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MONTCLAIR STATE UNIVERSITY

ROAD SALT-INDUCED SALINIZATION OF THE UPPER PAULINS KILL RIVER IN NEWTON, NEW JERSEY

by

Kristine Emily Rogers

A Master's Culminating Research Project Submitted to the Faculty of
Montclair State University
In Partial Fulfillment of the Requirements
For the Degree of
Master of Science,
Sustainability Science with a concentration in Sustainability Leadership
January 2023

College of Science and Mathematics
Earth and Environmental Studies

Advisor: Dr. Joshua Galster

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ROAD SALT-INDUCED SALINIZATION OF THE UPPER PAULINS KILL RIVER IN NEWTON, NEW JERSEY

A M.S. Culminating Research Project Report

Submitted in partial fulfillment of the requirements

For the degree of MASTER OF SCIENCE in

SUSTAINABILITY SCIENCE WITH A CONCENTRATION IN SUSTAINABILITY LEADERSHIP

by

KRISTINE EMILY ROGERS

College of Science and Mathematics

Montclair State University

Montclair, New Jersey

2023

ABSTRACT

Road salt application is a primary factor leading to the salinization of freshwater rivers and streams throughout the Northeastern United States and globally. Rising salinization within fresh water bodies is problematic because it can modify community structure and detritus processing within freshwater ecosystems, induce mortality among macroinvertebrates and other aquatic life, and mobilize metals that can pose harm to human health. Road salts also threaten surface and underground drinking water supplies, kill riparian vegetation, and corrode infrastructure, such as bridges and roads. This research examines 4 ½ years of continuous water quality monitoring data collected from two sensor stations along the Paulins Kill River in Newton, New Jersey to assess the seasonal impact that road salt is having on the river. Specific conductance and depth were examined during each season. The data showed that if precipitation fell when air temperatures were above freezing, conductivity and depth exhibited an inverse relationship. The additional freshwater from rainwater diluted the concentration of ions in the river, causing conductivity measurements to decrease as the river depth rose. When precipitation occurred when air temperatures were below freezing, however, conductivity levels rose along with the river's depth because road departments were applying road salt to Newton's streets. This research provides important implications for winter road management by public works departments and their impacts on local rivers.

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I. INTRODUCTION

In New Jersey, the Paulins Kill River is the third largest tributary to the Delaware River (Foodshed Alliance). The Paulins Kill Watershed contains a mix of different land uses including forests, agriculture, wetlands, and urban terrain (WRWMG, 2012). The region is mainly rural, with the exception of the Town of Newton, NJ (WRWMG, 2012). Urban lands are widely known to contribute excessive stormwater runoff and pollutant loading to local streams, deteriorating the health of freshwater resources and in-stream wildlife communities, like macroinvertebrates (Cooper et al., 2014; Castillo et al., 2018; Entrekin et al., 2019).

Over the past several decades rising chloride and pH levels have been observed in freshwater systems around the world and are contributing to a phenomenon known as Freshwater Salinization Syndrome (FSS) (Kaushal et al., 2018; Galella et al., 2021). FSS is caused by use of road salt as well as anthropocentric erosion of impervious surfaces (Galella et al., 2021) and threatens the health of macroinvertebrates, amphibians, and other aquatic and terrestrial organisms living within the floodplain (Entrekin et al., 2019; Karraker et al., 2008, Gillis, 2011; Wallace and Biastoch, 2016; Morgan et al., 2012). Freshwater salinization due to road salt applications is the focus of this independent study analysis in the Upper Paulins Kill Watershed.

The Paulins Kill, along with other major and minor rivers and streams in New Jersey, New York, Pennsylvania, and Delaware, comprise the Delaware River Watershed (Delaware River Watershed Initiative, 2017). The Delaware River is a drinking water source for 15 million people living within the Mid-Atlantic Region of the United States, and in recent years, the Delaware River has become a focus of conservation and land acquisition projects through a multi-partner work group called the Delaware River Watershed Initiative that was created to ensure that the river will be able to provide clean drinking water for watershed residents now and into the future (Delaware River Watershed Initiative, 2017).

In 2017 Stroud Water Research Center deployed continuous water quality monitoring sensors throughout the Delaware River Watershed as part of its EnviroDIY community science monitoring network funded through the Delaware River Watershed Initiative (Bressler et al., 2017). Interested nonprofit, academic, and community organizations within New Jersey, New York, Pennsylvania, and Delaware worked with Stroud Water Research Center to install the monitoring sensors on small streams throughout the Delaware River Watershed that have historically been excluded from stream monitoring programs. Sensor deployment locations were selected 1) at sites targeted for restoration via best management practice installation, 2) at highly-forested permanent protection properties containing reference quality streams, and 3) at locations where a sensor could provide significant educational engagement for students and community members. As part of the Delaware River Watershed Initiative, Stroud Water Research Center has worked with over 50 watershed groups, schools, and universities to deploy over 150 sensor stations throughout the Delaware Basin and 4 sensors within the Paulins Kill Watershed (Utah Water Research Laboratory, 2022).

This analysis utilized the water quality monitoring data collected at two sensor deployment locations along the Upper Paulins Kill River at Sussex County Community College (SCCC) and at Memory Park within the Paulins Kill Watershed (FIGURE 1). Both SCCC and Memory Park are located in the Town of Newton within Sussex County, New Jersey and have been collecting conductivity, temperature, depth, and turbidity data since 2017. The SCCC sensors are located at 41.06602°, -74.75547° within an approximately 1-meter-deep pool along an unnamed tributary to the Paulins Kill at the southern edge of the community college campus

(FIGURE 2, Map A) (Utah Water Research Laboratory, 2018b). The west branch of the Paulins Kill flows out of a small, developed area and through a wooded forest patch before it enters the SCCC campus and flows through a series of open water ponds and concrete pipes that discharge at the SCCC sensor station at the base of the community college campus (FIGURE 2, Map B). The east branch of the Paulins Kill also flows aboveground through some forested and developed areas upstream of the college campus (FIGURE 2, Map C). Below the pond on the east branch, the Paulins Kill is piped and flows beneath a large grass lawn before discharging at the SCCC monitoring station. The piped sections of the east and west branches of the unnamed tributaries to the Paulins Kill receive stormwater directly from the storm drains on campus.

The Memory Park sensor station is situated at 41.05928°, -74.74316° within a public park owned by the Town of Newton (Utah Water Research Laboratory, 2017). The park contains ballfields, a woodchipped playground area, and the Newton Department of Public Works yard; it is also adjacent to Newton's wastewater treatment plant. The Memory Park sensor station is located approximately 1 kilometer downstream from the SCCC sensor station.

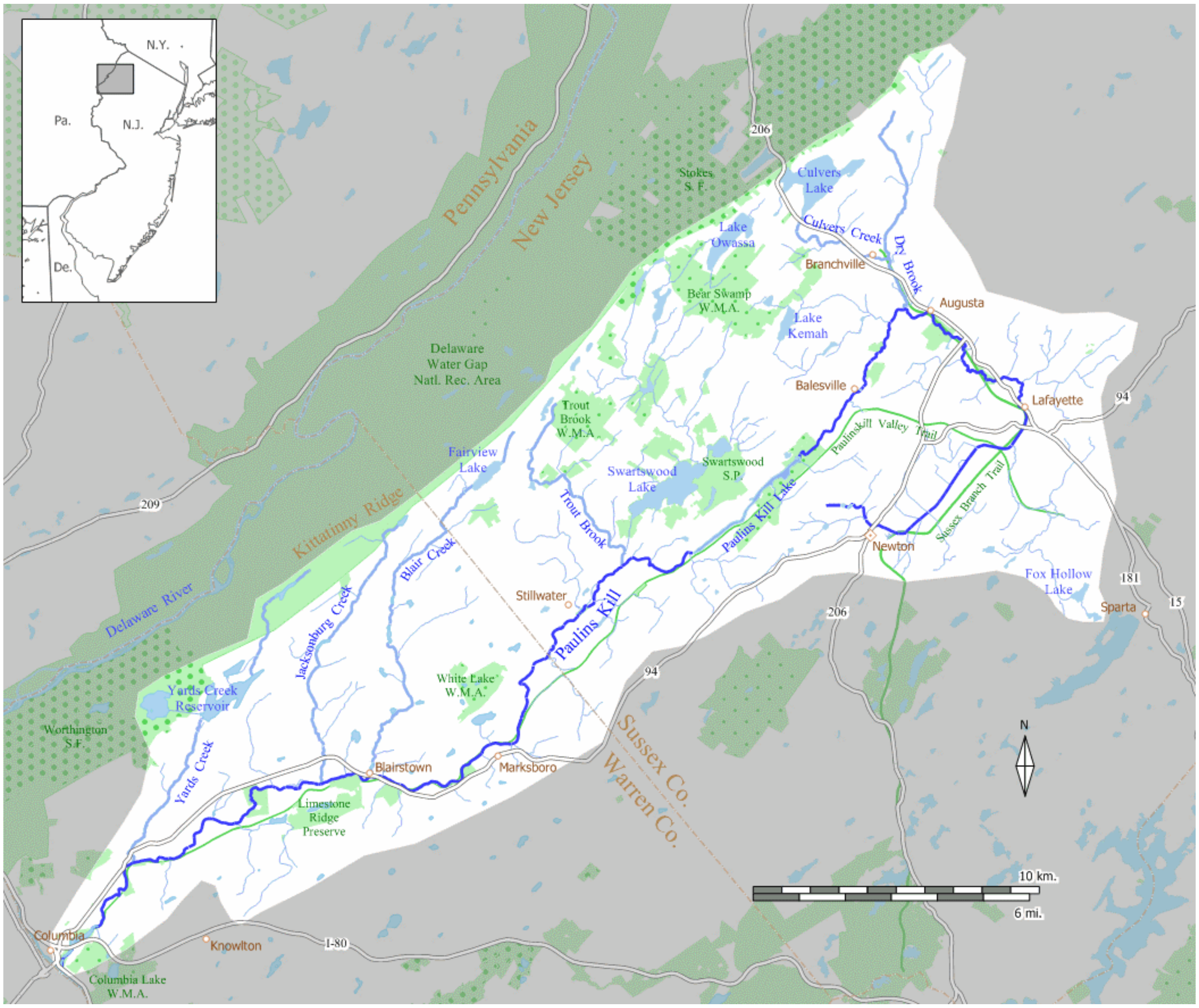
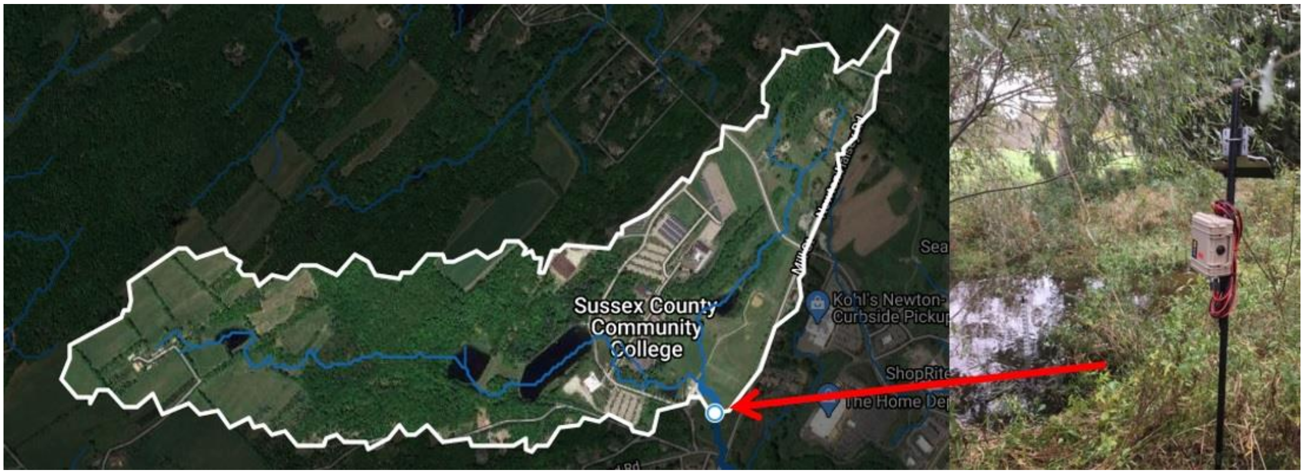


FIGURE 1: Map of the Paulins Kill Watershed, from its headwaters in Newton, NJ to its confluence with the Delaware River in Columbia, NJ.

Map source: https://foodshedalliance.org/pkw/

FIGURE 2: Maps of the SCCC drainage area

Map source: Model My Watershed (Stroud Water Research Center, 2017)



Map A: The SCCC drainage area with a red arrow showing the position of the sensor station in relation to other features on the SCCC campus.

Map B: The west branch of the Paulins Kill on the SCCC campus. The river flows through agricultural fields and ponds before being piped across the lawn areas to the sensor station at the southern edge of the campus.

Map C: The east branch of the Paulins Kill on the SCCC campus. The river flows through a neighborhood, a wooded area, and a pond on the SCCC campus before being piped underground beneath the open lawn to the sensor station.

FIGURE 3: Photos of the SCCC sensor station and the SCCC stormwater pipes that discharge at the sensor

FIGURE 4: Map of the Memory Park drainage area. The red star indicates the location of the Memory Park sensor station, and the yellow star indicates the location of the SCCC sensor station.

Map source: Model My Watershed (Stroud Water Research Center, 2017)

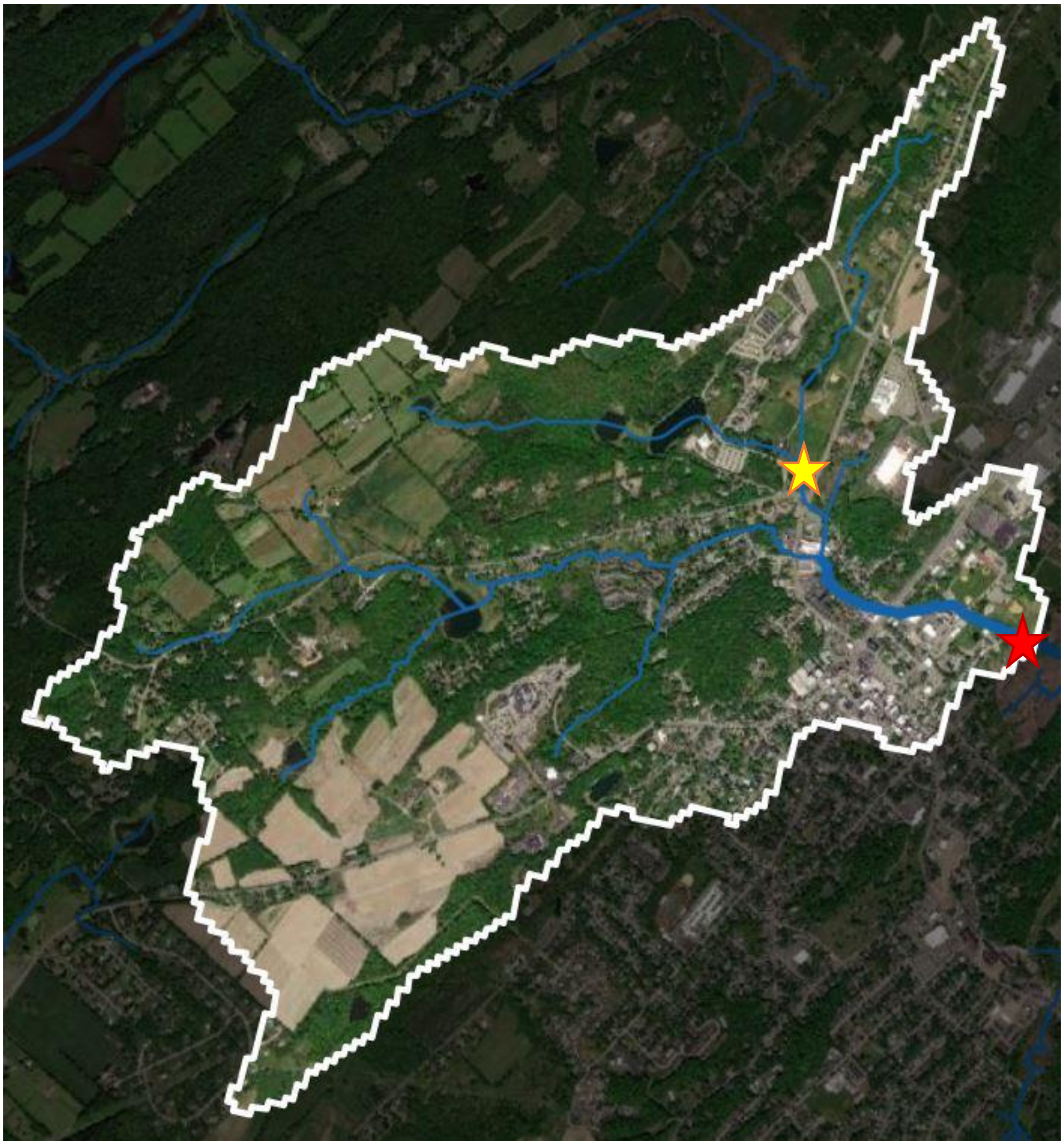


FIGURE 5: Photo of the Memory Park sensor station

II. METHODS

A METER Hydros 21 CTD (conductivity, temperature, and depth) sensor and a Campbell OBS-3+ turbidity sensor were installed at both locations (Bressler et al., 2017). The Memory Park sensors were deployed on June 30, 2017, and the SCCC sensors were deployed on October 12, 2017. Both stations collect conductivity, temperature, depth, and turbidity measurements at 5-minute intervals (Bressler et al., 2017). Data is stored internally on a microSD memory card and is also transmitted online via a solar panel-powered battery and annual 4G cellular plan to the Monitor My Watershed website (https://monitormywatershed.org/browse/) (Bressler et al., 2017).

Monitor My Watershed is a publicly-accessible data collection platform that uploads and graphically displays the data points collected by each sensor station that has been deployed across the Delaware River Basin; data points are uploaded every five minutes to the Monitor My Watershed website (Bressler et al., 2017). To complete this study, all SCCC and Memory Park data points were downloaded as CSV files from the Monitor My Watershed website and then saved as Excel files to generate graphs from the individual data points (Utah Water Research Laboratory, 2017; Utah Water Research Laboratory, 2018b).

Data were analyzed by season in order to assess the seasonal impact of road salt on the health of the stream. For this analysis, astronomical seasons were used to parse the data points into different time periods; “spring” consists of data from March 21-June 20 of a given year, “summer” contains data points from June 21-September 20, “fall” includes data from September 21-December 20, and “winter” contains data from December 21-March 20. The same astronomical season breakdown was used for each year that was analyzed as part of this data analysis.

Any datapoint that registered a value of -9999 indicates that the sensor failed to log a data value for a given parameter at the indicated timestamp (Bressler et al., 2017); such points were omitted from the analysis. Additionally, loss of the cell signal resulted in periodic sensor measurements failing to be transmitted to the Monitor My Watershed online database. These data omissions were manually corrected within the dataset to ensure that the comparisons between the recorded SCCC and Memory Park CTD values were examining measurements that were logged at the same point in time.

Conductivity and depth data collected by the METER CTD loggers are the emphasis of this independent study analysis. Conductivity is measured in microsiemens per centimeter (uS/cm) and is a measure of the how effectively a stream conducts electricity (Bressler et al., 2017). Conductivity is also related to the number of dissolved ions in a stream and is often used as a proxy to determine chloride levels within the river (Bressler et al., 2017). The METER CTD sensor contains a “vented differential pressure transducer” to record the pressure below the water in order to determine the depth of the stream (Decagon Devices Inc., 2016). Depth is measured in millimeters and is an important factor to analyze because of the effect that changing depth values have on the overall conductivity of the stream (Bressler et al, 2017).

Conductivity readings can also be influenced by the geological features of an area. I examined the bedrock geology of Newton using the New Jersey Department of Environmental Protection’s NJ GeoWeb online mapping tool (NJDEP, 2020b). Despite the close proximity of the SCCC and Memory Park sensor stations to one another, both sites are mapped as having different bedrock geological lithologies (FIGURE 6 and FIGURE 7). The different colored classifications on the map indicate that there is a geologic contact downstream of the SCCC campus and upstream of the Memory Park sensor station that separates one rock formation from the other.

To better understand the Upper Paulins Kill watershed context, both the SCCC and Memory Park drainage areas were mapped with USGS StreamStats (USGS, 2022a; 2022b) as well as Model My Watershed (Stroud Water Research Center, 2017). Using these online platforms, users can find the size of the drainage area that flows to each sensor station and also determine the percentage of the drainage area that is defined as “developed” land. Model My Watershed uses National Land Cover Database (NLCD) 2019 classes 21-24 (low, medium, and high intensity development) to define what constitutes developed land in its reports (MRLC, 2019).

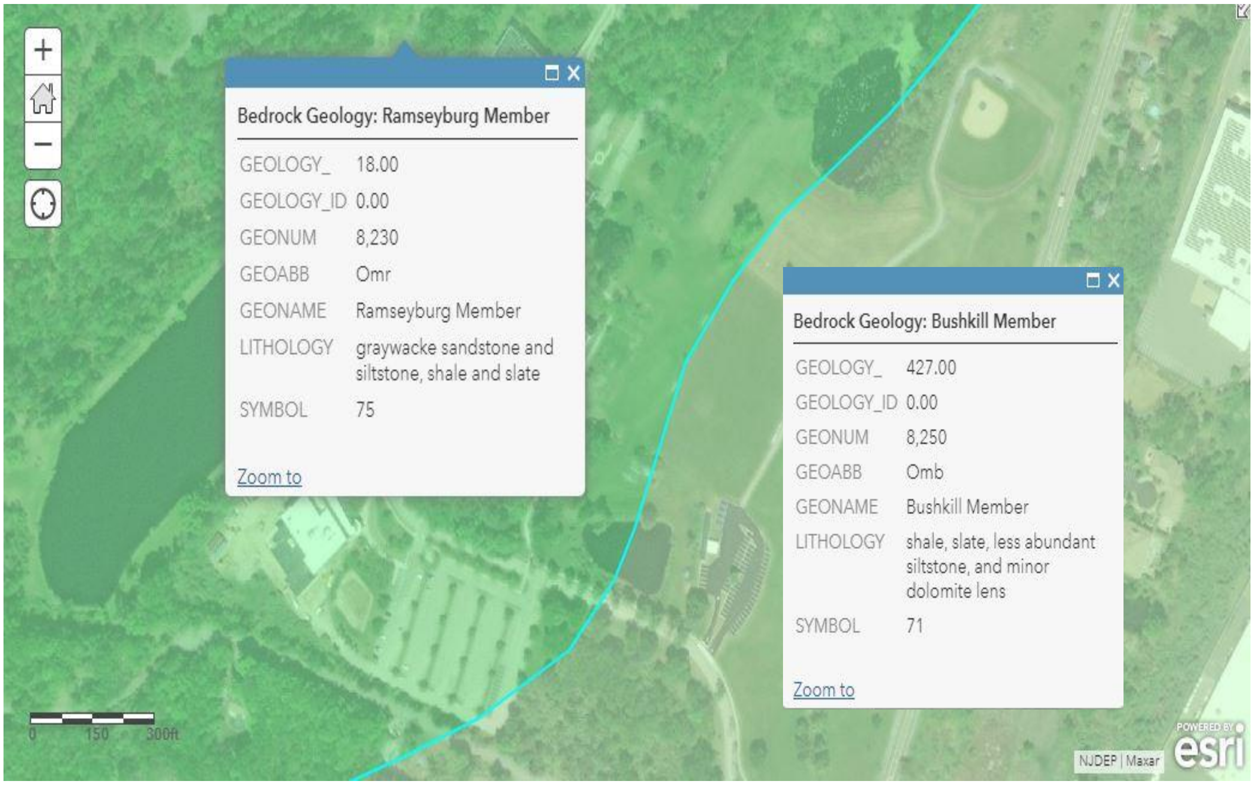
Each stream reach was also mapped according to the New Jersey Department of Environmental Protection’s (NJDEP) Surface Water Quality Standards. The Surface Water Quality Standards classify New Jersey surface water bodies based on pre-determined criteria, establish pollutant loading limitations for NJ waterways, and label appropriate designated uses for different classifications of surface waters (NJDEP, 2020a). The NJDEP’s ArcGIS Surface Water Quality Classification of New Jersey online mapping tool was used to determine the surface water quality stream classifications at SCCC and Memory Park in Newton, NJ (NJDEP Bureau of GIS, 2020).

Daily precipitation rain gauge readings reported to the CoCoRaHS (Community Collaborative Rain, Hail, and Snow) Network provided the precipitation data utilized in this study (CoCoRaHS, 2022). Specifically, this research applied precipitation data from CoCoRaHS station number NJ-SS-1, located within Andover Township, NJ, which is a neighboring municipality to Newton (CoCoRaHS, 2022). CoCoRaHS precipitation values are recorded to the hundredth of an inch; trace precipitation amounts (as indicated by a "T" in the "Gauge Catch in" column of the CoCoRaHS precipitation table) were interpreted as 0.00 inches of precipitation for purposes of this study. All CoCoRaHS station number NJ-SS-1 data were converted from inches into centimeters on Excel for use in this analysis.

NOAA's (National Oceanic and Atmospheric Administration) National Centers for Environmental Information online database provided the air temperature data that were used in this independent research project (2022). Daily minimum and maximum air temperatures (in Fahrenheit degrees) were downloaded as a CSV file from NOAA's online database (National Centers for Environmental Information, 2022). The minimum and maximum air temperatures used in this study were measured at station number USW00054779 at the Aeroflex-Andover Airport in Andover Township, New Jersey. The Aeroflex-Andover Airport is located approximately 6 kilometers away from SCCC and Memory Park. Daily air temperatures helped assess whether or not the observed precipitation on a given day was rain or snow/sleet/freezing rain. Precipitation data points were only classified as "rain" if both the maximum and minimum daily air temperatures were above 35°F (1.67°C). Although 32°F (0°C) is the freezing threshold for water, this study assumes that road departments begin to apply road salt to Newton's asphalt and concrete surfaces when temperatures are a few degrees above the freezing benchmark to ensure that ice does not form on the roadways and sidewalks, posing a safety hazard to drivers and pedestrians. Therefore, any precipitation that fell while air temperatures were below 35°F (1.67°C) was color-coded as "wintery mix" on the graphs developed for this research project (FIGURE 17).

In addition to analysis of past conductivity (uS/cm) and depth (mm) readings amassed on the Monitor My Watershed database, in winter 2022, I also completed conductivity (uS/cm) and chloride (mg/L) sampling at baseflow conditions, during salt spikes, and during dilution periods. This sampling helps measure the range of conductivity and chloride values observed at each station. When the historical ranges of each sensor station have been determined, rating curve equations can be developed to convert conductivity readings into chloride loading, which also provides context to future winter road salt analyses. Rating curves display data points in graphical form on an X-Y axis and are used to establish correlations among different parameters of data (Bressler et al., 2017). Once the relationship is established, researchers can use the information about one variable to predict the data for the other variable; for instance, chloride levels can be predicted from conductivity readings and total suspended solids can be predicted from turbidity measurements (Bressler et al., 2017).

Additional conductivity (uS/cm) and chloride (mg/L) measurements were taken throughout the winter 2021-2022 season to provide supplemental information to enhance the dataset collected by the continuous monitoring sensors. Conductivity (uS/cm) sampling was measured with a Hanna Dist 3 low-range (up to 2,000 uS/cm) or Hanna Dist 4 high-range (up to 20,000 uS/cm) handheld conductivity meter. The handheld conductivity meters were calibrated prior to the initial data collection and recalibrated each month in accordance with the manufacturer's recommendations; the Hanna Dist 3 meter was calibrated with Hanna Instruments' 1,413 uS/cm conductivity standard solution while the Hanna Dist 4 meter was calibrated with Hanna Instruments' 12,880 uS/cm conductivity standard solution. Chloride was measured with Hach QuanTab® Low Range (30-600 mg/L) and High Range (300-6000 mg/L) Chloride Test Strips. Handheld conductivity meter measurements and chloride test strip readings were collected at both the SCCC and Memory Park sensors at different points in the historical conductivity ranges for each site. The goal behind these point-in-time measurements was to collect data across a wide range of conductivity values (dilution events to winter conductivity spikes) to help create the most accurate rating curve for each site. Sampling with a handheld conductivity meter also helped to provide a level of quality assurance (QA) to confirm that the continuous monitoring station was properly functioning and recording accurate conductivity readings in comparison to the conductivity measurements recorded by the calibrated handheld meter. Live Monitor My Watershed readings directly from the website helped determine at what point in time to collect handheld conductivity meter and chloride testing strip data at each site. Efforts were made to ensure that sampling would occur across the full conductivity range.



Bedrock Geology: Ramseyburg Member

GEOLOGY_	18.00
GEOLOGY_ID	0.00
GEONUM	8,230
GEOABB	Omr
GEONAME	Ramseyburg Member
LITHOLOGY	graywacke sandstone and siltstone, shale and slate
SYMBOL	75

Zoom to

Bedrock Geology: Bushkill Member

GEOLOGY_	427.00
GEOLOGY_ID	0.00
GEONUM	8,250
GEOABB	Omb
GEONAME	Bushkill Member
LITHOLOGY	shale, slate, less abundant siltstone, and minor dolomite lens
SYMBOL	71

Zoom to

FIGURE 6: Bedrock Geology at the Sussex County Community College Campus

Data Source: New Jersey Department of Environmental Protection's NJ GeoWeb online mapping tool (NJDEP, 2020b).

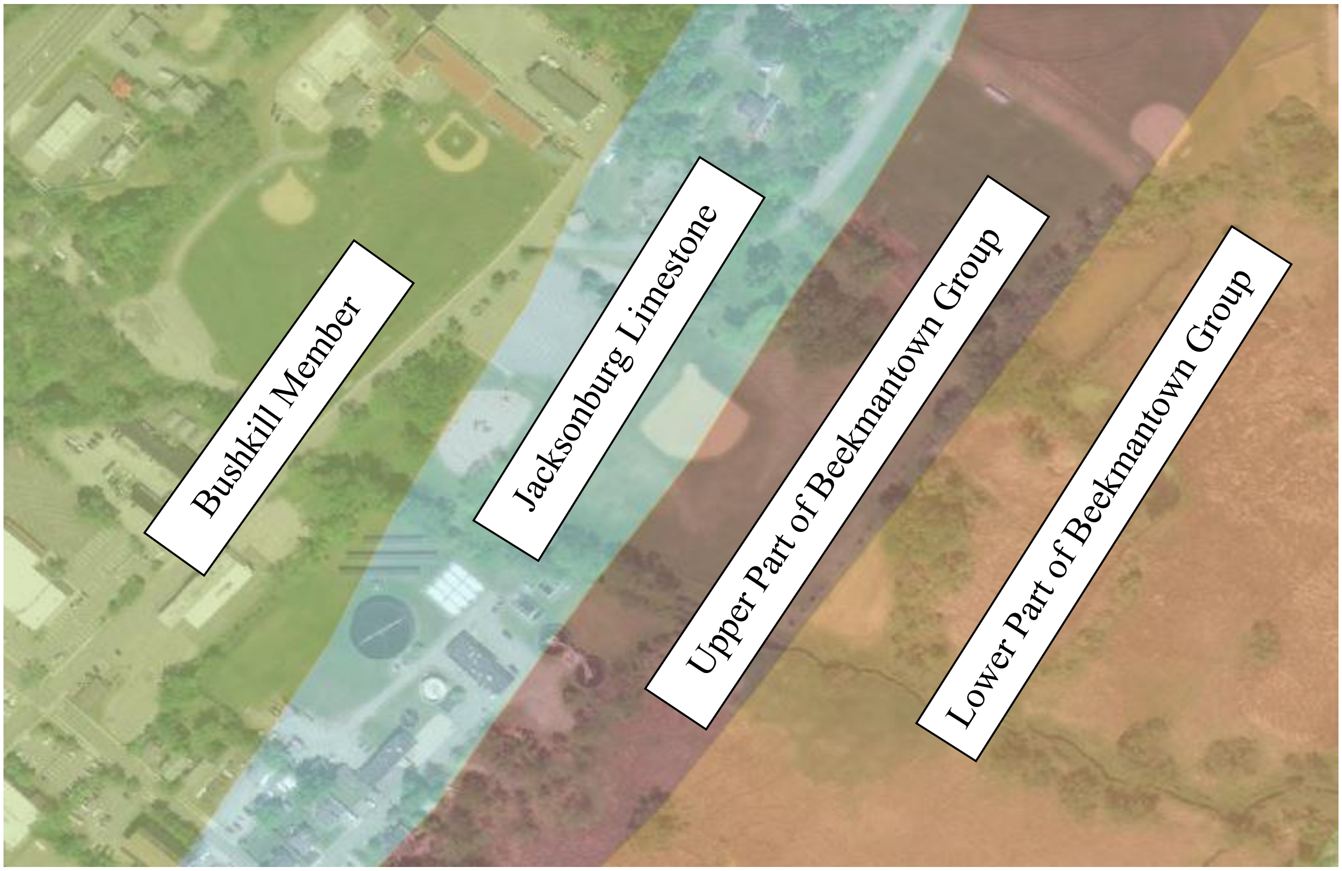


FIGURE 7: Bedrock Geology at Memory Park in Newton, NJ upstream of the sensor station

Data Source: New Jersey Department of Environmental Protection’s NJ GeoWeb online mapping tool (NJDEP, 2020b).

III. RESULTS

The Paulins Kill River at SCCC and Memory Park are both classified as FW2-NT stream reaches (NJDEP Bureau of GIS, 2020). FW2 is the generic freshwater classification for water bodies that do not meet the more rigorous standards of FW1-classified streams (high quality waters without anthropogenic wastewater discharges) (NJDEP, 2020a). Non-trout waters are streams that are not defined as trout production or trout maintenance according to the criteria outlined in N.J.A.C. 7:9B-1.15(c) (NJDEP, 2020a). Non-trout waterways are "not suitable for trout because of their physical, chemical or biological characteristics, but are suitable for a wide variety of other fish species" (NJDEP, 2020a).

The Paulins Kill Watershed encompasses a 458.2 square kilometer area within Sussex and Warren Counties in New Jersey (WRWMG, 2012). The Upper Paulins Kill Watershed, a 131.8 square kilometer region within Andover, Branchville Borough, Frankford, Fredon, Hampton, Lafayette, Sparta, Newton, and Sandyston Townships in Sussex County, NJ, was the emphasis of this independent research study (WRWMG, 2012). According to Model My Watershed, 17.26% of the land use in the SCCC drainage area is considered low, medium, and high intensity development based on National Land Cover Database classifications (Stroud Water Research Center, 2017). The Memory Park drainage area is classified as 25.39% developed (low, medium, and high intensity development) according to the National Land Cover Database (Stroud Water Research Center, 2017).

The Memory Park sensor is located approximately 1 kilometer downstream of the SCCC sensor in a more highly urbanized sub-watershed than the SCCC drainage area. The Memory Park sensor station is 0.4 kilometer downstream of Newton's wastewater treatment plant, and as stated by the USGS StreamStats report, 6.7 square kilometers drain to that point on the stream (USGS, 2022a). The SCCC drainage area is contained within the Memory Park drainage area so non-point source pollutants that enter the storm drains at the community college eventually flow through the Upper Paulins Kill River to the Memory Park sensor station.

According to the NJ GeoWeb data, the SCCC campus contains the Ramseyburg Member and Bushkill Member stratigraphic units which are both comprised of siltstone, shale, and slate (FIGURE 6) (NJDEP, 2020b). The watershed upstream of the Memory Park sensor station contains 4 different stratigraphic units including 1) Bushkill Member, 2) Jacksonburg Limestone, 3) Upper Part of Beekmantown Group, and 4) Lower Part of Beekmantown Group (FIGURE 7) (NJDEP, 2020b). The Jacksonburg Limestone stratigraphic unit primarily contains limestone, and the Upper and Lower Part of the Beekmantown Group is comprised of dolomite and to a lesser extent limestone.

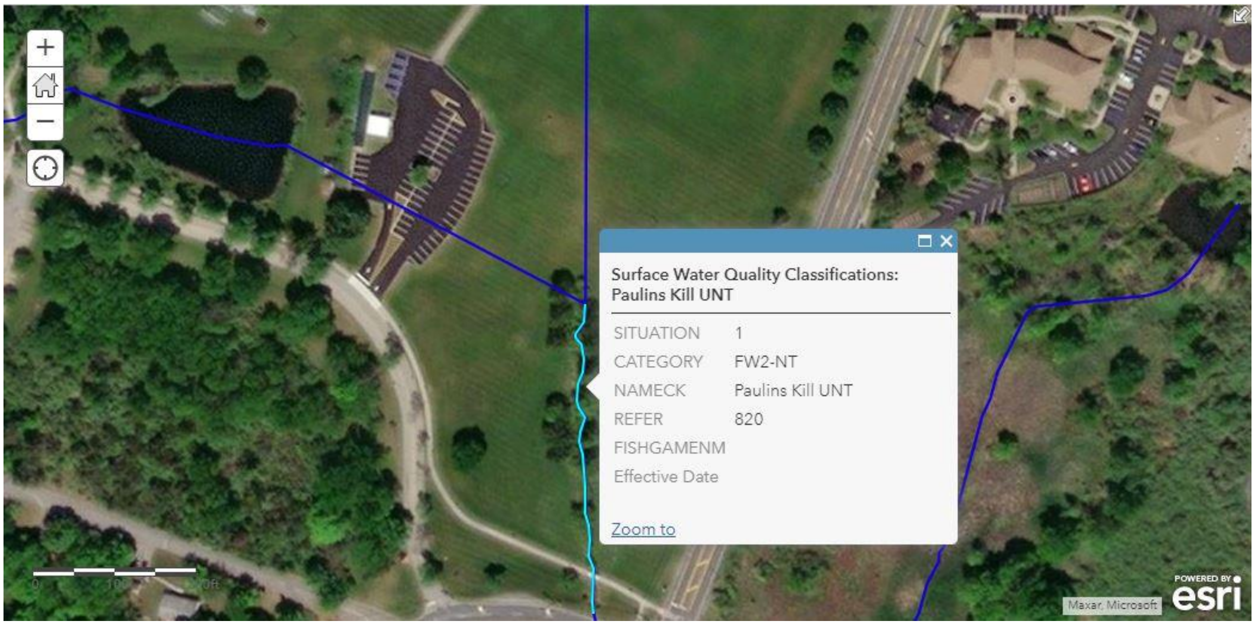
The maximum conductivity value recorded at the SCCC monitoring station was 5,327 uS/cm on February 13, 2019 (Utah Water Research Laboratory, 2018b). At Memory Park, the maximum conductivity across the 2017-2022 dataset was 24,044 uS/cm which occurred on March 6, 2020 (Utah Water Research Laboratory, 2017). Seasonal average conductivity at the SCCC sensor station across all seasons was 863 uS/cm in spring, 1149* uS/cm in summer (*based on a limited dataset: no data collected by SCCC sensor in summer 2018, and there were 2 months of missing data in summer 2021 when the CTD sensor needed to be repaired), 884 uS/cm in fall, and 884 uS/cm in winter (Utah Water Research Laboratory, 2018b). At Memory Park, seasonal average conductivity was 952 uS/cm in the spring, 879 uS/cm in the summer, 798 uS/cm in the fall, and 1,278 uS/cm in the winter (Utah Water Research Laboratory, 2017).

Comparison of Sussex County Community College (SCCC) and Memory Park Drainage Areas

	SCCC	**Memory Park**
Size of Drainage Area	1.5 square kilometers	6.7 square kilometers
Sensor Station Location	41.06602°, -74.75547°	41.05928°, -74.74316°
Land Use	17.26% developed land	25.39% developed land
Largest conductivity spike observed from 2017-2022	5,327 uS/cm	24,044 uS/cm

FIGURE 8: Table comparing the size, location (latitude/longitude), land use, and maximum conductivity spike observed within the SCCC and Memory Park drainage areas. The Memory Park drainage area is more highly urbanized and contains a larger maximum conductivity reading than the SCCC drainage area, signifying that road salt application to asphalt surfaces within the Memory Park drainage area is contributing to the elevated conductivity observed.

Data Sources: USGS StreamStats and Monitor My Watershed



Surface Water Quality Classifications: Paulins Kill UNT

SITUATION	1
CATEGORY	FW2-NT
NAMECK	Paulins Kill UNT
REFER	820
FISHGAMENM	
Effective Date	

FIGURE 9: The Paulins Kill at Sussex County Community College is classified as FW2-NT (Freshwater 2, Non-Trout) (NJDEP Bureau of GIS, 2020).

Surface Water Quality Classifications: Paulins Kill

SITUATION	1
CATEGORY	FW2-NT
NAMECK	Paulins Kill
REFER	820
FISHGAMENM	
Effective Date	

FIGURE 10: The Paulins Kill at Memory Park is classified as FW2-NT (Freshwater 2, Non-Trout) (NJDEP Bureau of GIS, 2020).

a. SPRING, SUMMER, AND FALL DATA PATTERNS

Data patterns at SCCC and Memory Park during the non-winter portions of the year indicate that as the depth (mm) of the river increases due to precipitation events and associated stormwater runoff, conductivity (uS/cm) readings at the sensor stations typically decrease as the input of freshwater dilutes the concentration of ions within the stream. This inverse relationship is reflected visually on X-Y secondary axis graphical displays of the data at the point in time when the depth and conductivity line graphs cross one another. For instance, during the 3.01-inch (7.65 cm) rainstorm that occurred in Newton on April 7, 2022, the rising Paulins Kill water depth resulted in the dilution of ions in the river and a corresponding decrease in conductivity at the Memory Park sensor station (FIGURE 11). Moreover, plotting summertime conductivity on the y-axis and depth on the x-axis produces a relatively flat graph with a slightly negative slope (FIGURE 12). During the summer, road salts are not being applied to Newton's streets so there is not as large of a conductivity range recorded at the sensor station as would be observed in the winter.

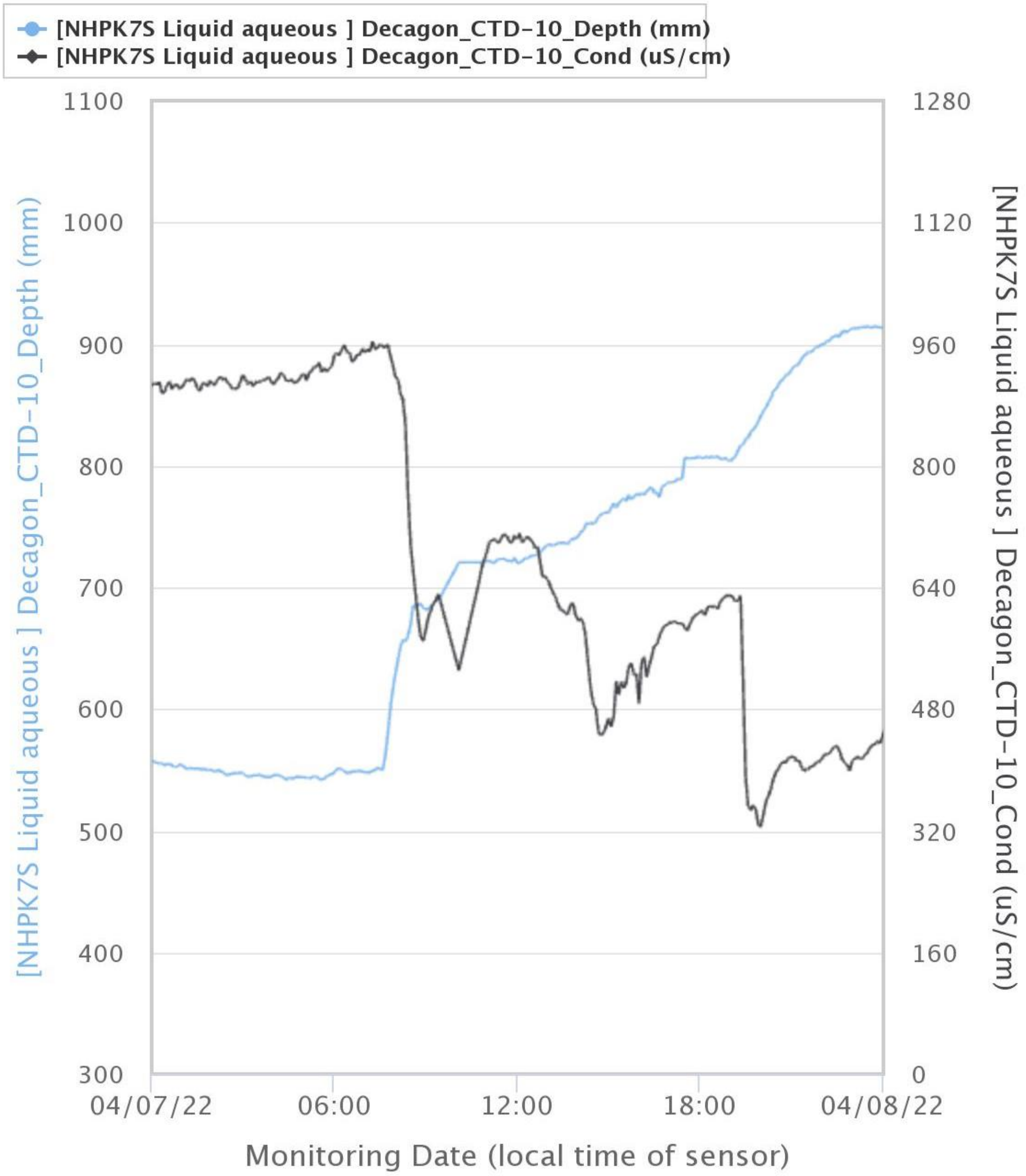


FIGURE 11: Inverse relationship between depth and conductivity at the Memory Park sensor station after a 3.01” (7.65 cm) rainstorm event in Newton, NJ on April 7, 2022

Graph source: (Utah Water Research Laboratory, 2017)

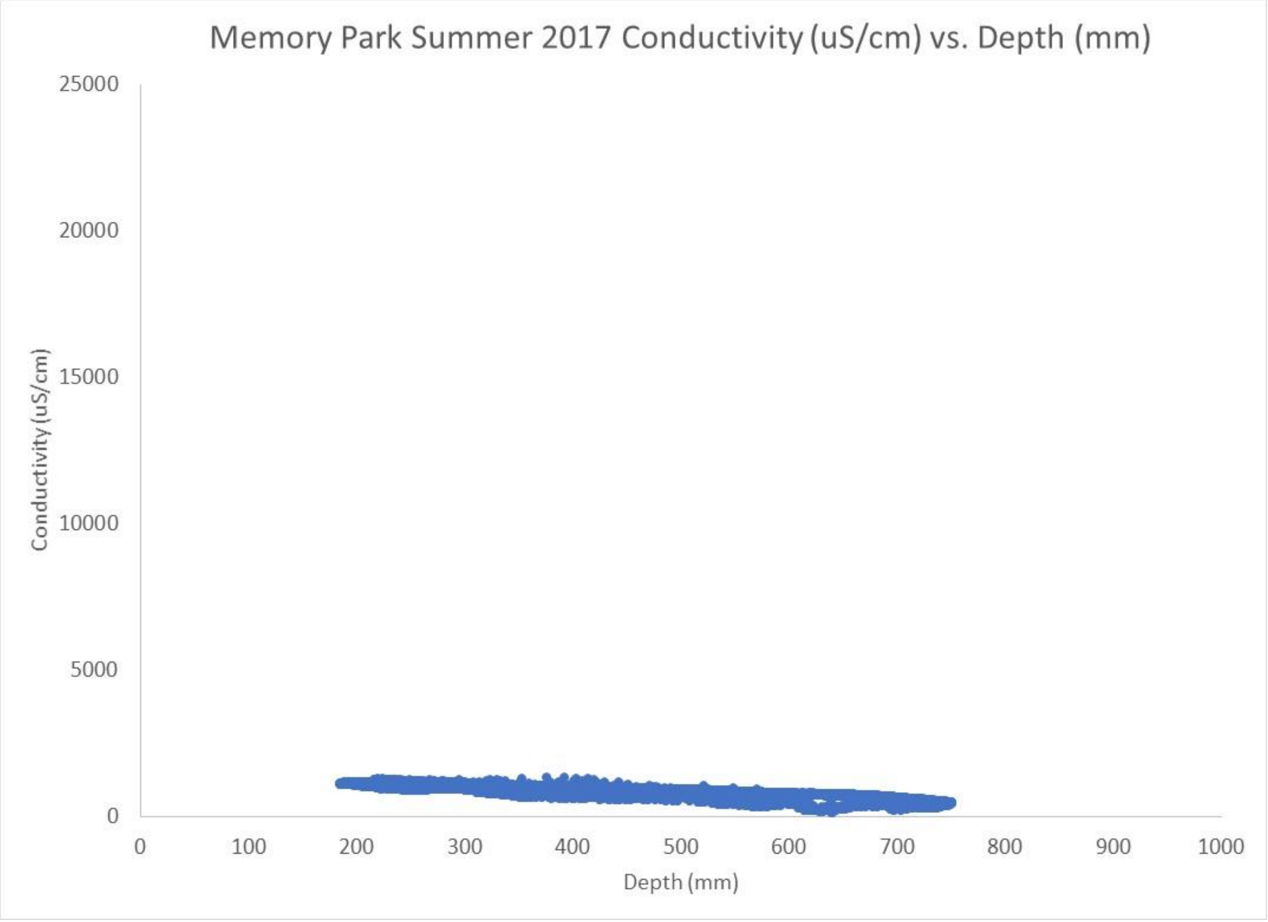


FIGURE 12: Summer 2017 comparison of depth in millimeters and conductivity in microsiemens per centimeter at the Memory Park sensor station. This graph demonstrates that conductivity spikes are not occurring in the summer because road salt is not being applied to Newton's streets.

b. WINTER DATA PATTERNS

SCCC and Memory Park winter data exhibit numerous depth increases associated with conductivity spikes. This may indicate that there is a flushing of the road salt that has been applied to asphalt roadways during below freezing precipitation events. Surging conductivity levels were typically followed by a rapid dilution of river water by lower conductivity rain and snow melt. Moreover, although the Memory Park drainage area encompasses the SCCC drainage area, during below freezing precipitation events, there is a lag time between the time when the conductivity levels begin to spike at SCCC and the time when the Memory Park sensor station records a conductivity spike. Additionally, the magnitude and duration of the conductivity spikes are larger at the Memory Park sensor station compared to the SCCC sensor station as shown in Figure 13 and Figure 14.

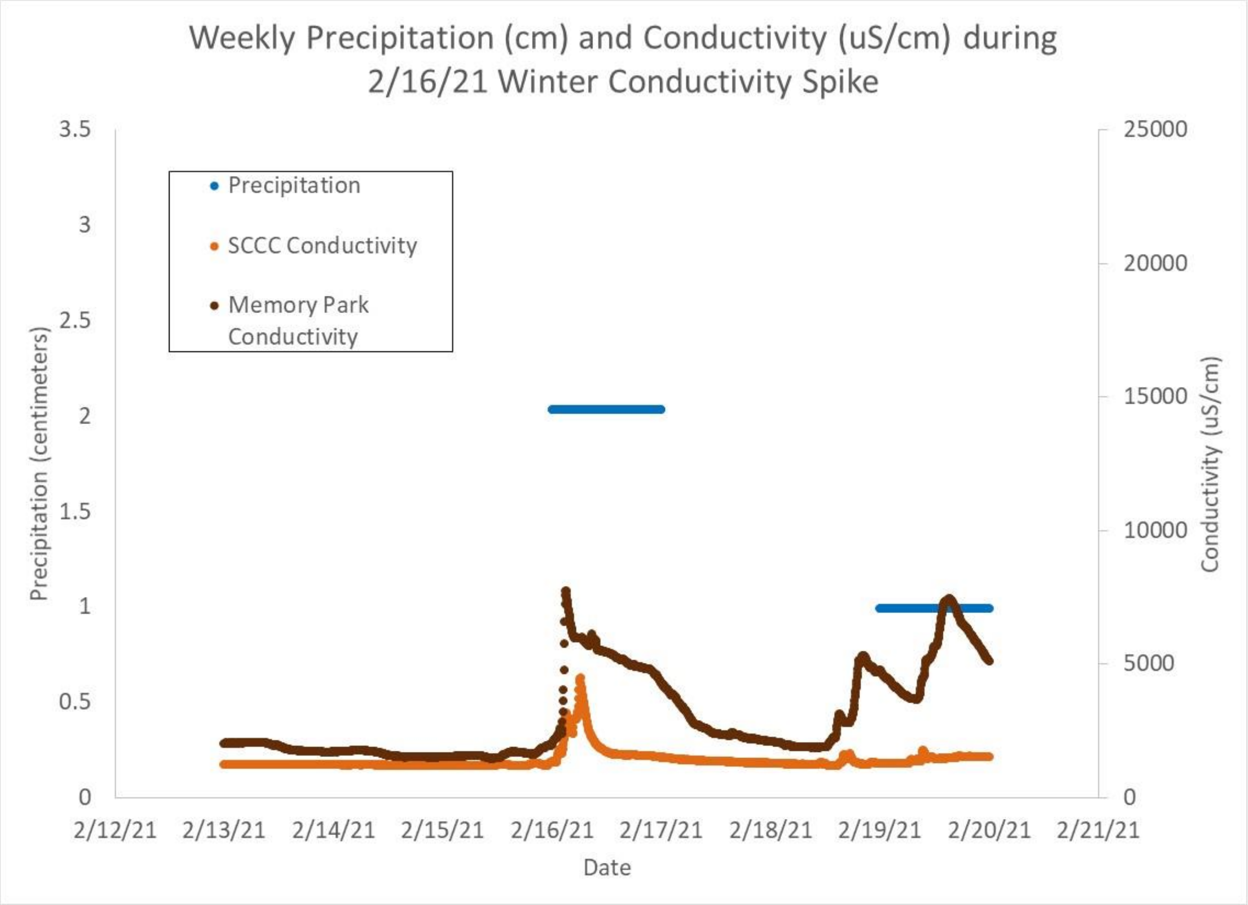


FIGURE 13: This graph depicts the rising conductivity at both the SCCC and Memory Park sensor stations in response to winter precipitation events when road salt would be applied. Notice that the magnitude and duration of the conductivity spikes are larger at the Memory Park sensor station compared to the SCCC sensor station. This is due to the higher percentage of imperious surfaces in the larger Memory Park drainage area and the resultant road salt being applied to the township's streets.

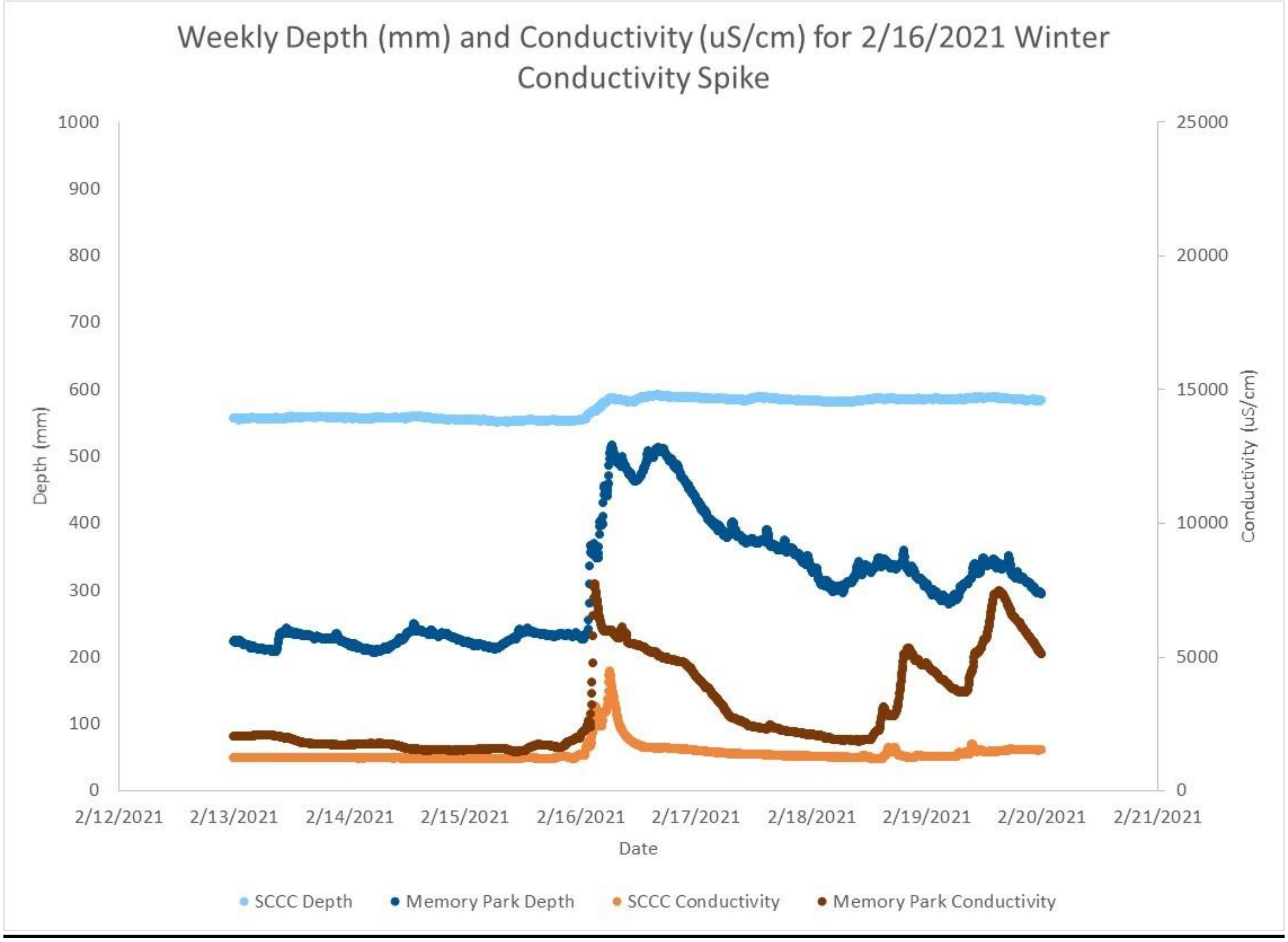


FIGURE 14: This graph depicts depth and conductivity changes over the course of one week in February 2021 at both the SCCC and Memory Park sensor stations. River depth and conductivity levels correspondingly rise because as snow, sleet, and freezing rain fall within the watershed, municipal road departments are simultaneously applying road salt to the streets which increases conductivity levels. Notice that the Paulins Kill depth only rose slightly on the SCCC campus because the sensor station is installed within a 1-meter-deep pool in the stream.

i. WINTER 2017-2018

In winter 2017-2018, the maximum conductivity reading at SCCC was 4,546 uS/cm on February 7, 2018 (Utah Water Research Laboratory, 2018b). During the same winter storm, the maximum conductivity spike recorded at Memory Park was 11,899 uS/cm on February 7, 2018 (Utah Water Research Laboratory, 2017). Conductivity and depth measurements at the Memory Park sensor station both concurrently rose during this winter precipitation event. This is contrary to the inverse relationship typically observed between conductivity and depth when air temperatures are above freezing in the spring, summer, and fall; in those instances, conductivity decreases as depth increases (FIGURE 11). The seasonal conductivity average at SCCC was 1,139 uS/cm and 1,457 uS/cm at Memory Park in December 2017-March 2018 (Utah Water Research Laboratory 2018; 2017). Unlike summer 2017 (FIGURE 12), winter 2017-2018 conductivity (FIGURE 16) shows a wider range because during winter precipitation events, road salts are applied to Newton’s streets which generates a corresponding spike in the conductivity measurements at the sensor station.

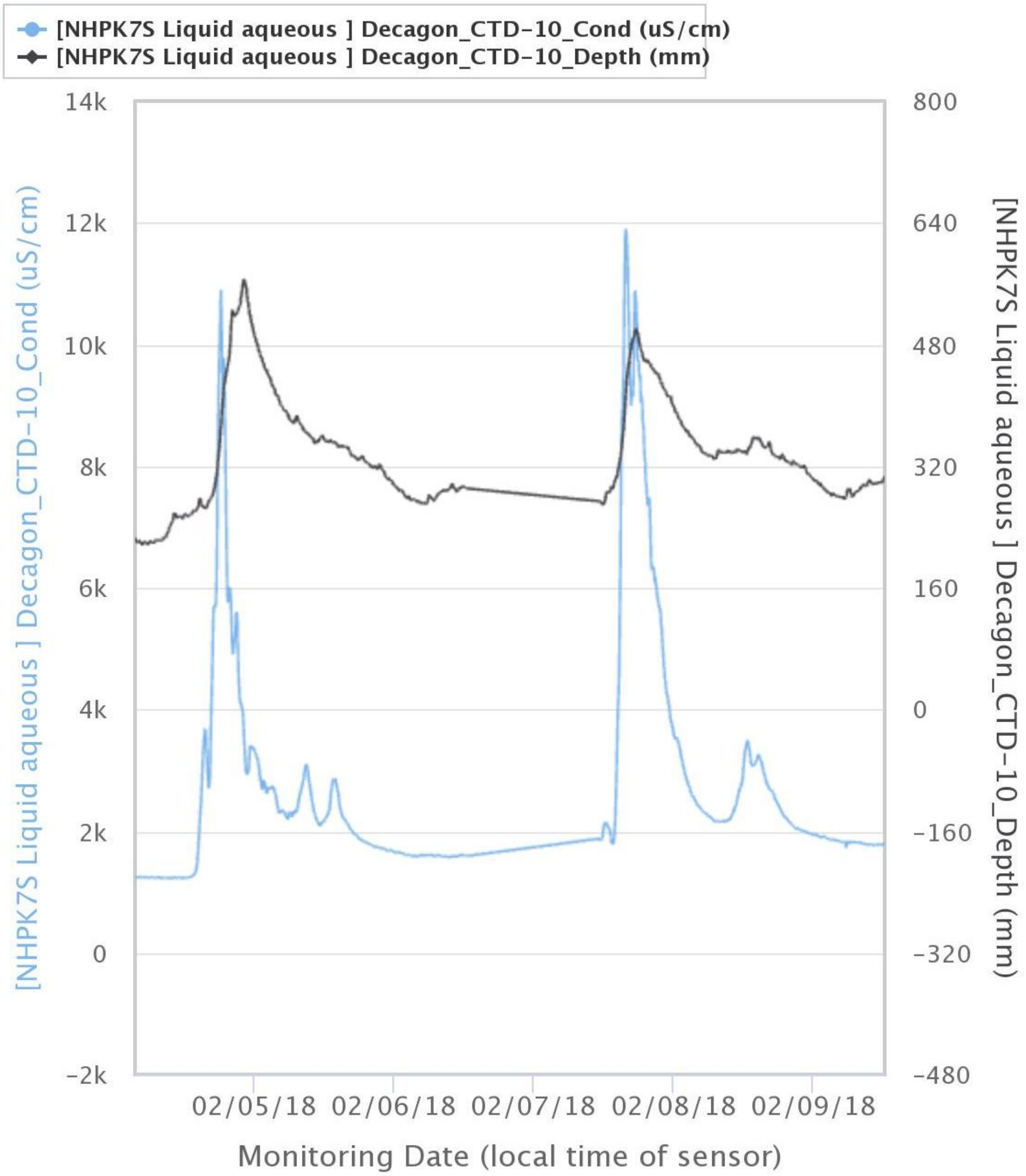


FIGURE 15: Graph comparing Paulins Kill conductivity and depth at the Memory Park sensor station during a February 2018 wintery mix precipitation event. This graph indicates that when precipitation (snow, sleet, freezing rain) falls on days with below freezing air temperatures, the depth and the conductivity levels within the Paulins Kill both begin to rise. The increase in conductivity is likely the result of road salts being applied to Newton's streets to prevent ice formation on the roadways. Road salt runoff entering the storm drains in Newton would increase the number of dissolved ions in the river and would increase the conductivity levels recorded at the Memory Park sensor station.

Graph Source: (Utah Water Research Laboratory, 2017)

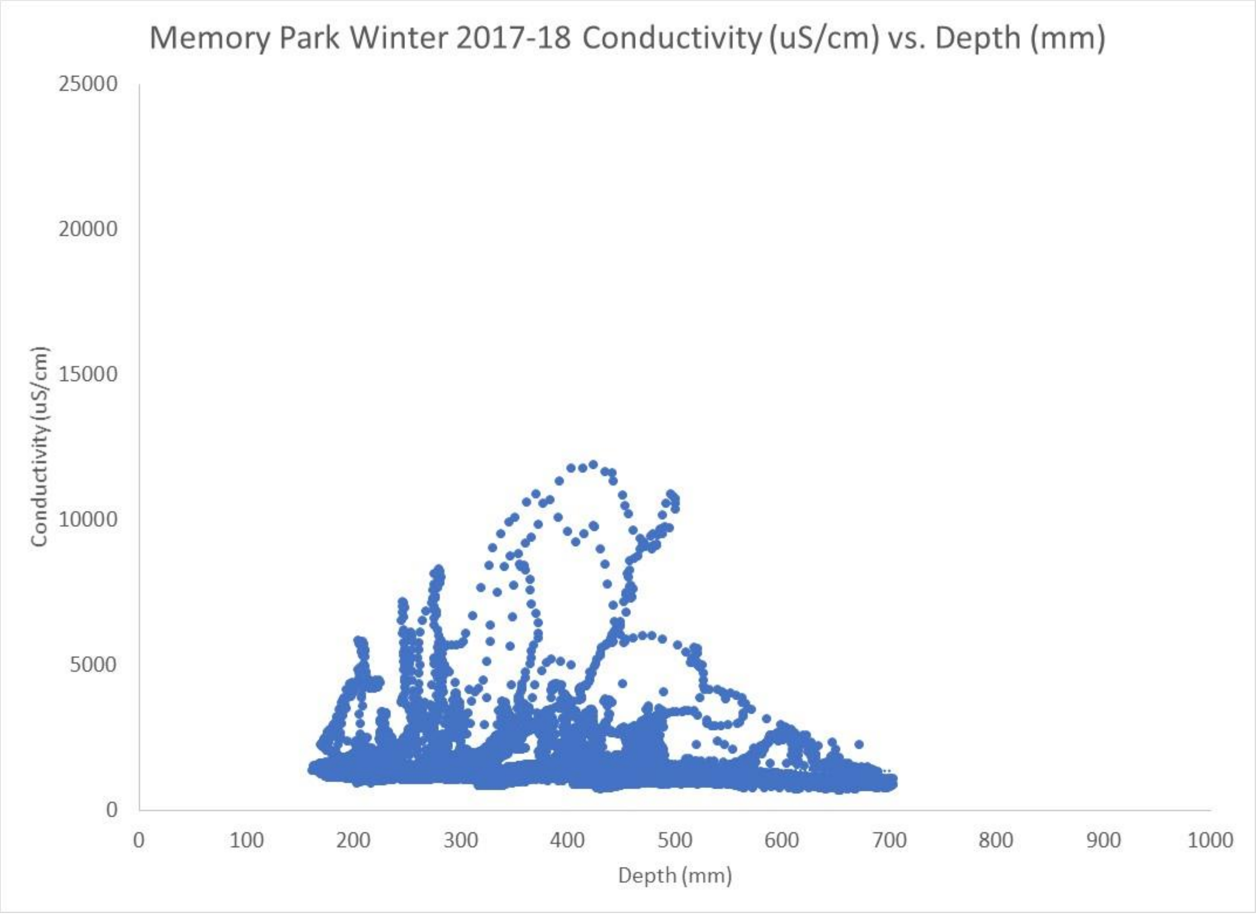


FIGURE 16: Graph comparing winter 2017-2018 depth versus conductivity levels at Memory Park. The loops visible on the graph demonstrate hysteresis patterns in the data where depth and conductivity peaks are asynchronous. Conductivity levels are significantly higher during winter 2017-2018 than during summer 2017 (FIGURE 12) because of the application of road salts that raise the conductivity levels of the Paulins Kill due to the addition of chloride-infused stormwater runoff flowing into the river.

<u>ii. WINTER 2018-2019</u>

In winter 2018-2019, the maximum conductivity spike recorded at the SCCC sensor station was 5,327 uS/cm on February 13, 2019 (Utah Water Research Laboratory, 2018b). At Memory Park, the maximum conductivity recorded that winter was 11,449 uS/cm, which was logged on January 20, 2019 (Utah Water Research Laboratory, 2017). The seasonal conductivity average was 723 uS/cm at SCCC and 1,058 uS/cm at Memory Park in winter 2018-2019 (Utah Water Research Laboratory 2018; 2017).

In December 2018, air temperatures in Newton were warm enough that precipitation fell as rain instead of as snow or ice. In these above freezing conditions, there was not a corresponding increase in conductivity measurements at the Memory Park sensor station. As shown in Figure 17, when air temperatures dropped to below freezing later that winter, the gray, wintery mix precipitation data points were correlated with conductivity increases at the sensor station, indicating that conductivity levels were likely rising due to road salt being applied to Newton's roadways.

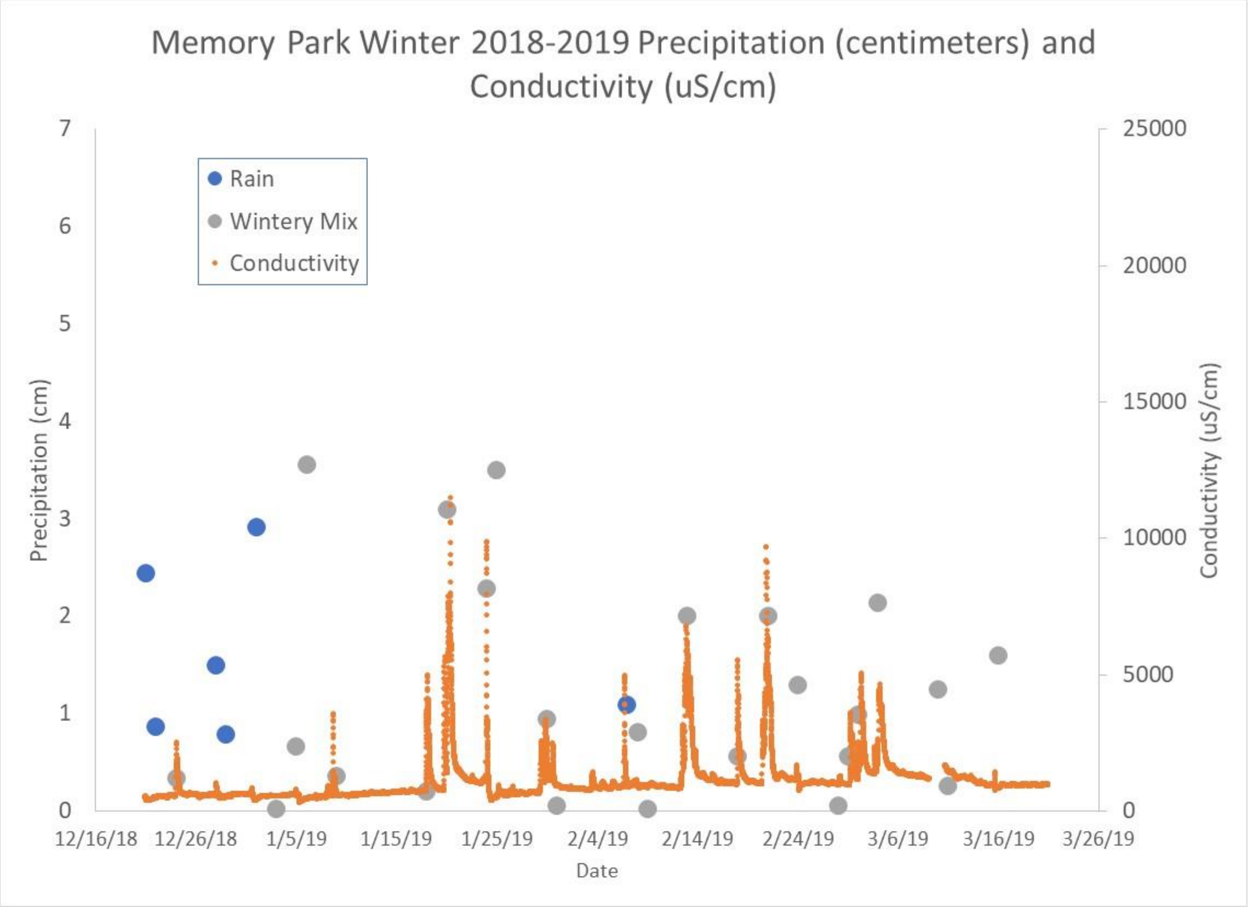


FIGURE 17: Winter 2018-2019 rain versus wintery mix precipitation data points in comparison to conductivity measurements recorded at the Memory Park sensor station. This graph shows that below freezing precipitation events (identified by the gray, circular dots on the graph) are correlated with conductivity increases recorded at the Memory Park sensor station. In December 2018, when precipitation fell in Newton as rain rather than snow (as depicted by the blue, circular dots on the graph), conductivity levels did not increase, likely because road salt did not need to be applied to asphalt streets and sidewalks during above freezing conditions. The one exception to this trend occurred on February 6, 2019 when there was an observed conductivity spike at the Memory Park sensor station despite the above freezing air temperatures in Newton. This may have occurred if weather forecasters incorrectly predicted that snow would fall on 2/6/2019, but air temperatures were warm enough that the wintery mix precipitation did not develop. Even so, the Newton Road Department may have begun pre-treating the roadways in preparation for the forecasted storm, which could have resulted in a conductivity spike at the sensor.

iii. WINTER 2019-2020

The maximum conductivity spike at the SCCC sensor station during winter 2019-2020 was 1,508 uS/cm on February 6, 2020 (Utah Water Research Laboratory, 2018b). During the same winter, the maximum conductivity spike recorded at Memory Park was 24,044 uS/cm on March 6, 2020 (Utah Water Research Laboratory, 2017). The seasonal conductivity average at SCCC was 839 uS/cm and 966 uS/cm at Memory Park in winter 2019-2020 (Utah Water Research Laboratory 2018; 2017).

iv. WINTER 2020-2021

Between December 21, 2020 and March 20, 2021, the maximum conductivity value recorded at the SCCC sensor station was 4,470 on February 16, 2021 (Utah Water Research Laboratory, 2018b). The maximum conductivity value recorded at Memory Park that season was 7,733 uS/cm which also occurred on February 16, 2021 (Utah Water Research Laboratory, 2017). The seasonal average conductivity at SCCC was 900 uS/cm and 1,581 uS/cm at Memory Park in winter 2020-2021 (Utah Water Research Laboratory 2018; 2017).

As depicted in Figure 18, on December 25, 2020, 2.1 inches (5.3 centimeters) of rain fell on a warm, above freezing day, which resulted in depth readings at the sensor steadily increasing and conductivity readings steadily decreasing as ion concentrations were diluted by the influx of rainwater into the Paulins Kill. Conductivity readings did not increase during this winter precipitation event because road salt would not have been applied to the roadways when precipitation fell during warm, above freezing temperatures.

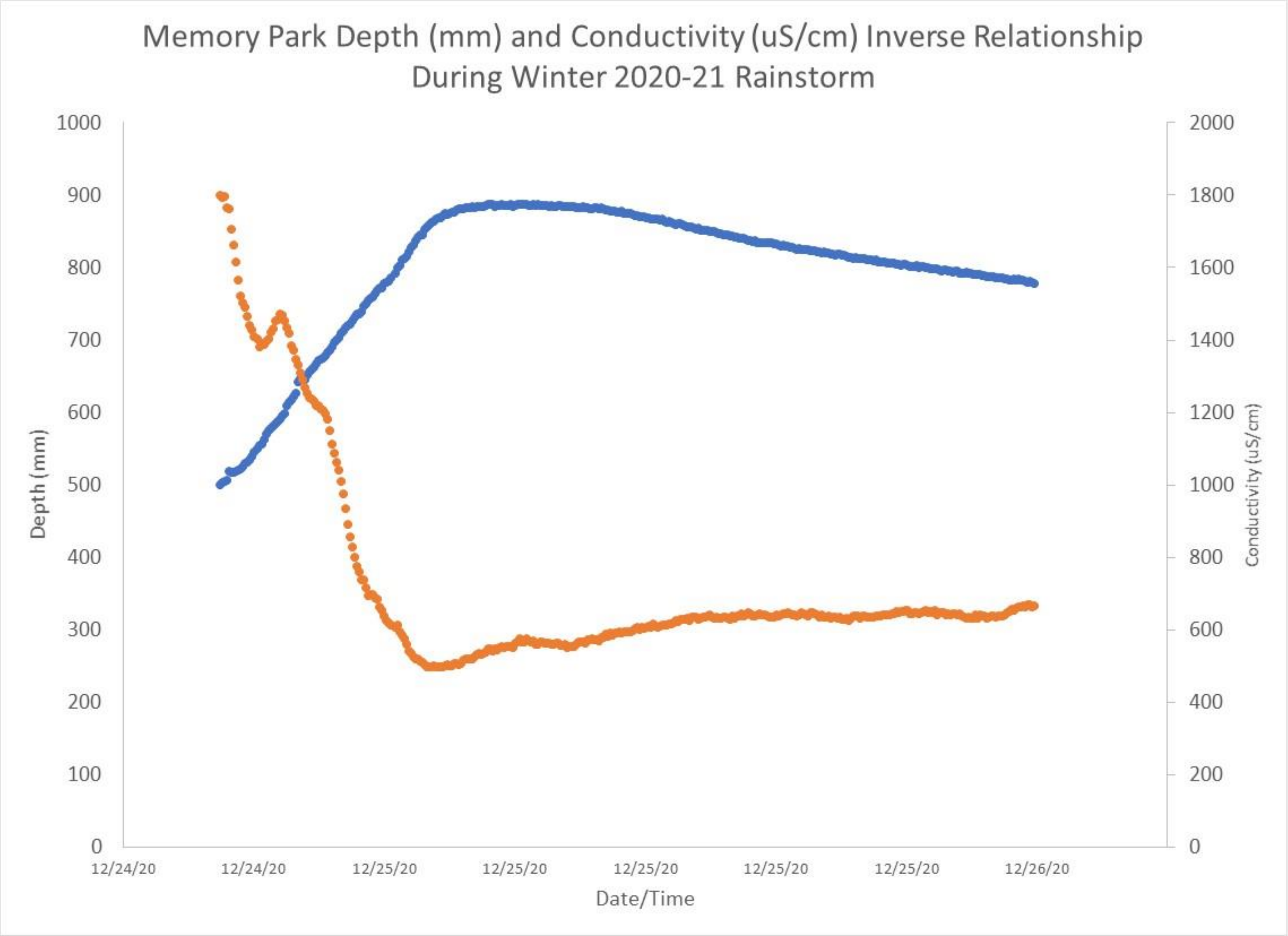


FIGURE 18:

Inverse relationship between conductivity and depth at Memory Park as precipitation fell in December 2020 as rain, rather than snow. Conductivity levels did not increase because road salt would not be applied to the road in above freezing conditions.

v. WINTER 2021-2022

During winter 2021-2022, the maximum conductivity reading recorded at the SCCC sensor station was 2,006 uS/cm on March 10, 2022 (Utah Water Research Laboratory, 2018b). The maximum conductivity spike at Memory Park was 11,821 uS/cm, which occurred on January 17, 2022 (Utah Water Research Laboratory, 2017). The seasonal conductivity average was 838 uS/cm at SCCC and 1,335 uS/cm at Memory Park in winter 2021-2022 (Utah Water Research Laboratory, 2018b; 2017). By comparison, in the 82.76% forested Mine Hill Brook Watershed in New York, the average conductivity during winter 2021-2022 was 27.9 uS/cm, and the maximum conductivity measurement recorded in December 2021-March 2022 was 44.2 uS/cm on February 1, 2022 (Stroud Water Research Center, 2017; Utah Water Research Laboratory, 2018a).

Hach QuanTab® chloride test strips were utilized to assess chloride levels within the Paulins Kill River at SCCC and Memory Park. At SCCC, chloride levels surpassed the U.S. EPA 230 mg/L chloride threshold on 3 of the 6 days when Hach chloride testing strips were used at the SCCC campus (Environmental Protection Agency, 2022) (FIGURE 19). At Memory Park, chloride levels surpassed 230 mg/L on 7 of the 7 occasions when sampling was conducted as part of this research project (Environmental Protection Agency, 2022) (FIGURE 20). Chloride samples were collected during winter snow and ice events as well as during non-precipitation days. These results are on par with a nationwide U.S. EPA study that determined 55% of all streams surveyed within the Northeastern U.S. surpassed the 230 mg/L chloride threshold during the winter (Clements and Kotalik, 2016).

In addition, during winter 2021-2022, I used Hanna Dist 3 and Dist 4 handheld conductivity meters at SCCC and Memory Park to conduct supplemental quality assurance sampling and measure conductivity levels at the ponds and Paulins Kill stream reaches within the SCCC campus that are upstream of the sensor station. On April 8, 2022, handheld conductivity meter readings measured rising conductivity levels as I moved downstream from SCCC's uppermost pond to the sensor station at the southern edge of community college campus. Sampling occurred approximately 18 hours after 7.65 cm of rain fell in Newton. The upper portion of the SCCC drainage area (near Little Hortons Pond and Hortons Pond) is forested and has little impact from impervious surfaces (FIGURE 2). Little Hortons Pond registered the lowest conductivity measurement on the community college campus at 57 uS/cm. However, immediately below Horton Pond, where the SCCC drainage area becomes more developed, conductivity levels steadily rose each time I moved downstream from one sampling point to another (FIGURE 22). The SCCC pond on the eastern branch of the Paulins Kill registered 534 uS/cm, the highest conductivity measurement collected during April 8, 2022 sampling (FIGURE 22). This sampling location is in a topographic low in the landscape and receives stormwater runoff from 2.5 acres of paved parking lots in the back portion of the community college campus. Although air temperatures were above freezing and no road salts were being applied to the SCCC campus on April 8, 2022, residual road salt from the paved parking lots and nearby surface soils may have flushed into the storm drains as a result of the intense rainfall and caused the elevated conductivity readings recorded at the SCCC campus. Additional spring sampling should be performed to confirm whether or not the pond along the eastern branch of the Paulins Kill continues to register the highest conductivity measurements on campus.

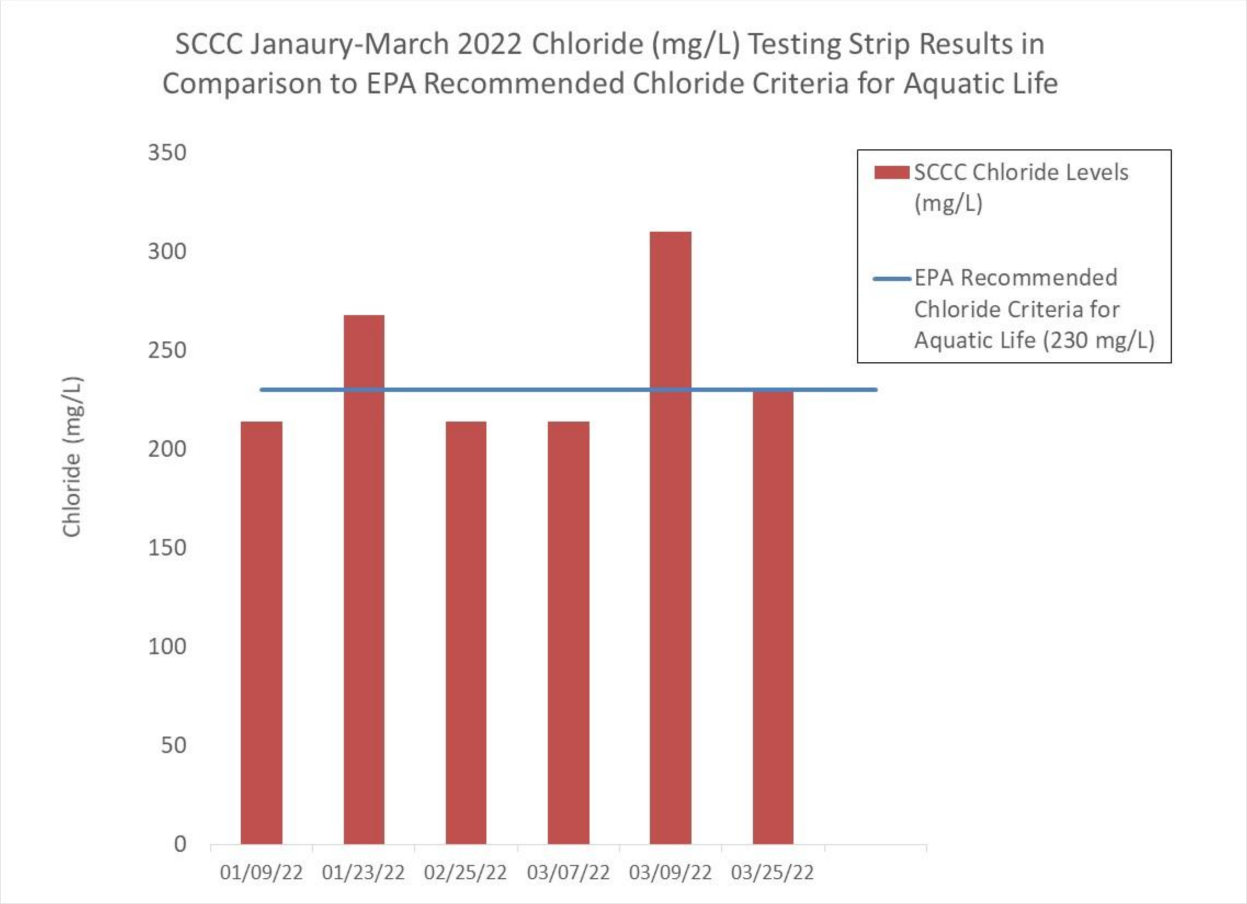


FIGURE 19: Hach chloride testing strip grab sampling results at SCCC in comparison to U.S. Environmental Protection Agency recommended chloride thresholds of 230 mg/L established to protect the health and safety of aquatic organisms. Chloride testing strips were used during wintery mix events as well as during precipitation-free days. Data show that winter chloride levels within the Paulins Kill frequently exceed the chloride levels deemed safe for aquatic life communities.

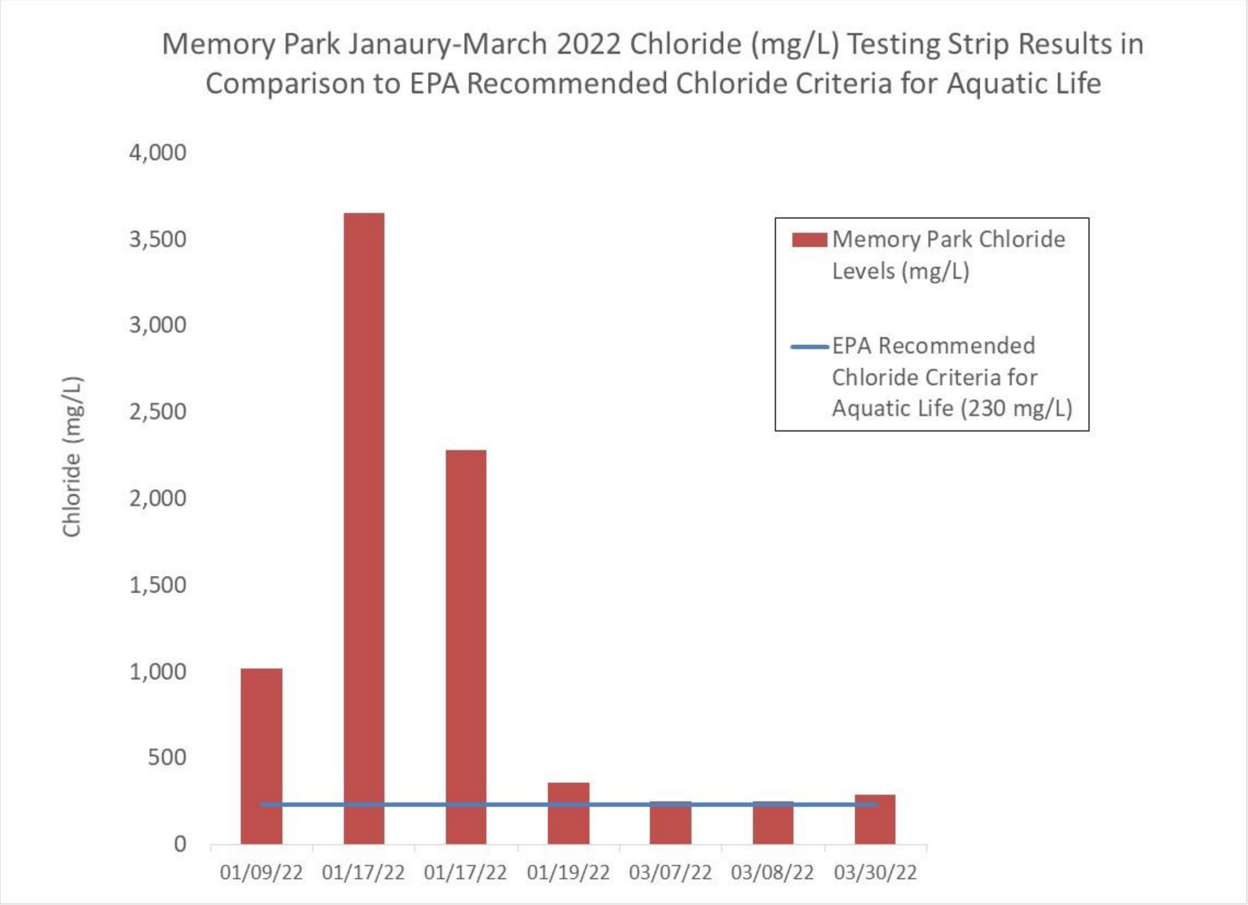


FIGURE 20: Hach chloride testing strip grab sampling results at Memory Park in comparison to U.S. Environmental Protection Agency recommended chloride thresholds of 230 mg/L established to protect the health and safety of aquatic organisms. Chloride testing strips were used during wintery mix events as well as during precipitation-free days. Data show that winter chloride levels within the Paulins Kill reach or exceed the chloride levels deemed safe for aquatic life communities. Note the different scale for the vertical axis compared to FIGURE 19.

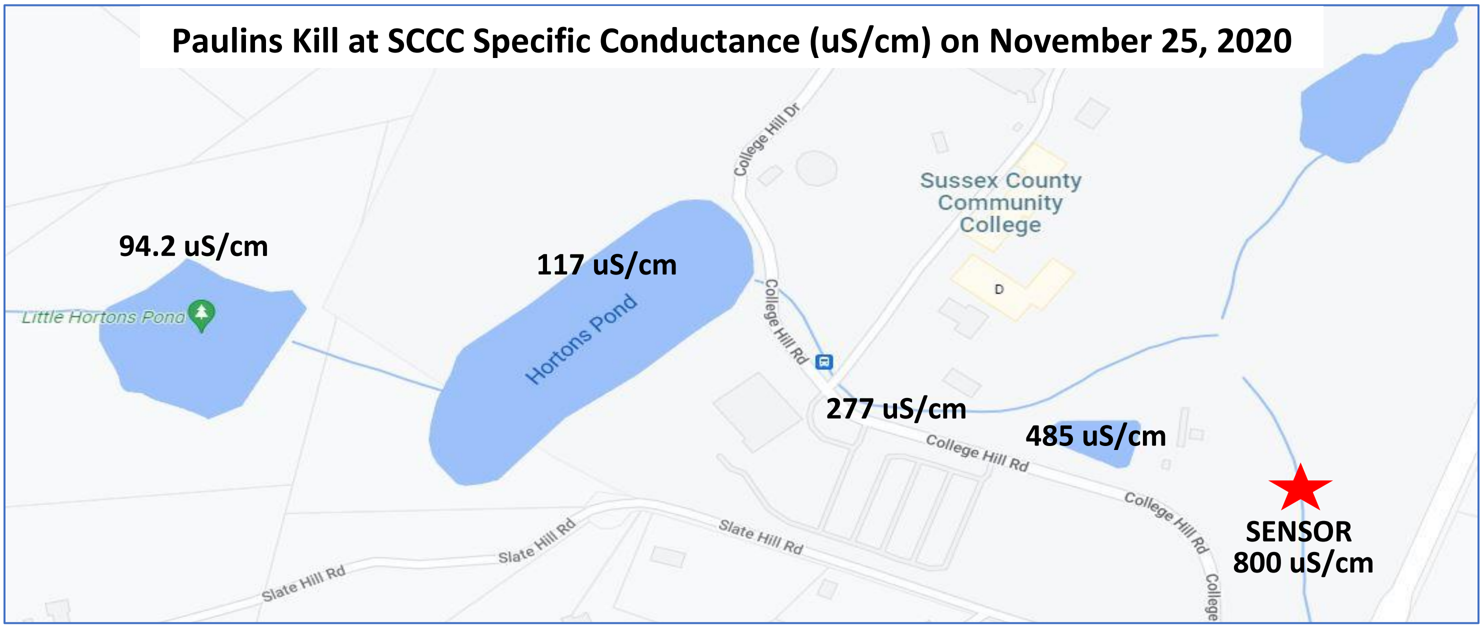
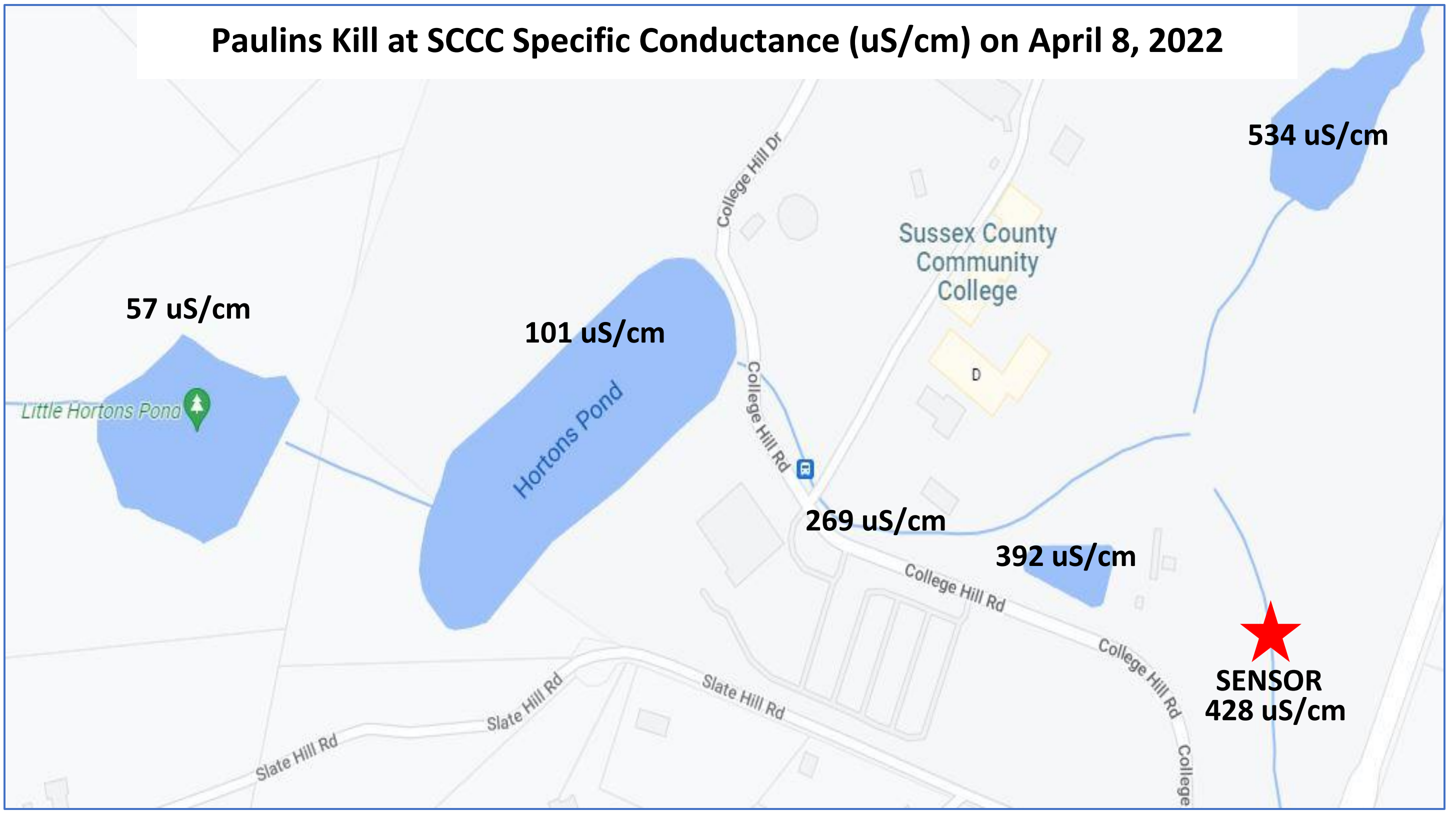


FIGURE 21: November 25, 2020 handheld conductivity meter readings at different points on the SCCC campus

This figure demonstrates how specific conductance levels increase as the Paulins Kill moves from Little Hortons Pond to the sensor station at the base of the campus. The upper portion of the watershed (near Little Hortons Pond and Hortons Pond) is forested and has little impact from imperious surfaces, but impervious surface cover increases immediately past Hortons Pond. These results indicate that winter road salt management at SCCC may be contributing to the elevated specific conductance measured on campus. Although these measurements were collected on an above-freezing, non-precipitation day when road salt was not being applied to the sidewalks, roads, and parking lots on campus, specific conductance levels were above recommended specific conductance levels. This may indicate that the soils are acting as a reservoir for chloride and contributing chloride to the Paulins Kill throughout the year (Cooper et al., 2014).



<u>FIGURE 22</u>: April 8, 2022 handheld conductivity meter readings at different points on the SCCC campus

This figure demonstrates how specific conductance levels increase as the Paulins Kill moves from Little Hortons Pond to the sensor station at the base of the campus. These measurements were collected 18 hours after a 3.01-inch (7.65 cm) rainstorm in Newton. Outside of winter storm events when road salt would be applied to the streets, conductivity levels decrease as river depth rises because the addition of rainwater dilutes the concentration of ions in the river water. Despite the rising depth of the river on campus as a result of this large rainstorm, specific conductance levels continued to increase throughout the campus as they also did on November 25, 2020 (FIGURE 21). This may indicate that the elevated specific conductance observed is resulting from residual road salt within the soil and groundwater, rather than impacts from limestone lithology. If limestone was the cause of the elevated specific conductance, one would assume that specific conductance levels upstream in the watershed (by Little Hortons Pond) would be nearly as elevated as the specific conductance levels measured by the sensor station at the base of the campus. The elevated conductivity in the pond at the northeast portion of campus may be the result of residual road salt being flushed off of the parking lots and other impervious surfaces in the back portion of the campus since the northeastern pond is situated within a topographic low in the landscape.

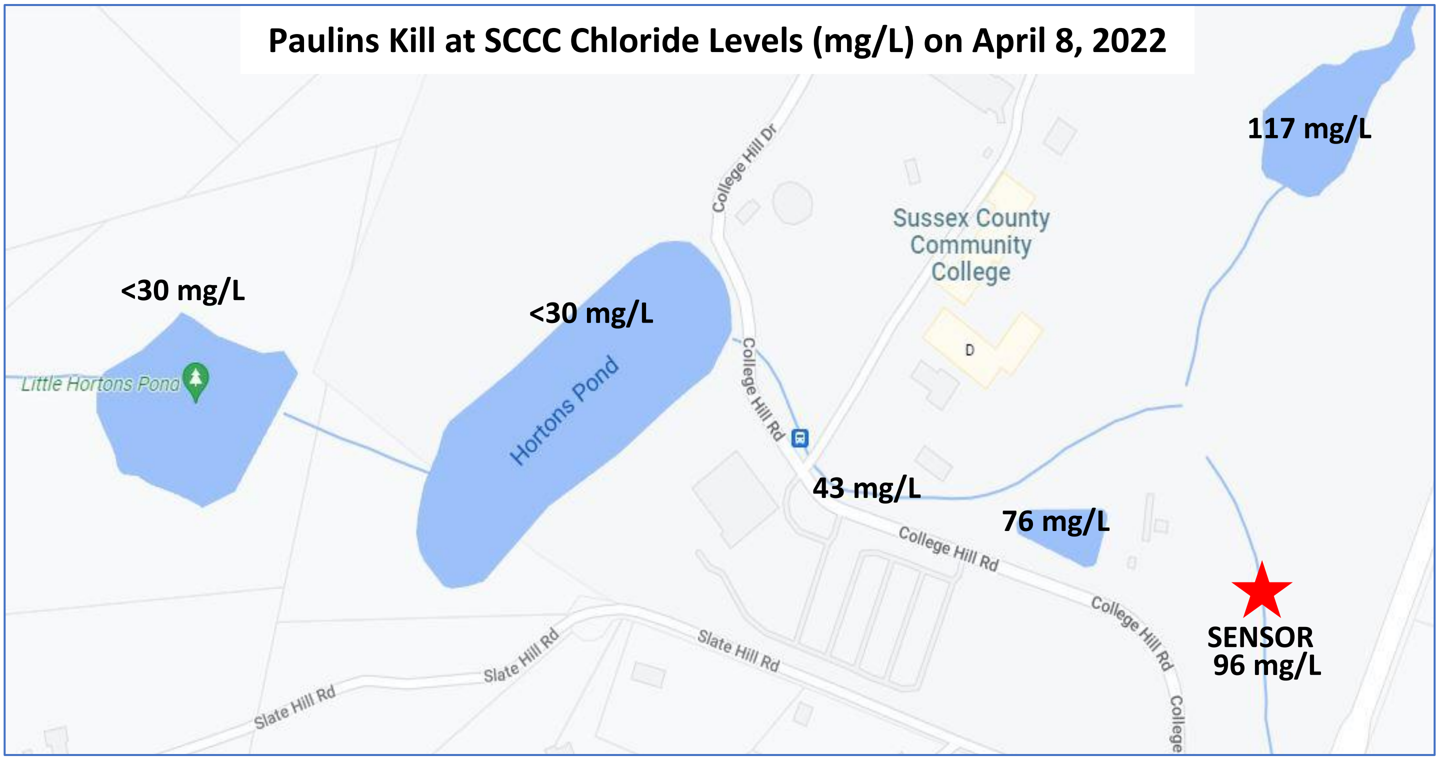


FIGURE 23: April 8, 2022 chloride testing strip (mg/L) measurements at different points on the SCCC campus

These chloride measurements were taken after a 3.01-inch (7.65 cm) rainstorm on April 7, 2022, when air temperatures were above freezing and road salt would not have been applied to the road. At Little Hortons Pond and Hortons Pond (both located within the forested portion of the watershed, upstream of the impervious surfaces on campus), chloride levels were below the lowest range measured by the Hach chloride testing strips (<30 mg/L). However, even during this non-road salt application period following a large rainstorm when chloride levels in the stream would be expected to be low, the lower portions of the campus recorded chloride measurements above the 50 mg/L threshold when aquatic insects can begin to be harmed by elevated chloride content in the river (Wallace and Biastoch, 2016). These chloride levels could be this high in April because of years of overapplication of road salt at SCCC that has now accumulated into the soil and will continue to leach chloride into the Upper Paulins Kill headwaters throughout the year. The chloride testing strip measurements at the northeastern pond were particularly pronounced which may be the result of residual road salt being flushed off of the parking lots and other impervious surfaces in the back portion of the campus. In addition to receiving chloride-laden stormwater runoff from the storm drains on campus, the northeastern pond is also situated within a topographic low in the landscape and would receive overland flow of contaminated runoff during the heavy downpours that fell on April 7, 2022.

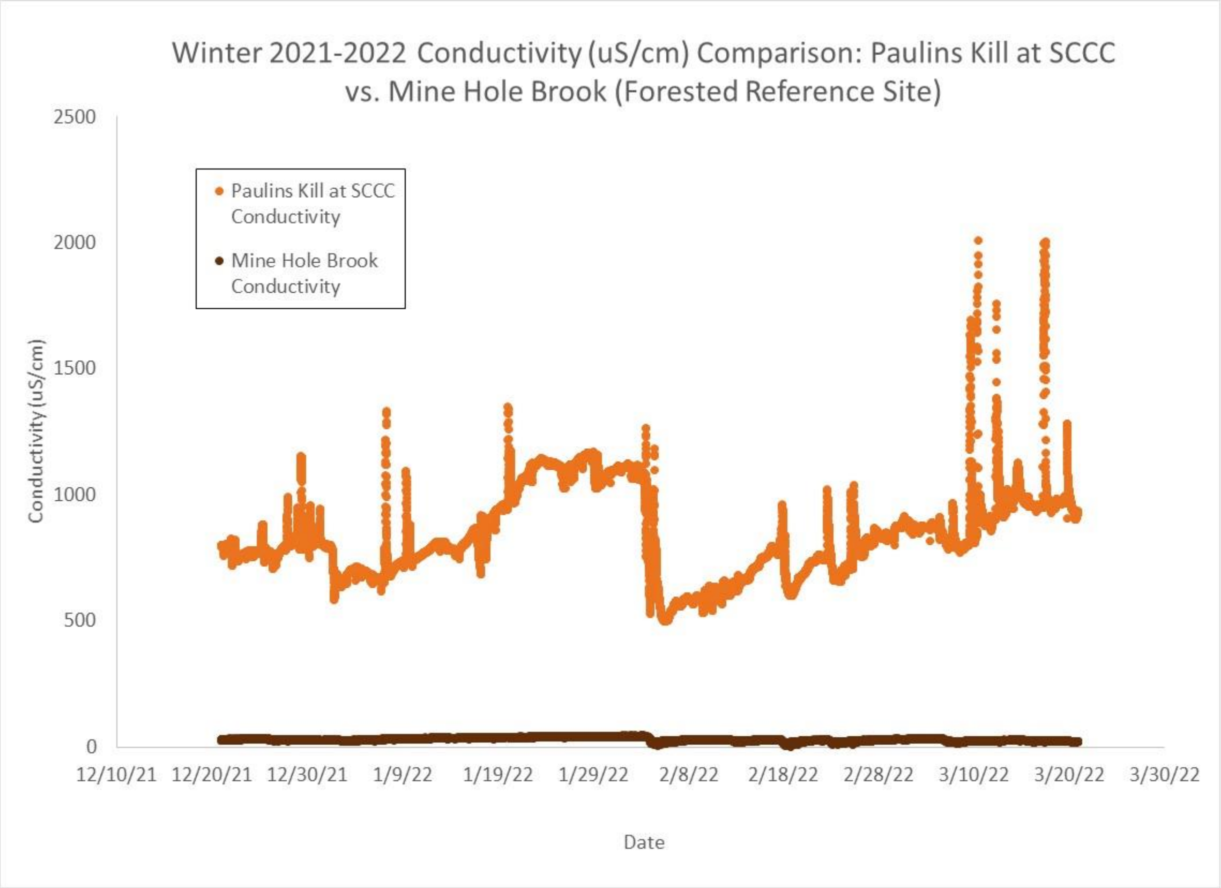


FIGURE 24: Winter 2021-2022 conductivity (uS/cm) comparison between the Paulins Kill River at SCCC and Mine Hole Brook. Although the Paulins Kill at SCCC and Mine Hole Brook are similar-sized streams in the same general region, Mine Hole Brook's watershed is highly-forested with little anthropogenic activity. With few impervious surfaces in the watershed, Mine Hole Brook does not exhibit the winter road salt impacts that are seen at SCCC in Newton, NJ. In Winter 2021-2022, the maximum conductivity (uS/cm) recorded at the Mine Hole Brook sensor station was 44.2 uS/cm compared to 2,005.5 uS/cm at SCCC (Monitor My Watershed).

IV. DISCUSSION

Use of Hach QuanTab® chloride test strips at the SCCC and Memory Park monitoring stations from January-March 2022 indicates that during winter precipitation events, chloride levels frequently exceed state thresholds (FIGURE 19 and FIGURE 20). NJDEP Surface Water Quality Standards for chloride contamination have been established to protect both aquatic life and human health. Chloride levels exceeding 250mg/L for humans and 230mg/L for aquatic life are considered chronic and those above 860mg/L are considered acute. (NJDEP, 2020a; Environmental Protection Agency, 2022). However, research reports also indicate that chloride levels as low as 50-90 mg/L showed the greatest taxa change for macroinvertebrates (Wallace and Biastoch, 2016), and chloride levels as low as 33-108 mg/L have altered fish diversity and abundance within stream ecosystems (Morgan et al., 2012). At SCCC and Memory Park, chloride levels surpassed 108 mg/L during each of the 12 chloride sampling events conducted as part of this research project; this indicates that aquatic life living within the Paulins Kill are being threatened by rising salinity even on days when road salt is not being applied to Newton's streets.

Furthermore, elevated conductivity, as a proxy measurement for chloride, has been observed during winter 2018-2022 at both SCCC and Memory Park and may indicate pervasive road salt contamination within the Paulins Kill. Generally, as depth increases, conductivity decreases because the rising water levels are lowering the concentration of ions in the stream through dilution (Jackson, 2020). During spring, summer, and fall, this inverse relationship between depth and conductivity exists because when air temperatures are above freezing, road departments do not need to apply road salt/de-icer to the streets during precipitation events, and consequently, conductivity readings at the sensor stations do not increase in response to precipitation as they would during winter below freezing precipitation events. However, during winter snowfall or freezing rain events, rising depth levels may not lead to an overall decrease in conductivity because road salt, such as sodium chloride (NaCl), is being applied to the asphalt, which may increase conductivity levels within the stream as a result of stormwater runoff (FIGURE 15).

This problem is exacerbated in the Town of Newton that has a highly impervious landscape. Urban land use is widely known to be detrimental to stream health (Cooper et al., 2014). It degrades stream biological communities, introduces chemical pollutants, and causes flashy and destructive storm flows that destroy riparian vegetation, erode banks, and disturb in-stream biological habitats (Cooper et al., 2014). High-frequency data analyzed by Moore et al. (2019) documented the correlation between rising specific conductance and chloride levels with heightened imperious surface coverage in a watershed. When imperious surfaces cover 10-20% of a watershed's landscape, as they do within the SCCC and Memory Park drainage areas, stream health tends to decline because of the influx of contaminated stormwater runoff that enters the river (Wickham, 2018).

Yet, stream health is not impeded in the same way within highly-forested watersheds, like Mine Hole Brook in New York State. Mine Hole Brook is approximately the same size and within the same general region as the Paulins Kill River, but Mine Hole Brook is considered a reference quality stream because of its high percentage of forest coverage and low anthropocentric impacts. According to the 2019 National Land Cover Database, the Mine Hole Brook drainage area is only 1.63% developed (Stroud Water Research Center, 2017). With few asphalt roads in the watershed, road salt is not applied as heavily during winter storms as it is in urbanized Newton, NJ. By comparing the winter 2021-2022 datasets for the two watersheds, it is clear that Mine Hole Brook does not exhibit significant conductivity spikes during below-freezing precipitation events. While the maximum conductivity spike recorded at SCCC during winter 2021-2022 was 2,006 uS/cm on March 10, 2022 (Utah Water Research Laboratory, 2018b), during the same day, the maximum conductivity observed at Mine Hole Brook was only 25.7 uS/cm (Utah Water Research Laboratory, 2018a). Stream conductivity levels this low are reflective of watersheds that are virtually absent of anthropogenic impediments and can be used as a comparison to highlight the significant impact that impervious surfaces are having on the Paulins Kill River in Newton.

Paved roads, ponds, and unshaded stream reaches upstream of the SCCC monitoring station are probable sources of the elevated water temperatures and conductivity issues in this headwaters region. Stormwater runoff from asphalt roads and parking lots at SCCC and other upstream lands is entering the storm drains and likely conveying road salts and de-icers directly into the river, causing wintertime conductivity and chloride spikes that surpass levels known to be toxic to macroinvertebrates. Jackson and Funk (2019) demonstrated that warmer water makes sodium chloride much more lethal to macroinvertebrates. In small, unshaded stream reaches, like the Paulins Kill at SCCC, the absence of a riparian forest buffer on campus may be elevating average stream temperatures to produce stream conditions that are more toxic to macroinvertebrates and other life within the stream.

Elevated conductivity (uS/cm) and chloride (mg/L) values (above 500 uS/cm and 230 mg/L, respectively) have been shown to pose severe impacts to aquatic life living in freshwater streams (Karraker et al., 2008; Environmental Protection Agency, 2022). Research conducted by Olson and Cormier (2019) found that mean natural background specific conductance in New Jersey is approximately 10 uS/cm (FIGURE 25), and in the eastern United States, average stream conductivity is generally <200 uS/cm (Griffith, 2014). The conductivity levels observed in Newton surpass 200 uS/cm even at baseflow conditions and are higher than what would be expected in a healthy, headwater stream in northern New Jersey (Griffith, 2014). Specific conductance levels this high may be detrimental to aquatic life by contributing to/exacerbating pollution problems further downstream (Entrekin et al., 2019; Karraker et al., 2008, Gillis, 2011; Wallace and Biastoch, 2016; Morgan et al., 2012). As freshwater streams become salinized, organisms can be negatively impacted as the rising chloride affects their ability to reproduce and maintain their water content at equilibrium (Castillo et al., 2018). A study in Appalachia found that mayfly (order Ephemeroptera) populations were negatively impacted by specific conductance levels as low as 200 uS/cm during the spring, leading to swift drops in relative abundance and species richness as salinity levels rose (Timpano et al., 2018). Loss of macroinvertebrates is incredibly detrimental to stream ecosystems because of the essential functions that aquatic insects perform including "nutrient recycling, primary production, decomposition, and transformation of material" (Castillo et al., 2018).

Rising chloride and specific conductance levels are particularly detrimental to organisms in the embryonic and juvenile stages. Gillis (2011) altered the salt concentration of river water to simulate the effect of a salt spike within the stream and found that freshwater mussels in the larval stage were acutely sensitive to NaCl. Yet, the majority of field and lab experiments use adult freshwater mussels that have a higher pollutant tolerance to test a species' contaminant exposure threshold, which may cause regulatory standards to be set too high to adequately safeguard larval mussels from chloride contamination (Gillis, 2011). Similarly, a study in the Adirondacks examined the effects of road salt on spotted salamanders (*Ambystoma maculatum*) and wood frogs (*Rana sylvatica*), both amphibians that breed within vernal pools (Karraker et al., 2008). The study found that survival rates within the embryonic and larval stages decreased at specific conductance levels as low as 500 uS/cm (Karraker et al., 2008). At the SCCC and Memory Park sensor stations, conductivity readings surpassed these thresholds even at baseflow conditions, demonstrating the widespread effects that may result to macroinvertebrate and amphibian communities as a result of non-point source road salt pollutants to the Paulins Kill River. During winter conductivity spikes, conductivity levels have surpassed 5,000 uS/cm at SCCC and 12,000 uS/cm at Memory Park, further threatening the aquatic life living in the Paulins Kill River (Utah Water Research Laboratory 2018; 2019).

Despite the demonstrated impact of rising salinization on stream and vernal pool community structure, impacts are not consistent among different species or from one season to another. Castillo et al. (2018) demonstrated that even among aquatic insects, different orders of macroinvertebrates exhibit different tolerances to rising chloride. In experimentation that tested LC50 rates (the concentration of chloride that resulted in the mortality of half of the organisms tested) of different macroinvertebrates, Odonata (dragonflies and damselflies), Coleoptera (beetles), Diptera (flies), and Hemiptera (true bugs) were the most tolerant to chloride while mayflies (Ephemeroptera) were the most sensitive.

While some species of wildlife are impacted by road salt runoff more than others, increasing chloride levels are widely believed to modify community structure within freshwater ecosystems. Chloride-contaminated runoff can alter riparian-stream pathways by 1) changing the composition and processing of detritus by microbial decomposers and macroinvertebrates in the stream, 2) varying salt uptake of streamside plants, and 3) increasing decomposer growth and dissolved organic matter creation (Entrekin et al., 2019). When detritivore growth rates change, that can lead to significant changes in carbon cycling within the riparian zone (Entrekin et al., 2019). Salinization in the watershed can also induce mortality of riparian plants and aquatic animals, changes to in-stream and terrestrial decomposer activity, and transformed interactions among species (Entrekin et al., 2019). Lab toxicity experiments typically overestimate aquatic insect tolerance to contaminants compared to studies conducted in the field because researchers often do not account for the indirect impacts of pollutants on stream ecosystems, such as those that alter organism interactions and decrease food resources (Clements and Kotalik, 2016).

Because annual precipitation is variable in New Jersey, conclusions should not be drawn from any one winter season's data alone. In cold, wet winters, below freezing temperatures combined with frequent precipitation events will typically result in township road departments applying road salt to the municipality's streets, but with the onset of climate change, warmer air temperatures may produce less snow and ice (New Jersey Department of Environmental Protection, 2020). According to the New Jersey Scientific Report on Climate Change, average air temperatures in New Jersey are expected to rise by 2.3°C to 3.2°C by mid-century, and the number of below-freezing days and total snow accumulation is expected to decrease (New Jersey Department of Environmental Protection, 2020). In addition, New Jersey precipitation levels are expected to increase by 4% to 11% over the next three decades, and the strength and occurrence of precipitation events are also expected to rise (New Jersey Department of Environmental Protection, 2020). As a result of the projected rising temperatures, this anticipated increase in precipitation will be more likely to fall as rain than snow (New Jersey Department of Environmental Protection, 2020), which may lead to a reduction in road salt applications across the Northeastern United States.

However, the damage caused by decades of road salt contamination may continue to pollute freshwater rivers and streams long after climate change decreases winter road salt applications due to chloride contamination of the soil that will continue to leach chloride into local water bodies (Cooper et al., 2014). A four-decade study of Sparkling Lake, Wisconsin illustrates that instead of chloride concentrations leveling off to reach a stable equilibrium, the rural watershed has seen a steady increase in chloride impairment as a result of road salt retention within the natural landscape; the watershed's ability to retain chloride has delayed chloride contamination from being detected and will also slow recovery once road salt applications diminish or cease (Dugan and Rock, 2021). Although soil is capable of storing chloride, when the storage capacity of the soil becomes reduced over time due to heavy chloride loading within the watershed, the groundwater that flows into lakes or rivers may be as highly concentrated with chloride as the chloride concentrations of the wider landscape (Dugan and Rock, 2021). In the Paulins Kill Watershed, chloride contamination could negatively impact the health of the river system as well as the drinking water supplies that residents rely on.

Residual chloride in the soil can contaminate underground wells, posing a direct impact to drinking water resources in the Paulins Kill. In Columbia, New Jersey, a NJDEP study of drinking-water wells found that sodium levels within the community were more than five times greater than the recommended chloride safety standards because of Columbia's close proximity to major highways, including Route 80, Route 94, and Route 46, that are significantly salted by road departments during below freezing precipitation events (Novak, 2019). This sodium chloride loading within the Paulins Kill threatens drinking water supplies for residents reliant on underground wells and has prompted the Knowlton government to initiate steps such as coordinating with public works departments to ensure that roadways are not excessively salted, rebuilding the town-owned road salt storage shed to prevent chloride runoff, and installing reverse osmosis treatment devices in homes whose wells have been impacted by chloride groundwater contamination (Scruton, 2021). While the chloride contamination in Columbia has been revealed through state-funded studies of residential wells, the Columbia, NJ example is not an isolated incident. In their study of streams adjacent to major highways in the Chesapeake Bay, Cooper et al. (2014) found that salinity levels remained elevated throughout the year within the urban Maryland watershed but also were heightened in a nearby reference stream, suggesting that groundwater is a reservoir for salt accumulation and that levels can remain heightened over the long-term.

Likewise, sodium chloride contamination of residential wells remains a widespread problem throughout the Northeastern United States. For instance, in a study of the impact of sodium chloride on private residential wells in New York State, Pieper et al. (2018) found that the extent of salt contamination within wells varied based on proximity to different features within the community; the levels were the most elevated in wells located downhill of rock salt storage features and then by wells located 30 meters or less of a significant roadway. In addition to heightened chloride levels in their drinking water, Pieper et al. (2018) also identified high levels of corrosion in underground wells impacted by road salt. Private well residents that experienced the most chloride drinking water contamination were also at greatest risk of leached metal exposure from the elevated incidence of corrosion within the plumbing of their wells (Pieper et al. 2018).

Excessive road salt application is not only damaging underground plumbing but also aboveground infrastructure. Sol Warren (2019) reported that the New Jersey Department of Transportation (NJDOT) applied almost 375,000 tons of rock salt, over 830,000 gallons of calcium chloride and nearly 1.2 million gallons of brine to New Jersey’s 13,000 miles of highways in winter 2017-2018. Across New Jersey’s highway system, approximately 29 tons of rock salt are being applied each year per mile of roadway, and these NJDOT figures do not include the thousands of miles of local roadways salted by township and county governments each winter season, demonstrating the ubiquitous nature of the freshwater salinization problem (Sol Warren, 2019). The Environmental Protection Agency estimates that rock salt is currently causing $5 billion in damage to bridges, roads, and vehicles within the United States each year due to the corrosion caused by road salt application (2020), and this figure is only going to increase as more and more watersheds experience rising chloride concentrations in the decades to come.

Human activities like urbanization, agriculture, and mining for resources are amplifying salinization of freshwater watersheds (Cunillera-Montcusí et al., 2022). Freshwater Salinization Syndrome causes a mix of different elements (chemical cocktails) to enter freshwater streams through ion exchange (Galella et al., 2021). Researchers observed the transport of metals and base cations was greatest during the height of snowstorms and often continued for a full day after the specific conductance levels topped out (Galella et al., 2021); this signifies that there is continuing cation transfer between soils and sediments within the river. Similarly, metal concentrations continued to be high for several days after peak specific conductance which shows that there is sustained movement of metals after road salt applications (Galella et al., 2021). Since the Delaware River is a surface water resource that provides drinking water to over 15 million people within the watershed (Delaware River Watershed Initiative, 2017), chloride and metal contamination of major tributaries, like the Paulins Kill, directly threaten drinking water supplies for residents of Pennsylvania, New Jersey, New York, and Delaware.

By analyzing the data collected at SCCC and Memory Park across 5 winter seasons, it is clear that the two drainage areas usually act in similar ways during winter storms but do not always show identical responses. The SCCC sensor station characteristically displays conductivity spikes that rise more rapidly in response to a precipitation event than the Memory Park sensor station; this is likely due to the fact that the Memory Park drainage area is larger than the SCCC drainage area so there is a lag time before conductivity and depth increases occur in response to a precipitation event (Granato, 2012).   Additionally, conductivity spikes recorded at the Memory Park sensor station are typically of a greater magnitude and longer duration than the conductivity increases at SCCC. Since the Memory Park drainage area is more highly developed than the SCCC drainage area, the Memory Park sensor station is receiving road salt runoff from a greater impervious surface area than SCCC, which is contributing to the substantial chloride loading to the river during winter storms.

Across the greatest magnitude conductivity spikes observed each winter season at SCCC and Memory Park, two of the five largest conductivity spikes occurred on the same days at SCCC and Memory Park (February 7, 2018 and February 16, 2021) (Utah Water Research Laboratory, 2018b; 2017). Throughout the three other winter seasons, Memory Park showed the largest conductivity spikes on January 20, 2019, March 6, 2020, and January 17, 2022 (Utah Water Research Laboratory, 2017), but the SCCC sensor station did not record its highest conductivity spike on these days. It is hypothesized that the SCCC sensor station did not exhibit its maximum winter conductivity spike on these dates because students were not on campus during these time periods so winter storm management would likely not be as reliant on road salt application. On January 20, 2019 and January 17, 2022, SCCC was closed for winter break and had yet to resume classes for the spring semester; as a commuter school with no residential students housed on the campus, the SCCC maintenance department would not have to apply as much road salt to sidewalks and parking lots during winter break as it otherwise would have if students were on campus attending classes and at risk of falling on black ice.

Despite the fact that the Memory Park sensor station recorded an all-time high conductivity reading of 24,044 uS/cm on March 6, 2020, there was no corresponding conductivity spike seen on March 6, 2020 or the days prior at SCCC (Utah Water Research Laboratory 2017; 2018). Additionally, according to the CoCoRaHS precipitation data, 0.01 inch (0.25 cm) of precipitation was collected at the rain gauge on March 5, 2020 and 0.00 inches (0.00 cm) of precipitation were recorded on March 6, 2020 (CoCoRaHS, 2022). There was also no major change in the Paulins Kill depth at either sensor station leading up to or following the March 6, 2020 Memory Park conductivity spike. NOAA air temperature data shows that the maximum air temperatures reported that week were in the low to upper 50s (^{o}F) with minimum air temperatures at or above the freezing mark (National Centers for Environmental Information, 2022). Since the air temperatures were above average and the rain gauge data shows that there were no major precipitation events leading up to the Memory Park conductivity spike on March 6, 2020, it is hypothesized that there was a large contaminant input upstream of the Memory Park sensor station but downstream of the SCCC sensor station that would have led to the observed conductivity spike. Such pollutant loading could have been caused by a chloride input into the river, by a discharge from the wastewater treatment plant upstream, or by contamination from some other unknown source within the watershed.

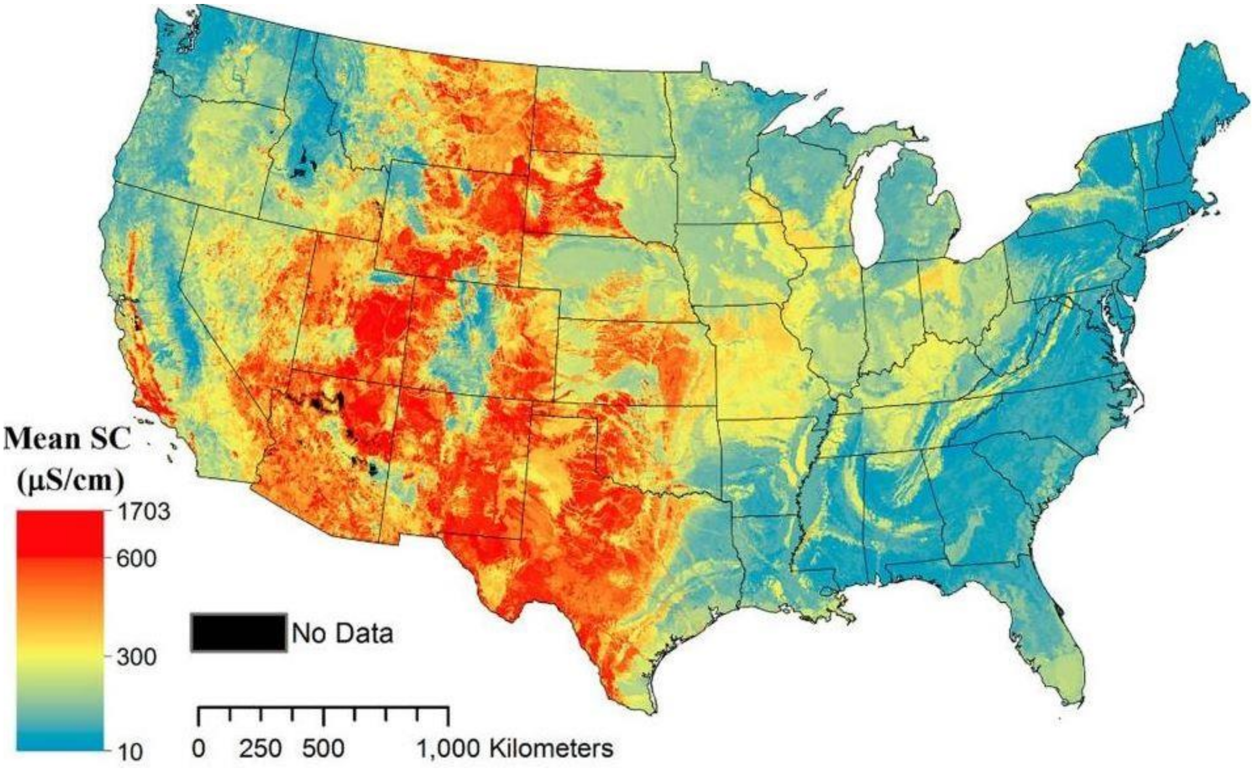


FIGURE 25: Map from Olson, J. R., & Cormier, S. M. (2019). Modeling spatial and temporal variation in natural background specific conductivity. *Environmental science & technology*, *53*(8), 4316-4325.

This map displays the mean natural background specific conductance in uS/cm for all stream reaches throughout the continental United States from 2001-2015. In New Jersey, natural mean specific conductance is approximately 10 uS/cm, significantly lower than the specific conductance measurements recorded at SCCC or Memory Park during any portion of the year.

a. IMPACT OF GEOLOGY

Limestone lithology can create higher-than-normal natural conductivity values (Helvey and Kochenderfer, 1987), and this type of natural elevated conductivity needs to be considered when evaluating the influence of conductivity on biota. Because of the significant conductivity spikes observed in the wintertime, it is highly likely that conductivity in this headwaters region is higher than natural levels, both at baseflow and during winter road salt/de-icer flushes (Olson and Cormier, 2019). Although there is limestone lithology in the Paulins Kill Watershed, if the elevated conductivity levels observed at SCCC and Memory Park were predominately caused by the geology of the region rather than winter road salt applications, then the conductivity levels at each sensor station would be elevated in the Paulins Kill throughout all months of the year and would not be significantly lower in the summer than the winter. However, mapping the bedrock of Newton using the online NJ GeoWeb database from the New Jersey Department of Environmental Protection demonstrates that the conductivity readings at both sensor stations may be influenced differently by their individual geological features (NJDEP, 2020b). While the SCCC drainage area is comprised of siltstone and shale lithology, the Memory Park drainage area is predominantly mapped as limestone lithology which may be elevating the conductivity readings at the sensor station because of the carbonate minerals washing into the river from the bedrock (Cary Institute).

Additionally, the soil composition at each location may have a direct impact on the observed conductivity differences occurring on days without winter precipitation events. For instance, according to the Web Soil Survey data report for SCCC, the community college campus contains a higher percentage of hydrologic soil class D soils than Memory Park (USDA-NRCS 2022a; 2022b). Hydrologic soil class D soils contain a high percentage of clay content and have a high runoff potential/low water infiltration rate (Mockus et al., 2007). According to the U.S. EPA, streams that flow through regions with clay soils typically have elevated conductivity because the landscape contains components that ionize when flushed into the stream (2012). The existence of a high percentage of clay in the SCCC campus soils may be contributing to the elevated conductivity readings at the SCCC sensor station even at baseflow conditions outside of storm events.

V. AREAS OF FUTURE RESEARCH

In order to try and account for differences in the data patterns observed at SCCC and Memory Park, a researcher should work to determine whether the two locations behave differently as a result of their geology. Additional emphasis should also be focused on the impact of the wastewater treatment plant upstream of the Memory Park sensor station since wastewater treatment plants have been found to be associated with heightened stream conductivity levels (Kaushal et al., 2018). Installing a secondary continuous monitoring sensor station within Memory Park but upstream of Newton's wastewater treatment plant would help a researcher quantify the impact of wastewater treatment discharges on the health of the Upper Paulins Kill within Newton. With two continuous monitoring stations installed within Memory Park, a researcher would be able to simultaneously compare the conductivity and depth measurements at the two different portions of Memory Park and determine whether or not there are significant data discrepancies as a result of treated water releases from the Newton wastewater treatment plant into the Paulins Kill River.

Other researchers should investigate the prevalence of metal mobilization through the stream channel during and after winter road salt applications. "Chemical cocktail" studies can investigate the type and amount of metal ions in Newton’s Upper Paulins Kill following below freezing precipitation events when road salt would be more likely to be applied to city streets in order to see if there is a statistically significant difference observed in metal concentration between the SCCC sub-watershed and the more urbanized Memory Park sub-watershed about 1 kilometer downstream.

Due to the relationship between water temperature and toxicity from saline inputs into the stream, another emphasis of future research should be to examine the impact of elevated specific conductance and chloride levels in relation to stream temperatures, especially during summer baseflow conditions. Although road salt applications would not be occurring during the summertime, researchers should examine the impact of specific conductance and chloride on macroinvertebrate communities during the warm months of the year since heightened stream temperatures have been linked to elevated mayfly mortality (Jackson and Funk, 2019).

Future studies should also examine the effectiveness of alternative ice melt solutions to determine whether a different winter road management strategy should be recommended for Sussex County Community College. With conductivity spikes observed during winter precipitation events, upcoming research can study whether road salt alternatives applied to asphalt surfaces at the community college campus would help to reduce chloride loading to the Upper Paulins Kill as well as the conductivity and chloride spikes observed at the SCCC and Memory Park sensor stations. Analysis should also examine whether chloride loading to the Upper Paulins Kill would be reduced by installing green infrastructure stormwater management practices on campus. For example, if a researcher can demonstrate that converting traditional asphalt parking lots into porous asphalt surfaces would reduce conductivity spikes by allowing precipitation to penetrate through the stones of the parking lot to the soil underneath without generating black ice, such best management practices can be implemented at SCCC.

VI. CONCLUSION

Although the data collected at the sensor stations cannot point to one specific cause of the year-round elevated conductivity observed at both sensor stations within Newton, initial findings demonstrate that the heightened conductivity rates may be caused by a combination of the bedrock geology of the Paulins Kill Watershed and road salt applications during below-freezing precipitation events. The above average conductivity (uS/cm) data recorded during the summer seasons (when no road salt was applied to asphalt streets) may demonstrate that limestone lithology is having an impact on conductivity rates within the Upper Paulins Kill (Helvey and Kochenderfer, 1987) or that the floodplain soils are functioning like a road salt reservoir and supplying chloride to the Paulins Kill during all months of the year (Cooper et al., 2014). However, the research collected and analyzed this semester demonstrates that there is a correlation between road salt applications and subsequent spikes in the conductivity levels that were recorded at both the SCCC and Memory Park sensor stations. Likewise, when daily minimum air temperatures were above freezing, precipitation fell as rain, and winter maintenance departments did not need to apply road salt to Newton's streets, explaining why conductivity spikes were not recorded on these days within the Monitor My Watershed dataset. Wintertime conductivity spikes are a cause for concern within the Paulins Kill Watershed and may be contributing to threats to in-stream and terrestrial wildlife, contamination of underground drinking wells, and economic costs such as corroded infrastructure (Karraker et al., 2008, Gillis, 2011; Castillo et al., 2018; Entrekin et al., 2019; Pieper et al. 2018; Kaushal et al., 2018). Before road salt application continues throughout another winter season, the SCCC administration and Newton Road Department should examine their levels of involvement in Paulins Kill chloride contamination and propose alternative management solutions to reduce the harm being inflicted on the greater Delaware River Watershed.

References

Bressler, D., Muenz, T., Johnson, R., Hicks, S., Ensign, S., & Damiano, S. (2017). EnviroDIY Monitoring Station Manual. Retrieved February 15, 2022, from https://www.envirodiy.org/knowledge-base/

Cary Institute. *Conductivity*. Cary Institute of Ecosystem Studies, www.caryinstitute.org/ sites/default/files/public/downloads/curriculum-project/conductivity_reading.pdf#:~:text =Geology%3A%20As%20water%20flows%2C%20it%20passes%20over%20 bedrock,dissolved%20carbonate%20minerals%20leaching%20in%20from%20the%20bedrock. Accessed 24 Apr. 2022.

Castillo, A. M., Sharpe, D. M., Ghalambor, C. K., & De León, L. F. (2018). Exploring the effects of salinization on trophic diversity in freshwater ecosystems: a quantitative review. *Hydrobiologia*, *807*(1), 1-17.

Clements, W. H., & Kotalik, C. (2016). Effects of major ions on natural benthic communities: an experimental assessment of the US Environmental Protection Agency aquatic life benchmark for conductivity. *Freshwater Science*, *35*(1), 126-138.

CoCoRaHS. (2022). Community Collaborative Rain, Hail & Snow Network: NJ-SS-1. Retrieved March 5, 2022, from https://www.cocorahs.org/ViewData/ListDailyPrecip Reports.aspx

Cooper, C. A., Mayer, P. M., & Faulkner, B. R. (2014). Effects of road salts on groundwater and surface water dynamics of sodium and chloride in an urban restored stream. *Biogeochemistry*, *121*(1), 149-166.

Cunillera-Montcusí, D., Beklioğlu, M., Cañedo-Argüelles, M., Jeppesen, E., Ptacnik, R., Amorim, C. A., ... & Matias, M. (2022). Freshwater salinisation: a research agenda for a saltier world. *Trends in Ecology & Evolution*.

Decagon Devices, Inc. 2016. Decagon CTD-10 sensor manual (Meter Hydros 21, as of 2018): http://manuals.dec agon.com/Manuals/13869_CTD_Web.pdf (http://manuals. decagon.com/Manuals/13869_CTD_Web.pdf). Version: October 25, 2016

Delaware River Watershed Initiative. (2017, December 20). Retrieved March 26, 2022, from https://4states1source.org/?msclkid=ef7bd6a0ad5211ecac043e2ac6df0f7e

Dugan, H. A., & Rock, L. A. (2021). The slow and steady salinization of Sparkling Lake, Wisconsin. *Limnology and Oceanography Letters*.

Entrekin, S. A., Clay, N. A., Mogilevski, A., Howard-Parker, B., & Evans-White, M. A. (2019). Multiple riparian–stream connections are predicted to change in response to salinization. *Philosophical Transactions of the Royal Society B*, *374*(1764), 20180042

Environmental Protection Agency. (2020, November). *Winter is Coming! And with it, tons of salt on our roads*. Retrieved March 27, 2022, from https://www.epa.gov/snep/winter-coming-and-it-tons-salt-our-roads

Environmental Protection Agency. (2022). *National Recommended Water Quality Criteria - Aquatic Life Criteria Table*. EPA. Retrieved April 10, 2022, from https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#table

EPA. (2012, March 6). *5.9 conductivity*. Water Monitoring and Assessment. Retrieved March 26, 2022, from https://archive.epa.gov/water/archive/web/html/vms59.html?msclkid=6036142ca7c711ecb4c893576a8e8370

Foodshed Alliance. (n.d.). Paulins Kill Watershed. map. Retrieved March 25, 2022, from https://foodshedalliance.org/pkw/.

Galella, J. G., Kaushal, S. S., Wood, K. L., Reimer, J. E., & Mayer, P. M. (2021). Sensors track mobilization of ‘chemical cocktails’ in streams impacted by road salts in the Chesapeake Bay watershed. *Environmental Research Letters*, *16*(3), 035017.

Gillis, P. L. (2011). Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: Implications for salinization of surface waters. *Environmental Pollution*, *159*(6), 1702-1708.

Granato, G.E., 2012, Estimating basin lagtime and hydrograph-timing indexes used to characterize stormflows for runoff-quality analysis: U.S. Geological Survey Scientific Investigations Report 2012–5110, 47 p., with digital media at http://pubs.usgs.gov/sir/2012/5110/.

Griffith, M. B. (2014). Natural variation and current reference for specific conductivity and major ions in wadeable streams of the conterminous USA. *Freshwater Science*, *33*(1), 1-17.

Helvey, J. D., & Kochenderfer, J. N. (1987). Effects of limestone gravel on selected chemical properties of road runoff and streamflow. *Northern Journal of Applied Forestry*, *4*(1), 23-25.

Jackson, J. K., & Funk, D. H. (2019). Temperature affects acute mayfly responses to elevated salinity: implications for toxicity of road de-icing salts. *Philosophical Transactions of the Royal Society B*, *374*(1764), 20180081.

Jackson, J. (2020, November). *Ecological Significance of Specific Conductance in Streams – Part 1. Monthly EnviroDIY-DRWI User Group Meetings*. Avondale; PA.

Karraker, N. E., Gibbs, J. P., & Vonesh, J. R. (2008). Impacts of road deicing salt on the demography of vernal pool-breeding amphibians. *Ecological Applications*, *18*(3), 724-734.

Kaushal, S. S., Likens, G. E., Pace, M. L., Utz, R. M., Haq, S., Gorman, J., & Grese, M. (2018). Freshwater salinization syndrome on a continental scale. *Proceedings of the National Academy of Sciences*, *115*(4), E574-E583.

Mockus, V., Werner, J., Woodward, D. E., Nielsen, R., Dobos, R., Hjelmfelt, A., & Hoeft, C. C. (2007). Hydrologic Soil Groups. In *Part 630 Hydrology National Engineering Handbook* (pp. 7–1-7–5). essay, USDA-Natural Resources Conservation Service.

Moore, J., Fanelli, R. M., & Sekellick, A. J. (2019). High-frequency data reveal deicing salts drive elevated specific conductance and chloride along with pervasive and frequent exceedances of the US Environmental Protection Agency aquatic life criteria for chloride in urban streams. *Environmental Science & Technology*, *54*(2), 778-789.

Morgan, R. P., Kline, K. M., Kline, M. J., Cushman, S. F., Sell, M. T., Weitzell Jr, R. E., & Churchill, J. B. (2012). Stream conductivity: relationships to land use, chloride, and fishes in Maryland streams. *North American journal of fisheries management*, *32*(5), 941-952.

MRLC. (2019). *National Land Cover Database 2011 (NLCD2011) Legend*. National Land Cover Database Class Legend and Description. Retrieved March 26, 2022, from https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description

National Centers for Environmental Information. (2022, March 12). *Climate Data Online Search*. National Climatic Data Center (NCDC). Retrieved March 27, 2022, from https://www.ncdc.noaa.gov/cdo-web/search

New Jersey Department of Environmental Protection. 2020. New Jersey Scientific Report on Climate Change, Version 1.0. (Eds. R. Hill, M.M. Rutkowski, L.A. Lester, H. Genievich, N.A. Procopio). Trenton, NJ. 184 pp.

NJDEP Bureau of GIS. (2020, March 27). *Surface Water Quality Classification of New Jersey*. Retrieved March 25, 2022, from https://gisdata-njdep.opendata.arcgis.com/datasets/ njdep: :surface-water-quality-classification-of-new-jersey/explore?location=40.128697 %2C-74.742650%2C23.00

NJDEP, Surface Water Quality Standards 1–113 (2020a). Trenton, NJ; N. J. A. C. 7:9B.

NJDEP. (2020b, December). NJ GeoWeb. Retrieved March 26, 2022, from https://njdep.maps.arcgis.com/apps/webappviewer/index.html?id=02251e521d97454aabadfd8cf168e44d

Novak, S. (2019, February 27). *A town found the source of its contaminated wells: Road salt. what's being done about it?* lehighvalleylive. Retrieved March 26, 2022, from https://www.lehighvalleylive.com/warren-county/2019/02/a-town-found-the-source-of-its-contaminated-wells-road-salt-whats-being-done-about-it.html

Olson, J. R., & Cormier, S. M. (2019). Modeling spatial and temporal variation in natural background specific conductivity. *Environmental science & technology*, *53*(8), 4316-4325.

Pieper, K. J., Tang, M., Jones, C. N., Weiss, S., Greene, A., Mohsin, H., ... & Edwards, M. A. (2018). Impact of road salt on drinking water quality and infrastructure corrosion in private wells. *Environmental science & technology*, *52*(24), 14078-14087.

Scruton, B. A. (2021, October 30). *Knowlton looks to use COVID relief funds to fix salty private wells for Columbia residents*. New Jersey Herald. Retrieved March 26, 2022, from https://www.njherald.com/story/news/2021/10/30/knowlton-nj-covid-relief-funds-fix-road-salt-columbia-wells/6195135001/

Sol Warren, M. (2019, March 21). Will Murphy's plan to constantly salt the roads wreak environmental havoc? Time will tell. Retrieved April 3, 2022, from https://www.nj.com/news/2019/01/will-murphys-plan-to-constantly-salt-the-roads-wreak-environmental-havoc-time-will-tell.html.

Stroud Water Research Center. (2017). Model My Watershed [Software]. Available from https://wikiwatershed.org/

Timpano, A. J., Schoenholtz, S. H., Soucek, D. J., & Zipper, C. E. (2018). Benthic macroinvertebrate community response to salinization in headwater streams in Appalachia USA over multiple years. *Ecological indicators*, *91*, 645-656.

USDA-NRCS. (2022a). (rep.). *Web Soil Survey: Memory Park Soils Report*. United States Department of Agriculture-Natural Resources Conservation Service. Retrieved February 13, 2022, from https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

USDA-NRCS. (2022b). (rep.). *Web Soil Survey: SCCC Soils Report*. United States Department of Agriculture-Natural Resources Conservation Service. Retrieved February 13, 2022, from https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

USGS. (2022a). (rep.). *Memory Park StreamStats*. United States Geological Survey. Retrieved from https://streamstats.usgs.gov/ss/.

USGS. (2022b). (rep.). *SCCC StreamStats*. United States Geological Survey. Retrieved from https://streamstats.usgs.gov/ss/.

Utah Water Research Laboratory. (2017, April 4). Monitor My Watershed: Paulins Kill upstream at Memory Park (NHPK7S). Retrieved February 11, 2022, from https://monitormywatershed.org/sites/NHPK7S/

Utah Water Research Laboratory. (2018a, January 25). Monitor My Watershed: Mine Hole Brook at Foordemoore Road. Retrieved April 15, 2022, from http://monitormywatershed.org/sites/PKMH2S

Utah Water Research Laboratory. (2018b, January 25). Monitor My Watershed: Paulins Kill at Sussex Co. Community College (NHPK9S). Retrieved February 11, 2022, from https://monitormywatershed.org/sites/NHPK9S/

Utah Water Research Laboratory. (2022). Monitor My Watershed. Retrieved March 27, 2022, from https://monitormywatershed.org/browse/

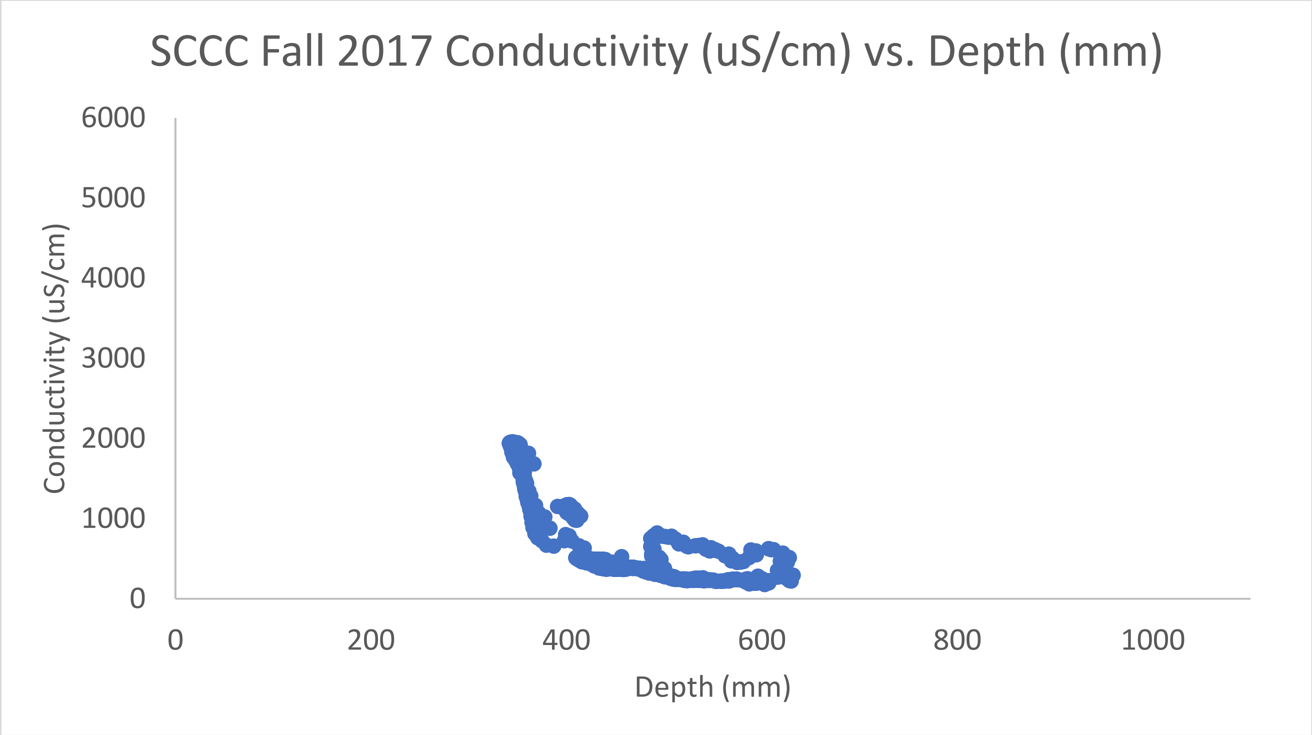
Wallace, A. M., & Biastoch, R. G. (2016). Detecting changes in the benthic invertebrate community in response to increasing chloride in streams in Toronto, Canada. *Freshwater Science, 35*(1), 353-363.

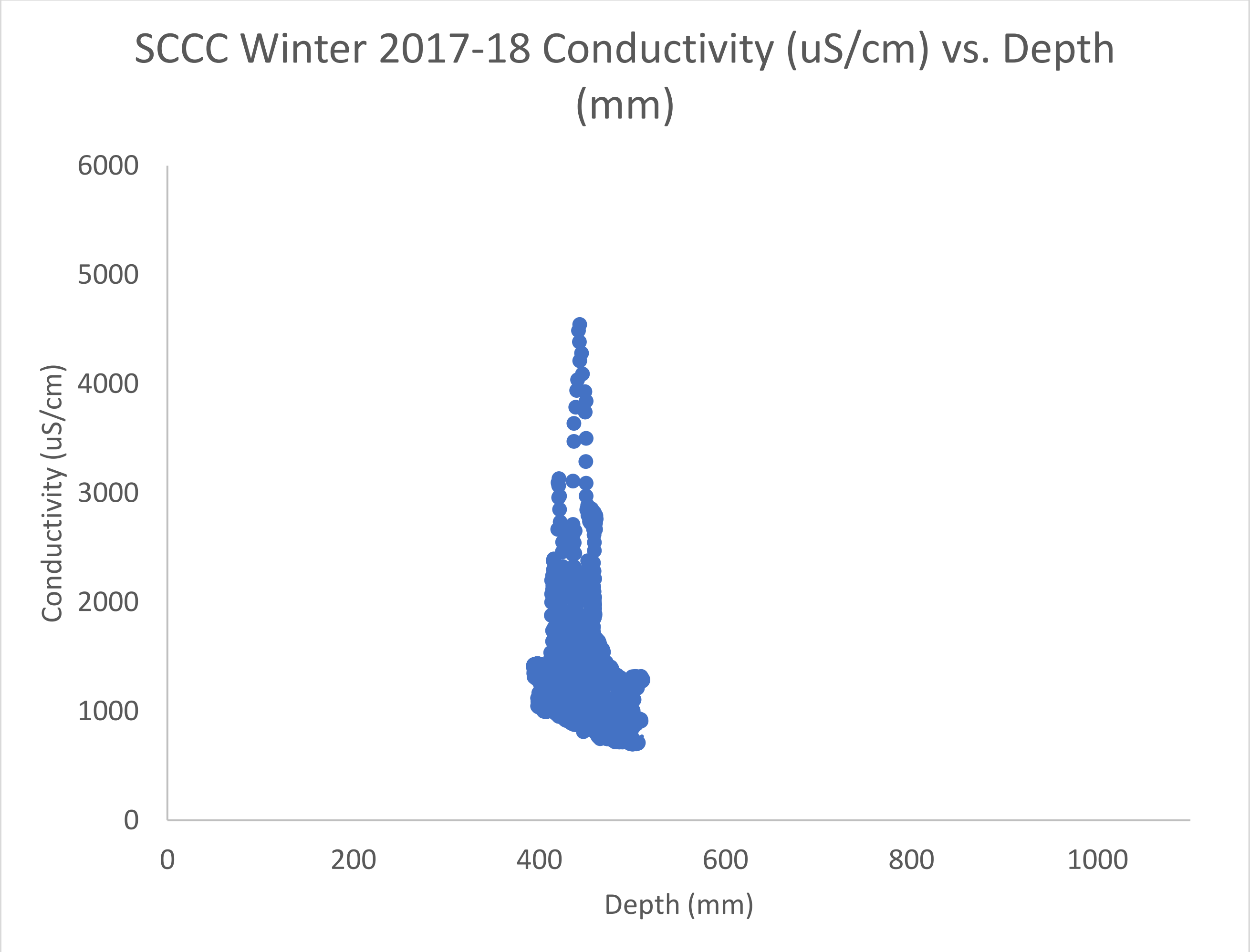
Wickham, J., EnviroAtlas Factsheet (2018). U.S. Environmental Protection Agency.

WRWMG. (2012). (rep.). *Upper Paulins Kill Watershed Restoration Plan*. Lafayette, NJ: Wallkill River Watershed Management Group, 1-226.

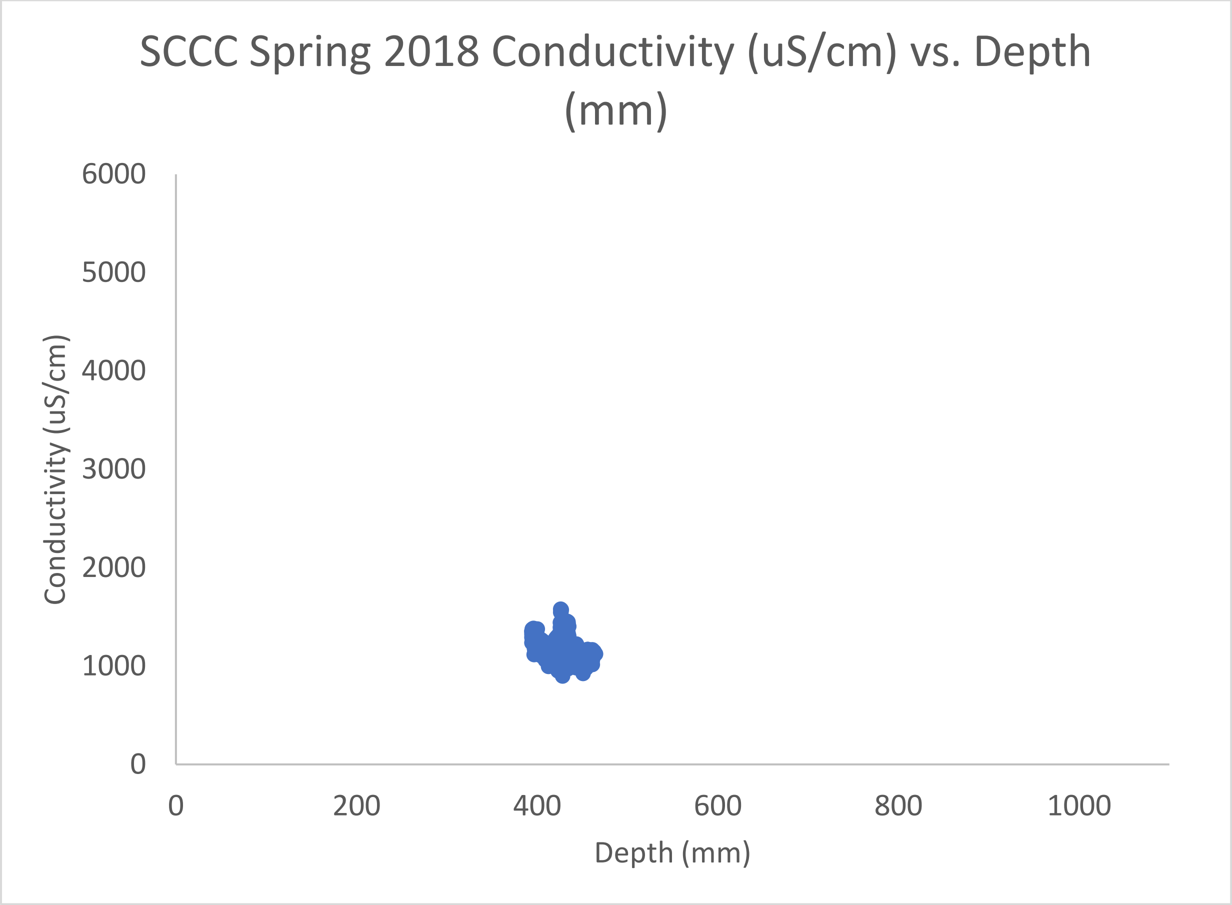
VIII. APPENDIX

SCCC CONDUCTIVITY (uS/cm) VERSUS DEPTH (mm) BY SEASON

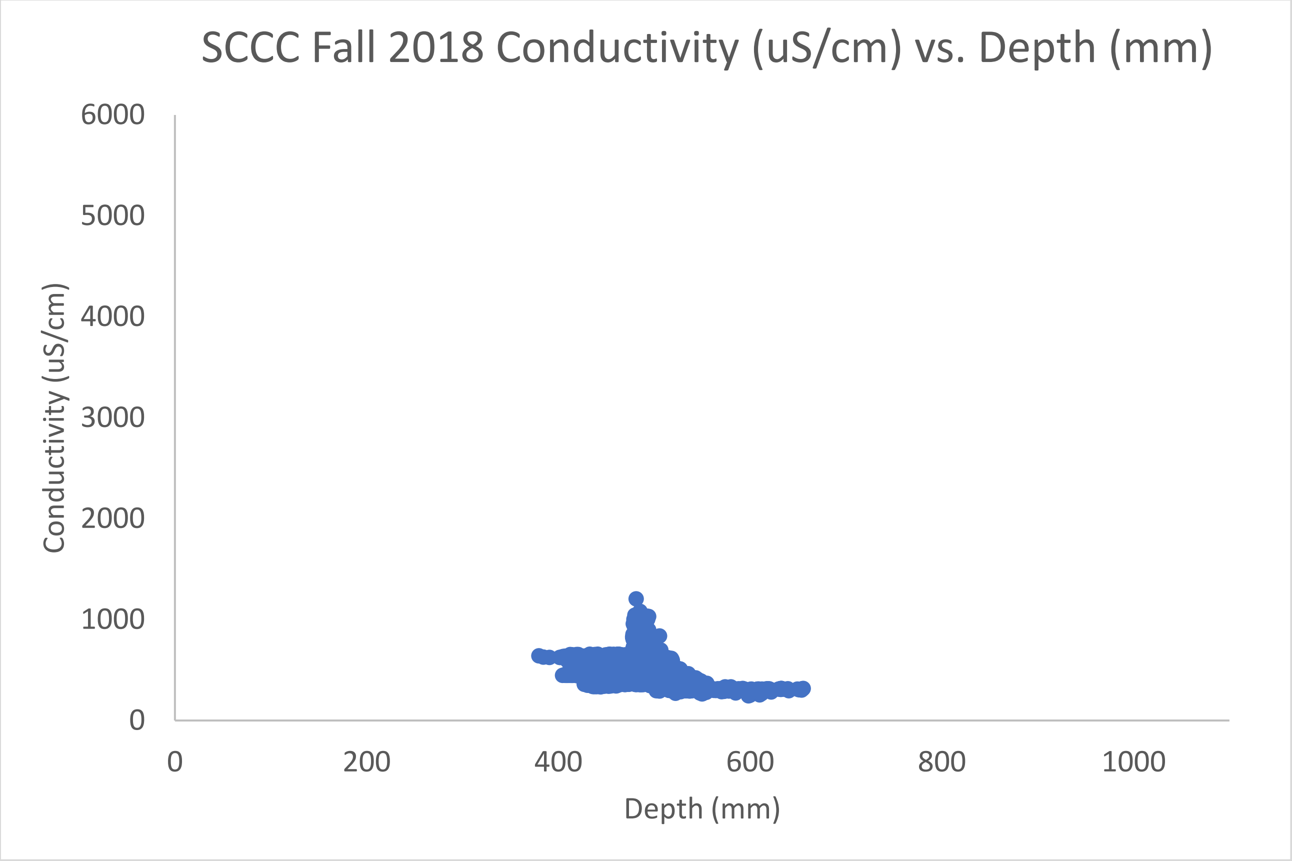




****BASED ON ONLY 1 MONTH OF SPRING 2018 DATA**



****SUMMER 2018: CTD SENSOR NEEDED TO BE REPAIRED; NO CONDUCTIVITY AND DEPTH DATA COLLECTED AT SCCC IN SUMMER 2018**


SCCC Fall 2018 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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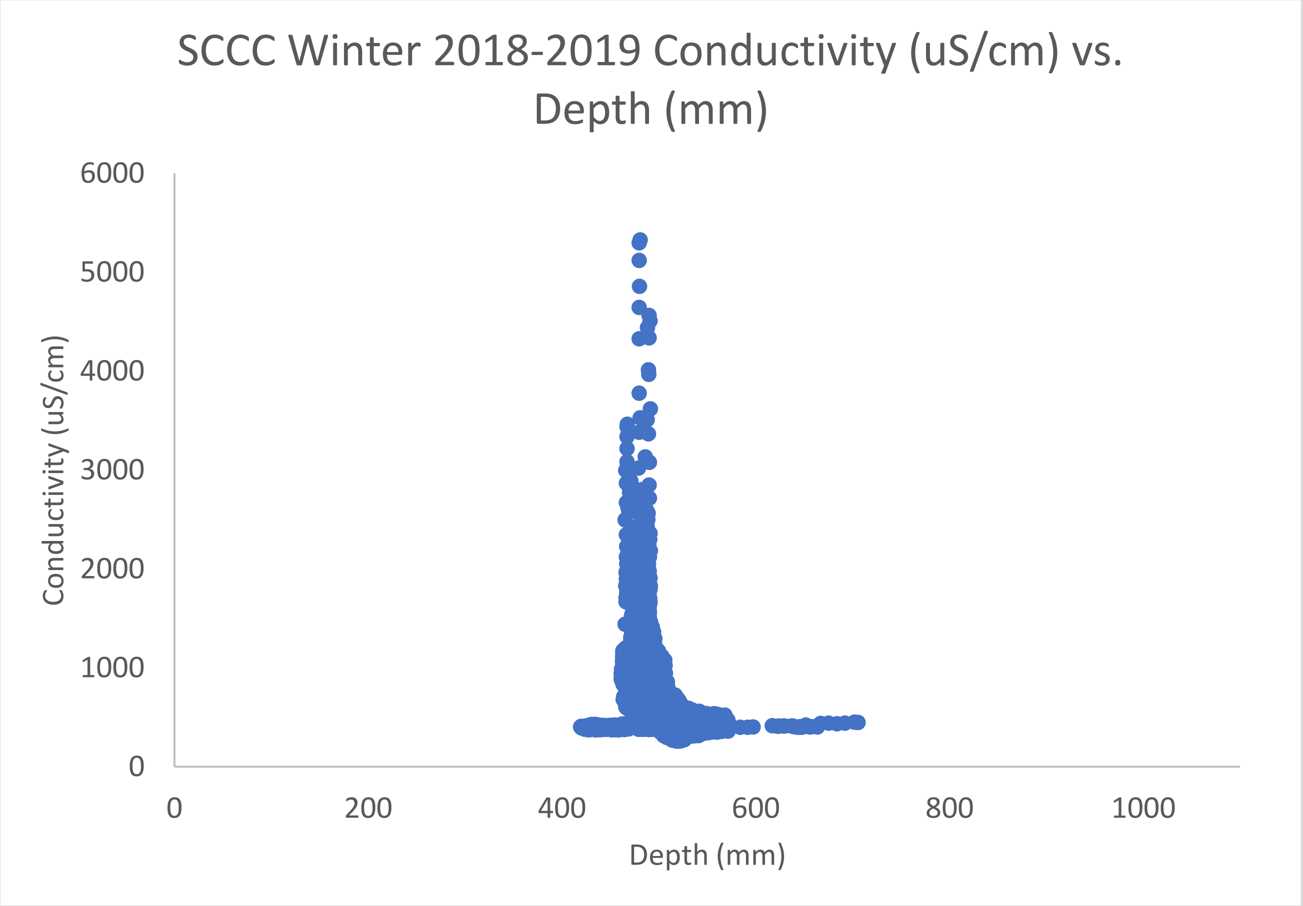
Depth (mm)


SCCC Winter 2018-2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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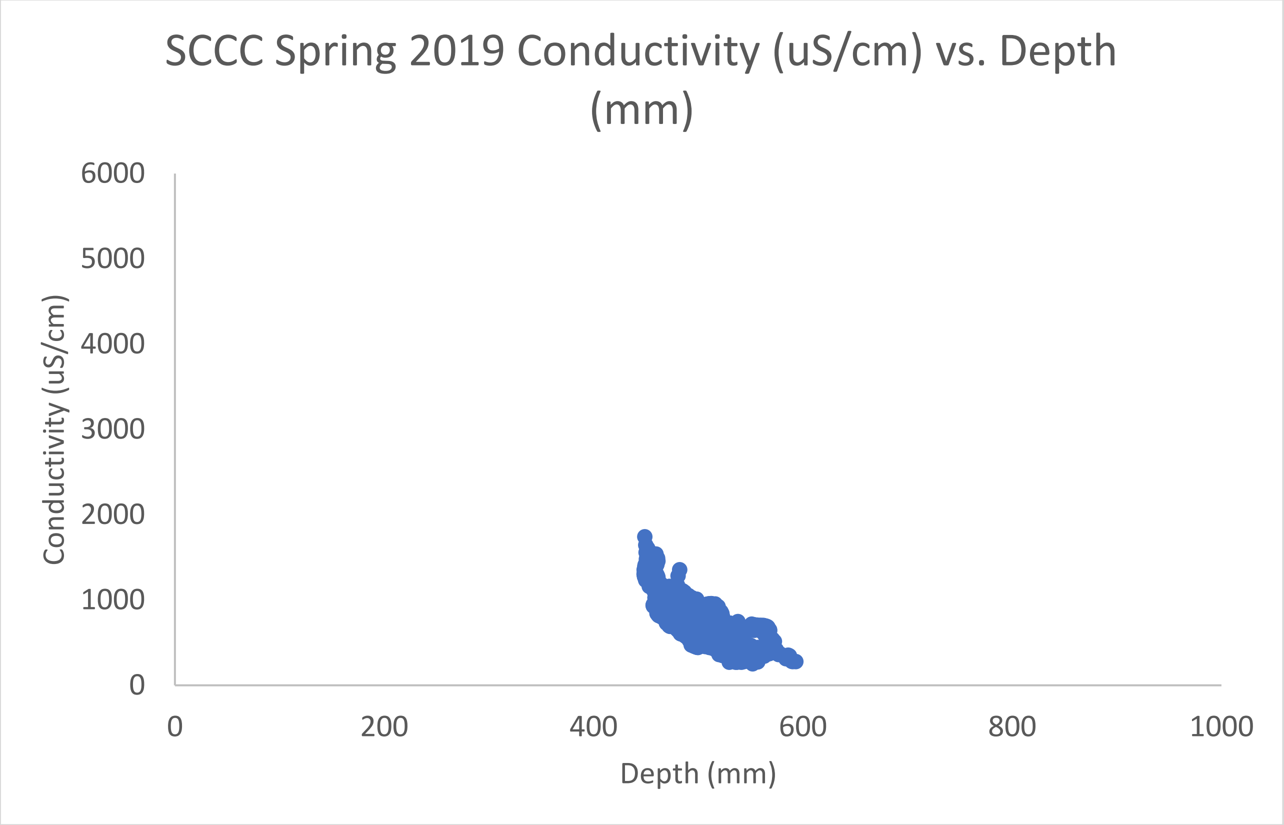
Depth (mm)


SCCC Spring 2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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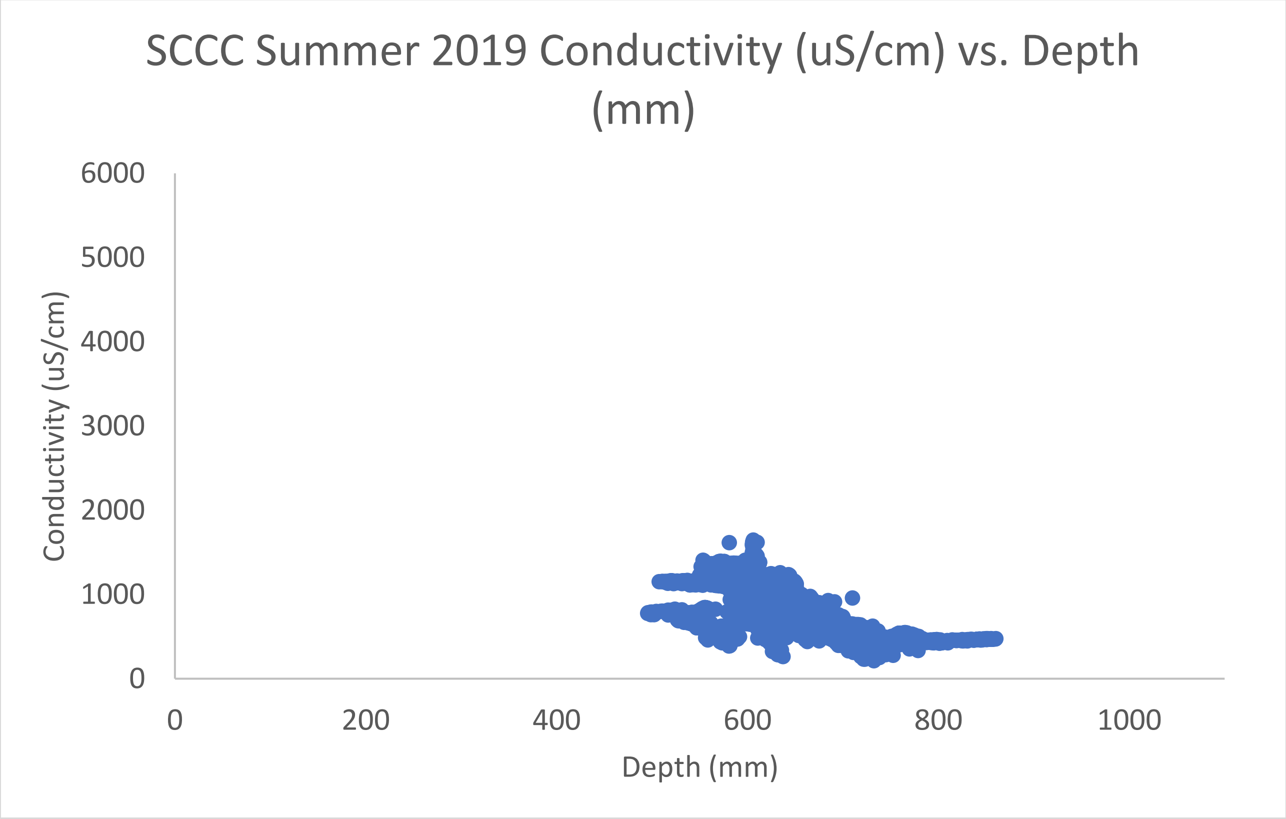
Depth (mm)


SCCC Summer 2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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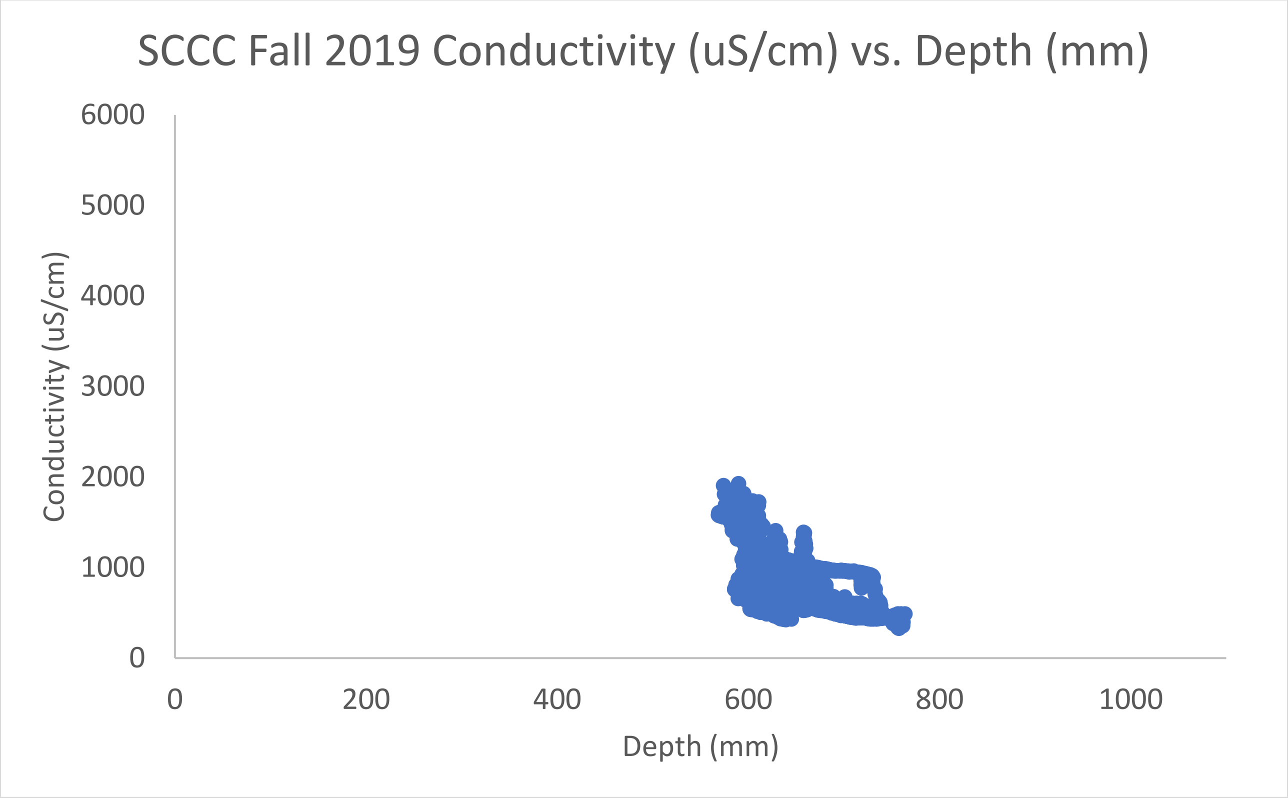
Depth (mm)


SCCC Fall 2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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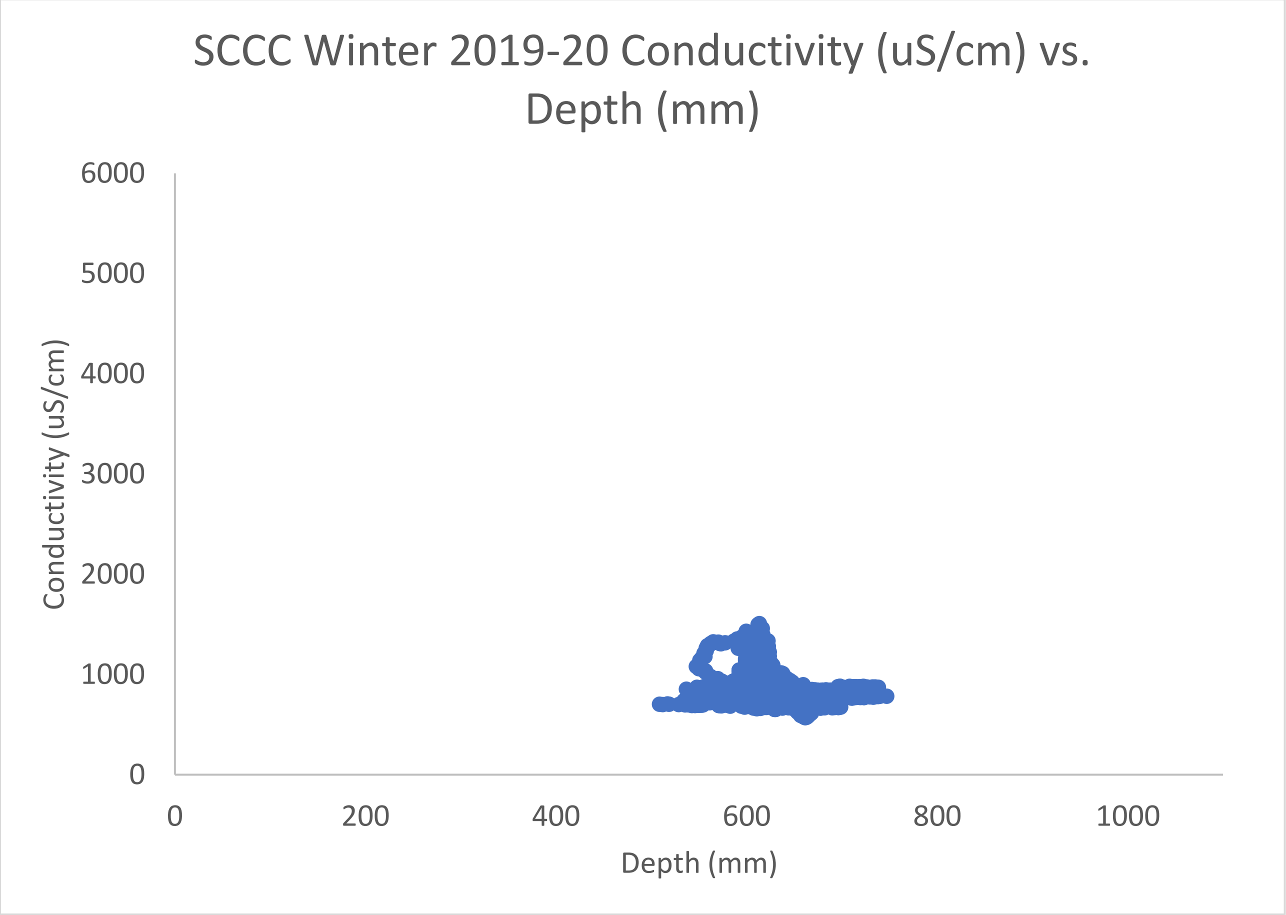
SCCC Winter 2019-20 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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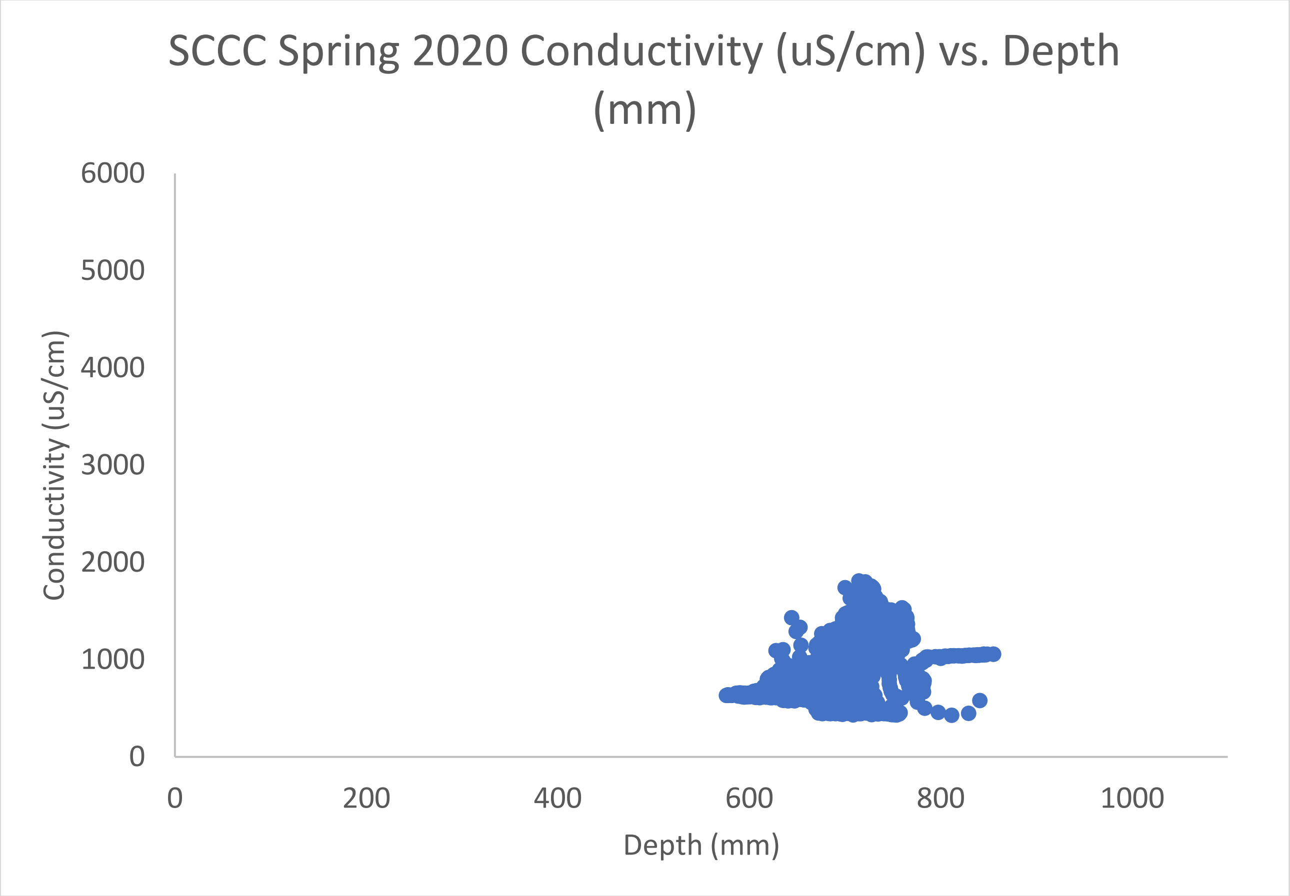
Depth (mm)


SCCC Spring 2020 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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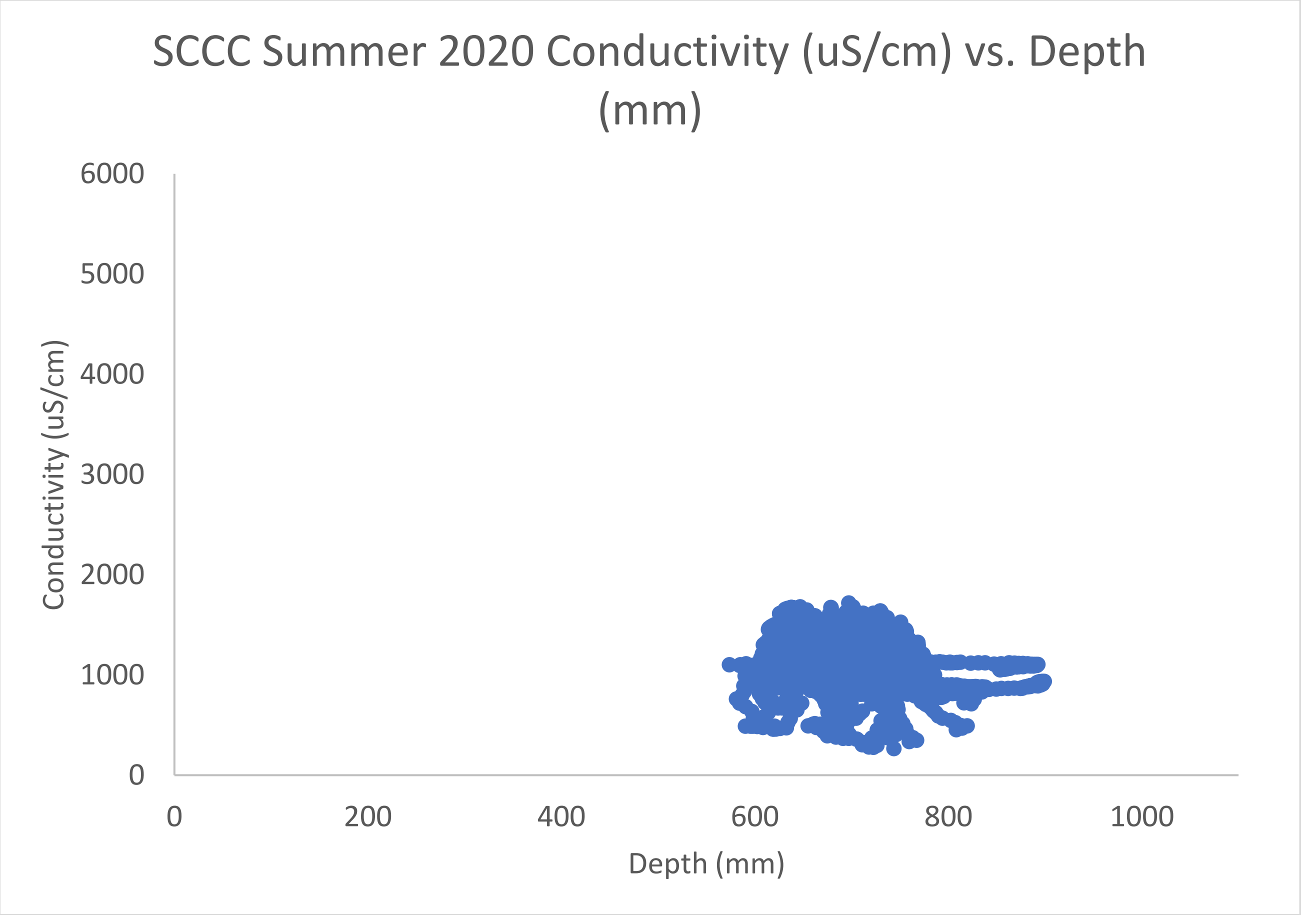
Depth (mm)


SCCC Summer 2020 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
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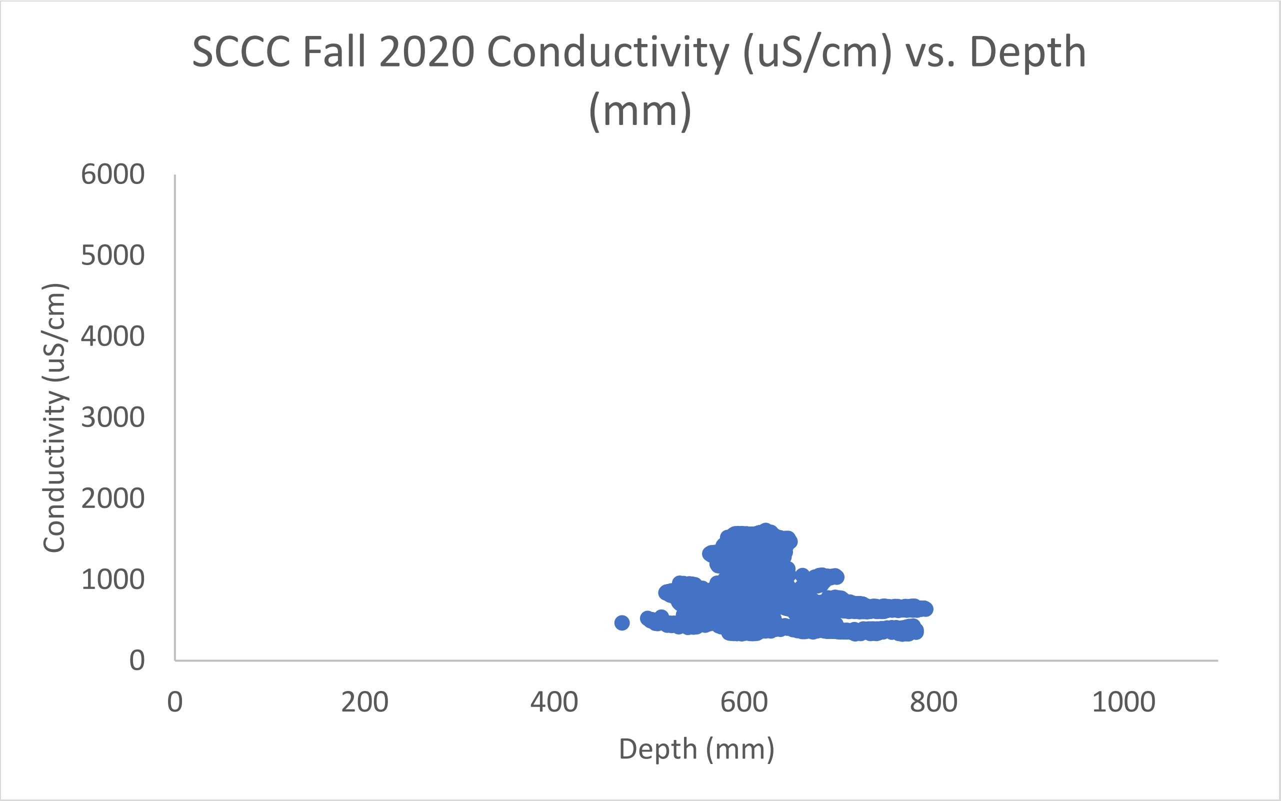
Depth (mm)


SCCC Fall 2020 Conductivity (uS/cm) vs. Depth (mm)
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Conductivity (uS/cm)
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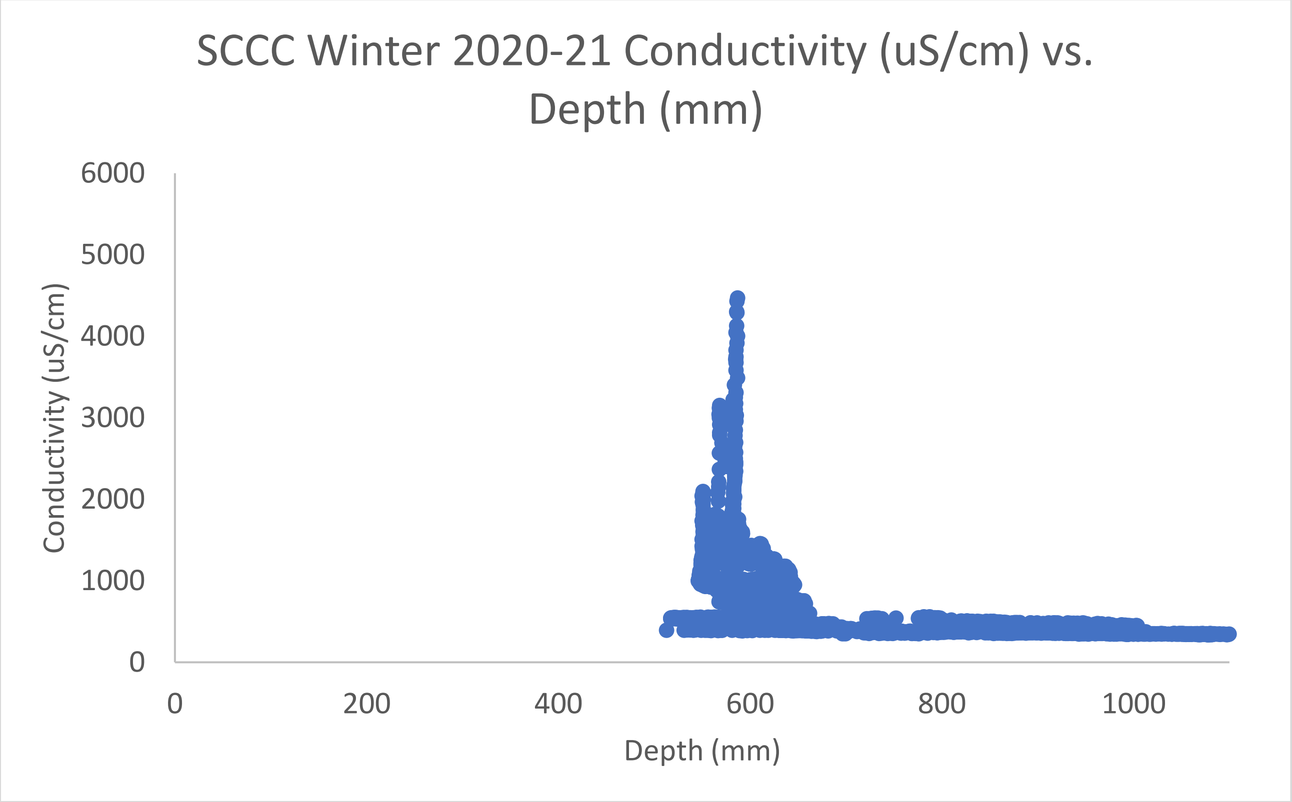
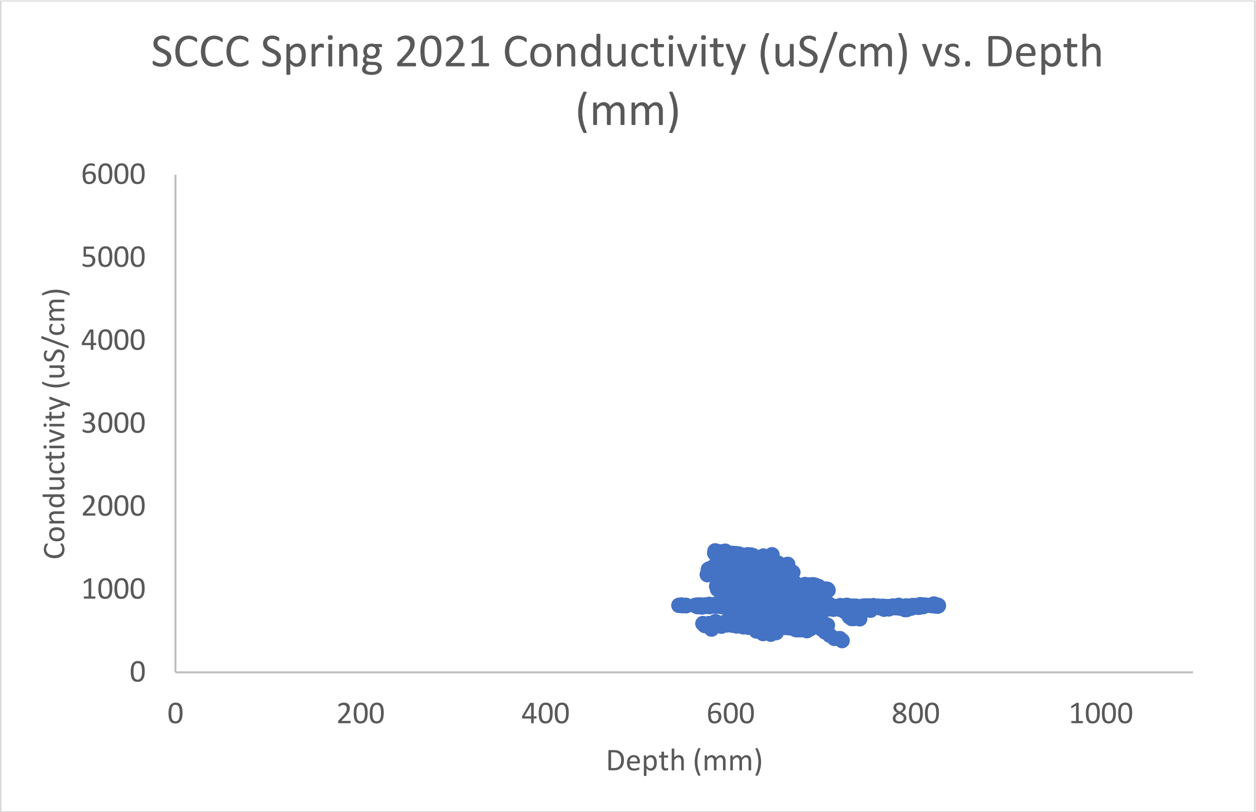
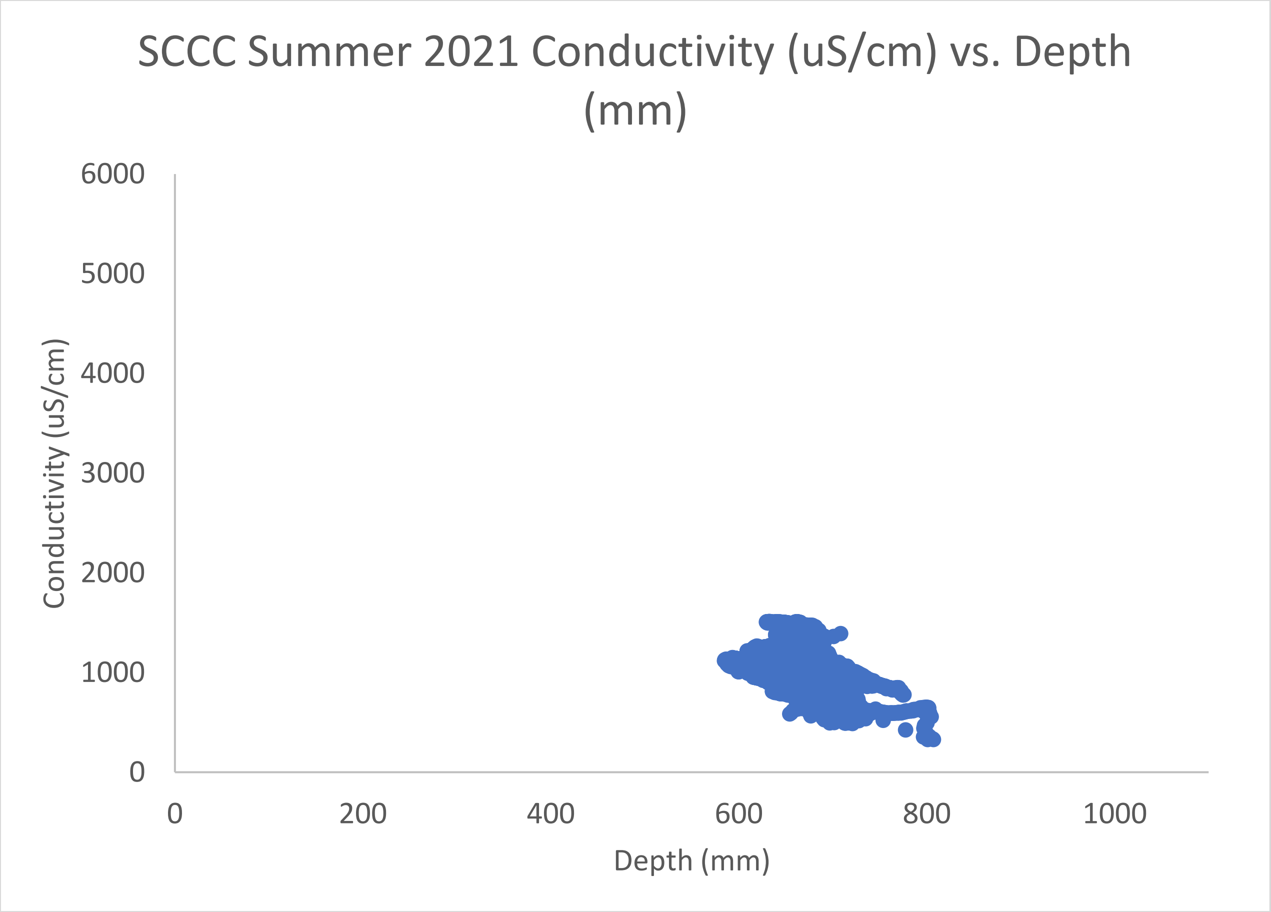
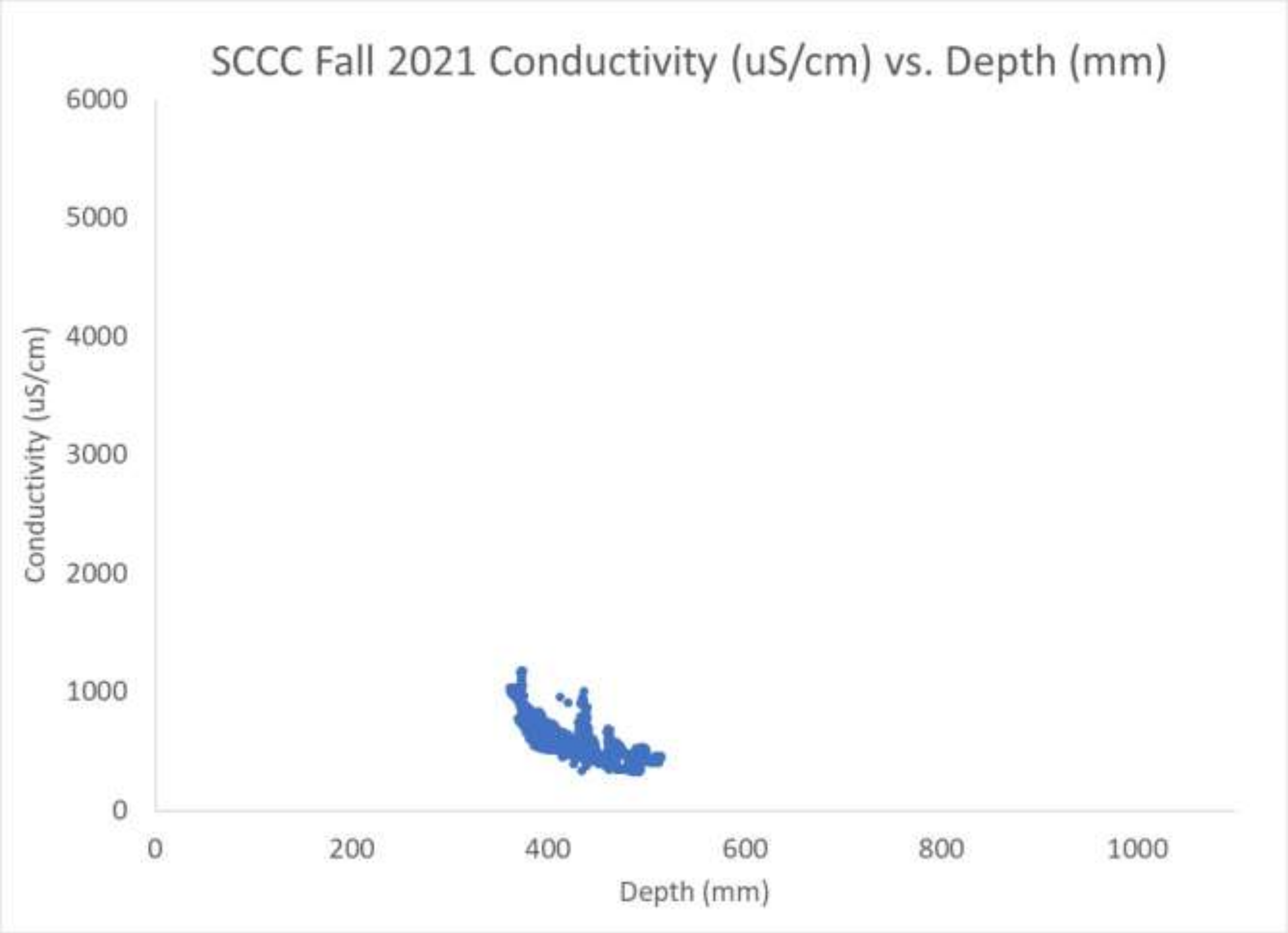
1000
Depth (mm)

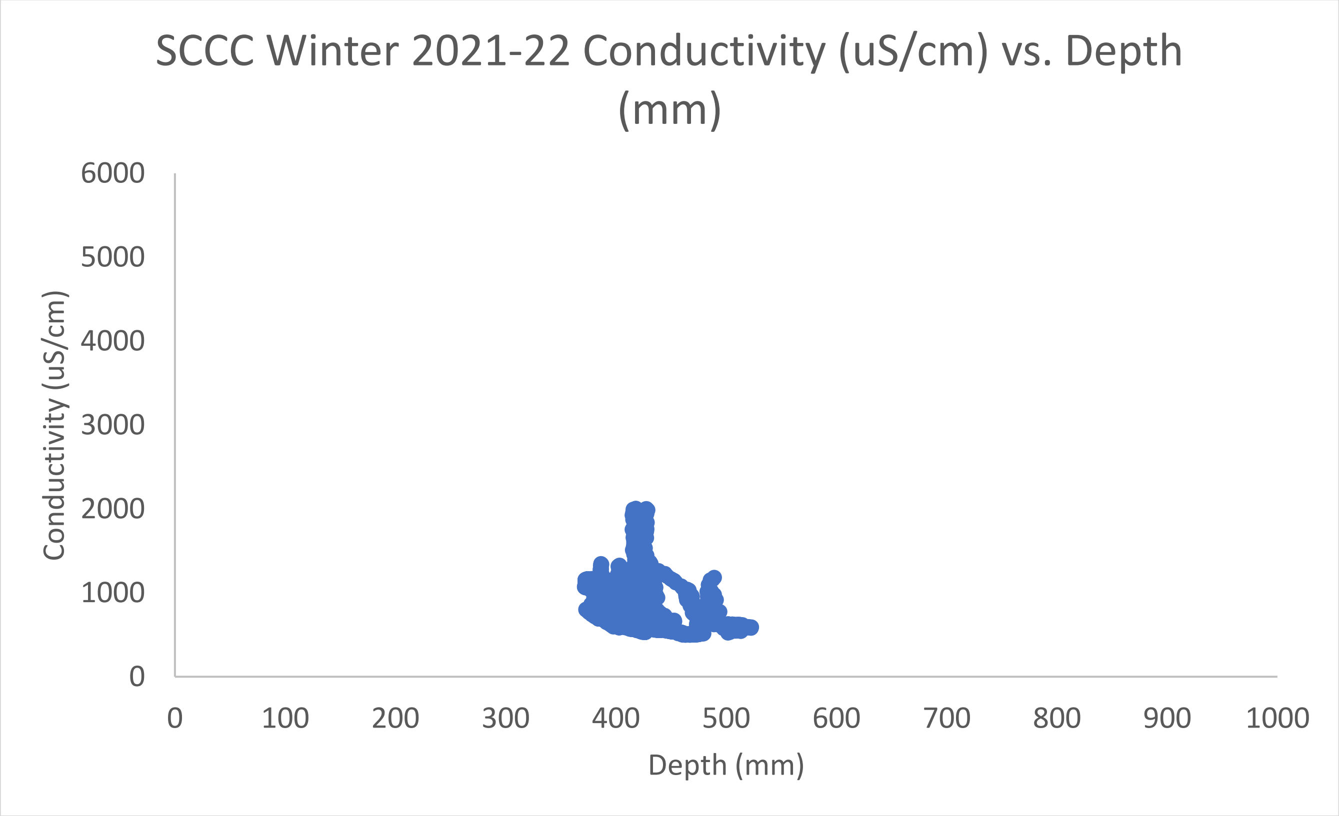

SCCC Winter 2020-21 Conductivity (uS/cm) vs. Depth (mm)
6000
5000
4000
3000
2000
1000
0
Conductivity (uS/cm)
0
200
400
600
800
1000
Depth (mm)



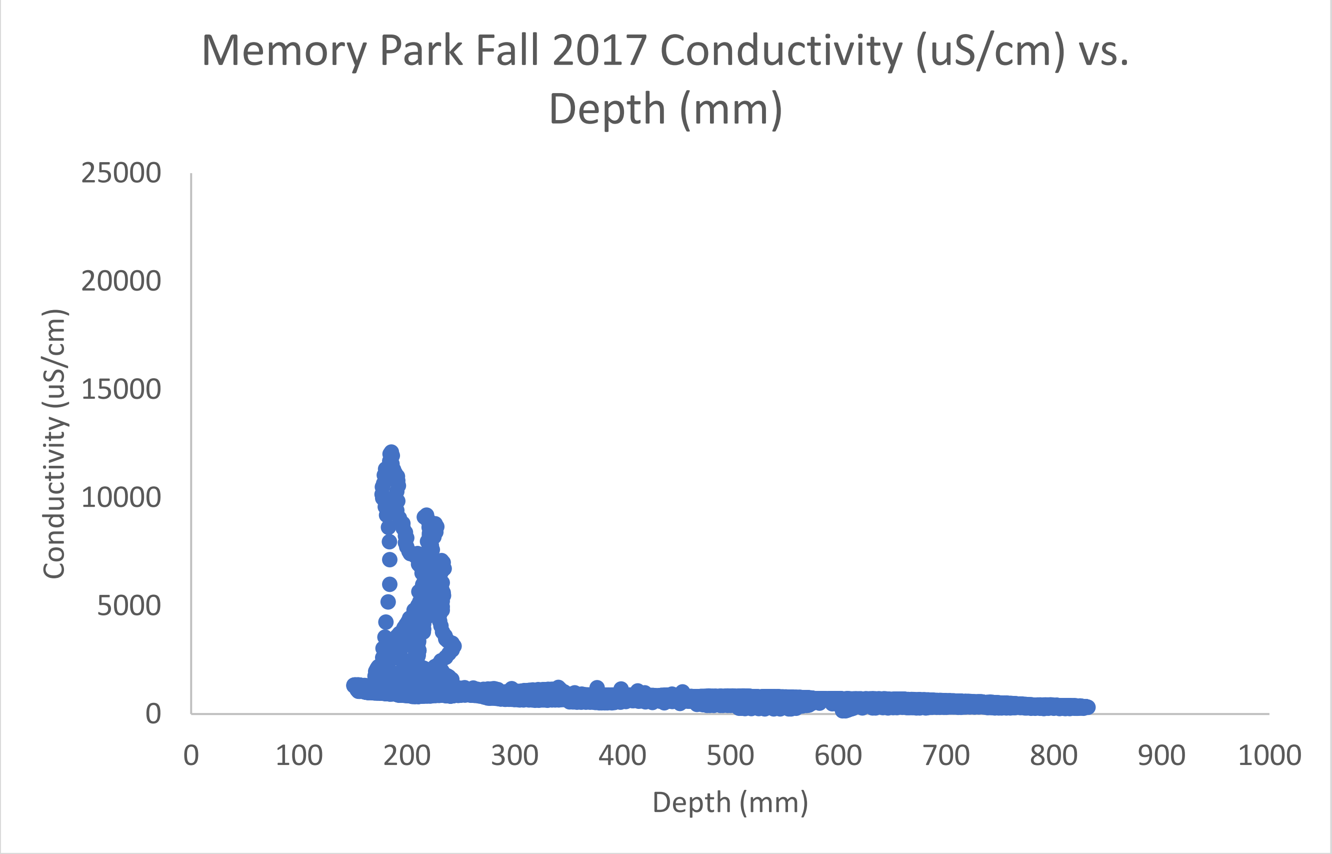
****BASED ON A LIMITED DATASET; MISSING SCCC CONDUCTIVITY AND DEPTH DATA IN AUGUST AND EARLY SEPTEMBER**

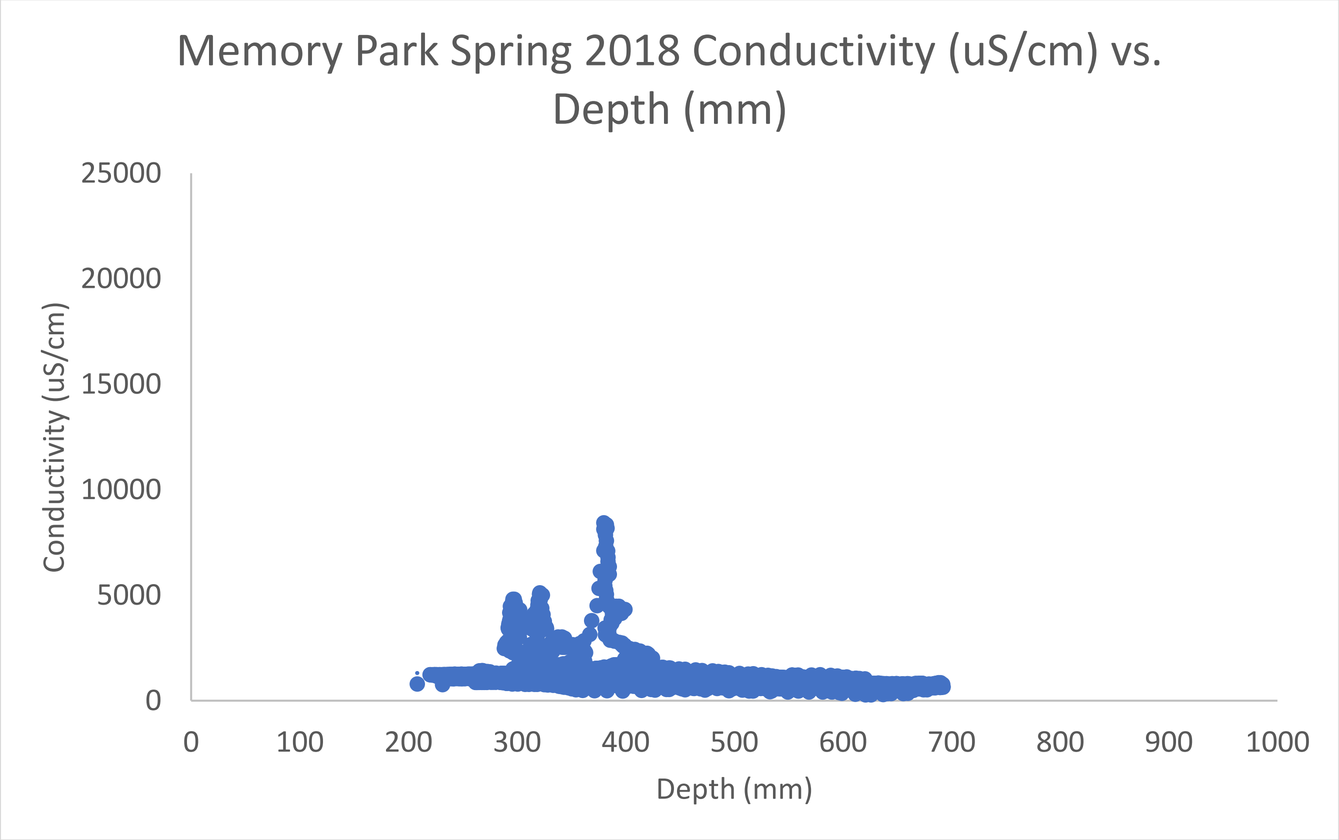


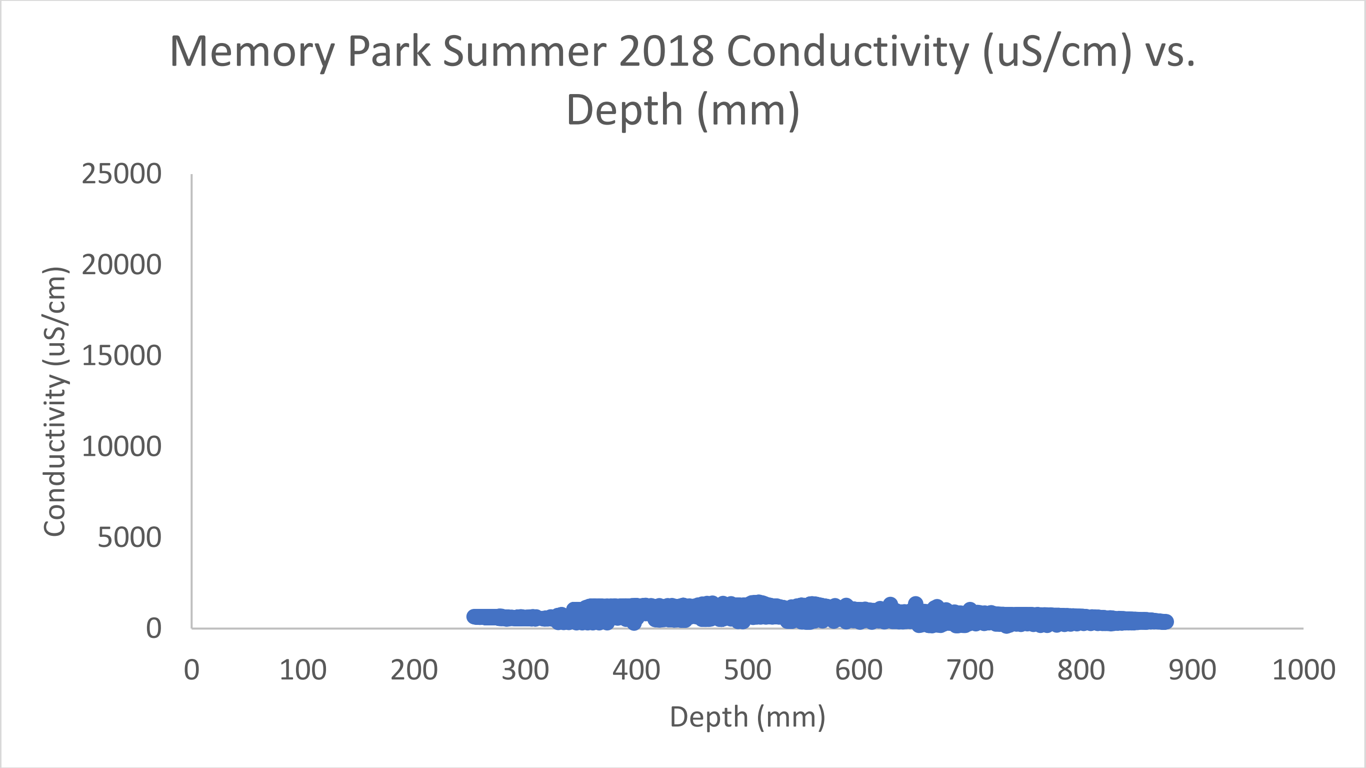

SCCC Fall 2021 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
6000
5000
4000
3000
2000
1000
0
0
200
400
600
800
1000
Depth (mm)

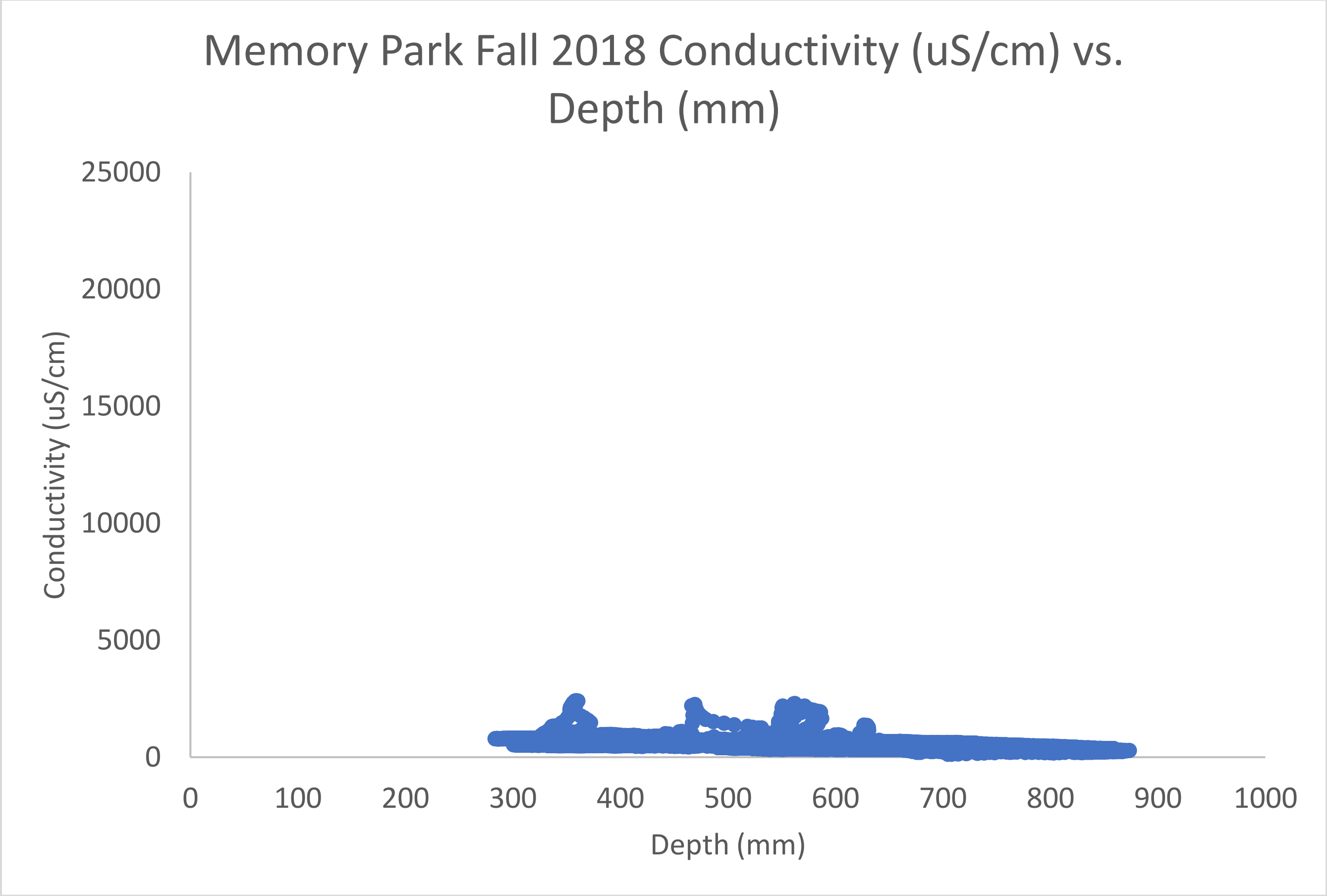

SCCC Winter 2021-22 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

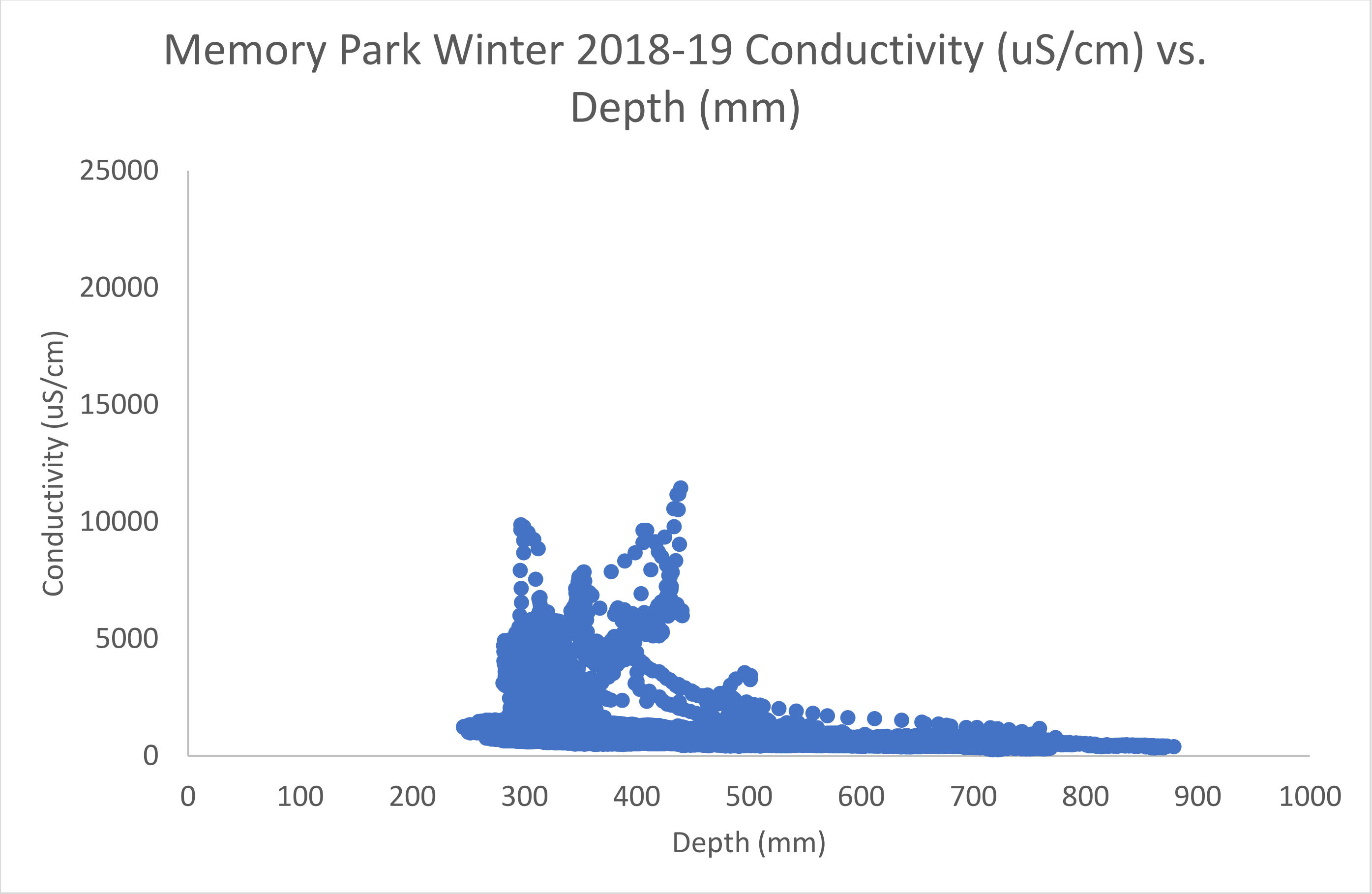
MEMORY PARK CONDUCTIVITY (uS/cm) VERSUS DEPTH (mm) BY SEASON

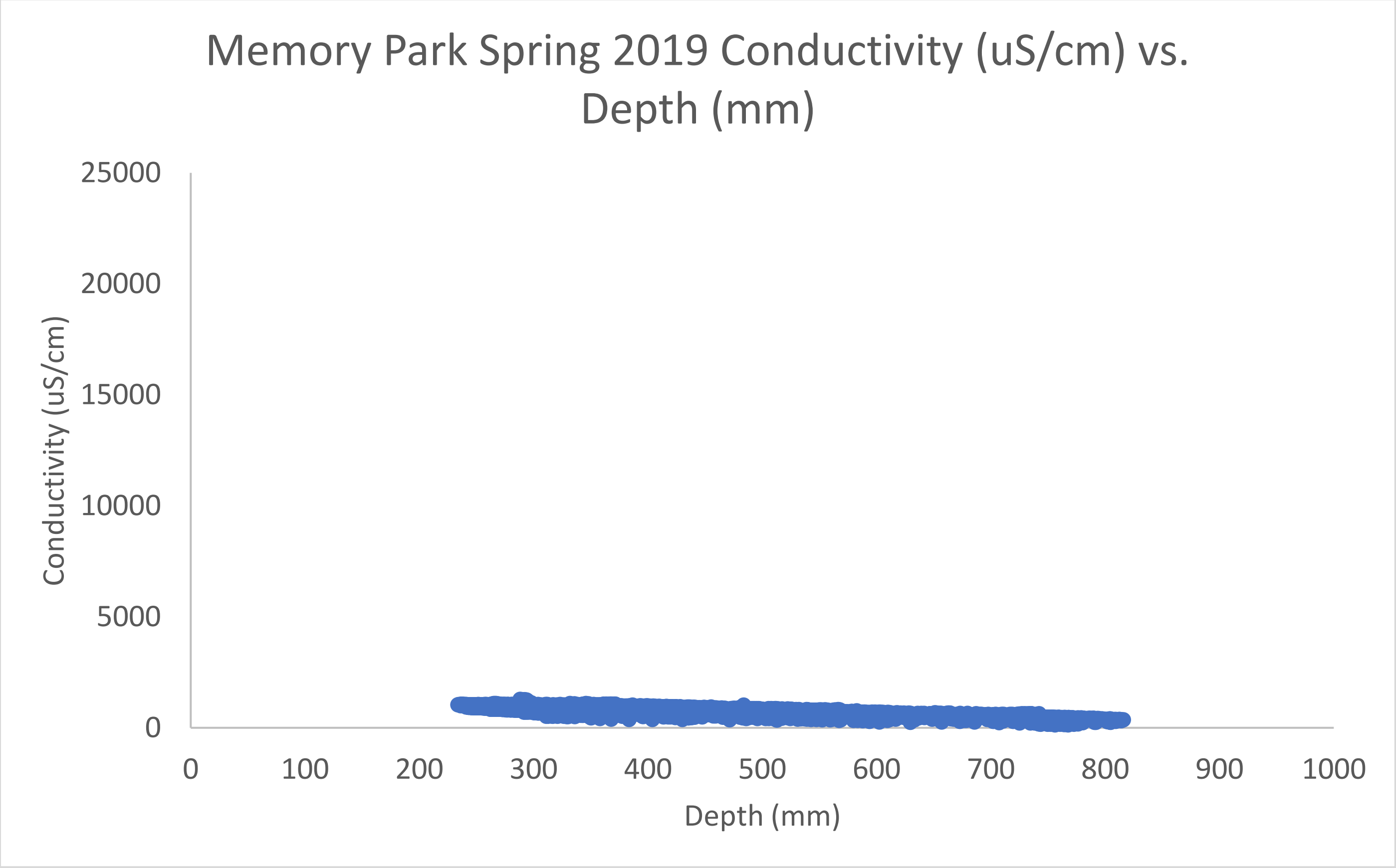


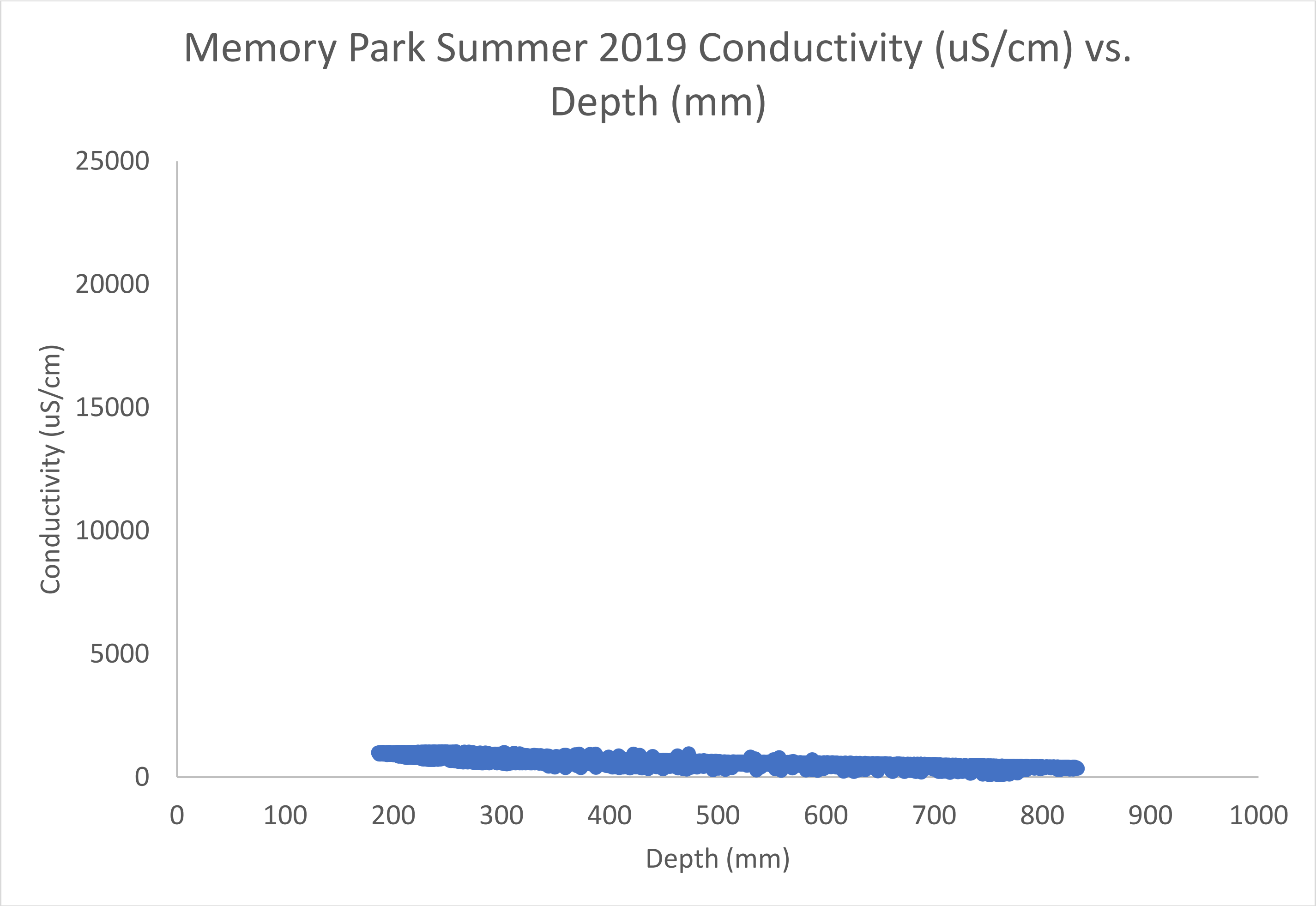


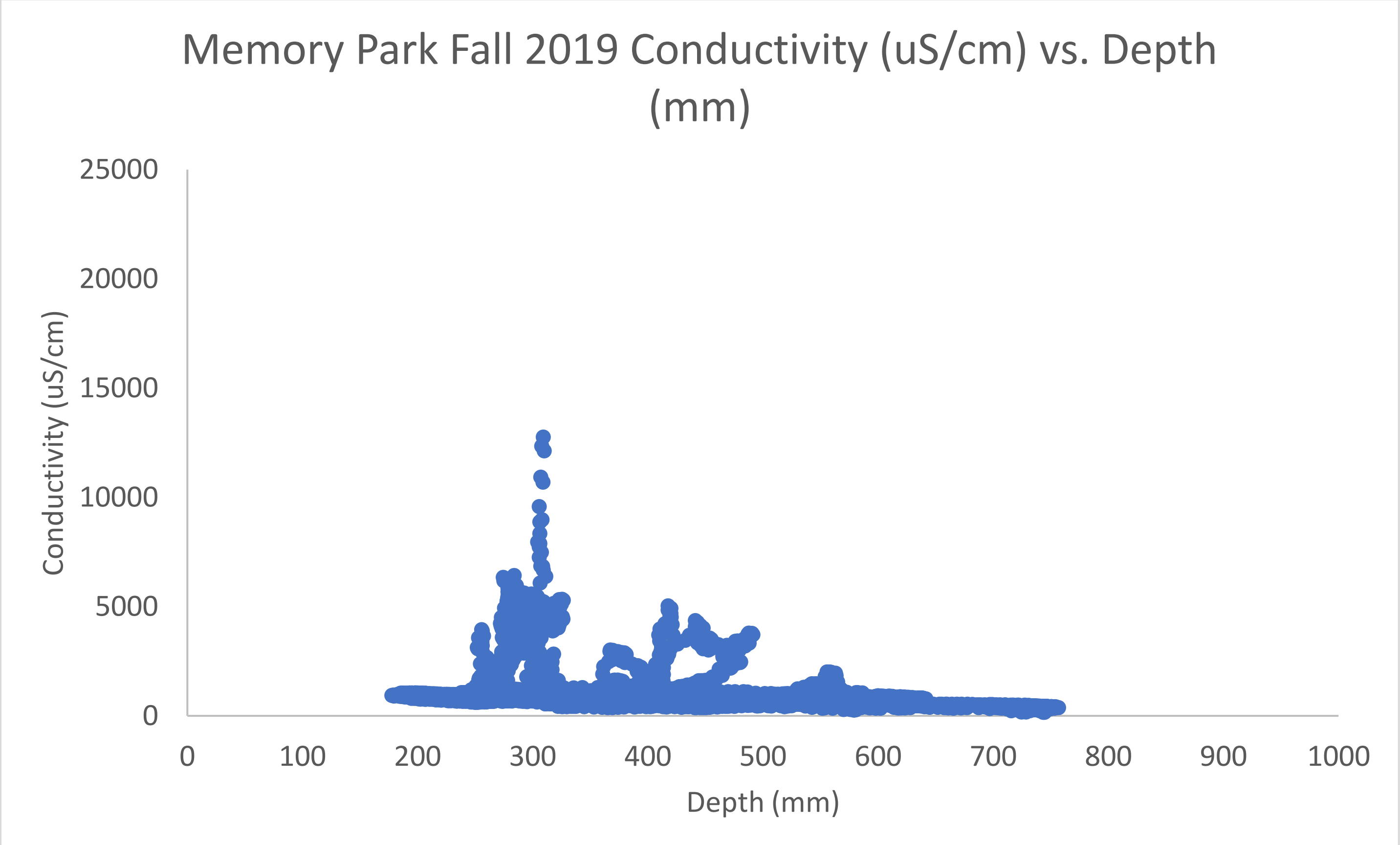

Memory Park Summer 2018 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

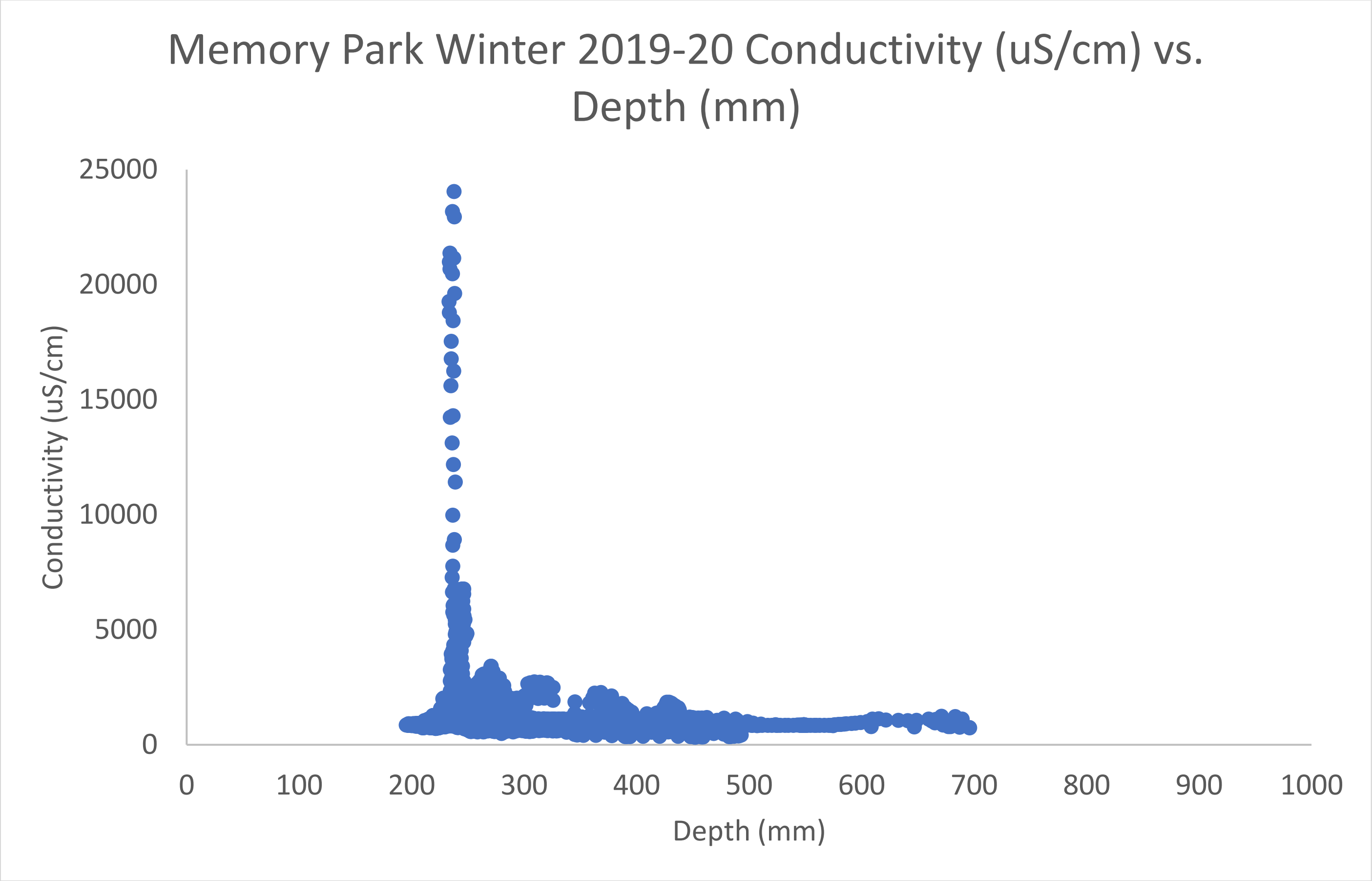

Memory Park Fall 2018 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

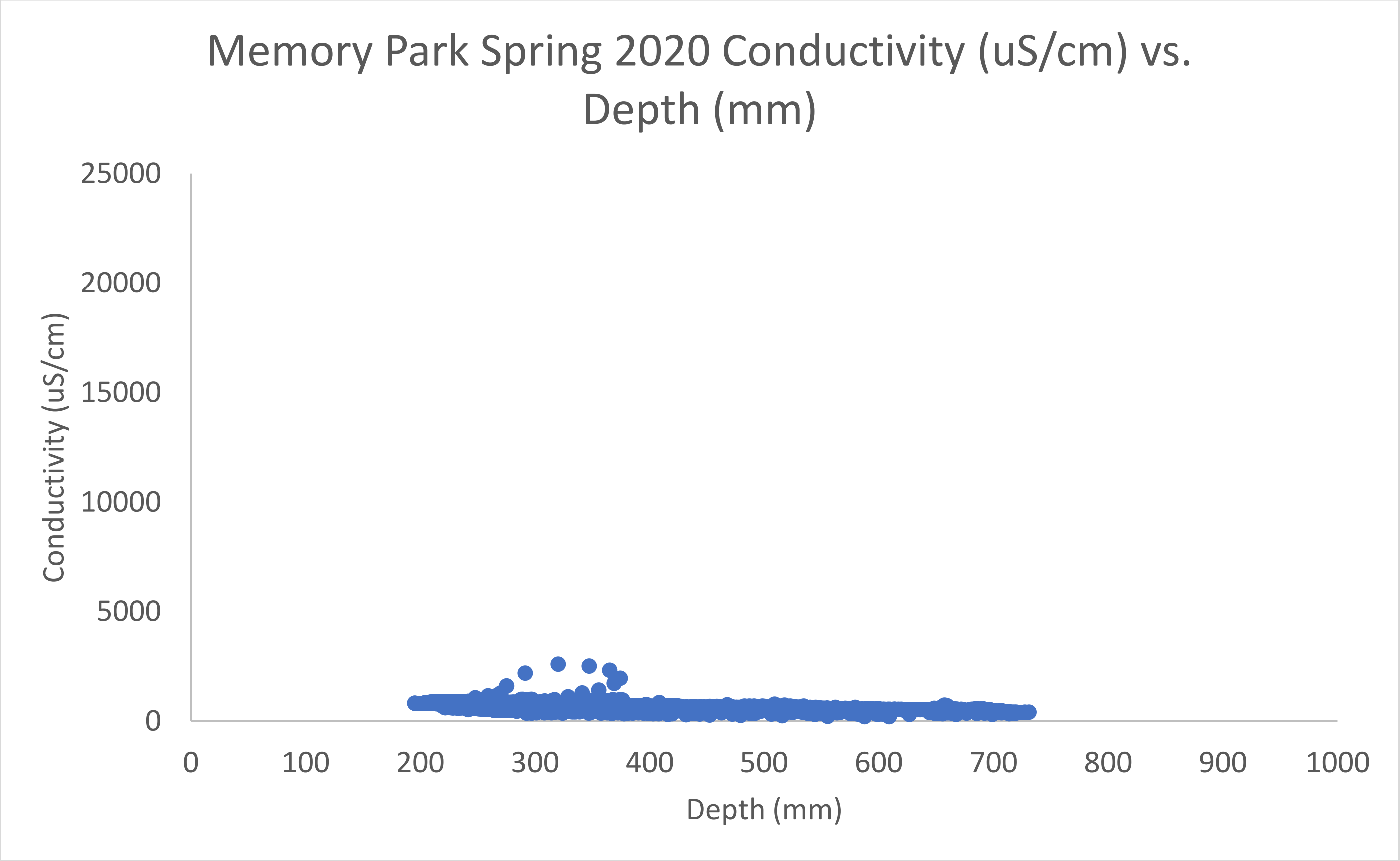

Memory Park Winter 2018-19 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

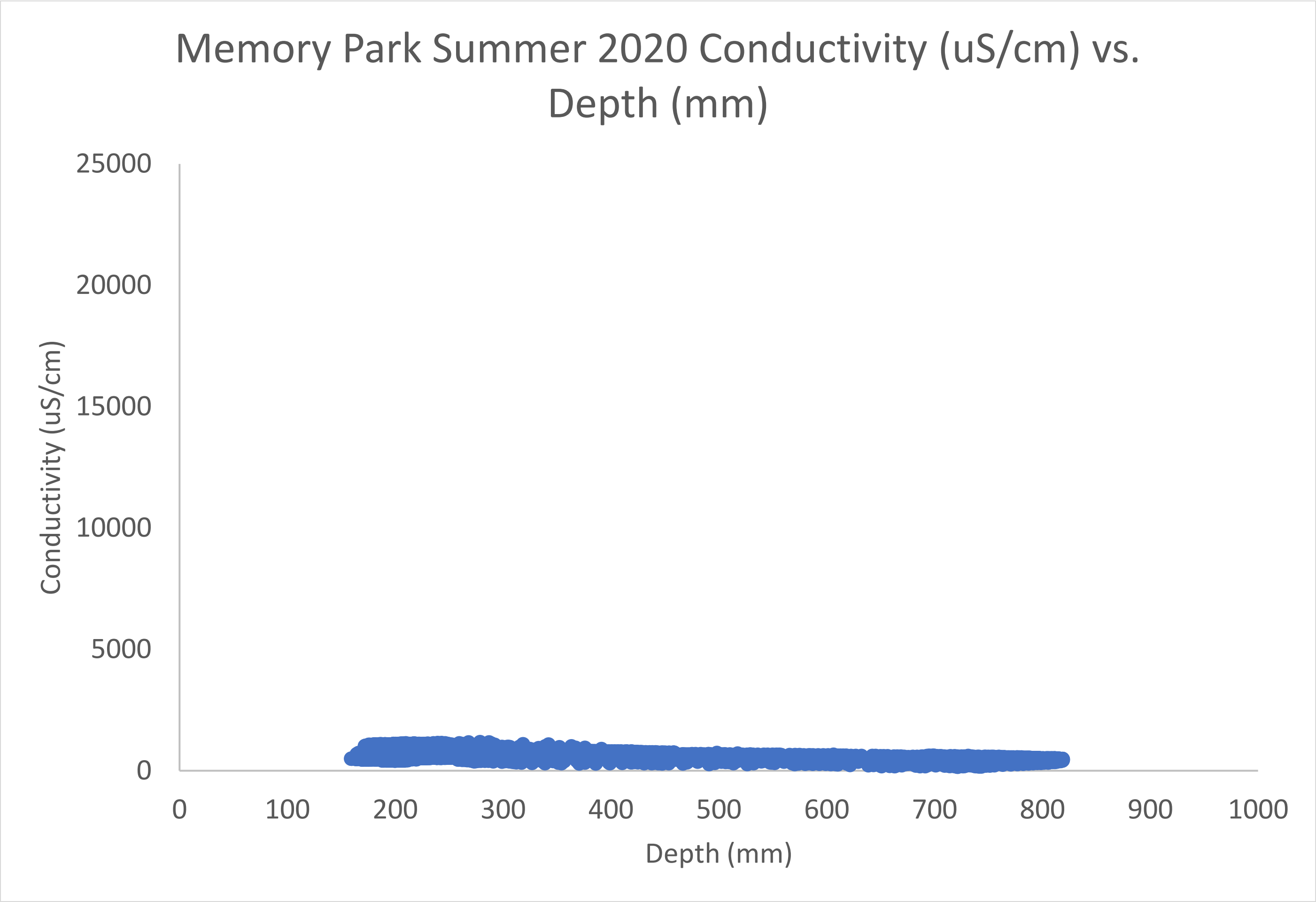

Memory Park Spring 2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

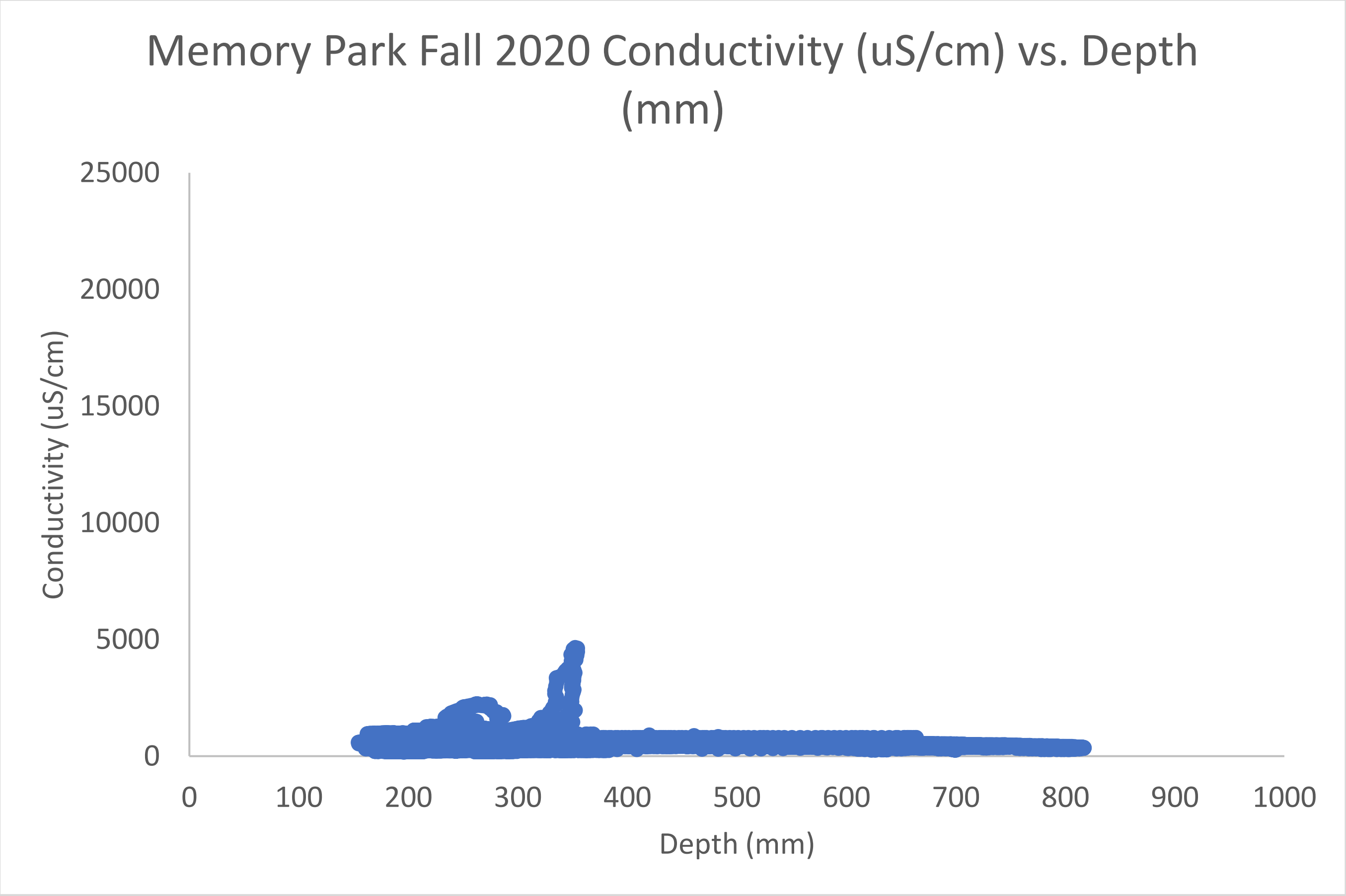

Memory Park Summer 2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

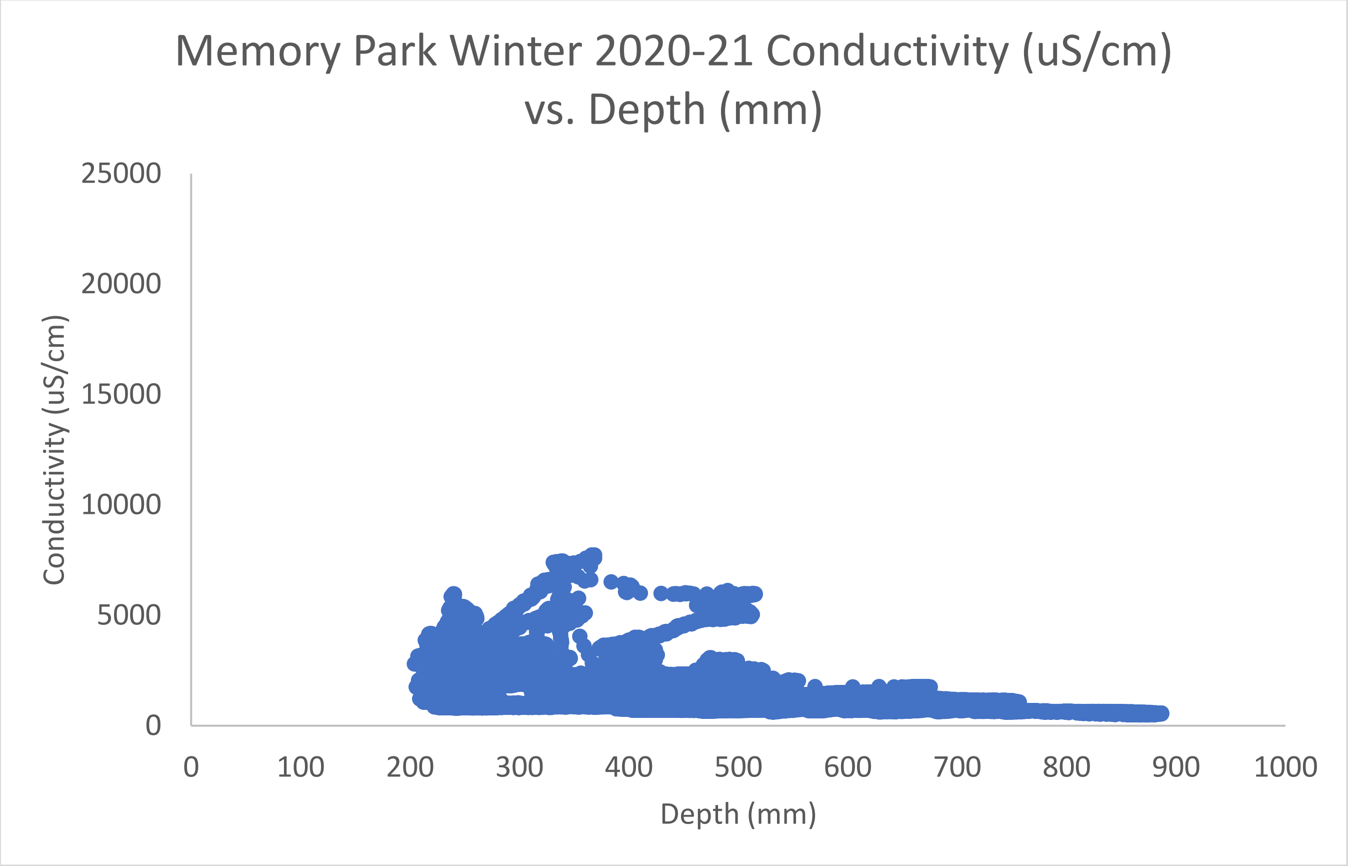

Memory Park Fall 2019 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

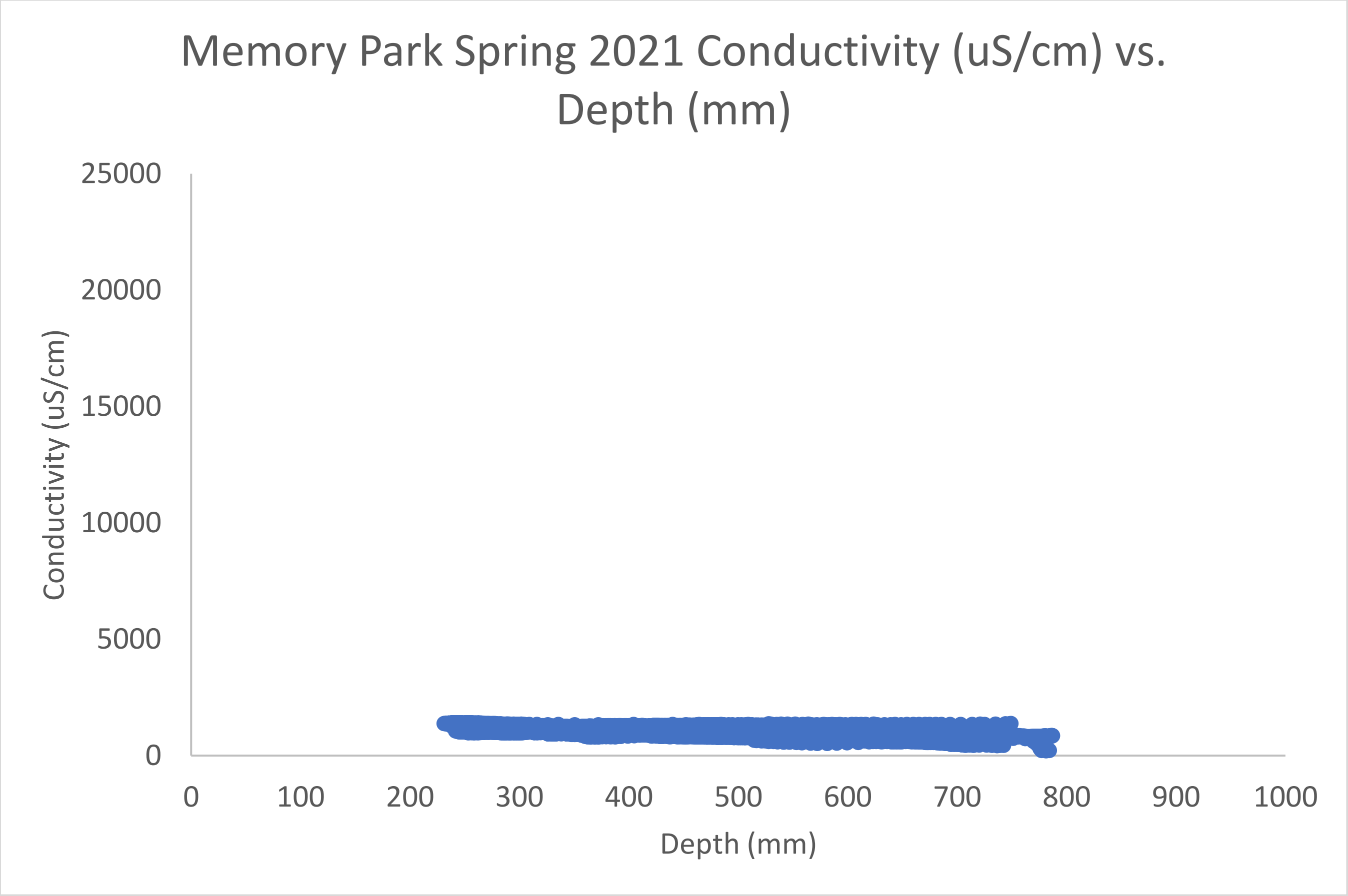

Memory Park Winter 2019-20 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

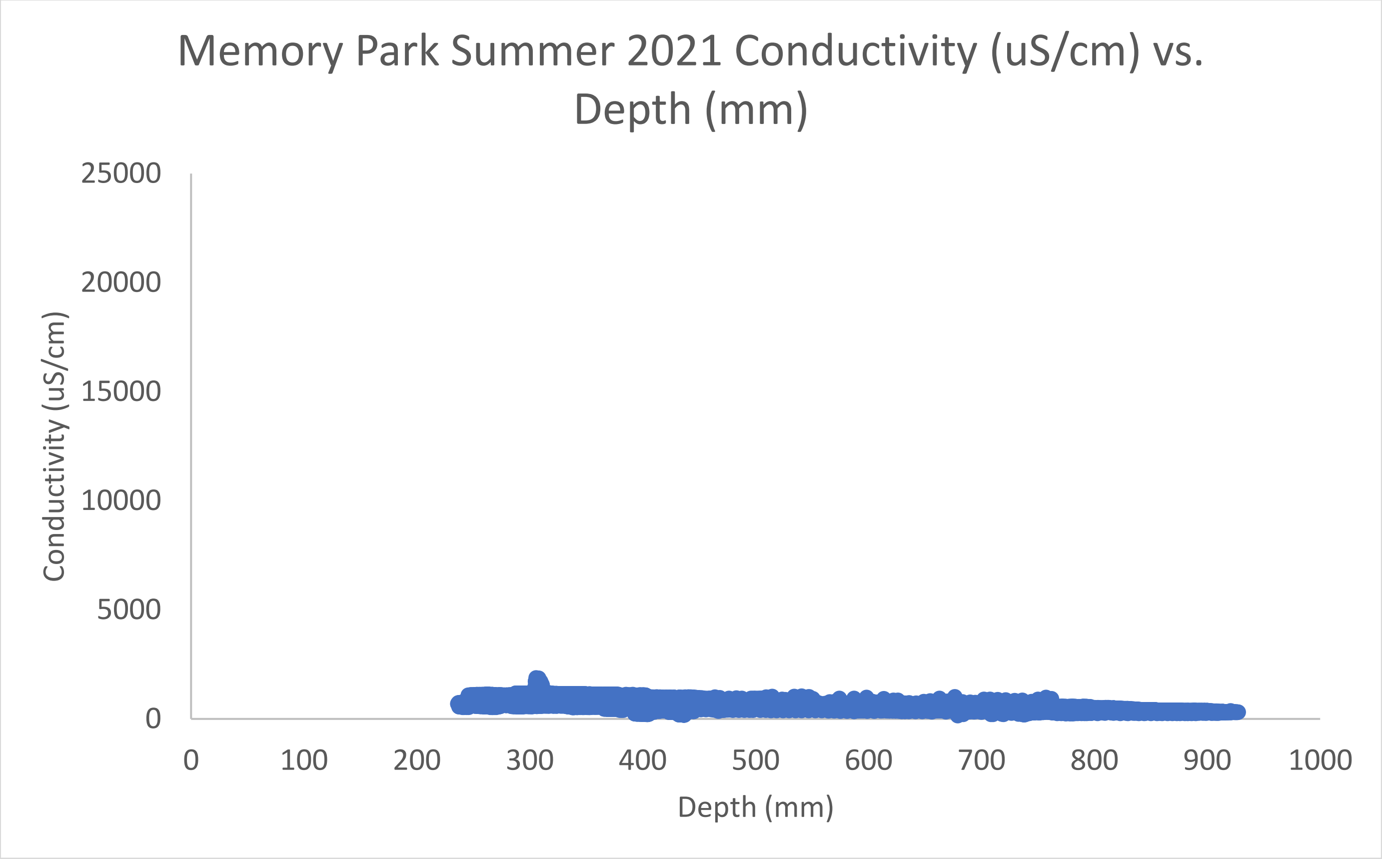

Memory Park Spring 2020 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

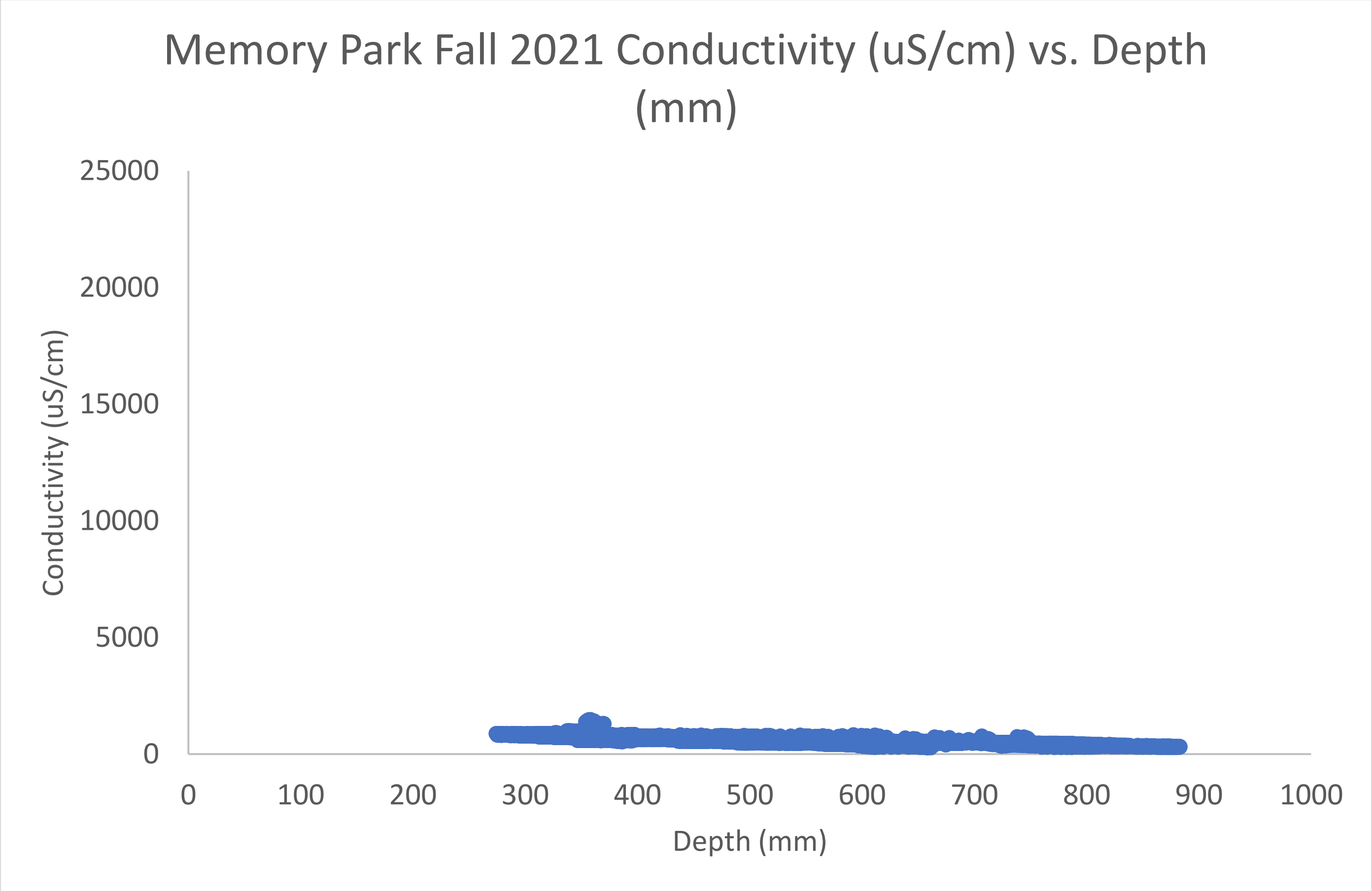

Memory Park Summer 2020 Conductivity (uS/cm) vs. Depth (mm)

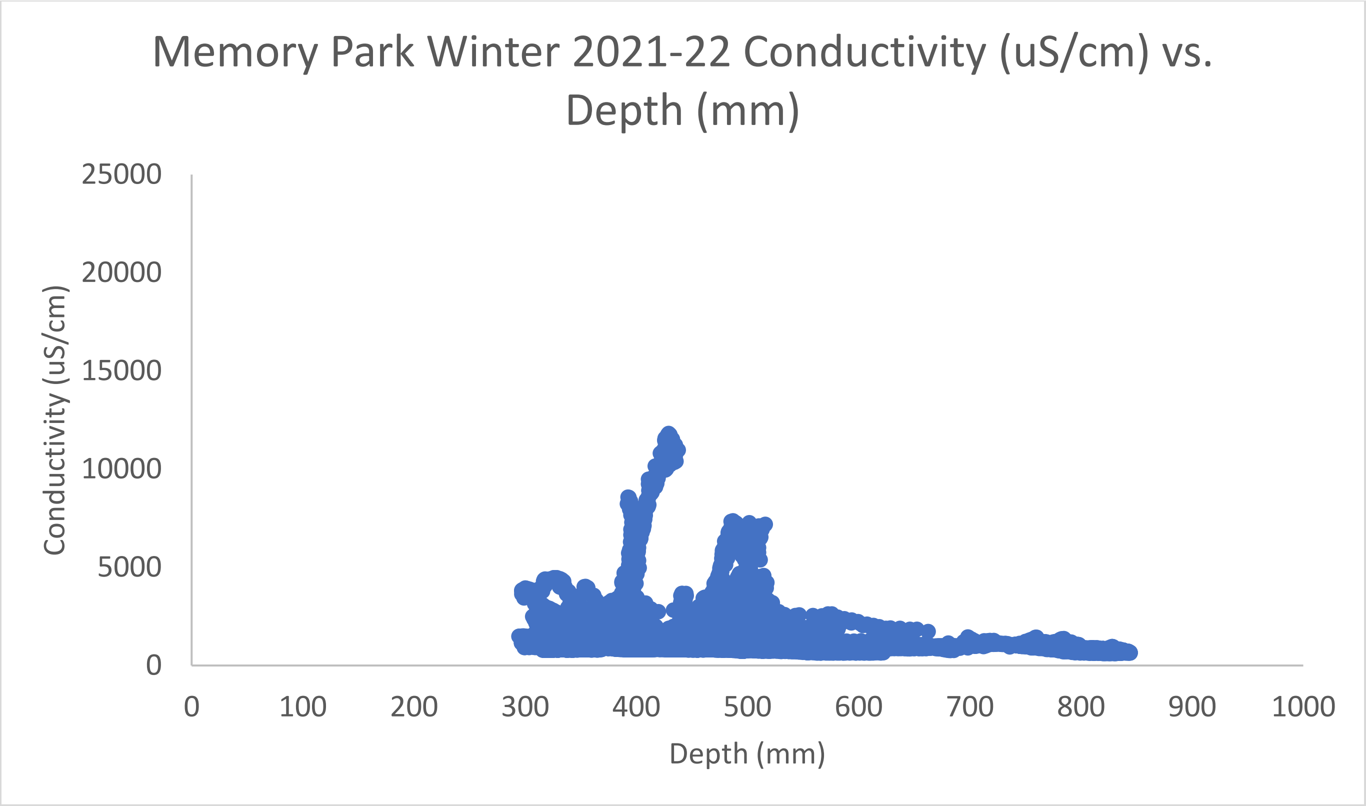

Memory Park Fall 2020 Conductivity (uS/cm) vs. Depth (mm)


Memory Park Winter 2020-21 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

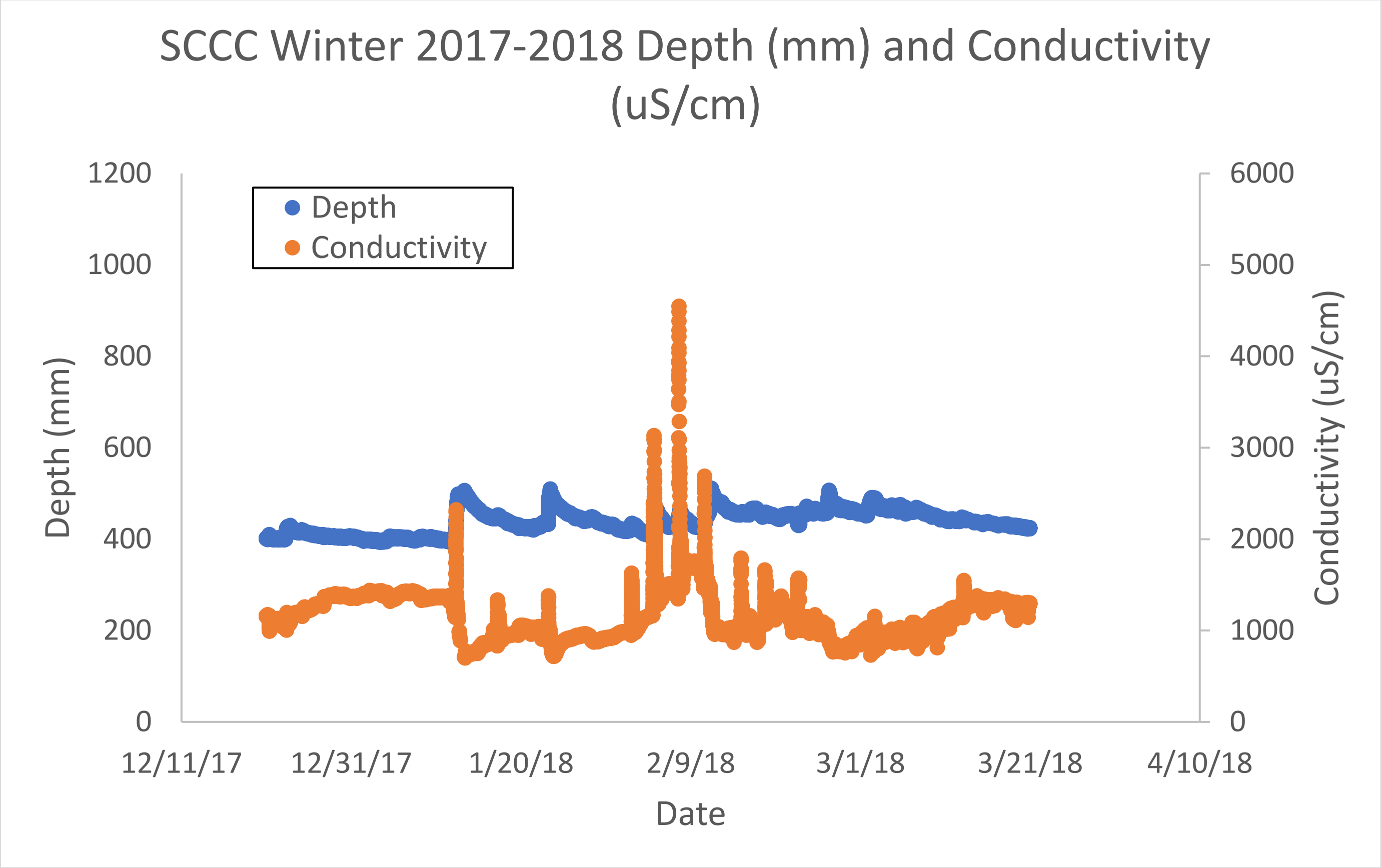

Memory Park Spring 2021 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

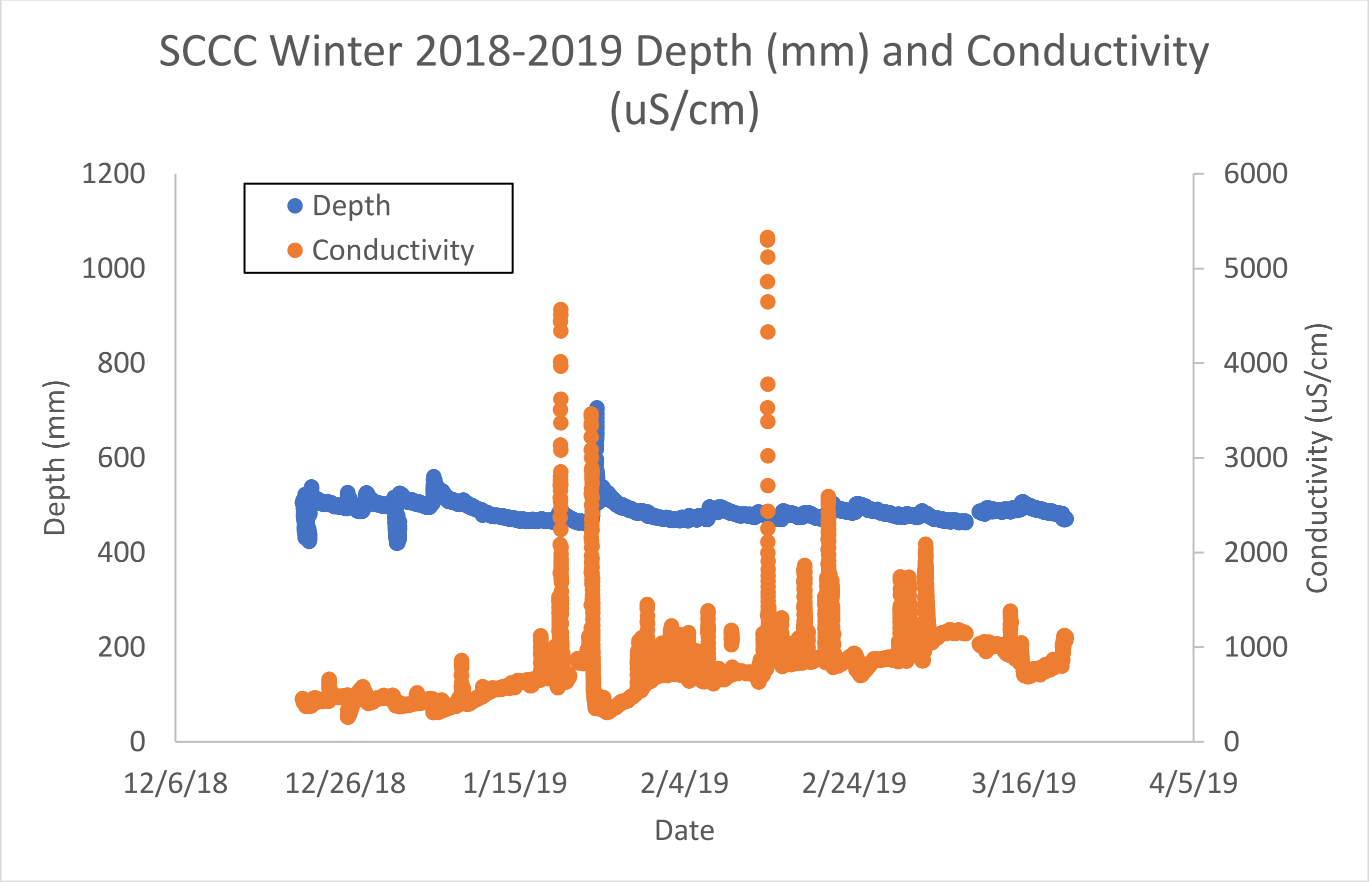

Memory Park Summer 2021 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

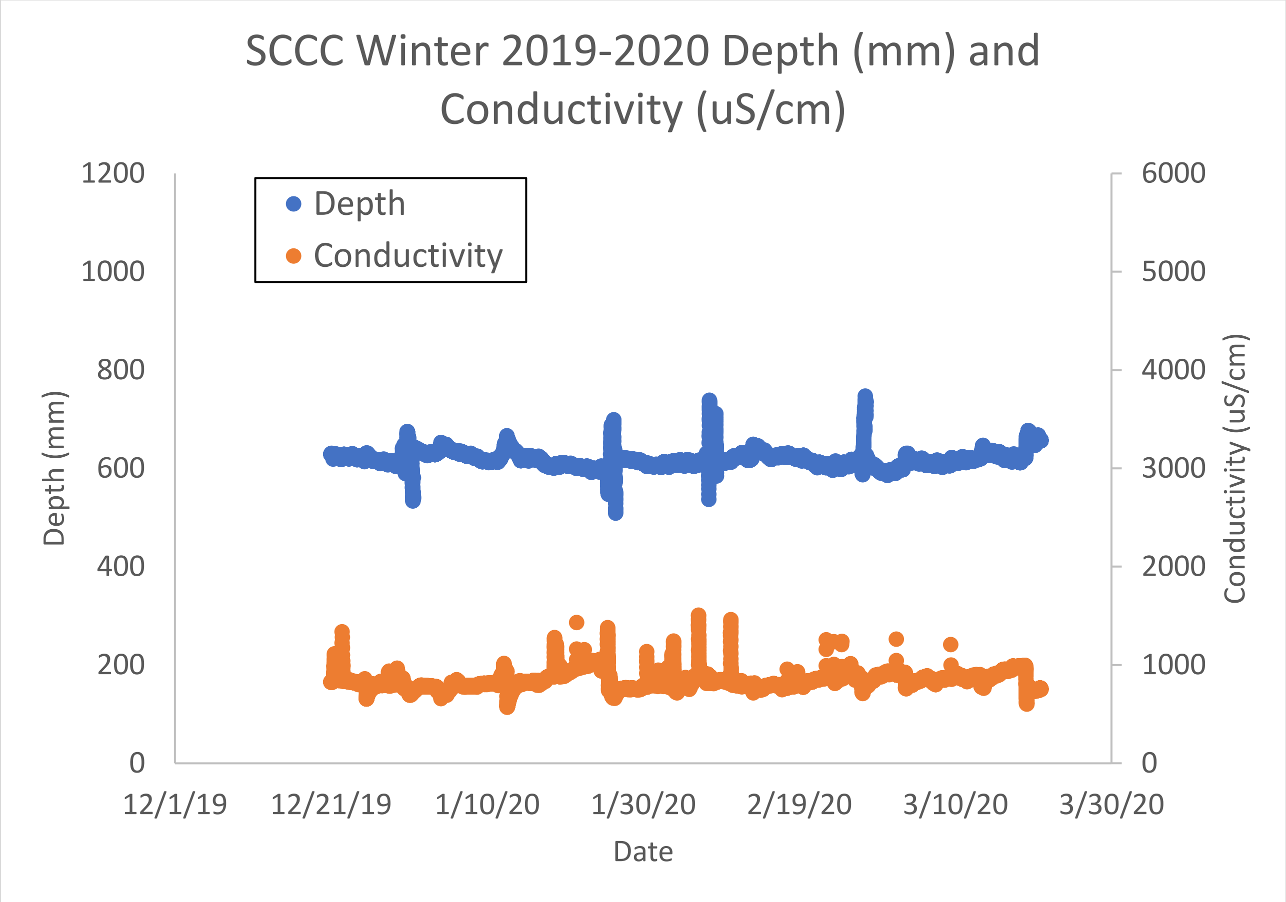

Memory Park Fall 2021 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)


Memory Park Winter 2021-22 Conductivity (uS/cm) vs. Depth (mm)
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
0
100
200
300
400
500
600
700
800
900
1000
Depth (mm)

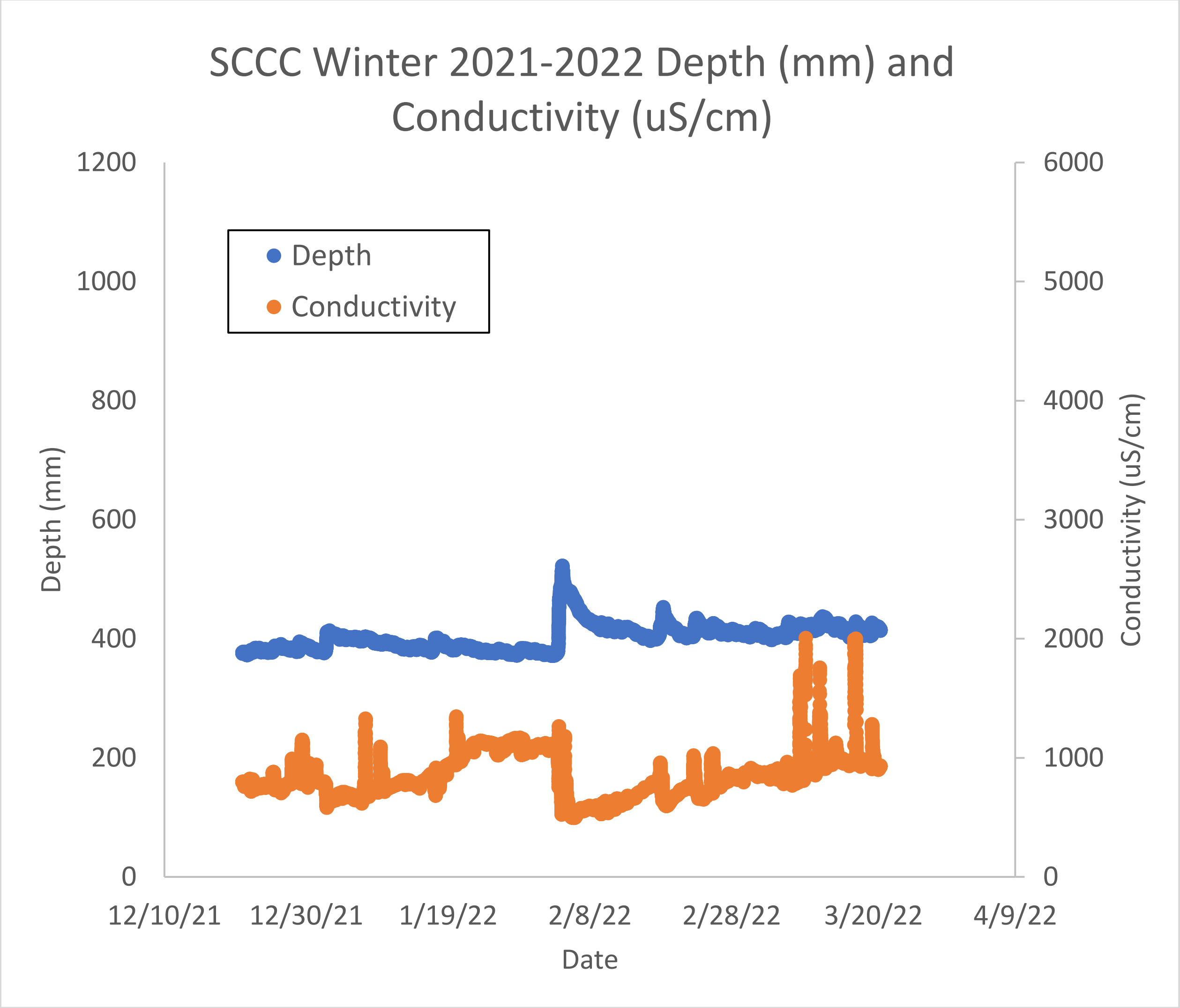
ANNUAL WINTER DEPTH (mm) VS. CONDUCTIVITY (uS/cm) AT SCCC



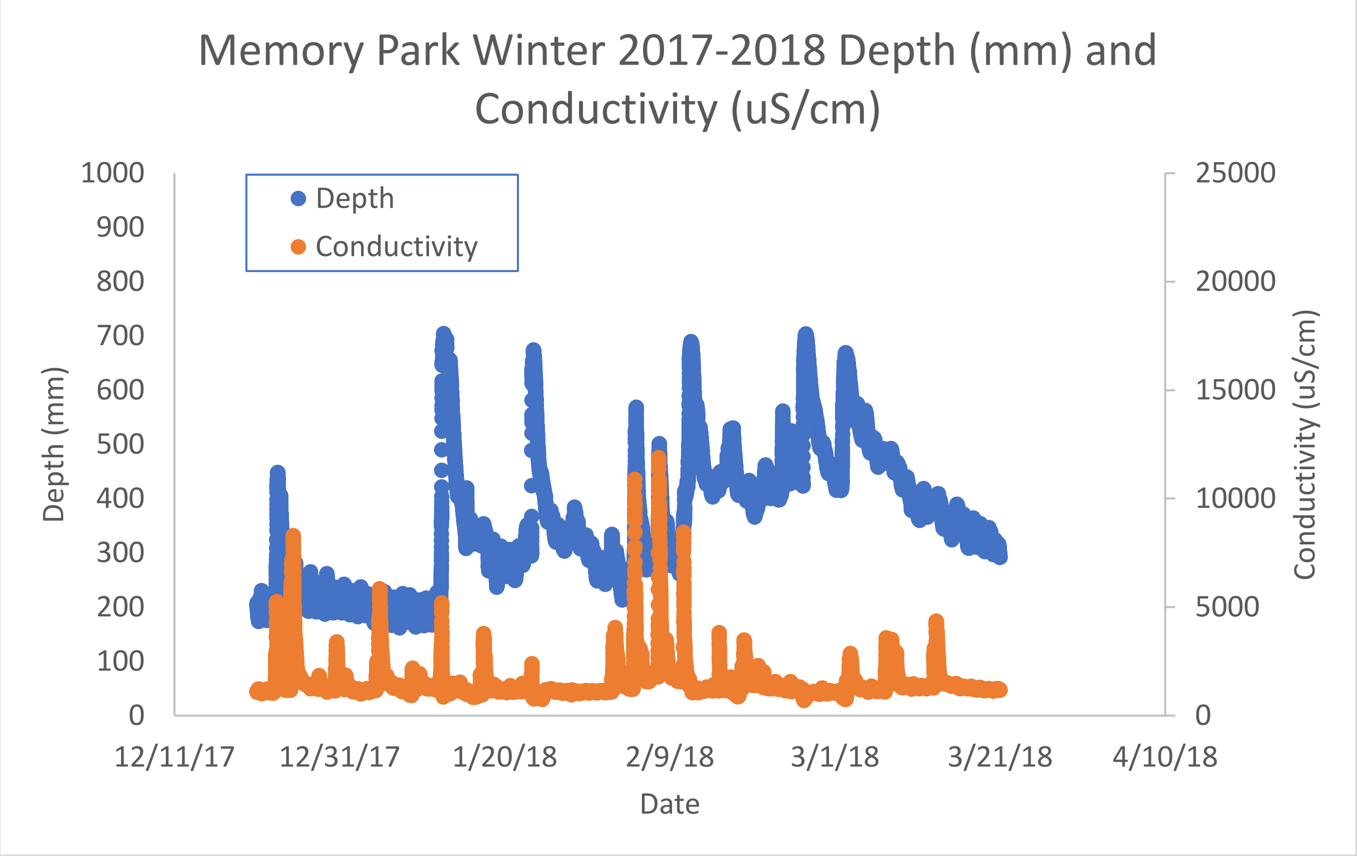


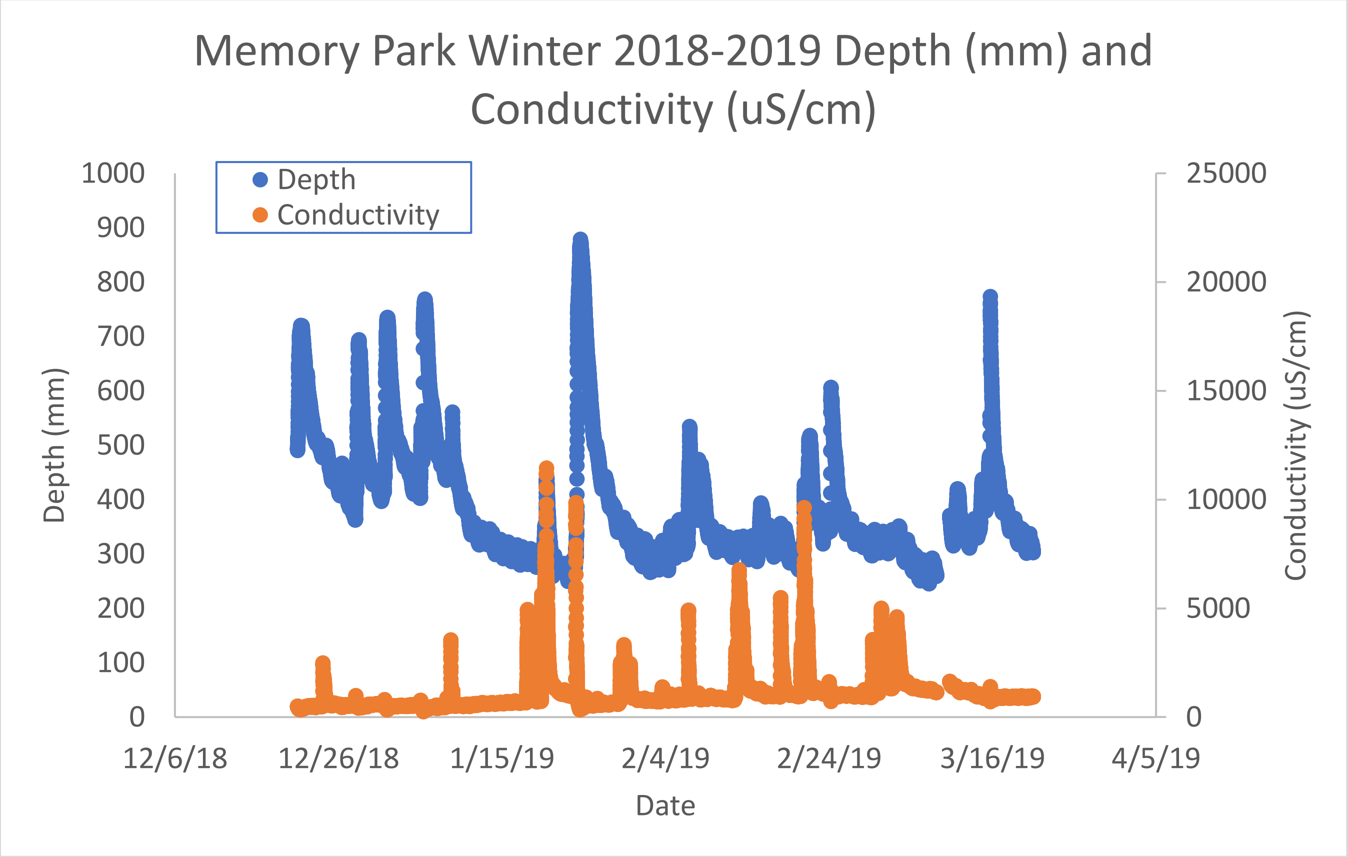

SCCC Winter 2019-2020 Depth (mm) and Conductivity (uS/cm)
● Depth
● Conductivity
Depth (mm)
1200
1000
800
600
400
200
0
Conductivity (uS/cm)
6000
5000
4000
3000
2000
1000
0
12/1/19
12/21/19
1/10/20
1/30/20
2/19/20
3/10/20
3/30/20
Date

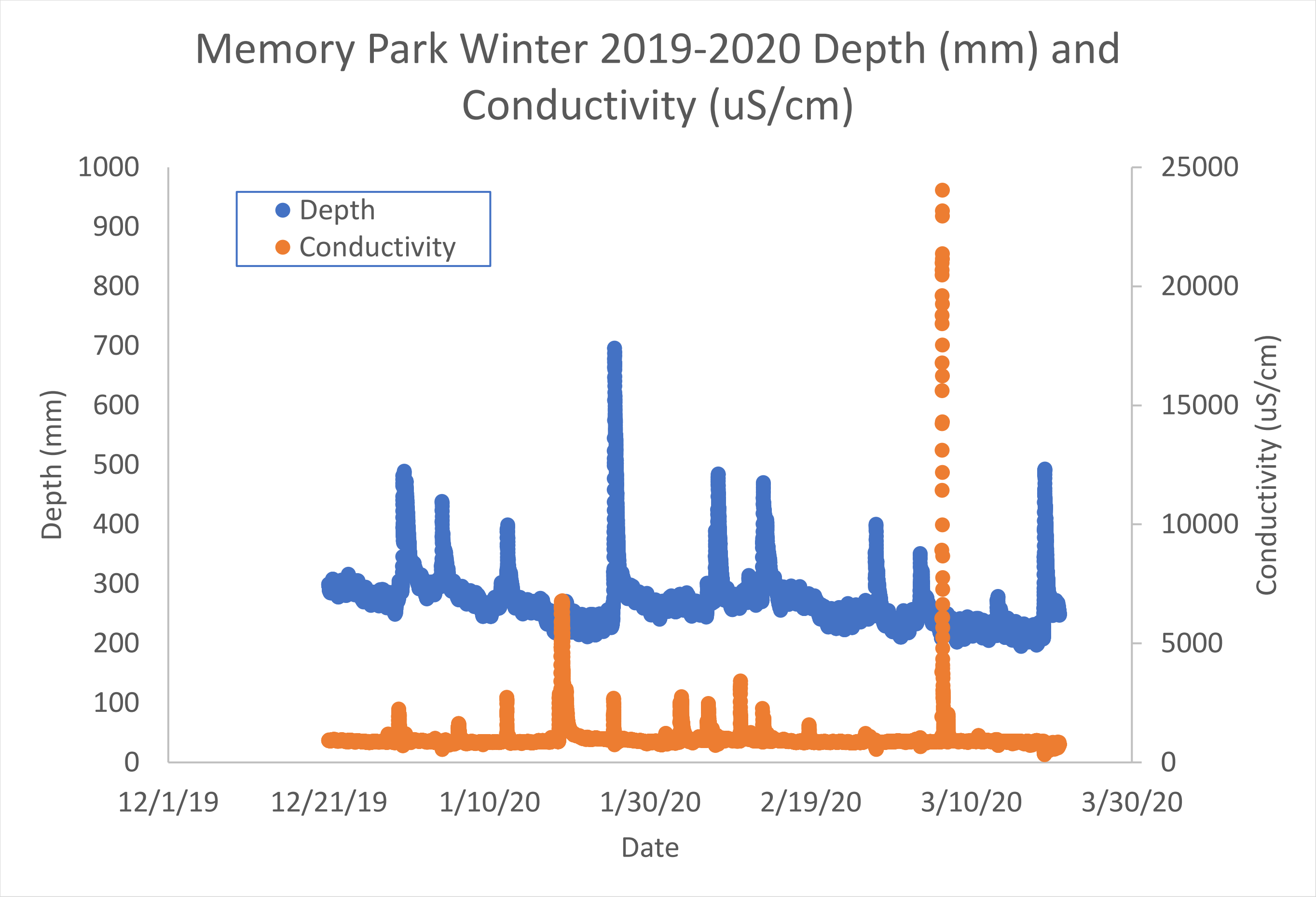

SCCC Winter 2020-2021 Depth (mm) and Conductivity (uS/cm)
● Depth
● Conductivity
Depth (mm)
1200
1000
800
600
400
200
0
Conductivity (uS/cm)
6000
5000
4000
3000
2000
1000
0
12/15/20
1/4/21
1/24/21
2/13/21
3/5/21
3/25/21
4/14/21
Date

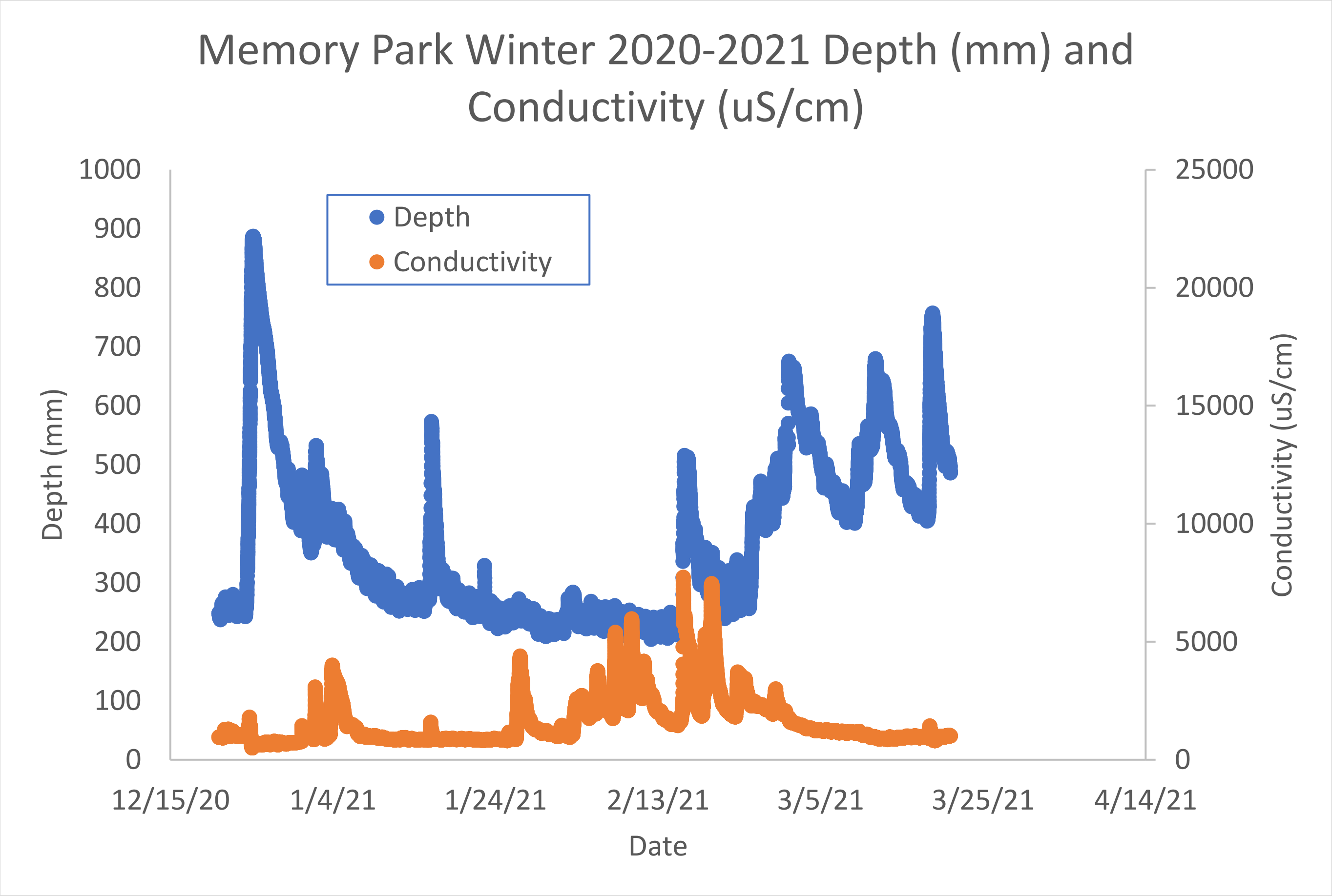

SCCC Winter 2021-2022 Depth (mm) and Conductivity (uS/cm)
● Depth
● Conductivity
Depth (mm)
Conductivity (uS/cm)
0
200
400
600
800
1000
1200
0
1000
2000
3000
4000
5000
6000
12/10/21
12/30/21
1/19/22
2/8/22
2/28/22
3/20/22
4/9/22
Date

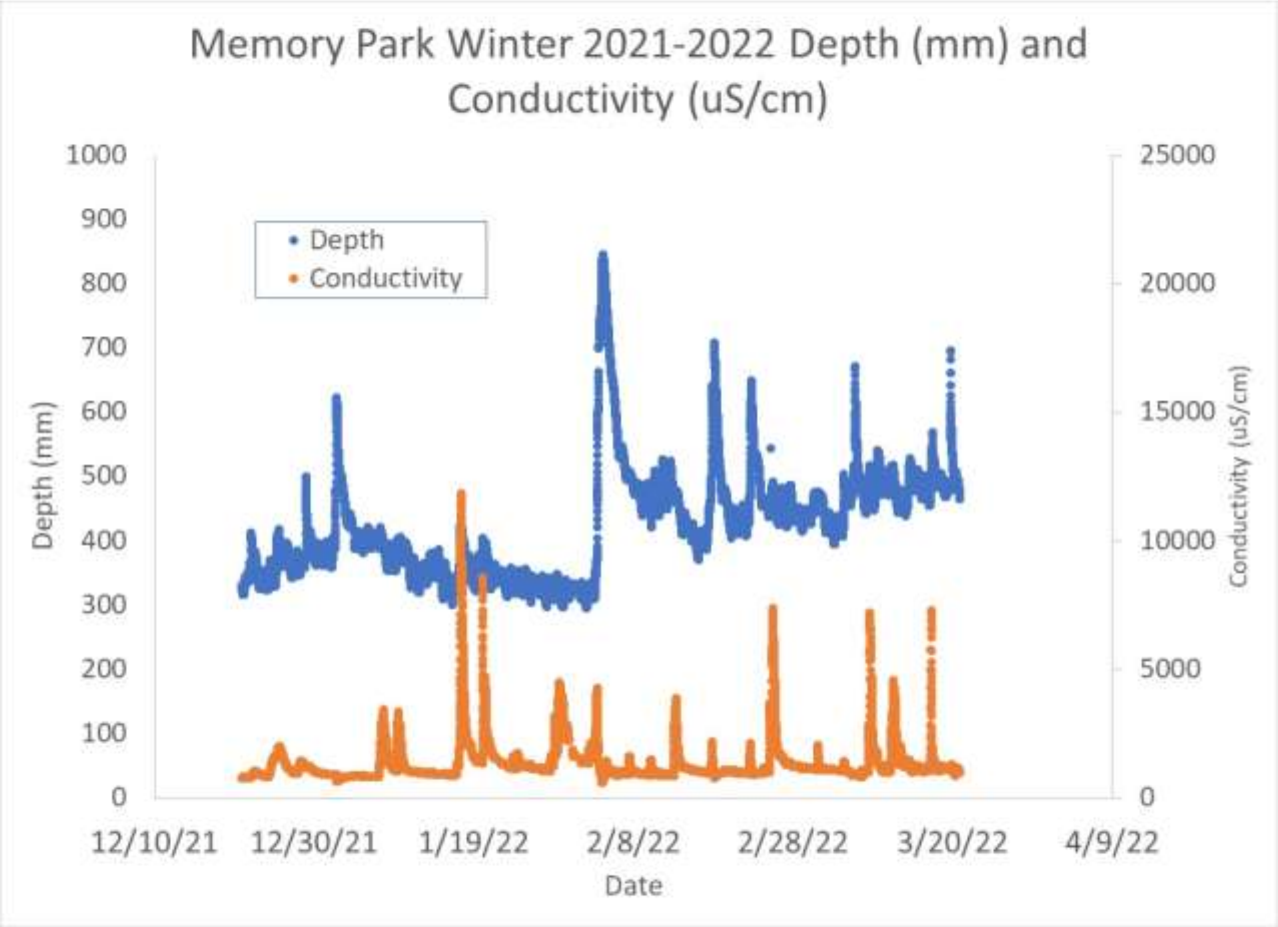
ANNUAL WINTER DEPTH (mm) VS. CONDUCTIVITY (uS/cm) AT MEMORY PARK



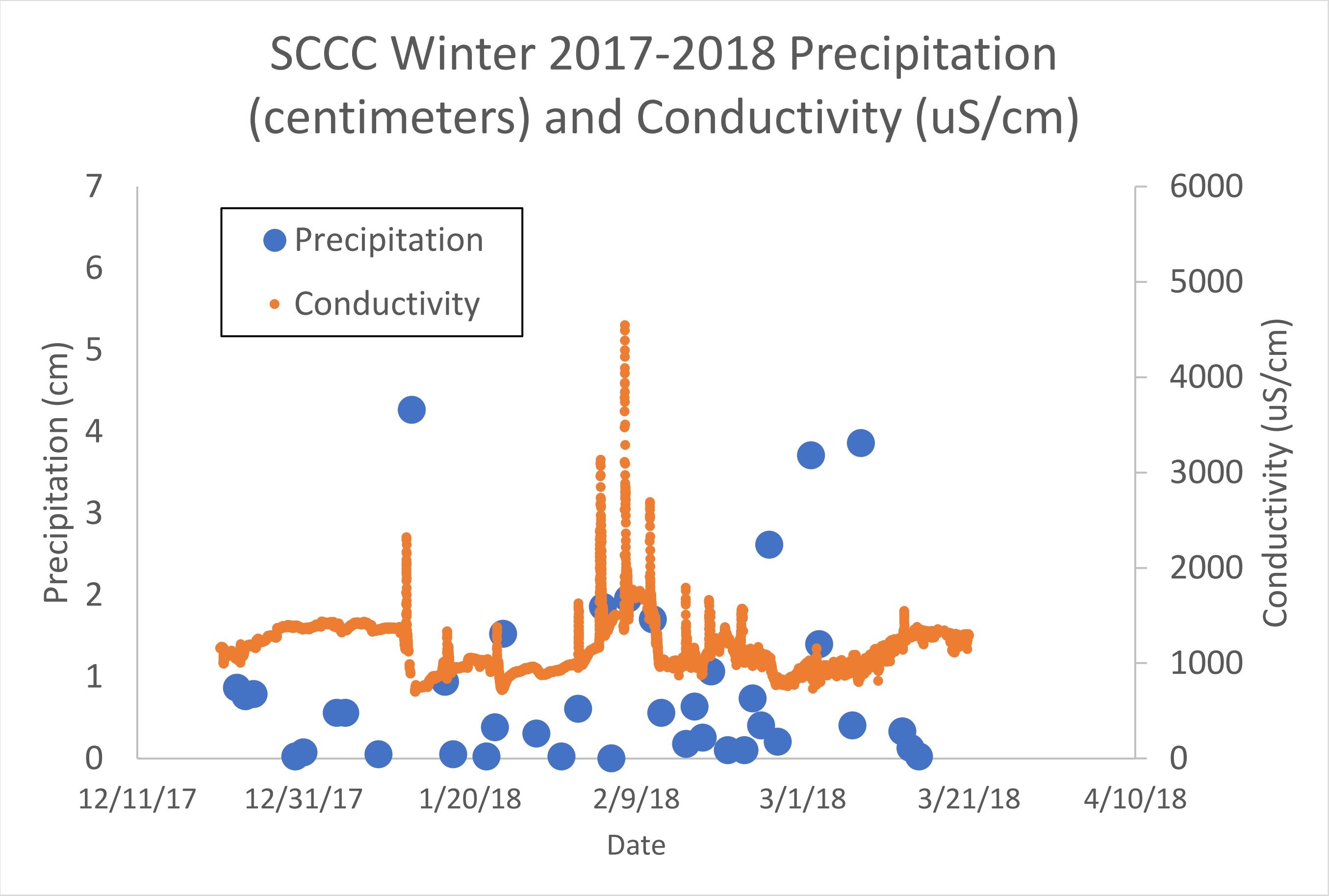


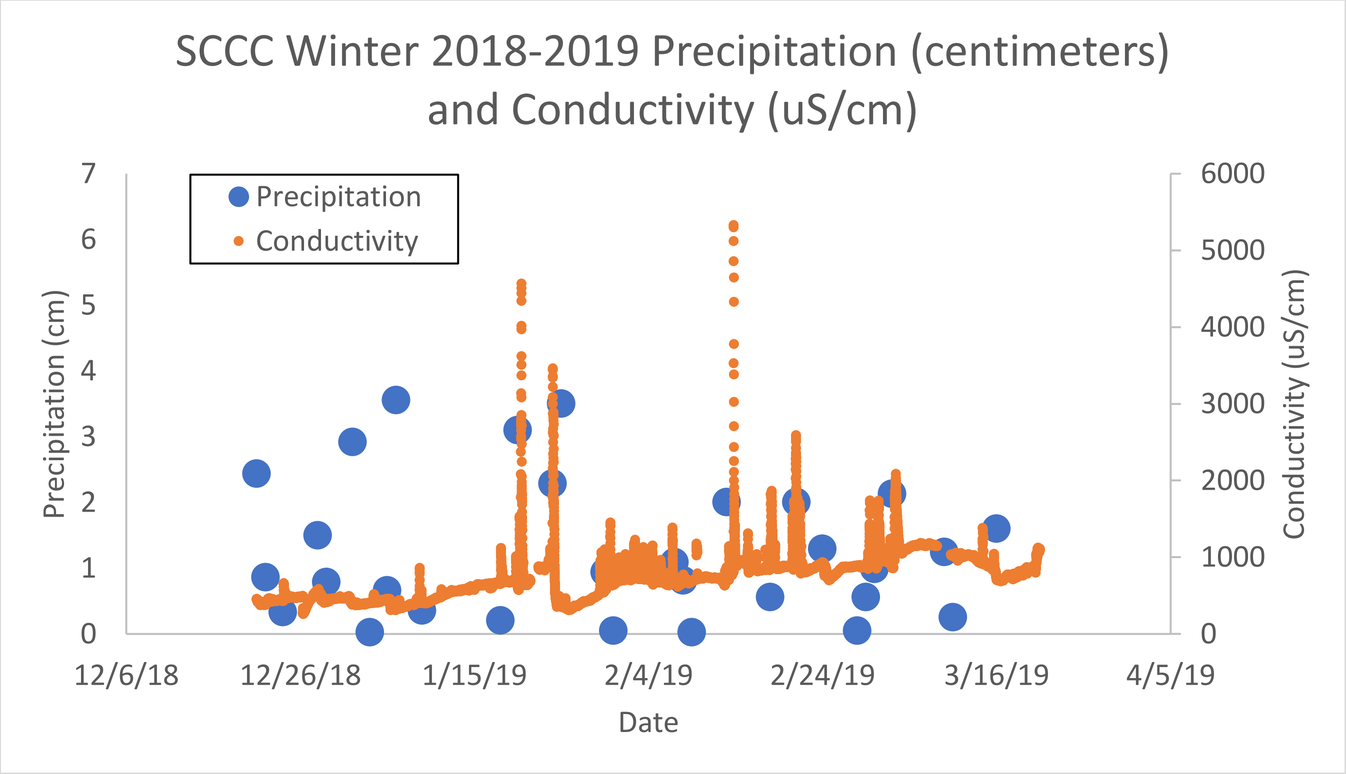

Memory Park Winter 2019-2020 Depth (mm) and Conductivity (uS/cm)
Depth
Conductivity
Depth (mm)
1000
900
800
700
600
500
400
300
200
100
0
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
12/1/19
12/21/19
1/10/20
1/30/20
2/19/20
3/10/20
3/30/20
Date

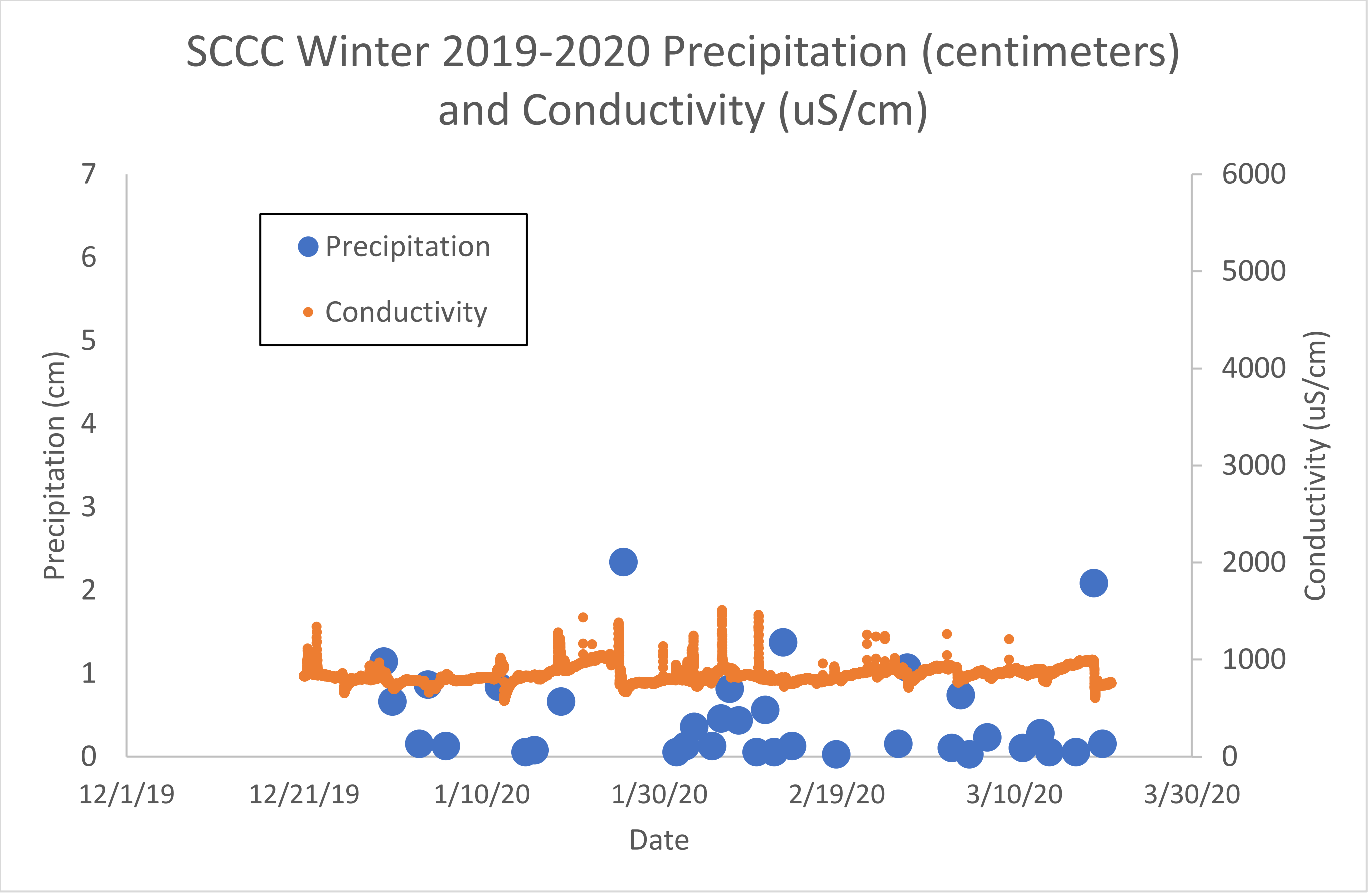

Memory Park Winter 2020-2021 Depth (mm) and Conductivity (uS/cm)
Depth
Conductivity
Depth (mm)
1000
900
800
700
600
500
400
300
200
100
0
Conductivity (uS/cm)
25000
20000
15000
10000
5000
0
12/15/20
1/4/21
1/24/21
2/13/21
3/5/21
3/25/21
4/14/21
Date

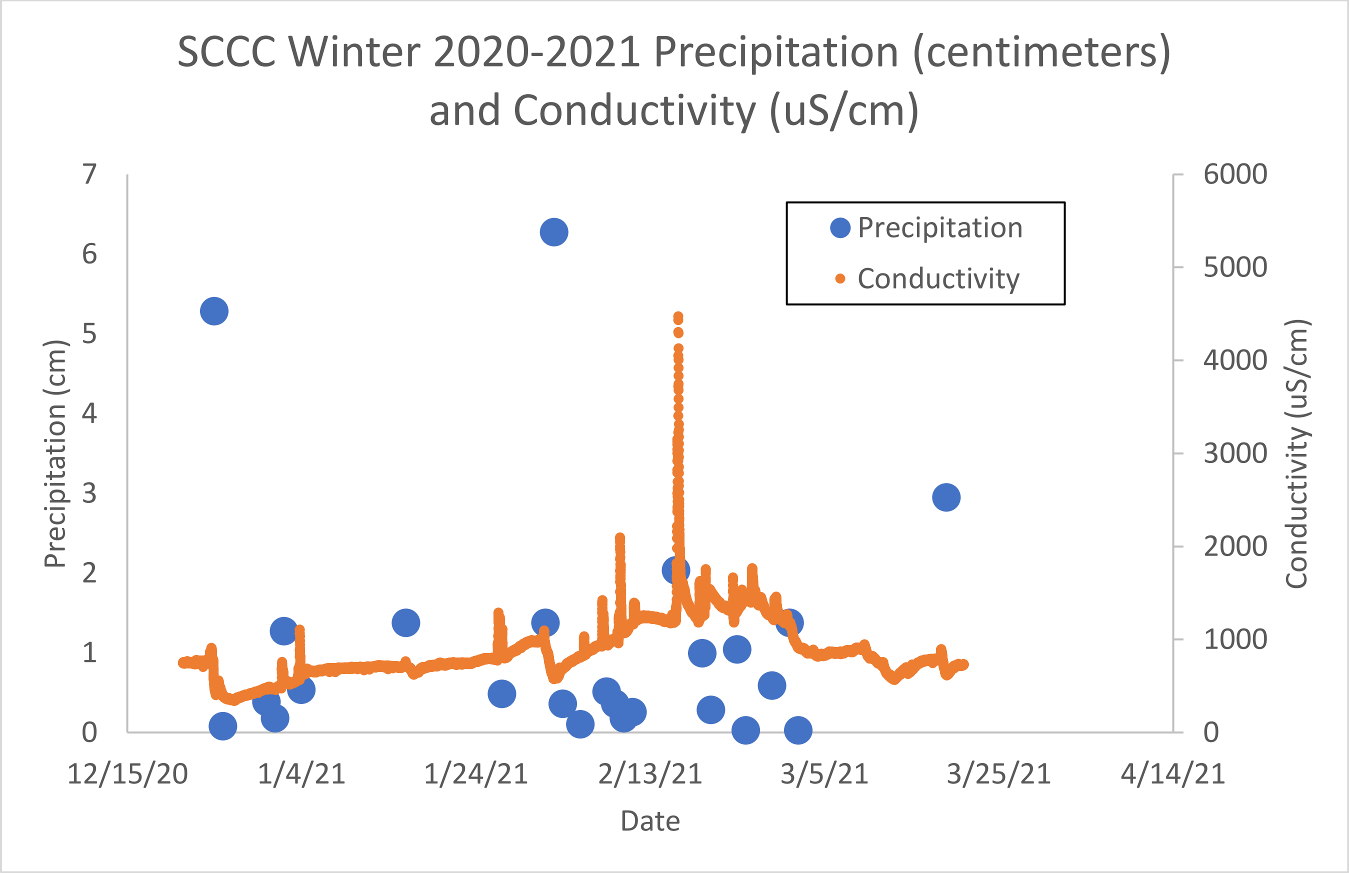

Memory Park Winter 2021-2022 Depth (mm) and Conductivity (uS/cm)
Depth (mm)
Conductivity (uS/cm)
● Depth
● Conductivity
1000
900
800
700
600
500
400
300
200
100
0
25000
20000
15000
10000
5000
0
12/10/21
12/30/21
1/19/22
2/8/22
2/28/22
3/20/22
4/9/22
Date

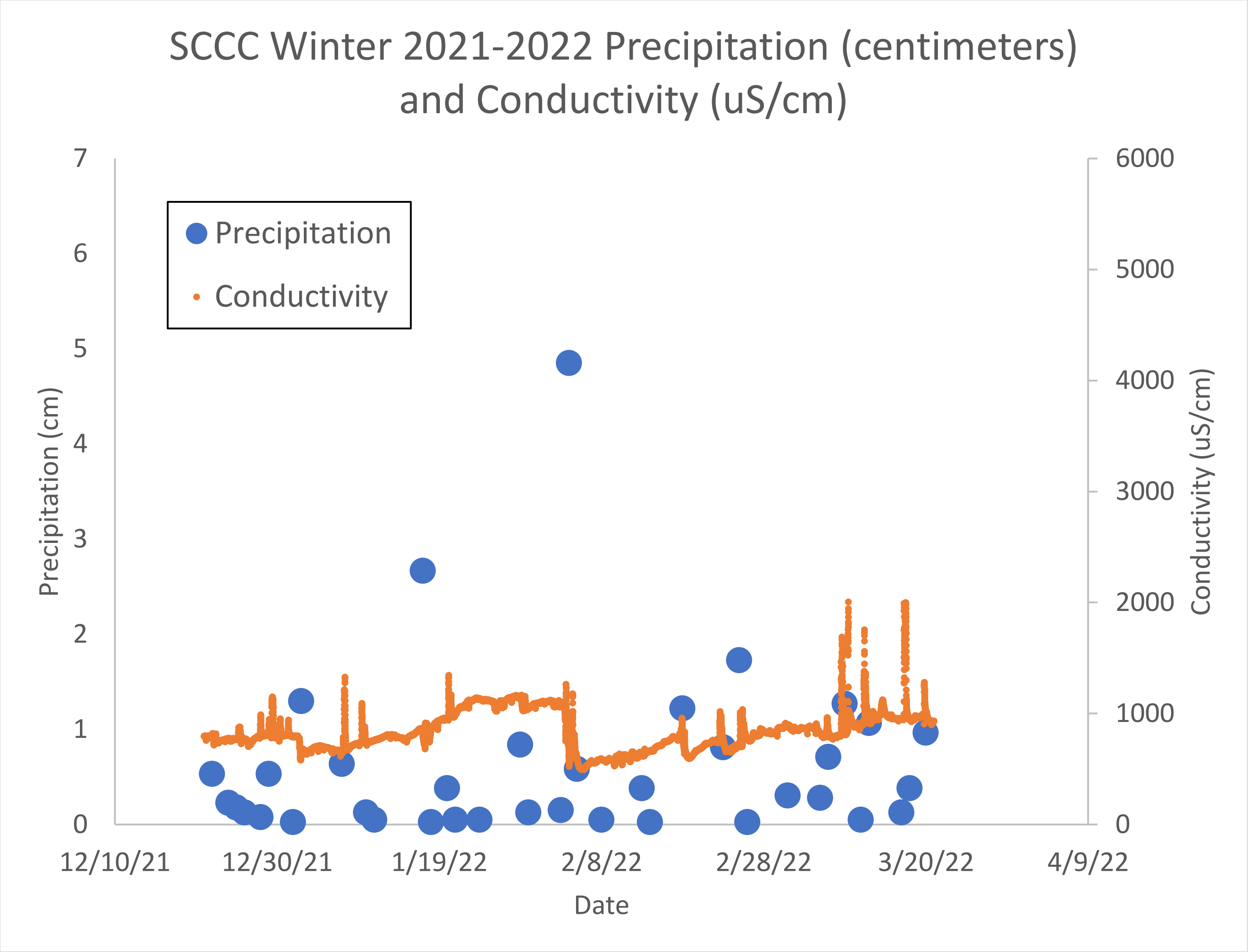
ANNUAL WINTER PRECIPITATION (cm) VS. CONDUCTIVITY (uS/cm) AT SCCC





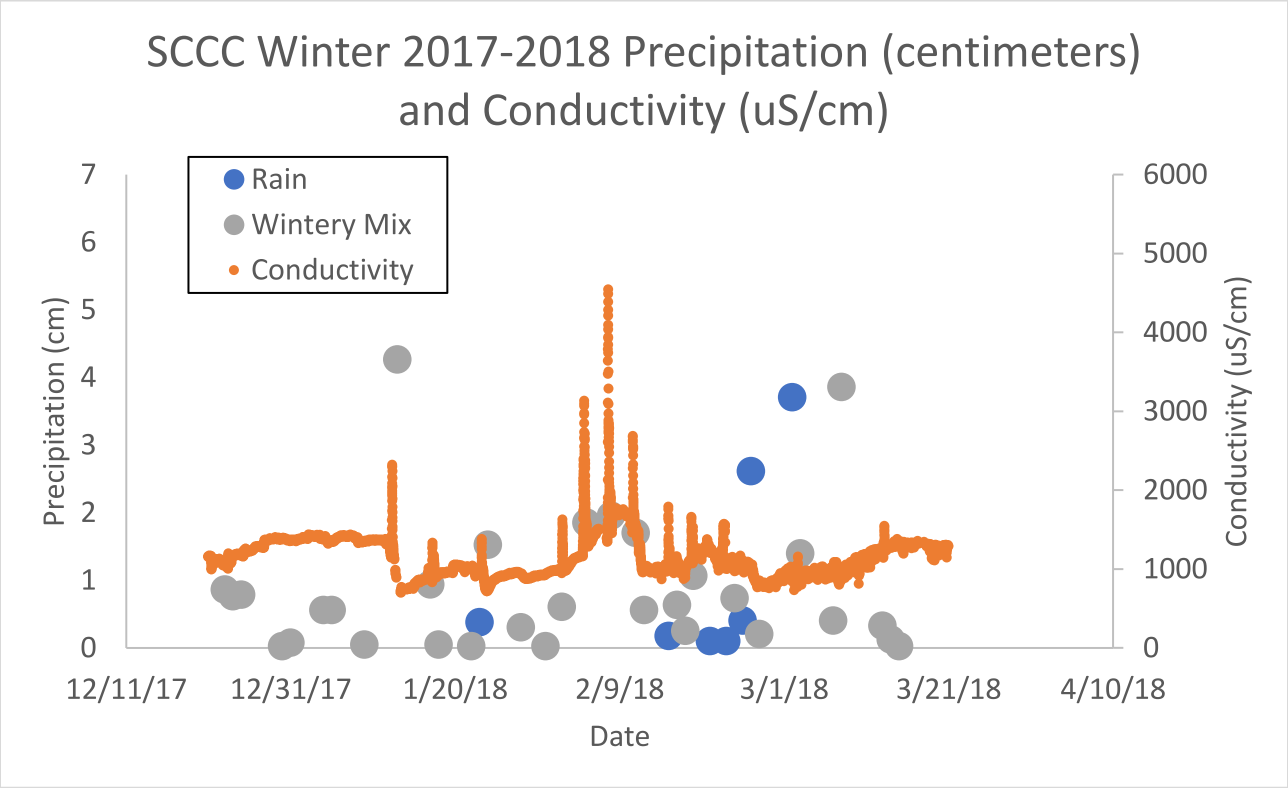

SCCC Winter 2019-2020 Precipitation (centimeters) and Conductivity (uS/cm)
Precipitation
Conductivity
Precipitation (cm)
7
6
5
4
3
2
1
0
Conductivity (uS/cm)
6000
5000
4000
3000
2000
1000
0
12/1/19
12/21/19
1/10/20
1/30/20
2/19/20
3/10/20
3/30/20
Date

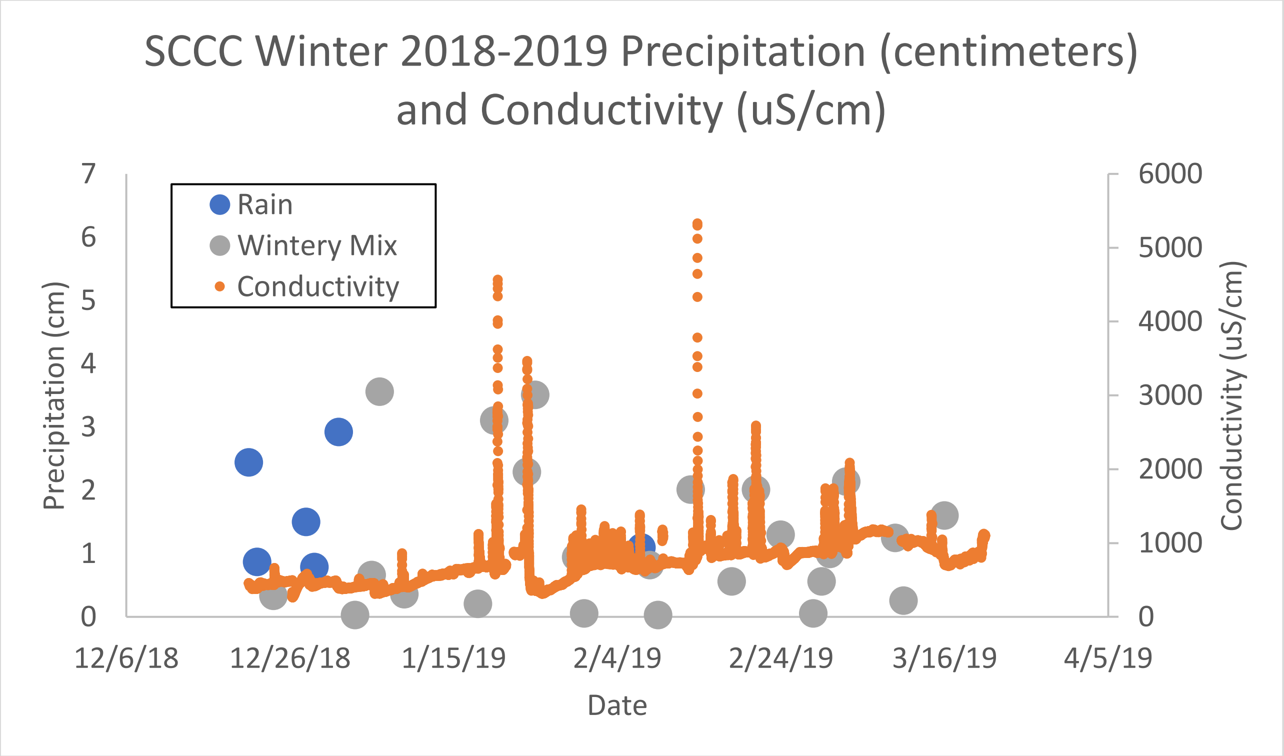

SCCC Winter 2020-2021 Precipitation (centimeters) and Conductivity (uS/cm)
Precipitation
Conductivity
Precipitation (cm)
7
6
5
4
3
2
1
0
Conductivity (uS/cm)
6000
5000
4000
3000
2000
1000
0
12/15/20
1/4/21
1/24/21
2/13/21
3/5/21
3/25/21
4/14/21
Date

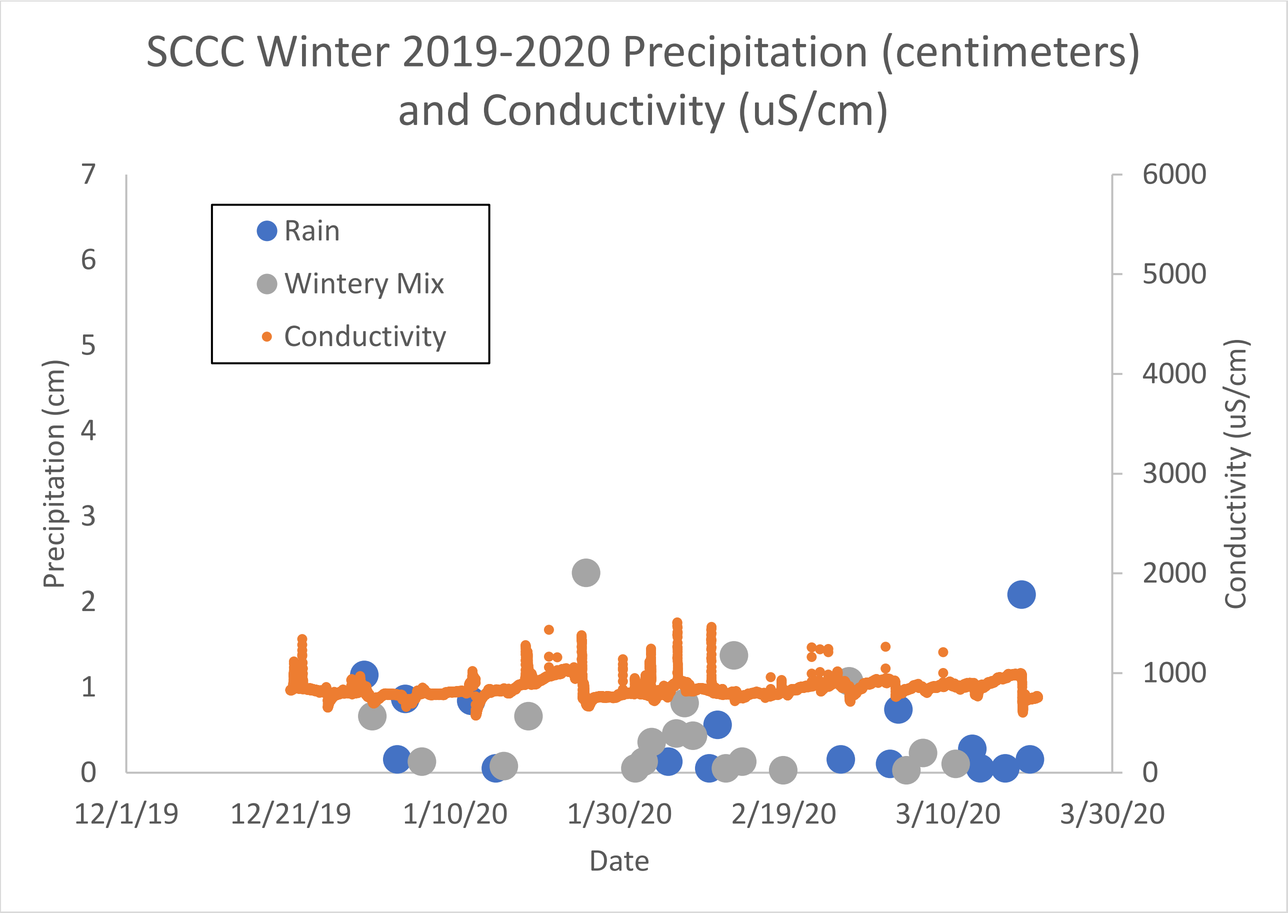

SCCC Winter 2021-2022 Precipitation (centimeters) and Conductivity (uS/cm)

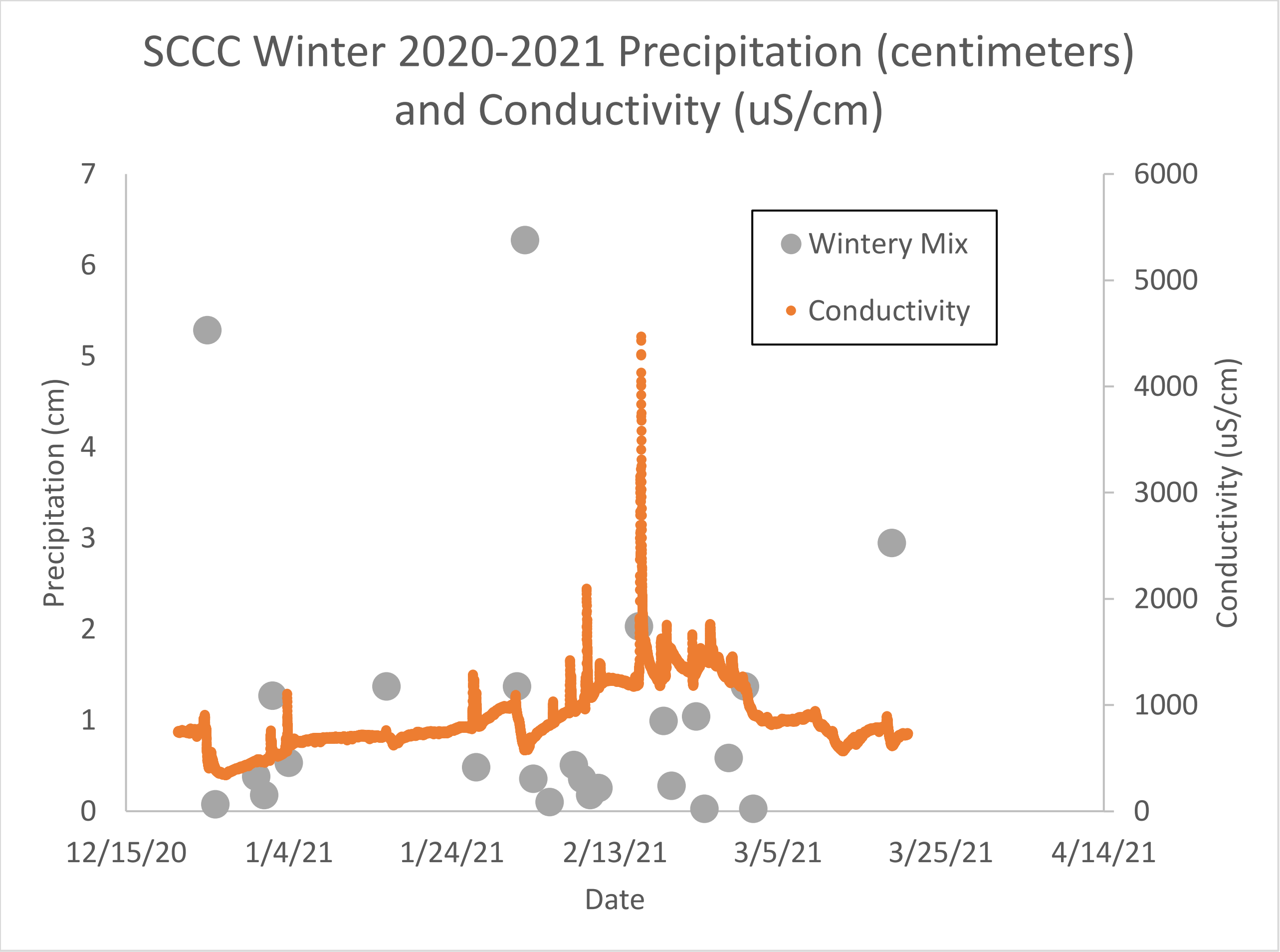
ANNUAL WINTER PRECIPITATION (cm) VS. CONDUCTIVITY (uS/cm) AT SCCC, DIFFERENTIATING RAIN VERSUS WINTERY MIX

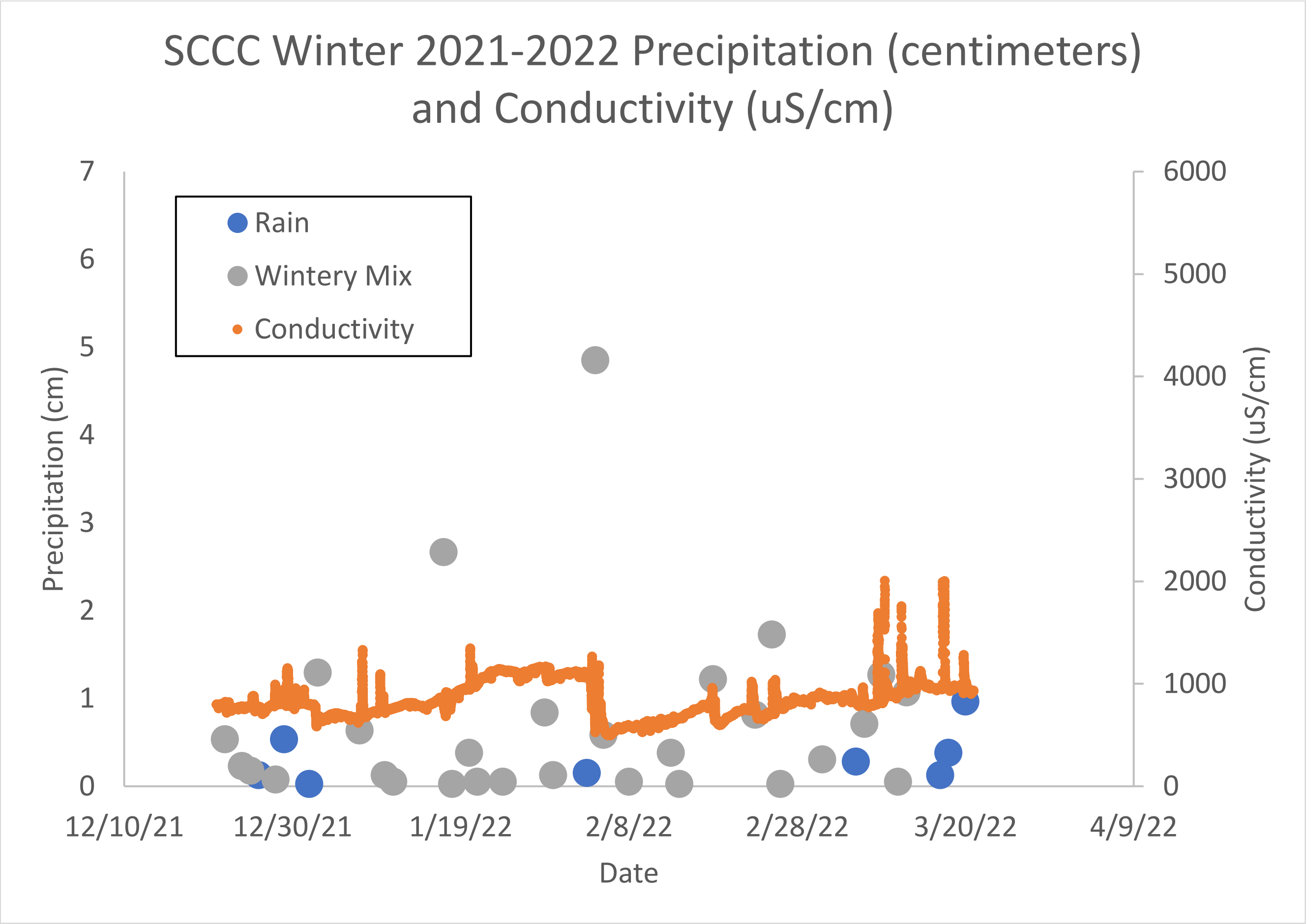
***PRECIPITATION DATA POINTS CLASSIFIED AS RAIN IF BOTH THE MAXIMUM AND MINIMUM DAILY AIR TEMPERATURES WERE ABOVE 35 DEGREES FAHRENHEIT**





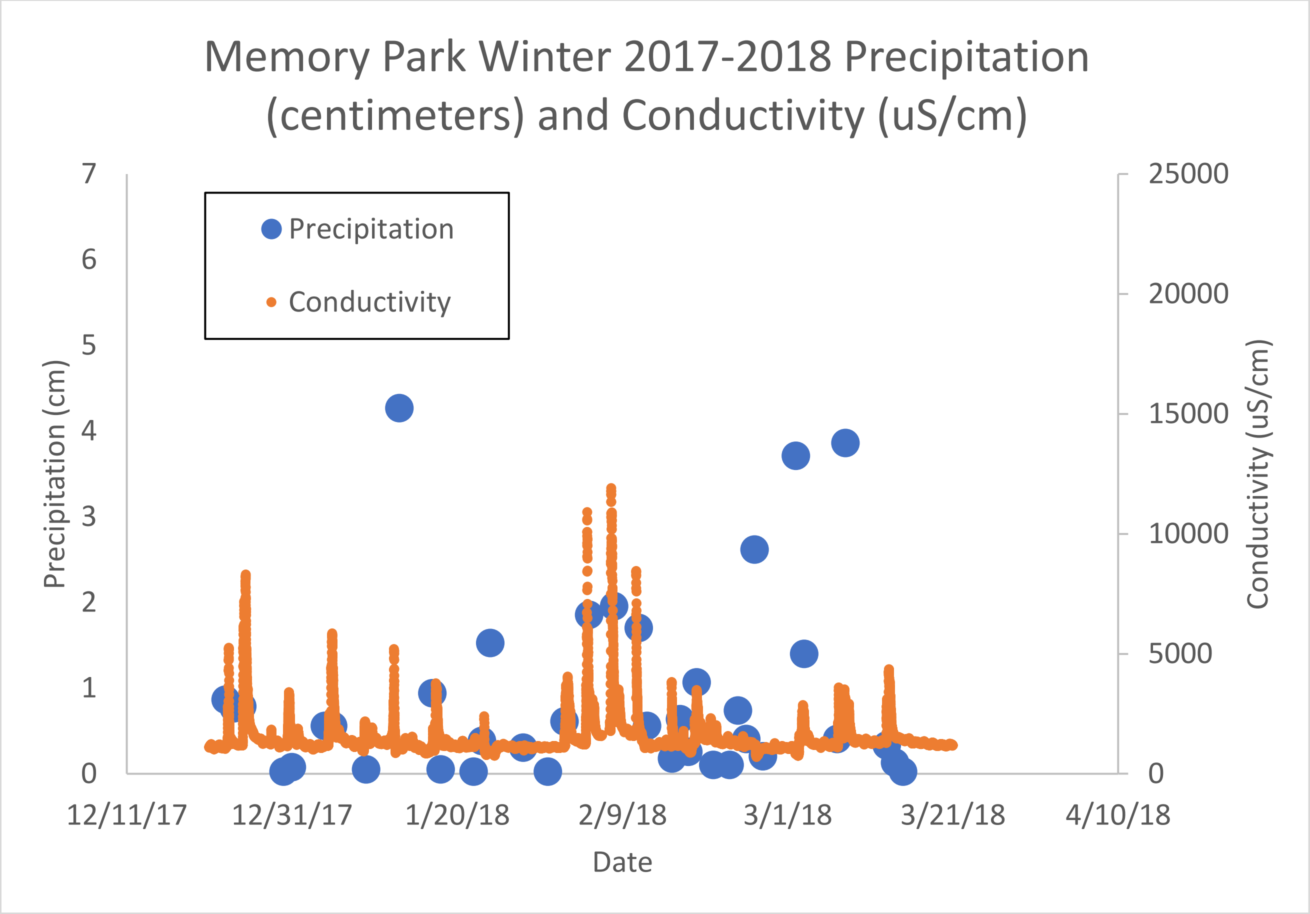

SCCC Winter 2019-2020 Precipitation (centimeters) and Conductivity (uS/cm)

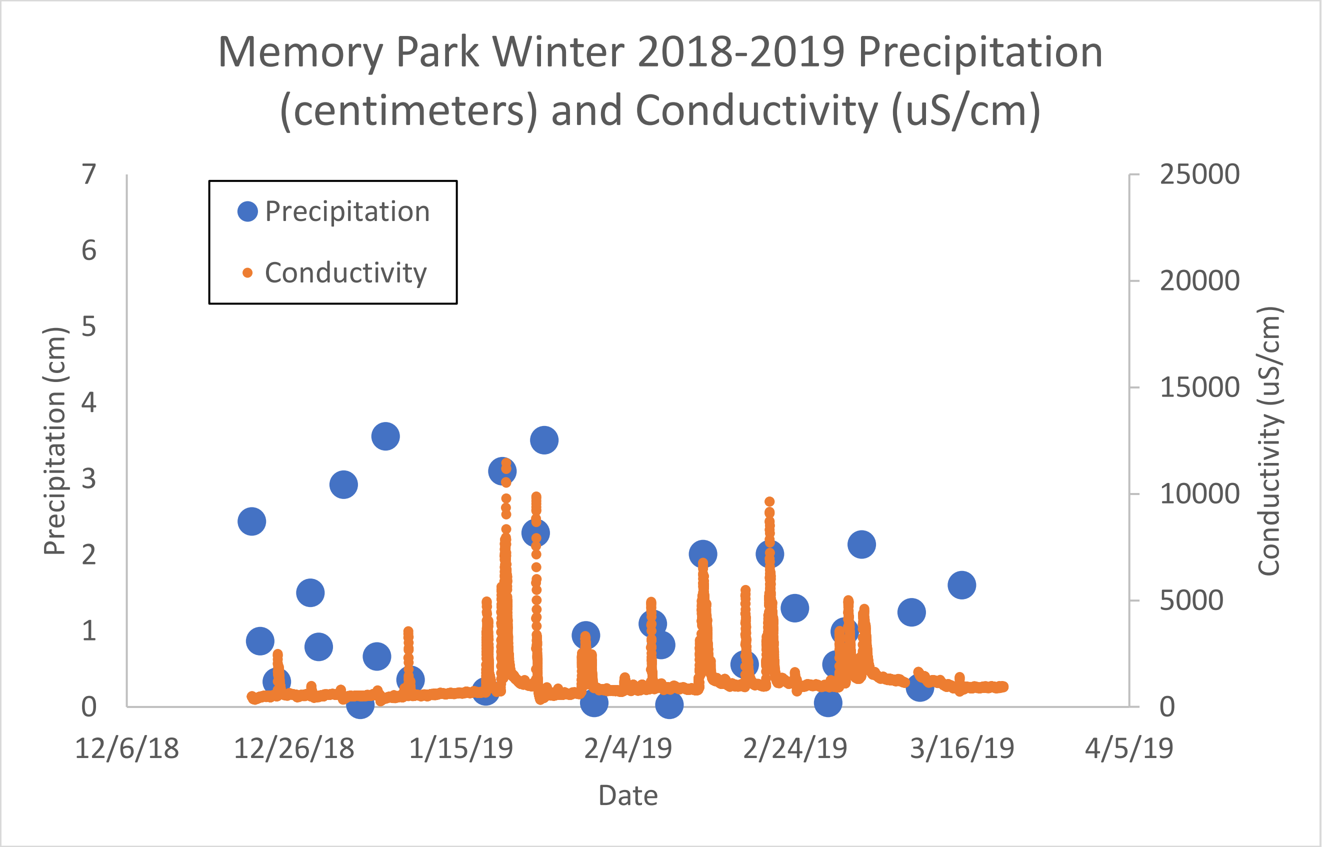

SCCC Winter 2020-2021 Precipitation (centimeters) and Conductivity (uS/cm)

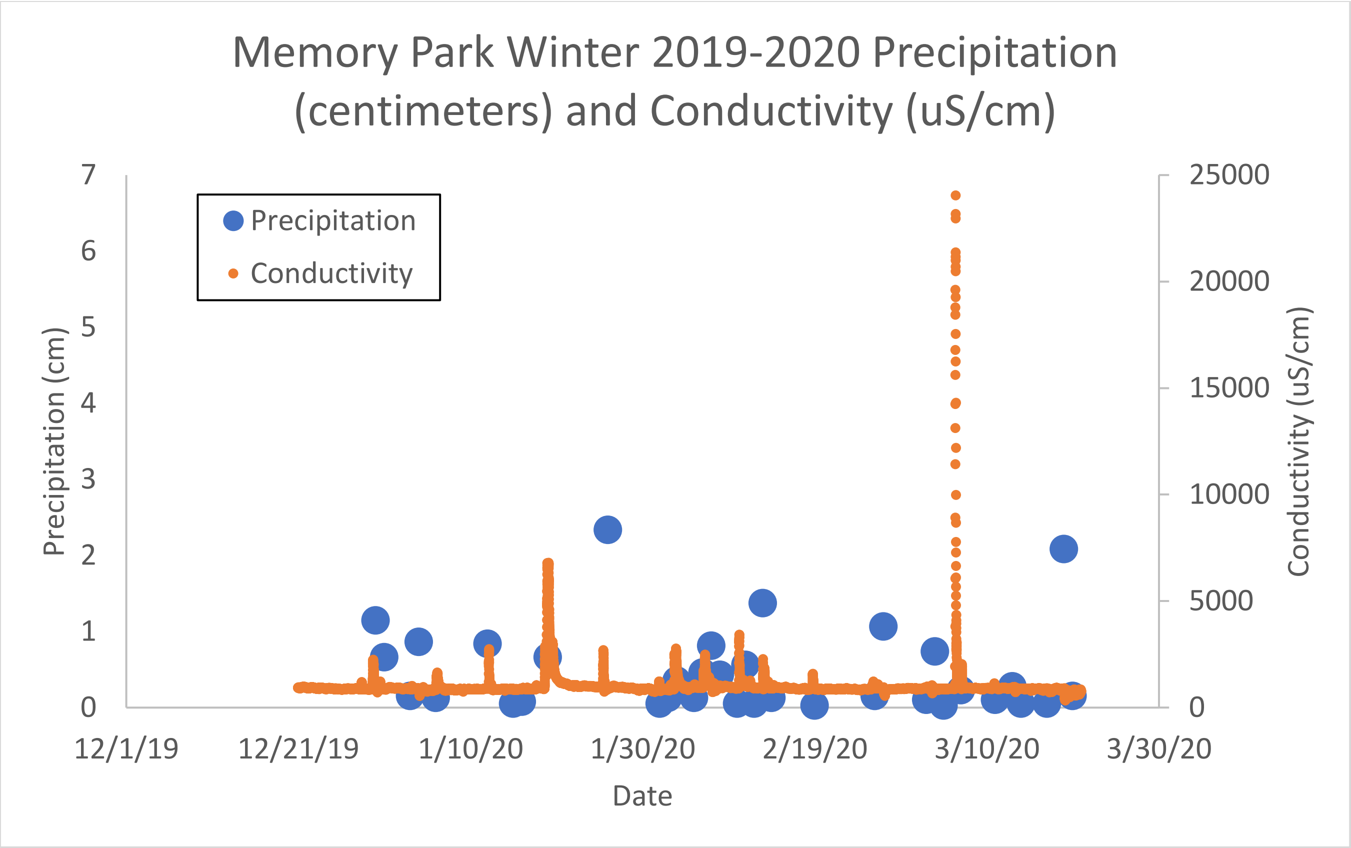


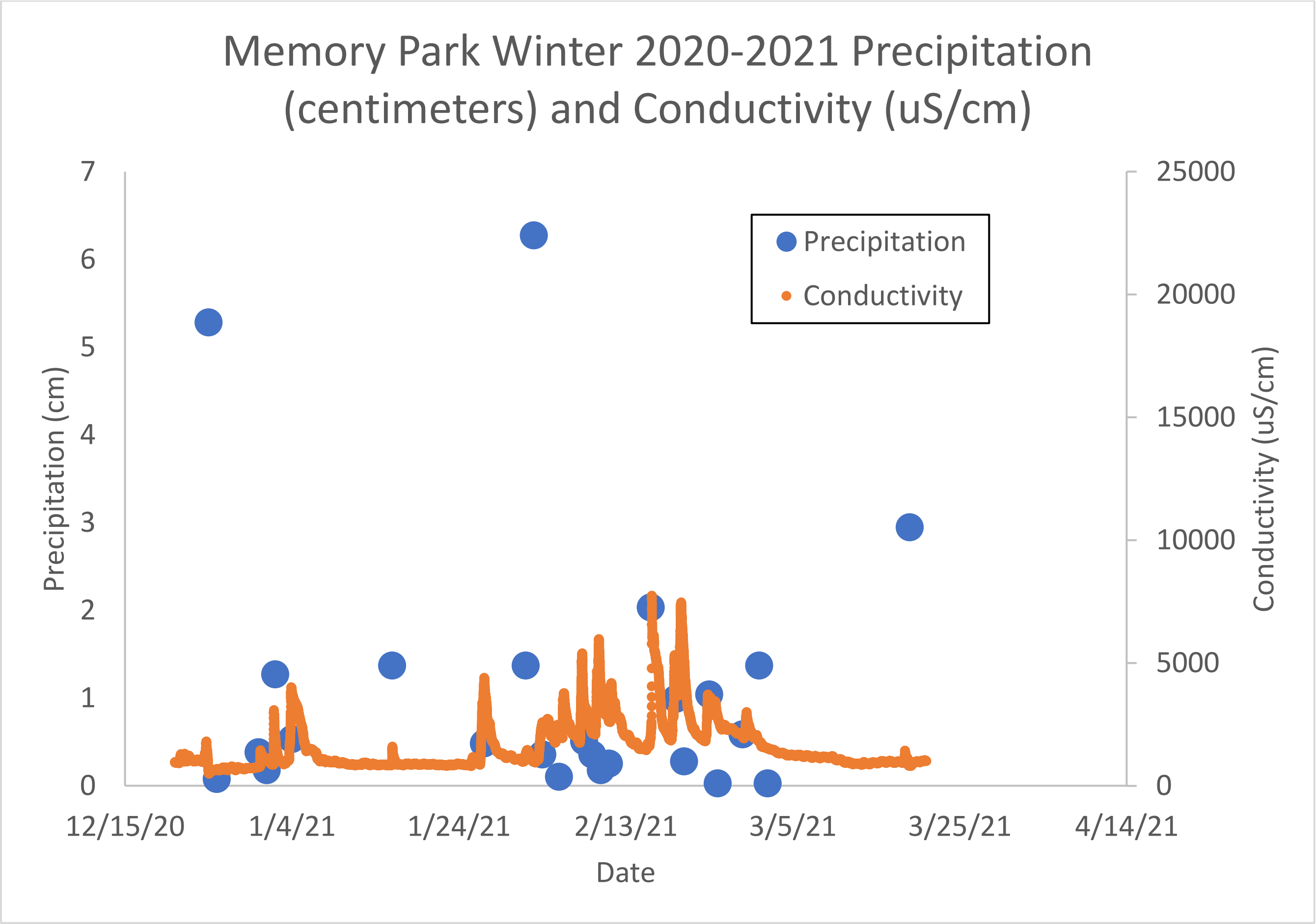
SCCC Winter 2021-2022 Precipitation (centimeters) and Conductivity (uS/cm)

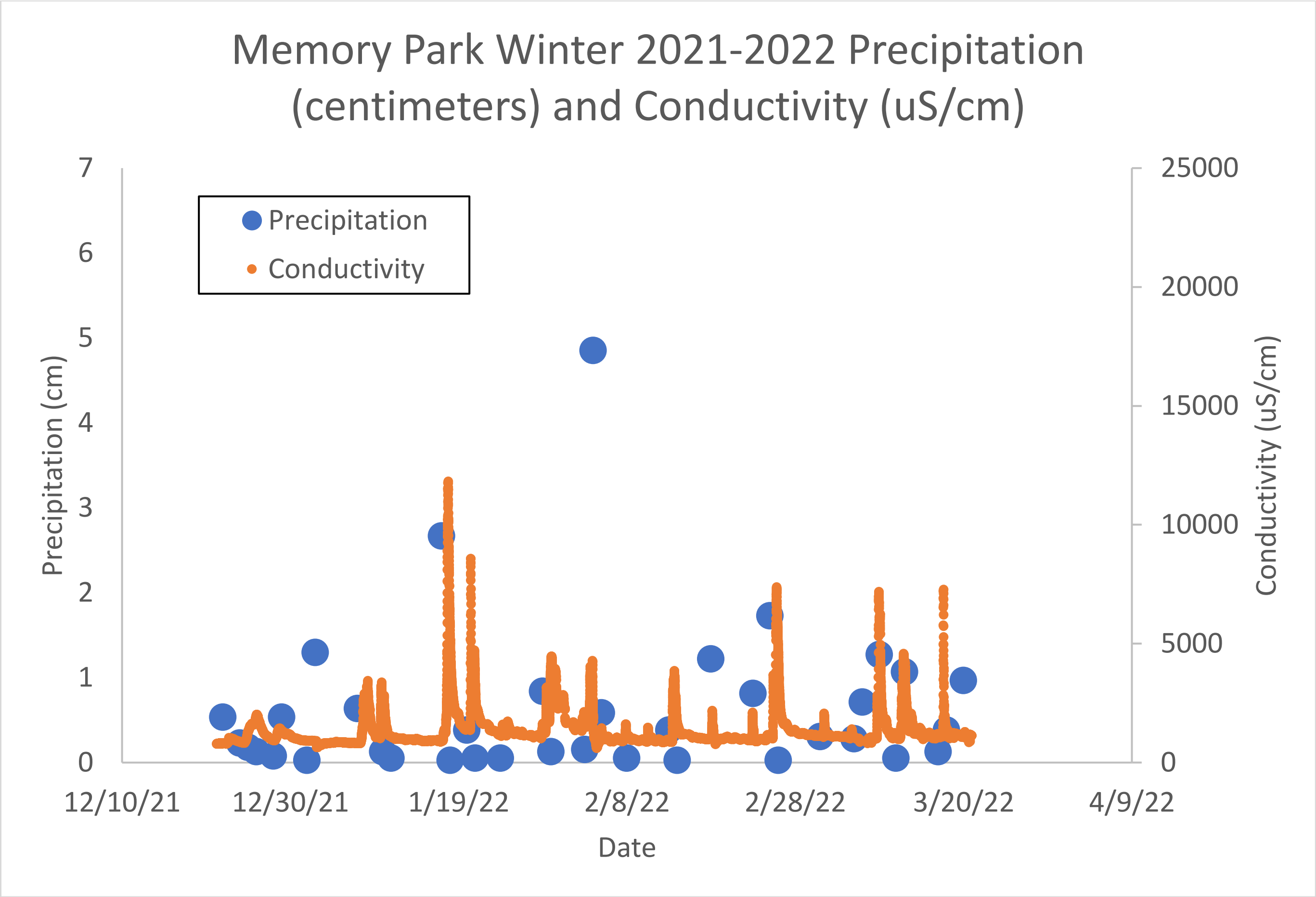
ANNUAL WINTER PRECIPITATION (cm) VS. CONDUCTIVITY (uS/cm) AT MEMORY PARK





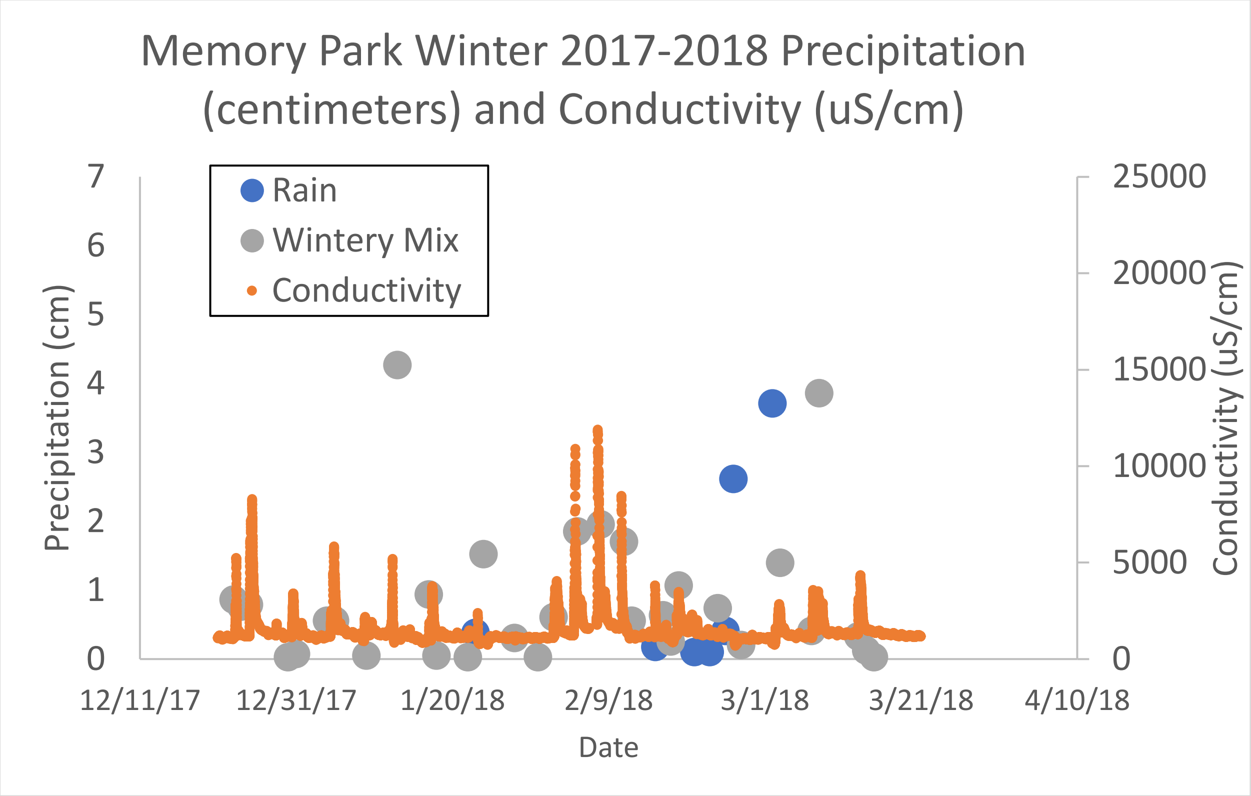

Memory Park Winter 2019-2020 Precipitation (centimeters) and Conductivity (uS/cm)
Precipitation
Conductivity
Precipitation (cm)
Conductivity (uS/cm)
Date
0
1
2
3
4
5
6
7
0
5000
10000
15000
20000
25000
12/1/19
12/21/19
1/10/20
1/30/20
2/19/20
3/10/20
3/30/20

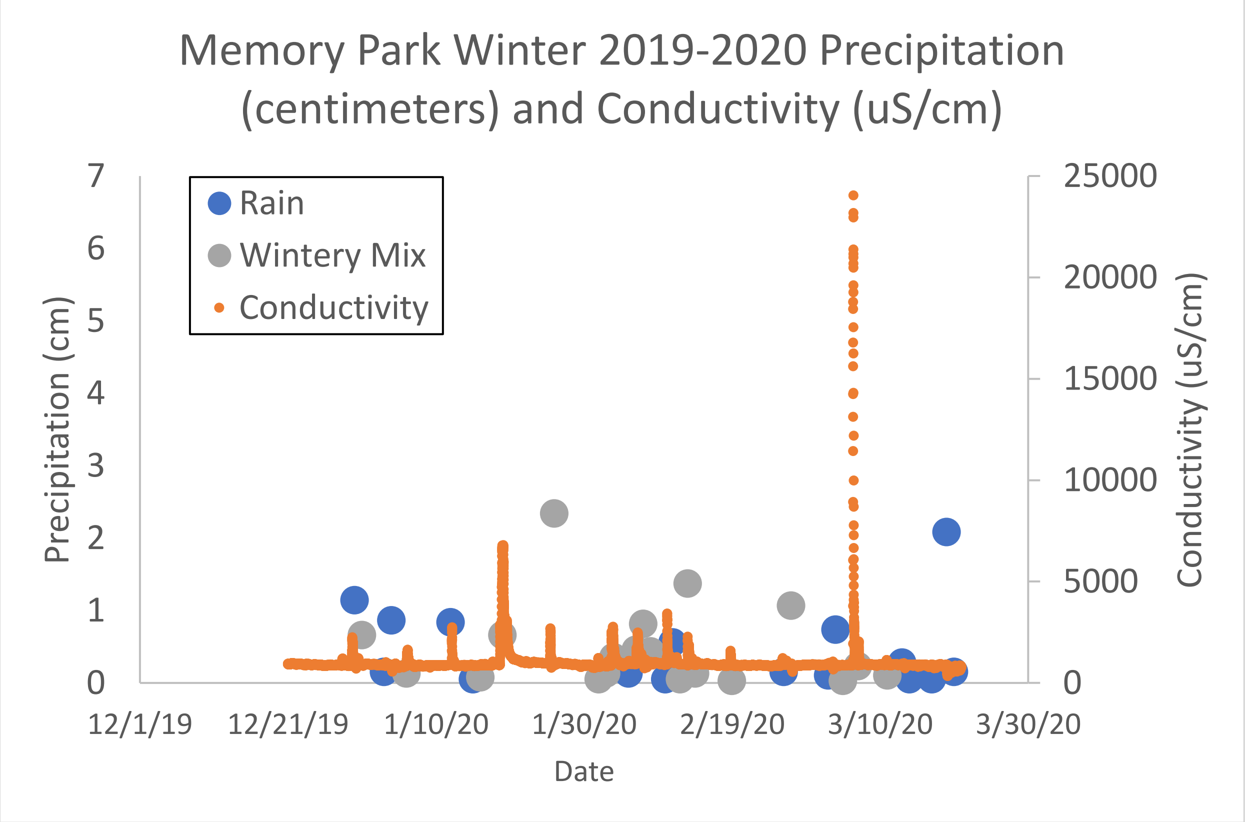

Memory Park Winter 2020-2021 Precipitation (centimeters) and Conductivity (uS/cm)
Precipitation
Conductivity
Precipitation (cm)
Conductivity (uS/cm)
Date
0
1
2
3
4
5
6
7
0
5000
10000
15000
20000
25000
12/15/20
1/4/21
1/24/21
2/13/21
3/5/21
3/25/21
4/14/21

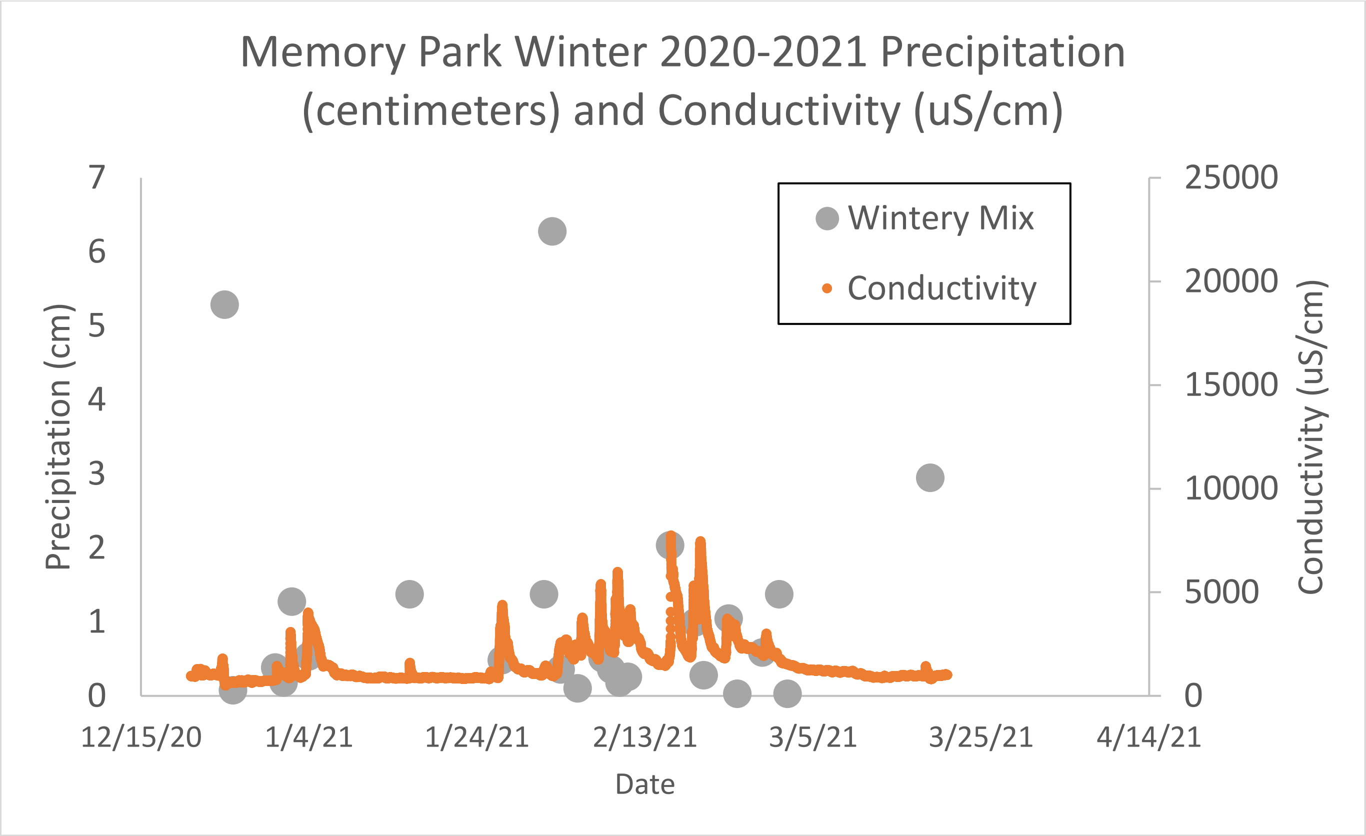

Memory Park Winter 2021-2022 Precipitation (centimeters) and Conductivity (uS/cm)
Precipitation
Conductivity
Precipitation (cm)
0
1
2
3
4
5
6
7
Conductivity (uS/cm)
0
5000
10000
15000
20000
25000
12/10/21
12/30/21
1/19/22
2/8/22
2/28/22
3/20/22
4/9/22
Date

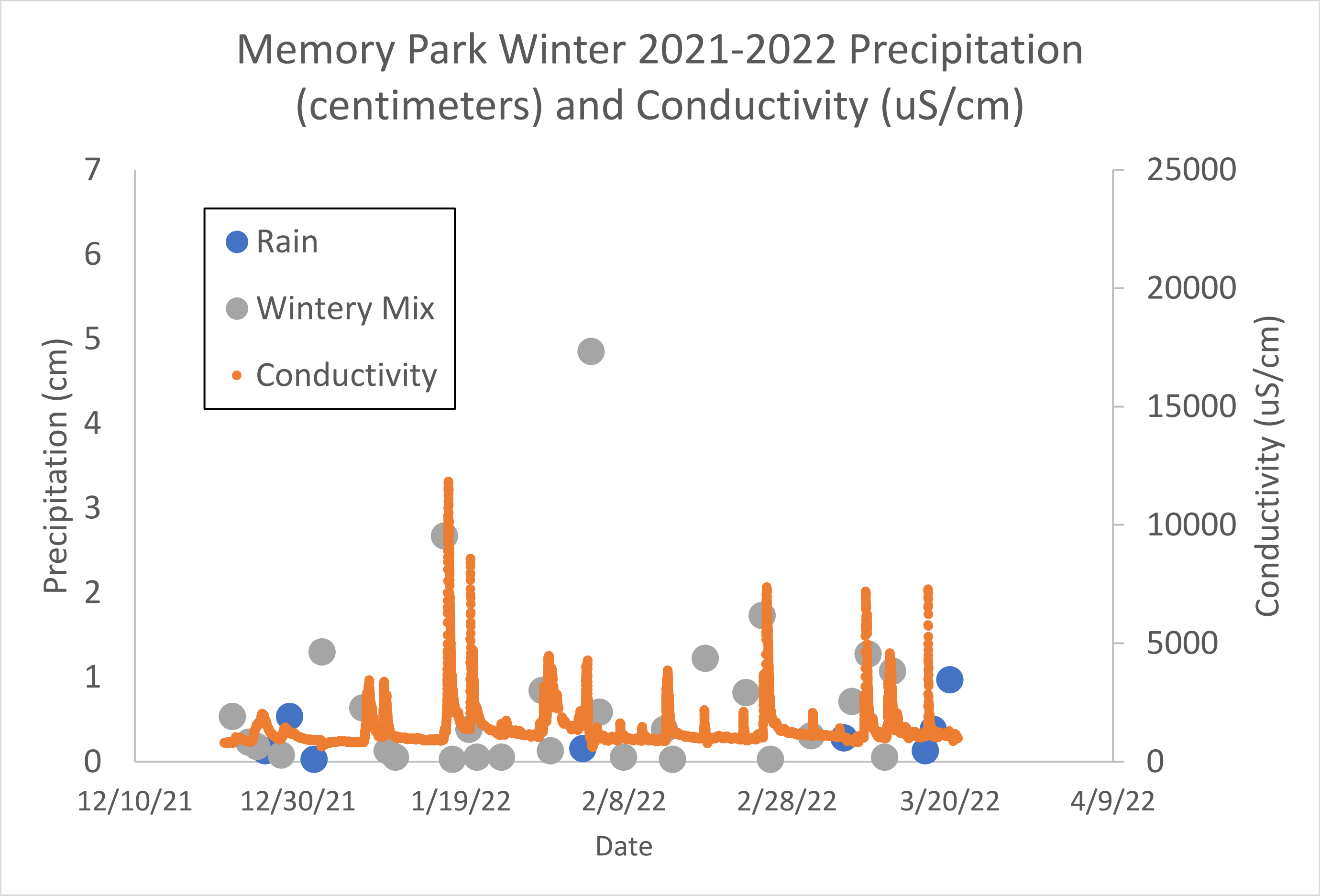
ANNUAL WINTER PRECIPITATION (cm) VS. CONDUCTIVITY (uS/cm) AT MEMORY PARK, DIFFERENTIATING RAIN VERSUS WINTERY MIX

*PRECIPITATION DATA POINTS CLASSIFIED AS RAIN IF BOTH THE MAXIMUM AND MINIMUM DAILY AIR TEMPERATURES WERE ABOVE 35 DEGREES FAHRENHEIT

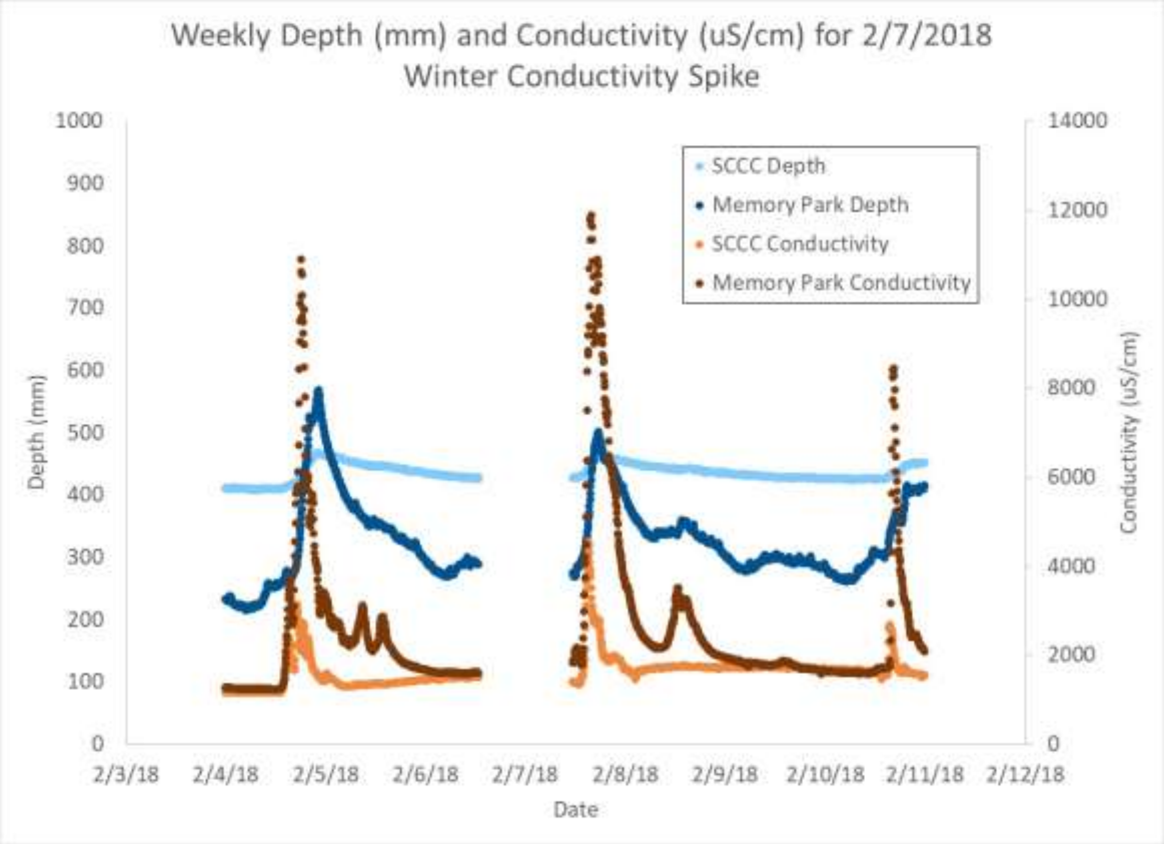


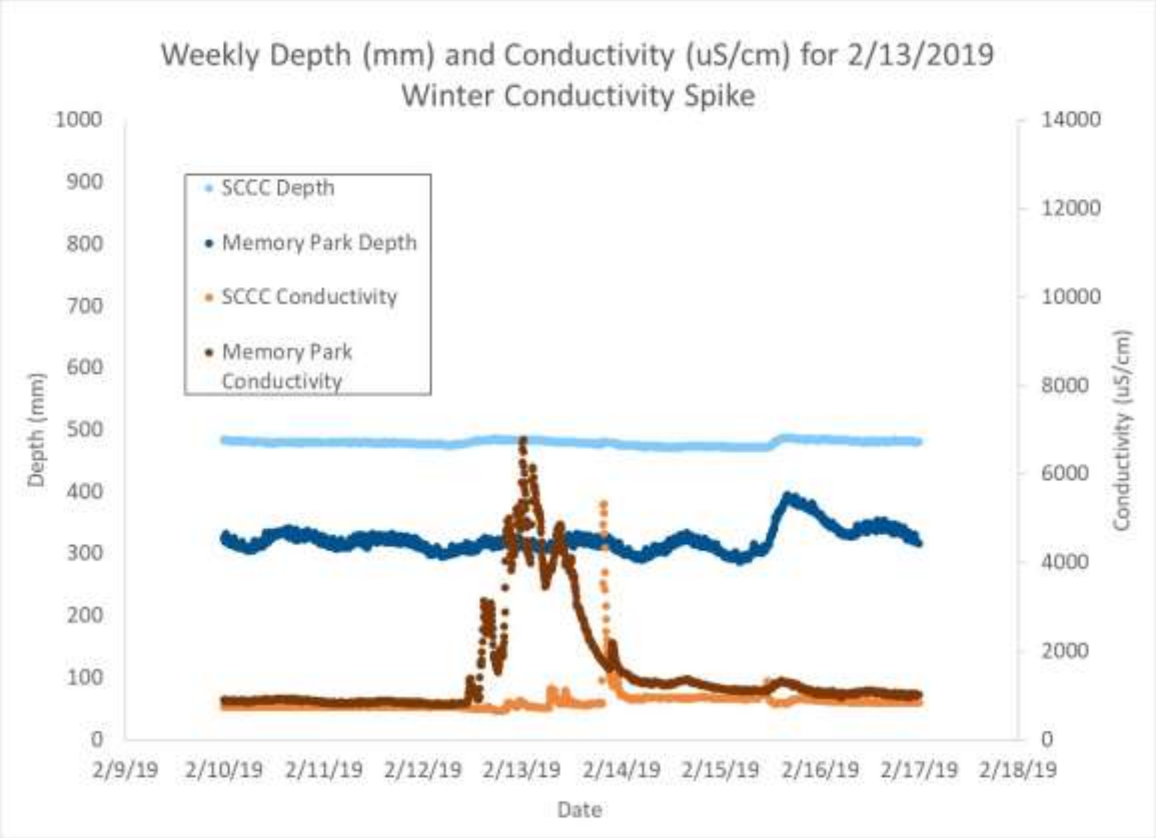


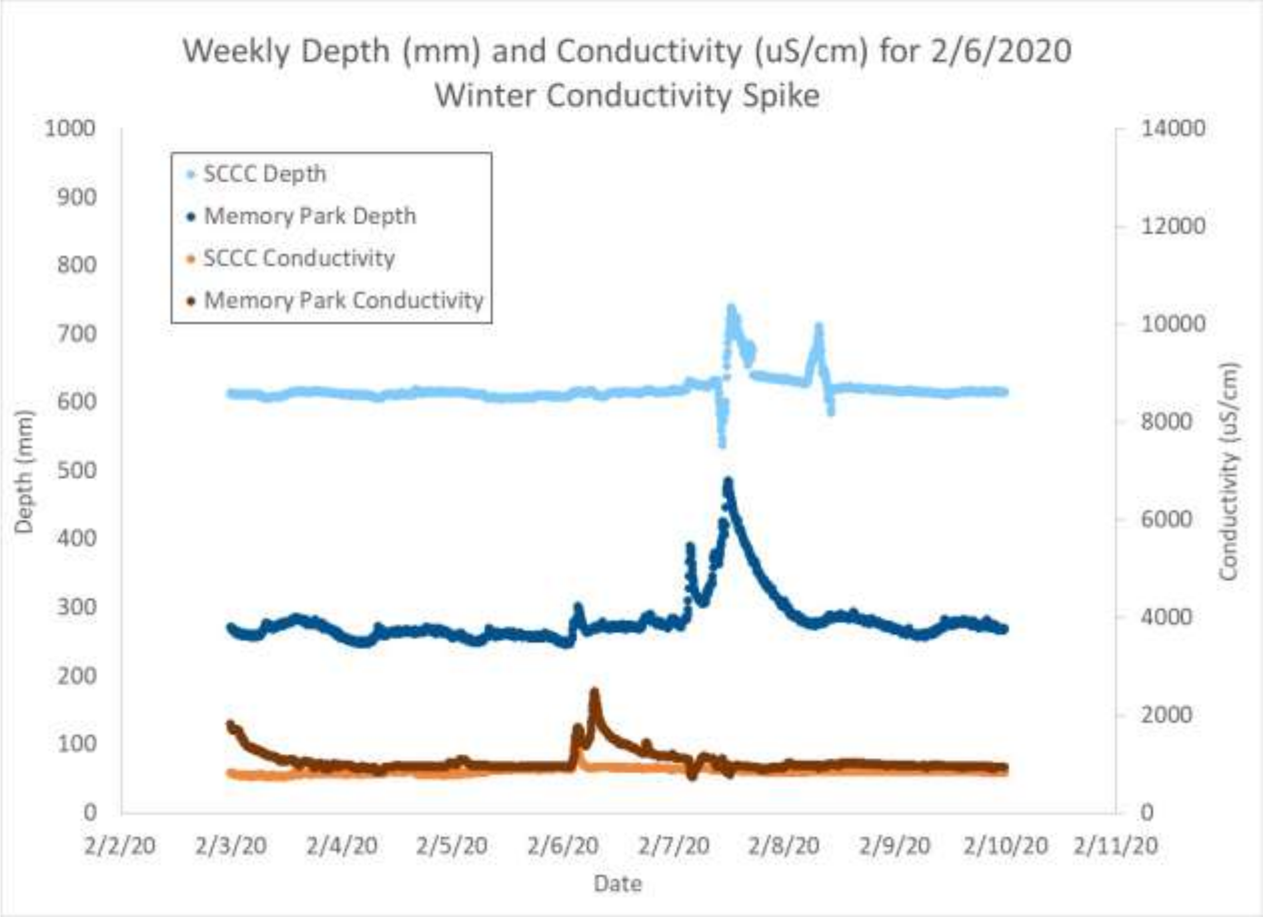

Memory Park Winter 2020-2021 Precipitation (centimeters) and Conductivity (uS/cm)
Wintery Mix
Conductivity
Precipitation (cm)
0
1
2
3
4
5
6
7
Conductivity (uS/cm)
0
5000
10000
15000
20000
25000
12/15/20
1/4/21
1/24/21
2/13/21
3/5/21
3/25/21
4/14/21
Date

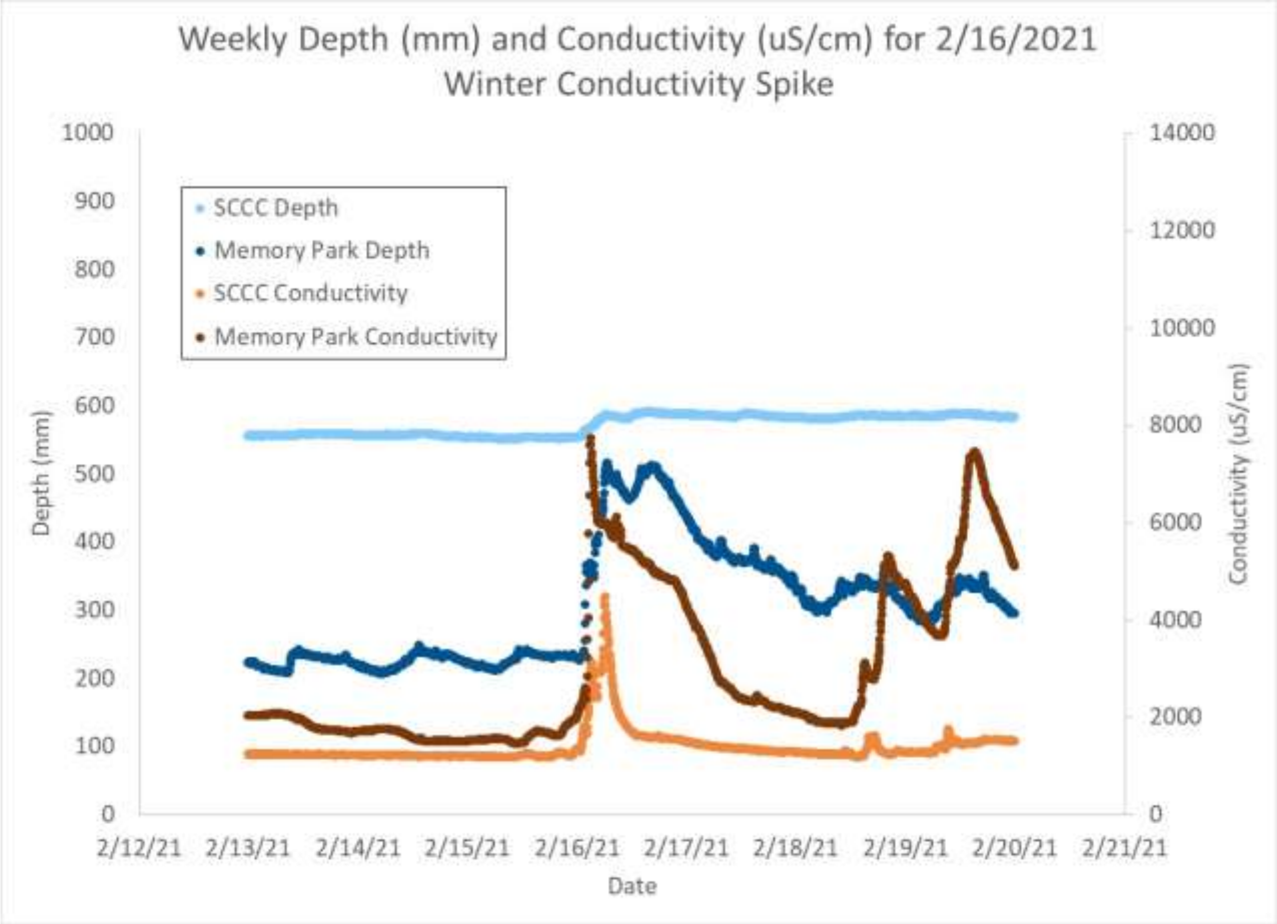

Memory Park Winter 2021-2022 Precipitation (centimeters) and Conductivity (uS/cm)
Rain
Wintery Mix
Conductivity
Precipitation (cm)
0
1
2
3
4
5
6
7
Conductivity (uS/cm)
0
5000
10000
15000
20000
25000
12/10/21
12/30/21
1/19/22
2/8/22
2/28/22
3/20/22
4/9/22
Date

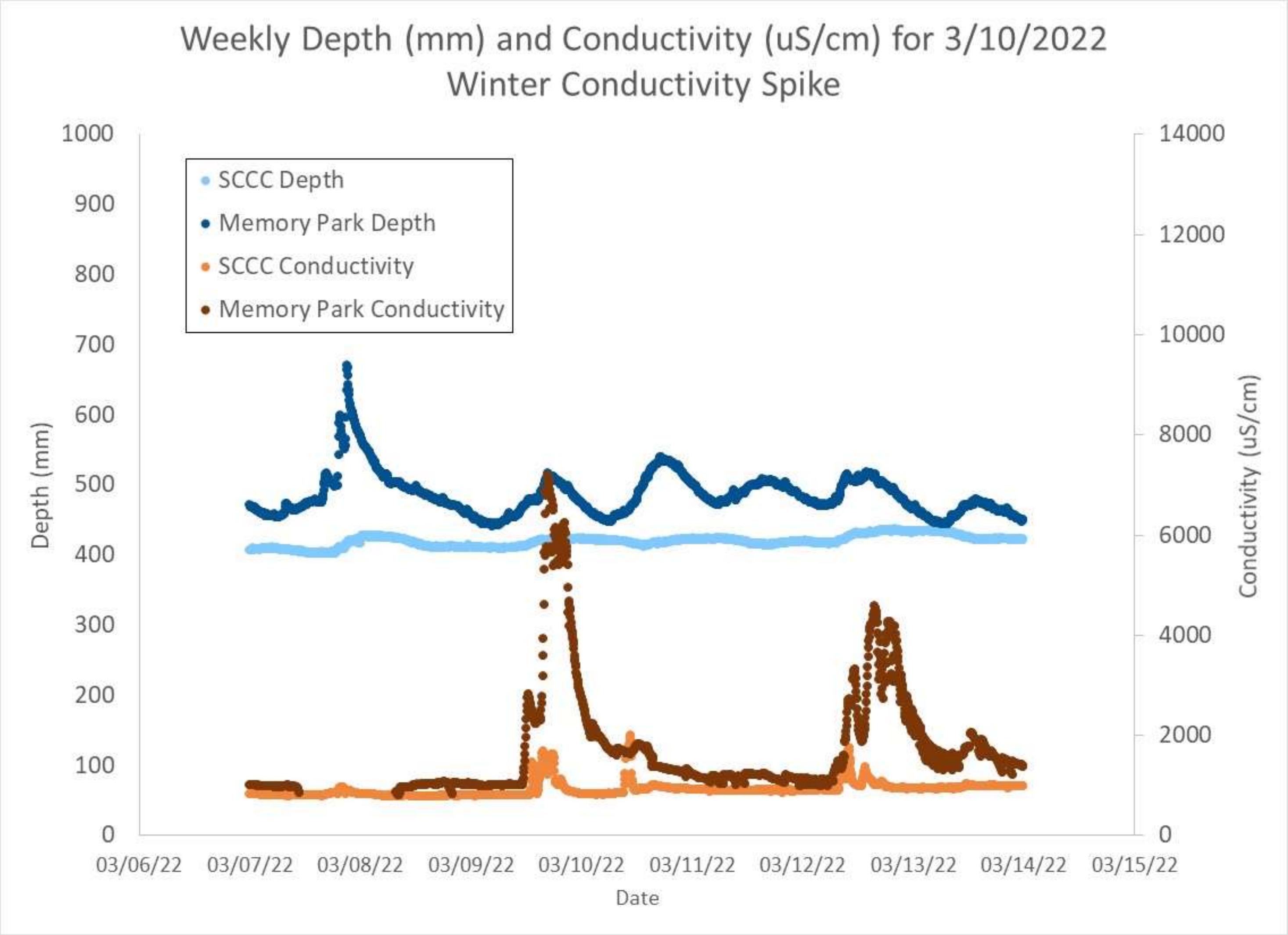
DEPTH AND CONDUCTIVITY COMPARISON BETWEEN SCCC AND MEMORY PARK SENSOR STATIONS FOR MAXIMUM CONDUCTIVITY SPIKE OBSERVED AT SCCC EACH WINTER SEASON



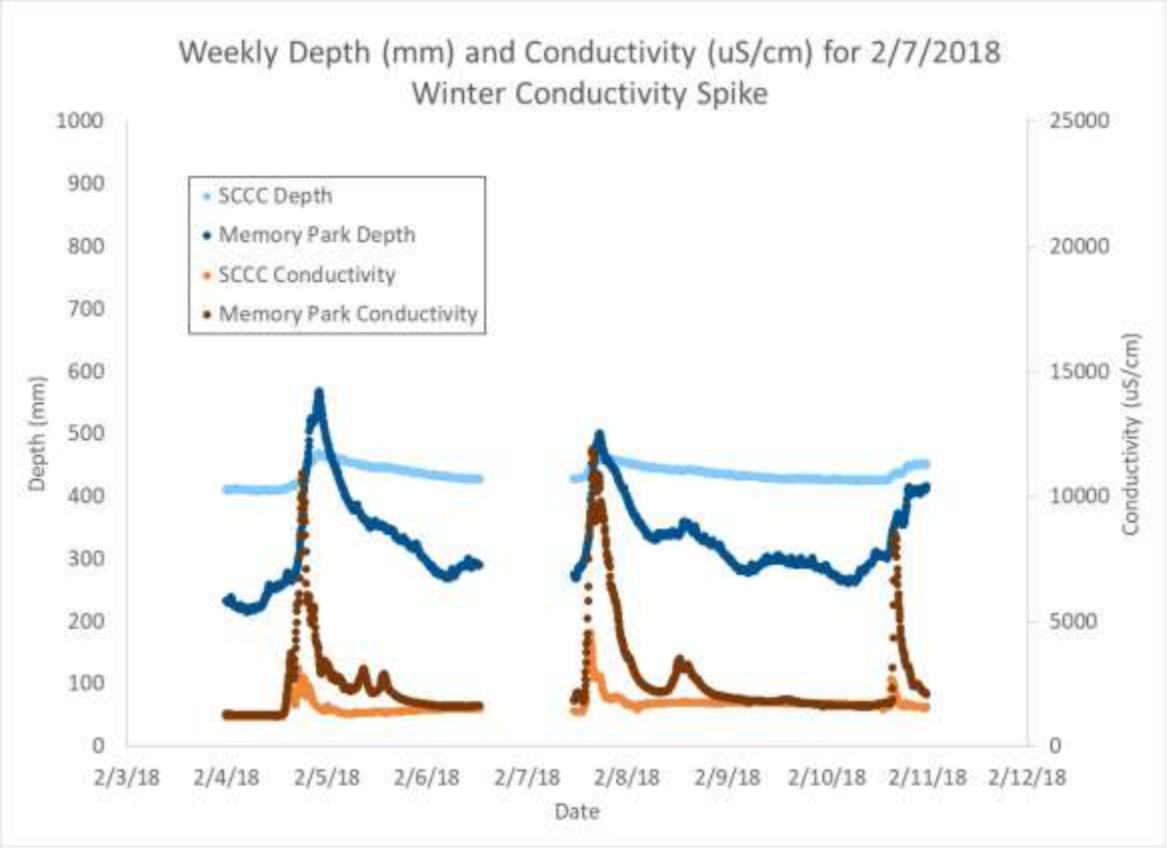


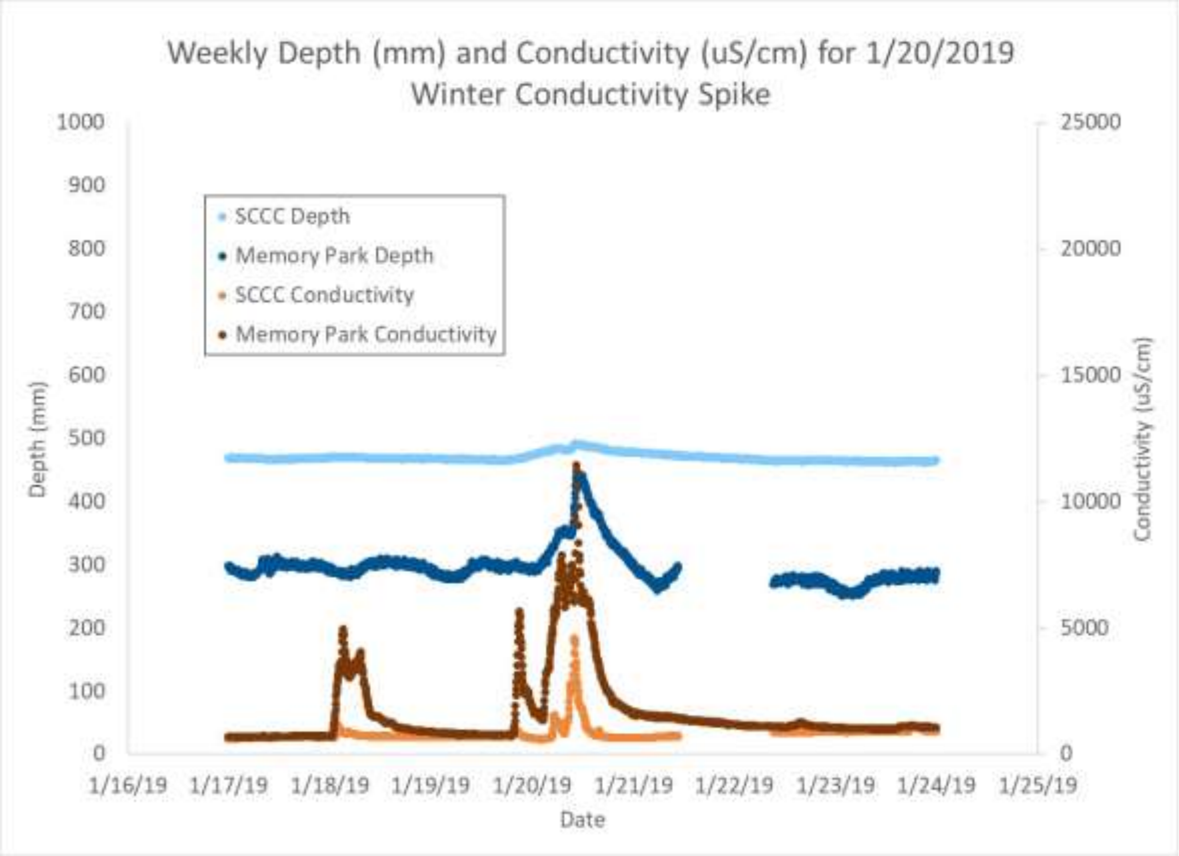

Weekly Depth (mm) and Conductivity (uS/cm) for 2/6/2020 Winter Conductivity Spike

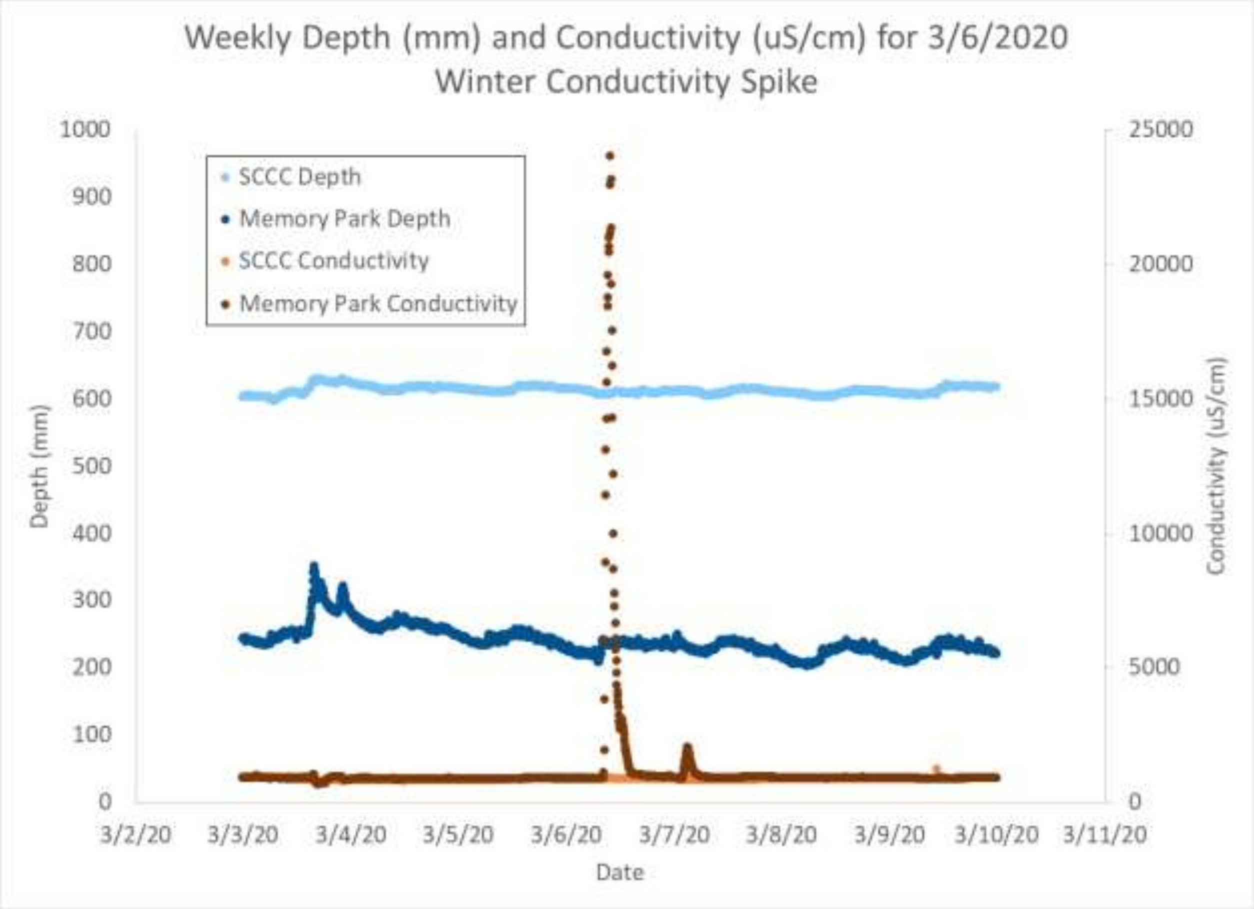

Weekly Depth (mm) and Conductivity (uS/cm) for 2/16/2021 Winter Conductivity Spike


Weekly Depth (mm) and Conductivity (uS/cm) for 3/10/2022
Winter Conductivity Spike
● SCCC Depth
● Memory Park Depth
● SCCC Conductivity
● Memory Park Conductivity
Depth (mm)
1000
900
800
700
600
500
400
300
200
100
0
Conductivity (uS/cm)
14000
12000
10000
8000
6000
4000
2000
0
03/06/22
03/07/22
03/08/22
03/09/22
03/10/22
03/11/22
03/12/22
03/13/22
03/14/22
03/15/22
Date

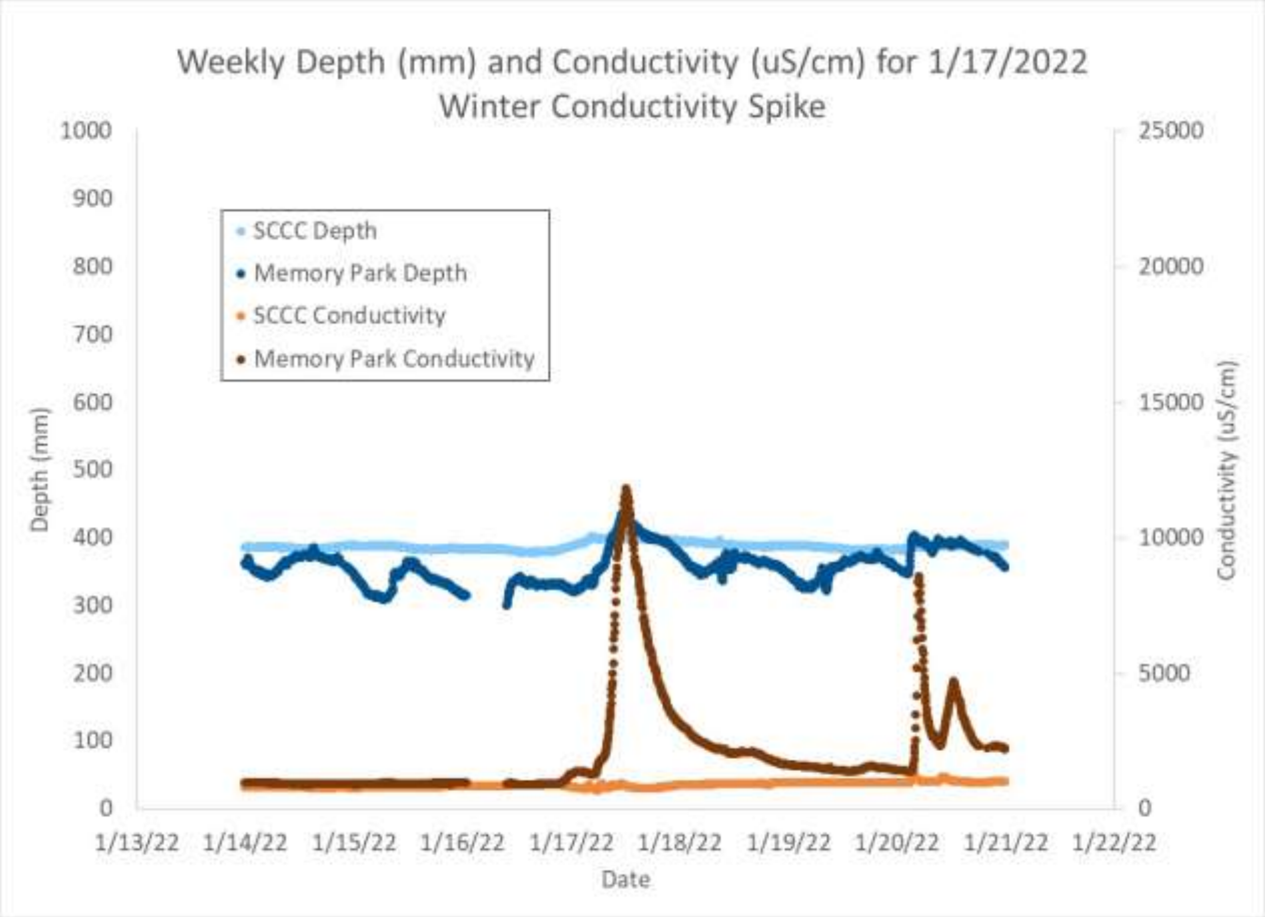
DEPTH AND CONDUCTIVITY COMPARISON BETWEEN SCCC AND MEMORY PARK SENSOR STATIONS FOR MAXIMUM CONDUCTIVITY SPIKE OBSERVED AT MEMORY PARK EACH WINTER SEASON





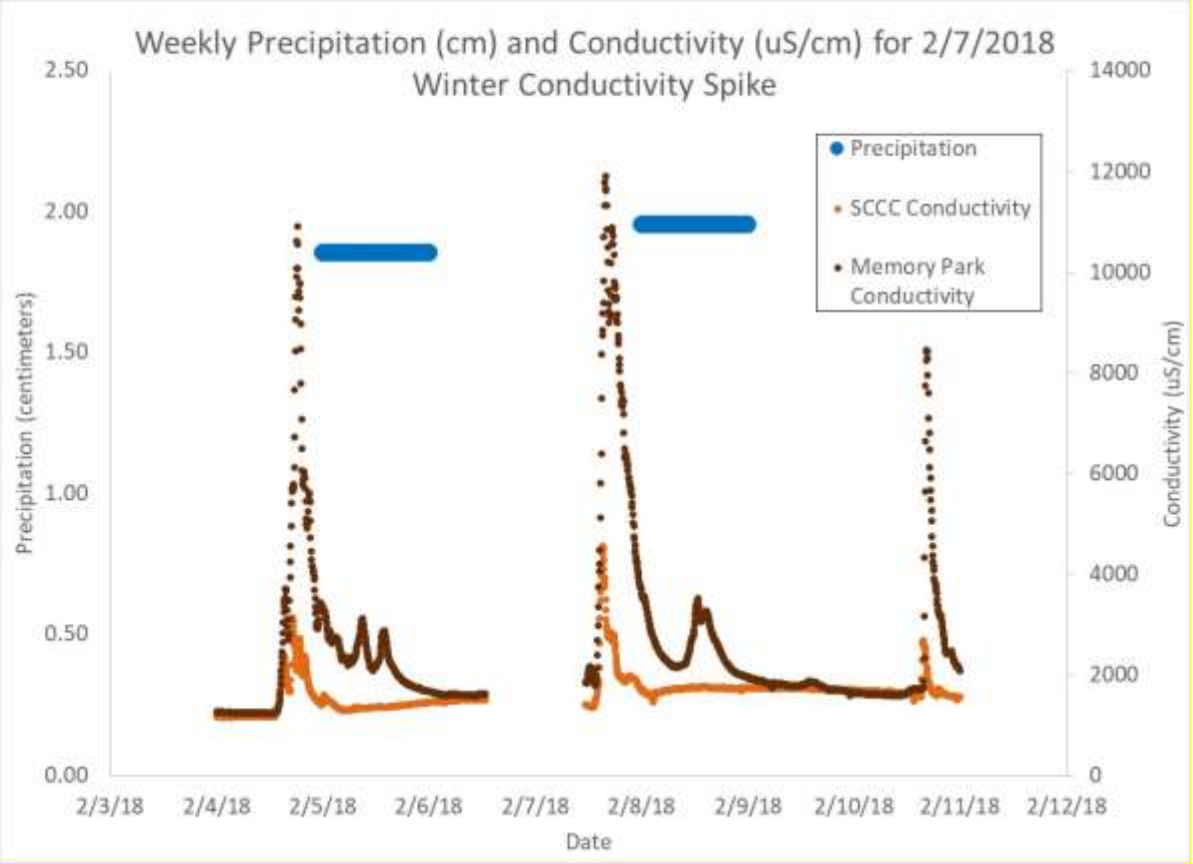


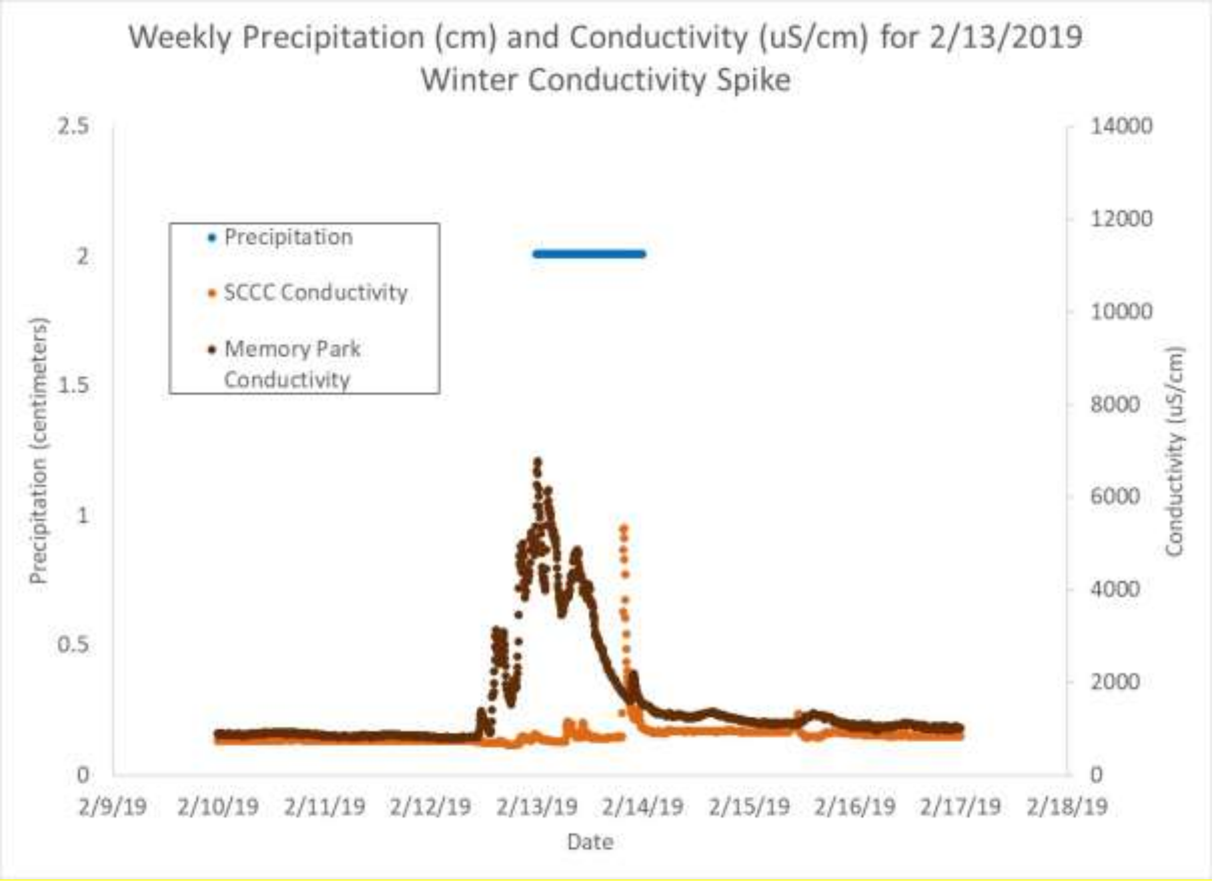
Weekly Depth (mm) and Conductivity (uS/cm) for 3/6/2020 Winter Conductivity Spike

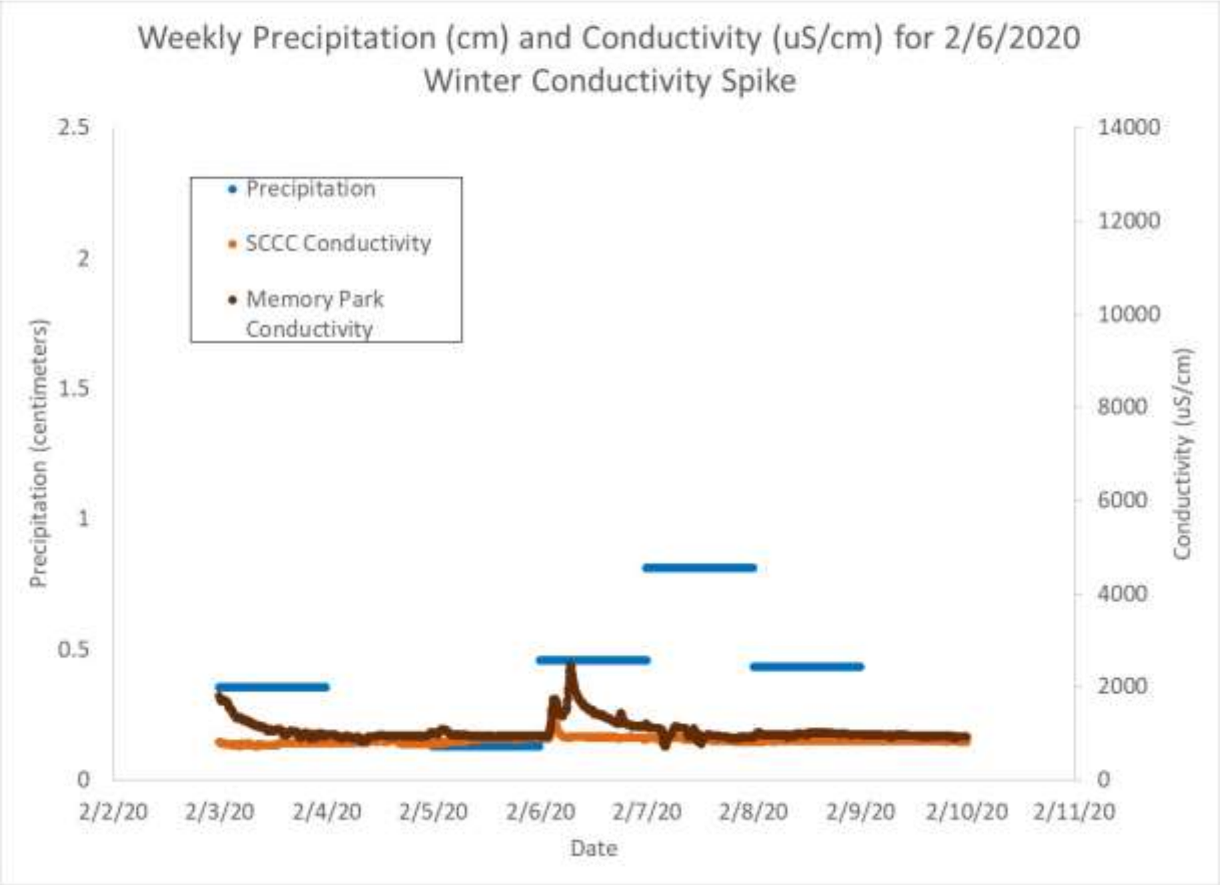


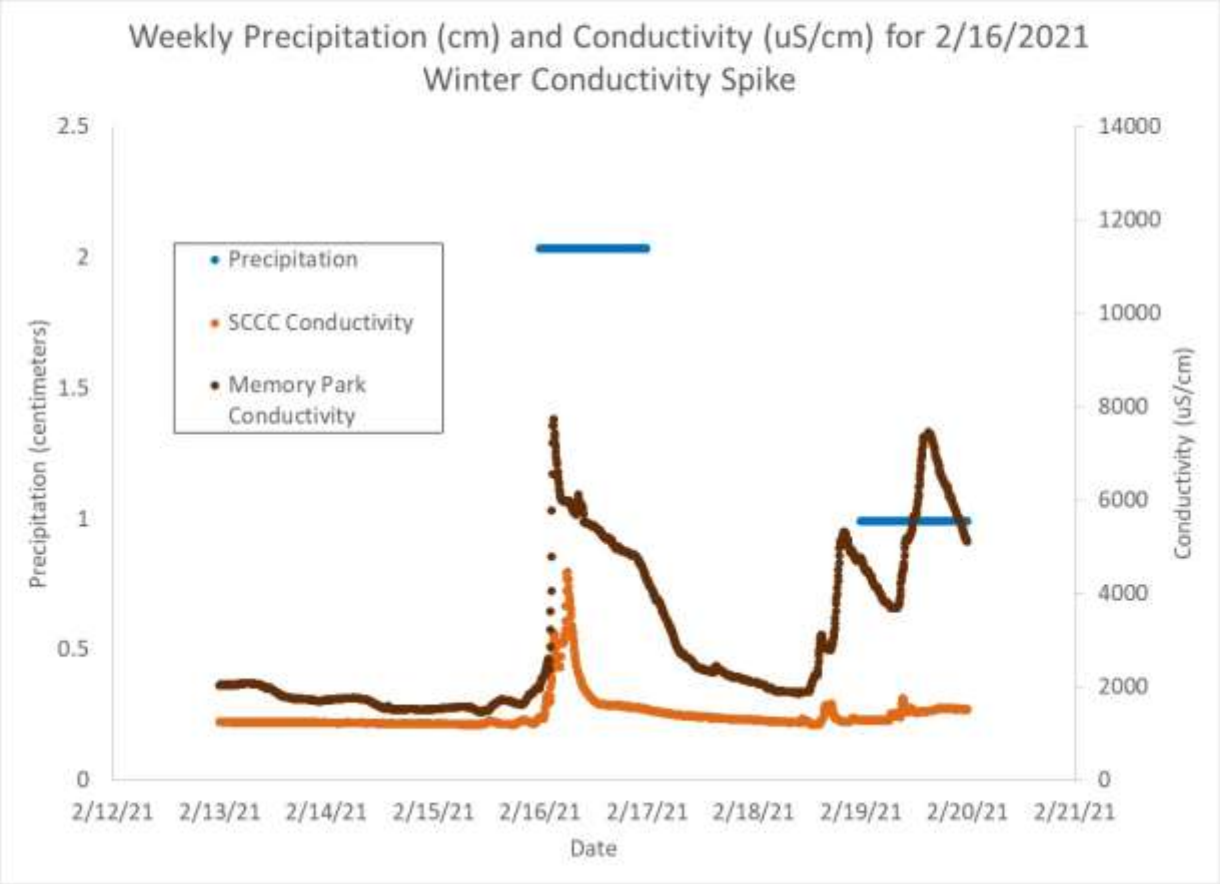
Weekly Depth (mm) and Conductivity (uS/cm) for 1/17/2022 Winter Conductivity Spike

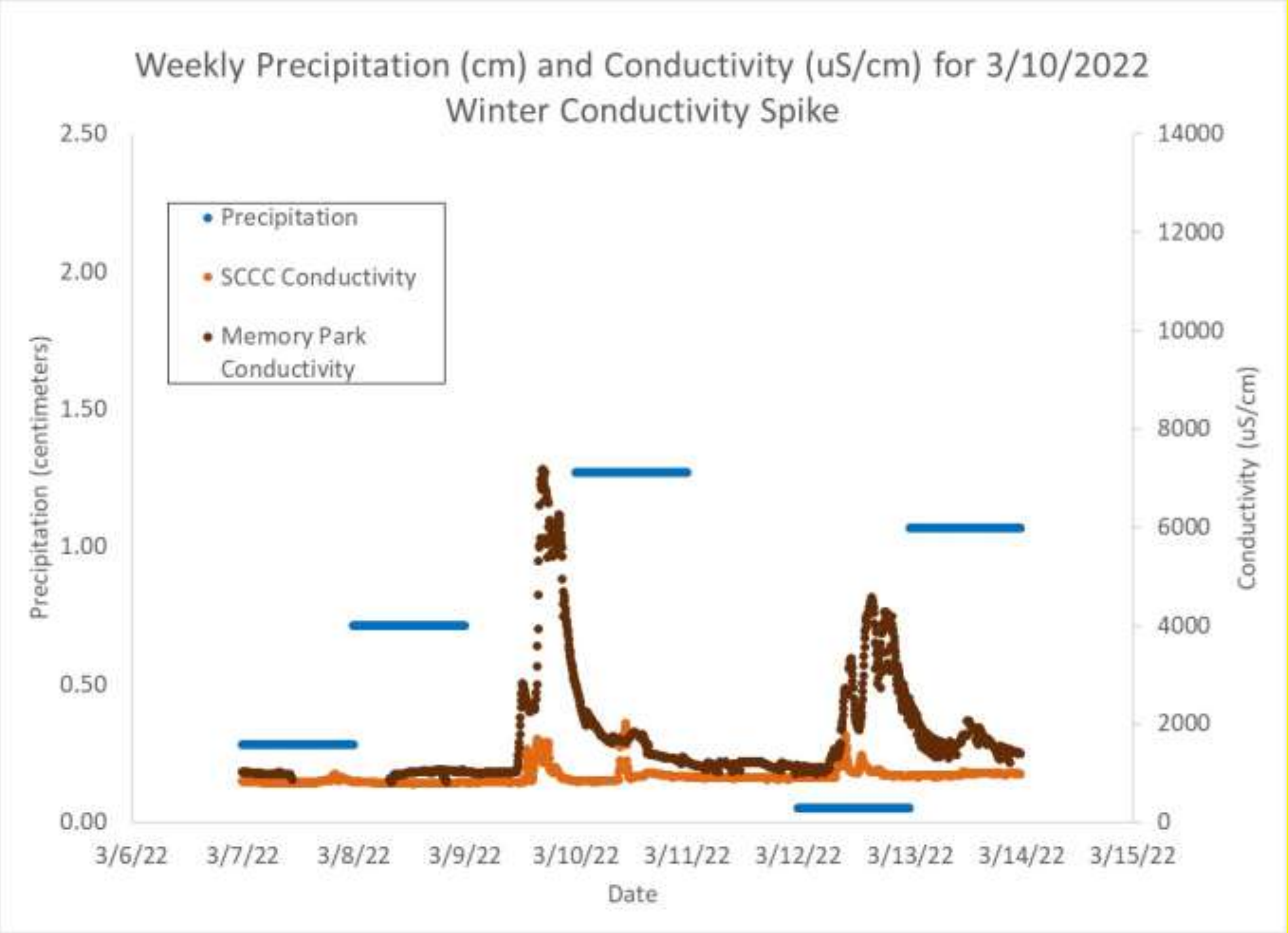
PRECIPITATION AND CONDUCTIVITY COMPARISON FOR MAXIMUM CONDUCTIVITY SPIKE OBSERVED AT SCCC EACH WINTER SEASON



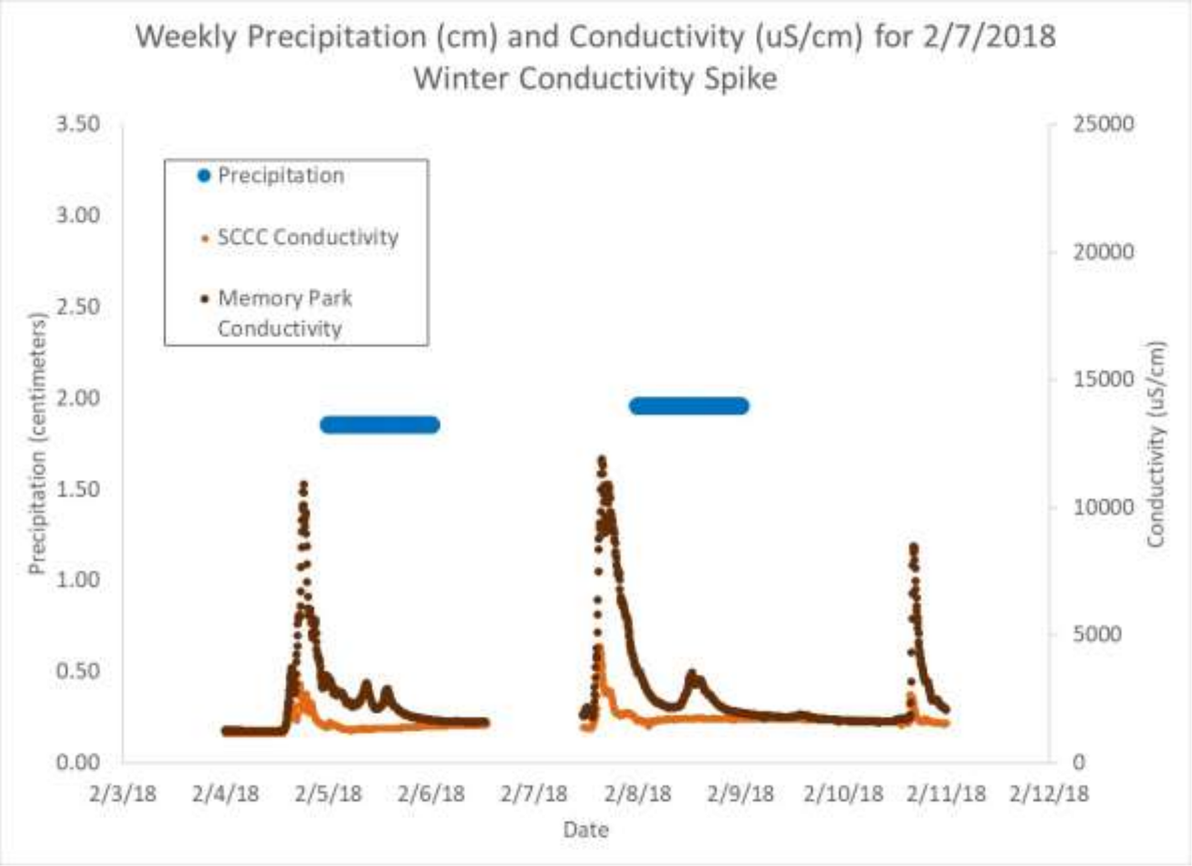


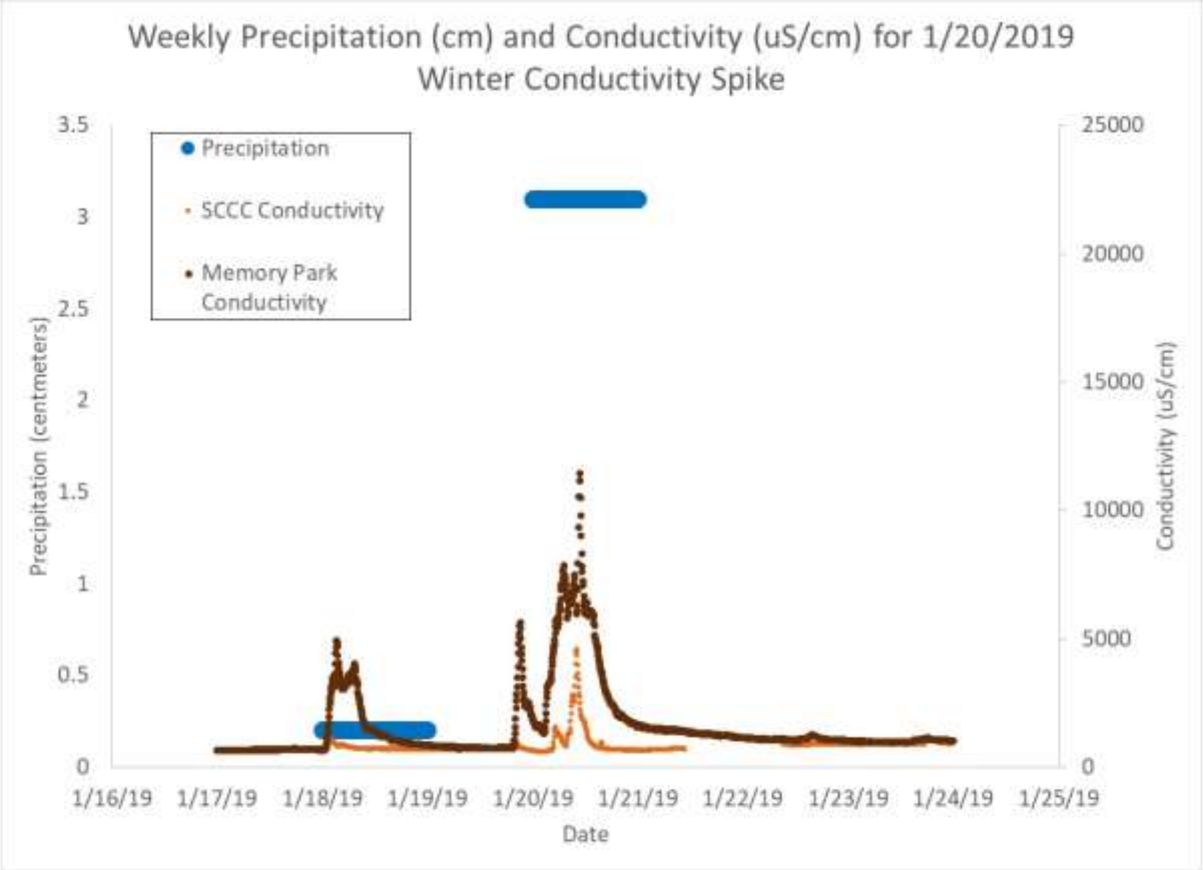

Weekly Precipitation (cm) and Conductivity (uS/cm) for 2/6/2020 Winter Conductivity Spike
Precipitation
SCCC Conductivity
Memory Park Conductivity
Precipitation (centimeters)
Conductivity (uS/cm)
2.5
2
1.5
1
0.5
0
14000
12000
10000
8000
6000
4000
2000
0
2/2/20
2/3/20
2/4/20
2/5/20
2/6/20
2/7/20
2/8/20
2/9/20
2/10/20
2/11/20
Date

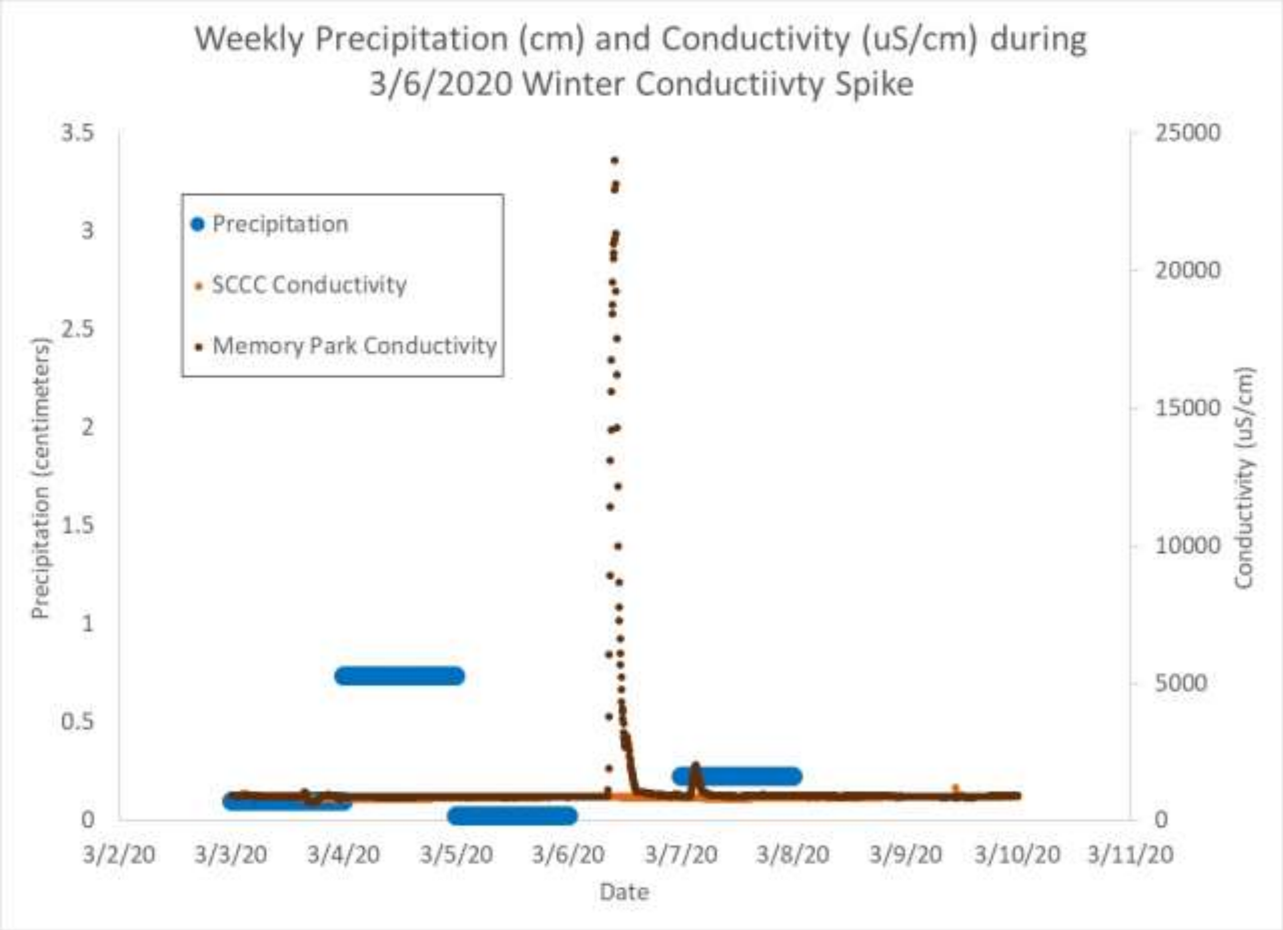

Weekly Precipitation (cm) and Conductivity (uS/cm) for 2/16/2021 Winter Conductivity Spike
Precipitation
SCCC Conductivity
Memory Park Conductivity
Precipitation (centimeters)
Conductivity (uS/cm)
2.5
2
1.5
1
0.5
0
14000
12000
10000
8000
6000
4000
2000
0
2/12/21
2/13/21
2/14/21
2/15/21
2/16/21
2/17/21
2/18/21
2/19/21
2/20/21
2/21/21
Date

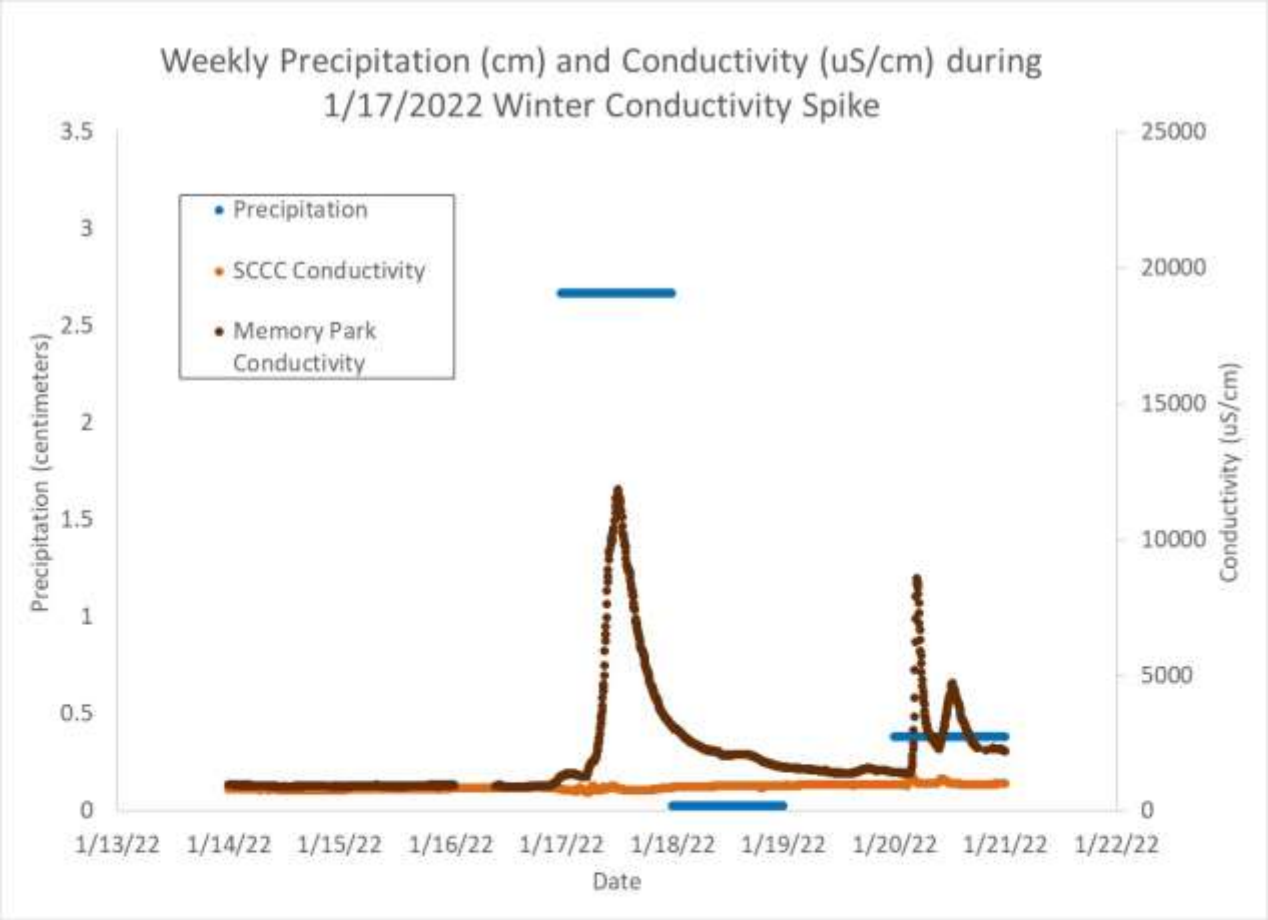

Weekly Precipitation (cm) and Conductivity (uS/cm) for 3/10/2022
Winter Conductivity Spike
● Precipitation
● SCCC Conductivity
● Memory Park
Conductivity
Precipitation (centimeters)
2.50
2.00
1.50
1.00
0.50
0.00
Conductivity (uS/cm)
14000
12000
10000
8000
6000
4000
2000
0
3/6/22
3/7/22
3/8/22
3/9/22
3/10/22
3/11/22
3/12/22
3/13/22
3/14/22
3/15/22
Date

PRECIPITATION AND CONDUCTIVITY COMPARISON FOR MAXIMUM CONDUCTIVITY SPIKE OBSERVED AT MEMORY PARK EACH WINTER SEASON

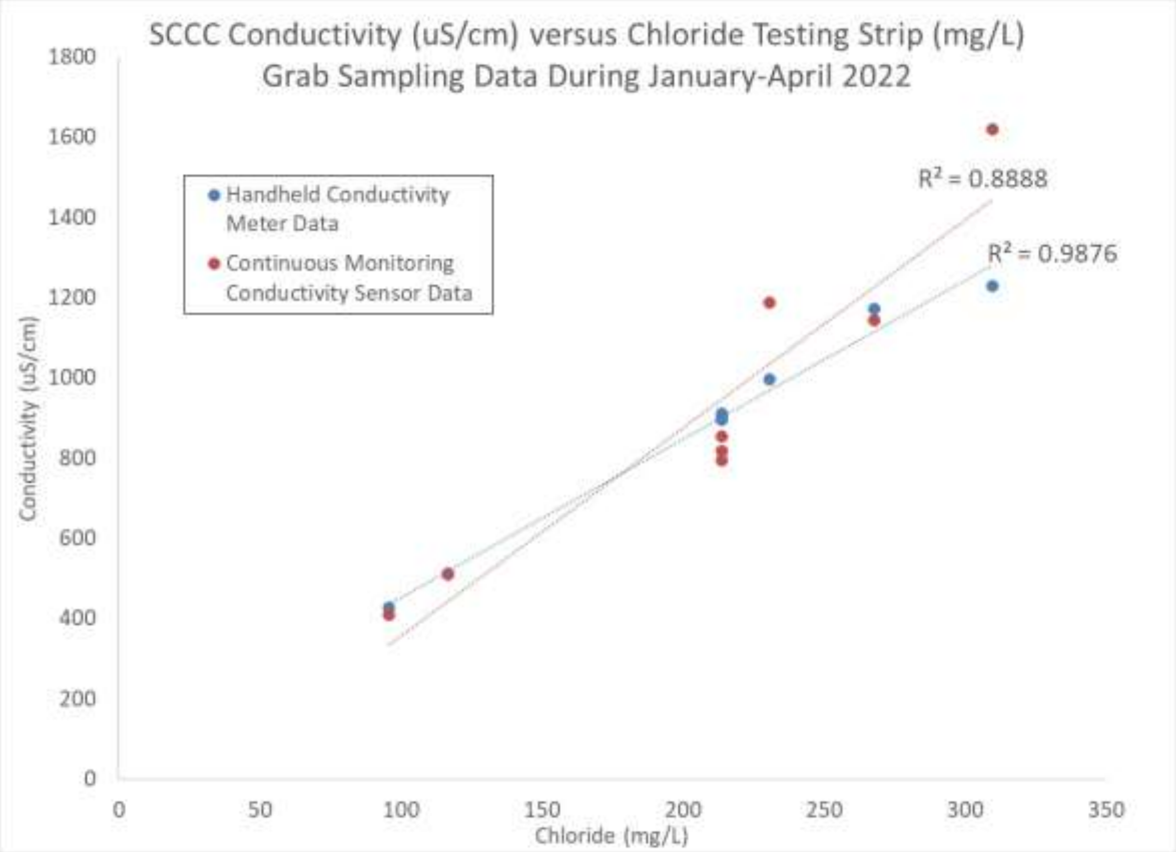


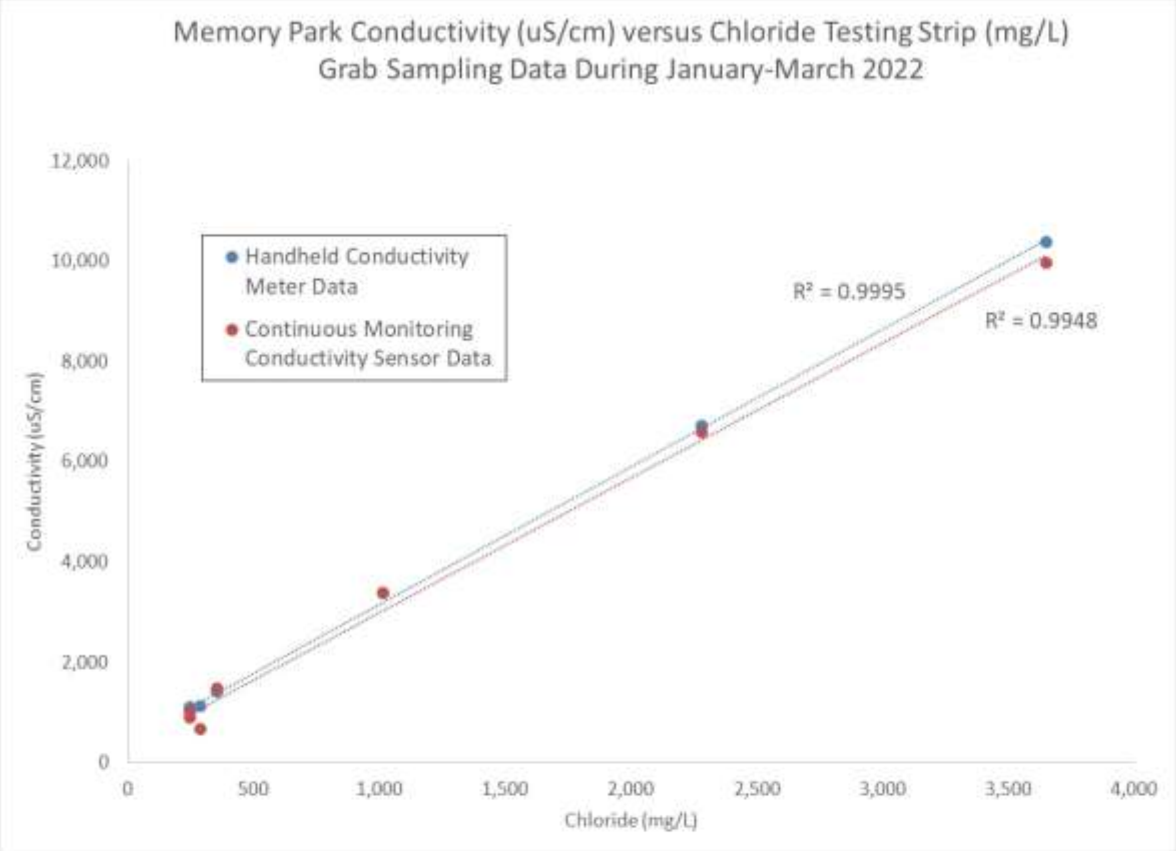



Weekly Precipitation (cm) and Conductivity (uS/cm) during 3/6/2020 Winter Conductiivty Spike
Precipitation (centimeters)
0
0.5
1
1.5
2
2.5
3
3.5
Conductivity (uS/cm)
0
5000
10000
15000
20000
25000
● Precipitation
• SCCC Conductivity
• Memory Park Conductivity
3/2/20
3/3/20
3/4/20
3/5/20
3/6/20
3/7/20
3/8/20
3/9/20
3/10/20
3/11/20
Date


Weekly Precipitation (cm) and Conductivity (uS/cm) during 1/17/2022 Winter Conductivity Spike
Precipitation (centimeters)
0
0.5
1
1.5
2
2.5
3
3.5
Conductivity (uS/cm)
0
5000
10000
15000
20000
25000
• Precipitation
• SCCC Conductivity
• Memory Park Conductivity
1/13/22
1/14/22
1/15/22
1/16/22
1/17/22
1/18/22
1/19/22
1/20/22
1/21/22
1/22/22
Date

RELATIONSHIP BETWEEN CHLORIDE AND CONDUCTIVITY GRAB SAMPLING DATA AT SCCC AND MEMORY PARK





SCCC AND MEMORY PARK CHLORIDE TESTING STRIP RESULTS (mg/L) IN COMPARISON TO U.S. ENVIRONMENTAL PROTECTION AGENCY CHLORIDE CRITERIA FOR DRINKING WATER (250 mg/L)