Comparative Analysis of Electrical Conductivity Dynamics in Urban and Suburban Streams of the Wildcat Creek Watershed, Manhattan, Kansas (2015-2026)

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Abstract

Road salt runoff is a major source of chloride in freshwater systems and can increase electrical conductivity (EC) in streams. Our study examined how stream discharge influences EC in urban and suburban areas of the Wildcat Creek watershed in Manhattan, Kansas, and how these patterns have changed between 2015 and 2026.

Water samples were collected weekly during late winter and early spring of 2026 at two sites: an urban location near Manhattan Avenue and a suburban location near Highland Ridge. EC measurements were compared with stream discharge data from a USGS gauge and a dataset collected in 2015 from the same watershed. EC was consistently higher at the urban site than at the suburban site in both study periods, indicating a persistent influence of urban land use, road density, and road salt inputs on stream chemistry. EC decreased during periods of higher discharge, suggesting dilution of dissolved ions under higher flow conditions rather than increased solute concentrations.

Compared to 2015, the 2026 data showed higher average discharge but lower overall EC at both sites despite similar precipitation patterns. These results indicate that land use characteristics, particularly urban development and associated road salt application, had a stronger influence on stream conductivity than variability in streamflow alone. Because EC is used as a proxy for dissolved ions such as chloride (Morgan et. al., 2012), elevated values may indicate increased exposure of freshwater ecosystems to salinization, which can contribute to physiological stress in aquatic organisms including macroinvertebrates, amphibians, and fish. These changes also have potential implications for downstream water quality and human water resources, particularly in regions experiencing continued urban expansion and winter road salt application.

1. Introduction

1.1 Causes of Road Salt Contamination

Road salt contamination is one of the most common forms of anthropogenic water pollution. As the compound used is primarily NaCl, chloride pollution has become an ever-increasing issue in waterways today. Other sources of pollution include human sewage, waste from livestock, industry disposal fields, and synthetic fertilizers, which in total make up the around 140 teragrams of Cl- used every year (Kelly et al., 2010). The majority of road salt application occurs in the winter and early spring months, causing contamination as rainfall and/or snowmelt events wash salt from the roadways into nearby water catchments. Throughout other portions of the year, treated wastewater, or TWW, is estimated to have a similar effect on chloride concentrations, but not to the level of road salts. This is corroborated by a marked decrease in chloride concentrations in waterways as their distance from roadways increases. Cl- concentrations have been increasing exponentially throughout the 20th and early 21st century, at first from industrial processes and now from road salt application (Dailey et al., 2014).

1.2 Effects of High Chloride Levels Within Stormwater

As chloride is a highly water-soluble chemical, it does not degrade easily and remains in water for long periods of time. There are multiple methods used for measuring Cl- concentration within waterways, the most common being counting Cl- ions and testing for electric conductivity. To get a conclusive reading of how many Cl- ions are in a water catchment, the amount of Cl- ions within a water sample can be counted, then extrapolated to the size and flow of the stream. This can be used similarly for Na ions to obtain specific measurements. Electrical conductivity testing can be beneficial to understand the effects of NaCl as a compound within waterways, as electrical conductivity has been shown to be directly correlated with NaCl concentrations (Kelly et al., 2019). This provides a better picture of how NaCl affects the composition of freshwater sources, but can also be less effective when seeking to separate the causes of high conductivity, as chloride in TWW also raises electric conductivity.

1.3 Freshwater Ecosystem Impacts

Freshwater systems are threatened globally by the use of road salts, which is causing an increase in salinization. Deicing agents have been known as a significant source of damage to freshwater ecosystems for decades. Authors Findlay and Kelly (2011) discussed how year-round sampling results showed that the salinity levels do not return to a healthy state during the warmer months. Summer concentrations were as high as monthly means observed during the winter season. These results prove that the long-lasting negative effects of continued over-application of road salt and exposure to high levels of chloride for an extended period of time could significantly alter the interconnected functions of a freshwater ecosystem.

Chloride levels are higher in urban areas than in non-urban areas due to a higher density of roadways. Runoff from roads is a general concern, and that concern grows with the application of road salts like NaCl. Stormwater runoff contains chemicals from road materials, chemicals applied to roads, contaminants from vehicles, and heavy metals from the deterioration of vehicle parts (Schuler & Relyea, 2018). This work emphasizes the concern for heavy metals being mobilized by salts into the soil profile and streams. Heavy metals from runoff are not readily bioavailable, but due to the chloride, the metals are transformed into a bioavailable species, which can increase the concentrations of heavy metals in the food web. Heavy metals can disrupt functions such as microbial processes, foodweb dynamics, and reduce services like carbon sequestration. They can accumulate in the soil profile, groundwater, or lakes. Road salts also alter ecosystem processes such as decomposition, nutrient cycling, and energy flow (Hintz & Relyea, 2019).

1.4 Freshwater Aquatic Organism Responses

Freshwater organisms rely on stable water chemistry to live. Factors like salinity, pH, and oxygen changes can disrupt the basic function of aquatic life (Haake et al., 2022). When salinity is increased in freshwater, organisms in the aquatic habitat usually don't respond well, and therefore, the population declines. Salt increases in water can lead organisms to expend their energy to regulate their internal balance. Therefore, organisms in high salinity environments are stressed, their growth rates are stunted or reduced, and mortality rates increase.

1.4.1 Producers & Decomposers

The basal trophic level is the backbone of an ecosystem. They produce what the next level in the food chain needs and decompose what all plants and organisms leave behind. They're very important because they transfer energy to higher trophic levels and maintain functions like nutrient cycling and decomposition. Without producers and decomposers, the whole system would collapse. Understanding how this trophic level is affected by salinity changes is crucial for research. Basal trophic level species examples are bacteria, phytoplankton, periphyton, macroalgae, and plants. Salinity affects the growth, reproduction, and survival of these species over time. Decreases in producers will lead to species decline and shift towards salt -tolerant species. Therefore, consumer population and diversity would decrease immensely over time (Schuler et al., 2017; Hintz & Relyea, 2019).

1.4.2 Zooplankton

The next step up in the food chain is zooplankton, which rely on producers as their major source of food. Zooplankton act as a stepping stone between producers and higher trophic levels. Salinity increases lead to decreases in zooplankton diversity because the salt- tolerant species remain over time. Zooplankton act as our indicators of water quality. They are important to us in more ways than one. If their diversity, abundance, or behavior changes, that is a key indicator that there is ecosystem stress (Hintz & Relyea, 2019; Miess & Dzialowski, 2024).

1.4.3 Macroinvertebrates

Mayflies, stoneflies, caddisflies, snails, and worms are all macroinvertebrates. These organisms are essential to a freshwater ecosystem. Macroinvertebrates keep streams healthy and promote biodiversity. Like zooplankton, these organisms are used to assess water quality and the condition of the ecosystem. Increases in salinity cause the community to shift due to certain species increasing and others decreasing. Physiological stress is a concern as well since increased salinity can disrupt osmoregulation and lead to cellular damage. Macroinvertebrates and especially their larvae are a big food source and are very sensitive to salt increases (Hintz & Relyea, 2019) .

1.4.4 Amphibians

Amphibians rely on freshwater ecosystems for reproduction, egg development, and larval development as well. Amphibians are also highly sensitive to salinity due to their permeable skin and insufficient ability to regulate salt balance. These species are very sensitive to changes in water chemistry and need more awareness for protection. Embryos have a hard time surviving because of the road salt runoff. There is an increased mortality rate during the early stages of life for many species, such as salamanders and frogs. These species can make homes near roads, which increases their risk for runoff and death before maturity. Amphibians can have deformities and delayed development due to salt increases. All of these factors can decrease amphibian populations, and in some areas, due to less protection, could lead to local extinction (Karraker et al., 2008; Jones et al., 2015).

1.4.5 Fish

Freshwater fish are adapted to low levels of salinity, and increasing salinity deteriorates their ability to maintain osmoregulation. Fish physiology can be increasingly disrupted with elevated levels of chloride, which lead to disrupted iron balance, increases in stress hormones, and reduced overall health. Intuitively, it can be concluded that since fish are near the top of a freshwater food chain, they are also receiving more stress from consuming other impaired trophic levels. These claims can be supported by the research done by authors Winter et al., 2026. Like amphibians, early life stages are also incredibly vulnerable to salinity. Mortality rates increase with increased salinity and lead to developmental problems. The eggs of these fish are being impacted by salt in the water, which obstructs processes inside the egg. Salt pulses in the water can cause lethal and sublethal effects amongst fish species. The extreme difference in salinity causes shock and fatal cellular damage. Heavy metals can be mobilized through fresh water, as mentioned before, which can cause an increase in toxicity for fish. Moreover, the adverse effects of salinity on the food chain can immensely affect fish and the entire freshwater food web with increases in concentration.

1.5 Human Risks

In addition to the direct effects of Cl-, high concentrations can also cause leaching of heavy metals through waterways. The heavy metals most often observed in waterways with high Cl- concentrations are lead (Pb), copper (Cu), mercury (Hg), arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), manganese (Mn), and zinc (Zn) (Lazur et al., 2020). Areas near roadways and car service shops had the highest concentrations of Cd, Pb, Ni, and Zn, while areas near large parking lots had more As and Mn (Barałkiewicz et al., 2014). Very minute amounts of these metals can be harmful to human health. They can also damage infrastructure, weakening bridges and causing corrosion in iron pipes. As chloride levels increase, the speed at which these issues occur increases exponentially (Lazur et al., 2020).

Heavy metals can percolate through the soil and into groundwater aquifers. Lead is easily mobile through the soil profile once bioavailable. Therefore, with an increase in chloride in surface water, there will be a continued increase in lead concentration in groundwater, which could lead to continued increased contamination levels in drinking water. Urban areas are more at risk due to the amount of salt being used. There are legal limits to the amount that can be applied by the city or county, but personal use cannot be regulated. It is increasingly common for people to use more road salt than what is needed, and it can stay around for a long time (Findlay & Kelly, 2011; Schuler & Relyea, 2018; Haake et al., 2022). Even though there are legal regulations from the study of Miess & Dzialowski 2024, the current thresholds are too high to protect the health of people and ecosystems. Their findings show that negative impacts can happen at much lower concentrations than what is currently legal.

1.6 Objectives

Our objectives for this study were as follows:

1. **Spatial:** Compare electrical conductivity (EC) between Manhattan Avenue (urban) and Highland Ridge (suburban) to assess the influence of land use impacts on stream chemistry.
2. **Temporal:** Compare 2015 and 2026 electrical conductivity datasets to evaluate the long-term effects of urbanization and road salt application on stream water quality.
3. **Hydrological:** Relate USGS discharge to electrical conductivity to assess the correlation between stormflow dilution and conductive ion transport.

2. Study Area

Research was conducted at two stream locations in Manhattan, Kansas. The first location was an urban location to the east of Manhattan Avenue. Wildcat Creek is the stream we sampled from, and this area we classified as urban due to the higher density of building construction and close proximity to a large road. The second location was located north of Highland Ridge, along the same Wildcat Creek. This location we classified as our suburban location due to the low density of housing and apartment buildings. The Highland Ridge location had significantly less water but consistent flow. The Manhattan Avenue location was consistently stagnant but had more water.

This study area was important for the research experiment because it allowed for the comparison along the same stream with two different urban densities. Sampling at both of these streams allowed the results to reflect the effect of runoff from the higher-populated or less populated road networks on the streams. This area maintained extensive road salt application in the previous months due to winter weather in the Midwest. Other areas across the United States have seen similar or even more extensive road salt applications, indicating an application for this study in similar locations across the nation.

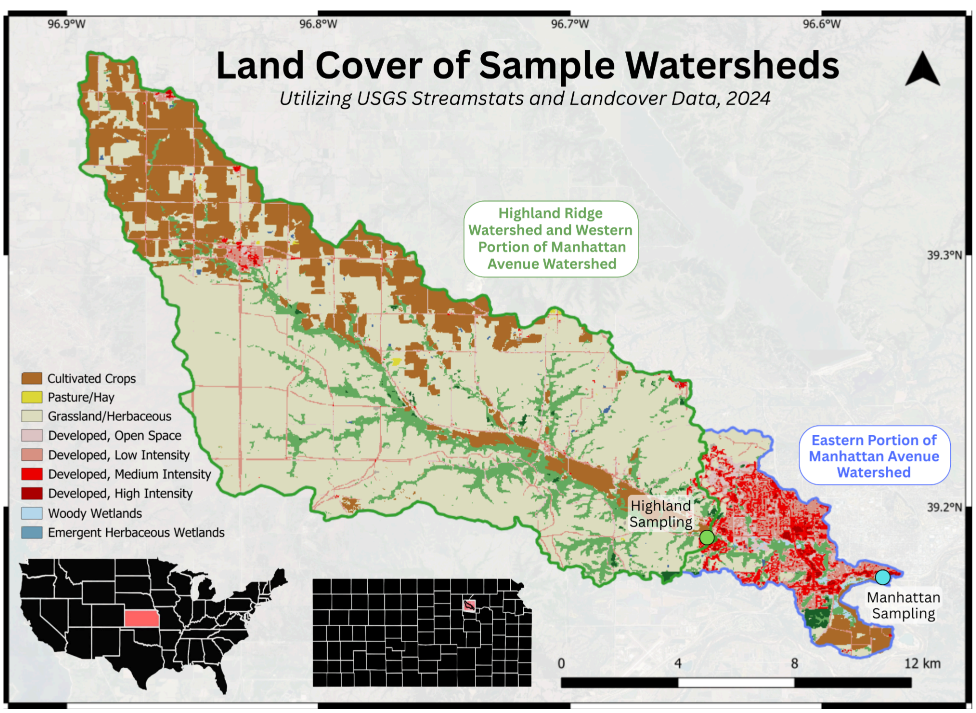

Figure 1-
This map shows land cover of the Wildcat Creek study area, including watershed delineation used in this report.

3. Methodology

3.1 Sampling Process

Two stream locations were chosen for data sampling, one urban and one suburban. These locations were decided based on 2015 data gathered by a group under Dr. Matthew Kirk, a professor at Kansas State University, utilizing the same streams. In that data, the Highland Ridge location and Manhattan Avenue location were similarly distinguished. In that study, the former was considered “rural”, but additional construction in the area indicates that the location would better fit into a “suburban” classification.

Three 5mL filtered samples were taken at each location between 4:30pm and 5:30pm every Wednesday from February 11th to March 18th, with the suburban location sampled before the urban location in each sampling instance. The collection of three samples at each location ensured consistency. In multiple instances, organics movement or streamflow changes were observed, and may have formed a heterogeneous environment. The increased sampling ensured that such heterogeneity was less impactful, and that a single mistake in sampling could be determined as an outlier if the other two samples at that location were consistent. Ultimately, samples at each location for each day showed no discrepancies, indicating the three-sample strategy was an extra precaution.

To ensure further consistency, vials were rinsed with filtered stream water before sampling to reduce contamination and maintain sample quality. Samples were collected from the middle of the stream when possible to better represent overall stream conditions and reduce edge effects near banks. Filters were used for a single location only to avoid cross-site contamination, and the same filter was used for all three replicates at each location to ensure identical processing. Vials were chilled immediately after collection and refrigerated until analysis to preserve sample quality and prevent changes in composition.

3.2 Data Sources

Land cover data were obtained from the USGS MRLC Viewer, using datasets compiled through 2024. Geospatial analysis was conducted in ArcGIS Pro to calculate the percentage of urban land use within each watershed. For this study, “urban” land cover includes the categories “Developed, Open Space,” “Developed, Low Intensity,” “Developed, Medium Intensity,” and “Developed, High Intensity,” with no weighting applied to the different categories.

Watershed delineation for each location used USGS StreamStats data, with each watershed defined to end at its respective sampling point. Discharge data were gathered from the USGS water monitoring station on Wildcat Creek, which was located within the city boundaries. Because both sampling locations were on the same stream, discharge at this station was assumed to be representative of flow conditions at each sampling site.

Discharge data was gathered from the USGS water monitoring station along Wildcat Creek, within a half-mile of the Highland Ridge location, which is within the city boundaries. Because each of the sample locations are of the same stream, changes in discharge at this location should reflect changes at each of the sample locations. Precipitation data was collected from a NOAA precipitation station located on the campus of Kansas State University, also within city limits.

3.3 Electrical Conductivity vs. Chloride

In regards to road salt contamination, chloride sampling is commonly used to describe the impact of road salt runoff into surrounding surface water. In this instance, the decision was made to utilize electrical conductivity as an indirect proxy for road salt contamination due to potential difficulties in obtaining funding for both chloride and electrical conductivity monitoring. Two primary factors played a role in this decision.

The first factor was that chloride concentration tends to be far more volatile than electrical conductivity in Wildcat Creek, with the aforementioned 2015 data containing an average chloride concentration of 49.9mM at the Manhattan Avenue location, but with a standard deviation of 25.6mM and significant week-to-week swings. Six sample dates was deemed too few to provide an unskewed examination of road salt contamination in the watershed, and the more general electrical conductivity proxy was deemed more likely to yield useful results for a six-week examination of the watershed.

The second factor was the ease of obtaining large quantities of electrical conductivity data from probes, compared to lab-oriented chloride data, allowing for a future in which these streams are monitored in a more permanent fashion using electrical conductivity. When the same data are compared across time periods, they become more useful, and so it was deemed more valuable for electrical conductivity data to be chosen so that future samples of these locations can more affordably compare results to both 2026 and 2015.

3.4 Analysis

The primary purpose of the analysis was to provide a basis for comparison with the 2015 stream data. This included calculating standard deviation between samples, comparing results between the two sampling locations, and calculating a ratio between electrical conductivity and discharge to evaluate whether variation in discharge could help explain differences in conductivity.

While the 2015 dataset spans samples collected between June 4th, 2014 and August 31st, 2015, only the first six samples following winter thaw were used for comparison. This subset was selected to focus on stream recovery after winter conditions and to maintain an equal number of samples between datasets, ensuring a consistent baseline for comparison.

To examine trends in the data, a Mann-Kendall test was performed. The alpha level was set at 0.1 to accommodate the relatively small sample size. To quantify differences in electrical conductivity between locations and between the two time periods, both one- and two-tailed t-tests were conducted using the same alpha level of 0.1.

4. Results and Discussion

The two locations we surveyed were streams beside Manhattan Avenue and Highland Ridge. These locations were compared by urban land cover, electrical conductivity, discharge values, and precipitation values. We also analyzed these results comparatively using the values collected from Dr. Kirk's research in 2015. This helped us get a short-term and a long-term measure of how water quality changes over time when exposed to stormwater.

4.1 Urban Land Cover

The Manhattan Avenue location was classified as the urban location, both in our research and in the study performed in 2015. We noted a significant increase in total urban development over the decade between the studies, with Manhattan Avenue initially showing 9.58% urban land cover and growing to 12.68% by the beginning of 2026. Because the Manhattan Avenue location showed higher urban land cover, it likely experienced more direct car and human pollution. We also noted a land cover increase in the Highland Ridge location, labeled as suburban for study, and rural for the 2015 study. Highland Ridge grew from 4.19% urban land cover to 6.07%. As the city of Manhattan grew in population, we expected that total urban land cover would increase and affect the water quality.

4.2 Electrical Conductivity

Figures 2 and 3 below demonstrate the average electrical conductivity of each set of samples over the 2026 sampling period. Manhattan Ave. (*Figure 2*) shows significantly higher electrical conductivity values than Highland Ridge, with a range of 0.600-0.837 mS/cm (*Figure 3*). Highland Ridge showed lower values with less variation, ranging from 0.657-0.707 mS/cm. The high urban land cover percentage at Manhattan Ave suggests that an increase in car traffic on nearby roadways led to an increase in chemical runoff from these roads into the sampling stream. As Highland Ridge also shows significant urban land cover, it likely experienced similar but muted effects within the stream. The chemicals from car traffic, road salt, and other anthropogenic pollutants likely increased the electrical conductivity in both of these locations over the decade. When looking at the 2026 trend line from *Figure 2*, the slope values are negative, showing that electrical conductivity decreases throughout the sampling period. This coincides with a decrease in road salt application as dissolved ions decrease. The 2026 trend line from *Figure 3* demonstrates a low positive slope, suggesting that road salt levels stayed relatively consistent at this location resulting in a uniform electrical conductivity range.

When compared to the data from the 2015 study, electrical conductivity at Manhattan Ave. showed a much higher range, from 0.872-1.087 mS/cm. Electrical conductivity at Highland Ridge was also higher during this time period, ranging from 0.728-0.872 mS/cm. Despite both of these locations having less respective urban land cover, the overall electrical conductivity values from 2015 were much higher than in 2026. Both data sets were also within the normal range of electrical conductivity, stated by the EPA as 0.05-1.5 mS/cm (EPA, 2012).

4.3 Discharge and Precipitation Values

Discharge in 2026 was much higher than in 2015, with the 2026 average being 4.477 ft^3/s and the 2015 average being 2.192 ft^3/s. Higher electrical conductivity values occurred with lower discharge values, indicating that elevated discharge is not causing higher electrical conductivity as previous studies have found. Precipitation values were very similar over the years, with values at 2.333 in/week in 2015 and 0.255 in/week in 2026. This also suggests that changes in precipitation values are not correlated to changes in electrical conductivity, as electrical conductivity was notably different between both sample groups. Overall, these results indicate that streamflow conditions alone do not explain variability in electrical conductivity, and that timing and transport of dissolved ions are likely more important controls in this system.

4.4 Future Research

More study is needed to understand the full scope of electrical conductivity variability. A longer sampling period would provide a more robust measure of how electrical conductivity changes over a full year, similar to how sampling was performed in the 2015 study. Extending the study duration would also allow for a greater number of data points and stormwater events to be captured across different seasonal conditions, making results more accurate, reliable, and conclusive. We could also examine factors such as chloride ion levels more directly to determine whether chloride shows a similar negative correlation to discharge, as observed in our electrical conductivity results. This would help confirm whether conductivity is acting as a consistent proxy for chloride concentration under varying hydrologic conditions. Another unexplored area of study is testing rural locations in areas with urban land cover showing as less than 4%. Including these sites would provide a clearer baseline condition and a more complete range of land use impacts. This would ultimately give a more conclusive picture of how strongly land cover is correlated to electrical conductivity within watersheds, and how these relationships change across increasingly urbanized systems.

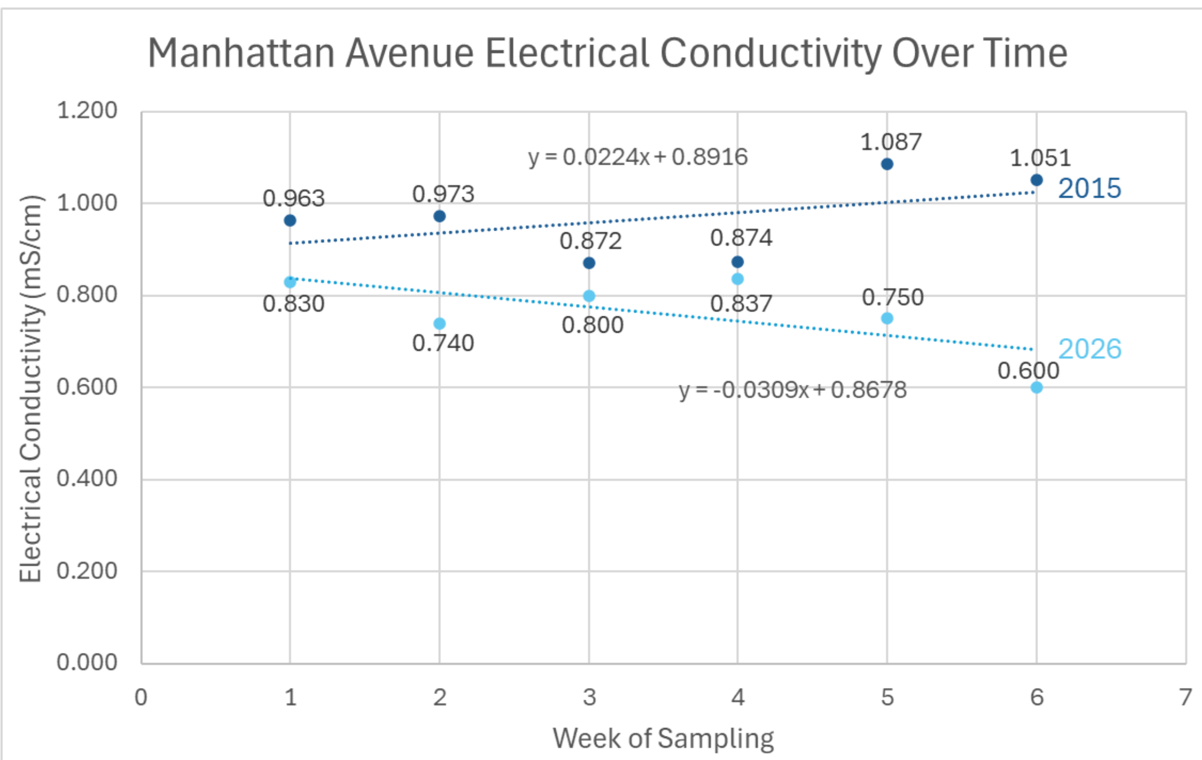

Figure 2-
This graph shows the changes in electrical conductivity at the Manhattan Avenue location as recorded in the 2015 and 2026 data sets. 2015 data sampling began Jan 16th, and 2026 data began Feb 11th. Both of these sampling sets began after the last week of winter snowfall.

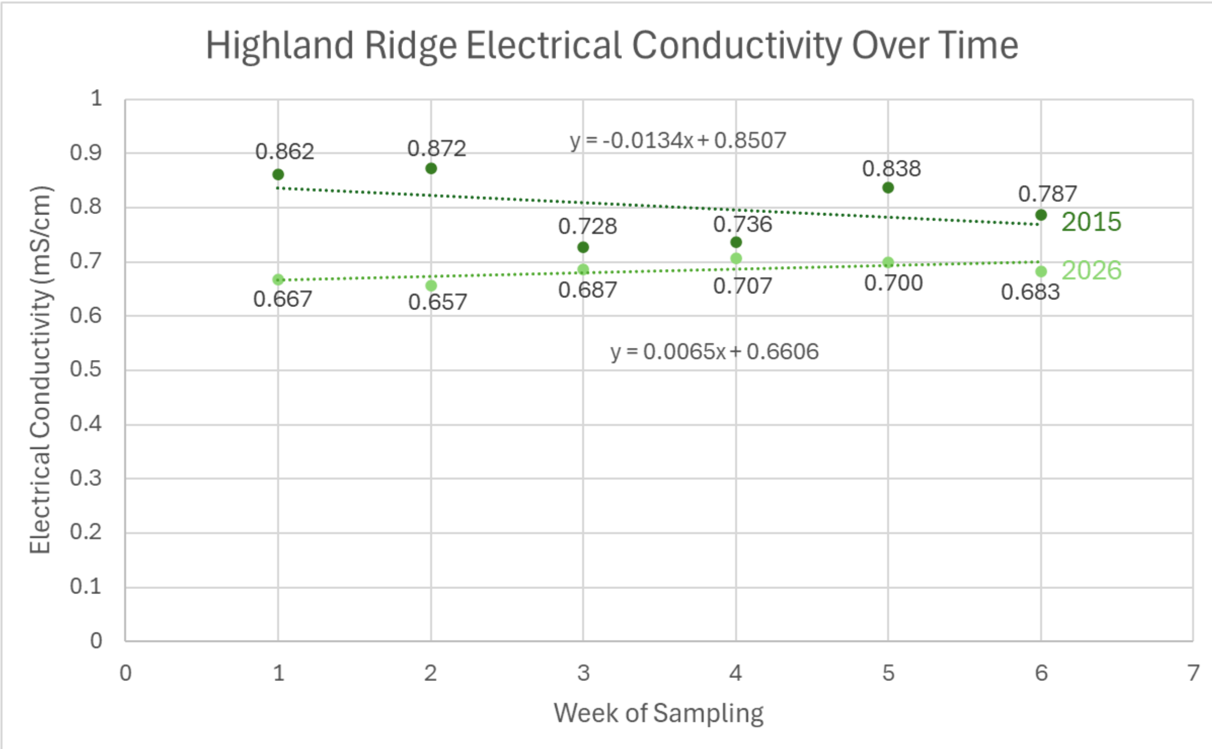

Figure 3-
This graph shows the changes in electrical conductivity at the Highland Ridge location as recorded in the 2015 and 2026 data sets. 2015 data sampling began Jan16th, and 2026 data began Feb 11th. Both of these sampling sets began after the last week of winter snowfall.

5. Conclusion

In exploring both urban and suburban locations during the 2015 and 2026 sampling periods, we have comparatively analyzed electrical conductivity in conjunction with multiple different factors. Urban locations showed significantly higher electrical conductivity values than suburban locations in both sampling periods. We also found that discharge was negatively correlated to electrical conductivity, a point that should be further researched. As climate change increases the variability of rain events, understanding the responses of freshwater streams to anthropogenic pollution becomes even more crucial. Urban development continues to grow, increasing the electrical conductivity within these areas, which could have detrimental effects on aquatic life and human health. Overall, these findings highlight the persistent influence of urbanization and road salt inputs on stream chemistry, reinforcing the importance of continued monitoring of Wildcat Creek and similar urbanizing watersheds over time.

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