Seasonal Salt Content in the Neuse River

https://github.com/atf35/CarpenterFischerMacDonald_ENV872_EDA_FinalProject

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1 Rationale and Research Questions

The maintenance of healthy and functioning water systems is critical not just to human life, but also to the survival of countless other species and their interconnected ecosystems. Conductivity, or the ability of water to pass an electrical current via dissolved salts and other minerals, is a strong indicator of salinity, a key component of water quality. Changes in conductivity over time suggest potential salt and mineral pollutants entering the system, and also potential salinization over time.

For this study, we will analyze how specific conductance varies over time. In particular, we will address the impact of winterizing the roadways with salt on water quality. Our main research question is: *Is salting the roads a main driver in changes to water conductivity, or are other minerals a significant factor?* Here, we chose to analyze water quality and flow data from the Neuse River in Kinston, North Carolina from 1976 to 2022. We chose this river due to familiarity with the data and its proximity to an urban center (Kinston pop = 20,398).

We used the following research questions to guide our work:

1. How does specific conductance vary over time and seasonally?
2. Is calcium, magnesium, or sodium the driver of specific conductance?

2 Dataset Information

Neuse River water quality and discharge data at Kinston, North Carolina. The gage information comes from the United States Geologic Survey (USGS) National Water Information Systems (NWIS) database. USGS gage stations typically collect discharge and a subset collect water quality data. This water quality data may include nutrient concentrations, concentrations of chlorophyll a, specific conductivity, and concentrations of certain ions. Since seasonal salinity trends and their potential sources are the focus of this study, the water quality data being examined includes specific conductivity and concentrations of calcium, magnesium, and sodium in the water column. Specific conductivity will be used as a proxy for salinization, and the relative amounts of each salt ion will be examined in the hopes of identifying a potential source of any seasonal salinity increases, in particular the contribution of road salts to salinization.

To obtain both sets of data, the dataRetrieval package was used to connect directly to the NWIS database and pull water quality and discharge data without needing to download any files. Both sets of data are pulled starting in 1976 and end at the most recent data point in the database in 2022.

Table 1: Summary of the data used.

Dataset	Info
NeuseWQ	Water quality data collected at USGS gage 02089500
NeuseFlow	Discharge data collected at USGS gage 02089500
Retrieved from	USGS NWIS database with dataRetrieval package
Variables	Specific conductivity, calcium, sodium, & magnesium concentrations, sample date, discharge
Date Range	1976 through 2022, wrangled to 2013 through 2022

3 Exploratory Analysis

The first step we took in our initial exploratory analysis was to wrangle the water quality (WQ) dataset to include only the columns of interest. This included the sampling dates and concentrations for specific conductance, calcium (Ca), sodium (Na), and magnesium (Mg), which were each given separate columns. This dataset contains monthly observations, however, not necessarily sampled on the first of each month. We wrangled the WQ dataset to round the dates to the first of the month to ensure that there are evenly spaced time steps across the years, a necessary condition for time series analyses.

We plotted the specific conductance over time to visualize any gaps in our dataset (Figure 1). We see that the WQ dataset contains many long periods of missing data for specific conductance. Since these missing periods frequently span across many years, we chose to look at WQ data from 2013 through 2021 (Figure 2). There are no missing data points from this period of time, and will therefore not require any interpolation of this dataset.

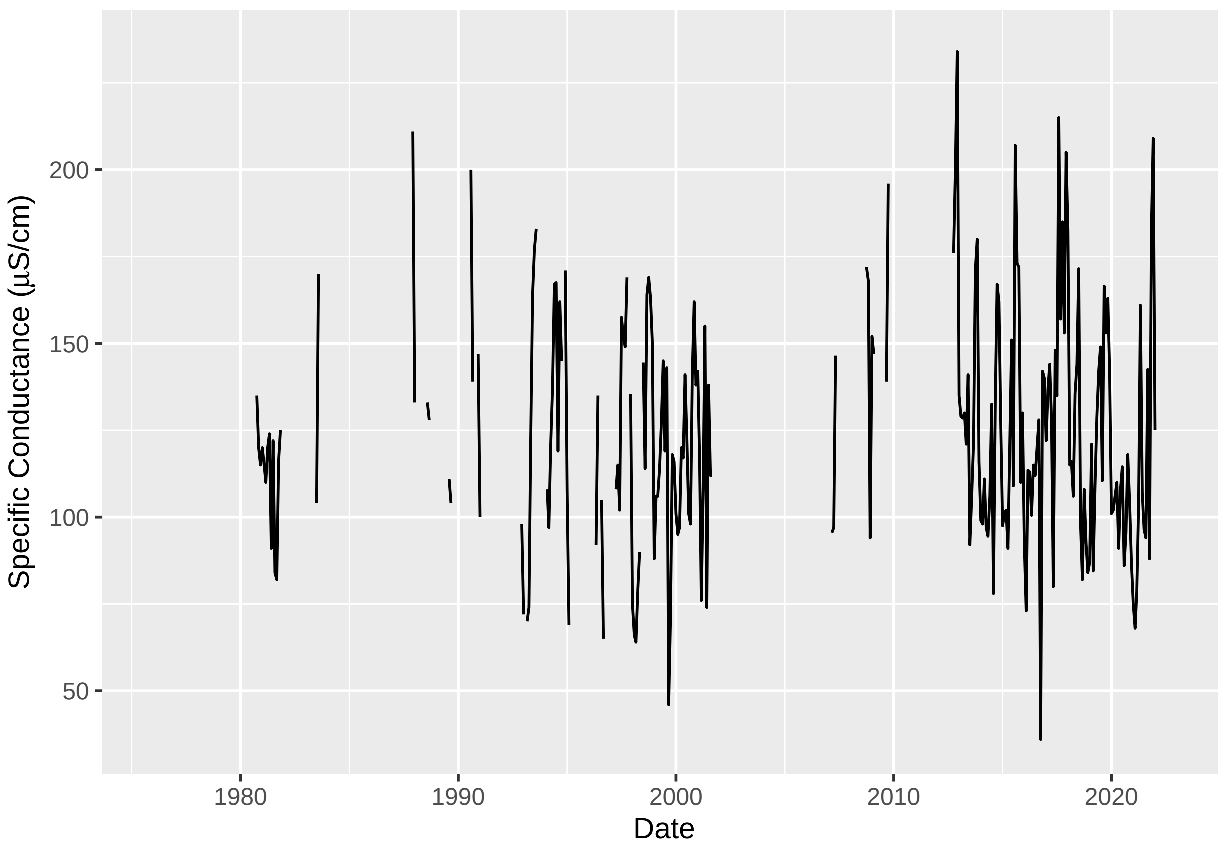

Figure 1: Specific Conductance in the Neuse River

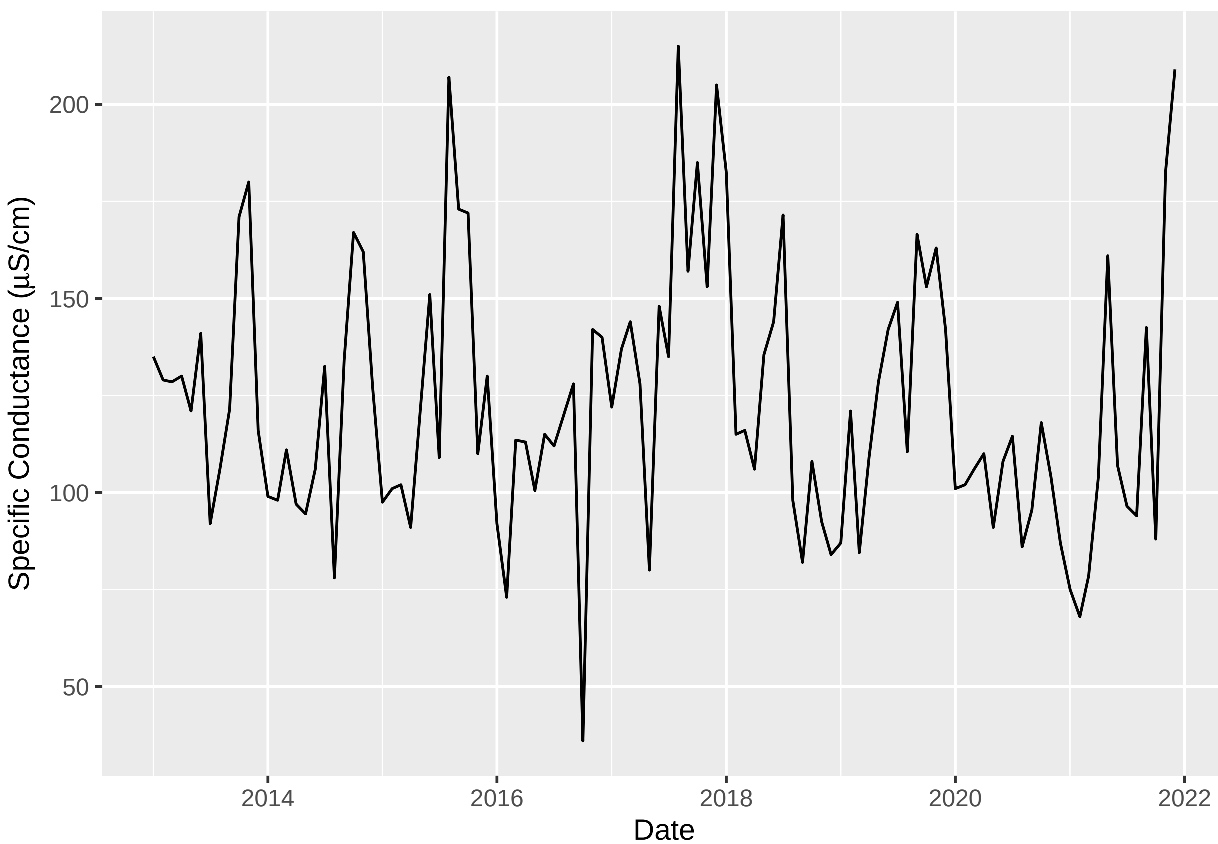

Figure 2: Specific Conductance in the Neuse River from 2013 through 2021.

We are also interested in the flow of the Neuse River because this factor may affect salinity. For example, higher discharges may dilute any salinity and drier periods may reflect higher salt content. We started by wrangling the flow dataset to include the parameters of interest, sampling date and discharge (Figure 3).

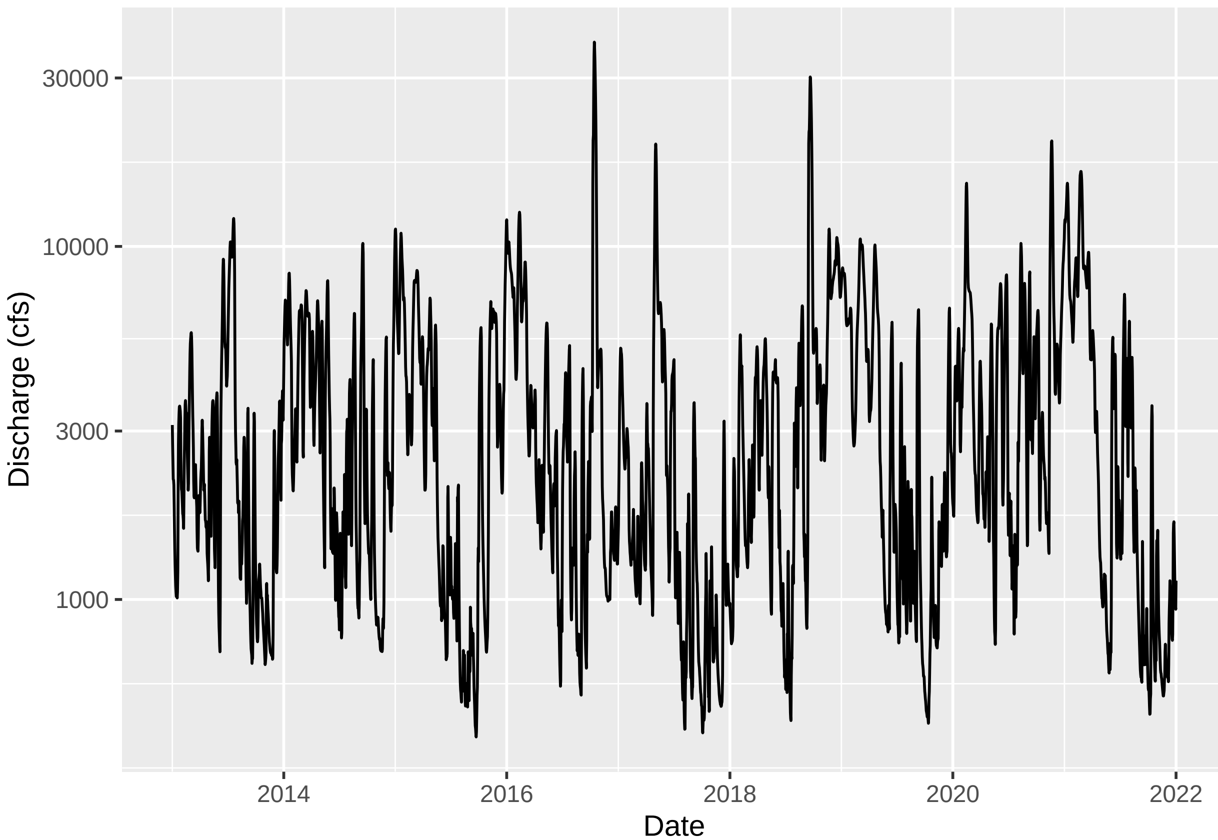

Figure 3: Discharge in the Neuse River from 2013 through 2021.

4 Analysis

4.1 Question 1: How does specific conductance vary over time and seasonally?

4.1.1 Is the specific conductivity of the Neuse River monotonically changing over time?

To determine whether specific conductance varies over time, we first constructed and decomposed the time series data. The time series decomposition of specific conductivity shows a seasonal component in the Neuse River (Figure 4). To test whether the Neuse River exhibits a monotonic trend in specific conductance, we conducted a seasonal MannKendall test. With a p-value > 0.05, we accept the null hypothesis that there the specific conductance of the Neuse River exhibits no monotonic trend (Table 2), meaning that specific conductivity is neither increasing or decreasing over time (Figure 5).

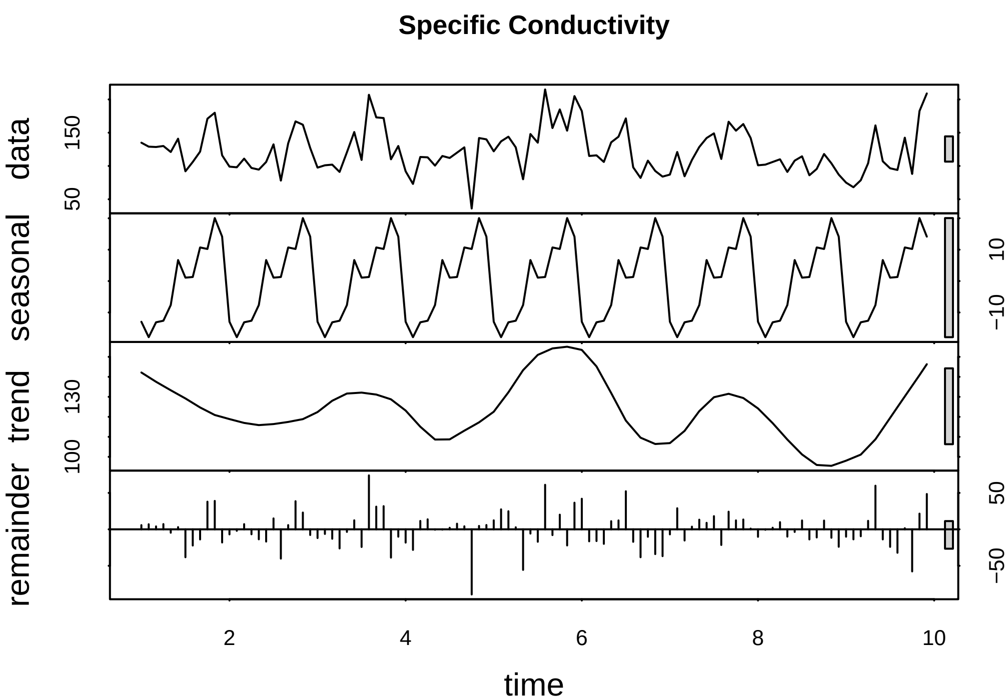

Figure 4: Time Series Decomposition of Conductivity in the Neuse River.

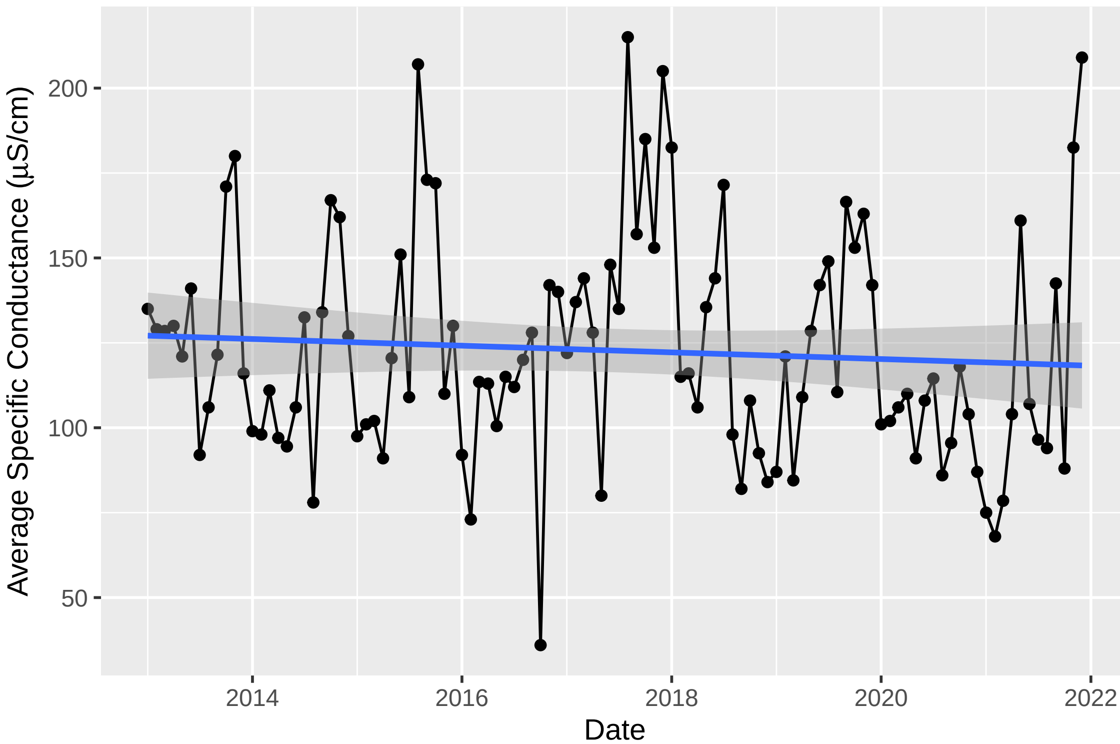

Figure 5: Specific Conductance in the Neuse River does not exhibit a monotonic trend over time.

Unsurprisingly, the time series decomposition and seasonal MannKendall tests of calcium (Ca) (Figures 6-7), magnesium (Mg) (Figures 8-9), and sodium (Na) (Figures 10-11) show that the these minerals also do not exhibit monotonic trends over time (p-values in Table 2), meaning that mineral content is also neither increasing or decreasing over time.

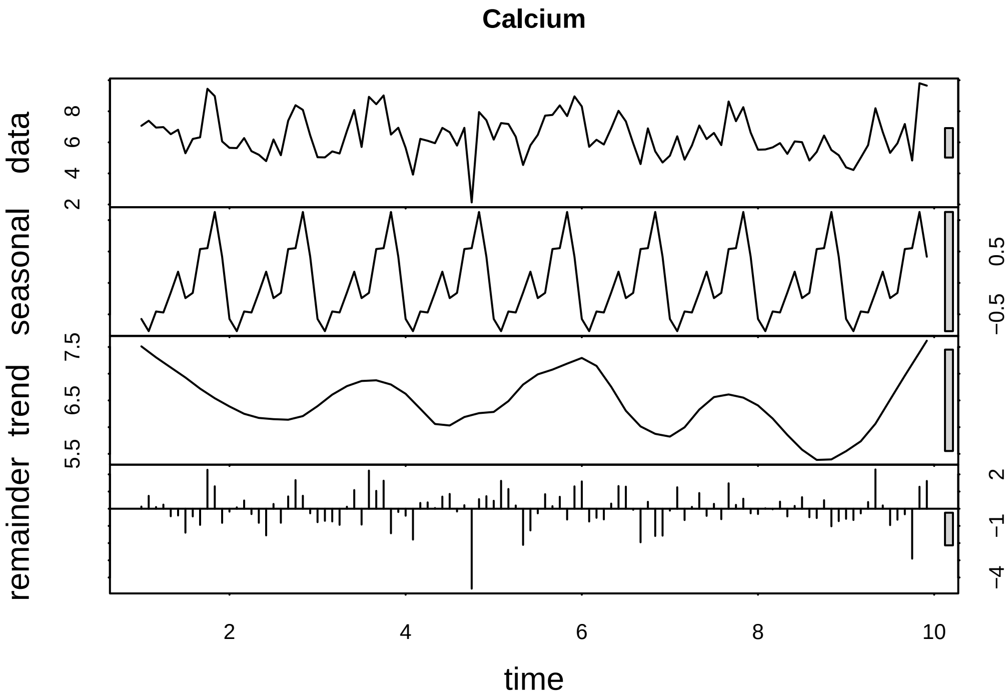

Figure 6: Time Series Decomposition of Calcium in the Neuse River.

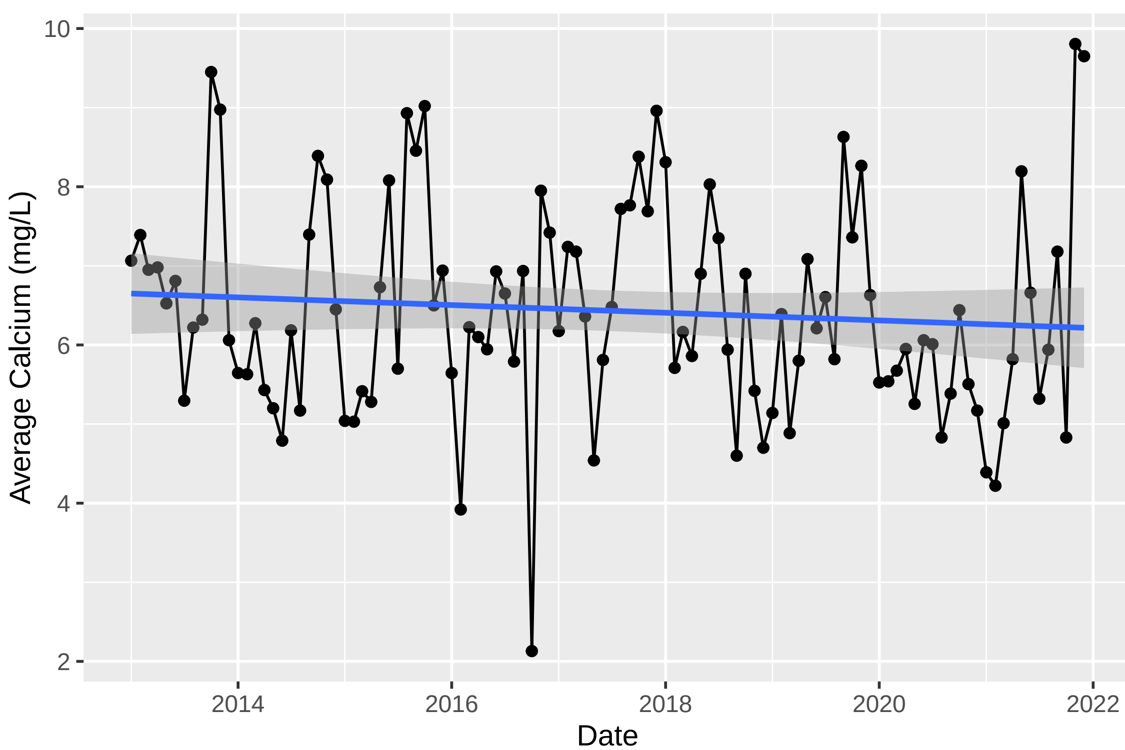

Figure 7: Calcium in the Neuse River does not exhibit a monotonic trend over time.

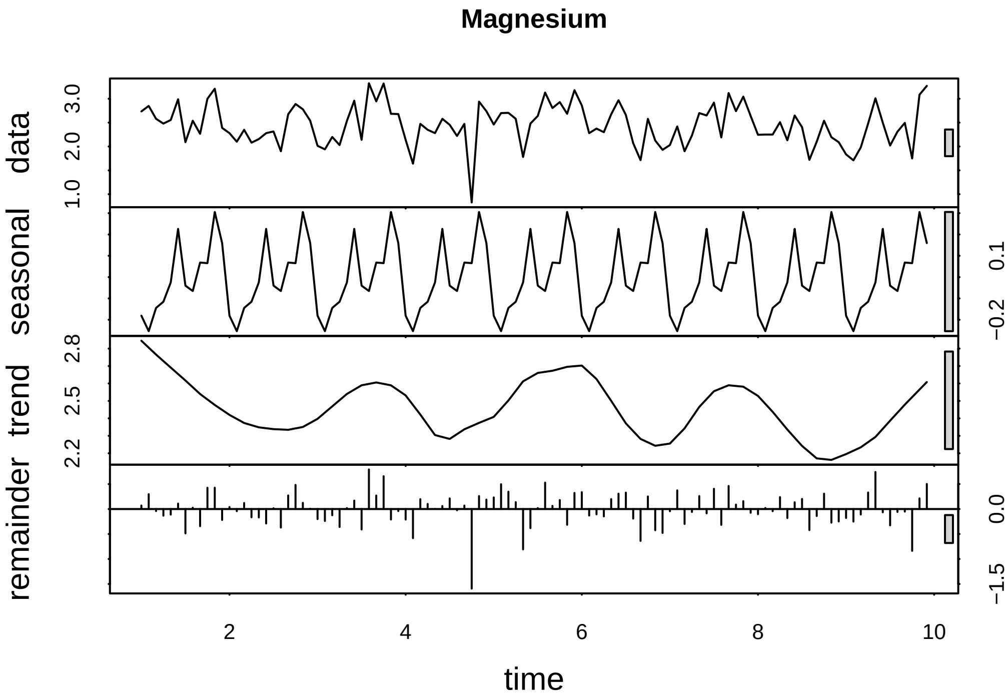

Figure 8: Time Series Decomposition of Magnesium in the Neuse River.

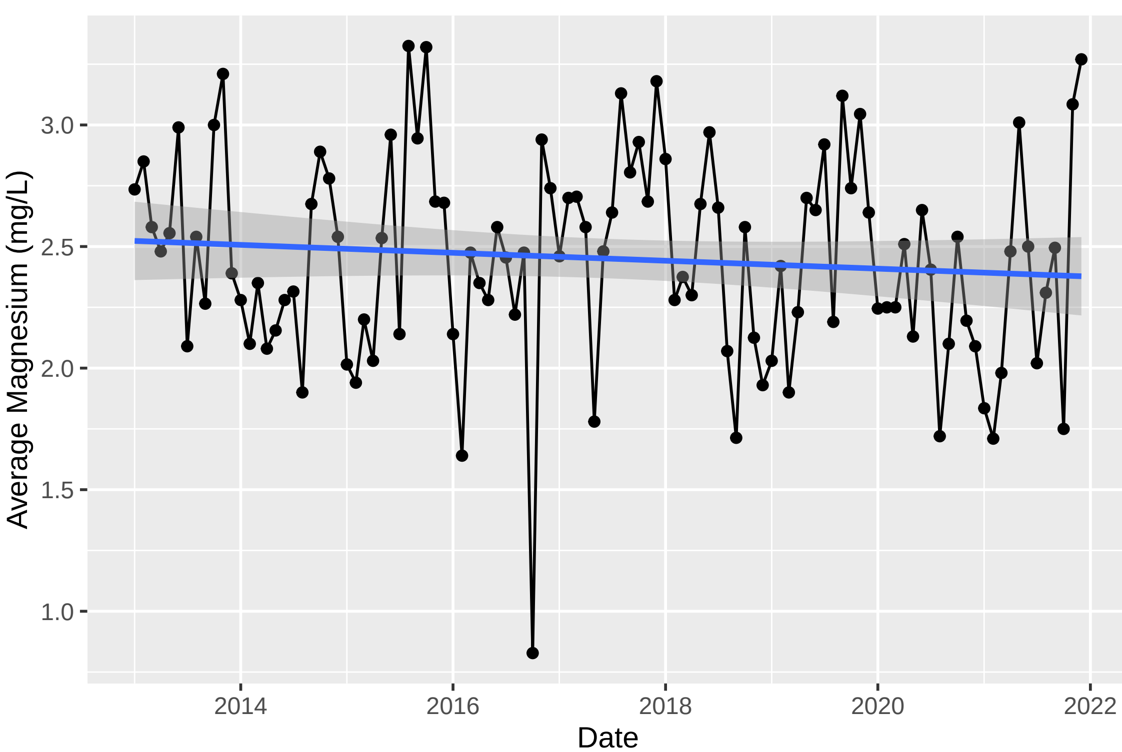

Figure 9: Magnesium in the Neuse River does not exhibit a monotonic trend over time.

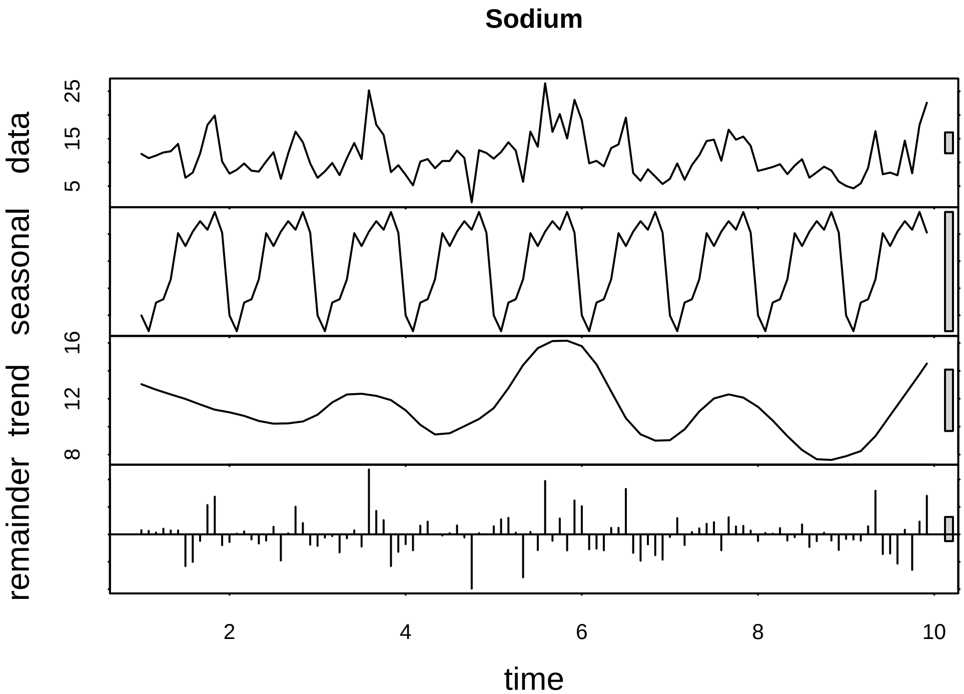

Figure 10: Time Series Decomposition of Sodium in the Neuse River.

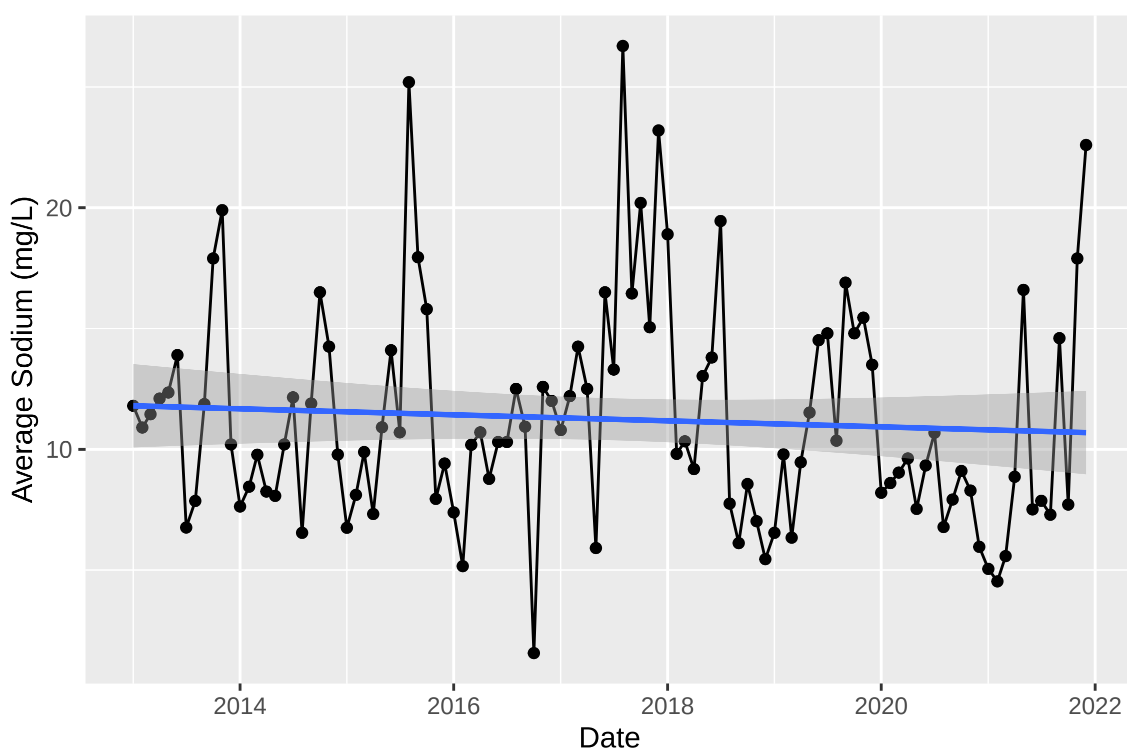

Figure 11: Sodium in the Neuse River does not exhibit a monotonic trend over time.

We also constructed and decomposed the time series for our flow dataset to determine whether discharge could be affecting our salinization results. The decomposition shows that discharge in the Neuse River basin has a seasonal component and a trend (Figure 12). The seasonal MannKendall test shows that discharge exhibits a monotonic trend over time, with flow significantly increasing year after year (p-value = 3.368e-07) (Figure 13, Table 2). This increasing trend in flow may be masking increases in salt content in the river, as increased flow will dilute an increased salt content to the same concentration, hiding an increase in salt deposition to the river.

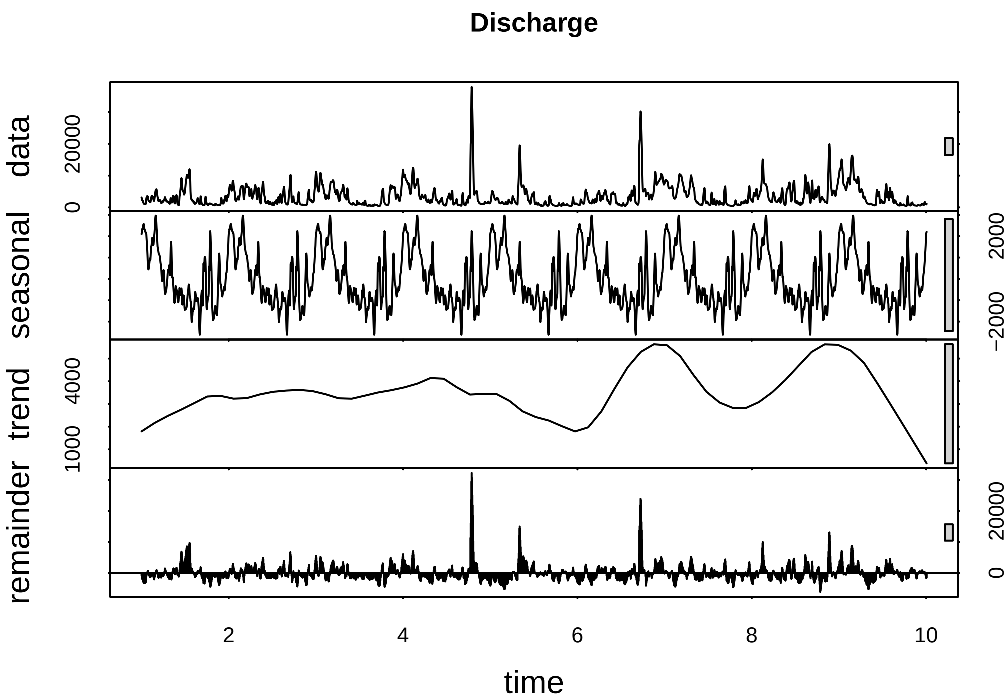

Figure 12: Time Series Decomposition of Discharge in the Neuse River.

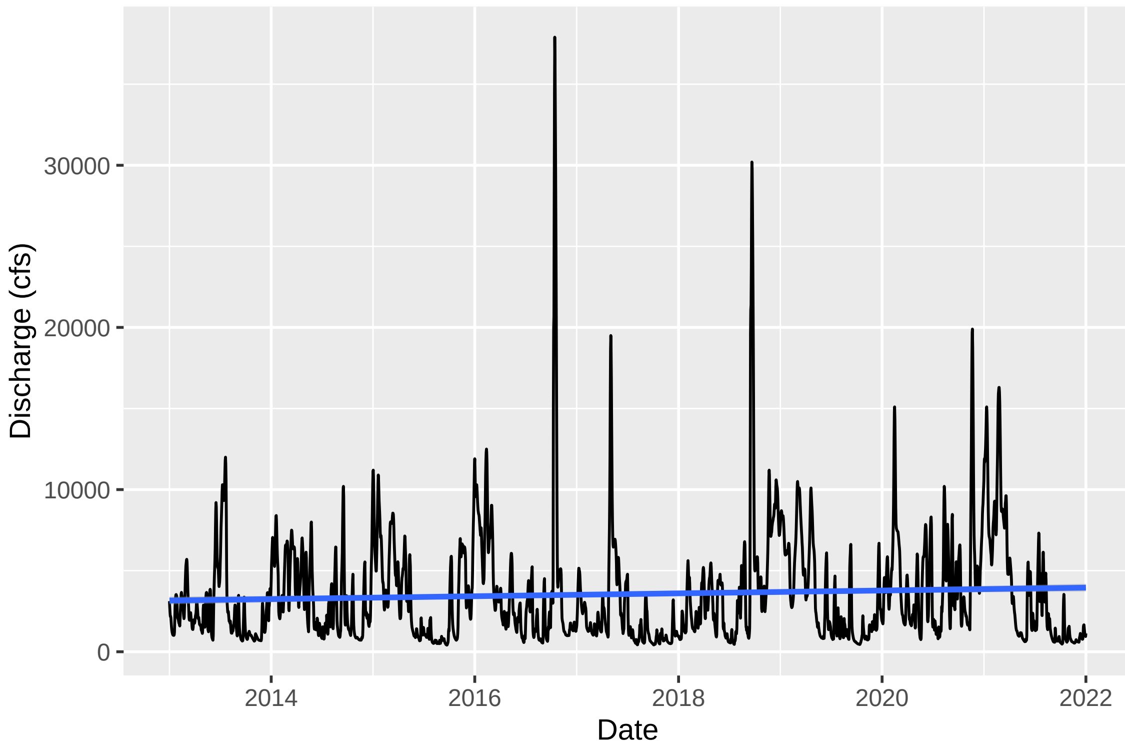

Figure 13: Discharge in the Neuse River does exhibit a monotonic trend over time.

Table 2: P-values for Seasonal Mann-Kendall tests.

Measure	P-value
Conductivity	0.25276
Calcium	0.1038
Magnesium	0.29151
Sodium	0.091911
Discharge	3.368e-07

After running the the Seasonal MannKendall test, we have found no significant change in the Neuse River over time for conductivity (p-value = 0.25276)(Table 2). However, we were able to reject the Null for flow data, and determine there has been a significant increase in discharge over time (p-value = 3.368e-07) (Table 2).

4.1.2 Is there seasonality in specific conductivity and flow of the Neuse River?

We plotted each mineral by specific conductance and colored by the day of the year (DOY) to visualize any seasonal patterns within a year (Figure 14). If the specific conductance or the different minerals exhibited seasonality, we would expect to see clusters of the same color within the plot. Although our time series analysis showed a seasonal component, we see that the DOY coloring shows no patterns, and thus, specific conductance and the minerals of Ca, Mg, and Na do not have any seasonal trend over the year. However, we do see that Na shows the strongest correlation with specific conductance out of all the minerals shown (stronger positive trend).

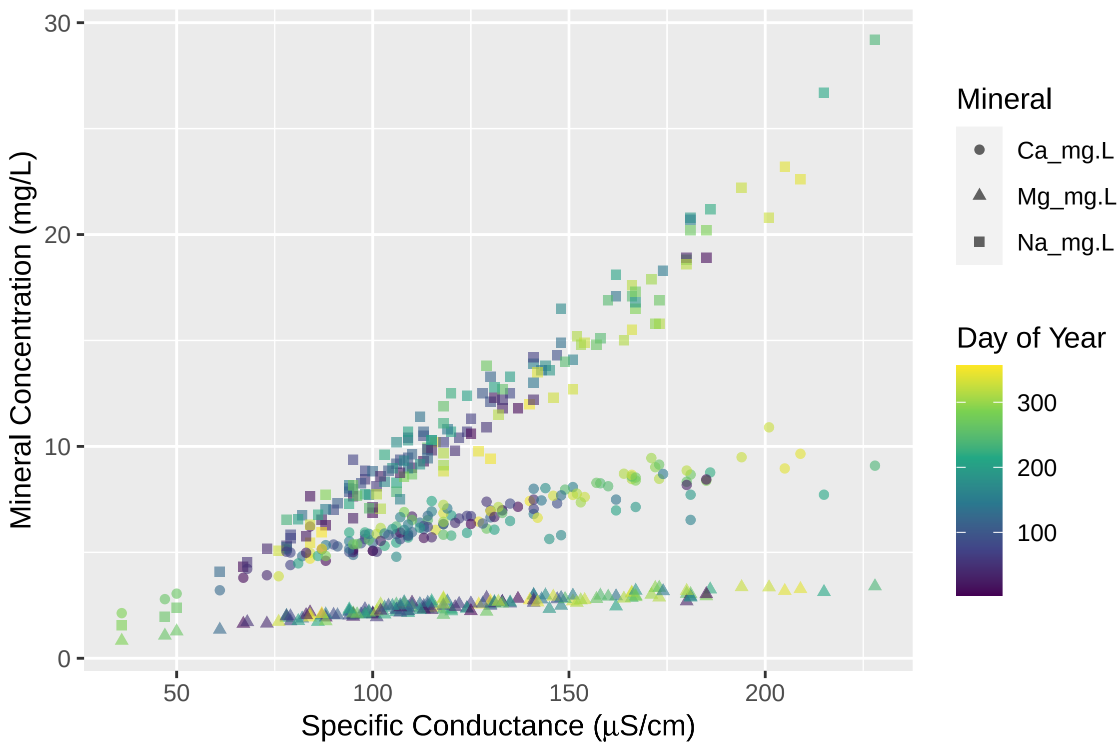

Figure 14: Salts by Specific Conductivity over the Year

We also plotted boxplots of specific conductance and discharge for each month to visualize any seasonality over a year (Figure 15). We would expect to see high values of specific conductance in winter months when salts are applied to roads before/after snowfall, and low values specific conductance values in the summer months when road salts are not applied. We do not see any strong seasonal specific conductance trends in these plots. However, viewing the boxplots in conjunction with discharge, we see that there is generally an inverse relationship between the two. As discharge is high in winter months, specific conductance is low, likely because the minerals are diluted.

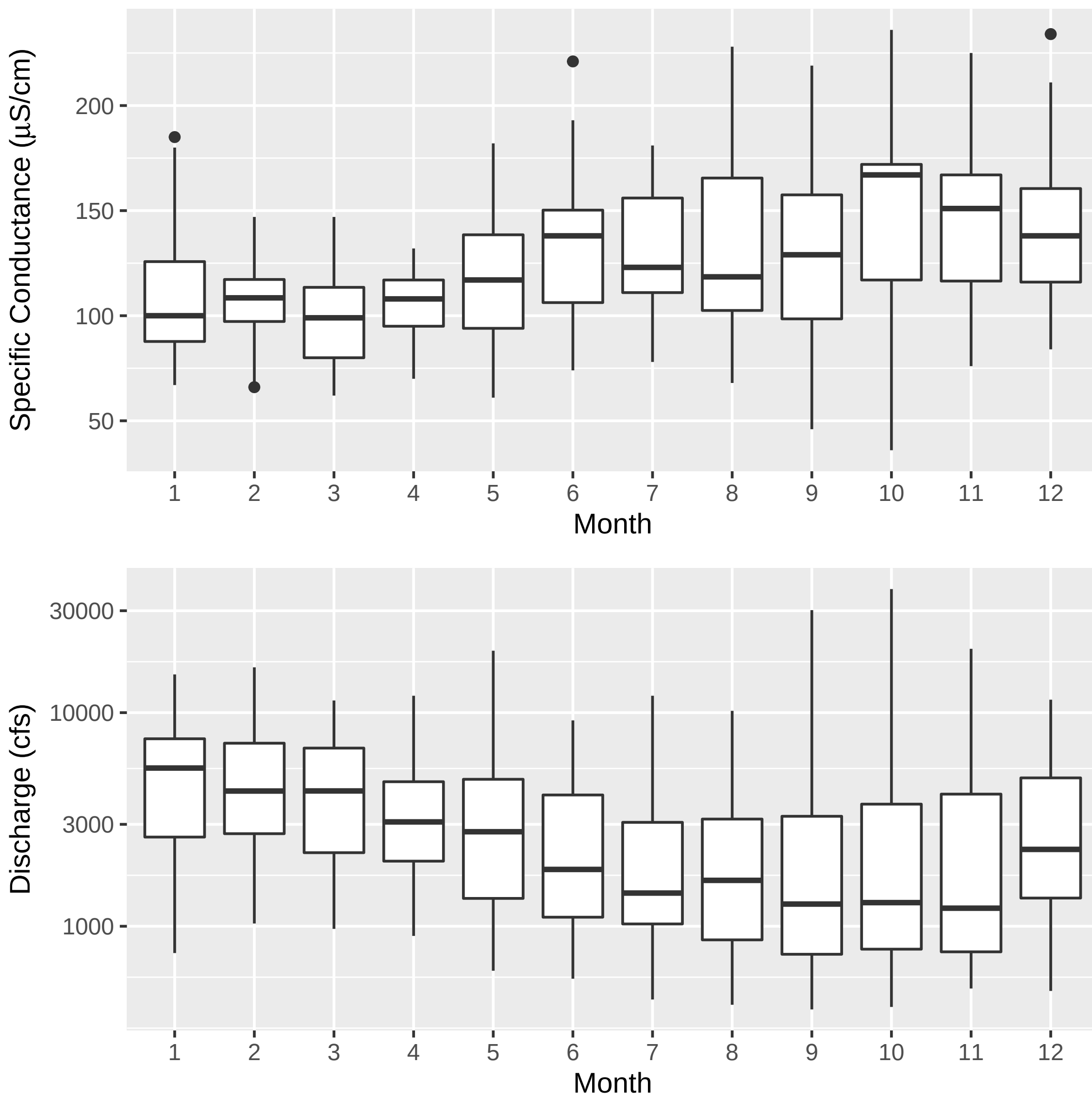

Figure 15: Comparison of specific conductance and discharge over the months.

4.2 Question 2: Is calcium, magnesium, or sodium the driver of specific conductance?

While there is not much seasonality in the specific conductance found at this site in the Neuse River basin, the salt ions measured can still be examined to see if one or another appears to be driving the conductivity. It appears as though sodium is the ion most closely associated with the specific conductivity found at this site, as this ion both most closely aligns with the patterns seen in the data and also is the most abundant ion.

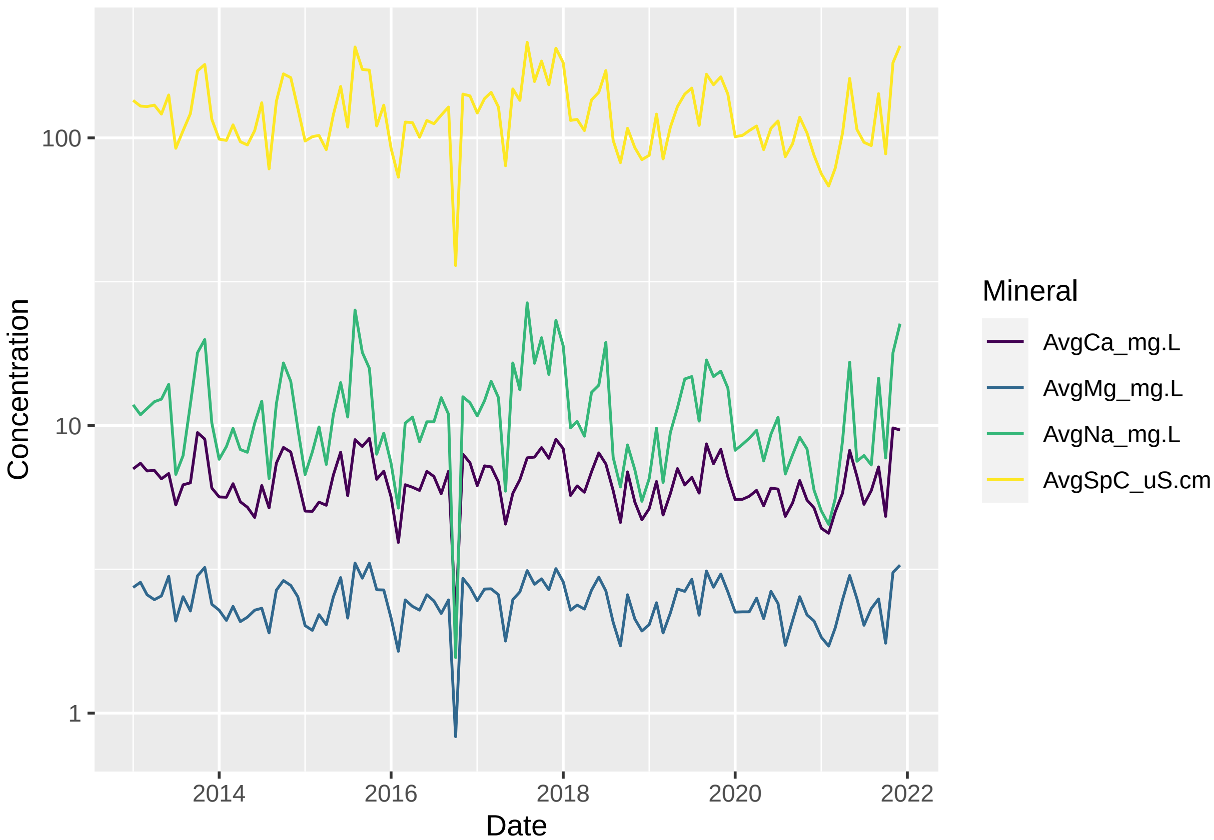

Figure 16: Specific Conductivity and Salts in the Neuse River from 2013 through 2021

We also examined the correlation between each mineral ion and specific conductivity and plotted them in figure 17 (below). Sodium is the most closely correlated with specific conductivity (r-squared = 0.955), followed by magnesium (r-squared = 0.854), and calcium (r-squared = 0.831). All three minerals are pretty highly correlated with specific conductivity, indicating they all play a pretty significant role in the salinity of the river, but sodium has a more significant impact. These findings corroborate what we saw above in that sodium is likely more of a driver of salinity in the Neuse than the other two minerals.

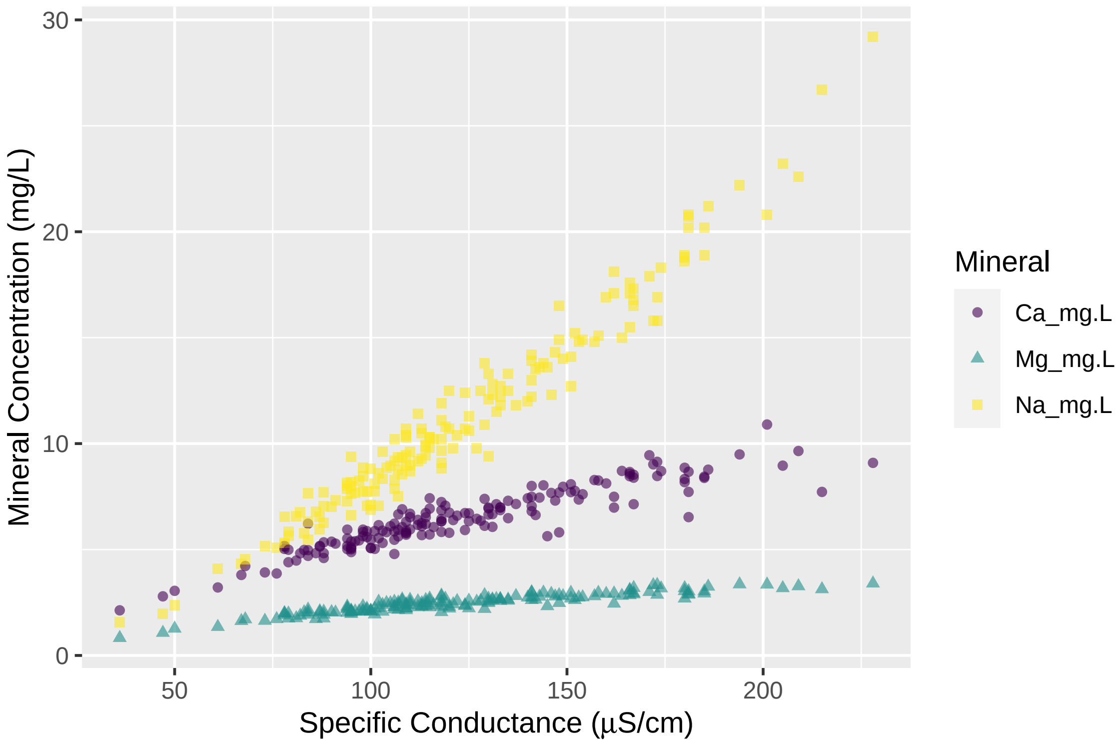

Figure 17: Salts by Specific Conductivity.

5 Summary and Conclusions

The Neuse River at Kinston does not show strong seasonality in salinity and appears to show stationarity in salinity levels over the study period from 2013-2022. Specific conductance, the proxy we used to examine salinity, showed marginal seasonal trends when examined with a time series decomposition(Figure 4) and no discernible seasonal pattern when plotted by the day of the year (Figure 14). Discharge similarly shows some marginal seasonality, and also shows a slight increasing trend. This slight increasing trend is interesting because it could hide a similarly-scaled increase in salinity over the same time period, as increased discharge would dilute increased salinity effectively to show no change. Interestingly, the change over the year in salinity was inversely correlated with discharge (Figure 15). This potentially indicates that any seasonal change in discharge is not due to changes in salt influx into the stream, but rather to changes in the amount of water available to dilute the salt content already in the stream. This would partially explain why there is not a strong seasonal component to the data for each mineral or specific conductivity, since the variation is due to variability in discharge rather than salt content.

Sodium appears to have the strongest impact on specific conductance, indicating that it perhaps is the main driver of the salinity that does exist in the Neuse River. Sodium is the most abundant ion in the water, magnesium and calcium had lower concentration. Sodium also has a higher correlation with specific conductivity than the other two minerals, indicating that sodium ions are the likely driver of salinity in the Neuse over magnesium or calcium ions.

Overall, this is good news for the Neuse, indicating that at Kinston, which is relatively far down the watershed, upstream uses of salts do not cause seasonal changes in the river. The location of Kinston in the watershed has been brought up in this analysis multiple times because it is significant. This gage site is potentially far enough downstream from where road salt would be used to have the salinity be insignificant by the time the water reached Kinston. This gage was chosen in part because it actually measures the salinity data we were interested in (and in part because we knew it was a pretty good dataset), but a future study would be interesting to compare the data at Kinston to similarly collected data at a gage site further upstream, like at Clayton, which is relatively close to the major metro area around Raleigh where road salt is also likely to be more prevalent than in smaller population areas.