Comparison of baseflow and stormflow water chemistry at Main Barton and Eliza Springs

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Abstract

We compared baseflow and stormflow water chemistry at two adjacent karst springs, Main Barton and Eliza Springs. To investigate baseflow water quality, we used paired grab baseflow data (2002–2020) from each spring that included measurements of specific conductance, dissolved oxygen, temperature, pH, and turbidity. To investigate stormflow water chemistry, we used continuous 15-minute data (May 2018—September 2020) with measurements of the same five parameters. Both the paired grab baseflow and continuous 15-minute datasets spanned a range of aquifer conditions from severe drought to high aquifer levels. Our results from the paired grab baseflow data showed that Main Spring had significantly lower specific conductance and temperature, and higher dissolved oxygen than Eliza Spring, but median differences were very small (2.50 µS/cm, 0.06 mg/L, and 0.02°C respectively) relative to both seasonal and stormflow variability. Overall, baseflow water quality differences between the two springs appeared greater at both low (< 40 cfs) and high (>80 cfs) aquifer levels. Our results from the continuous 15-minute data showed the response to storm events (as indicated by specific conductance drop) was of greater magnitude at Main Spring, and the difference in storm responses between the two springs was dependent on total event rainfall amount. There was no observed lag in the timing of specific conductance drops for 34 of 35 storm events between the two springs. Our findings suggest that ongoing continuous 15-minutes monitoring at Main Barton Spring sufficiently represents baseflow and stormflow water chemistry at both springs, especially when addressing habitat concerns of two endangered salamander species present at the springs. Our findings also provide more detail to our current understanding of water quality and aquifer flow dynamics at a range of flow conditions and at smaller time scales at Main Barton and Eliza Springs.

Keywords: Barton Springs, Eliza Spring, water chemistry, baseflow, stormflow

Introduction

The four major spring outlets of the Barton Spring complex include Main Barton Spring (Parthenia Spring), Eliza Spring, Old Mill Spring (Zenobia Spring or Sunken Garden Spring), and Upper Spring. The Barton Springs complex is the fourth largest spring complex in Texas (Brune 2002), and the recharge zone of the Barton Springs segment of the Edwards Aquifer extends about 20 miles north-south and 3–10 miles east-west. From the recharge zone, groundwater generally flows east and northeast to the Barton Springs complex (Figure 1A).

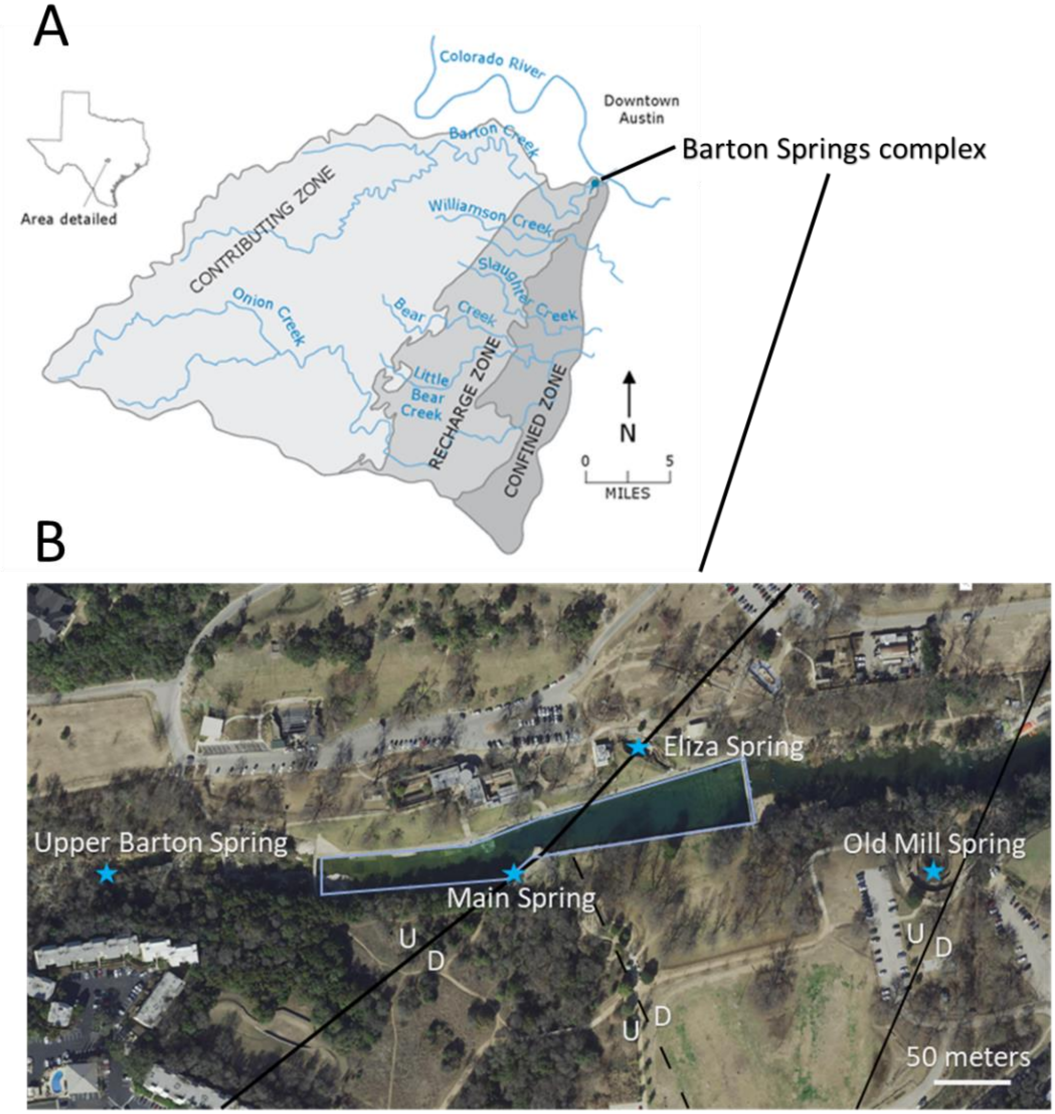

Figure 1 (A) Location of Barton Springs segment of the Edwards Aquifer with contributing zone, recharge zone, and confined zone of the aquifer labeled. (B) Aerial overview of Barton Springs complex. Black lines show major faults and black dashed line shows a smaller antithetical fault with direction of displacement labeled up (U) and down (D). Figure 1A modified from Slade et al. 1986.

The four spring outlets are habitat for two federally endangered salamander species, Barton Springs salamanders (*Eurycea sosorum*) and Austin blind salamanders (*Eurycea waterlooensis*), each of which are endemic to this aquifer system. Habitat associated with Eliza Spring and Main Barton Spring (hereafter "Main Spring") support the largest and second largest observable populations of Barton Springs and Austin blind salamanders (Bendik and Dries 2018), and water quality monitoring at the Barton Springs complex is an obligation of the Barton Springs Pool Habitat Conservation Plan. Also, Main Spring discharges into Barton Springs Pool, a major recreational attraction hosting over 1.5 million visitors each year. All four spring outlets contribute flow to lower Barton Creek, just upstream of the confluence with Lady Bird Lake, a reservoir of the Colorado River in downtown Austin, Texas.

Of the four major spring outlets, Main Spring and Eliza Spring are located relatively close to one another (~105 m apart) and are positioned along the same SW-NE trending normal fault (Figure 1B). This normal fault has about 15 meters of displacement offsetting the Georgetown Formation from the Edwards Group, it is oriented parallel to regional groundwater flow, and it likely serves as a shared conduit flow path between the two springs (Saribudak and Hauwert 2017). Another smaller antithetic fault, with about 9 meters of displacement just south of the pool, may also serve as a shared conduit to Main and Eliza Springs.

A 40-year history of groundwater dye tracing in the Barton Springs segment by the City of Austin (COA) and Barton Springs Edwards Aquifer Conservation District (BSEACD) has established a close hydrogeologic connection between Main and Eliza Springs (Hauwert et al. 2004; Hunt et al. 2006; Zappitello et al. 2019). These groundwater dye tracing studies show that Main Spring and Eliza Spring have many shared flow paths, but Main Spring can sometimes receive water recharged near Sunset Valley in the Williamson Creek watershed that Eliza Spring does not receive (Hauwert et al. 2004).

The karst springs of the Barton Springs complex are susceptible to large and transient changes in water chemistry due to (1) changing baseflow levels between drought and wet conditions, (2) rapidly recharging surface runoff following storm events (Johns 2006; Mahler et al. 2006), and (3) point source pollution introduced directly into the aquifer (Sydow et al. 2020; Zappitello et al. 2020). Extensive past work by the COA, United States Geological Service (USGS), and others have described the water quality of the Barton Springs complex and identified many similarities between Main Spring and Eliza Spring in particular (Garner 2005; Herrington and Hiers 2010; Mahler et al. 2006; Porras 2014; Porras 2016). These studies mostly used grab baseflow water chemistry data collected at monthly or quarterly time intervals. Other studies have analyzed continuous 15-minute water quality data at the Barton Springs complex over several days up to a few weeks to investigate stormflow water quality at the springs (City of Austin, 1997; Johns 2006; Mahler et al. 2006). This study builds on past work by analyzing a longer baseflow water chemistry dataset (2000—2020) and a longer continuous 15-minute water chemistry dataset (May 2018—September 2020), identifying differences in baseflow and stormflow water chemistry between the two springs across a range of baseflow conditions and storm event characteristics.

Continued improvement of our understanding of the relationship between these two springs is needed to inform management decisions, especially emergency response protocols. City of Austin staff currently use the continuous 15-minute, real-time water quality data provided by instrumentation at Main Springs (USGS station 0815500) as an approximation for water quality at the other springs in the Barton Springs complex, especially for Eliza Spring given its historically noted similar chemistry to Main Spring and its large population of endangered salamanders. One question this study sought to answer was if continued use of the Main Spring sonde as a proxy for water quality in Eliza is appropriate under all circumstances, especially in the event of a catastrophic spill. This information is further useful in predicting water chemistry differences between the two springs in drought and understanding the susceptibility of each to water quality degradation following storm events. Differences in stormflow and baseflow water chemistry may also indicate different flow paths to springs that have not yet been confirmed through dye trace studies.

Methods

Data Collection

For this study, we used data from two data collection methods. One method obtained paired grab baseflow water quality data (2002–2020) of specific conductance (μS/cm), dissolved oxygen (mg/L), temperature (°C), pH, and turbidity (NTU) from the COA Water Resources Monitoring Database for Main Spring and Eliza Spring. The data were collected mostly on a quarterly basis with some periods of approximately monthly data. The paired data met the following criteria: data from both springs were collected under baseflow conditions, data were collected on the same day and by the same team, and the same model of water quality sonde was used at both springs. Available data that did not meet these criteria were excluded.

We obtained 91 paired grab baseflow samples for specific conductance, temperature, and pH. We only obtained 87 paired grab baseflow samples for dissolved oxygen and 53 for turbidity since four dates had missing dissolved oxygen data and turbidity was not always measured during routine baseflow sampling. We took the difference between the values of each data pair and any paired differences not within three standard deviations of the sample mean were noted as outliers. Several outliers appeared to be from data entry errors. For example, outlier temperature pairs were off by 1.02 °C and 2.00°C, and some data had negative values which were likely input errors. The removing of these data resulted in excluding 2 data pairs for specific conductance, 3 for dissolved oxygen, 2 for temperature, 3 for pH, and 2 for turbidity from the analysis.

For the second data collection method, we collected specific conductance, dissolved oxygen, temperature, pH, and turbidity at 15-minute intervals from May 2018—August 2020 at Main Spring and Eliza Spring. We collected this data at Main Spring from an existing USGS water quality monitoring site (0815500), which uses a multi-sensor YSI EXO2 datalogging sonde that is maintained by the USGS in partnership with the COA. USGS staff services the sonde every three to four weeks for cleaning and recalibration, and data are quality checked before receiving a final data quality status. At Eliza Spring, COA staff alternated the deployment of two Hydrolab MS5 datalogging sondes to collect the same suite of parameters at 15-minute time intervals. Each unit was serviced about every four weeks for cleaning and recalibration by COA staff, and data were quality checked by COA staff. Both sondes were time-synched and positioned directly into spring outlets during data collection.

We also obtained continuous 15-minute discharge data of the Barton Springs complex (excluding discharge from Upper Spring) online from the USGS. Discharge at Barton Springs is based on a stage-discharge rating curve that relates levels in a monitoring well (YD 58–42–903) just south of Barton Springs Pool and periodic manual flow measurements by COA, BSEACD, and USGS staff in Barton Creek just downstream of Barton Springs Pool. Daily average discharge at Barton Springs since 1991 has ranged from 13—131 cfs (U.S. Geological Survey, 2023), and this study defines discharge as low (< 40 cfs), medium (40-80 cfs) and high (> 80 cfs) discharge. Hourly rainfall data (May 2018—September 2020) averaged over the six contributing watersheds (Barton, Williamson, Slaughter, Onion, Bear, and Little Bear Creeks) of the Barton Springs Zone were obtained from RainVieux, Inc.

Analytical Methods

To compare baseflow water quality between Main Spring and Eliza Spring, we used the 2002–2020 dataset of paired grab baseflow measurements of specific conductance, dissolved oxygen, temperature, pH, and turbidity. To determine if there were differences between water quality parameters from the two springs, we performed Wilcoxon signed-rank tests on the paired data for each of the five parameters.

We used the continuous 15-minute data to compare stormflow water quality between Main and Eliza Springs. We selected specific conductance to quantify storm responses at the two springs because specific conductance responds more readily and consistently than the other four parameters to storm events. Recharging water from rainfall contributes to spring flow and lowers the specific conductance of the water at the springs such that the magnitude of specific conductance change corresponds to the magnitude of recharge (Johns 2006; Mahler et al. 2006).

To determine the magnitude of the specific conductance change during each storm event, we calculated the difference between the initial specific conductance and the minimum specific conductance for each event. First, we defined the start times of individual storms programmatically using the Inter-Event Time Definition (IETD) package in R-Studio and 1-hour rainfall data from Vieux, Inc. The IETD is the minimum rainless period between two independent rainfall events. We used an IETD value of 24 hours and a minimum rainfall threshold of 0.15 inches. The IETD package output provided start times and end times for each rain event (and the output also provided maximum rainfall intensity and total rainfall for each storm event). Starting or initial specific conductance values for each storm were selected by using the IETD start time. Then the minimum specific conductance value for each storm event was also selected. Storm events were manually excluded from analysis if a storm start time was in the falling limb of the specific conductance curve from a previous storm, if no specific conductance dilution curve occurred for either spring, or if there was no data present from one or more instruments. For a given storm event, if any rainfall occurred after the specific conductance minimum, it was excluded from the total rainfall for each event.

We selected 50 storm events from May 2018 through September 2020 using the IETD package and inputting hourly total average rainfall data in the 6 contributing watersheds. We removed 6 storm events due to missing 15-minute specific conductance data, 6 storms were removed because the storms started during the falling limb the of the specific conductance curve from a prior storm, and 3 storms were excluded because there was no specific conductance response at either spring. We used the remaining 35 subsets of specific conductance data from the qualifying storm events to compare the magnitude of storm responses between Main and Eliza Springs.

To determine if there was a difference in storm response between Main and Eliza Springs, we performed a Wilcoxon signed-rank test on the paired values corresponding to the overall change in specific conductance following all 35 qualifying storm events. We used a general additive model (GAM) to determine if the paired differences in storm responses showed any relationship with aquifer flow condition (discharge at Barton Springs), maximum rainfall intensity, and total rainfall for each storm event.

Finally, to quantify any time lags in the initial storm responses between the two springs, we performed a separate cross-correlation analysis using the continuous 15-minute specific conductance data at Main and Eliza Springs for each of the 35 qualifying storm events. The cross-correlation analyses were performed only from the start of each storm (as defined previously by the output from the IETD package) to the time of either spring reaching its specific conductance minimum.

Results

Main Spring had a median baseflow specific conductance that was 2.50 μS/cm lower than Eliza Spring ($P < 0.001$), and the baseflow range in specific conductance for the two springs varied from 576 μS/cm to 751 μS/cm (Figure 2). Dissolved oxygen was 0.06 mg/L higher at Main Spring ($P < 0.04$), and the baseflow range varied at both springs varied from 3.99 mg/L to 7.79 mg/L. Temperature was 0.02 °C lower at Main Spring ($P < 0.01$), and the baseflow range at both springs varied from 19.31 °C to 22.32 °C. There was no difference between baseflow pH and turbidity at the two springs.

LOESS smooth curves show visually that each of the five water quality parameters have distinct overall patterns of variability across the range of aquifer flow conditions. (Figure 3A). For example, specific conductance and temperature was highest and dissolved oxygen was lowest during low flow conditions (< 40 cfs) at both springs. Loess smooth curves show visually that turbidity generally increased with increasing flow conditions and pH remains constant across different flow conditions. (Figure 3A).

LOESS smooth curves also show the magnitude of difference between the two springs for each of the five parameters varied across a range of aquifer flow conditions (Figure 3B). For example, during low aquifer flow conditions at Barton Springs (< 40 cfs), the difference in specific conductance between the two springs was greater than at higher aquifer flow conditions (> 80 cfs). Differences between the two springs in dissolved oxygen appear to be the greatest at both low and high flow conditions, and temperature differences between the two springs appear to be the greatest at high flow conditions (Figure 3B).

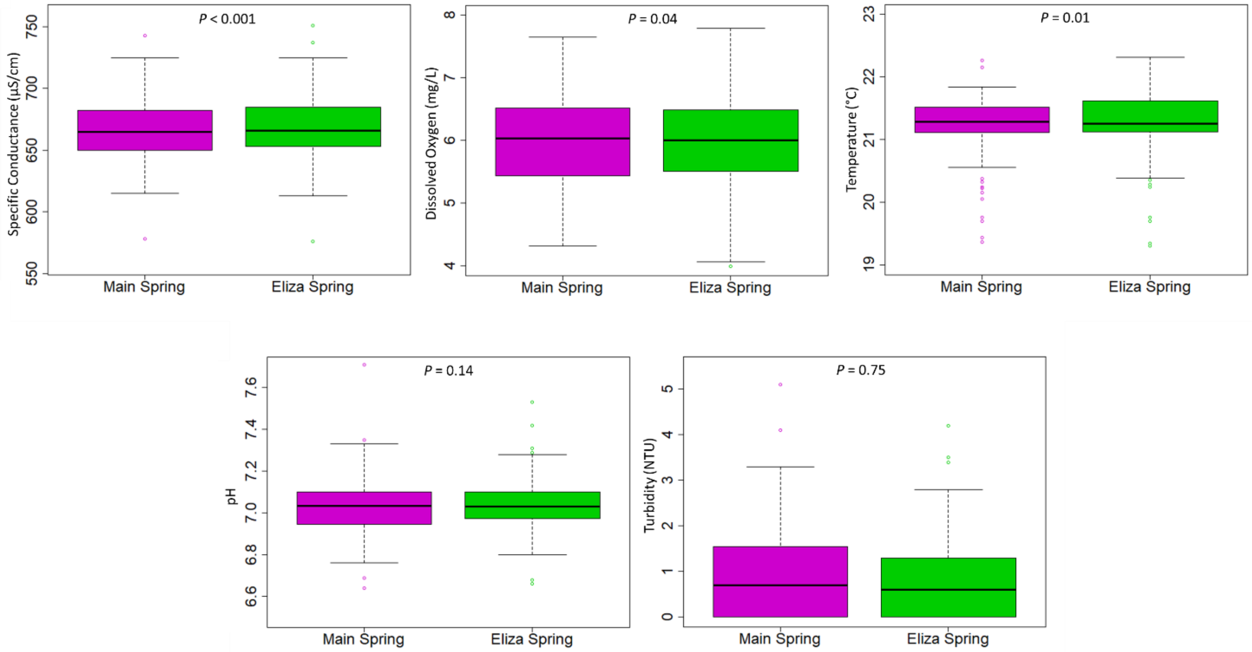

Figure 2 Results of each Wilcoxon signed-rank test. Specific conductance, dissolved oxygen, and temperature had median differences that were significant. Median differences between pH and turbidity were not significant. Note significant differences in baseflow water quality parameters are small compared to natural variability.

Our results showed that the median decline in specific conductance over all 35 storm events was 3.50 μS/cm greater ($P < 0.001$) at Main Spring than Eliza Spring. Of the 35 storm events, Main Spring had a greater magnitude specific conductance decline following 26 events, the two springs had the same magnitude of decline following 1 event, and Eliza Spring had a greater magnitude specific conductance decline following 8 events. Figure 4 shows one example of a typical storm event.

Results from our GAM model showed that total rainfall had a significant ($p < 0.001$) relationship in predicting the paired differences in specific conductance responses between the springs following the 35 storm events. The adjusted R-squared for the model including only total rainfall as a smooth predictor was 0.464 and the deviance explained was 54.1%. The difference in storm responses between the two springs increased as total rainfall increased, but this relationship appears less consistent for very large storm events (Figure 5). Peak rainfall intensity and daily average discharge at Barton Springs showed no significant relationship in predicting the paired differences in specific conductance storm responses.

Cross-correlation analyses of the same qualifying 35 storm events showed a very similar timing in the specific conductance responses between the two springs. During 34 of the 35 storm events there was no lag in the falling limb of the specific conductance curve between Main Spring and Eliza Spring. During one storm event there was a lag in the response of the falling limb at Eliza Spring relative to Main Spring. During this storm event, Eliza Spring specific conductance data had a 4-step lag (60 minutes) in the response of the falling limb of the specific conductance dilution curve. This storm was a relatively small event (average rainfall of 0.63”) under very low aquifer conditions (~29 cfs), and the storm had the lowest peak rainfall intensity of any storm event.

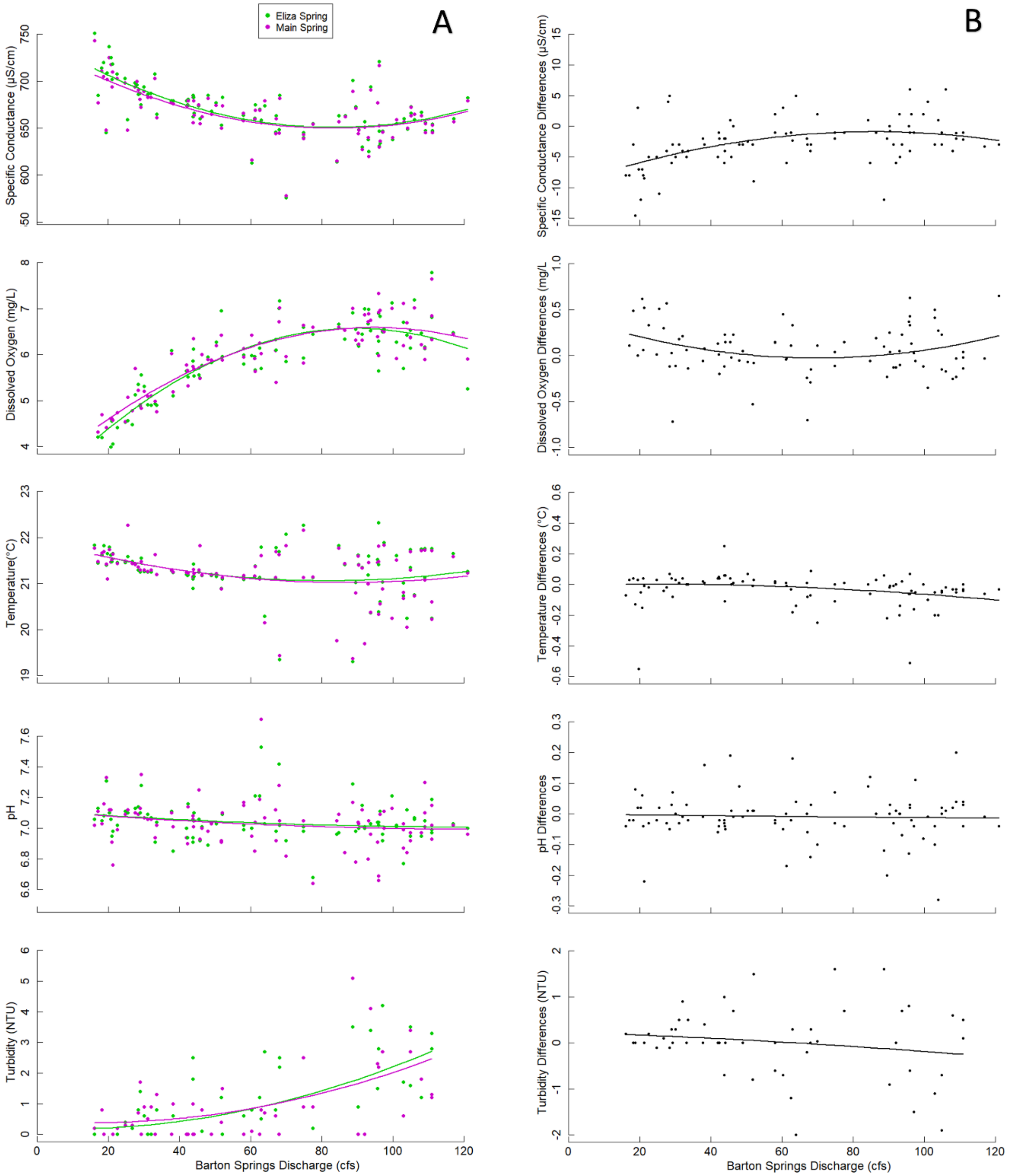

Figure 3 (A) Grab baseflow data of specific conductance, dissolved oxygen, temperature, pH, and turbidity at Main Spring (purple) and Eliza Spring (green) with total Barton Springs discharge. LOESS smooth curves show trends in data with discharge. Note only specific conductance, dissolved oxygen, and temperature had significant differences between paired data ($P < 0.05$). (B) Difference between paired data for each of the five parameters with total Barton Springs discharge. Loess smooth curves show trends in differences between the springs with discharge.

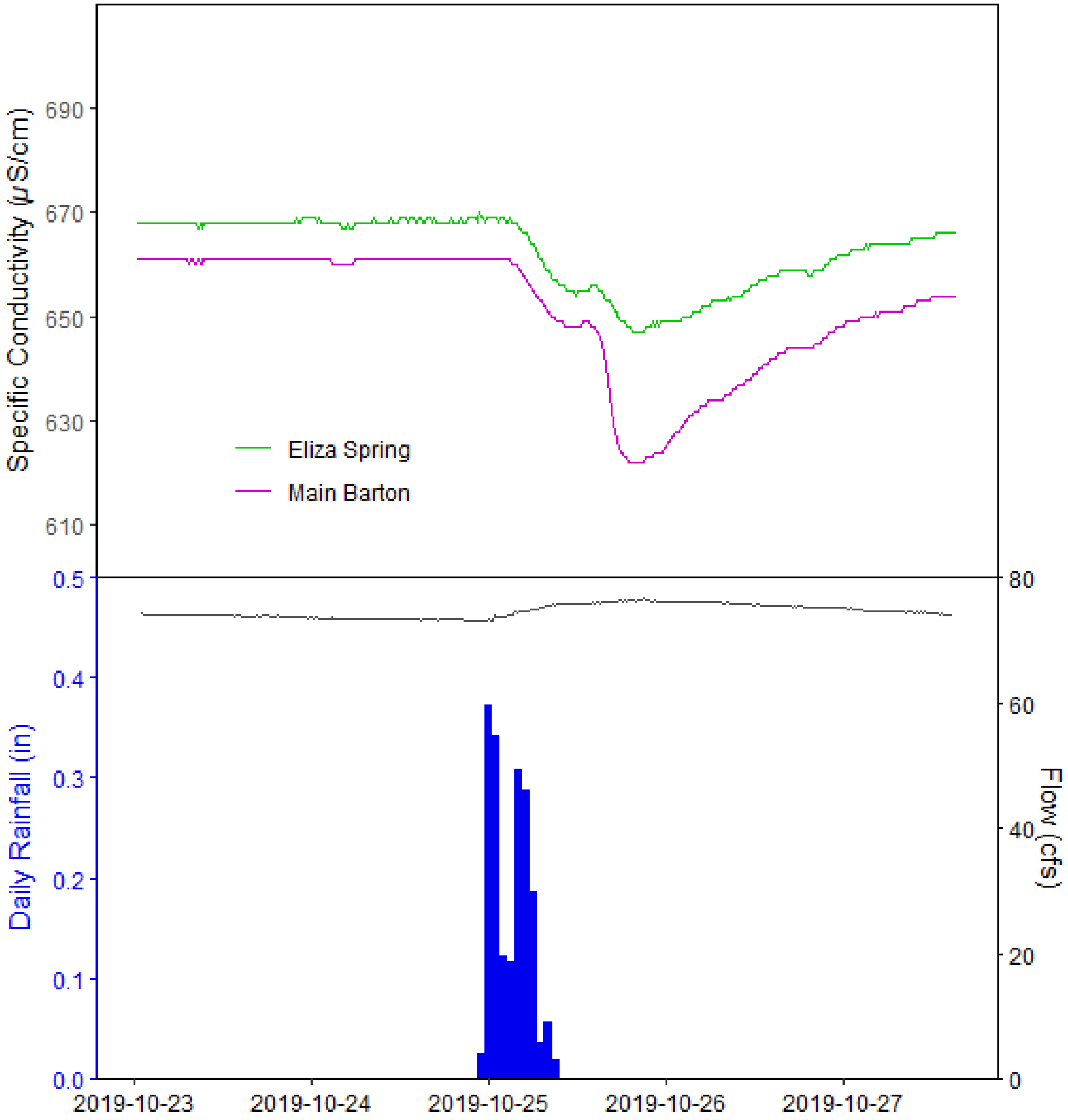

Figure 4 (top) Continuous 15-minute specific conductance at Main Spring and Eliza Spring during storm event in October 2019. (bottom) Continuous 15-minute discharge data of Barton Springs complex and hourly rainfall for Barton Springs Zone

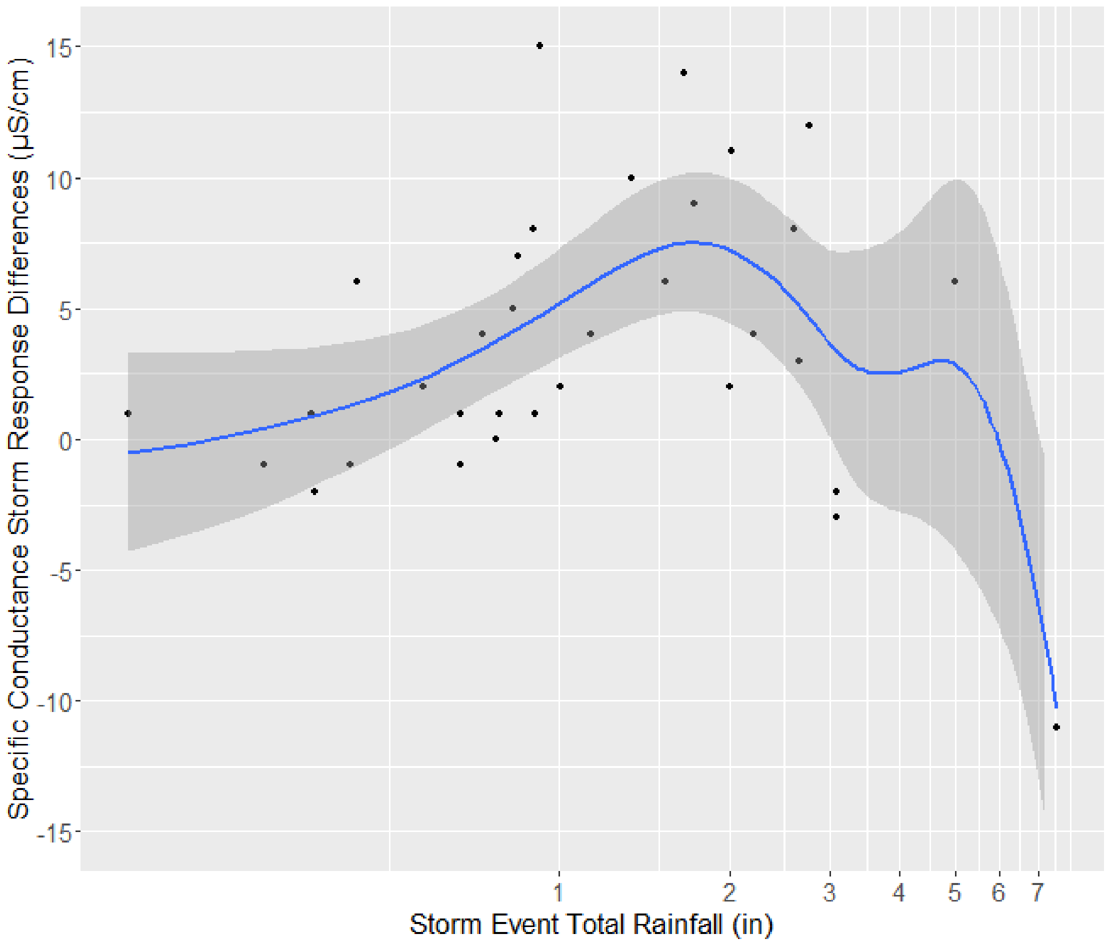

Figure 5 Trend line from general additive model (GAM) showing the relationship between the difference in storm-based specific conductance drops between Main Spring and Eliza Spring (positive values indicate higher magnitude response at Main Spring) and total rainfall volume for the corresponding storm event.

Discussion

Results from this study are largely consistent with past studies that show the differences in baseflow and stormflow water chemistry at Main Spring and Eliza Spring to be relatively small (Herrington and Hiers 2010; Mahler et al. 2006) and even indistinguishable (Garner 2005). We found very small differences in baseflow specific conductance, dissolved oxygen, and temperature between the two springs, and the amount of difference appears to vary with aquifer flow conditions. We found the total decline in specific conductance following storm events was greater at Main Spring, and the difference between the two spring's total specific conductance decline was correlated with total event rainfall. There was no lag in the timing of the specific conductance declines between the two springs for 34 of 35 storm events. Although any difference in the baseflow and stormflow water chemistry between the two springs are very small compared to natural baseflow and stormflow variation, the results from this study add context and detail to past water quality and hydrogeologic studies at the springs.

For example, past studies suggest that an increase in specific conductance and decrease in dissolved oxygen at Main and Eliza Springs during low flow conditions (< 40 cfs) are caused by an increased relative contribution of water from the saline zone of the Edwards Aquifer (Senger et al. 1984; Johns 2006) or due to leakage from the underlying Trinity Aquifer (City of Austin, 1997). We found that at lower flows (< 40 cfs) the increase in specific conductance and decrease in dissolved oxygen appears greater at Eliza Spring than at Main Spring. Therefore at lower aquifer flow conditions, Eliza Spring may receive a larger proportion of water from a source with higher total dissolved solids and lower dissolved oxygen like the saline zone or Trinity Aquifer, and/or Main Spring may receive water from an additional flow path with lower specific conductance and higher dissolved oxygen. The potential connection of Eliza Spring to the Trinity Aquifer was also supported by a turbidity plume that arrived at Eliza Spring, and no other spring in the complex, on February 20, 2024, during drilling of a multiport monitoring well into the Glen Rose Formation (at 408.5–438.5 ft depth) just south of Barton Springs Pool (COA and BSEACD unpublished data). Furthermore, despite Main and Eliza Springs sharing very similar water chemistry, some analyses have shown Eliza Spring water chemistry trends are more like Old Mill Spring than Main Spring (Herrington and Hiers 2010), which has the highest contribution of water from the saline zone and/or the Trinity Aquifer of all the springs in the complex (Johns 2006).

Groundwater tracing studies suggest that Main Spring and Eliza Spring largely share the same flow paths, but Main Spring has some flow paths not shared by Eliza Spring. This is based on results from 18 traces where injected dye was detected at both springs and two traces where dye was only detected at Main Spring (Hauwert et al. 2004; Hunt et al. 2005, Smtih et al. 2006, Johnson et al. 2012, Zappitello and Johns 2018). During these two traces, dye was injected into upland sinkholes (Dry Fork Sink and Whirlpool Cave) that are relatively close to Barton Springs and have relatively short groundwater travel times of 3 to 8 days (Hauwert et al. 2004). Our results from comparing storm responses suggest that Main Spring receives proportionally more stormflow than Eliza Spring following storm events. This supports dye trace findings that Main Spring has local, relatively direct flow paths in common with Upper Spring that do not flow to Eliza Spring and that become active following storm events.

Our results support and add to past interpretations on the relative timing that groundwater tracers arrive at the springs. The precision of groundwater dye arrival times has been limited by using less frequent (hours—daily) and non-synchronized sampling. Past work shows dye mostly arrived at the two springs within the same or overlapping sampling interval, but dye sometimes arrived one sampling interval later at Eliza Spring. This indicates that dye sometimes arrived at Eliza Spring 0 to 24 hours after Main Spring (Hauwert et al. 2004; Hunt et al. 2006). When a 2017 a drilling operation caused an accidental release of three sediment pulses into an aquifer conduit ~1.4 km southwest of the springs, synced continuous 15-minute data showed the first sediment pulse was detected at Main and Eliza Springs during the same measurement (lag time of 0 to 15 minutes), and the next two sediment pulses were detected at Eliza Spring one measurement after they were detected at Main Spring, indicating a lag less than 30 minutes (Sydow et al. 2020; Zappitello et al. 2020). Using our 15-minute continuous data, we found no evidence of a lag in specific conductance responses between Main and Eliza Springs for 34 of 35 storm events, but the storm event with the lowest peak rainfall intensity had a 60-minute lag at Eliza Spring. Based on our results and past work, there is no evidence that groundwater tracers of any kind arrive at Eliza Spring prior to Main Spring (except for the 2024 sediment plume than was only observed at Eliza Spring). Tracers during storm events are typically detected in the same measurement based on 15-minute data (lag of <15 minutes) while tracers introduced to the aquifer through the surface or through a well during baseflow conditions can have a lag of minutes to hours at Eliza Spring.

Past City of Austin water chemistry trend analysis of the Barton Springs complex have considered both changes to aquifer conditions and whether the system is actively recharging as predictors of water quality at the springs (Turner 2000, Herrington and Hiers 2010, Porras 2016). Given that baseflow and stormflow dynamics differ at Main and Bartons Springs and are likely different for other springs in the complex, future water chemistry trend analysis could use more flexible methods, like the Weighted Regressions on Time, Discharge, and Season (Helsel et al. 2020), that allow more flexibility in detecting water chemistry trends that may be dependent on aquifer flow conditions or water chemistry trends that may only be present at certain aquifer conditions.

City of Austin staff currently use the continuous 15-minute, real-time water quality data at Main Springs (USGS station 0815500) as an approximation for water quality at other springs in the complex. This study provides evidence that the current continuous monitoring at Main Spring is likely sufficient to address day-to-day water quality concerns at both springs in consideration of endangered salamander populations; differences in baseflow and stormflow water quality between the two springs is very small compared to natural seasonal variation. However, in the event of an activation of the Barton Springs Catastrophic Spill Plan or other unknown incident, additional monitoring at Eliza Spring may be prudent.

Recommendations

- Continue to use data from USGS station located at Main Spring (0815500) as an approximation for real-time 15-minute water chemistry at Eliza Spring for day-to-day management considerations. Initiate direct 15-minute water chemistry measurements at Eliza Spring in the event of a spill risk.
- Use findings from this study to inform future water chemistry trend analysis at the Barton Springs complex.
- Conduct a similar continuous monitoring study at the other sites in the Barton Springs complex simultaneously to determine similarities and differences in baseflow and stormflow water chemistry across the complex.
- Execute dye tracing study from the newly installed multiport well near Barton Springs Pool to the springs in the Barton Springs complex. Tracing from the different isolated zones may show unique flow paths to the springs are present and validate the water chemistry differences observed at the springs.

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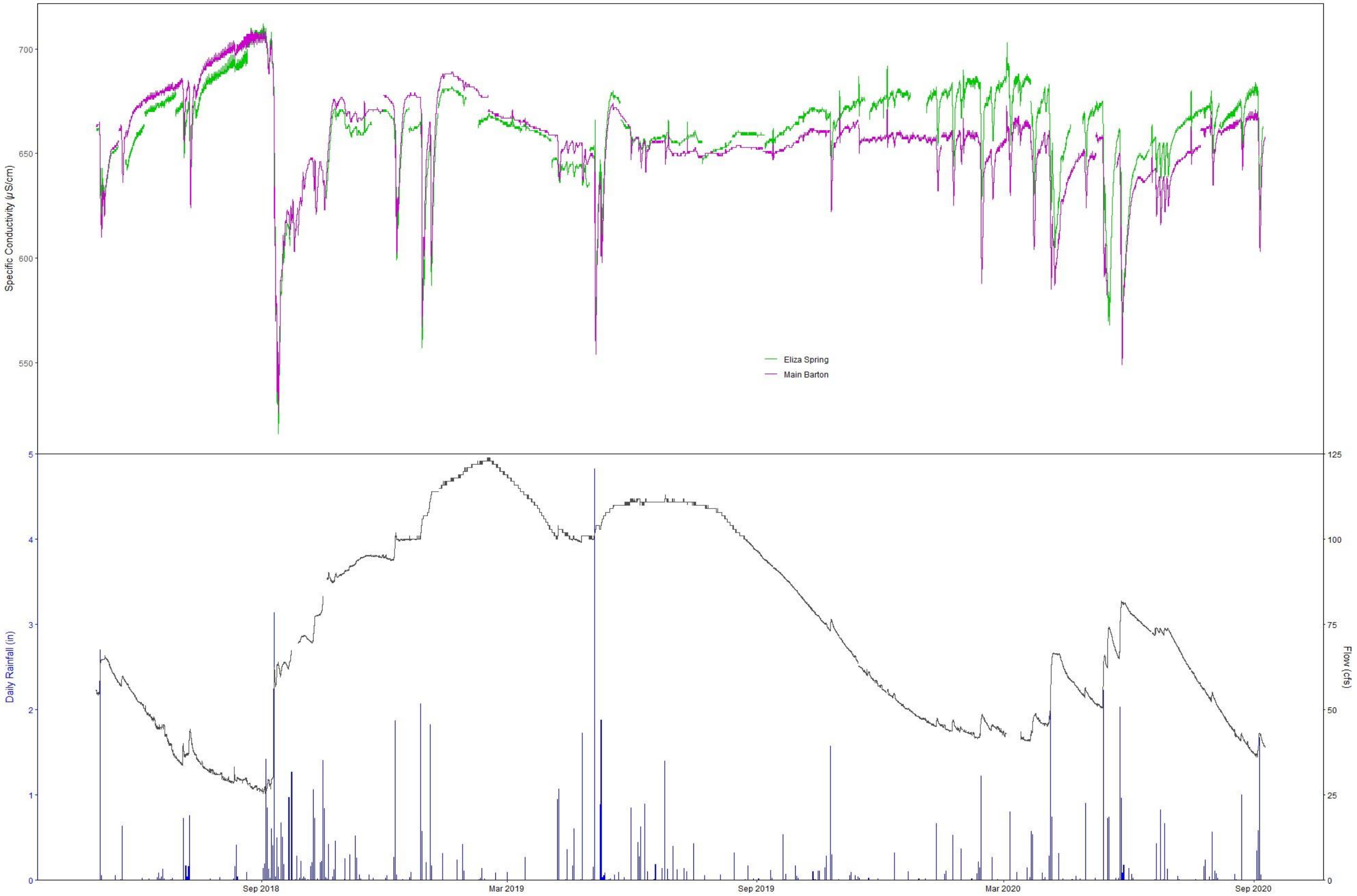
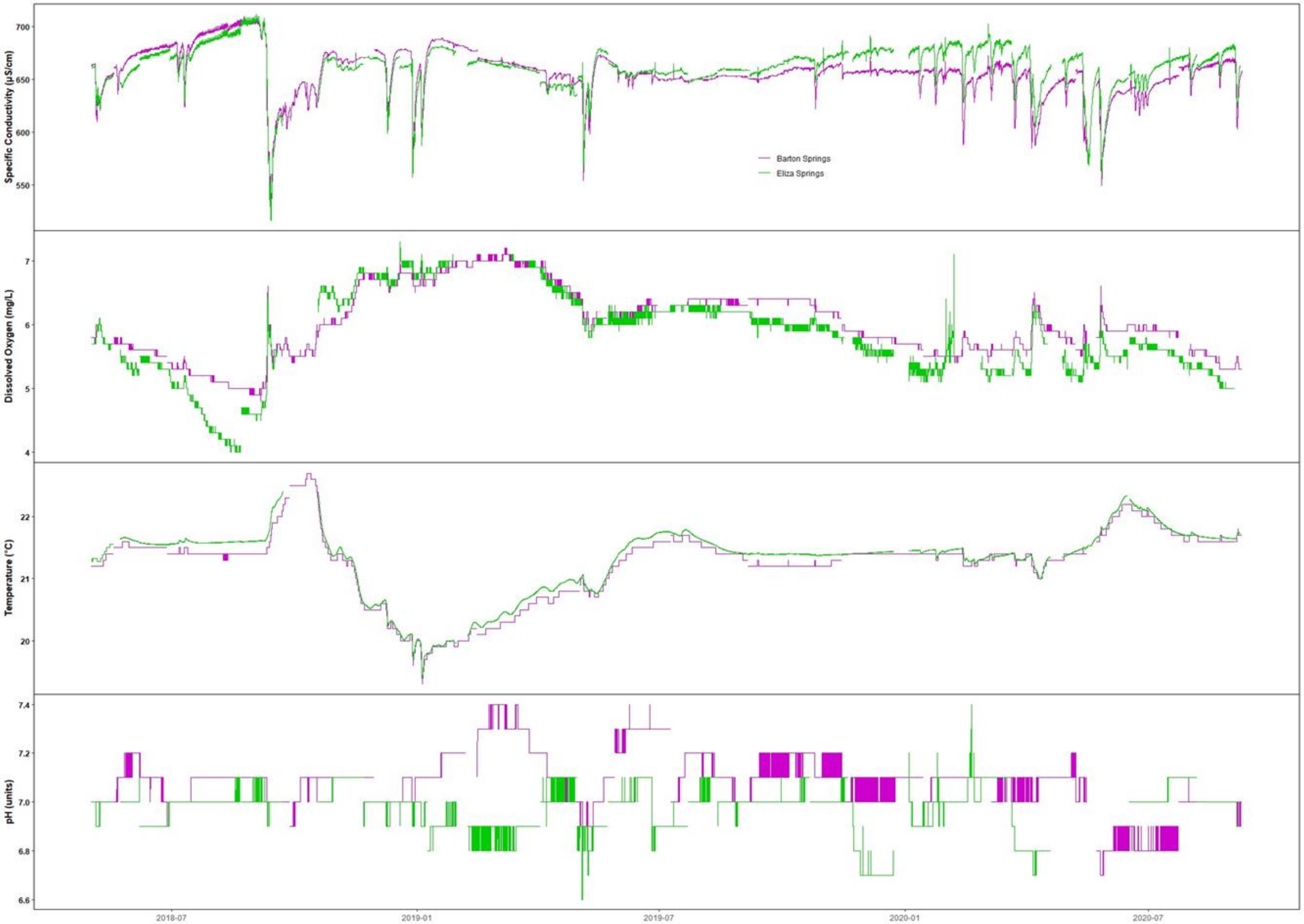
Appendix A



Appendix A (top) Continuous 15-minute specific conductance data of Main Spring and Eliza Spring from May 2018–September 2020. (bottom) Continuous 15-minute discharge data of Barton Springs complex from USGS site 0815500 and RainVieux daily rainfall data averaged over the six watersheds that contribute recharge to Barton Springs.



Appendix B Continuous 15-minute data of specific conductance, dissolved oxygen, temperature, and pH from May 2018 through September 2020.