Stream Monitoring Station in Big Chico Creek

Honors Research in Environmental Science

Department of Geological and Environmental Sciences

Andrea Villegas-Fregoso

Advised by Dr. Sandrine Matiasek

Acknowledgements

I would like to thank Dr. Sandrine Matiasek, an amazing advisor and mentor, for the immense support always. I am very grateful for having been a part of her Environmental Chemistry Lab for the last two years and for all I got to experience.

I would also like to give a big thank you to Yovvani Mojica Perez who was always a part of the fieldwork, willing to endure the cold temperatures of Big Chico Creek.

This project really couldn't have been done without Bill Koperwhats. I am very grateful for his help keeping the station going, for partaking in the diving and swimming, and for accompanying us on our trips to Henning Hole.

Thank you to the Big Chico Creek Ecological Reserve for supporting our research and allowing us to work there.

I would like to thank those who have helped fund this project including Chico STEM Connections Collaborative (CSC^2), the Department of Geological and Environmental Sciences, and COAST.

There have been a lot of contributors in documenting data from Big Chico Creek including multiple students and faculty from Chico State as well as community members, and I am happy to have my work contribute to these efforts in monitoring the creek and contributing to the understanding of Big Chico Creek.

Most importantly, I would like to acknowledge that the site for this project and the land we are on here in Chico is land that sustained the Mechoopda people, recognized as the Mechoopda Indian Tribe of Chico Rancheria, where Native Americans from several villages and neighboring tribes resided.

Table of Contents

Executive Summary

Monitoring stream water quality on a continuous basis benefits human and aquatic health by identifying changes in water composition in response to singular events such as storm events or wildfire, and by capturing long-term trends due to land use and climate changes. This study focuses on continuously monitoring Big Chico Creek, a tributary to the Sacramento River, to examine the seasonal and event-based variability of water quality at an upper watershed location with minimal anthropogenic influence. Long-term monitoring is important to detect changes in stream composition early on, enabling mitigation and adaptation to limit negative impacts on the aquatic ecosystem. While a rating curve is being established to understand the annual streamflow pattern of the creek, relationships between stage and water quality parameters were studied. The monitoring station has been recording stage, electrical conductivity, and water temperature every fifteen minutes since July 2019. This study summarizes data collected between July 2019 and February 2021.

Results focus on overall and seasonal trends, storm events, and baseflow characteristics of Big Chico Creek. Electrical conductivity, a measurement of salinity, was within the range of salinity in U.S. rivers and within the recommended range during summer months to support healthy fish. An inverse relationship was observed between electrical conductivity and stage during the rainy season (R^2 = 0.71). Another relationship was observed between electrical conductivity and water temperature, but this relationship differed between rainy and dry periods, resulting in an overall moderate correlation (R^2 = 0.53). Both relationships exhibited hysteresis patterns, reflecting the relative dominance of groundwater and surface water contributions to streamflow. Baseflow characteristics were established during late summer/early fall, when the diurnal behavior of water quality parameters in Big Chico Creek was studied, further revealing the role of specific water fluxes to the creek.

This study contributes a better understanding of the Big Chico Creek behavior by documenting its daily and seasonal variations in water quality, establishing a baseline for water resources management.

Introduction

Monitoring stream water quality on a continuous basis benefits human and aquatic health by identifying changes in water composition in response to singular events such as storm events or wildfire, and by capturing long-term trends due to changes in land use or climate. Long-term monitoring is important to detect changes in stream composition early on, enabling mitigation and adaptation measures that can limit negative impacts on the aquatic ecosystem (Fig. 1, 2) (Burt et. al, 2014).

Figure 1. Fry in Big Chico Creek.

An important measurement for monitoring a stream is streamflow, or discharge, which is the amount of water flowing through a stream at a point in time (USGS, 2019c). Knowing the streamflow of a stream is useful for predicting floods, managing and allocating water, and for recreational uses among other things (USGS, 2019c). Continuous monitoring of streamflow also facilitates studying the existing relationships between discharge and other water quality parameters such as salinity (Livingstone, 1963).

A common method for gathering continuous streamflow data consists in establishing a stage-discharge relationship. By continuously monitoring the water level (stage), and by taking frequent streamflow measurements (discharge), a stage-discharge relationship can be obtained (USGS, 2019c). From this relationship, streamflow can be calculated from stage measurements, and the annual streamflow hydrograph for a creek can be established. The California Department of Water Resources has a monitoring station in Big Chico Creek at the Bidwell Park golf course, though it was only reporting streamflow data during high flow periods until the Camp Fire occurred in November 2018. It is now reporting hourly stage and streamflow.

Figure 2. Water snake sunbathing.

Continuous monitoring of water quality in Big Chico Creek (BCC) would be beneficial for the City of Chico since the creek is an integral part of the city as it flows through Bidwell Park, is used to fill Sycamore pool, and it also has the potential to be affected by urban and agricultural land uses as it enters the Central Valley in Chico. It would also serve to document BCC's response to storm events, land management, change in climate, and changes in water composition.

The aim of my research is to maintain a stream monitoring station in BCC upstream of anthropogenic influence, identify seasonal variations in water quality, evaluate how storm events affect water quality in BCC, and characterize baseflow conditions in BCC. Efforts to establish a rating curve have begun at this location to study the relationships between streamflow and water quality parameters, in the meantime, however, stage will be used to study these relationships. The main water quality parameters that this research focuses on are electrical conductivity and water temperature.

Conductivity is a measurement of the ability of water to pass an electrical current. The average electrical conductivity in U.S. rivers ranges between 50 µS/cm to 1500 µS/cm, and the range for water supporting fish is between 150 to 500 µS/cm (EPA, 2012). There are many factors that affect electrical conductivity including the local geology, the presence of inorganic dissolved solids which can carry either a negative or positive charge, and organic compounds that have a lower conductivity in water (EPA, 2012). Electrical conductivity is therefore acknowledged as a measure of salinity since dissolved salts and other organic chemicals conduct electrical current (EPA, 2012). Additionally, electrical conductivity is directly related to water temperature, higher water temperature increases electrical conductivity since it can dissolve more minerals from nearby rocks (EPA, 2021) (USGS, 2021d). Aside from anthropogenic influences, it could also be impacted by discharge from anthropogenic sources such as urban runoff or a sewage system (EPA, 2012).

Monitoring water temperature is useful in detecting changes in Big Chico Creek as it influences the types of organisms able to live in water, mainly through its impact on the dissolved oxygen content which decreases as temperature increases (USGS, 2021d).

Objectives

- Maintain a stream monitoring station in BCC upstream of anthropogenic influence
- Identify seasonal patterns in water quality parameters in BCC
- Evaluate how storm events affect water quality parameters in BCC
- Characterize baseflow conditions in BCC

Site Description

Big Chico Creek Watershed

The Big Chico Creek watershed flows south-west covering an area of about 72 mi^2 (Fig. 3) (USFWS, 2006). Originating near Colby Mountain at an elevation of about 6,000 ft, Big Chico Creek travels down 45 mi through the southern Cascade foothills to the Sacramento River (USFWS, 2006). The total descent encompasses an elevation difference of 5,880 ft (USFWS, 2006). Big Chico Creek is a fourth order perennial stream, flowing year-round (Perkins, 2013). It is common during the summer for BCC to dry before reaching the Sacramento River due to infiltration and evaporation that occur in the agricultural Central Valley (USFWS, 2006)

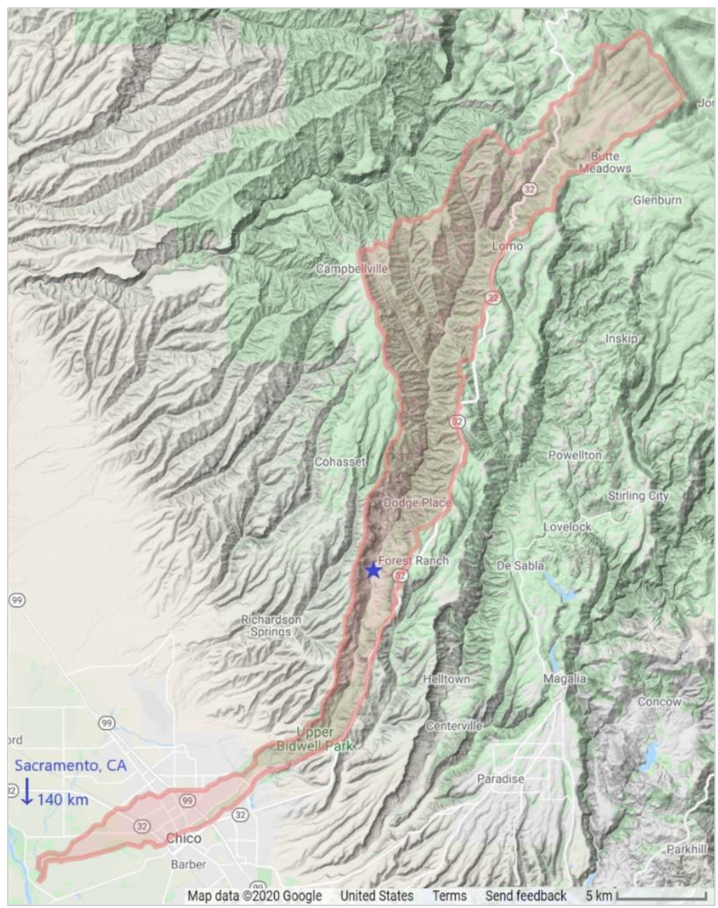


Figure 3. BCC watershed map with a blue star indicating study site.

The BCC watershed experiences a Mediterranean climate with hot dry conditions in the summer, and wet, cooler conditions in the winter (Britannica, 2019). The upper Big Chico Creek watershed experiences snow during the winter, contributing to BCC baseflow by snowmelt in late spring (BCCER, 2021).

California is currently experiencing drought conditions and Butte County is experiencing extreme drought conditions (Simeral & Gutzmel, 2021). As of May 12, 2021 the Northern Sierra had received 22.9 inches of precipitation this water year, almost half of the historical average (Fig. 4).

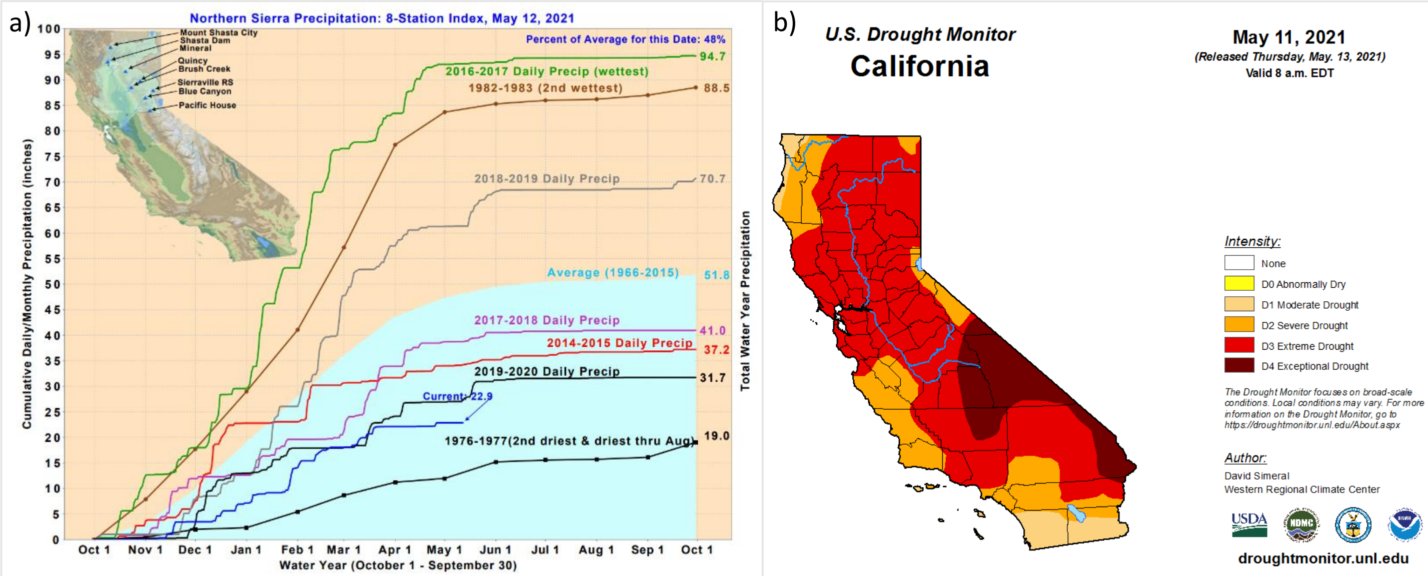


Figure 4. (a) California's Northern Sierra Total Water Year Precipitation (CDEC, 2021) and (b) current drought conditions of California (Simeral & Gutzmel, 2021).

Henning Hole

The study site is situated at the Big Chico Creek Ecological Reserve (BCCER) near an area known as Henning Hole (Fig. 5). It is located in the upper Big Chico Creek watershed at an elevation of 889 ft where it experiences minimal anthropogenic influence (Fig. 3).

Figure 5. View of the monitoring station and the creek

Figure 6. Sierra newt.

Some fish species present in BCCER include spring run Chinook salmon, steelhead, rainbow trout, brown trout, and California roach (FISHBIO, 2019). Sierra newts are also common to the area and utilize Big Chico Creek as a mating location (Fig. 6).

The geology of the area from top-to-bottom consists of the Tuscan Formation, followed by the Lovejoy Basalt, and finally the Chico Formation (Fig. 7). The Tuscan formation is composed of primarily layered ash and lahars, the Lovejoy Basalt include Miocene volcanic rock, and the Chico Formation is composed of marine sedimentary rock with fossiliferous marine sandstone (USFWS, 2006). At the monitoring site, the creek has carved into the Chico formation with a steep cliff seen across the bank (Fig. 5).

During winter temperatures at BCCER can reach below freezing while they reach above 100°F during the summer and annually BCCER receives an average precipitation of about 40 inches (BCCER, 2021).

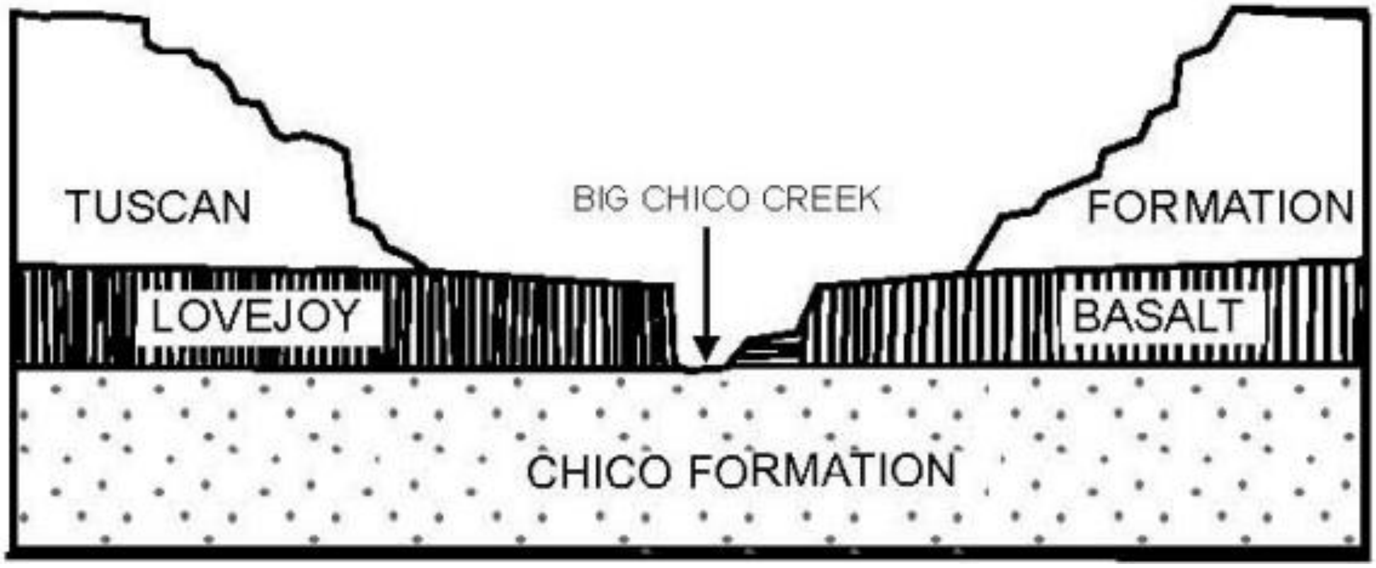


Figure 7. Generalized geology profile of Upper Bidwell Park, similar to the profile of the monitoring site. (USFWS, 2006).

Methods

The monitoring station consists of a Campbell Scientific data logger (CR1000) with sensors measuring EC and water temperature (CS547A-L), air temperature and relative humidity (HMP45C-LQ), and stage (CS451) (Fig. 8). It was established in July 2019 at Henning Hole at the Big Chico Creek Ecological Reserve and has been continuously collecting data every 15 minutes. It is run on a 12V battery located in the monitoring box. Air temperature and relative humidity data collection stopped in June of 2019 due to instrumentation issues.

Table 1. Model and details of instruments used in the monitoring station.

Model	Details
CR100 Data Logger	Operating Temperature Range: -25° to +50°C (standard)
CS547A-L Electrical Conductivity Probe	Conductivity Measurement Range: ~0.005 to 7 mS cm^{-1} Conductivity Accuracy: ±5% of reading (for 0.44 to 7.0 mS cm^{-1} range)
CS451 Pressure Transducer	Temperature Accuracy: ±0.2°C Standard Accuracy Option: ±0.1% full-scale-range TEB
Air Temperature HMP45C-LQ	Accuracy at 20°C: ±1% RH (against factory reference)
Teledyne STREAMPRO ADCP (Acoustic Doppler Current Profiler)	Water Velocity Profiling range 0.1 m to 2 m standard Velocity range ±5 m/s Accuracy ±1% of water velocity relative to ADCP, ±2 mm/s

Figure 8. Monitoring box (left) attached to tree and sensor attached to structure (right).

The monitoring box is attached to a tree on the bank of Big Chico Creek and stores the data logger and battery (Fig. 8). The wiring connecting the data logger to the sensors runs through a protective tubing (Fig. 8). The structure that holds the sensors consists of three cement-filled cinderblocks that prevent movement of the sensors on the creek bed, metal pipe, and square perforated tubes for the sensors to be attached to using u-bolts (Fig. 8).

Precipitation data was retrieved from the California Data Exchange Center (CDEC) using data collected from July 1, 2019 to October 11, 2020 at station ID DEC, or De Sabla the closest station to the study site (~5 mi). The elevation difference between the two sites is about 1,900 ft.

Results & Interpretation

Overview

Data analysis and visualization used data collected between July 1, 2019 and February 11, 2021 except for 64 days between September 3, 2019 and November 6, 2019 due to a monitoring station battery issue, and wildlife damaging the wiring of the pressure transducer sensor resulting in lack of stage data after October 28, 2020 (Fig. 9,10,12).

Stage and Precipitation

Stage in Big Chico Creek displayed a consistent response to storm events reported for the De Sabla station located near BCCER (Fig. 9) (DWR, 2021). The storms contributed storm runoff to the creek and led to periods of increased stage, observed as stormflow peaks with rising and falling limbs (Fig. 9).

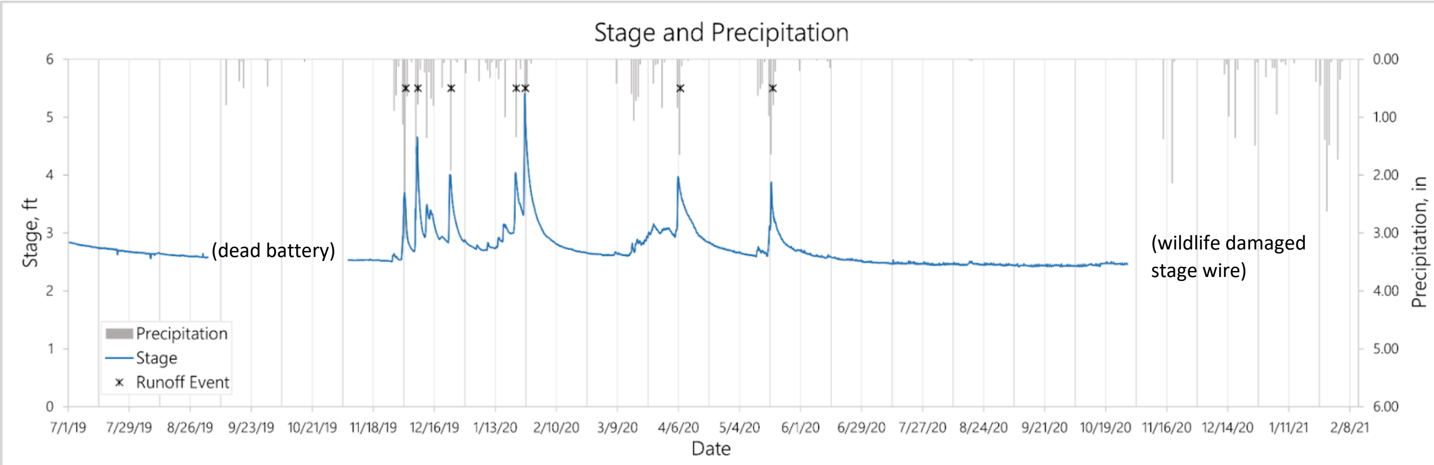


Figure 9. Stage hydrograph at the monitoring station and hyetograph using data collected at the nearby De Sabla station for the study period. Studied storm events are identified with stars.

The maximum stage was observed on February 11, 2021 at 5.41 ft relative to the sensor datum, the minimum was observed on September 15, 2020 at 2.42 ft, and the average was 2.71 ft (Table 2). Baseflow stage was about 2.4 ft, and occurred between June and November (Fig. 9).

Table 2. Summary of stage values in Big Chico Creek.

Stage, ft		Date
Max	5.41	2/11/2021
Min	2.42	9/15/2020
Average	2.71	

Electrical Conductivity and Stage

The maximum electrical conductivity at Big Chico Creek was observed on September 6, 2020 at 186 µS/cm, the minimum was observed on February 2, 2021 at 47 µS/cm, the average was 142 µS/cm (Table 3). These values were within the average range for U.S. rivers, between 50-1500µS/cm (EPA, 2012). Electrical conductivity and stage displayed a direct relationship, specifically during storm events, where electrical conductivity decreased as stage increased (Fig. 10). This observation was confirmed by a positive correlation using a linear regression (R^2=0.71) (Fig. 11). These results are consistent with salts being less concentrated at higher water levels in rivers, as salts are diluted during periods of greater flow (Livingstone, 1963).

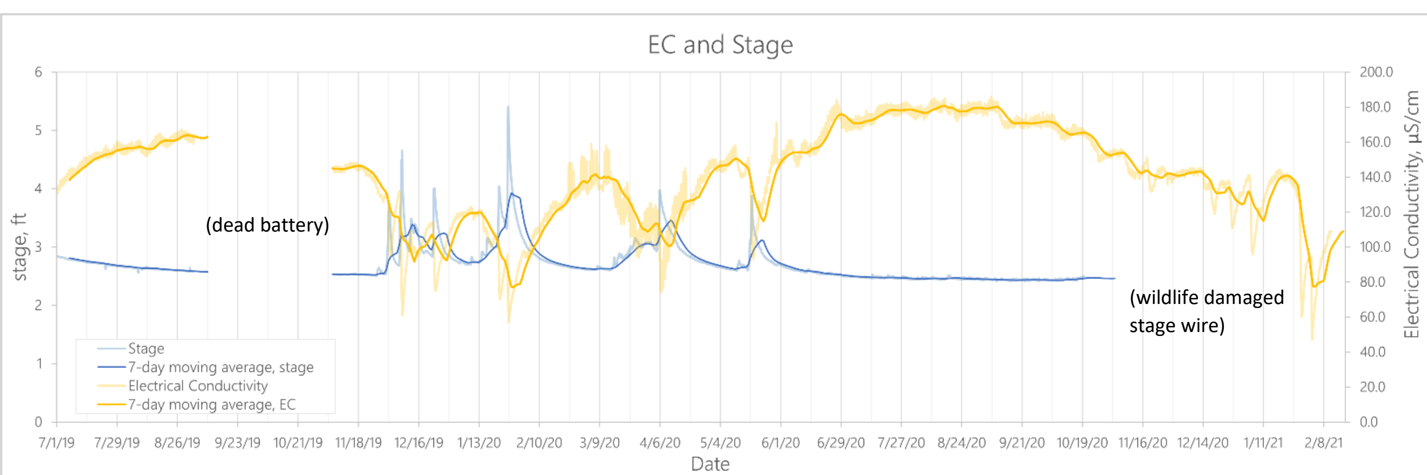
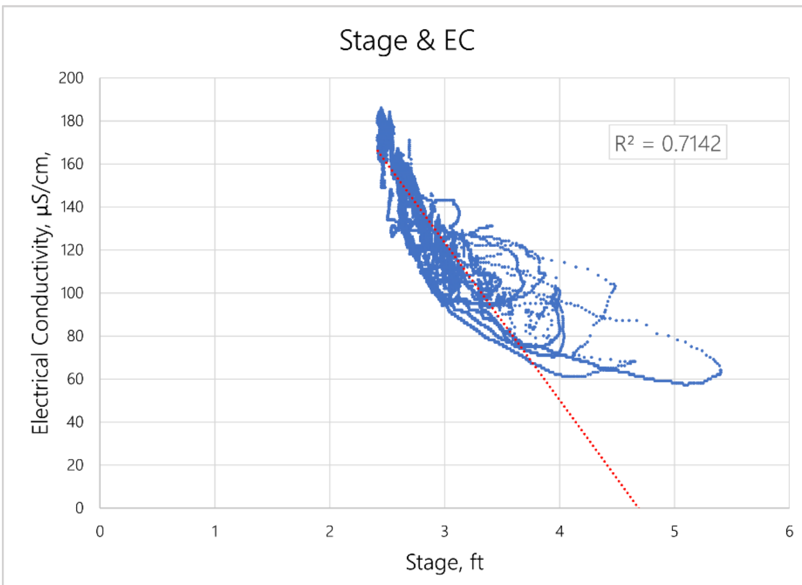


Figure 10. Temporal variability of electrical conductivity and stage displayed as 15-min measurements and 7-day moving averages.

Table 3. Summary of electrical conductivity values in Big Chico Creek.

Electrical Conductivity, µS/cm		Date
Max	186	9/6/20
Min	47	2/2/21
Average	142	

A hysteresis loop is visible in the stage-electrical conductivity plot (Fig. 11), when two different values of electrical conductivity can be observed for the same stage value, reflecting a dependence on antecedent conditions; whether stage is increasing at the beginning of the storm or decreasing towards the end. This is commonly observed for the relationship between discharge and chemical composition during storm events (Johnson & East, 1982). The hysteresis pattern shows that the relationship between electrical conductivity and stage is not linear and that it depends



on the relative flow contributions of surface runoff and shallow groundwater.

Figure 11. Electrical conductivity as a function of stage. The red dotted line represents the linear regression between these parameters.

While there is not a universally established relationship between electrical conductivity and stage, the patterns observed in Big Chico Creek indicate that storm events impact electrical conductivity in the creek through the dilution of salts by stormflow. Flow path also likely controls salinity levels in the creek depending on where water has flown and picked up salts, whether it is groundwater, surface runoff, or soil water flow.

Water Temperature and Electrical Conductivity

The average temperature of Big Chico Creek was 12.6°C with the highest temperature being 25.3°C on June 26, 2020 and lowest temperature being 2.8°C on January 27, 2021 (Table 4). During baseflow conditions, water temperature and electrical conductivity displayed a direct relationship where they increased and decreased together (Fig. 12). During storm events, they displayed an indirect relationship; at the onset of a storm event, water temperature increased while electrical conductivity decreased (Fig. 12). This change in relationship resulted in a moderate correlation (R^2=0.53) between water temperature and electrical conductivity during the monitoring period (Fig. 13). A hysteresis pattern was also observed between these parameters; two electrical conductivity values can be observed for a given water temperature (Fig. 13). This could be representative of the diurnal characteristics of water temperature and electrical conductivity.

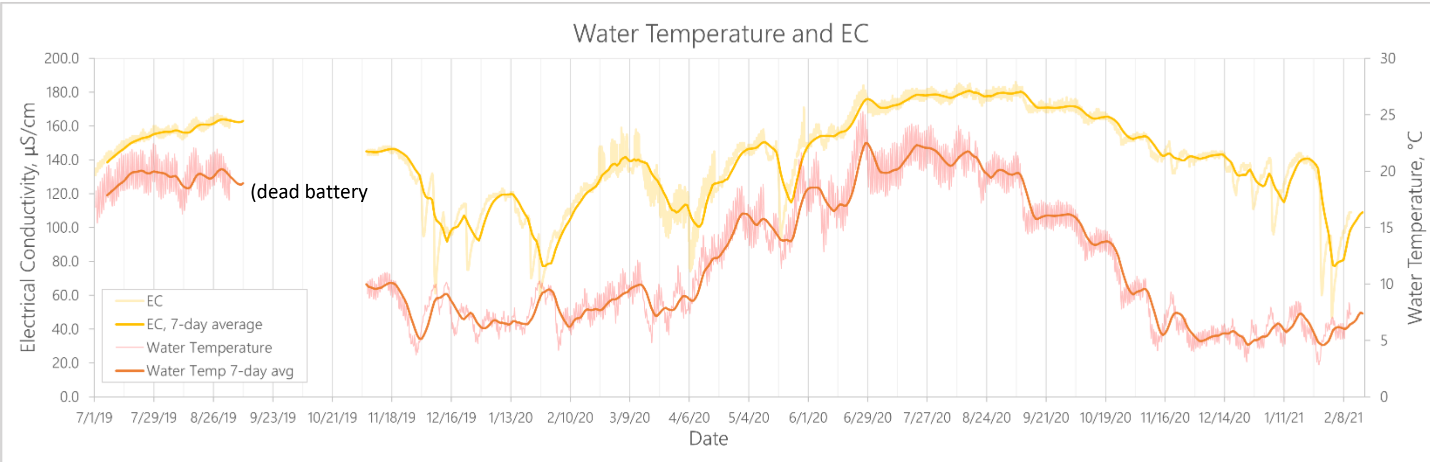


Figure 12. Temporal variability of water temperature and electrical conductivity displayed as 15-min measurements and 7-day moving averages.

Table. 4. Summary for water temperature values in Big Chico Creek.

Water Temperature, °C		
Max	25.3	06/26/2020
Min	2.8	01/27/2021
Average	12.6	

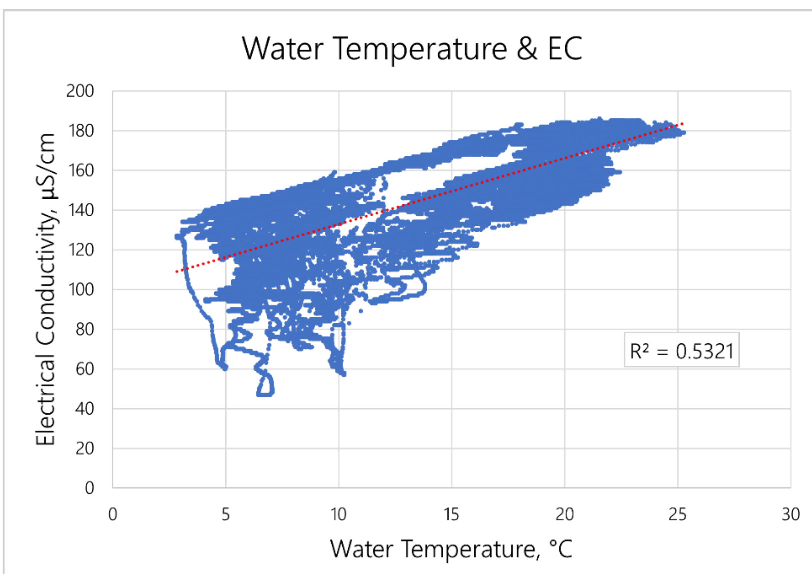


Figure 13. Electrical conductivity as a function of water temperature. The red dotted line represents the linear regression between these parameters.

Seasonal Observations

Electrical Conductivity and Water Temperature

Big Chico Creek experienced the lowest salinity levels occurred during the winter months, ranging between 47 µS/cm and 152 µS/cm, and averaging 115 µS/cm (Table 5). The highest salinity levels occurred during the summer months with electrical conductivity ranging between 131 µS/cm and 186 µS/cm, averaging 165 µS/cm (Table 5). It is within the range for healthy fish populations during the summer months, between 150-500 µS/cm (EPA, 2012).

Water temperature was also highest during the summer months ranging from 12.8°C to 25.3°C, and averaging 19.9°C (Table 6). It was also lowest during the winter months ranging from 2.8°C and 10.3°C, and averaging 6.7°C.

Table 5. Summary table for seasonal electrical conductivity values in Big Chico Creek.

Electrical Conductivity, µS/cm			
	Max	Min	Average
Spring	171	74	130
Summer	185	131	165
Fall	186	126	157
Winter	152	47	115

Table 6. Summary table of seasonal water temperature values in Big Chico Creek.

Water Temperature, °C			
	Max	Min	Average
Spring	21.7	4.8	12.1
Summer	25.3	12.8	19.9
Fall	21.7	3.7	11.6
Winter	10.3	2.8	6.7

Overall electrical conductivity and water temperature displayed similar seasonal and monthly variability; they were highest during the summer and lowest during the winter (Fig. 14). Preceding the rainy season, during the warm summer months, increased evapotranspiration decreases streamflow and increases salt content in the creek, resulting in greater salinity and electrical conductivity values (Fig. 14) (Livingstone, 1963; USGS, 2021a). Electrical conductivity displayed more monthly variability than water temperature, likely because a broader range of environmental factors can affect salinity, including water temperature.

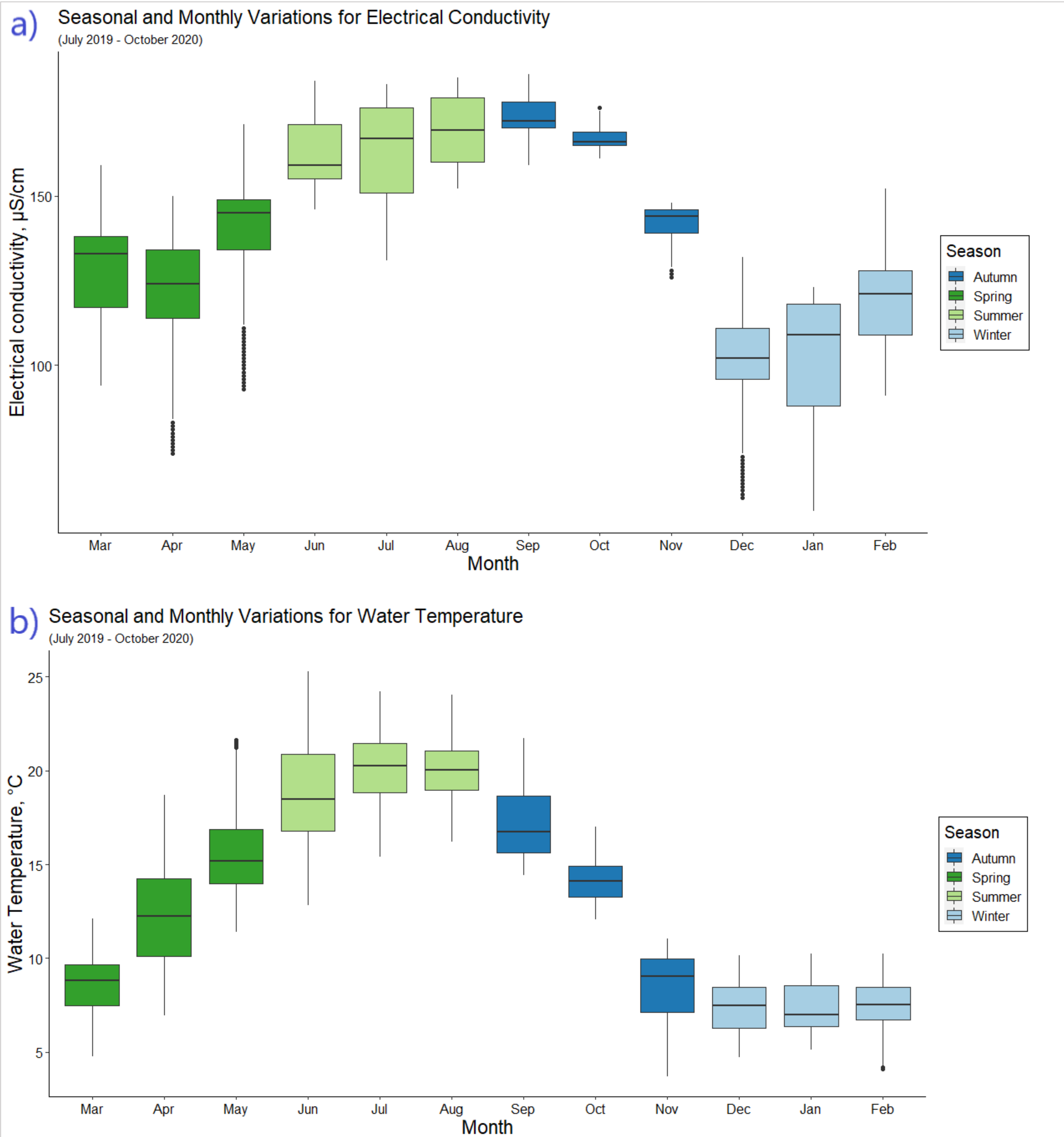


Figure 14. Monthly variations of electrical conductivity (a) and water temperature (b). The bottom of the boxes represents the 25th percentile, the top of the boxes is the 75th percentile, the height of the boxes is the interquartile range (IQR), the line within the box is the median, the dots represent outliers, and the ends of the vertical lines are the max and min (Galarnyk, 2018).

Storm Events

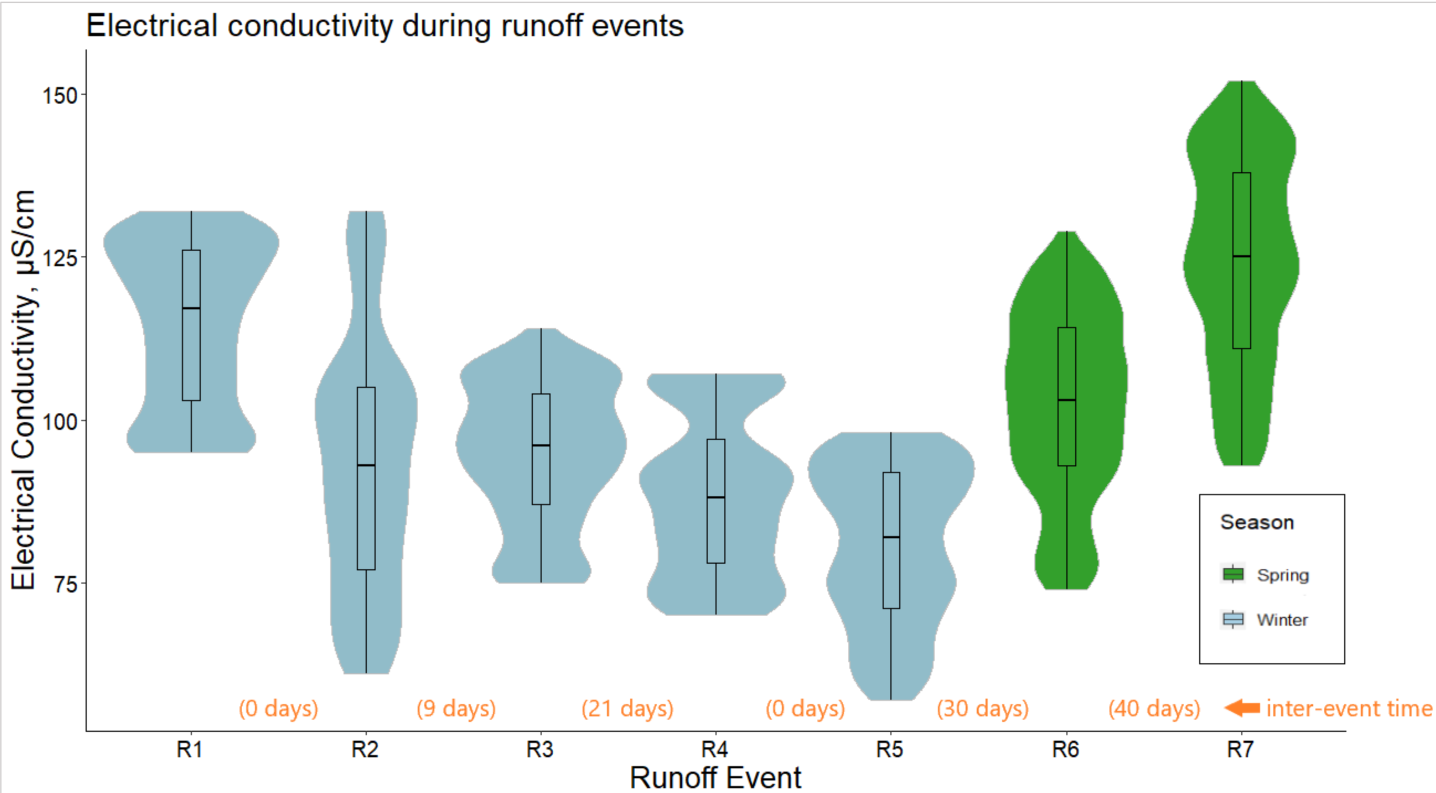


Figure 15. Electrical conductivity values in Big Chico Creek during 7 storm runoff events. Inter-event times are provided along the x axis. The violin plot combines a box plot with a kernel density plot to visualize the distribution of the data (Lewinson, 2019).

Following the "first-flush" event of the storm season, consecutive winter storm events resulted in decreasing electrical conductivity trends between November 2019 and February 2020 (Fig. 15). Electrical conductivity decreased more noticeably between storms with the shortest inter-event time (Fig. 15). Spring storms had a greater inter-event time and only decreased electrical conductivity temporarily (Fig. 10, 15). Electrical conductivity likely decreased in the winter due to the dilution of salts by storm flow (Livingstone, 1963). Spring storms were not enough to counter the seasonal trend of increasing electrical conductivity (Fig. 14, 15) (Strady et. al., 2017).

Baseflow Conditions

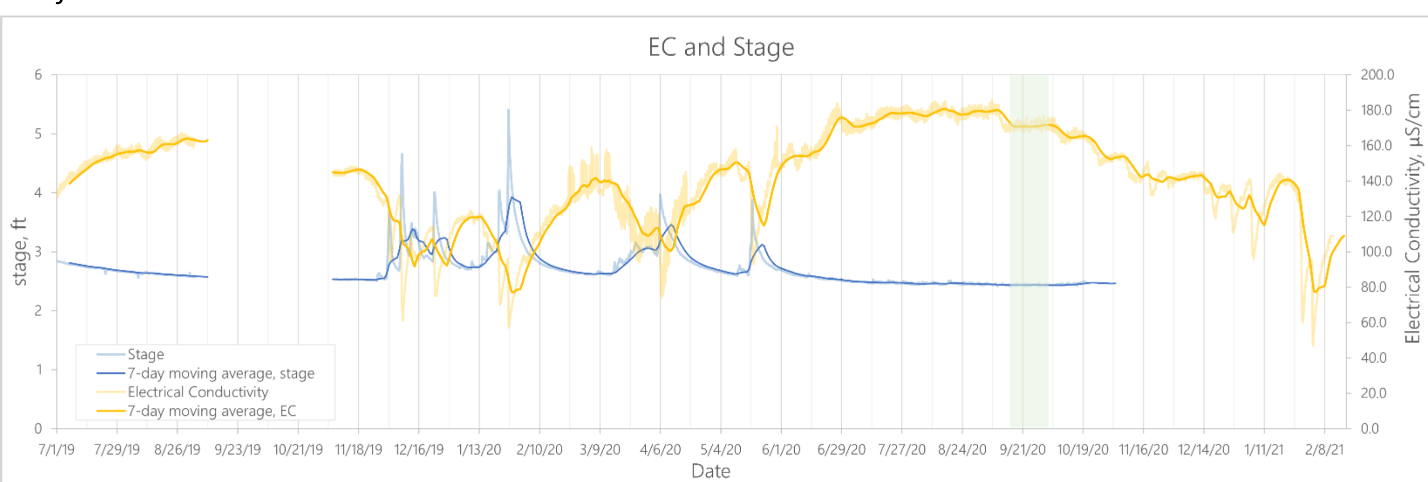


Figure 16. Electrical conductivity and stage hydrograph with green shaded area indicating the 18 days of baseflow conditions that were analyzed.

Baseflow conditions were studied between September 17, 2020 and October 5, 2020 since this time period appeared the most consistent in water composition and devoid of major disturbances (Fig. 16).

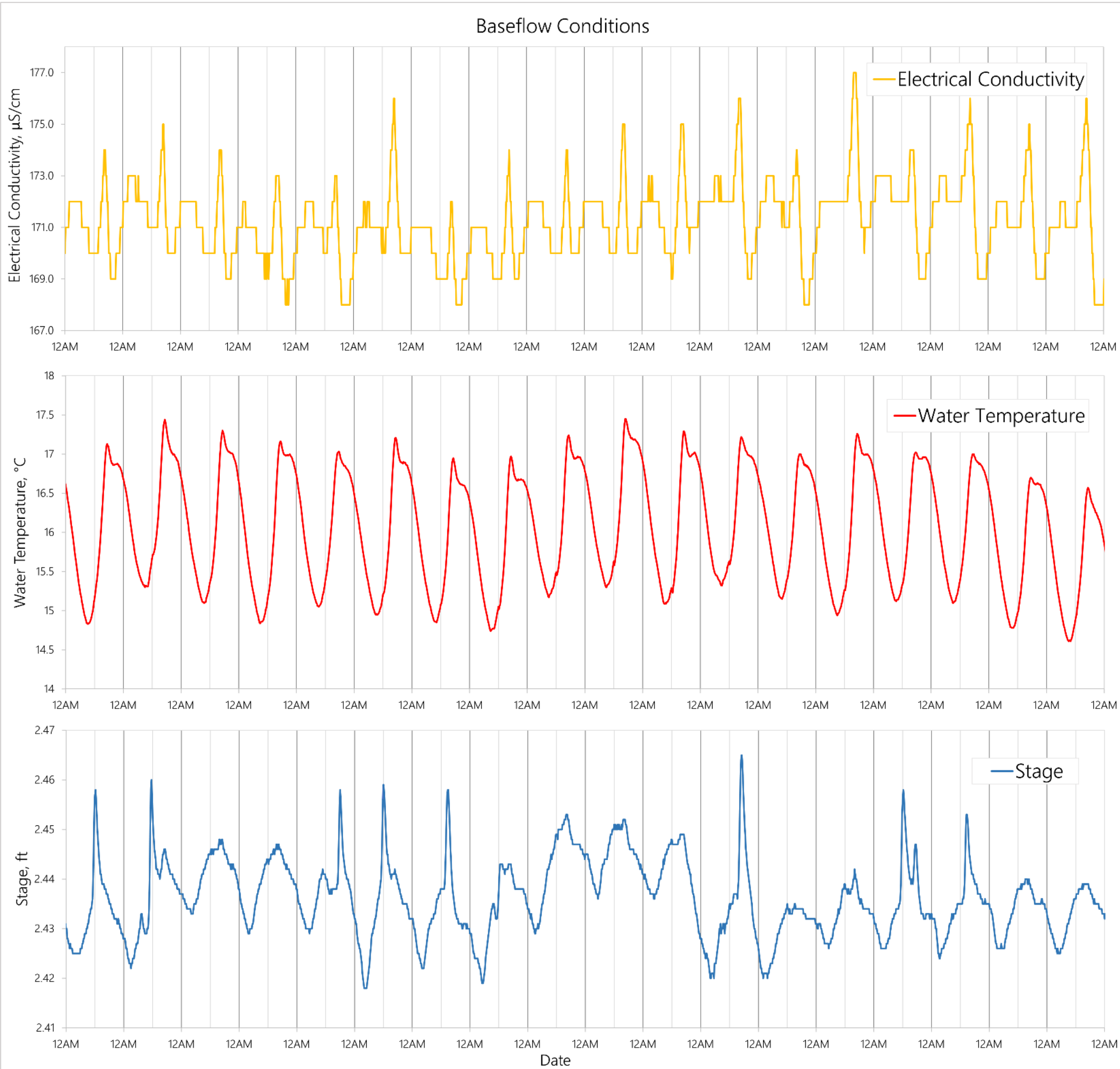


Figure 17. Electrical conductivity, water temperature, and stage for 18 days during baseflow conditions.

The visible sinusoidal patterns were indicative of diurnal variability for all three water quality parameters (Fig. 17). While water temperature and stage had one occurrence of daily minimum and maximum, electrical conductivity displayed two daily minima and maxima (Fig. 17). A double-peak in electrical conductivity was observed in a previous study on the Yadkin-Pee Dee River system in North Carolina, although it was attributed to a wastewater treatment plant located upstream (Harned & Meyer, 1983). The highest and lowest daily electrical conductivity values were selected to determine maximum and minimum times.

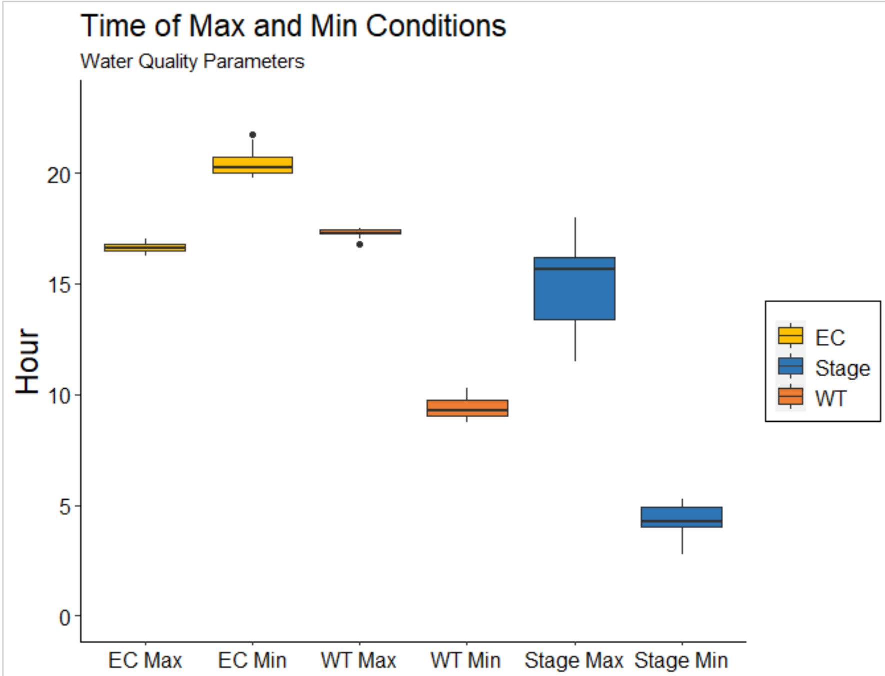


Figure 18. Boxplot of the time of maxima and minima for electrical conductivity, stage, and water temperature.

During baseflow conditions in late September and early October, water temperature and electrical conductivity both peaked around 5 PM, while water temperature was lowest at 9 AM, and electrical conductivity was lowest at around 8 PM (Fig. 18). Stage peaked around 3 PM and was lowest around 4 AM (Fig. 18).

Stage was expected to peak early morning and be lowest in the afternoon following peak water temperature because of water loss through evaporation and plant transpiration (Cuevas et. al., 2010; Marciniak & Szczucińska, 2016). These observations indicate that evapotranspiration is not likely to be the dominant mechanism of water loss in the watershed, or at least is not a direct control, and that other factors likely affect the daily variability of stage. These factors could include the timing of the shade occurring on the creek in the canyon and the presence of a rock wall on the right bank of this monitoring site which limits the connectivity between the creek and the surrounding landscape. Another possibility is that plant evapotranspiration could be beginning to slow down during late summer and early fall as primary productivity is slowing down and deciduous vegetation starts senescing.

Knowing that during baseflow Big Chico Creek is primarily contributed by discharge from the Tuscan and Chico Formations (Perkins, 2013), peak salinity somewhat coinciding with peak stage suggests that baseflow at this location is mainly contributed by groundwater seepage passing through the more saline Chico Formation (USGS, 2021b). These observations suggest that while Big Chico Creek may be a losing stream below the 5-Mile bridge during baseflow conditions (GRA, 2020), it could be a gaining stream at this site possibly due to its location within the canyon serving turning the stream into a drainage point for groundwater.

Conclusions

This monitoring station has contributed the start of long-term continuous monitoring dataset of Big Chico Creek, establishing a baseline for water quality in the creek where anthropogenic disturbance is minimal.

Key conclusions from the data collected from Big Chico Creek between July 2019 through February 2021 include:

- Relationships existed between stage and electrical conductivity, and between electrical conductivity and water temperature, varied with flow regimes (baseflow or stormflow conditions).
- Salinity was within the range of salinity in U.S. rivers and was generally within the healthy range for fish during the summer months (EPA, 2012).
- Seasonal variability was evident for electrical conductivity and water temperature, both following similar trends; highest during summer, lowest during winter.
- Electrical conductivity exhibited a distinct bimodal pattern during late summer baseflow conditions.
- Unexpected timing for stage minima and maxima was observed during late summer baseflow conditions.

Seasonal variability in salinity was expected from Big Chico Creek since water composition is associated with stream discharge (Livingstone, 1963). Future work is still necessary to improve our understanding of Big Chico Creek. Some focus areas may include studying the interaction between surface water and groundwater to explain the timing of peak stage, studying the reason for the bimodal diurnal variability of electrical conductivity, and studying the relationship between the vegetation and the creek, especially during late summer baseflow conditions.

There are plans of adding additional sensors to the monitoring station to increase its scope by including pH and dissolved oxygen, and dreams of establishing a second monitoring station after Big Chico Creek has passed through the City of Chico. Moving forward, current and future data from this monitoring station has the potential to be used in conjunction with other research, filling gaps of knowledge regarding Big Chico Creek.

References

Big Chico Creek Watershed Alliance (BCCWA) (2021). Hydrology/Geologic Processes. *Existing Conditions Report.* BCCWA. Accessed May 2021. https://www.csuchico.edu/bccer/_assets/documents/bigchicocreekwatershed-ecr.pdf

Britannica, T. Editors of Encyclopaedia (2019). *Mediterranean Climate*. Encyclopedia Britannica. https://www.britannica.com/science/Mediterranean-climate

California Data Exchange Center (CDEC). (2021), *Northern Sierra Precipitation: 8-Station Index, May 12, 2021.* CDEC. http://cdec4gov.water.ca.gov/reportapp/javareports?name=PLOT_ESI.pdf

California Department of Water Resources (DWR). (2021), *De Sabla (DWR) (DES).* Department of Water Resources California Data Exchange Center. Accessed May 2021. https://cdec.water.ca.gov/dynamicapp/QueryDaily?s=DES&end=2021-02-23&span=603days.

Cuevas, J., Calvo, M., Little, C., Pino, M., & Dassori, P. (2010). Are diurnal fluctuations in streamflow real?. *Journal of Hydrology and Hydromechanics*, *58*(3), 149.

Environmental Protection Agency (EPA). (2012*), 5.9 Conductivity.* EPA Water: Monitoring & Assessment. https://archive.epa.gov/water/archive/web/html/vms59.html

FISHBIO (2019). (rep.). *Big Chico Creek 2019 Fish Population Survey*. FISHBIO. Retrieved from https://www.csuchico.edu/bccer/_assets/documents/fishbio-2019-bcc-survey.pdf

Galarnyk, M. (2018). *Understanding Boxplots*. towards data science. https://towardsdatascience.com/understanding-boxplots-5e2df7bcbd51.

Groundwater Resources Association of California (GRA). (2020). *A Tale of Two Waters? Groundwater and Surface Water-an Interconnected Resource*. Groundwater Resources Association of California (GRA). https://www.grac.org/events/356/.

Harned, D., & Meyer, D. (1983). *Water quality of North Carolina streams* (No. 2185-E). U.S. Geological Survey (USGS).

Lewinson, E. (2019). *Violin plots explained*. towards data science. https://towardsdatascience.com/violin-plots-explained-fb1d115e023d.

Livingstone, D. A. (1963). *Chemical composition of rivers and lakes* (Vol. 440). US Government Printing Office.

Marciniak, M., & Szczucińska, A. (2016). Determination of diurnal water level fluctuations in headwaters. *Hydrology Research*, *47*(4), 888-901.

Simeral, D., & Gutzmer, D. (2021). *U.S. Drought Monitor California*. U.S. Drought Monitor. https://droughtmonitor.unl.edu/CurrentMap/StateDroughtMonitor.aspx?CA.

Strady, E., Dang, V. B. H., Némery, J., Guédron, S., Dinh, Q. T., Denis, H., & Nguyen, P. D. (2017). Baseline seasonal investigation of nutrients and trace metals in surface waters and sediments along the Saigon River basin impacted by the megacity of Ho Chi Minh (Vietnam). *Environmental Science and Pollution Research*, *24*(4), 3226-3243.

U.S. Fish and Wildlife Service (USFWS) (2006). (rep.). *Evaluation of Iron County for Proposed Fish Ladder Structure Repair and Construction*. U.S. Fish and Wildlife Service. Retrieved from https://www.fws.gov/lodi/anadromous_fish_restoration/afrp-documents/documents/Iron_Canyon_Final_Report.pdf

U.S. Geological Survey (USGS). (2021a). *Evapotranspiration and the Water Cycle*. Accessed May 2021. USGS. https://www.usgs.gov/special-topic/water-science-school/science/evapotranspiration-and-water-cycle?qt-science_center_objects=0#qt-science_center_objects.

U.S. Geological Survey (USGS). (2021b). *Rivers Contain Groundwater*. USGS. Accessed May 2021. https://www.usgs.gov/special-topic/water-science-school/science/rivers-contain-groundwater?qt-science_center_objects=0#qt-science_center_objects.

U.S. Geological Survey. (2021c). *How Streamflow is Measured*. USGS. Accessed May 2021. https://www.usgs.gov/special-topic/water-science-school/science/how-streamflow-measured?qt-science_center_objects=0#qt-science_center_objects.

U.S. Geological Survey. (2021d). *Temperature and Water*. USGS. Accessed May 2021. https://www.usgs.gov/special-topic/water-science-school/science/temperature-and-water?qt-science_center_objects=0#qt-science_center_objects.

Vogt, T., Hoehn, E., Schneider, P., Freund, A., Schirmer, M., & Cirpka, O. A. (2010). Fluctuations of electrical conductivity as a natural tracer for bank filtration in a losing stream. *Advances in Water Resources*, *33*(11), 1296-1308.

Ward, A. D., & Trimble, S. W. (2004). *Environmental Hydrology* (2nd ed.). CRC Press LLC.