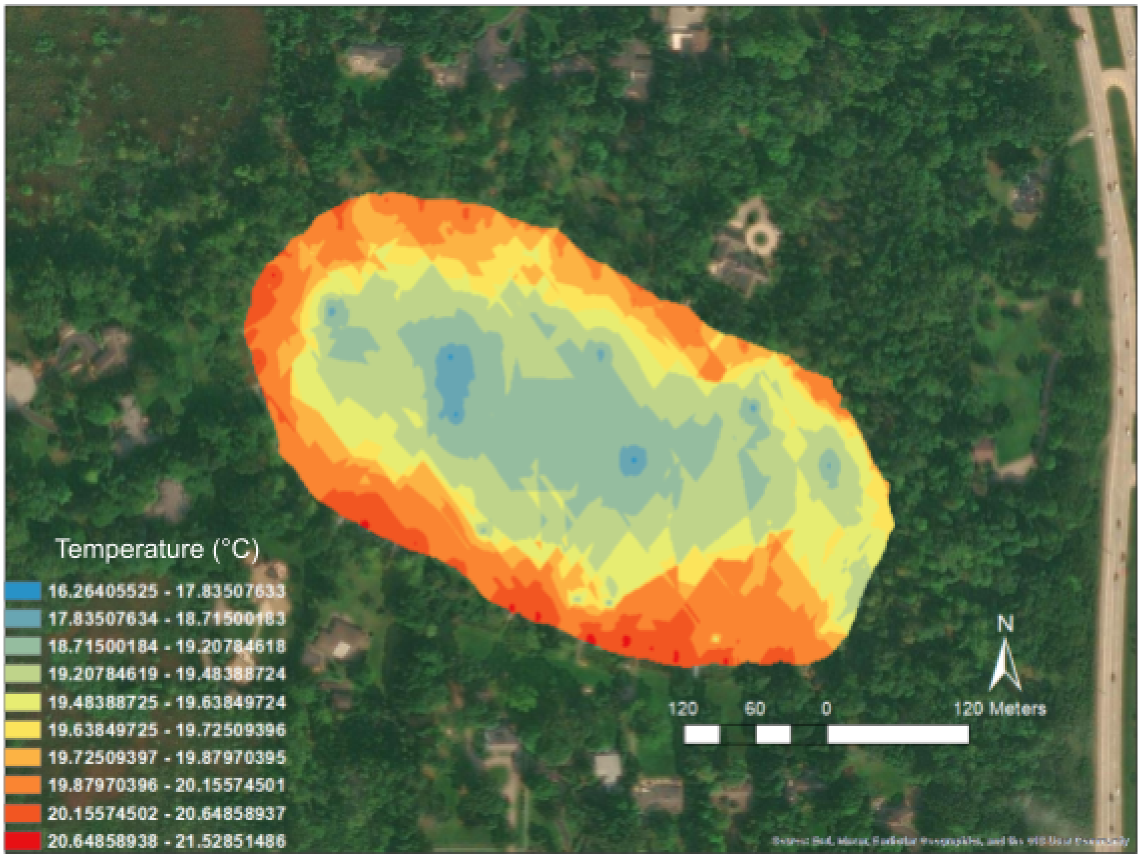

Figure 7: CoKriging map of temperature along the bottom of Church Lake. Note that temperature values listed are calculated using depth as another variable and therefore do not represent absolute values.

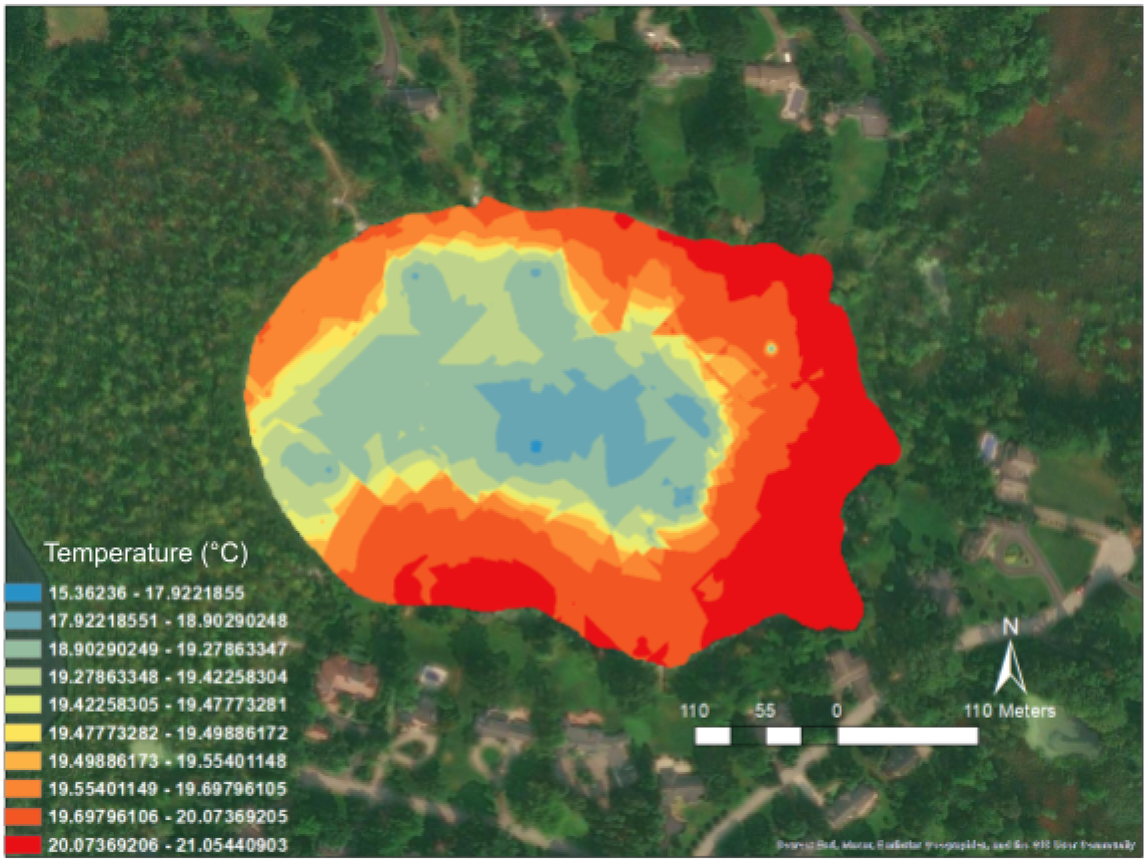

Figure 8: CoKriging map of temperature along the bottom of Middleboro Lake. Note that temperature values listed are calculated using depth as another variable and therefore do not represent absolute values.

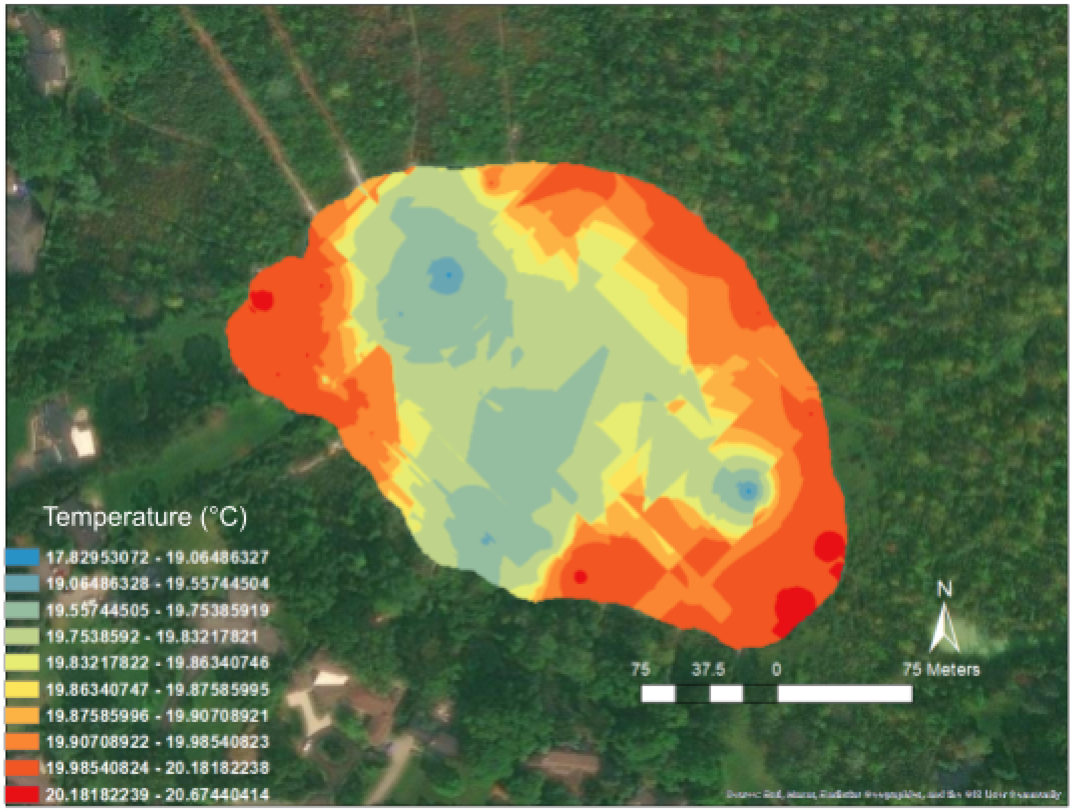

Figure 9: CoKriging map of temperature along the bottom of Westboro Lake. Note that temperature values listed are calculated using depth as another variable and therefore do not represent absolute values.

Groundwater Data:

Overall, chloride data indicate that both groundwater and surface water across the tri-lake system has been polluted with elevated levels of chloride. All samples collected exceeded the Michigan chronic value for chloride (150 mg/L), meaning that not only are these concentrations elevated above typical levels for freshwater systems, but that they are high enough to cause ecological harm (Michigan Department of Environment, Great Lakes, and Energy, 2021) (Figure 10). Church Lake had the highest chloride concentration detected, which came from the piezometer located on the west end and was double the chronic limit. The next highest sample came from the piezometer on the east end of Middleboro Lake. Since these piezometers are located on the upstream and downstream ends of the wetland that flows in between Church Lake and Middleboro Lake (Figure 2), this suggests polluted groundwater is flowing from east to west between the two lakes. While all samples had elevated concentrations, the three sites furthest to the west (MB West and both WB sites) had higher chloride concentrations in surface water than in groundwater (Figure 10). However, sample sizes were too small to analyze for differences between lakes and locations of samples (east vs. west). If more samples were taken from each lake, there may have been greater differences between groups. The setup of this study did not allow for extensive statistical analysis since its main goal was to identify the presence of chloride pollution.

In contrast to chloride concentrations, which were consistently elevated throughout all sample sites, SRP concentrations varied from non-detectable to extremely elevated. The highest concentrations came from groundwater taken from Westboro Lake at both sites where concentrations were ~40-50× greater than other groundwater and surface water samples (Table 1). SRP in both groundwater and surface water samples were the lowest out of those collected in Church Lake with levels at or below the detection limit of 0.005 mg/L. Groundwater and surface water samples also increased in SRP concentration moving from east to west across the system (Table 1). Although there were drastic differences in SRP concentrations between sites and type of sample (groundwater vs. surface water), the sample sizes were too small to be able to test for statistical significance.

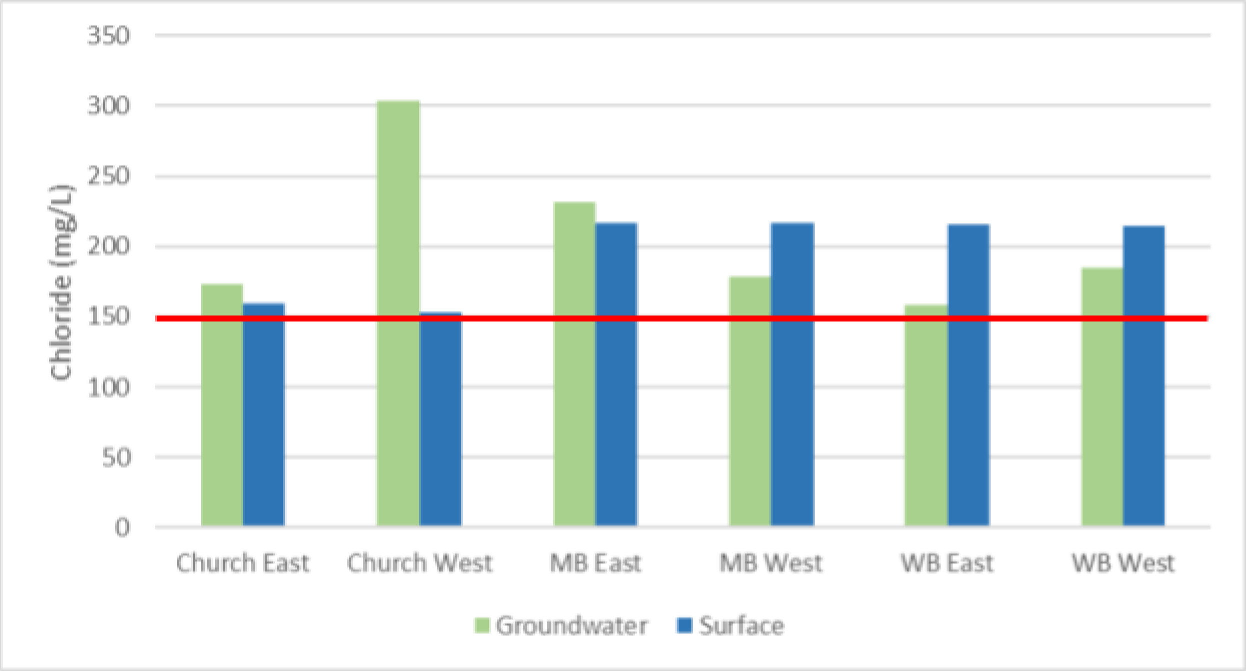

Figure 10: Graph of groundwater and surface chloride concentrations (mg/L) compared to Michigan's chronic limit (red line). MB indicates Middleboro Lake samples and WB indicates Westboro Lake samples.

Table 1: SRP concentrations (mg/L) of groundwater and surface water samples. Cells are color coded to depict low concentrations in green, moderate in yellow, and high in red. Detection limit for SRP is 0.005 mg/L.

Site location	**Groundwater SRP (mg/L)**	**Surface SRP (mg/L)**
Church East	**0.005**	**<0.005**
Church West	**<0.005**	**<0.005**
Middleboro East	**0.038**	**0.008**
Middleboro West	**0.031**	**0.007**
Westboro East	**1.112**	**0.008**
Westboro West	**1.530**	**0.012**

Discussion:

There are several studies that indicate that road salt pollution can infiltrate groundwater, causing issues with drinking water and potentially creating a pathway for pollution. Many of these studies have focused on Lake Ontario, which has a substantial groundwater input coming from areas that are heavily urbanized (Mackie et al., 2022; Meriano et al., 2009; Williams et al., 1999). A variety of sampling methods were used to assess chloride pollution, such as sampling from groundwater springs and long term monitoring wells. Some samples ranged up to 2,840 mg/L, although sites further away from urban centers tended to have concentrations less than 200 mg/L (Mackie et al. 2022; Williams et al., 1999). While chloride exists naturally in groundwater, this wide range of conditions and the increase in concentration in groundwater closer to urban areas indicates that urbanization is most likely a key factor due to the increase in road surfaces requiring salting for safe winter driving conditions. Additionally, a mass balance was calculated on groundwater in the Lake Ontario area and it was found that 50% of road salt applied enters the subsurface of the ground and contaminates groundwater (Meriano et al., 2009). There are also rising concerns about road salt pollution in Michigan due to groundwater's prevalence in the state and the many communities that use it for drinking water. Similar to the Lake Ontario area, increasing chloride levels in groundwater have been observed, particularly near urban centers (Steinman et al., 2022). Concern for road salt pollution in groundwater is generally two-fold because of its importance as a freshwater source and its ability to pollute other bodies of water.

Although temperature and specific conductivity maps throughout the tri-lakes system did not reveal specific locations of groundwater seepage, groundwater appeared to be present since collection was successful using piezometers in the littoral zones. Additionally, all chloride samples collected were above the Michigan chronic limit, suggesting that concentrations are above what would normally be expected of a freshwater system. Most likely this is indicative of road salt pollution, but chloride levels in the area before road salt pollution was introduced are unknown, leaving no historical standard to compare current conditions to. While all samples were above the chronic limit, surface samples in Middleboro and Westboro Lakes had higher concentrations than groundwater, potentially indicating that surface inputs of chloride are greater. However, these data provide evidence that the system is rich with chloride, meaning that not only are the lakes being affected, but potentially the groundwater, as well. Combined with the specific conductivity maps, there is evidence that road salt pollution in Middleboro

Lake specifically is inhibiting seasonal lake turnover in the lake's deepest sections, similar to Church Lake (Foley & Steinman, 2023).

Groundwater may also be acting as a pollution pathway for phosphorus since concentrations were highly elevated in samples from Westboro Lake, although surprisingly, the very high groundwater SRP concentrations are not reflected in the surface water of this lake. The exact source of phosphorus in this system is unknown. According to homeowner knowledge, none of the houses located on or near Westboro Lake use septic tanks, which is a common source of nutrient pollution. Some homeowners use fertilizers, but many have switched to non-phosphorus based versions because of nutrient pollution issues in their lake. There is also no farmland in the area, so agricultural pollution cannot explain these elevated levels. The elevated SRP concentrations may reflect a legacy source of P that is still being released over time (cf. Sharpley et al. 2013).

The results of this study align with others that have found similar issues with road salt infiltrating groundwater and acting as a source of chloride pollution. While these studies have used either permanent monitoring wells or groundwater springs to sample for chloride pollution, their findings support the idea that groundwater can act as a pollution pathway (Mackie et al., 2022; Meriano et al., 2009; Williams et al., 1999). Particularly compared to the studies in the Lake Ontario area, the tri-lakes system is on a much smaller scale, but the same concerns apply. There are few surface inputs into the lakes, making groundwater input highly likely. Hence, any pollution affecting groundwater will most likely impact the lakes. It is notable, however, that some of the samples collected in these other studies differ from those collected from the tri-lakes system since they were taken from springs or deeper permanent monitoring wells. The groundwater collected in this study was shallower with piezometers being installed 1.5 m into sediments, so the impact on deeper groundwater stores and aquifers in this area is unknown.

Overall, this study indicates that groundwater is a part of the road salt pollution issue in this area with it potentially acting as a pollution pathway. However, further study is required to determine the extent of road salt pollution in groundwater, particularly since the monitoring wells made with drive-point piezometers were relatively shallow compared to other studies (Meriano et al., 2009). Therefore, while shallow groundwater confirms that the area is saturated with chloride, the state of deeper groundwater is unknown. Additionally, more groundwater sites in the region should be sampled for both nutrient and chloride pollution to determine the degree of pollution throughout the area, as well as establish baseline (i.e., non-polluted) concentrations of SRP and chloride. It would also be beneficial for sampling to extend throughout the year since there might be seasonal variations in concentrations. Managing inputs of polluted stormwater into freshwater ecosystems is essential, particularly if road salt pollution is a wide-spread issue throughout the area. Groundwater is a vital source of drinking water for many communities, thus any threats to its health are threats to those who rely on it.

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