Spatiotemporal Analysis of Water Quality between 2017-2023 for Campus Creek, Manhattan, Kansas

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This study of Campus Creek is completed, in part, to meet the requirements of the Natural Resources and Environmental Sciences senior capstone project at Kansas State University. The lead instructor for the course and director of the NRES Secondary Major is Dr. J.M. Shawn Hutchinson and the project team advisor is Dr. J.M. Shawn Hutchinson from the Department of Geography and Geospatial Sciences.

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Abstract

The NRES Capstone class group projects brings individuals with unique backgrounds together to tackle one project. Our group set out to identify the water quality of a local stream due to the ever rising need for more sources of clean water. We regularly collected samples from Campus Creek over a three week period. Temperature and observations of debris were documented at each site. Each sample was tested at the Kansas State University Soil Testing Laboratory to measure total suspended solids, total dissolved solids, electrical conductivity, pH, total nitrogen, total phosphorus, total chlorine, and total sulfur. Through the statistical program of R, we ran a Shapiro, Levene, ANOVA, and Kruskal-Wallis Test for our analyses. We determined that pH, total phosphorus, total nitrogen, and total sulfur were statistically significant. We compared our findings to the 2017 study of Campus Creek. We found a statistically significant relationship between total solids and time, indicating the volume of total solids of Campus Creek has been increasing over time. Additionally, we calculated a Water Pollution Index (WPI) value for both years and determined that the water quality of the stream has improved over time. Further monitoring of Campus Creek could prove beneficial to managing and maintaining its high aquatic ecology water quality.

Introduction

The proper function of water ecosystems and the services they provide depends upon a balance of factors in the environment, such as temperature, pH levels, chemical concentrations, physical conditions, and biotic interactions. Human activities have a wide range of impacts on these systems, including adding pollutants and reducing biodiversity, overall leading to a reduction in the quality of essential ecosystem services. Ecosystem services provide high quality water for consumption and recreation while maintaining biodiversity. The effects that humans have on these factors of our environment vary depending upon what type of activity occurs within it. Three main human activities that have major impacts on aquatic environments around the globe, and here at home, are agriculture, urbanization, and industrialization. Each type of activity contributes different kinds of physical changes to the environment and different types of chemical pollutants from point and nonpoint sources (Carpenter et al. 1998, Lin et al. 2009).

The impacts of urbanization on water systems, such as elevated concentrations of nutrients and contaminants, altered channel morphology and stability, and reduced biotic richness have been well documented (Fashae et al. 2019, Tao et al. 2010, Turner et al. 2021). The pollutants associated with urbanization are different from that of agriculture, due to differences in land-use and the abundance of impermeable surfaces. Moreover, the multitude of petroleum driven vehicles and industrial processes in urban environments can lead to what is called "urban stream syndrome" (Meyer et al. 2005). Chemicals from lawn pesticides, fertilizers, and various hydrocarbons have been documented at much higher concentrations in urban environments (Line et al. 1997). These negative effects can become more severe when coupled with the increasing intensity and frequency of rain events associated with climate change that we are currently seeing and the fact that much of the urban infrastructure was not designed to deal with the types and quantities of pollutants that we have today (Turner et al. 2021). All of these factors underscore the importance of understanding the effects that our activities as a society have on our surrounding environment, especially aquatic systems that contribute so much to our health, vitality, and happiness.

Study Area

To that end, our NRES capstone group based our study on the water quality of an urban stream near and dear to us, namely, Campus Creek. We wanted to get a better idea of what kind of pollutants it contained and if there were any water quality factors that would be significant with regards to regulations and guidelines for maintaining a healthy aquatic ecosystem, as there has been similar interest in the creek in the past, as well as much land-use change and construction in the upstream watersheds of our target sites. We also wanted to compare our data to a previous NRES study on Campus Creek done in 2017, in which some of the pollution factors that we wanted to test for were also determined (total solids, pH, and electrical conductivity) (Olney 2017).

Although there are no substantial records of Campus Creek's history, that does not mean that the creek does not serve an important role. Part of the 410-acre Campus Creek Basin which is the largest basin located on K-State's campus, Campus Creek serves an integral role as the heart of the storm water drainage basin on

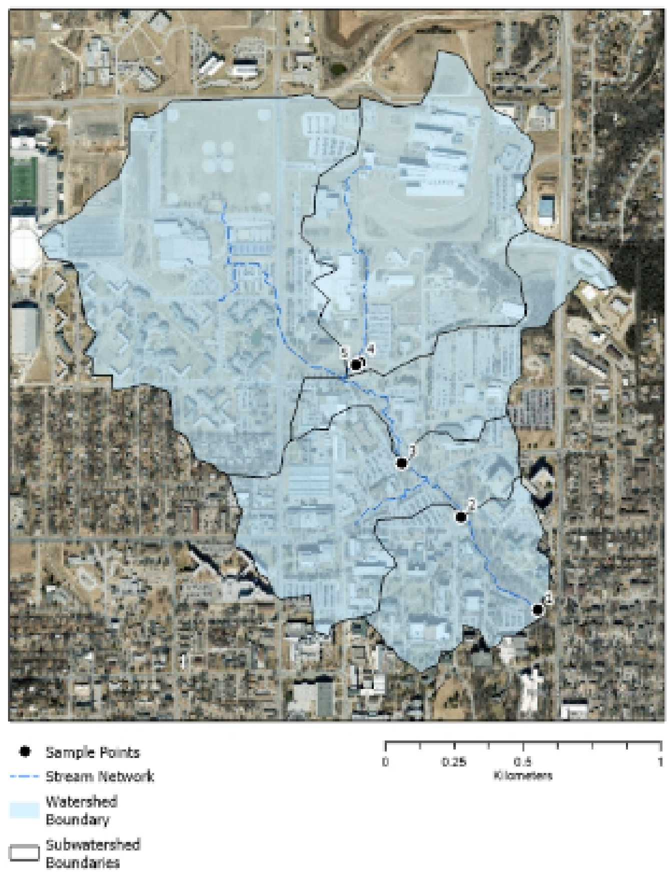

Figure 1. Water shed boundary of Campus Creek. Site locations are indicated through sample points.

K-State's campus. Campus Creek is fed by multiple detention basins and drainage pipes and flows in a southeasterly direction towards a reinforced concrete box, which was installed sometime in the past, and moves stream water under N. Manhattan Ave where it will join the City of Manhattan's smaller reinforced concrete box which runs underneath Bertrand St. carrying flow east to the Tuttle Creek Blvd. Channel.

KSU Facilities Planning personnel have indicated that several areas of Campus Creek frequently experience flooding issues in larger storm events. Campus Creek has been known to overflow onto Claflin Rd., Old Claflin Rd., Petticoat Ln., and even the reinforced concrete box at N. Manhattan Ave. has been known to overflow. There are many drainage pipes around campus that discharge into Campus Creek. From large green spaces to parking lots and buildings, there are many different types of surfaces that water may runoff off of before it enters Campus Creek.

Research Question and Objectives

We set out with a very clear research question: what is the water quality in Campus Creek and how is it changing over time? To answer this question, we set three distinct objectives. First, compare water quality parameters from each sample site between 2017 and 2023 through ANOVA and Tukey analyses. If an ANOVA or Tukey Test was deemed an inappropriate analysis technique, a Kruskal-Wallis and Dunn Test is to be employed. Second, determine if there is a significant trend in measures of water quality over time using a linear regression model and significance of slope using a T-Test. Third, calculate the Water Pollution Index for Campus Creek subwatersheds using current sample data and locations.

Materials and Methods

Sample Collection

We selected five key locations along Campus Creek. In order to monitor any potential change over time, the first three selected sample sites correlated with the 2017 study of Campus Creek. Following a north projection, the last two sites were selected based on their location in the overlapping watersheds as well as distance from parking lots. In our 2023 sampling period, we sampled once a week for three weeks at approximately the same time at each location.

At each site we began by first collecting a water sample in a 500 mL plastic bottle. Each sample was collected in a manner in which the current flowed directly into the partially submerged bottle. Temperature was recorded at each site through the use of a digital thermometer. An initial pH value was measured through the use of litmus paper. Pictures of each site were taken to document sources of debris. Once samples were collected, each sample was then processed by Kansas State University Soil Testing Laboratory. At the Soil Testing Laboratory, samples were processed to determine levels of total suspended solids in milligrams per liter, total dissolved solids in milligrams per liter, electrical conductivity in millisiemens per centimeters, pH, total nitrogen in parts per million, total phosphorus in parts per million, total chlorine in parts per million, and total sulfur in parts per million. The 2017 study retrieved data on the water parameters of pH, conductivity, turbidity, dissolved oxygen and total solids (Olney, 2017).

Water Pollution Index Calculation

We used the 2020 standardized Water Pollution Index developed by Mobarok Hossain and Pulak Kumar Patra to quantify pollution. Hossain and Patra's formula to test water quality was based on observed concentration of pollutants and their permissible concentrations. Overall, they created four categories to categorize water: less than 0.5 was categorized as excellent quality, 0.5 to 0.75 was categorized as good quality, 0.75 to 1 was categorized as moderately polluted, and greater than 1 was categorized as highly polluted (Hossain and Patra 2020).

To begin to calculate the WPI, we first determined the parameter limit value for each parameter through $PLi = 1 + \left(\frac{Ci - Si}{Si}\right)$. For each parameter (PLi), we subtracted the standard permissible limit (Si) from the observed concentration of the parameter (Ci) (Hossain and Patra 2020). The standard permissible limits were based on aquatic ecology standards (EPA 2015, KDHE 2017). The observed concentrations were measured in the Soil Laboratory. We then divided that value by the standard permissible limit and added one. From here we used $\mathbf{WPI} = \frac{1}{n} \sum_{i=1}^{n} PLi$. WPI is calculated by taking the sum of the parameter limits (PLi) multiplied by one over the number of parameters (n) (Hossain and Patra 2020).

Data Analysis

Through the statistical program of R, we began by visualizing our data through the use of boxplots, *Figure* 2. From here, we ran a Shapiro Test in order to analyze the normalized distribution of the data. Next, we ran a Levene Test to assess the equality of variances. The parameters that were deemed insignificant under these two tests were then ran through a One-Way ANOVA Test to compare the means and determine if any were statistically significant between them. The parameters that were deemed significant under the Shapiro Test then underwent further analysis through the Kruskal-Wallis Test. Parameters that were deemed to be significant under the One-Way ANOVA underwent further analysis through a Tukey Honest Significant Difference Post-Hoc Test to determine where any significant differences among parameters occurred. A trend analysis was conducted on the overlapping parameters between 2017 and 2023 including total solids, electrical conductivity, and pH. Our trend analysis consisted of a linear model, estimated using ordinarily least squares, between the parameter and time.

Results

Summary Statistics

Seven of the ten measured parameters did not exceed the aquatic standard levels including: temperature, total dissolved solids, electrical conductivity, pH, total nitrogen, total chlorine, and total sulfur. On average, total suspended solids and total phosphorus did not exceed the aquatic standard level; however, there were a couple of instances in which these parameters exceeded the standard levels, as depicted in Table 1.

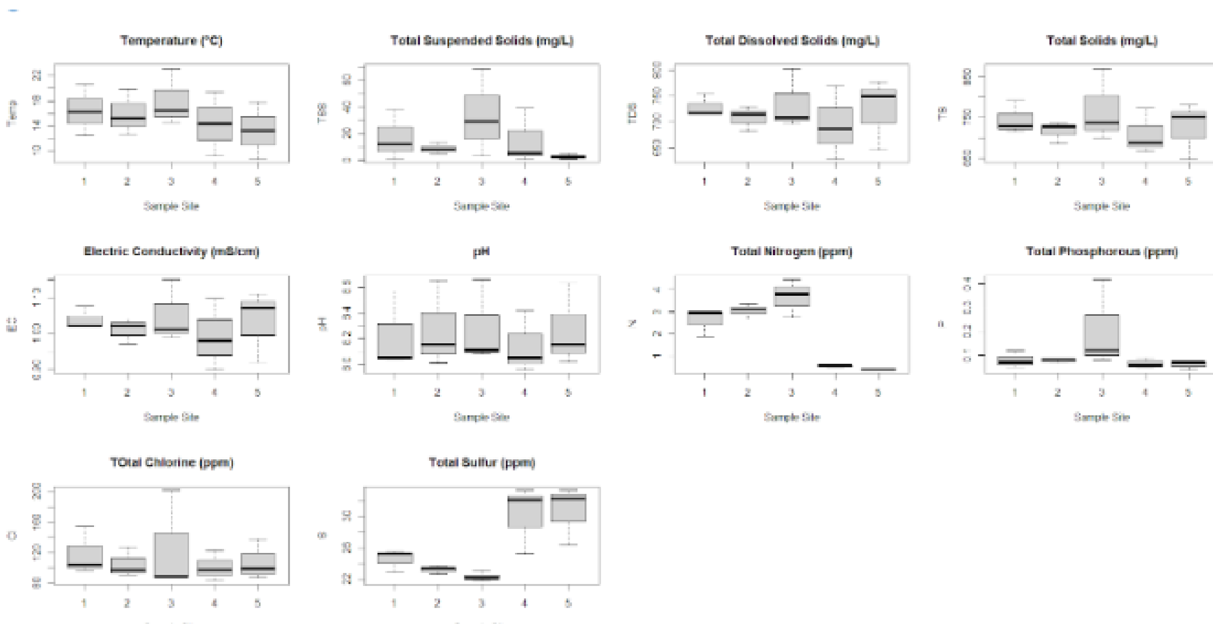

Figure 2. Boxplots of Campus Creek 2023 parameters by sample sites.

Site Analysis

Overall, four of the ten tested parameters were determined to be significant at a 0.01 percent confidence level. Under the Shapiro Test, pH and total phosphorus was significant. Similarly, total nitrogen and total sulfur was determined to be significant under a One-Way ANOVA test. Table 2 documents the remaining parameters which showed no significant results. From the results of our Tukey Honest Significant Difference Post-Hoc Test for total nitrogen, there were several differences between sites including: site 4 to site 1, site 5 to site 1, site 4 to site 2, site 5 to site 2, site 4 to site 3, and site 5 to site 3, as depicted by Figure 3. Total sulfur only showed significant differences between site 3 to site 4 and site 3 to site 5, as depicted by Figure 4.

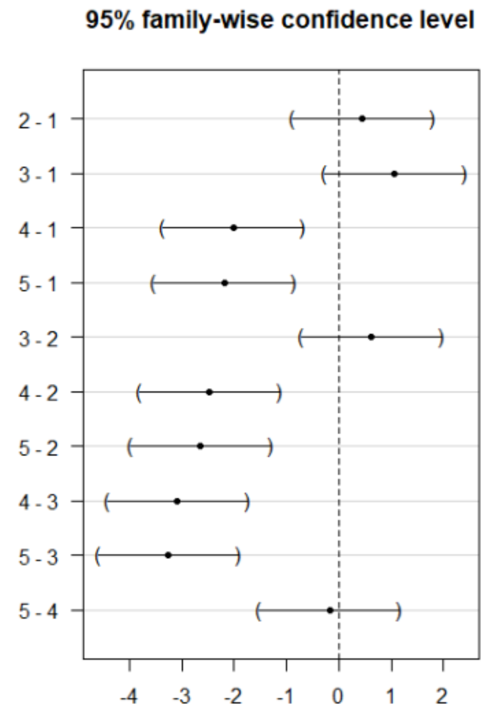

Figure 3. 2023 Campus Creek Tukey Honest Significant Difference Post-Hoc of total nitrogen in

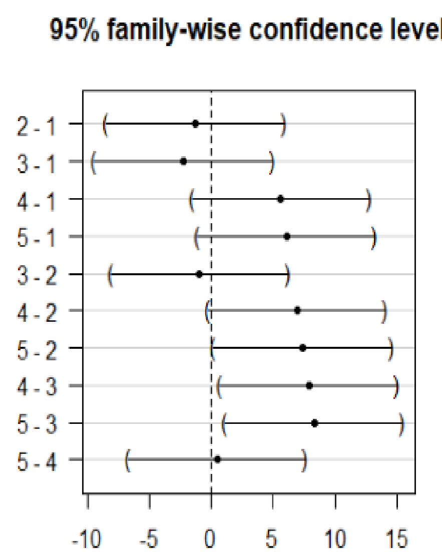

Figure 4. 2023 Campus Creek Tukey Honest Significant Difference Post-Hoc of total sulfur in parts per million.

Trend Analysis

Our linear model for total solids and time demonstrated a statistically significant and substantial proportion of variance with a R^2 value of 0.57 within a 95 percent confidence interval. Overall, the effect of time was deemed statistically significant and positive. Therefore, we see that as time increases, the quantity of total solids increases. Contradictory, our linear model for electrical conductivity and time showed a statistically insignificant relationship with a weak proportion of variance having a R^2 value of 0.06 within a 95 percent confidence interval. The effect of time in this manner was not statistically significant and had a negative correlation. Though not statistically significant, electrical conductivity shows a loose negative trend over time. Similarly, our linear model for pH and time showed a statistically insignificant relationship with a weak proportion of variance having a R^2 value of 0.10 within a 95 percent confidence interval. Time did not have a significant effect on this parameter but showed a positive correlation.

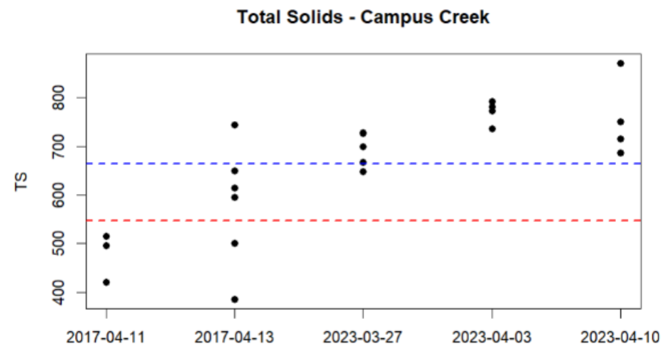

Figure 5. Campus Creek trend curve for total solids. Spacing between time is distorted and the presented line is not exact to relationship.

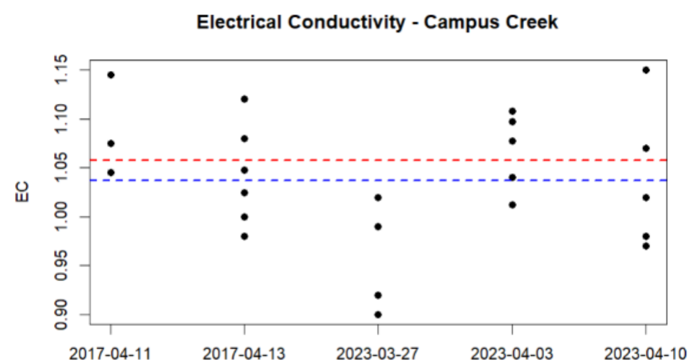

Figure 6. Campus Creek trend curve for electrical conductivity. Spacing between time is distorted and the presented line is not exact to relationship.

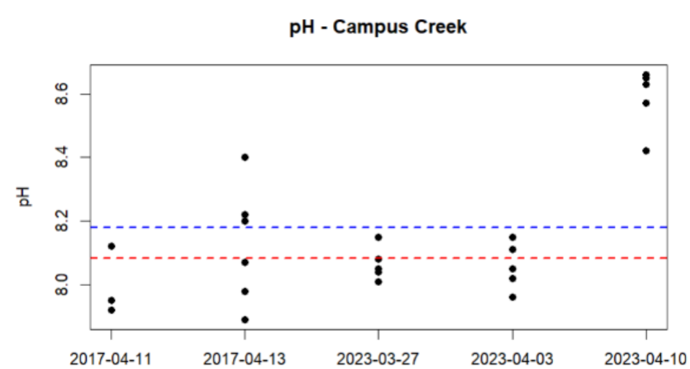

Figure 7. Campus Creek trend curve for pH. Spacing between time is distorted and the presented line is not exact to relationship.

Water Pollution Index

The 2017 Water Pollution Index value for the entire stream was determined to be 0.50195, or of good quality. The 2023 WPI value for the entire stream was determined to be 0.410572, or of excellent quality. At an individual site analysis, Site 3 for both 2017 and 2023, did not rank as excellent quality and increased in numerical value over time, as documented in Table 3. Moreover, Site 1 in 2017 did not rank as excellent quality; however, it increased in quality by 2023.

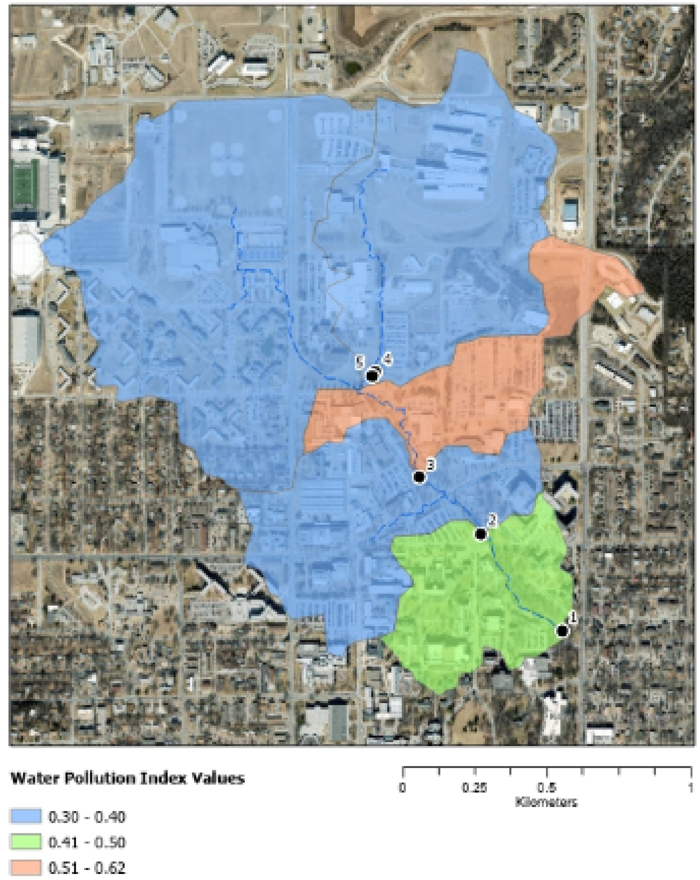

Figure 8. Campus Creek water pollution index values throughout watersheds. All values below 0.5 are of excellent aquatic ecological quality.

Discussion

Discrepancies

In analyzing our results from our study this year, we were able to compare it to a previous study, Environmental Assessment of Campus Creek at K-State, that was conducted in the spring of 2017 (Olney et al. 2017). In this study, the pH and conductivity levels, turbidity, and total solids (TS) were sampled and analyzed. Collections were made three consecutive times at three separate locations (sites 1, 2, and 3), for each of the four factors, over the course of two dates throughout the course of a single week

(04/11/2017 and 04/13/2017). This is in comparison to the 2023 study that had conducted sampling one time at five different sites, over the course of three weeks.

Another difference between the two studies was that the WPI from 2017 was calculated using only two parameter variables (pH and conductivity levels) versus the study from 2023 that had ten different parameter variables. The previous study's trend analysis graphs were also distorted, which made it difficult to get accurate data points from their graphs to compare with the data that was collected in 2023.

Possible Sources of Pollution

When comparing the results from the Shapiro Test, Levene Test, One-Way ANOVA Test, and Kruskal-Wallis Test, it's seen that total nitrogen and total sulfur levels were outliers in regions 4 and 5 compared with the other locations. For total nitrogen, the levels at sites 4 and 5 were significantly lower than sites 1-3, while total sulfur levels at sites 4 and 5 were significantly higher than sites 1-3. A couple of possible sources of these pollutants are increased nitrogen levels from the application of fertilizers surrounding the Campus Creek watershed, as well as the construction sites that are happening on the northeast and northwest side of the Campus Creek watershed. On the northeast side, K-State athletics is currently in the progress of building a new Indoor Football Practice Facility. On the northeast side of the Campus Creek watershed, the U.S. Department of Agriculture is in the progress of building a National Bio and Agro-Defense Facility and has been since 2019.

Recommendations

For the Wildcat Creek region, it would be recommended to investigate further potential factors that are causing the change in nitrogen and sulfur levels in regions 4 and 5. While the levels for these regions, as well as all the other levels, are at an acceptable value, it would be recommended for them to not get worse. One suggestion that we have would be for K-State staff to monitor these levels at the same sampling areas that we did. Sampling could look like collecting water in each of these five sampling locations, twice a year, once in the spring during the wet season and once in the fall during the dry season. This will help in creating a long-term collection of data, allowing one to look at trends and make adjustments later on if needed. If other studies were to be conducted in the future over Campus Creek, there would then be a larger collection of data that will help set baseline conditions.

Another suggestion is in regard to the quality of Campus Creek's aesthetic beauty and appearance. We noted various litter and other debris throughout the stream and surrounding area of Campus Creek, so we suggest removing as much unwanted debris as possible to create a more beautiful landscape for the K-State community and frequent visitors.

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Appendix

Site	Date	Temp. (℃)	TSS (mg/L)	TDS (mg/L)	TS (mg/L)	EC (mS/cm)	pH	N (ppm)	P (ppm)	Cl (ppm)	S (ppm)
1	4/11/2017				515	1.145	7.92				
1	4/11/2017				495	1.075	7.95				
1	4/11/2017				420	1.045	8.12				
2	4/13/2017				595	1.048	7.98				
2	4/13/2017				385	1.025	7.89				
2	4/13/2017				500	1	8.07				
3	4/13/2017				745	1.12	8.2				
3	4/13/2017				615	1.08	8.22				
3	4/13/2017				650	0.98	8.4				
1	3/27/2023	12.5	12	716	728	1.02	8.04	2.94	0.07	97.14	22.94
2	3/27/2023	12.6	13	714	727	1.02	8.01	3.33	0.07	91.02	22.65
3	3/27/2023	14.6	3	696	699	0.99	8.08	3.78	0.08	87.69	21.84
4	3/27/2023	9.2	39*	629	668	0.9	8.05	0.63	0.06	83.51	25.26
5	3/27/2023	8.8	2	646	648	0.92	8.15	0.39	0.04	87.32	26.42
1	4/3/2023	16.2	38*	754	792	1.077	8.05	2.96	0.12*	104	25.52
2	4/3/2023	15.2	8	728	736	1.04	8.15	3.12	0.08	96.88	23.42
3	4/3/2023	16.4	29	708	737	1.012	8.11	4.45	0.12*	88.66	22.14
4	4/3/2023	14.4	5	768	773	1.097	7.96	0.51	0.05	96.96	32.06
5	4/3/2023	13.2	5	776	781	1.108	8.02	0.41	0.07	98.96	32.26
1	4/10/2023	20.6	1	715	716	1.02	8.57	1.87	0.05	154.31	25.26
2	4/10/2023	19.9	5	682	687	0.97	8.65	2.67	0.08	127.87	23.77
3	4/10/2023	23.1	69*	802	871	1.15	8.66	2.75	0.42*	201.06	23.08
4	4/10/2023	19.4	1	686	687	0.98	8.42	0.58	0.09	122.48	33.31
5	4/10/2023	17.8	1	749	750	1.07	8.63	0.4	0.07	137.49	33.33

Table 1. Campus Creek 2017 and 2023 measured parameters. Temperature (Temp) was measured in degrees celsius. Total suspended solids (TSS) was measured in milligrams per liter. Total dissolved solids (TDS) was measured in milligrams per liter. Total solids (TS) was measured in milligrams per liter. Electrical conductivity (EC) was measured in millisiemens per centimeter. Total nitrogen (N) was measured in parts per million. Total phosphorus (P) was measured in parts per million. Total chlorine (Cl) was measured in parts per million. Total sulfur (S) was measured in parts per million. *Marked values exceed the aquatic ecological standard.

			ANOVA Test		**Kruskal-Wallis Test**	
Pollutant	**Shapiro Test**	**Levene Test**	**F-Value**	**P-Value**	**Chi-Square**	**P-Value**
Temp (°C)	0.06907	0.9944	0.53469	0.7137		
TSS (mg/L)	0.3748	0.3912	1.0606	0.4248		
TDS (mg/L)	0.8962	0.7643	0.29431	0.8751		
TS (mg/L)	0.7484	0.8412	0.47039	0.7567		
EC (mS/cm)	0.8695	0.7812	0.27941	0.8847		
pH	0.001135*	0.9987			1.4886	0.8287
N (ppm)	0.1794	0.3838	26.52	0.00002642*		
P (ppm)	0.003119*	0.3969			5.9877	0.2001
Cl (ppm)	0.09505	0.8811	0.23273	0.9137		
S (ppm)	0.1345	0.5978	6.5715	0.007348*		

Table 2. Campus Creek 2017 and 2023 statistical analysis results. Temperature (Temp) was measured in degrees celsius. Total suspended solids (TSS) was measured in milligrams per liter. Total dissolved solids (TDS) was measured in milligrams per liter. Total solids (TS) was measured in milligrams per liter. Electrical conductivity (EC) was measured in millisiemens per centimeter. Total nitrogen (N) was measured in parts per million. Total phosphorus (P) was

measured in parts per million. Total chlorine (Cl) was measured in parts per million. Total sulfur (S) was measured in parts per million.

Year	**Site**	**WPI Value**
2017	1	0.505787
2017	2	0.498556*
2017	3	0.501513
2017	Average	0.50195
2023	1	0.400733*
2023	2	0.362665*
2023	3	0.61553
2023	4	0.358567*
2023	5	0.304443*
2023	Average	0.410572*

Table 3. Campus Creek Water Pollution Index values by year by site. Averages took into account all available parameters measured for the entire system. WPI values less than 0.5 indicate excellent water quality. WPI values 0.5 to 0.75 indicate good water quality. WPI values 0.75 to 1 indicate moderately polluted water. WPI values greater than 1 indicate highly polluted water. *Marks excellent water quality.

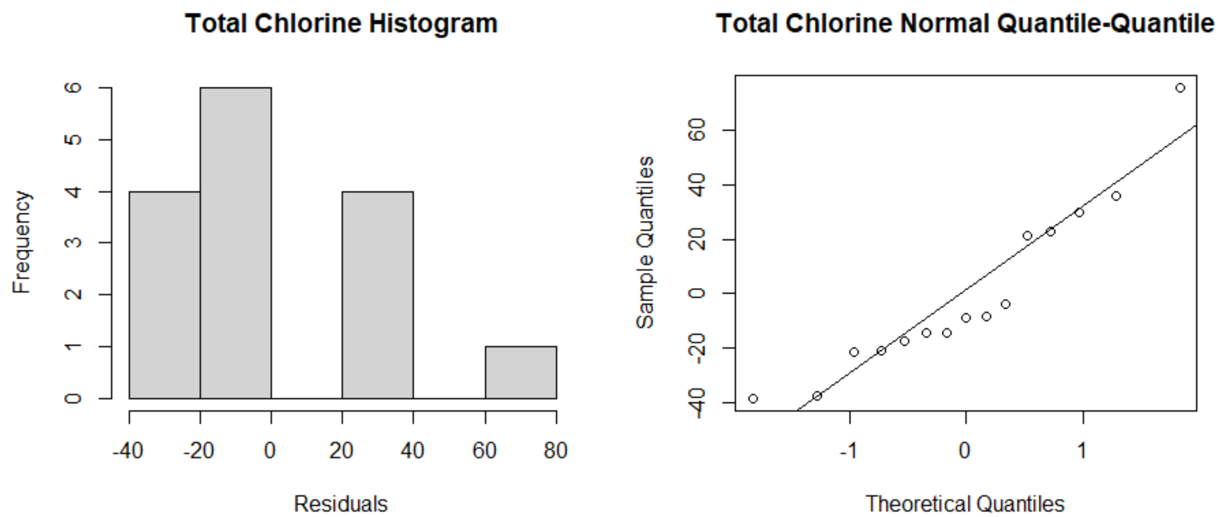

Figure 9. Total chlorine (ppm) histogram and normal quantile-quantile plots for Campus Creek 2023.

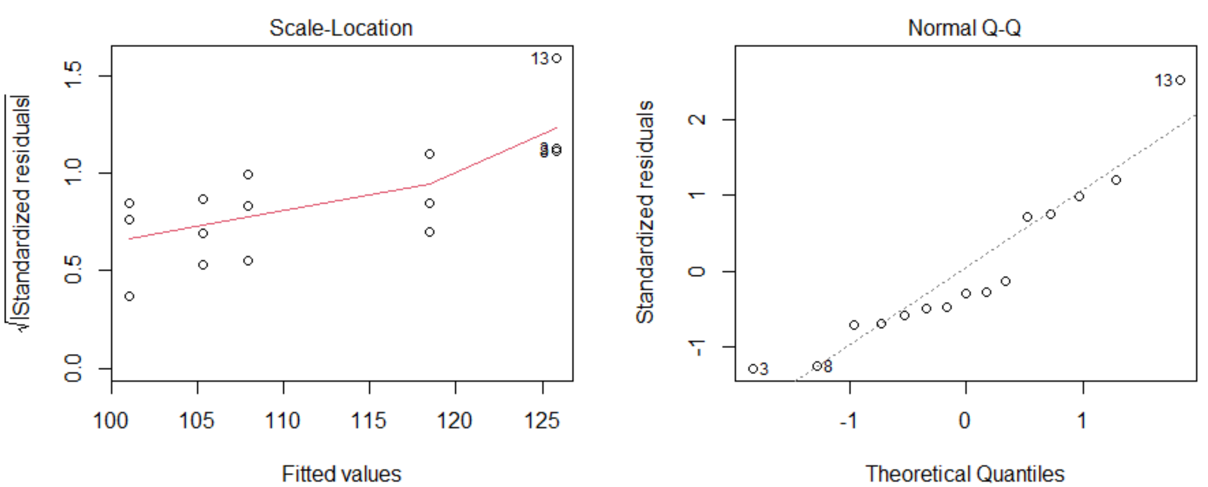

Figure 10. Total chlorine (ppm) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

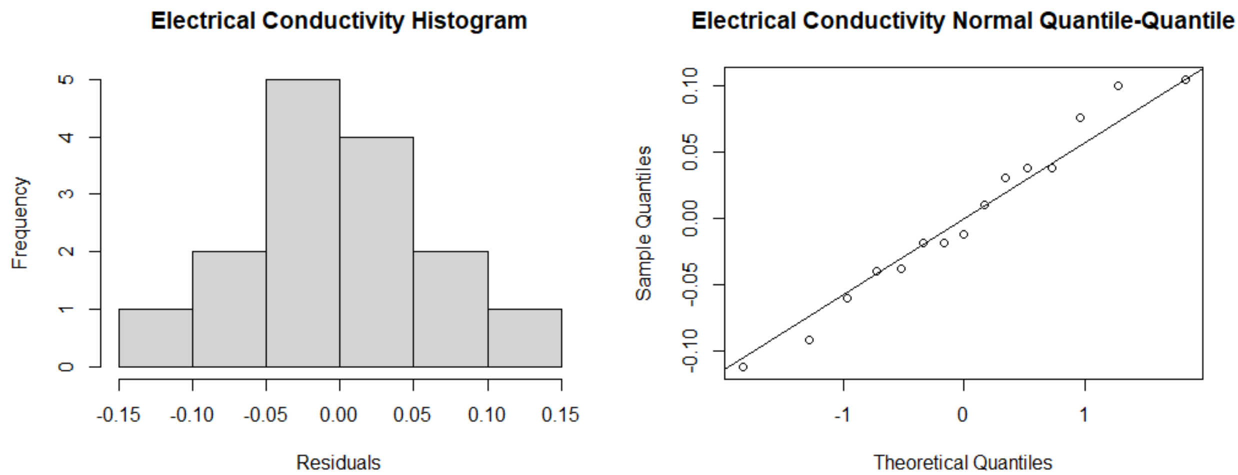

Figure 11. Electrical Conductivity (mS/cm) histogram and normal quantile-quantile plots for Campus Creek 2023.

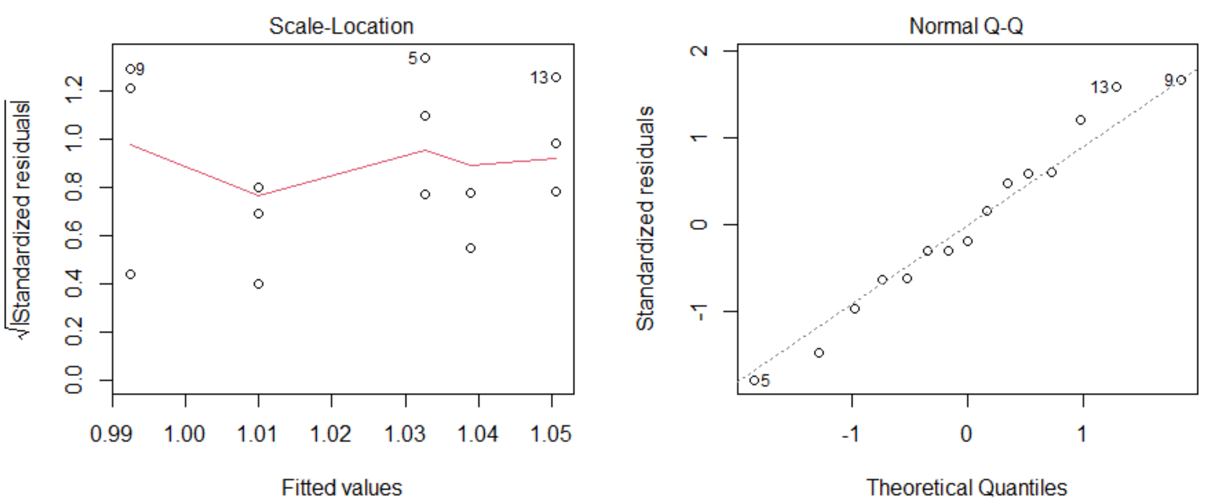

Figure 12. Electrical conductivity (mS/cm) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

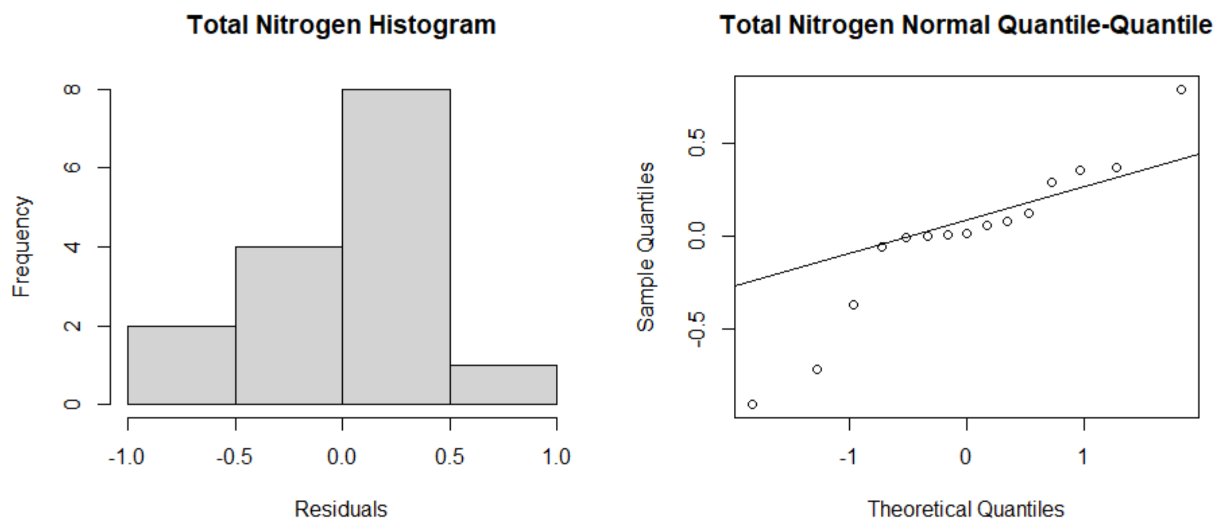

Figure 13. Total nitrogen (ppm) histogram and normal quantile-quantile plots for Campus Creek 2023.

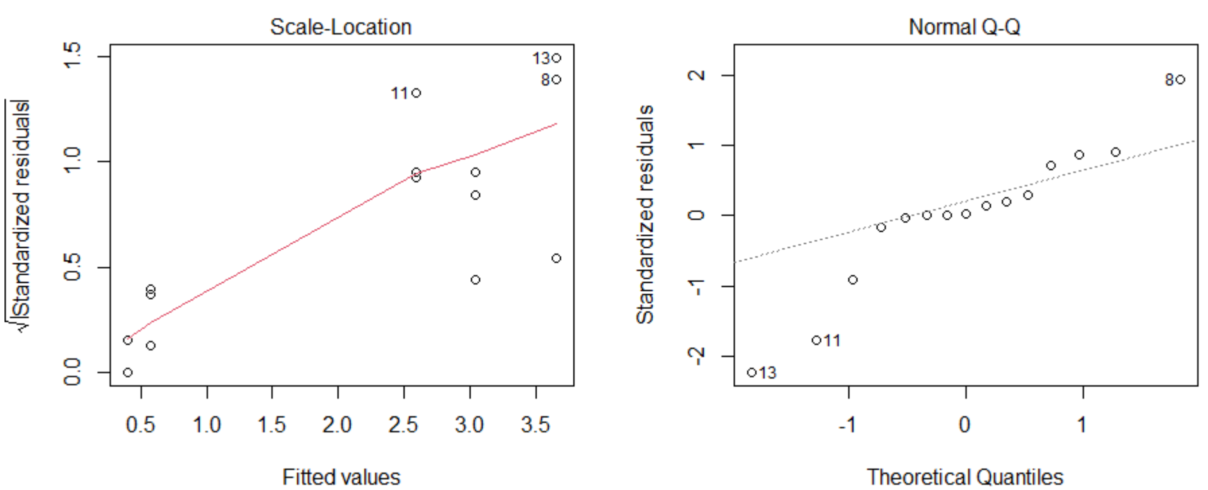

Figure 14. Total nitrogen (ppm) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

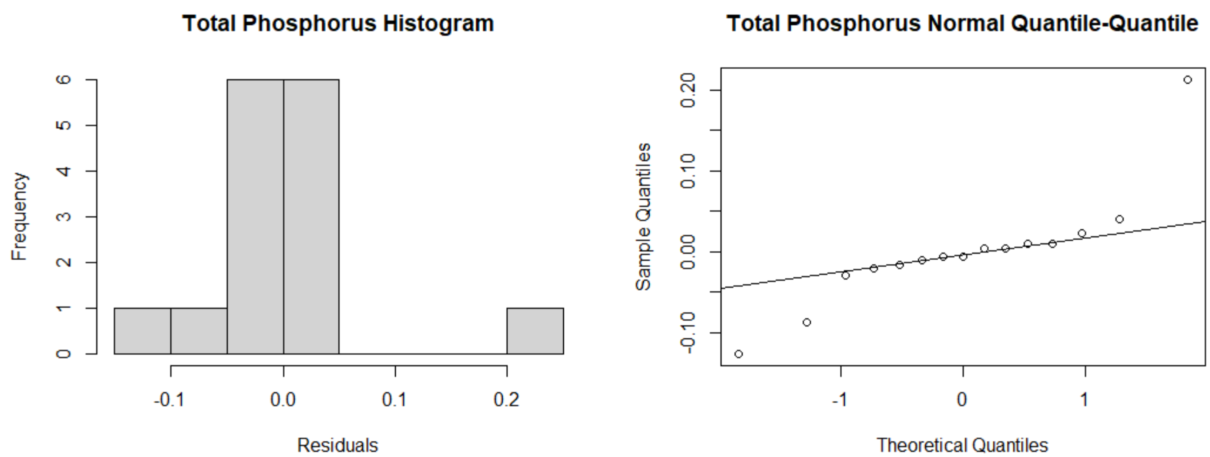

Figure 15. Total phosphorus (ppm) histogram and normal quantile-quantile plots for Campus Creek 2023.

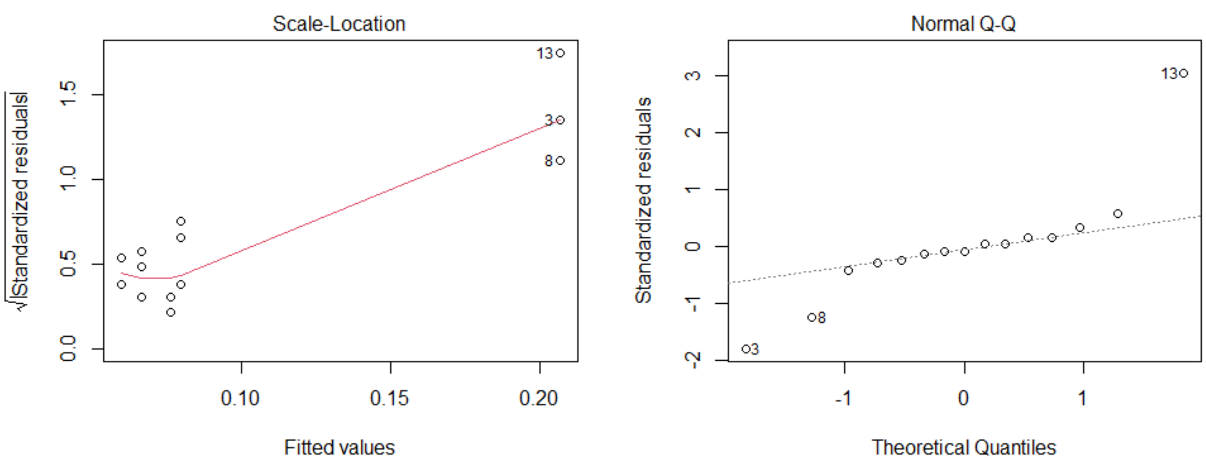

Figure 16. Total phosphorus (ppm) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

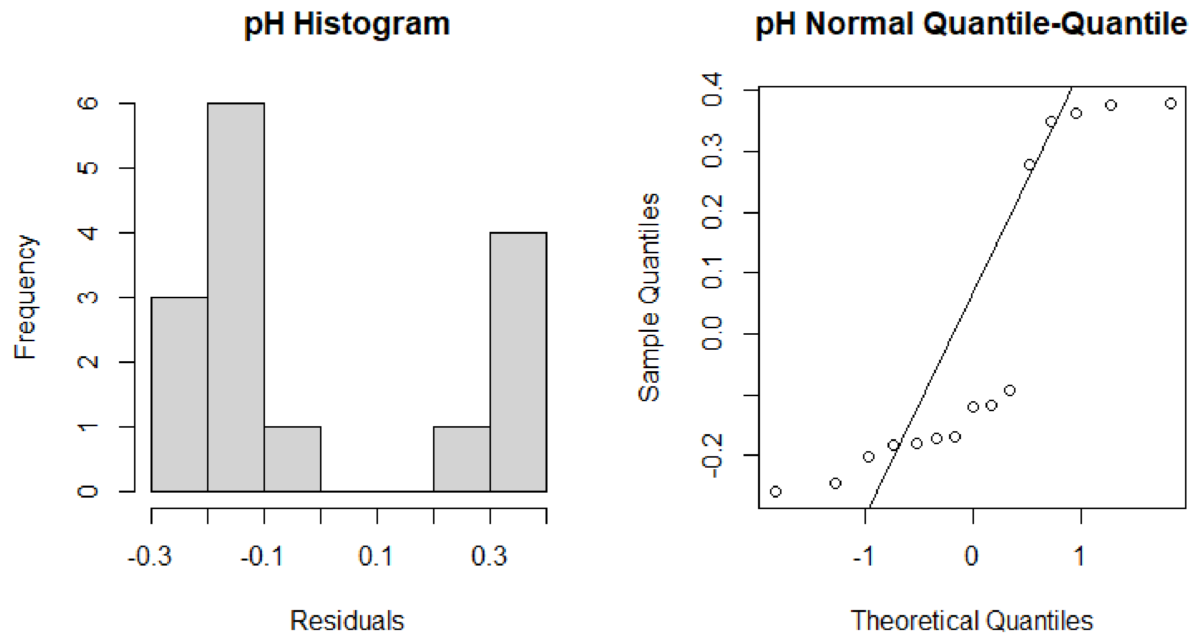

Figure 17. pH histogram and normal quantile-quantile plots for Campus Creek 2023.

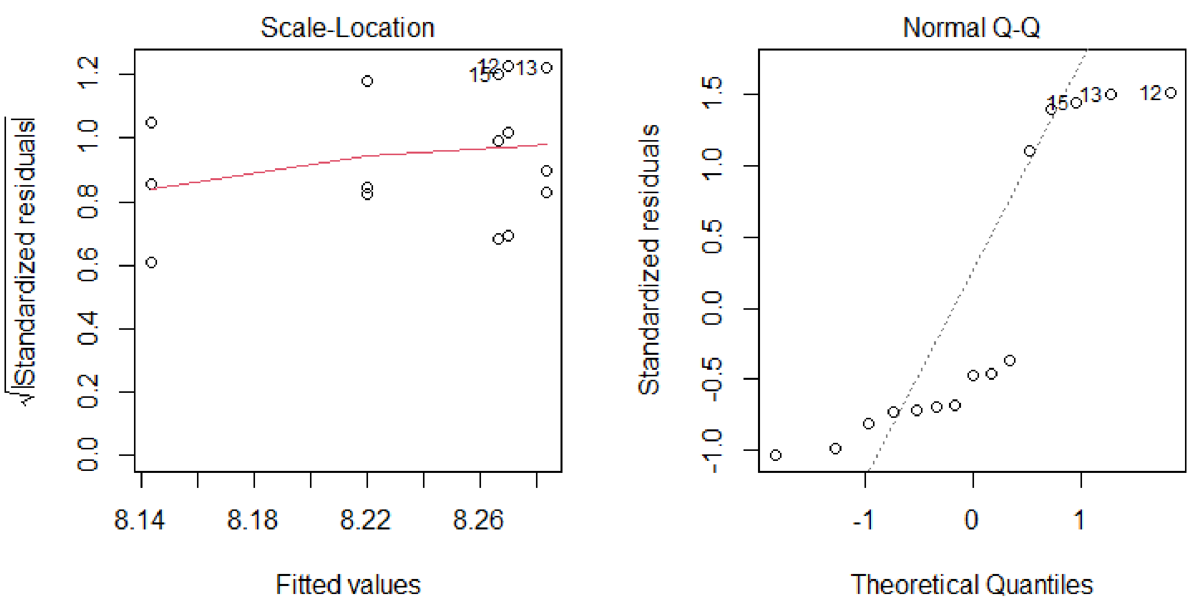

Figure 18. pH standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

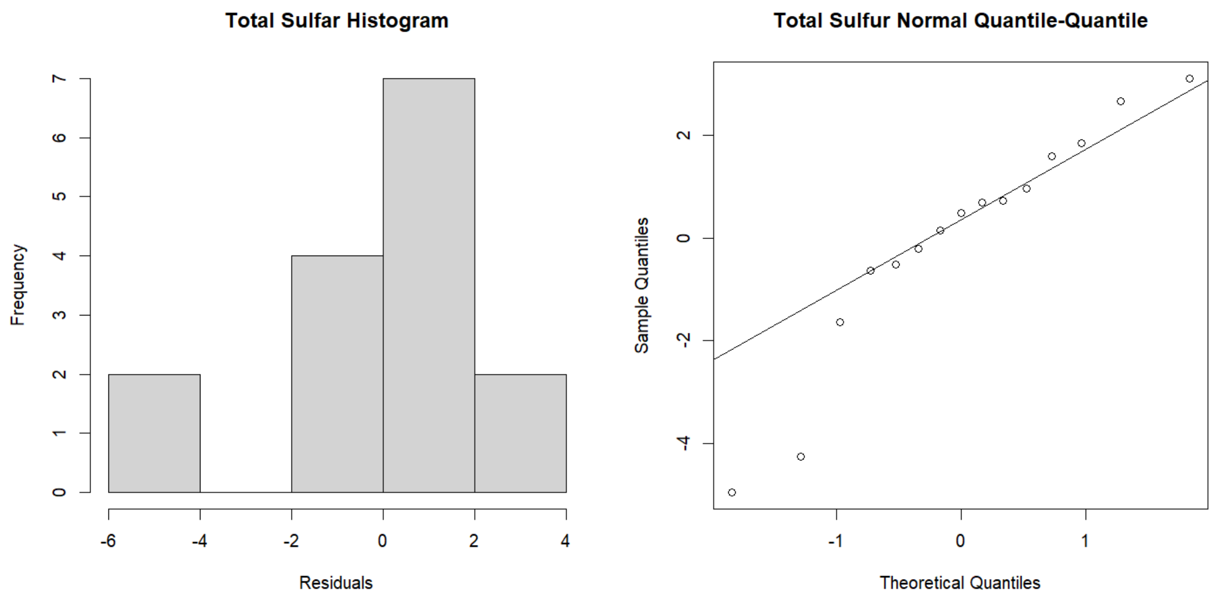

Figure 19. Total sulfur (ppm) histogram and normal quantile-quantile plots for Campus Creek 2023.

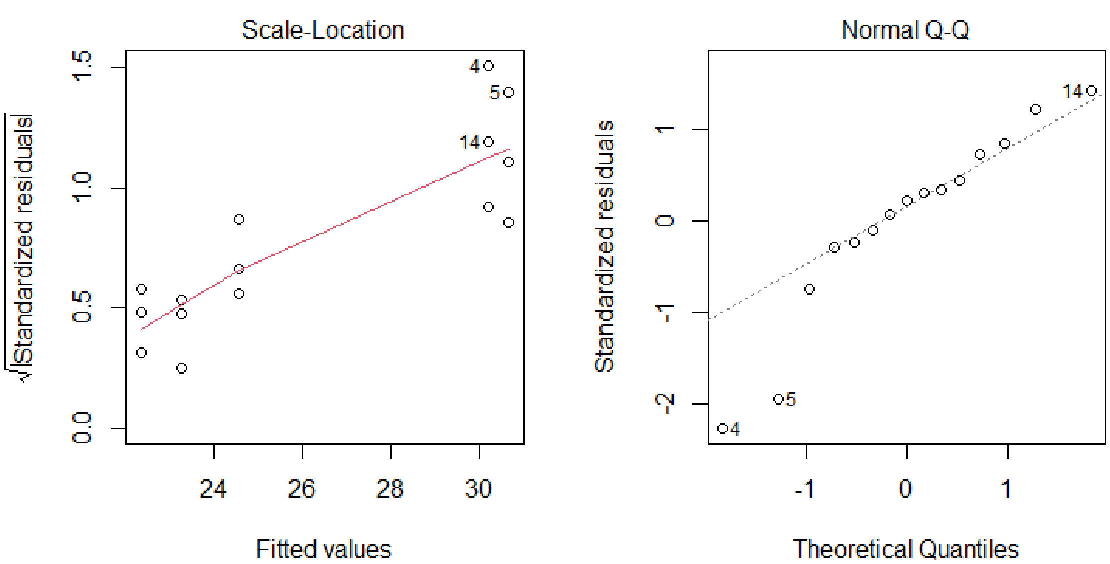

Figure 20. Total sulfur (ppm) solids standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

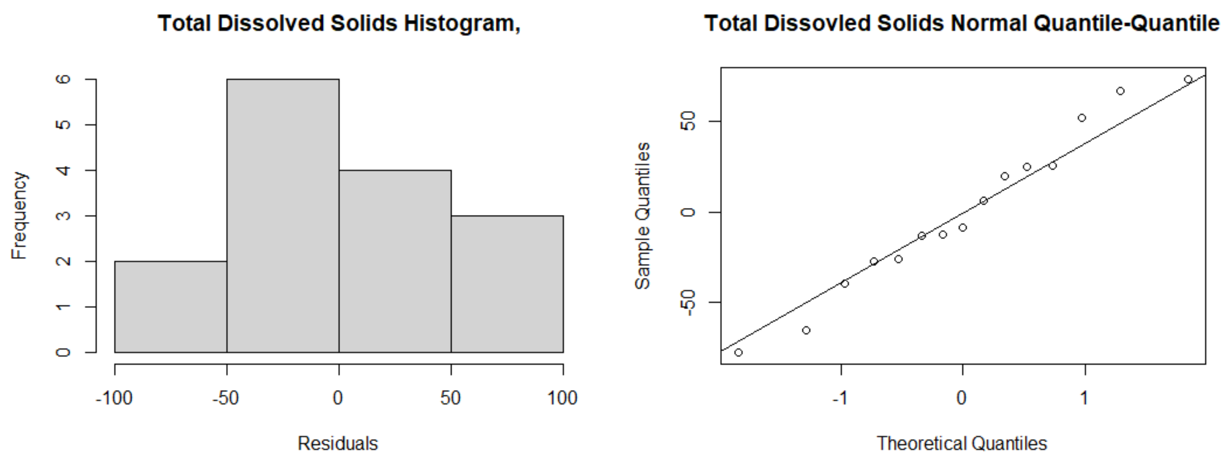

Figure 21. Total dissolved solids (mg/L) histogram and normal quantile-quantile plots for Campus Creek 2023.

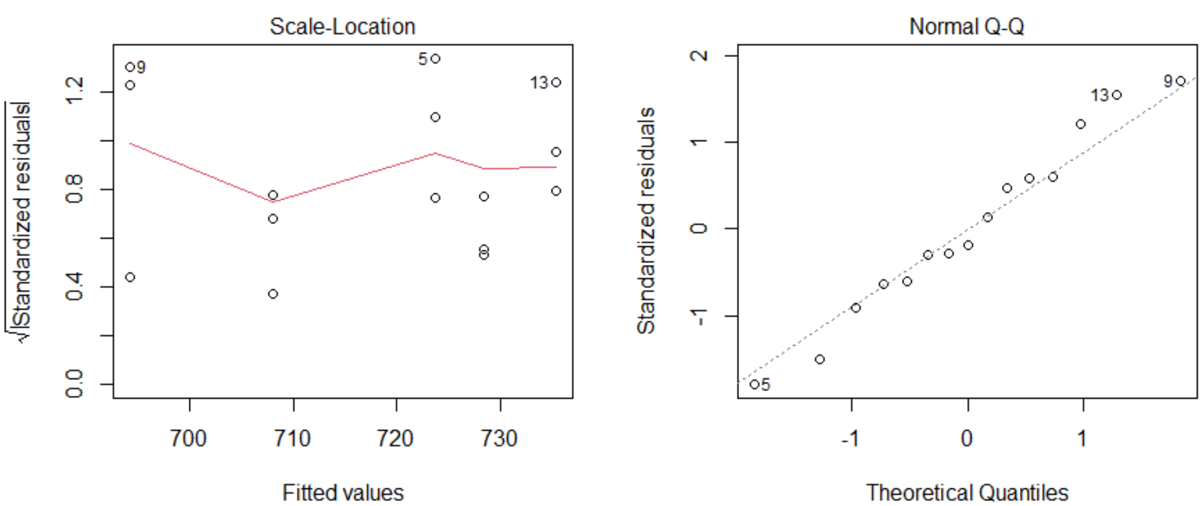

Figure 22. Total dissolved solids (mg/L) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

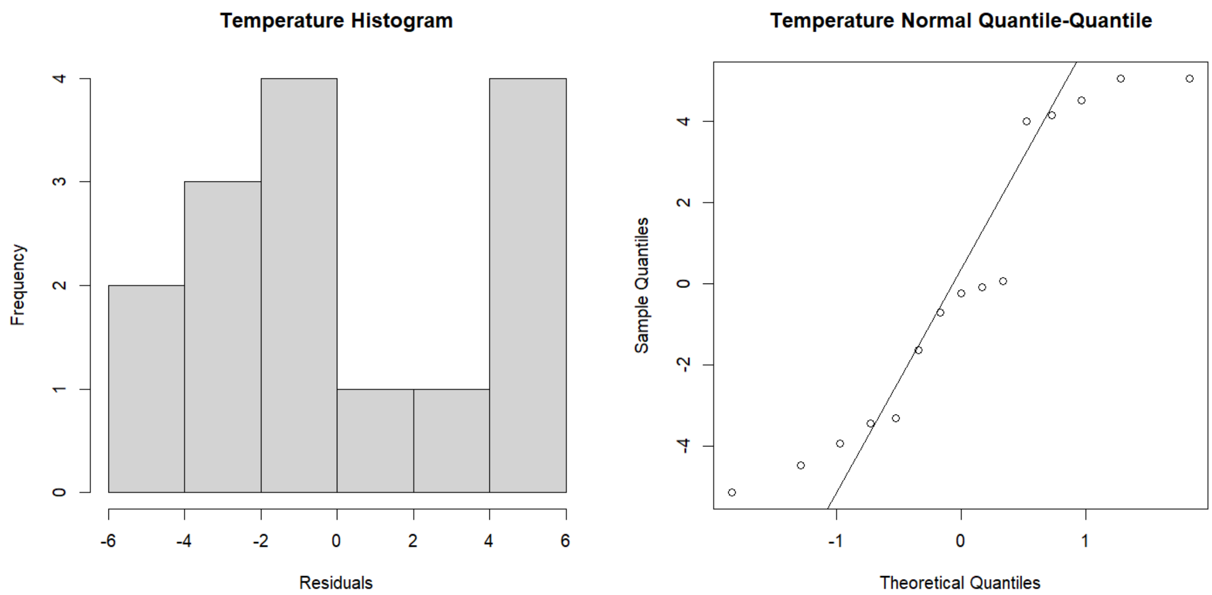

Figure 23. Temperature (°C) histogram and normal quantile-quantile plots for Campus Creek 2023.

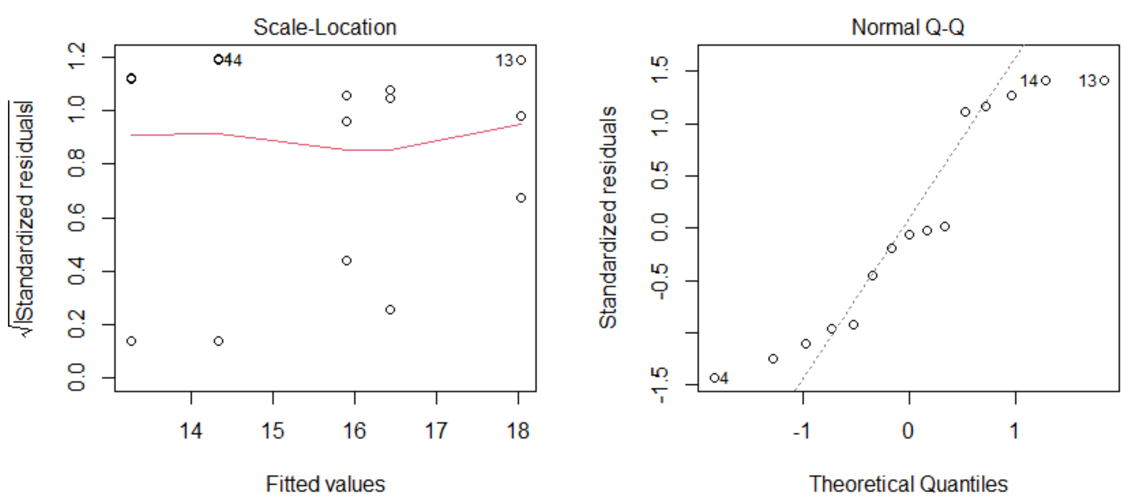

Figure 24. Temperature (°C) solids standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

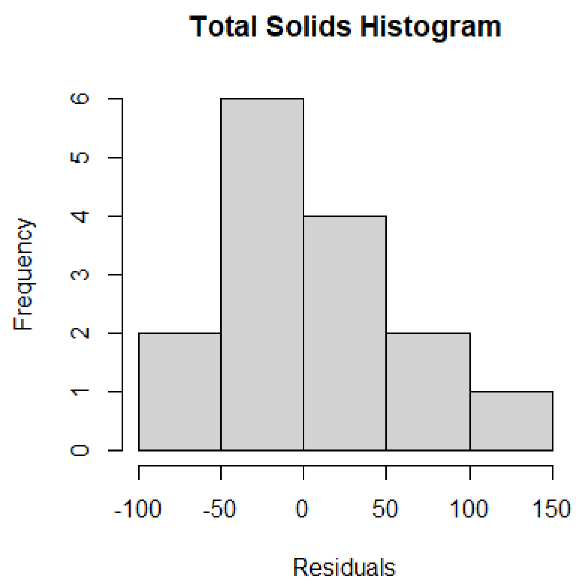

Figure 25. Total solids (ppm) histogram and normal quantile-quantile plots for Campus Creek 2023.

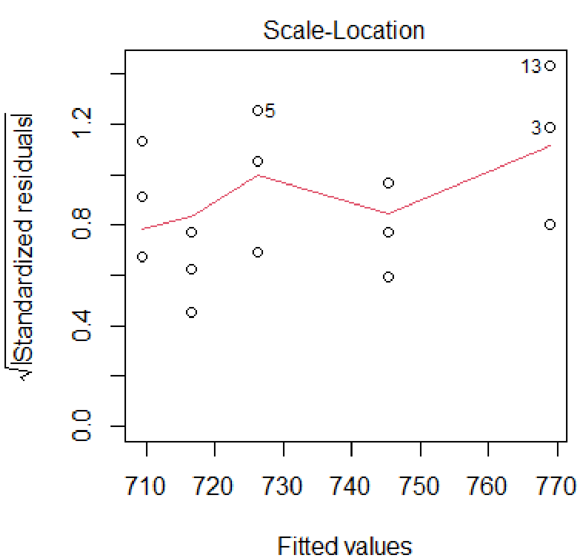

Figure 26. Total solids (ppm) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.

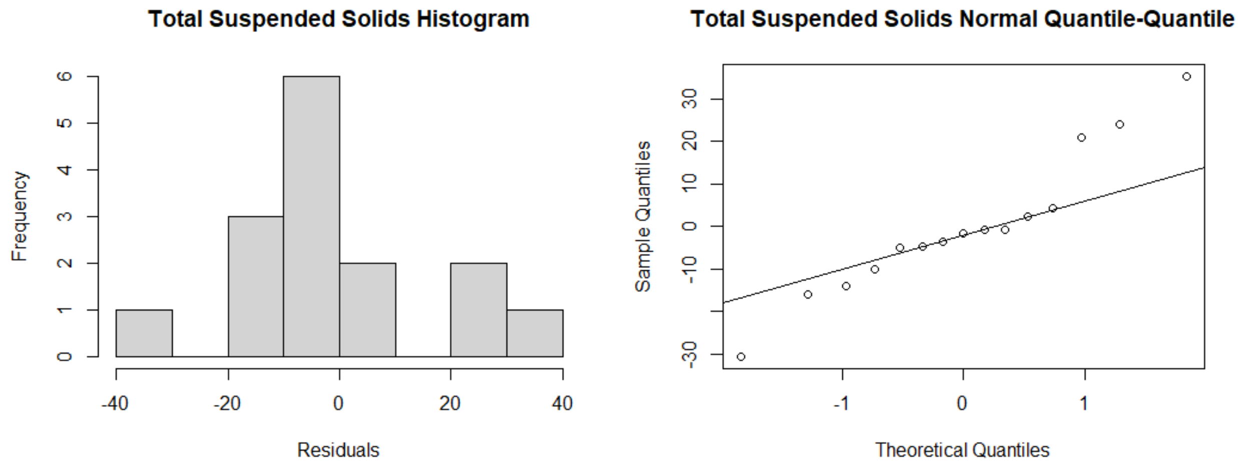

Figure 27. Total suspended solids (ppm) histogram and normal quantile-quantile plots for Campus Creek 2023.

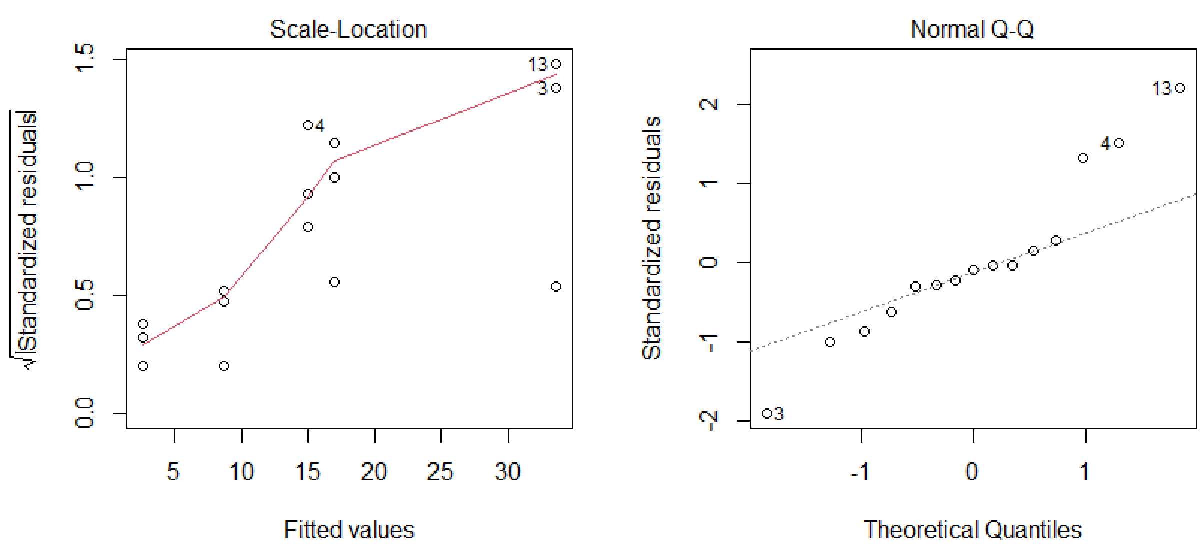

Figure 28. Total suspended solids (ppm) standardized residuals scale location and normal quantile-quantile for Campus Creek 2023.