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Hayden Jordan
hjordan3@vols.utk.edu

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PURSUIT

Spatial Distribution of Water Quality Parameters Using Kayak-Mounted Sensor

HAYDEN JORDAN
Advisor: Dr. Paul Ayers

On behalf of the Biosystems Engineering and Soil Sciences Department of the University of Tennessee, Knoxville, water quality testing was conducted at the confluence of the New River and Clear Fork in the Big South Fork National River and Recreation Area on July 22, 2015. This testing aimed to determine the feasibility of using a kayak-mounted water quality collection system to measure the spatial distribution of water quality parameters (i.e. temperature, conductivity, pH, turbidity, and dissolved oxygen) in a given body of water. In addition to the water quality data collected by the spatial water quality analyzer, GPS and depth were collected, and the gathered data was thematically mapped in ArcGIS. Results revealed a 25-second offset between the time it took for the collection system to draw water from the river and the time it took for the system to record the water quality of that spatial point within the river. USGS Real-Time water data, as well as measurements taken in a lab setting, confirmed that the 25-second offset was a valid conclusion taken from the collected data. As a result, this study indicated that the kayak-mounted spatial water quality analyzer provides a practical means of collecting spatial water quality parameters representative of a given stretch of river.

The author can be reached at hjordan3@vols.utk.edu.

Introduction

As environmental regulations regarding the pollution of rivers and streams have tightened around the nation, water quality monitoring has become an important tool in determining the health of aquatic ecosystems. Waterways can become polluted from various sources such as industry, construction, and agriculture. The effects of pollutants entering into the waterways can range from the degradation of previously healthy ecosystems to the endangerment of wildlife and certain aquatic species. Furthermore, these pollutants have the potential to contaminate waterways that human populations rely on for drinking and/or recreation (Ness et al, 2015). Specifically, Section 303(d) of the Federal Water Pollution Control Act (Clean Water Act) requires that states develop a compendium of the streams and lakes that are "water quality limited" or are expected to fail water quality standards in the next two years and need additional pollution controls ("Proposed Final Version," 2014). Thus, pollutants and their sources can be identified and rehabilitation options considered.

Based on the senior design project conducted by University of Tennessee Biosystems Engineering students Alysse Ness, Alex Shpik, and Ryan Vernich, this project aimed to apply in-situ, autosampling sensor technology to collect the spatial distribution of water quality parameters representative of a given river length, width, and depth. The water sampling system designed by Ness, Shpik, and Vernich was mounted to a canoe and collected water samples at three different river depths: shallow, medium, and deep, while traveling from bank to bank. Because of the design's ability to sample at various depths, this system operates well in slow-moving bodies of water consisting of depths greater than 4 meters and widths greater than 30 meters. However, these sampling parameters, coupled with the canoe's large size, prevent this system from operating well in conditions where streams are shallow and the water is swift. The transportation of the canoe system is also cumbersome; therefore, it is not ideal for testing in remote locations.

Testing was conducted at the confluence of the New River and the Clear Fork (36°25'27.59"N, 84°37'25.37"W) in the Big South Fork National River and Recreation Area on July 22, 2015. The convergence of these two rivers provide ideal conditions for the testing of the kayak-mounted spatial water quality analyzer. At this particular location, a demarcation line is formed as the two respective rivers come into contact with one another, and it remains distinctly visible for approximately 30 meters as the water particles from each stream mix. The well-defined demarcation is caused by the disparate watersheds of the two rivers. Water that flows into the New River runs off land that is primarily used for agriculture and coal mining. The water that makes up the Clear Fork mostly flows out of the protected areas within the surrounding park.

Design

With this in mind, the spatial water quality analyzer for this project was designed such that it could compactly fit in a modified, water-tight box that would be secured within the deck hatch of a kayak. To account for shallow depths and sub-surface obstructions in the river, the system was designed so that it sampled continuously from a single depth of 1 meter and had the versatility to shorten the sampling depth as needed. The system is designed to draw water through a 1.5-meter long, 1.3 centimeter diameter hose with an 18 centimeter long, 1 centimeter diameter hose inserted into the bottom. The one centimeter tubing has plastic mesh netting attached to the bottom to filter out larger debris, as well as a 300-gram iron weight attached so that it will sink into the water. As the tubing enters the water tight box, the water flows through a Shurflo filter before entering into the 6.7 liters per minute Shurflo centrifugal pump. After leaving the pump, the water is pushed into a one-liter flow cell. The water tight box is modified such that the flow cell extends out of the top of the box, allowing one to easily screw in the 6920 YSI Multiparameter Water Quality Sonde, as seen in Figure 1. This YSI Sonde measures and logs temperature, conductivity, pH, turbidity, and dissolved oxygen at one second intervals ("6-Series Multiparameter", 2014). The output cable from the YSI Sonde is fed back into the water tight box and into a NMEA combiner, which logs the aforementioned water quality parameters. The water then leaves the YSI Sonde and flows into a two and a half foot, half-inch hose before being expelled back into the body of water being sampled.

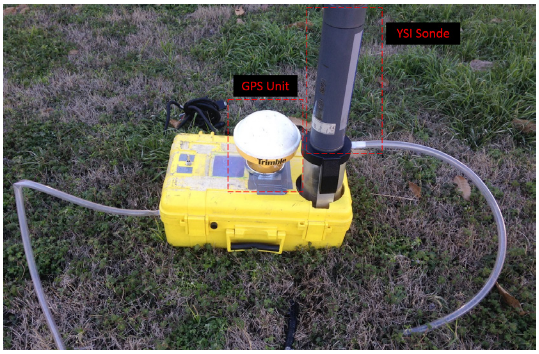

Fig. 1: The above image depicts the external design of the kayak-mounted, spatial water quality analyzer. The TRIMBLE AgGPS receiver is attached to the outside of the water-tight box via a magnetic plate. The flow cell and the YSI Sonde extend out of the box through a pre-cut opening.

A TRIMBLE AgGPS 114 receiver is magnetically attached to the outside and top of the water-tight box with power and output cables fed back into the water tight box through a small hole. The power and output cables for the shallow water depth sensor contained within the hull of the kayak are also fed through the same hole. As seen in Figure 2, the NMEA combiner, which is placed inside a lidless, plastic container, takes the three inputs of water quality, depth, and GPS and outputs to a SDR2 data recorder. Also placed inside the plastic container, the SDR2 data recorder writes the data strings once every second to a SDR card, which stores the collected data and can be used for further data analysis. A 12-volt, 5 A-h Werker battery is used to power the various components within the system. The battery size was chosen based on its ability to meet the required power needs as well as its ability to fit compactly within the water tight box. Other features of the overall design of the system includes an "On/Off" switch that is screwed into the top of the water tight box, allowing for it to be accessed easily by the operator. The viewing window at the top of the box allows the user to confirm that the unit is functioning properly during the data collection process. A metal plate was added to the top of the box so that the TRIMBLE AgGPS receiver could be magnetically attached to the box.

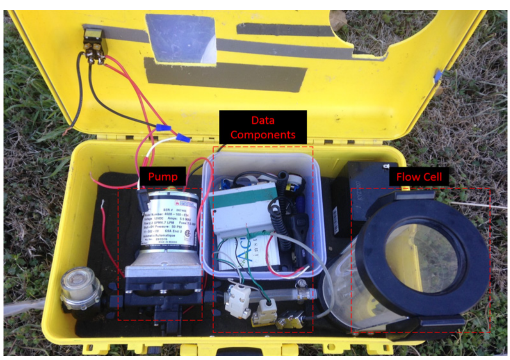

Fig. 2: The above image depicts the various internal components of the design including the pump, NMEA combiner, SDR2 data receiver, and the one-liter flow cell.

Design

A team of three experimenters arrived at the waters of Confluence in the Big South Fork National River and Recreation Area at 11:00 am EST.

After surveying the river for potential danger and prepping the equipment, the kayak was placed into the water. In order to prevent sediment from entering the YSI Sonde, the original one meter length inlet tube was positioned such that the intake was 0.3 meters below the water lever, which kept the tubing from dragging along the bottom of the river.

After ensuring that the system was pumping water at the appropriate flow rate, we used the handheld GPS to place a waypoint, which stores the GPS coordinates and the timestamp associated with a set location. Data collection began at 11:59:58 EST according to this waypoint. The kayak was maneuvered across the mouth of the New River and then over to the mouth of Clear Fork. After allowing time for the YSI Sonde to establish a basis for the water quality in Clear Fork, the operator began performing parallel passes across the confluence of the two rivers at 3 meter intervals. An example of one of these cross-sections can be seen in Figure 3. Once seven cross-sections were complete, the kayak was maneuvered to the location where a final waypoint was placed to signify the end of data collection at 12:20:46 EST. Pictures and videos were taken at each step to digitally document the staging and collecting processes.

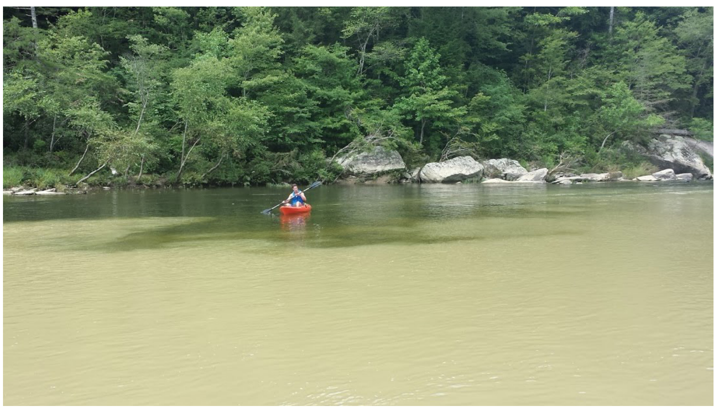

Fig. 3: The demarcation line formed by the convergence of the New River and the Clear Fork as the kayak is maneuvered along a cross-section pass is depicted above. The milky colored water represents the New River, while the darker colored water characterizes that of the Clear Fork.

Results

Analysis of the data collected by the kayak-mounted, spatial water quality analyzer was completed at the Ayers Lab at the University of Tennessee, Knoxville. An example of the data from the depth sensor, GPS receiver, and the YSI Sonde is given below (Figure 4).

```
$GPRMC,160901,A,3625.472010,N,08437.414281,W,001.56,229.0,220715,3.1,W,D*2
$SDDBT,03.55,f,01.16,M,00.59,F*0F
$PNOLE,2,C
$YSI,1,24.47,5,134,18,7.84,203,30.5,212,8.35*4E
$GPRMC,160902,A,3625.471716,N,08437.414642,W,001.53,221.9,220715,3.1,W,D*2
$SDDBT,04.43,f,01.45,M,00.73,F*01
$PNOLE,2,C
$YSI,1,24.47,5,134,18,7.85,203,30.6,212,8.35*4C
$GPRMC,160903,A,3625.471404,N,08437.414976,W,001.51,224.1,220715,3.1,W,D*2
$SDDBT,04.13,f,01.35,M,00.68,F*09
$PNOLE,2,C
$YSI,1,24.48,5,134,18,7.85,203,30.7,212,8.35*42
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Fig. 3: : The above graphic displays three seconds worth of data written to the SD card from the depth sensor, GPS receiver, and the YSI Sonde. The data string beginning with the sequence '$GPRMC' represents the GPS location of the kayak system at that particular second in testing. The sequence of '$SDDBT' corresponds to the depth of the river. 'PNOLE' signifies that the TRIMBLE GPS receiver is collecting locations via a differentially corrected signal (AgGPS 114 Operational Manual, 2000). Furthermore, the data string preceded by the sequence '$YSI' contains the water quality parameters being measured by the YSI Sonde.

The data were imported into ArcGIS, and the track log from Hayden Jordan's course of travel was displayed. A base map was then uploaded to verify that the track log was plotting over the correct geographical area and that there were no errors during the data trimming process. The base map showed that the GPS points depicted the correct track log.

After ensuring that the GPS locations were correct, the water quality data was then thematically mapped with GPS. After studying the thematic plots of temperature, conductivity, pH, turbidity, and dissolved oxygen, it could be seen that there was a definite offset between when the water quality data was taken in real time and when the data was stored into the SDR2. This was in concordance with the conclusion made by the senior design team during similar lab testing. The results of these in-lab tests concluded that the sensor response time of the YSI Sonde was approximately 12 seconds (Ness et al., 2015). However, this 12-second offset did not take into account the transport time of the intake water to the flow cell or the time to fill the flow cell with water. Therefore, taking into consideration all three of these time constants, as well as using a visual assessment technique, analysis of the data conveyed that the offset was approximately 25 seconds. In other words, the time it took for the system to record the water quality of a spatial point within the river was 25 seconds after that water was drawn from the river and into the intake hose. The data were accordingly modified by by adding 25 seconds to each data point.

Each of the five water quality parameters measured by the YSI Sonde (temperature, pH, electric conductivity, turbidity, and dissolved oxygen) were then plotted using the 25-second offset. Furthermore, the overall range over which each water quality parameter was measured was then divided into five subsets of equal ranges. These subsets are thematically depicted by their corresponding color, as seen in Figures 5, 6, 7, 8, and 9.

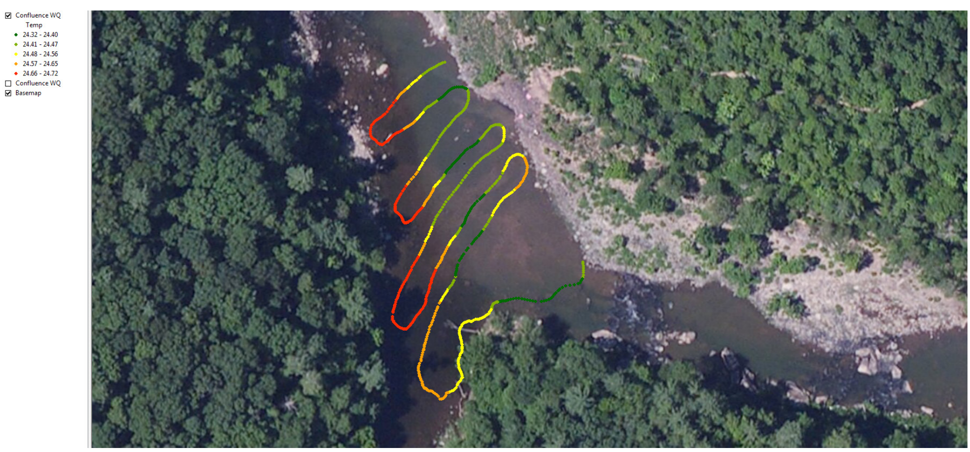

Fig. 5: ArcGIS image depicting the water temperature (measured in degrees Celsius) at each recorded GPS location.

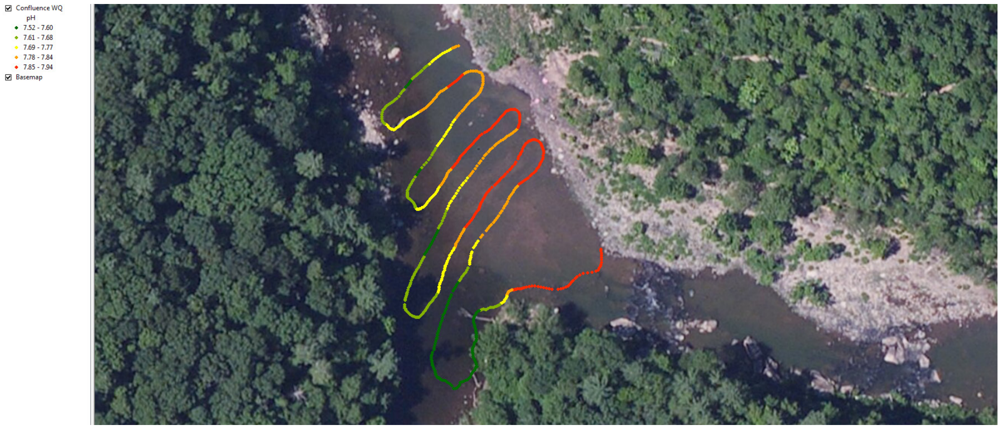

Fig. 6: ArcGIS image depicting water pH (measured in standard units) at each recorded GPS location.

Fig. 7: ArcGIS image depicting water electric conductivity (measured in micro-Siemens per centimeter). at each recorded GPS location.

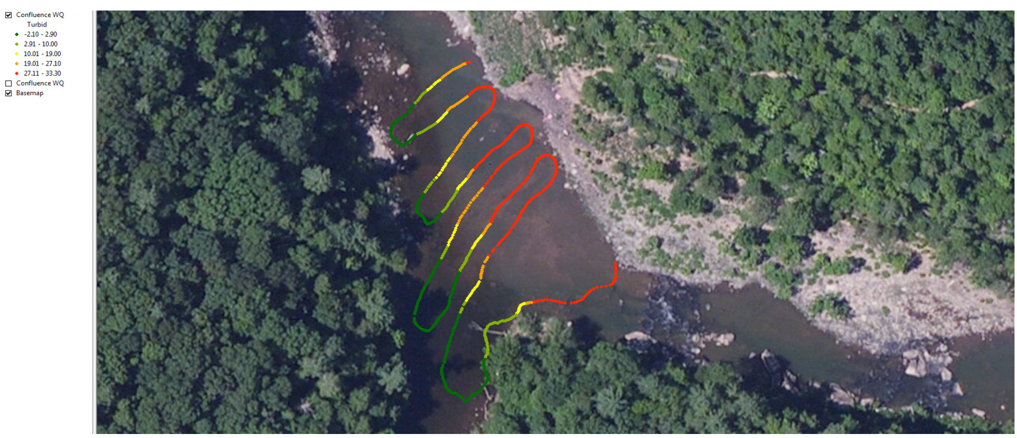

Fig. 8: ArcGIS image depicting water turbidity (measured in + (NTU)) at each recorded GPS location. The ranges for each colored subset are as follows: -2.20-2.90 (dark green); 2.91-10.00 (light green); 10.01-19.00 (yellow); 19.01-27.1 (orange); 27.11-33.30

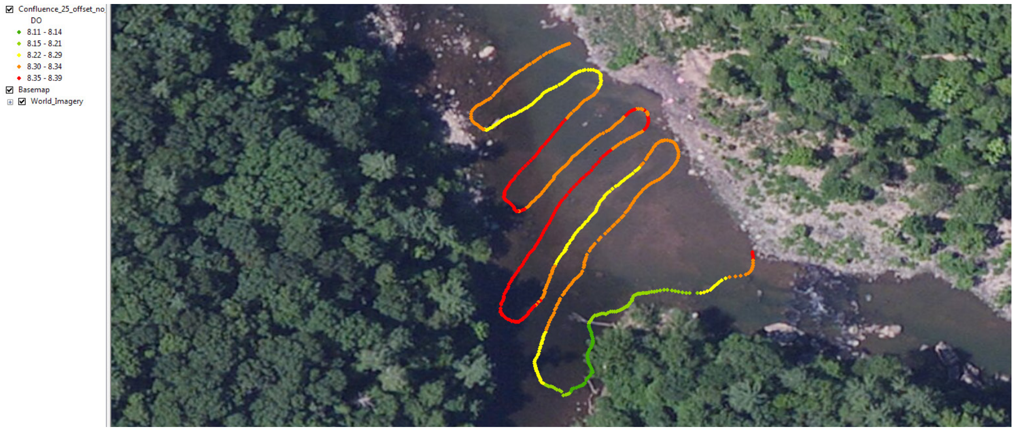

Fig. 9: ArcGIS image depicting water dissolved oxygen (measured in milligrams per liter) at each recorded GPS location. The ranges for each colored subset are as follows: 8.11-8.14 (dark green); 8.15-8.21 (light green); 8.22-8.29 (yellow); 8.30-8.34 (orange); 8.35-8.39 (red).

To further investigate and validate the decision to offset the data by 25 seconds, USGS Real-Time water data was obtained for the New River and Clear Fork via USGS streamflow collection stations. Because the data recorded by these stations was given on the USGS website in the form of plots, approximations were made for the water quality values for the time at which testing was conducted. Since these recording stations take static samples, whereas the samples are taken dynamically with the kayak-mounted spatial water quality analyzer, the recorded data readings for the water quality parameters of pH, turbidity, and dissolved oxygen were not analyzed. Comparisons were therefore only made between temperature and conductivity.

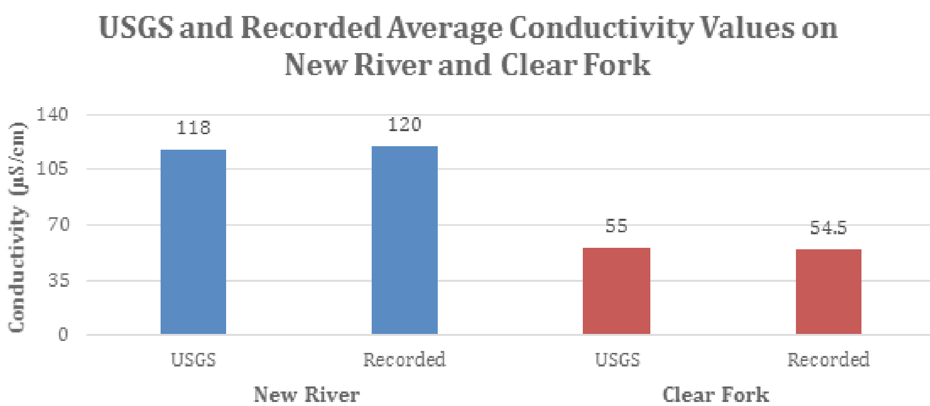

Figure 10: The above bar graph depicts the comparison between the USGS and the recorded average conductivity values on the New River and the Clear Fork.

As seen in Figure 10, there was strong agreement between the average conductivity values recorded for the New River and the Clear Fork during the Confluence testing and those recorded by the USGS streamflow collection stations on that same day ("USGS Current Conditions", 2015). Likewise, a strong agreement can be seen in Figure 11, which shows the average temperatures for the New River and the Clear Fork. It should be noted that the USGS gauges for the New River and Clear Fork are located at points upstream from Confluence. As a result, the elevation difference between the collection stations and the testing location could have caused the slight difference in the temperatures recorded by each respective party.

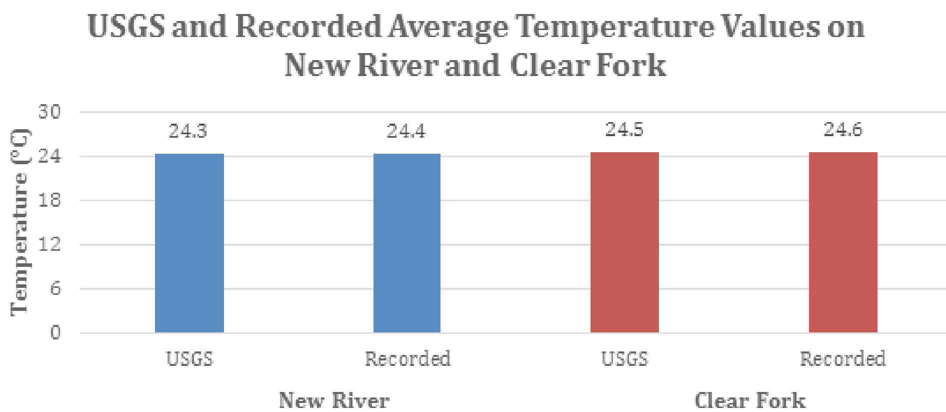

Figure 11: The above bar graph depicts the comparison between the USGS and the recorded average conductivity values on the New River and the Clear Fork.

Discussion

Prior to conducting the experiment at Confluence, in-lab testing performed by the senior design team of Ness, Shpik, and Vernich had determined that the sensor response time of the YSI Sonde was approximately 12 seconds. As stated before, this did not account for the transport time or the flow cell filling time (Ness et al., 2015). By thematically overlaying the collected data on top of the ArcGIS base maps, our team used each point's geospatial location in relation to the New River and the Clear Fork to evaluate and quantify the projected point's visual attributes. This allows one to evaluate how accurately the associated color attribute represents the unique geo-spatial point within either the New River or the Clear Fork. Figures 5-9 present strong relationships between the unique geospatial location of each data point (relative to its location with respect to the demarcation line) and the water quality parameters of temperature, pH, conductivity, and turbidity. Only dissolved oxygen presents a skewed thematic map with respect to the demarcation line. This may be due to the very small range over which the YSI Sonde measured the dissolved oxygen. Additionally, different water quality sensors can have different water quality response times ("6-Series Multiparameter", 2014). These results, coupled with those obtained in the senior design lab testing explained above, reveal that it is reasonable to use the determined 25-second offset as truth for the Confluence data set.

It was expected that the data gathered by the YSI Sonde would differ with respect to where the water sample was taken (either the New River or Clear Fork). As the water sampling system moved further away from the demarcation line, the recorded values would become more unique to the river in which the system was collecting, depending on the water quality parameter being measured. Figure 10 shows that as anticipated, there was a marginal change in water temperature as the collection unit passed between the two rivers. The change was expected to be negligible as the difference between the measurements of the two USGS streamflow collection stations was minor. Contrastingly, Figure 11 shows a drastic change in the average conductivity measured within each river, with the New River having a much larger electric conductivity than the Clear Fork. Once again, this data agrees with the anticipated results based on the data taken by the USGS gauges. The agricultural landscape that the New River flows through should cause the conductivity levels in the water to rise as a result of additional chloride, phosphate and nitrate ions entering the river from the agricultural runoff. The alignment of the data shown in Figures 10 and 11 with the expected results further solidifies the viability of using the kayak-mounted design.

Conclusions

Based on the data that was collected during the testing conducted at Confluence in the Big South Fork National River and Recreation Area on July 22, 2015, the kayak-mounted, spatial water quality analyzer is an effective system to gather the spatial water quality parameters of a desired stretch of river. Furthermore, this design successfully operated under the desired constraints of compactly being mounted to the deck hatch of a kayak while maintaining functionality such that it could collect the spatial water quality parameters from a single depth of shallow, fast-moving bodies of water. Using the data points collected by the YSI Sonde, as well as the GPS points collected by the TRIMBLE AgGPS receiver, thematic maps were generated so that each GPS location could be linked with its associated geospatial water quality parameter. We concluded that a 25-second offset consistently existed between the time it took for the pump to draw water from the river to when the system recorded the water quality of that spatial point within the river. Although this determined offset time is double the 12-second offset found by Ness, Shpik, and Vernich, a justifiable parallel can be drawn between the two. That is, the response time of the YSI Sonde's sensors is significantly delayed, and this delay is affected by the configuration of the water sampling system. In relation to the environmental applications for which this system was designed, this study suggests that the compact kayak-mounted design will not limit the effectiveness to which this system measures the spatial distribution of water quality parameters, and therefore, is a viable design.

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