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Groundwater Movement in Boiling Spring, Onyx Spring, Yelton Spring, Wilkins Spring, Hudgens Spring and Natural Bridge Spring

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GROUNDWATER MOVEMENT IN BOILING SPRING, ONYX SPRING, YELTON SPRING, WILKINS SPRING, HUDGENS SPRING AND NATURAL BRIDGE SPRING

by

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Approved by:

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ABSTRACT

Onyx Spring, Boiling Spring, Yelton Spring, Wilkins Spring, Hudgens Spring, and Natural Spring are located on public land in Pulaski and Phelps County, Missouri. They were selected randomly to determine groundwater movement and compare water chemistry from the springs that are connected.

Using a dye tracing method, we were able to determine the direction of groundwater flow and a water multiparameter sonde was used to characterize the water chemistry at each point of the springs. As a result, from the six springs studied only three springs are connected which are Yelton, Onyx and Boiling Spring. Regarding to water chemistry this study has observed temperature, pressure, dissolved oxygen, specific conductance, total dissolved solids, salinity, potential of hydrogen and oxidation-reduction potential. The values of all springs connected have similar values before and after dye injection.

We compared the groundwater pathways to other dye tracing experiments to see overall pattern of water movement and this study can probe one more time that springs that are connected is Yelton Spring, Boiling Spring that discharges in Gasconade River. Knowing the water system in the area can let us understand the size of areas susceptible to contamination. Further interpretations can affirm the unique pathways of the karst system.

ACKNOWLEDGMENTS

I am grateful to my advisor Dr. Jeffrey Cawlfield whose dynamic energy pushed me to complete my thesis. I thank my former team at the Department of Natural Resources Groundwater Section who were part Trebor, Trayce, Erin, Laura, Jon, Gracie, Scott, David for providing me the opportunity to use their information in this thesis. At the same time, I give thanks to my committee members Dr. Maurer and Dr. Grote for being part of my journey toward completion to graduate as a master on Geological Engineering.

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NOMENCLATURE

Symbol	Description
cfs	Cubic feet per second
gpm	Galon per minute
TDS	Total dissolved solids
Sal	Salinity
F	Fahrenheit
ppt	Parts per trillion
ppm	Parts per million
uS	Microsiemens
cm	Centimeter
DO	Dissolved oxygen
mg	Milligrams
L	Liters
PH	Potential of hydrogen
mm	Millimeters
Hg	Mercury
ORP	Oxidation-reduction potential
SC	Specific conductance
MDNR	Missouri Department of Natural Resources
USGS	United States Geological Survey

1. INTRODUCTION

1.1. GENERAL INTRODUCTION

In cooperation with the Groundwater Section at Missouri Department of Natural Resources I participated in a subsurface hydraulic investigation in public area around Phelps County and Pulaski County to determine groundwater flow in six springs. We used a dye tracing method for determining groundwater movement in Onyx Spring, Boiling Spring, Yelton Spring, Wilkins Spring, Hudgens Spring and Natural Bridge Spring. The dye tracer used was fluorescein. Results of dye-tracing investigations demonstrate that there is indeed a connection between Yelton Spring, Boiling Spring and Wilkens Spring. After 15 days under spectrophotometer test dye appeared in Yelton Spring and Wilkens Spring. After 34 days in Boling Spring. Additionally, this research tries to compare water quality parameters in the springs that are connected. Dye tracing is a helpful method to determine groundwater flow. This knowledge can help to understand how fast water flows and find connections between springs. In addition, we can determine potential impacts if contamination affects the area. The geology in this area is related to karst system. The main formations are Gasconade, Rubidoux, and Cotter Formations in the lower Ordovician series in the Ordovician System -Lower Paleozoic of the Ozark Region. The injection point took place in Mill Creek at Phelps County. This area was chosen because it is above the springs and bedrock was exposed more often.

1.2. PURPOSE AND SCOPE

The purpose of this study is to determine groundwater movement in 6 locations around the Mill Creek. This was accomplished by using a dye tracing method to understand at what direction water is flowing as well as compare the water chemistry of main parameters among springs that are connected. From more the 3000 springs in Missouri it was randomly selected 6 springs around the Mill Creek area in Phelps and Pulaski County covering 11 miles in all locations. The duration of experiment to exercise dye tracing ranged between May 3, 2023, to August 28, 2023, during late spring and summer period.

1.3. THESIS ORGANIZATION

This thesis contains five sections. Section 1 contains introduction and main purpose of authoring my thesis. Section 2 contains literature review regarding springs, geology, and general ideas of water chemistry. Section 3 contains the methods of dye tracing. Section 4 contains the results and discussions of the work. Finally, section 5 contains the conclusions and recommendations of the work.

2. LITERATURE REVIEW

2.1. SPRINGS

2.1.1. Definition. A spring is a water body where water naturally flows out from the ground. Water is continually replenished from subsurface (Kirk, 1919). Springs have attracted humans to settle closely where water is abundant, but it is important to balance recharge with human consumption (Rosen, 2015). Springs also provide aquatic habitats to animal and vegetal species that has adapted to special conditions like not sufficient solar light (Rosen, 2015).

2.1.2. Springs in Missouri. Missouri has many springs, caves, and sinkholes due to the karst geology. Missouri has more than 3000 springs (Hornbeck T., 2012). Because of the fracture flow and permeable soils, the springs are susceptible to contamination (Feder G., 1982).

2.1.3. Classification of Springs. It is complex, so a straightforward way to classify relies due to discharge rates as in the Table 2.1 (Feder G., 1982).

Table 2.1 Rate Flow Classification.

Magnitude	**Discharge**
First	1000 cfs
Second	10-100 cfs
Third	1-10 cfs
Fourth	1000 gpm
Fifth	10-100 gpm

2.1.4. Other Way to Classify Springs. As well as the rate of flow, other characteristics or peculiarities of springs have risen many names and classes, but none of the systems of classification can include all springs. In general, a splendid work to classify springs mentions that there are two factors that are based on source of the water and rock structure that brings flow to the discharge point. In Figure 2.1 we can see two categories where the first number (1) are springs due to deep-seated waters, juvenile and connate, admixed with deeper meteoric water and the number two (2) springs due to meteoric and occasionally other waters moving as ground water under hydrostatic head. (Kirk, 1919).

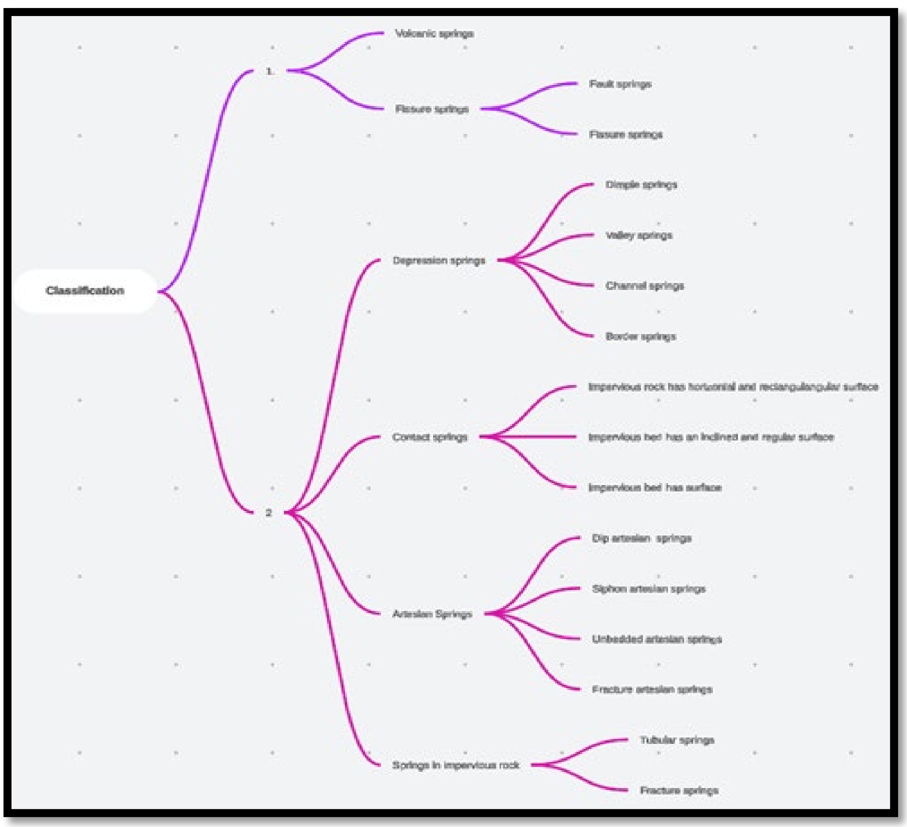

Figure 2.1 Classification of Springs (Division of Geology and Land Survey , 1992).

2.2. GEOLOGY

2.2.1. Mill Creek. Mill Creek flows on and above sedimentary rocks like sandstone. It belongs to the northernmost part of the Ozark Karst province. Mill Creek is an influent to the Little Piney Creek and the Little Piney Creek flows into Gasconade River about 2.5 miles from this intersection (Kaufmann, 2002). Mill Creek is a large stream. There are two sections inside Mill Creek one below Yelton spring as gaining spring and above it is a losing stream.

2.2.2. Boiling Spring. Boiling Spring is located at +37.889654 N, -92.035100 W and 700 feet above sea level in Pulaski County (Missouri Department of Natural Resources, 2023). The geology is like Onyx Spring as they are remarkably close (See Figure 2.2).

karst terrain. Boiling Spring flows up in the Gasconade River. It is considered a major spring and at the same time is one of the 15 larger springs in Missouri. From 1923 to 1964 the maximum discharge was 528 cfs and a minimum of 297 cfs (Feder G., 1982).

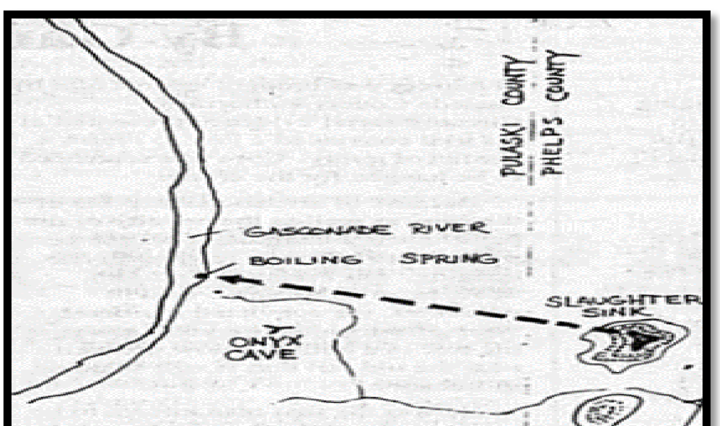

Figure 2.2 Karst Topography in Boiling Spring (Keberlin, 1901).

2.2.3. Onyx Spring. is located at +37.885835 N, -92.032693 W and 800 feet above sea level in Pulaski County (Missouri Department of Natural Resources, 2023). This spring is related to the geology above Gasconade River that includes big layers of dolomite (Magnesium/calcium carbonate). The structural geology are anticlines that went into erosion. The outcroppings display third type of magnesian limestone, of the Ordovician System. Pulaski county is dominated by this type of limestone (Keberlin, 1901).It also presents a second sandstone on the top of the cave together with fissures that have dissolved calcium carbonate as its filler material (See Figure 2.3). There is no presence of geological structures. The Onyx cave originally was called Boiling Spring Cave and was a quarry in central Missouri. It partially was exploited for Onyx deposit and stopped when cost of extraction rose. Onyx is a semi-precious variety of mineral chalcedony (Keberlin, 1901).

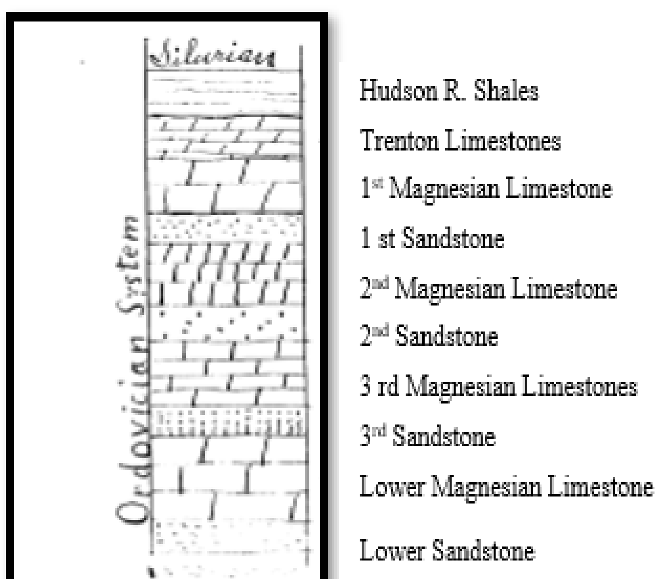

Figure 2.3 Onyx Geology (Keberlin, 1901).

2.2.4. Yelton Spring. Yelton Spring is located at +817442 N, -91.940062 W and 850 feet above sea level in Phelps County (Missouri Department of Natural Resources, 2023) in Mark Twain National Forest (See Figure 2.4). It discharges at the Gasconade Dolomite bluff in the west part of Mill Creek. When the flow is minimum as 5 feet below normal pool surface it is “Estevelle”, a karst feature that can work both as discharge and recharge point. (Kaufmann, 2002).

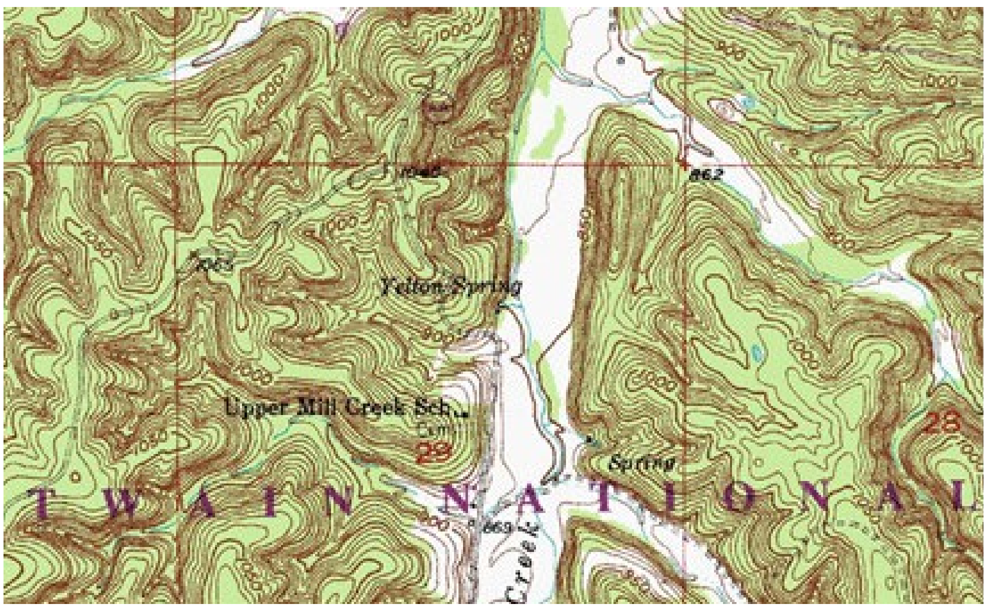

Figure 2.4 Yelton Spring at Mark Twain National Forest (United States Geological Survey, 2024).

2.2.5. Wilkins Spring. Wilkins Spring is located at +37.835555 N, -91.937491 W and 825 feet above sea level in Phelps County (Missouri Department of Natural Resources, 2023). Wilkins is an alluviated spring formed in karst system. This spring discharges from the Ozark Plateaus aquifer system. It discharges in a lake in a 2-acre pond in an open property belonging to the Mark Twain National Forest (See Figure 2.5).

In 1952 to 1964 the maximum discharge reported was 16 cfs and a minimum of 4.5 cfs (Feder G., 1982).

Figure 2.5 Drone Picture in Wilkins Spring (Robert Charity Photography, 2021).

2.2.6. Hudgens Spring. Hudgens Spring is located at +37.851554 N, -91.943806 W and 790 feet above sea level in Phelps County (Missouri Department of Natural Resources, 2023). Spring that its outcrop is based on the Gasconade Dolomite formation. This last one presents a coarse-grained and light gray dolomite, medium to massive bedded: weathers to massive, pitted surface (Thompson, 1991). It has various discharge points behind a small gravel bar on the east side of Mill Creek. The flow discharge is difficult to estimate because discharges occur at many points along the site. A solution plan of this complexity is walking dawn through the canal formed before it enters to the next creek or else take measurements before the intersection between the discharge and the creek and after the same intersection (See Figure 2.6). Subtract those values and you can have an estimation. (Kaufmann, 2002).

Figure 2.6 Intersection View of Hudgens Spring.

2.2.7. Natural Bridge Spring. Natural Bridge Stone is located at +37.847298 N, -91.920055 W and 950 feet above sea level in Phelps County (Missouri Department of Natural Resources, 2023). It is located close to the Mill Creek and is also by the Mark Twain National Forest inside Natural Bridge at Kaintuck Hollow (See Figure 2.7).

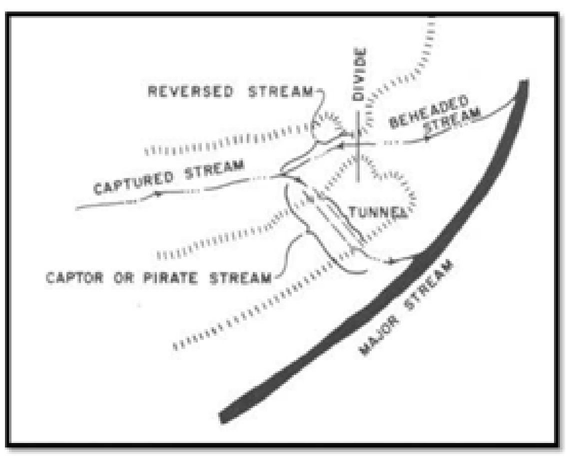

Figure 2.7 Natural Bridge Spring at Kaintuck Hollow (Missouri Department of Natural Resources, 2023).

2.3. DYE TRACING

2.3.1. Introduction. Karst terrain develops from ancestral landscape of surface-flowing streams, which leaves a defined pattern, apparently if caves were developed from ancestral watersheds determining groundwater movement would be unnecessary, but lithology, structural and hydrologic factors lead a more complex system. Therefore, groundwater flow not always follows ancestral surface watershed boundaries. Under this circumstances dye tracing is a powerful method to solve these ambiguities (Currens J., 1996). When applying dye tracing is recommended to follow standardized protocols and ask experienced professionals to get best advice.

2.3.2. Dye Traces. The widely used dye since last century has been fluorescein (Turner Designs, 2024). Fluorescein (resorcin-phthalein, diresorcin phthalein, tetraoxyphthalophenone, uranin, Kruger's indicator) is a coal-tar product. (Fuller M., 1906). The quantity of dye trace is based on flow conditions as for example studies conducted by the U.S. Geological Survey usually limit the maximum concentration of fluorescent dye at a water-user withdrawal point to 0.01 mg/L (Hubbard and others, 1982).

2.3.3. Qualitative and Quantitative Dye Tracing. If you are looking to determine connectivity between a shallow hole and springs qualitative is appropriate tool. In contrast quantitative tracing is accurate when the spring or other recovery point is already known then you can determine hydraulic coefficients and velocity as well (Currens J., 1996).

2.3.4. Dye Application Procedures. It is recommended to prepare a water and dye mixture at 0.5 pounds in one gallon before going to field because factors like wind can make it difficult to apply. Second, apply dye directly to injection point so that way it immediately can drain and avoid photo decay. Third try to find a strategy to make the dye flow like applying water before injection and after as well (Unites States Environmental Protection Agency, 1988). In case the point of injection does not have access to transport water tanks, then check the forecast for the possibility of rain to push the dye in the subsurface.

2.3.5. Dye Recovery and Charcoal Packets. Dye is recovered in charcoal packets previously installed in strategic points. Regularly, packet is collected and replaced by a new one weekly. The one collected is analyzed in a spectrometer to see peak curves of fluorescein to see if dye has passed through the charcoal packets.

2.3.6. Spectrometer Use and Calibration. A spectrometer normally is used to analyze charcoal packets, but the importance relies on calibration accuracy, so let the calibration run for one hour or according to the spectrometer manual use.

2.3.7. Curve Responses. A fluorescent compound exhibits an excitation peak at 498 nm and an emission peak at 517 nm as seen in Figure 2.8 (AAT Bioquest, 2024).

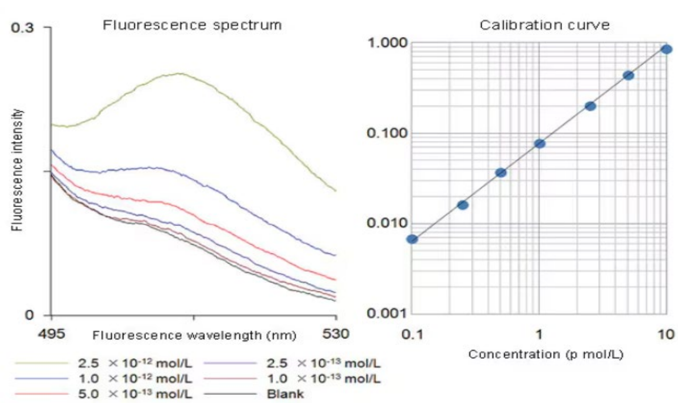

Figure 2.8 Fluorescein Curve Responses (Horigome J., 2024).

2.4. GENERAL IDEAS ABOUT WATER CHEMISTRY

2.4.1. Groundwater in Missouri. The water quality is influenced by vulnerability of contamination, hydrology, physiography, precipitation, geology, topography, soil type, land use and water use. In general, we can divide in 8 areas of water quality characterization in Missouri (See Figure 2.9). In area 1 "Northwestern Missouri" water has elevated levels of sulfates, chloride, iron, manganese from glacial materials. The geology has glacial drift, Pennsylvanian shales, limestones, sandstones. In area 2 "Northeast Region" geology is extensive plains, rolling hills, glacial drift, Pennsylvanian sandstones, shales, and Mississippian limestones. In area 3 "Alluvial Regions" the alluvial materials of the valley are composed of clay, silt, fine to coarse sand and fine to medium gravel. In area 4 "West Central Province" some aquifers yield water that may be too mineralized for good domestic use. In area 5 "Springfield Plateau Province" located the southern part of Missouri, and the water type is made of calcium bicarbonate, freshwater-saltwater interface is evident, high sulfate concentrations and it has nutrients and pesticides and near there are mining areas like Kansas, Oklahoma. In area 6 "Salem Plateau Province" has calcium-magnesium, bicarbonate type, and total dissolved solids of 500 mg/l and is Ozark aquifer included. In area 7 "Saint Francois Mountain" located at the southeastern part of Missouri has a high concentration of lead and zinc/sulfate. It is a region of mining too. In area 8 "Southeast lowland Province" some part contains more calcium, magnesium, bicarbonate and iron in contrast to the south where water is soft less minerals (Division of Geology and Land Survey , 1992).

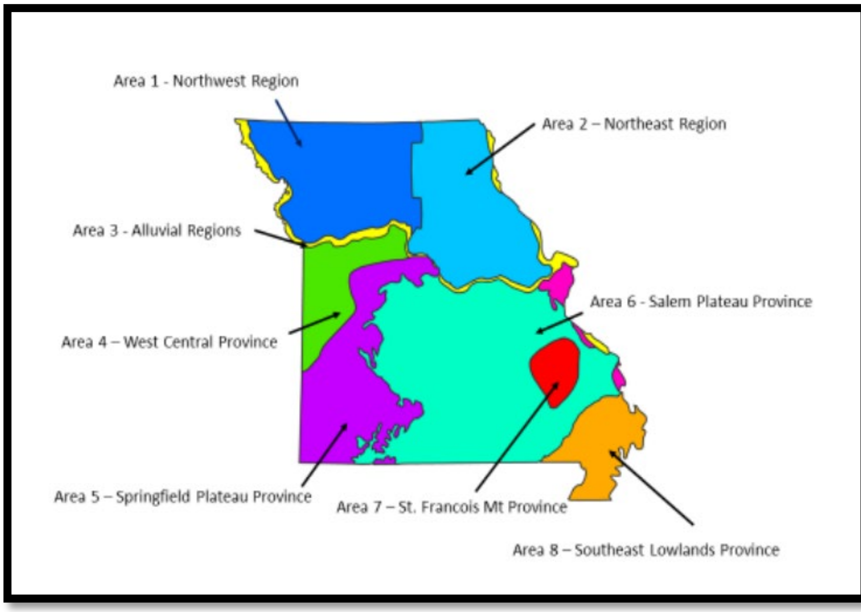

Figure 2.9 Water Quality in Missouri (Division of Geology and Land Survey , 1992).

2.4.2. Water Chemistry Parameters. In this study we are going to focus in eight parameters to see water chemistry such as temperature, pressure, dissolved oxygen, specific conductance, total dissolved solids, salinity, potential hydrogen, and oxidation-reduction.

2.4.2.1. Temperature. This parameter measures average kinetic energy expressed in different scales. Temperature influences amount of dissolved gas in water, rate of plant growth and photosynthesis, toxicity, metabolic rate, and sensitivity of living organisms. (Missouri Stream Team , 2017).

2.4.2.2. Pressure. Pressure measures the strength of water flow through the channel of discharge. A scale can be millimeters of mercury (Missouri Stream Team , 2017).

2.4.2.3. Dissolved oxygen. Dissolved oxygen is one of the most important water parameters because indicates if aquatic life can survive or not like fishes. Critical values affect life in streams, so recommended value 0.0005% dissolved oxygen as minimum (Missouri Stream Team , 2017).

2.4.2.4. Specific conductance. Specific conductance measures the ability of water to conduct electrical current. It is measured in microsiemens per centimeter. Monitoring this value determines if water quality has been altered by anthropogenic or natural sources. A median specific conductance in the Delta River basin fluctuates from 27 to 424 microsiemens per centimeter (Unites States Geological Survey, 2012).

2.4.2.5. Total dissolved solids. This parameter measures the amount of organic and inorganic particles in water like minerals, salts, ions that are dissolved in water. It is measured in mg/L. This parameter is related to specific conductance. (Unites States Geological Survey, 2012).

2.4.2.6. Salinity. Salinity is the dissolved salt content in a body of water. The value of 0.5ppt or 0.05% good for drinking and irrigation, above this is problematic.

2.4.2.7. Potential hydrogen. This parameter measures the acidity or basicity of water, from 0-7 acid, from 7 to 14 basic. A normal stream has potential hydrogen range of 6.5-9 (Missouri Stream Team , 2017).

2.4.2.8. Oxidation-reduction. It measures the ability of the water body to cleanse itself or break down waste products. The value that represents a sanitized water has a minimum of 650 Mv (Portland State University, 2009).

3. METHODOLOGY

3.1. GENERAL INTRODUCTION

In total six locations to detect dye were monitored together with the water chemistry. The total length of the survey from Boiling Spring to point of injection is 14 miles. Next, I am going to summarize in table 3.1 GPS coordinates.

Table 3.1 Location of Springs and Point Injection.

Location Name	Longitude	Latitude	Elevation (feet)
Boiling Spring	-92.035100	37.889654	700
Onyx Spring	-92.032693	37.885835	800
Yelton Spring	-91.940062	37.817442	850
Wilkins Spring	-91.937491	37.835555	825
Hudgens Spring	-91.943806	37.851554	790
Natural Bridge Spring	-91.920055	37.847298	950
Point of Injection	-91.929980	37.789230	1000.66

As part of the strategy of dye tracing the point of injection was in the upward elevation at the Mill Creek expecting dye will travel downgradient (See Figure 3.1). Natural Bridge Spring is located down but it is at the eastern side from perpendicular direction of Mill Creek. Also, it is seen that Yelton and Wilkins are close in distance just 1 mile apart from each other, and they have just 25 feet of difference regarding to elevation and at the same time Onyx and Boiling are the second closest in distance, but they have 100 feet elevation difference. Finally, Hudgens is at the average point between point of injection and Boiling.

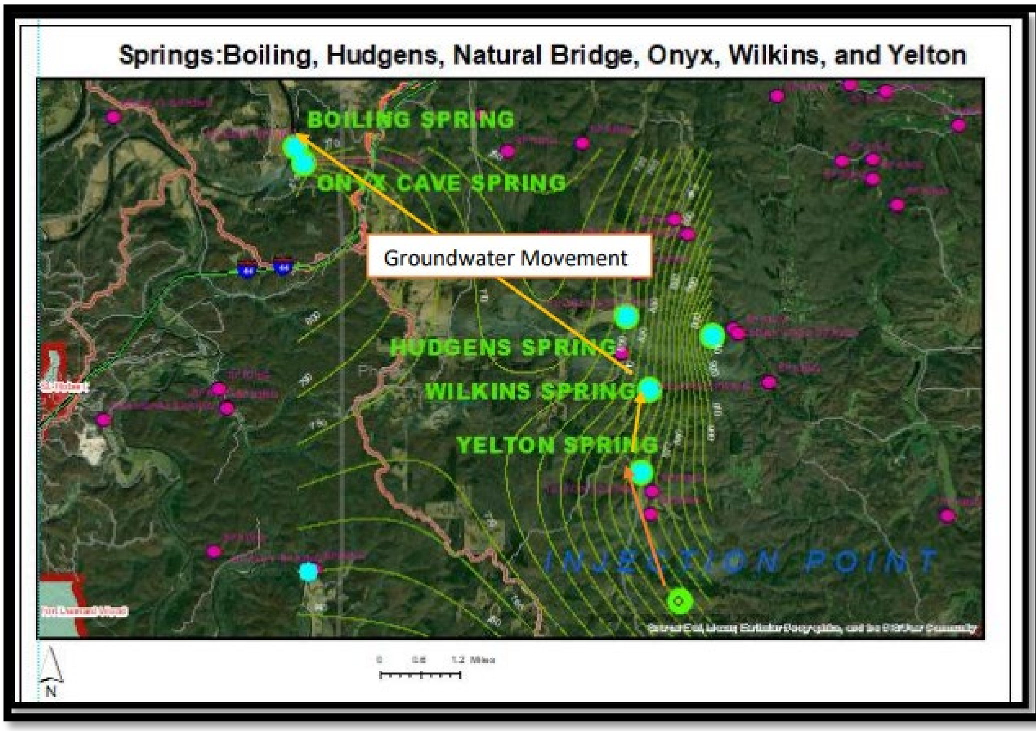

Figure 3.1 Point of Injection and Springs.

3.2. TRACER ANALYSIS

Following the standards of dye tracing, the charcoals packet previously deposited in each spring underwent laboratory analyses with the intention to find dye. The charcoal is covered with ammonium hydroxide by 3 drops of standard pipette and distilled water that covers at least 75% of the 4 ml quartz vial. Next, the sample goes to the spectrometer for light electron stimulation to find typically 570 light fluorescence.

3.2.1. Procedures for Starting the F7000 Spectrometer. Next, I will describe steps to scan samples and methods setting to get wavelength graphs and relative intensity.

1. Begin by turning on the computer. Then power on the SF as well.
2. On the computer screen click the F1 Solution 2.1 under programs, this will pop up the menu. The spectrometer start will result.
3. Wait for the spectrometer to hit for 60 minutes.
4. Prepare to run signal-to-noise ratio. Place the sample in the quartz cuvette and place it in the sample chamber.
5. To start the signal/noise ratio scan, go to utility on the main menu and next select sensitivity, click ok. The scan will start and take approximately 13 minutes.
6. When the scan is complete, the data will be displayed on the screen.
7. Enter the calculated data from the screen into the corresponding categories on the chart given. Click cancel, then ok, when done.
8. The signal-to-noise ratio (peak to peak) should be at least 100, and the drift should be 2%, if ok, click cancel, then click ok.
9. Fill out the dye laboratory analysis summary completely with appropriate data. This data should be entered in the spreadsheet found in the T drive under water/trace analysis.

3.2.2. Wavelength Data Processing. In summary in Figure 3.2 we can see main steps to process wavelength data (Hitachi High Technology Corporation, 2006).

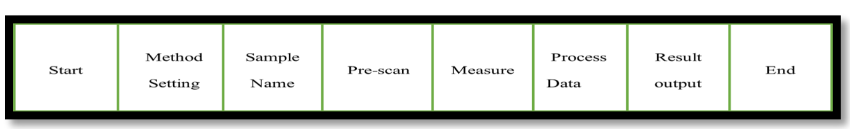

Figure 3.2 Wavelength Scan Steps.

3.2.3. Curve Interpretation. Once the graph is generated, the y-axis is the relative intensity that quantifies the amount of an ion produced in relation to the amount of the most abundant ion (the base peak and has arbitrary units) and x-axis is the wavelength measure in nanometers as seen in Figure 3.3 (Jackson G., 2022). Criteria for determining fluorescein dye recoveries in elutants from charcoal samplers indicates that there must be at least one fluorescence peak in the range of 514.5 to 519.6 nm in the sample as seen in Table 3.2 (Aley T. & Beemam S., 2015).

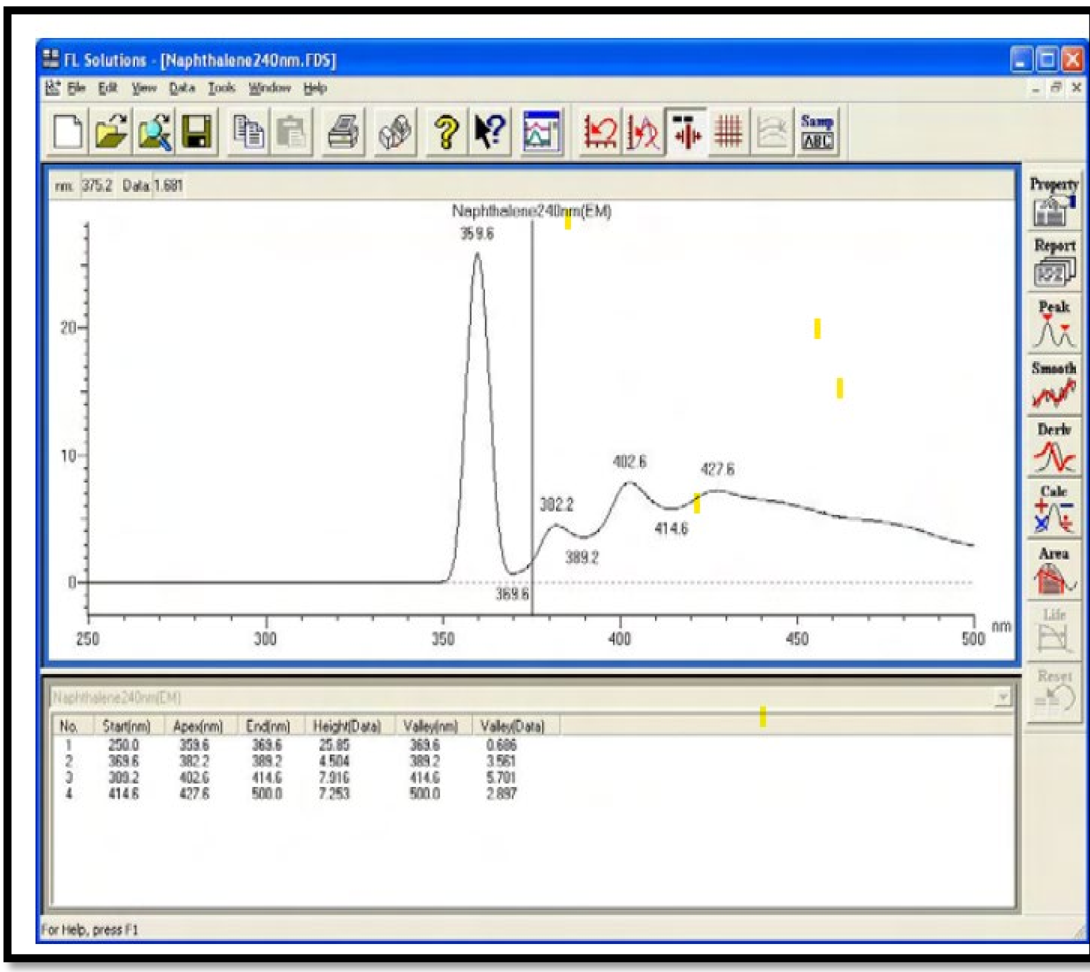

Figure 3.3 Example of Peak Wavelength (Hitachi High Technology Corporation, 2006).

Table 3.2 Normal Emission Wavelength Ranges.

Fluorescent Dye	Normal Acceptable Emission Wavelength Range(nm)	Detection Limit (ppb)
Fluorescein	514.1-519.2	0.025

3.3. WATER CHEMISTRY ANALYSIS

3.3.1. Procedures for Starting Multiparameter Water Quality Sonde YSI.

The use of YSI sonde is quite simple but involves calibration regularly. Next, I am going to summarize steps to sample water in all the multiparameter like conductivity, specific conductivity, salinity, total dissolved solids, temperature, potential hydrogen, oxidation-reduction potential.

1. To get started connecting sonde to computer and check calibration.
2. Prepare sonde for use by installing probes and a clean geomembrane.
3. Place internal batteries.
4. To start discrete measurements, the sonde is connected via communication cable to the contact point.
5. Save data and download in text file measurements collected.
6. Store equipment and end.

3.3.2. Principles of Operation of Multiparameter Sampler. To measure specific conductance, the sondes utilize a cell with four pure nickel electrodes. Salinity is determined automatically from temperature by using equation found in Standard Methods for the Examination of Water and Wastewater (Lane B., 2012). Total dissolved solids result as a conversion from specific conductance as seen in Figure 3.4. The ORP sensor consists of a platinum button found on the tip of the probe. The sondes employ a field replaceable PH electrode for the determination of hydrogen ion concentration. In the same way for pressure and dissolved oxygen, it has specialized sensors (Lane B., 2012).

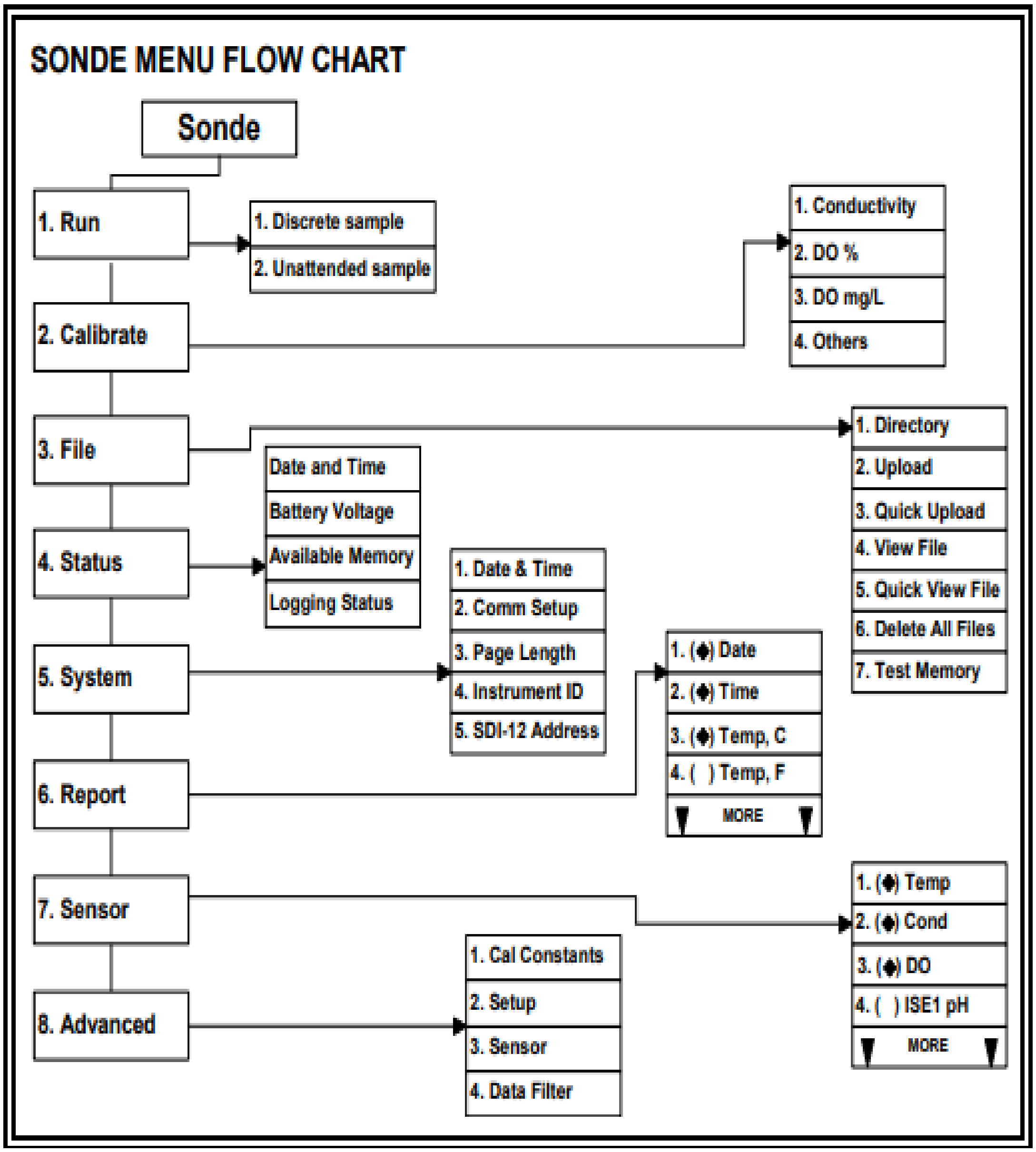

Figure 3.4 Sonda Menu Flow Chart (Lane B., 2012).

4. RESULTS AND DISCUSSIONS

4.1. CURVES OF WAVELENGTH AND FLUORESCEIN INTENSITY

To analyze wavelength spectrum profiles samples were collected weekly and between June 12, 2023, to August 23, 2023. The date of injection was July 19, 2023. The background analysis in most location was July 11,2023, except Boiling Spring that was earlier June 22, 2023. Same way analysis after dye injection were in July 25,2023; August 3, 2023; August 8, 2023; August 15,2023 and August 23, 2023

4.1.1. Background of Boiling Spring Before Fluorescein Tracer. From Spectrometer 7000 F 1 profile was created accordingly before date of dye injection. In figure 4.1 as it is seen there is no fluorescein peak between range 514.4 nm to 519.6 nm, then water is without tracer.

The sample that was collected for fluorescent tracer dye analysis was recovered in a charcoal packet on June 22, 2023, as seen in Figure 4.1.

Sometimes not all the criteria are met for a straightforward determination of tracer dye in a sample, so background samples aids in the interpretation of the emission fluorescence graphs. (Aley T. & Beemam S., 2015).

4.1.2. Boiling Spring After Fluorescein Tracer. From the 5 opportunities of field trip to Boiling Spring 80 % of samples were recovered, only one sample was not recovered on August 7, 2023, because of external and unknown factors. Therefore, for the next time a form of sticker was leaved to get notice sample is important for ongoing study. On August 15, 2023, a peak of fluorescein intensity was observed as the first-time confirming dye arrival after 27 days of dye injection as seen in Figure 4.4 and the following week also prevalence as seen in Figure 4.5. In contrast in Figure 4.2 there is a false peak because the charcoal packet collected was altered as it was found dried in a different location outside the spring and in Figure 4.3 not peak observed.

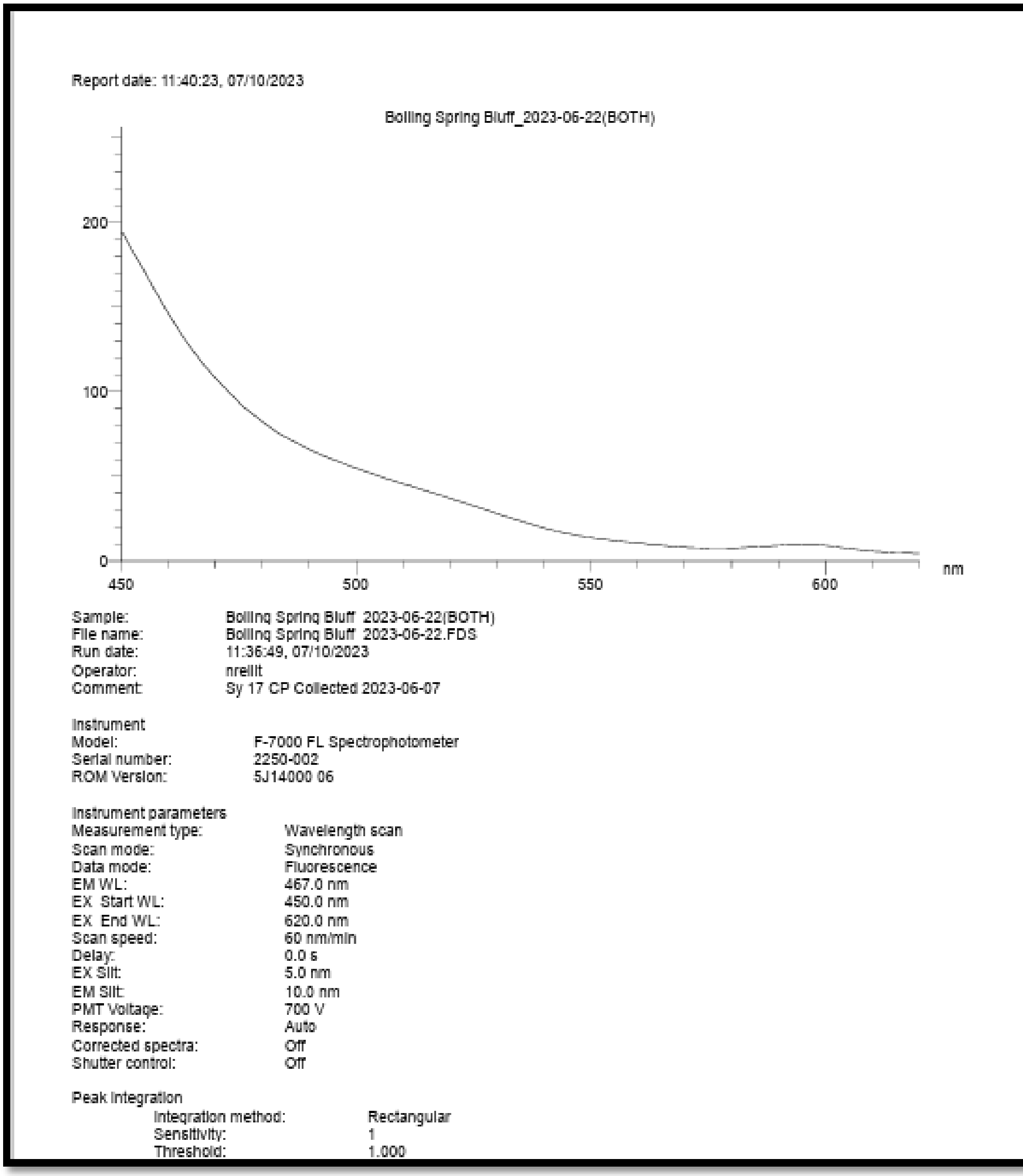

Figure 4.1 Sample Test Spectrum of Boiling Spring Before Dye Injection 6/22/23.

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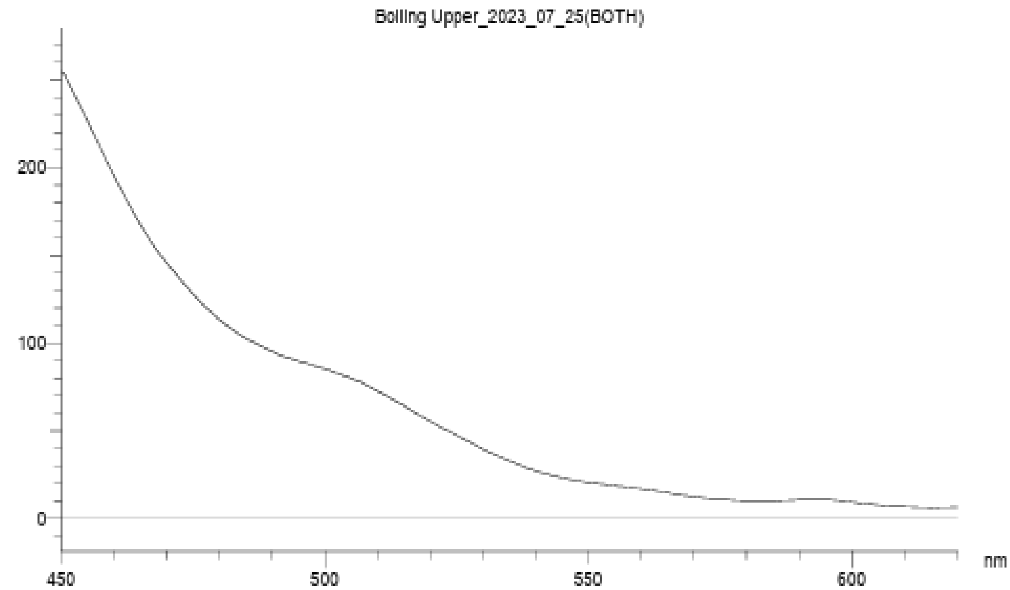


Sample: Boiling Upper 2023 07 25(BOTH)
File name: Boiling Spring Bluff 2023-07-25.FDS
Run date: 10:32:25, 07/28/2023
Operator: nreillt
Comment:

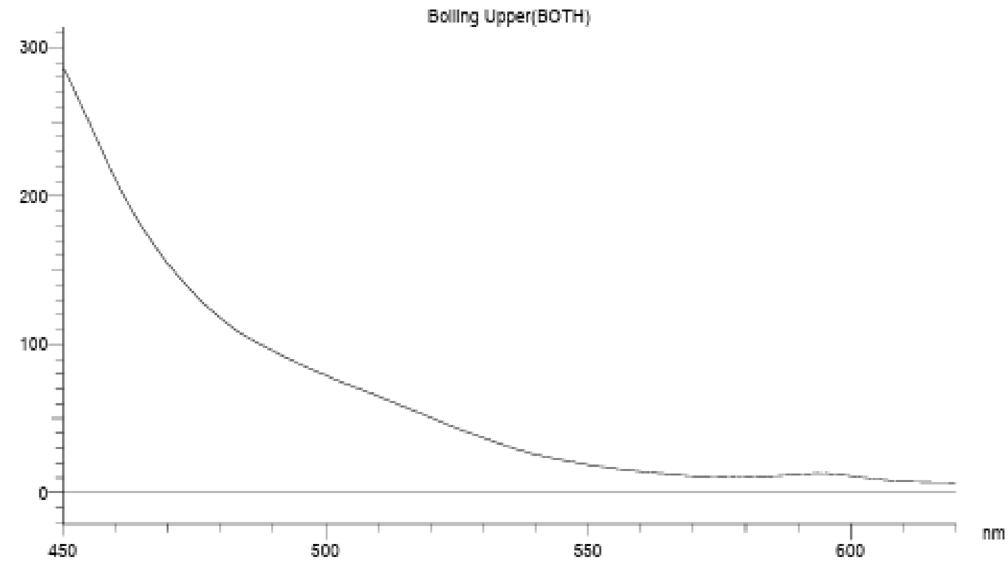
Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Peak integration
Integration method: Rectangular
Sensitivity: 1
Threshold: 1.000

Figure 4.2 Sample Test Spectrum of Boiling Spring 6 Days After Dye Injection 7/25/23.

Report date: 12:22:17, 08/03/2023



Sample:	Boiling Upper(BOTH)
File name:	Boiling Spring Bluff 2023-08-02.FDS
Run date:	12:17:32, 08/03/2023
Operator:	nrcoril
Comment:	Boiling Upper

Instrument

Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Peak Integration

Integration method:	Rectangular
Sensitivity:	1
Threshold:	1.000

Figure 4.3 Sample Test Spectrum of Boiling Spring 14 Days After Dye Injection 8/2/23.

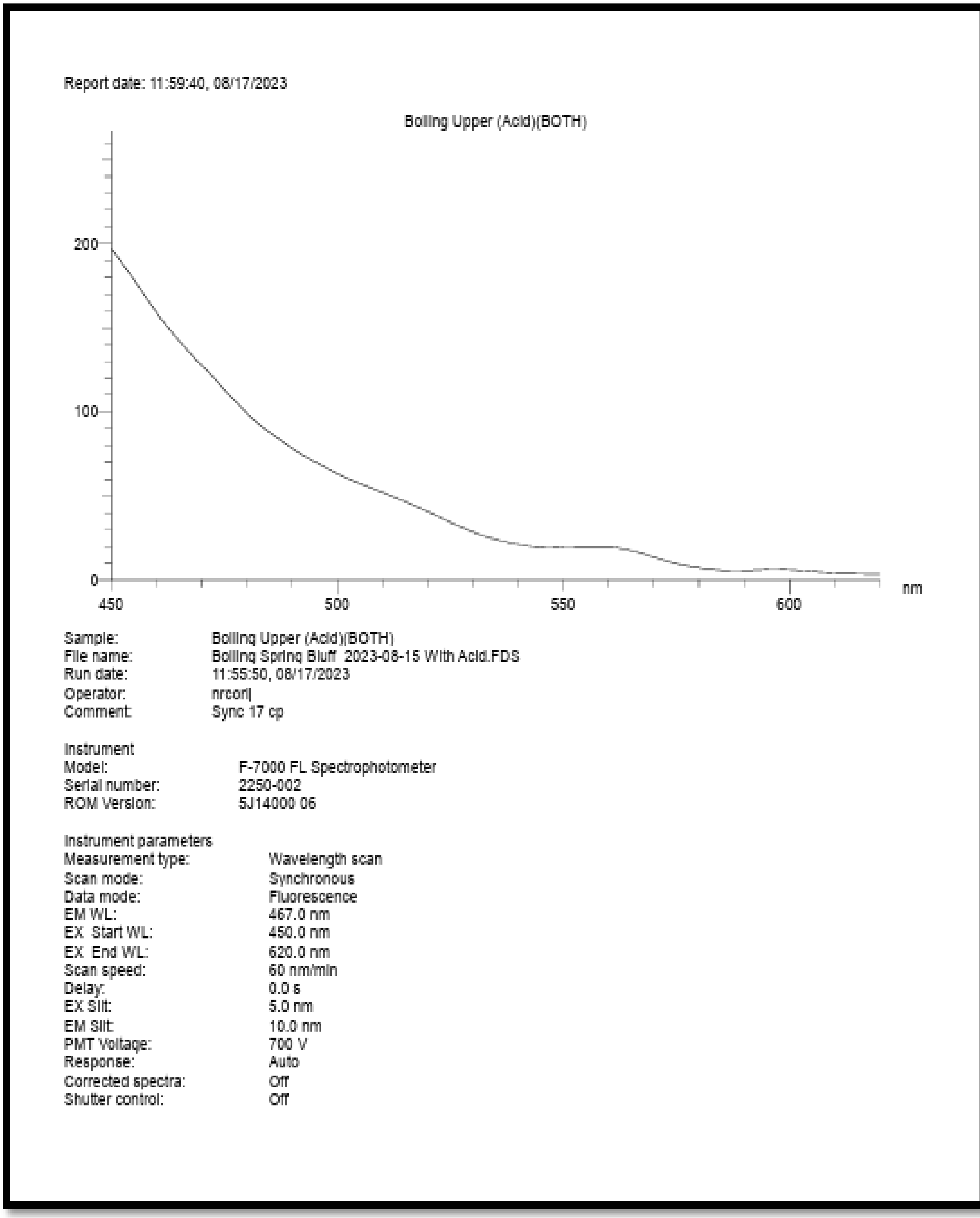


Figure 4.4 Sample Test Spectrum of Boiling Spring 26 Days After Dye Injection 8/15/23.

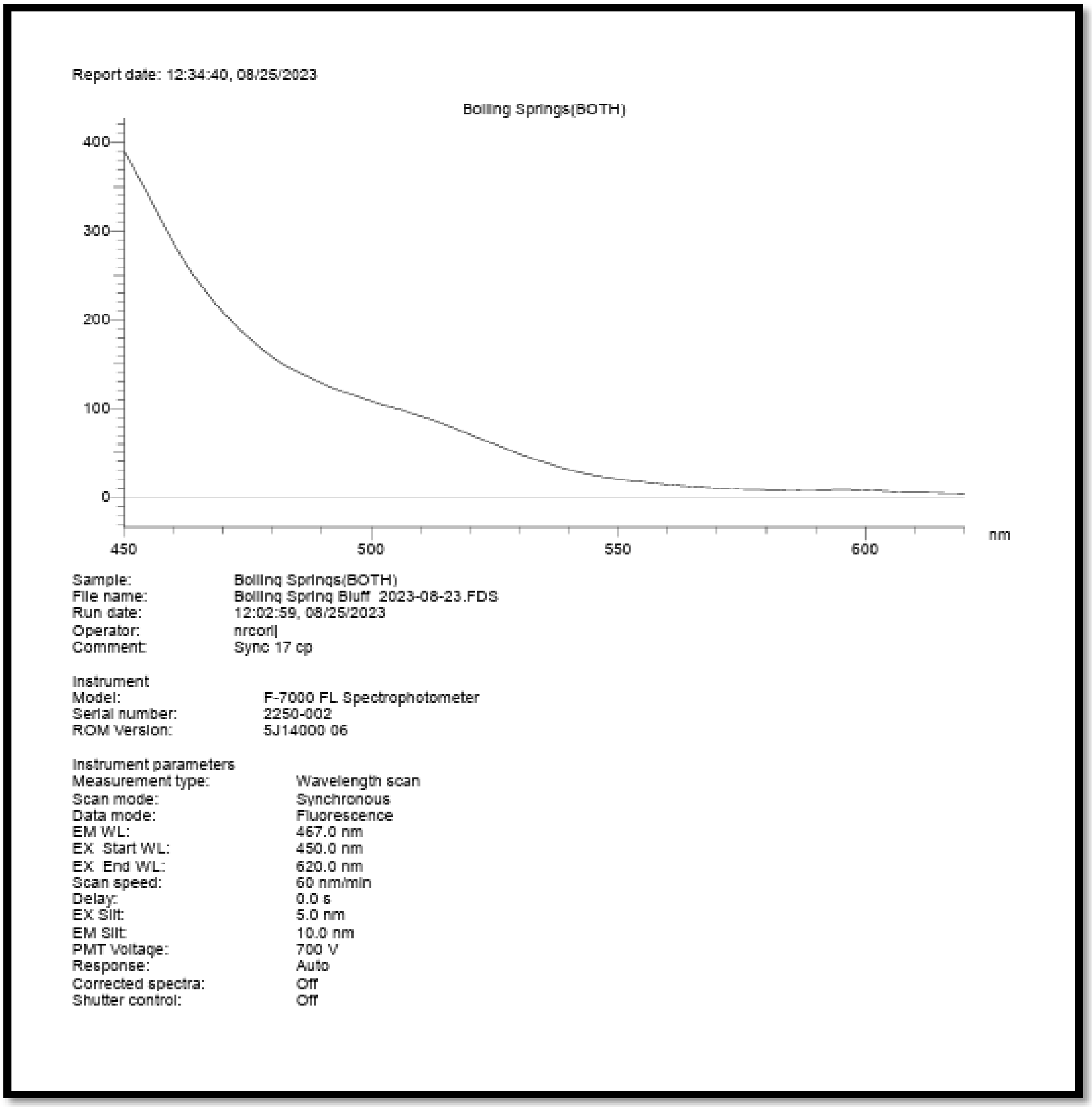


Figure 4.5 Sample Test Spectrum of Boiling Spring 35 Days After Dye Injection 8/23/23.

4.1.3. Background of Onyx Spring Before Fluorescein Tracer. From Spectrometer 7000 F 1 profile was created accordingly before date of dye injection. In figure 4.6 as it is seen there is no fluorescein peak between range 514.4 nm to 519.6 nm, then water is without that tracer. The sample that was collected for fluorescent tracer dye analysis was recovered in a charcoal packet on July 11, 2023, as seen in Figure 4.6.

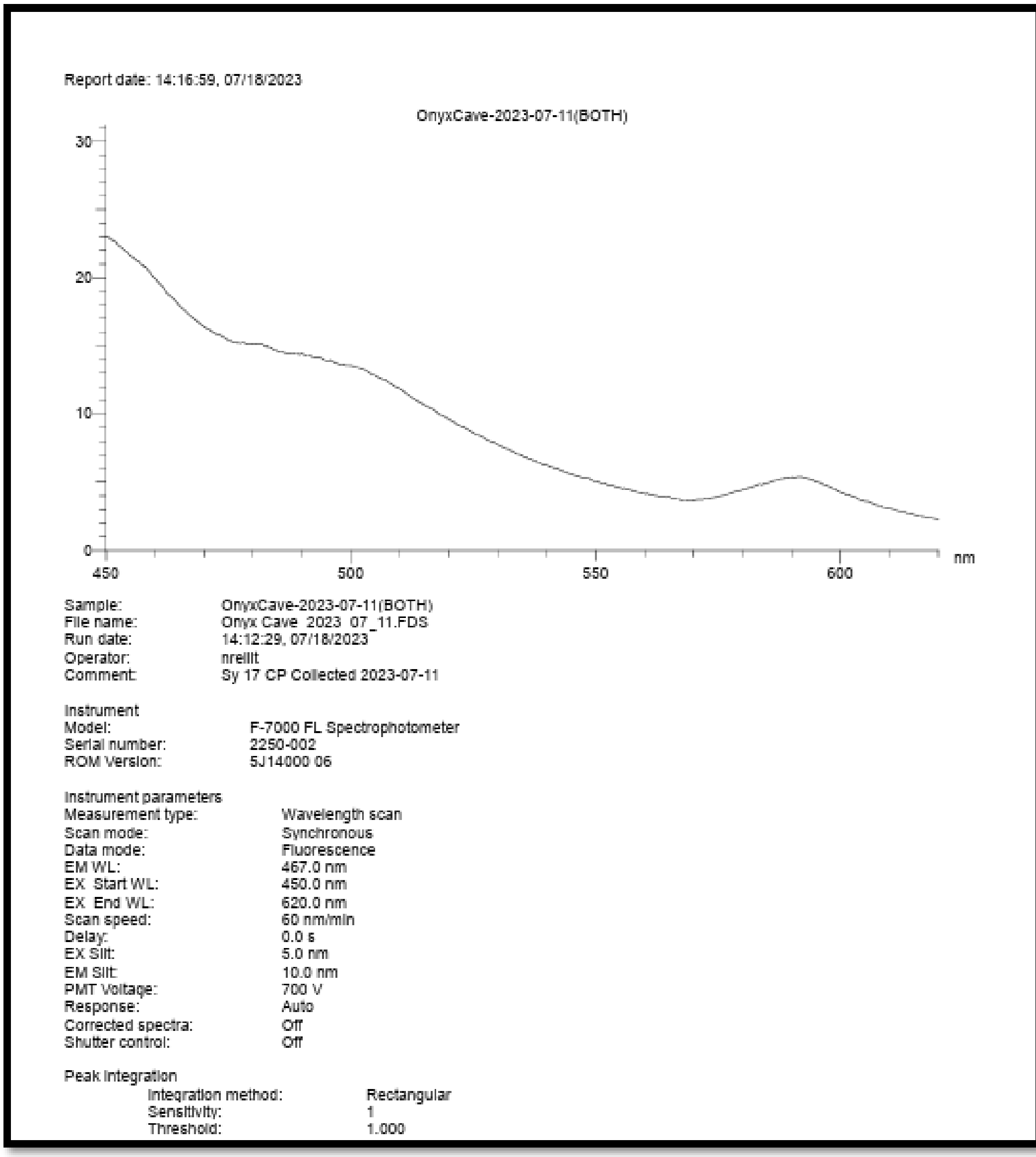


Figure 4.6 Sample Test Spectrum of Onyx Spring 11 Days Before Dye Injection 07/12/23.

4.1.4. Onyx Spring After Fluorescein Tracer. It was recovered at 100 % charcoal packets in the five opportunities of fieldtrip to Onyx Spring, but they were often dried because of the summer season, except on August 15, 2023. The result of this successful date did not show up dye under spectrometer analysis as seen in Figure 4.10.

On July 25, 2023, the sample was dried as seen in Figure 4.7, so no fluorescein intensity peak. On August 3, 2023, the sample was dried as seen in Figure 4.8, so no fluorescein intensity peak. On August 8, 2023, the sample also was dried as seen in Figure 4.9, so no fluorescein intensity peak. Finally, on August 23, 2023, the sample was also dried as seen in Figure 4.11.

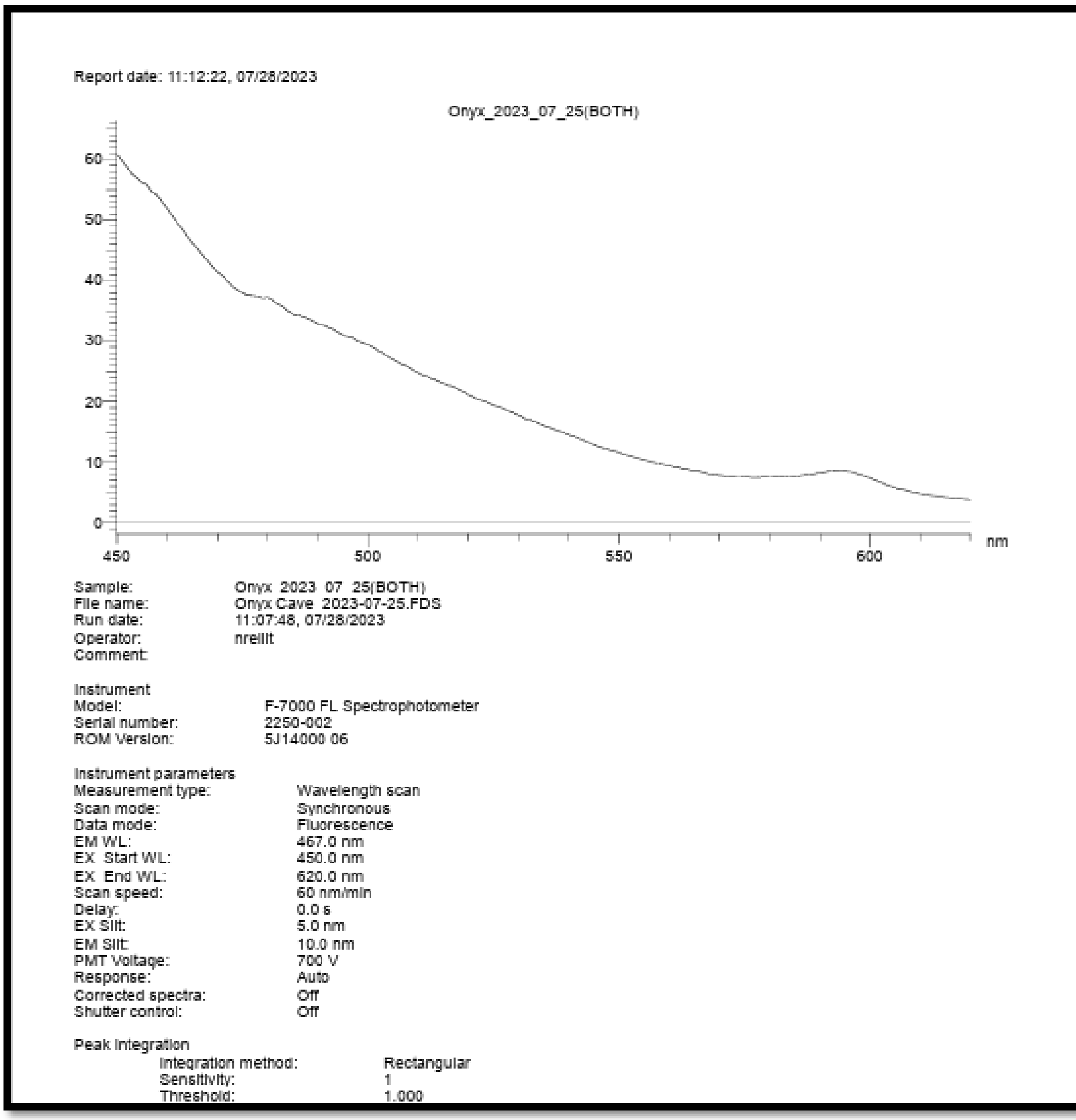
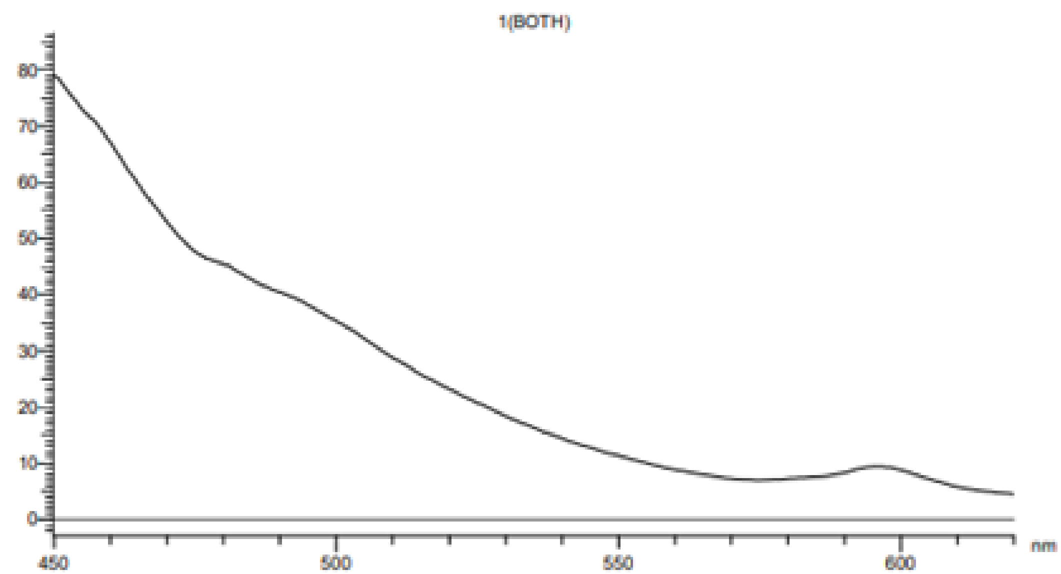


Figure 4.7 Sample Test Spectrum of Onyx Spring 6 Days After Dye Injection 07/25/23.

Report date: 12:15:06, 08/03/2023



Sample: 1(BOTH)
File name: Onyx Cave_2023-08-02.FDS
Run date: 12:10:20, 08/03/2023
Operator: nrcorlj
Comment:

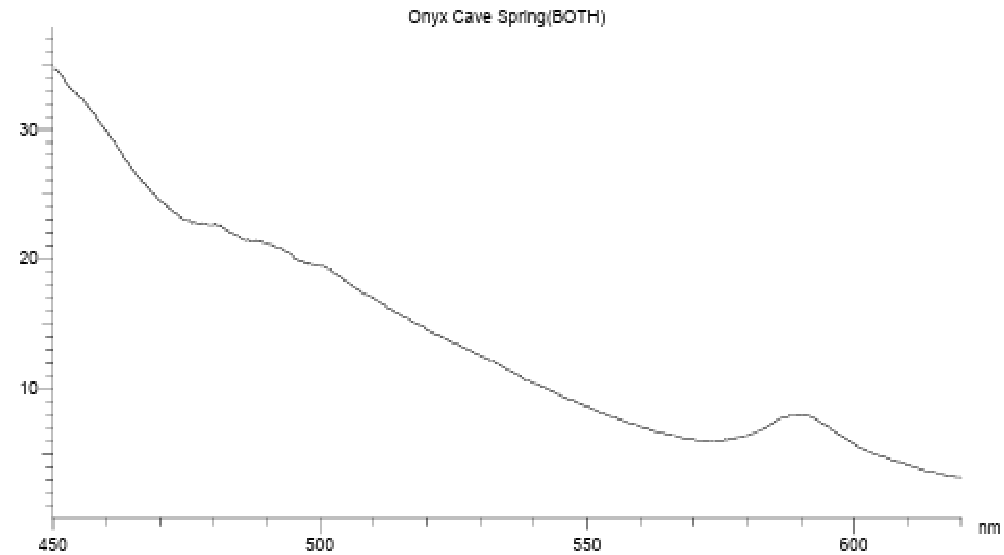
Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Peak integration
Integration method: Rectangular
Sensitivity: 1
Threshold: 1.000

Figure 4.8 Sample Test Spectrum of Onyx Spring 14 Days After Dye Injection 08/2/23.

Report date: 14:49:38, 08/09/2023



Sample:	Onyx Cave Spring(BOTH)
File name:	Onyx Cave 2023-08-7.FDS
Run date:	14:45:19, 08/09/2023
Operator:	nrcorl
Comment:	SY17CP

Instrument

Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

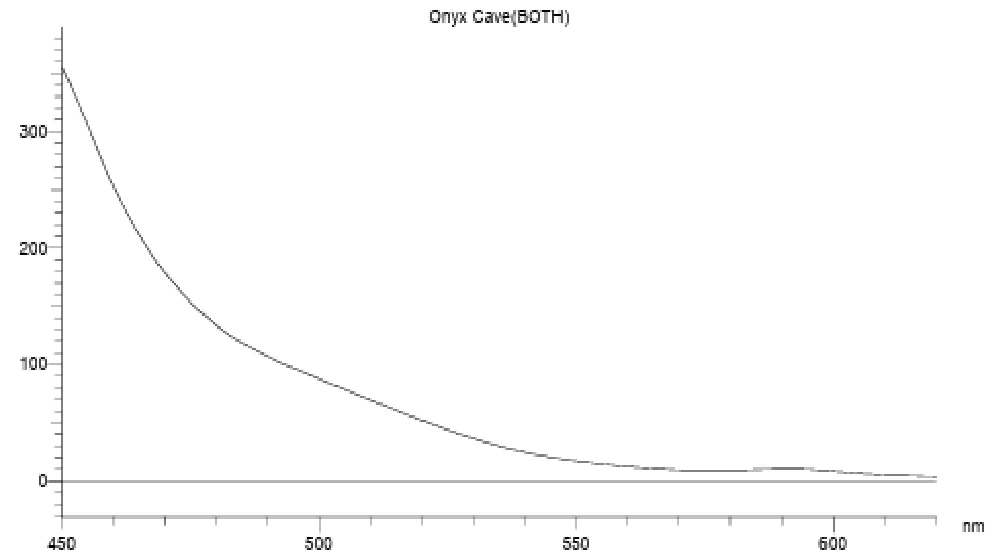
Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Peak integration

Integration method:	Rectangular
Sensitivity:	1
Threshold:	1.000

Figure 4.9 Sample Test Spectrum of Onyx Spring 19 Days After Dye Injection 08/7/23.

Report date: 11:32:38, 08/17/2023



Sample: Onyx Cave(BOTH)
File name: Onyx Cave 2023-08-15.FDS
Run date: 11:28:56, 08/17/2023
Operator: nrcorl
Comment: Sync 17 cp

Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Peak integration
Integration method: Rectangular
Sensitivity: 1
Threshold: 1.000

Figure 4.10 Sample Test Spectrum of Onyx Spring 27 Days After Dye Injection 08/15/23.

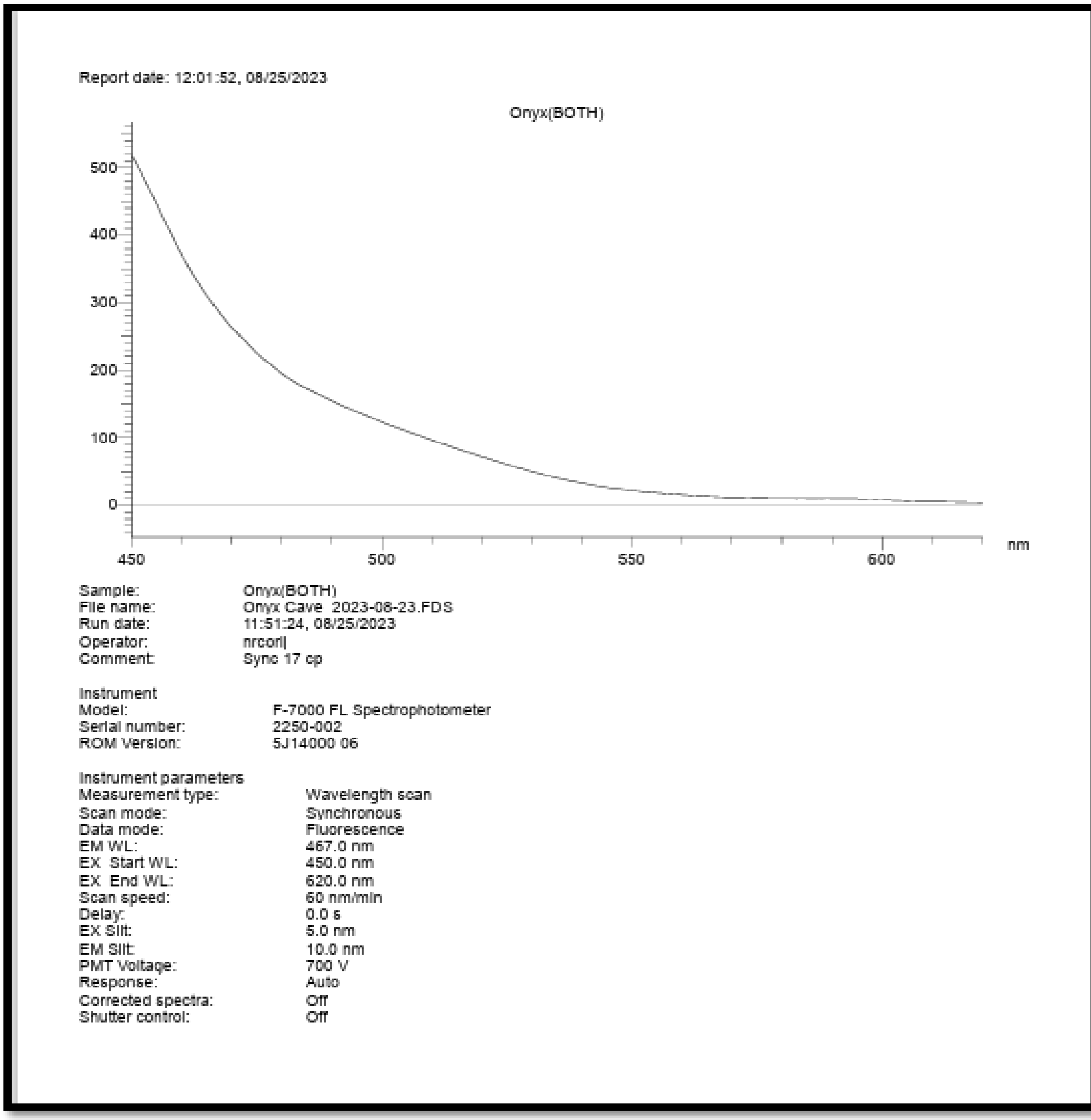


Figure 4.11 Sample Test Spectrum of Onyx Spring 35 Days After Dye Injection 8/23/23.

4.1.5. Background of Yelton Spring Before Fluorescein Tracer. From Spectrometer 7000 F 1 profile was created accordingly before date of dye injection. In figure 4.12 as it is seen there is no fluorescein peak between range 514.4 nm to 519.6 nm, then water is without that tracer. The sample that was collected for fluorescent tracer dye analysis was recovered in a charcoal packet on July 11, 202, as seen in Figure 4.12.

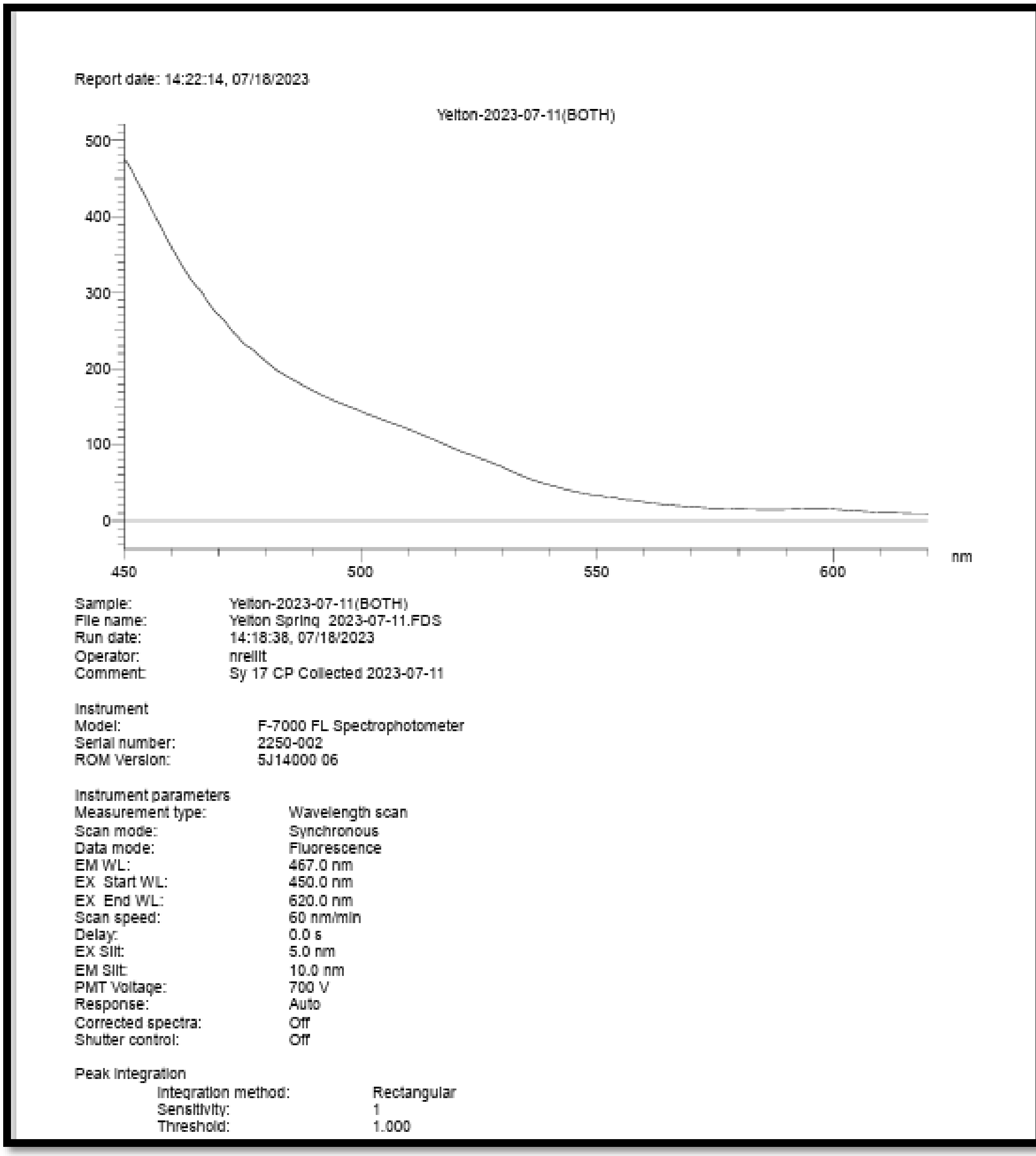


Figure 4.12 Sample Test Spectrum of Yelton Spring 8 Days Before Dye Injection 07/11/23.

4.1.6. Yelton Spring After Fluorescein Tracer. From the 5 opportunities of field trip to Yelton Spring it was recovered 100 % of samples. Following weekly analysis on August 3, 2023, a peak of fluorescein intensity was observed as first-time confirming dye arrival after 14 days of dye injection as seen in Figure 4.14 and it prevalences on August 8, 2023, August 15, 2023, and August 23, 2023, as seen in Figure 4.15, 4.16, 4.17 respectively. In contrast on July 25, 2023, the fluorescein intensity is not appreciated as seen in Figure 4.13.

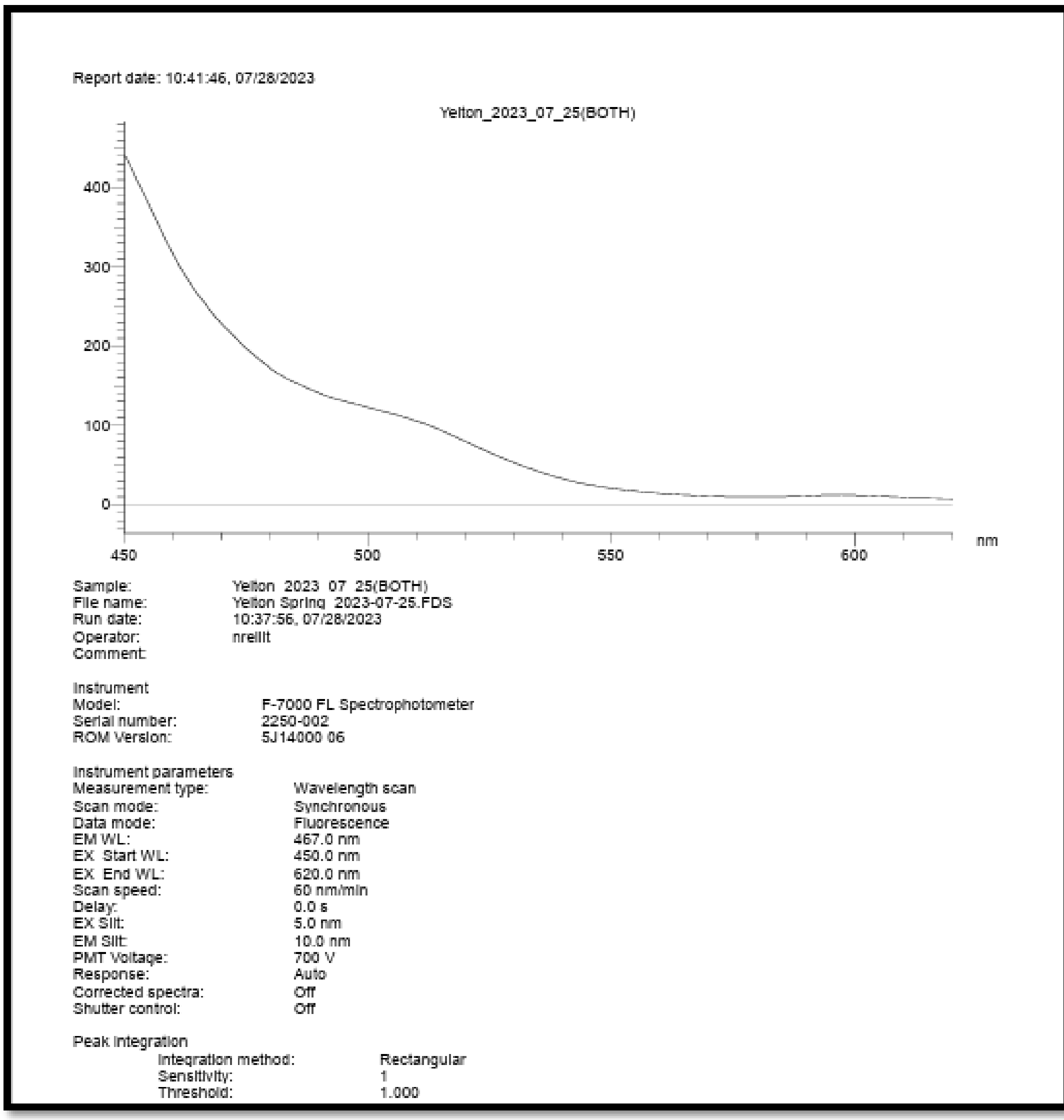
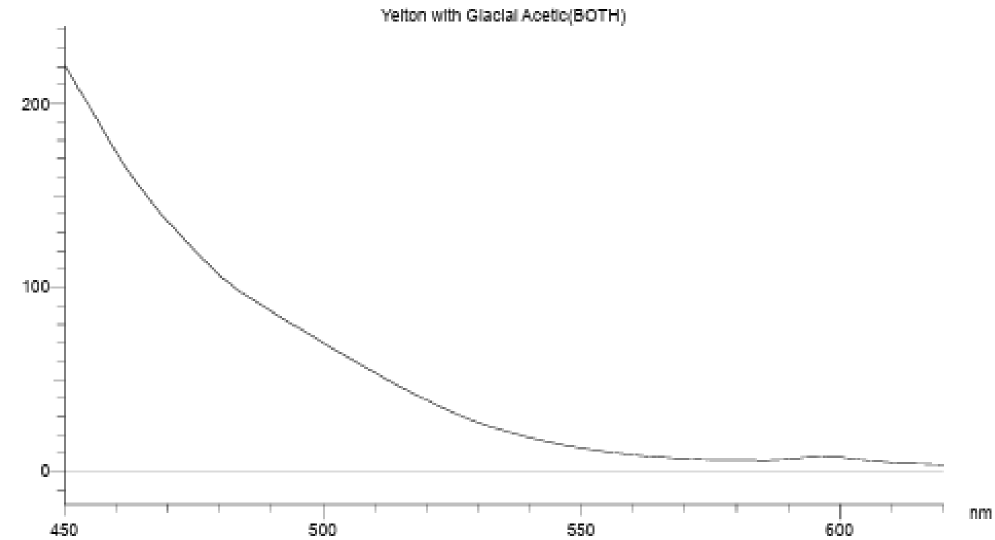


Figure 4.13 Sample Test Spectrum of Yelton Spring 6 Days After Dye Injection 7/25/23.

Report date: 12:53:16, 08/03/2023



Sample:	Yelton with Glacial Acetic(BOTH)
File name:	Yelton Spring 2023-08-02 with Glacial Acetic.FDS
Run date:	12:49:28, 08/03/2023
Operator:	nrcorlj
Comment:	

Instrument

Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

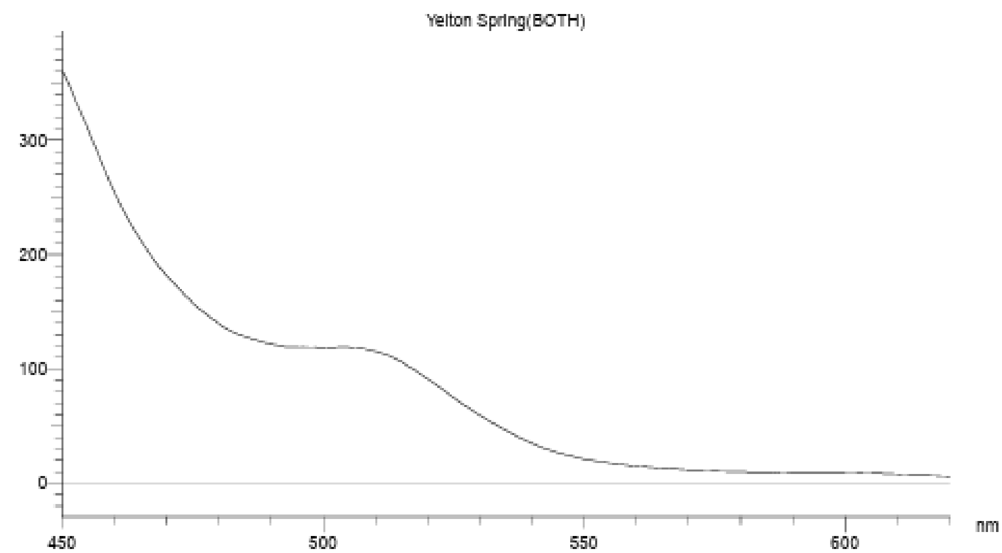
Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Peak integration

Integration method:	Rectangular
Sensitivity:	1
Threshold:	1.000

Figure 4.14 Sample Test Spectrum of Yelton Spring 14 Days After Dye Injection 8/2/23.

Report date: 14:55:09, 08/09/2023



Sample:	Yelton Spring(BOTH)
File name:	Yelton Spring 2023-08-07.FDS
Run date:	14:50:35, 08/09/2023
Operator:	nrcorij
Comment:	SY17CP

Instrument

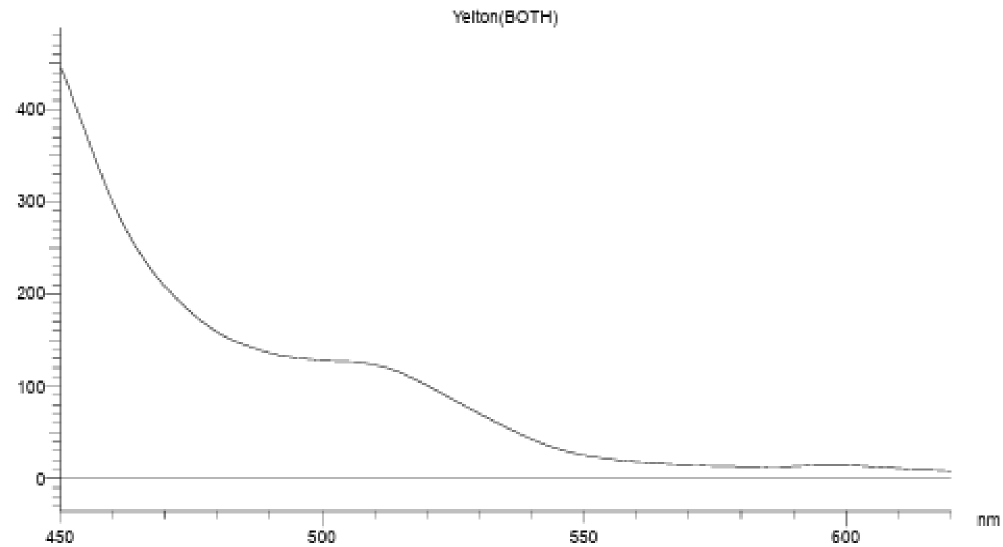
Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Figure 4.15 Sample Test Spectrum of Yelton Spring 26 Days After Dye Injection 8/7/23.

Report date: 11:53:45, 08/17/2023



Sample:	Yelton(BOTH)
File name:	Yelton Spring 2023-08-15.FDS
Run date:	11:47:01, 08/17/2023
Operator:	nrcoril
Comment:	Sync 17 cp

Instrument

Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Peak Integration

Integration method:	Rectangular
Sensitivity:	1
Threshold:	1.000

Figure 4.16 Sample Test Spectrum of Yelton Spring 19 Days After Dye Injection 8/15/23.

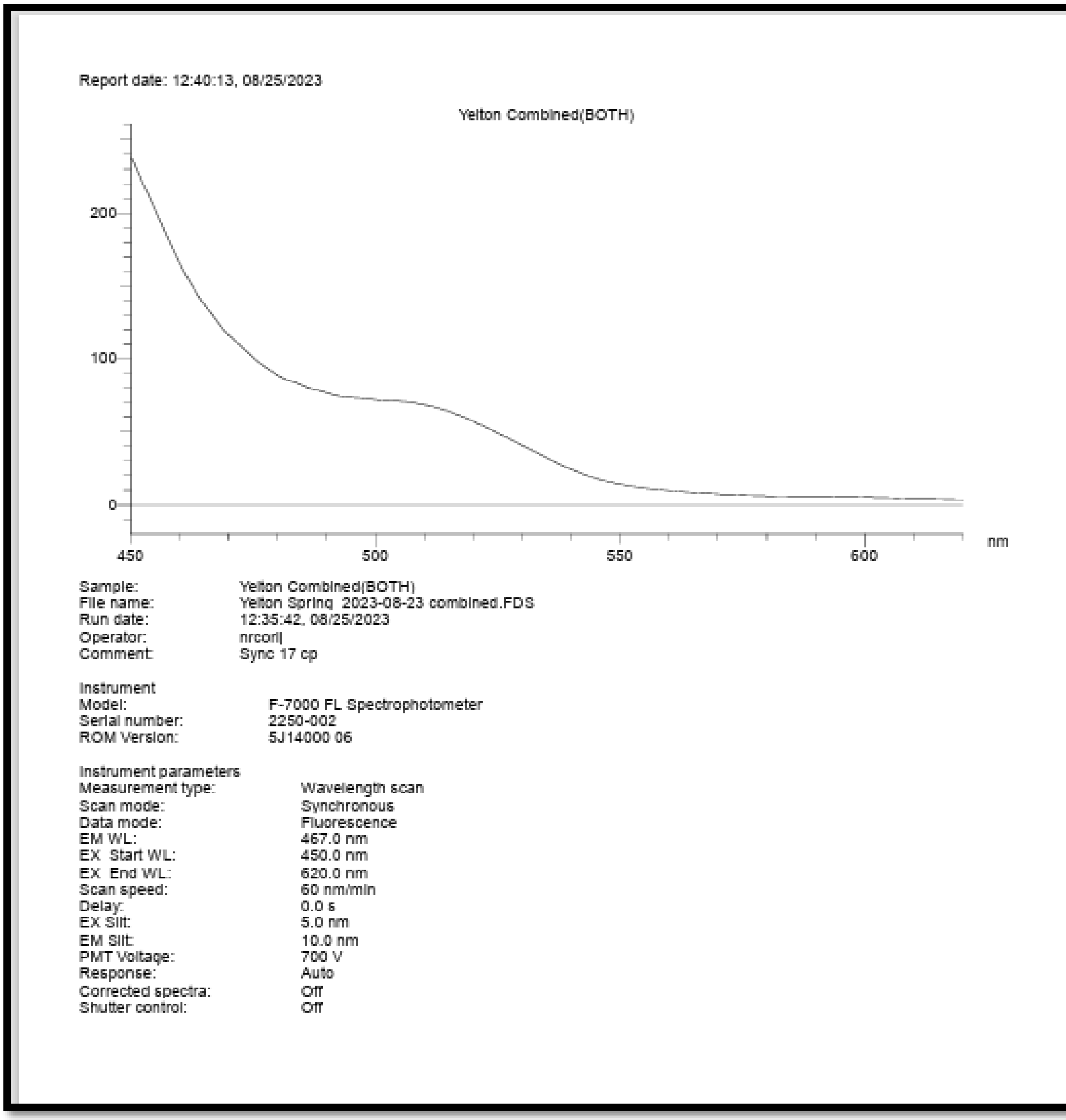


Figure 4.17 Sample Test Spectrum of Yelton Spring After 35 Days of Injection 8/23/23.

4.1.7. Background of Wilkins Spring Before Fluorescein Tracer. From Spectrometer 7000 F 1 profile was created accordingly before date of dye injection. In figure 4.18 as it is seen there is no fluorescein peak between range 514.4 nm to 519.6 nm, then water is without that tracer. The sample that was collected for fluorescent tracer dye analysis was recovered in a charcoal packet on July 11, 2023, as seen in Figure 4.18.

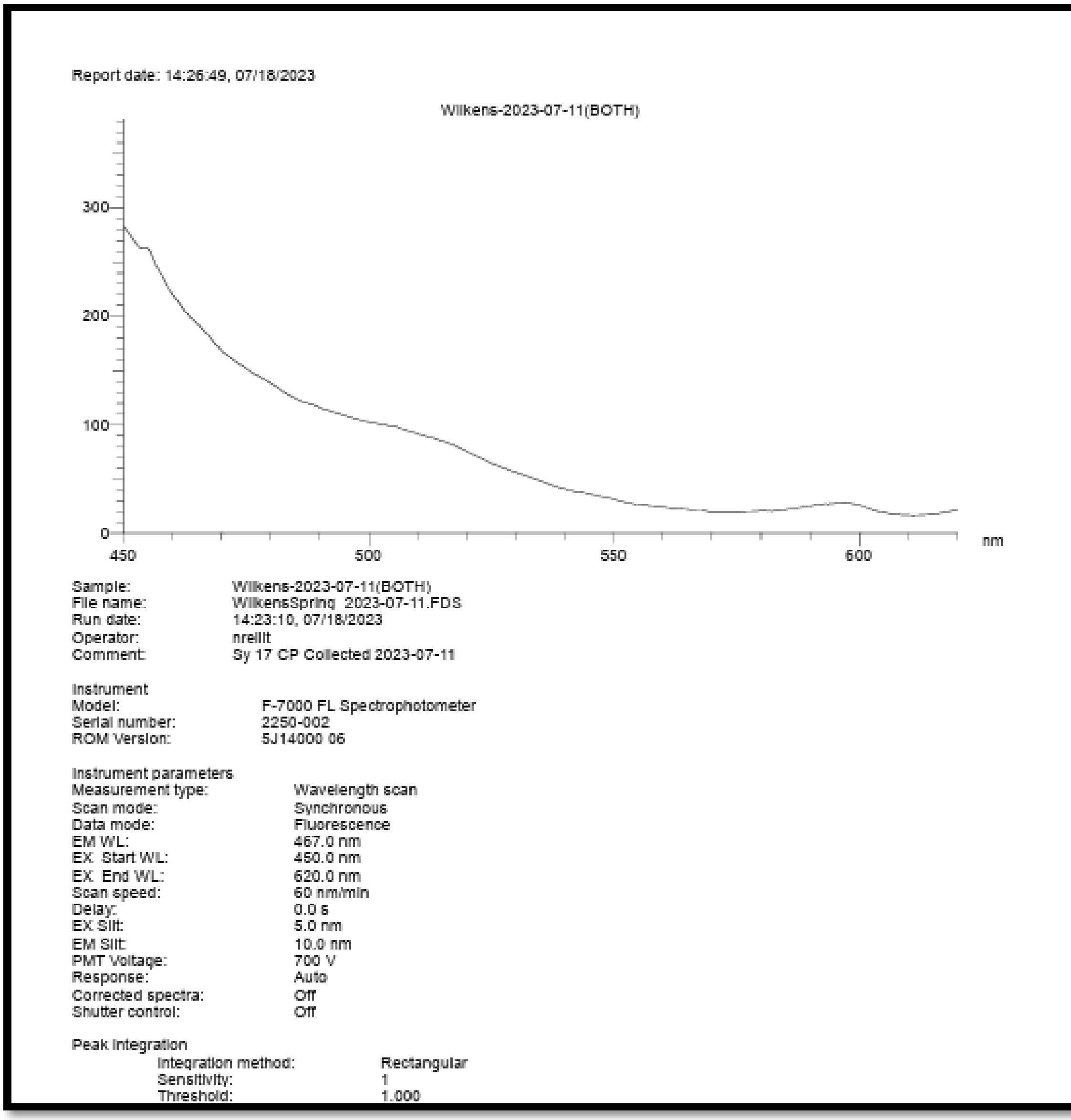


Figure 4.18 Sample Test Spectrum of Wilkins Spring 8 Days Before Dye Injection 07/11/23.

4.1.8. Wilkins Spring After Dye Injection. From the 5 opportunities of field trip to Wilkins Spring we recover 100 % of samples. Following weekly analysis on August 3,2023, a peak of fluorescein intensity was observed as first-time confirming dye arrival after 14 days of dye injection as seen in Figure 4.20. It prevalences on August 23, 2023, as seen in Figure 4.23. However, on August 7, 2023, and August 15, 2023, there is not dye recovery as seen in Figure 4.21 and 4.22 respectively as further interpretations might suggest the dye did not touch the charcoal packet because of the low flow rate of the season. Finally, on July 25, 2023, a peak Fluorescein intensity was negative dye recovery as it was very early time as seen is Figure 4.19.

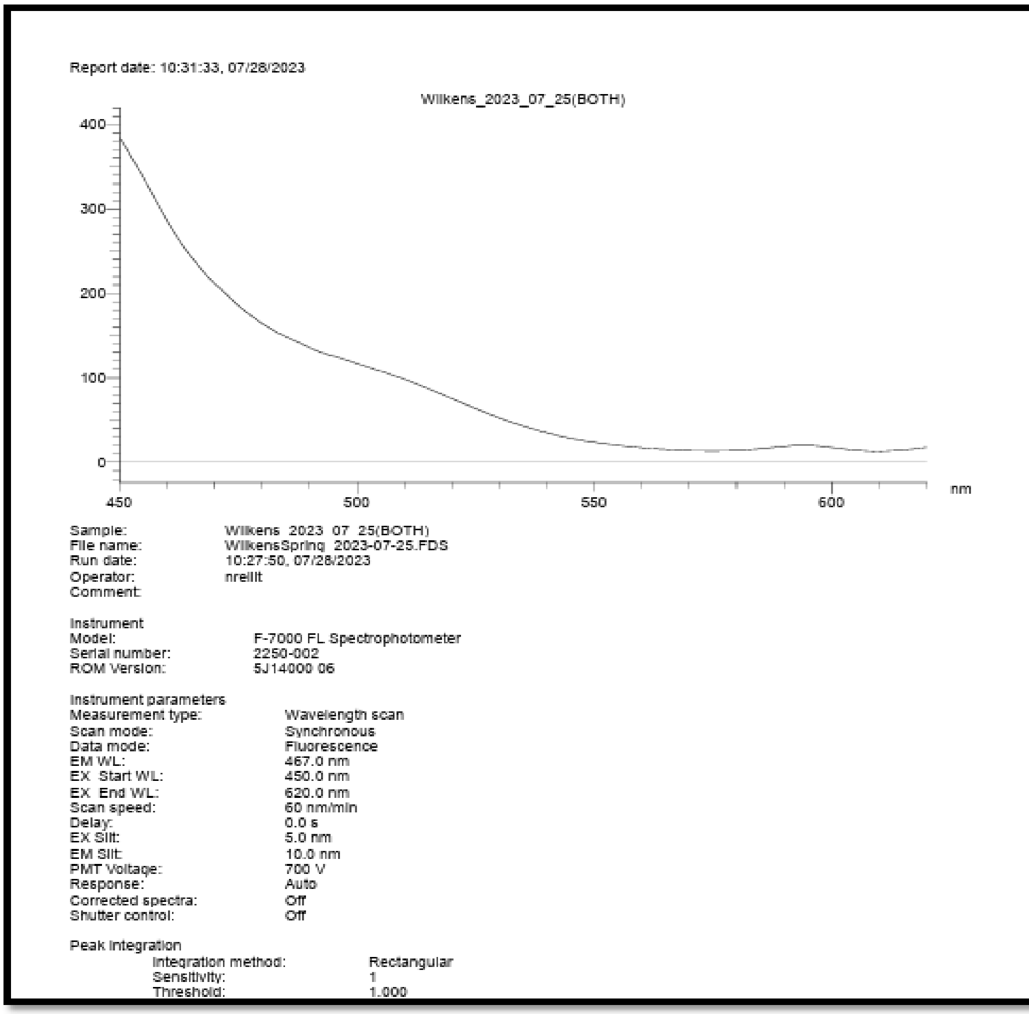
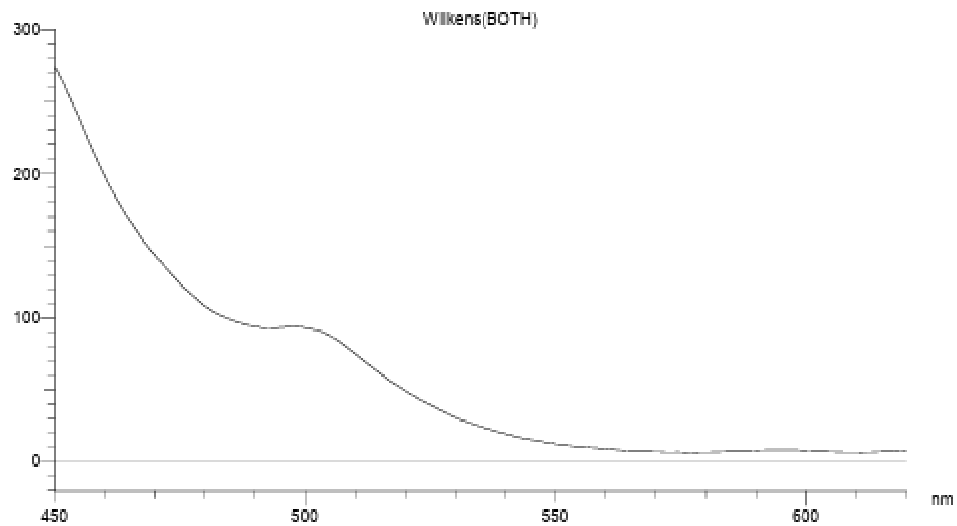


Figure 4.19 Sample Test Spectrum of Wilkins Spring 6 Days After Dye Injection 07/25/23.

Report date: 12:32:21, 08/03/2023



Sample: Wilkens(BOTH)
File name: WilkensSpring 2023-08-02.FDS
Run date: 12:28:30, 08/03/2023
Operator: nrcoril
Comment: Wilkens

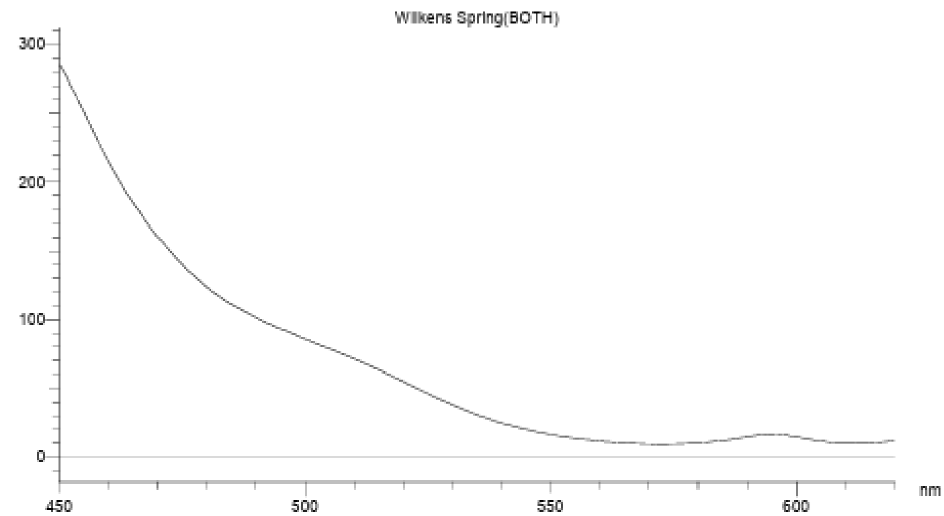
Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Peak integration
Integration method: Rectangular
Sensitivity: 1
Threshold: 1.000

Figure 4.20 Sample Test Spectrum of Wilkins Spring 14 Days After Dye Injection 08/3/23.

Report date: 15:00:47, 08/09/2023



Sample: Wilkens Spring(BOTH)
File name: WilkensSpring 2023-08-07.FDS
Run date: 14:56:32, 08/09/2023
Operator: nrcorl|
Comment: SY17CP

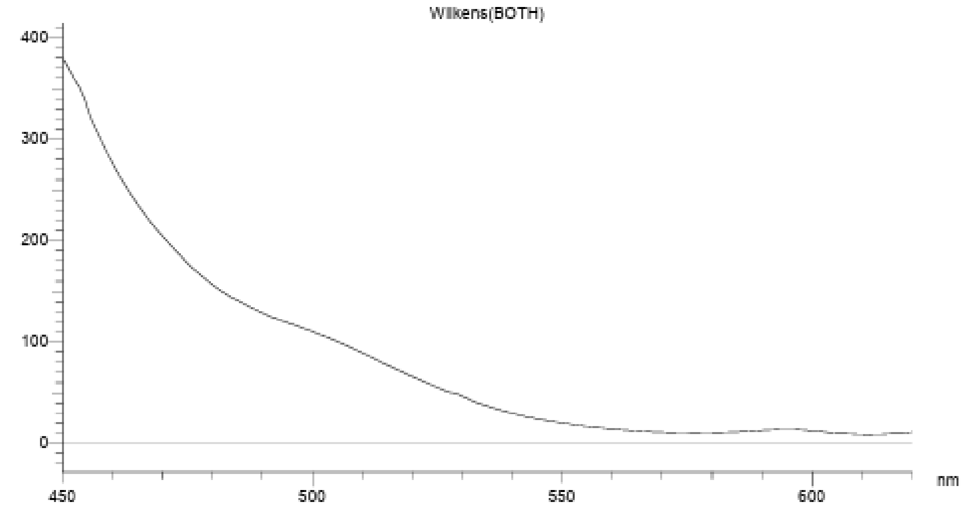
Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Peak integration
Integration method: Rectangular
Sensitivity: 1
Threshold: 1.000

Figure 4.21 Sample Test Spectrum of Wilkins Spring 19 Days After Dye Injection 08/7/23.

Report date: 12:05:05, 08/17/2023



Sample: Wilkens(BOTH)
File name: WilkensSpring_2023-08-15.FDS
Run date: 12:01:15, 08/17/2023
Operator: nrcoril
Comment: Sync 17 cp

Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Peak integration
Integration method: Rectangular
Sensitivity: 1
Threshold: 1.000

Figure 4.22 Sample Test Spectrum of Wilkins Spring 27 Days After Dye Injection 08/15/23.

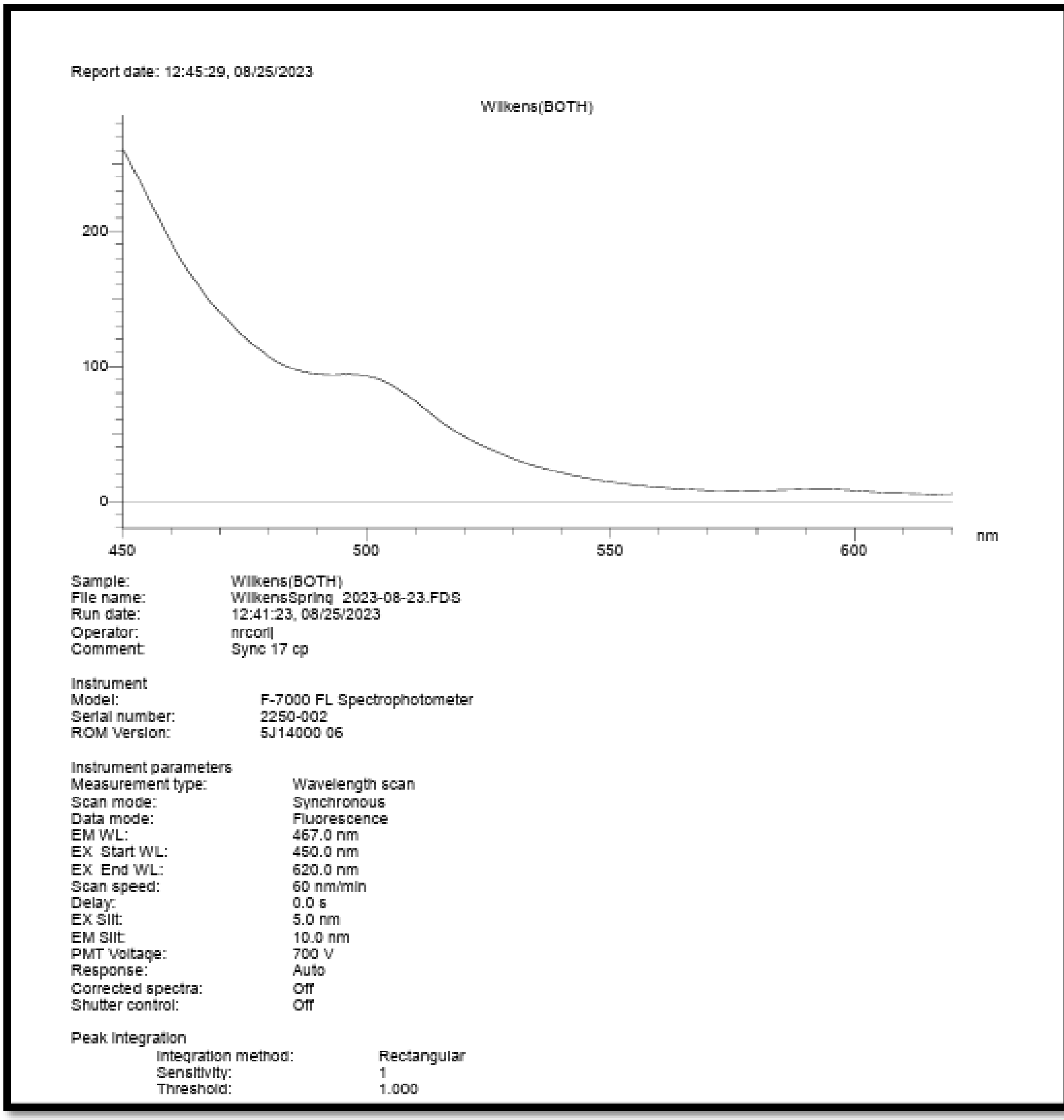


Figure 4.23 Sample Test Spectrum of Wilkins Spring 35 Days After Dye Injection 08/23/23.

4.1.9. Background of Hudgens Spring Before Fluorescein Tracer. From Spectrometer 7000 F 1 profile was created accordingly before date of dye injection. In Figure 4.24 as it is seen there is no fluorescein peak between range 514.4 nm to 519.6 nm, then water is without that tracer. The sample that was collected for fluorescent tracer dye analysis was recovered in a charcoal packet on July 11, 2023.

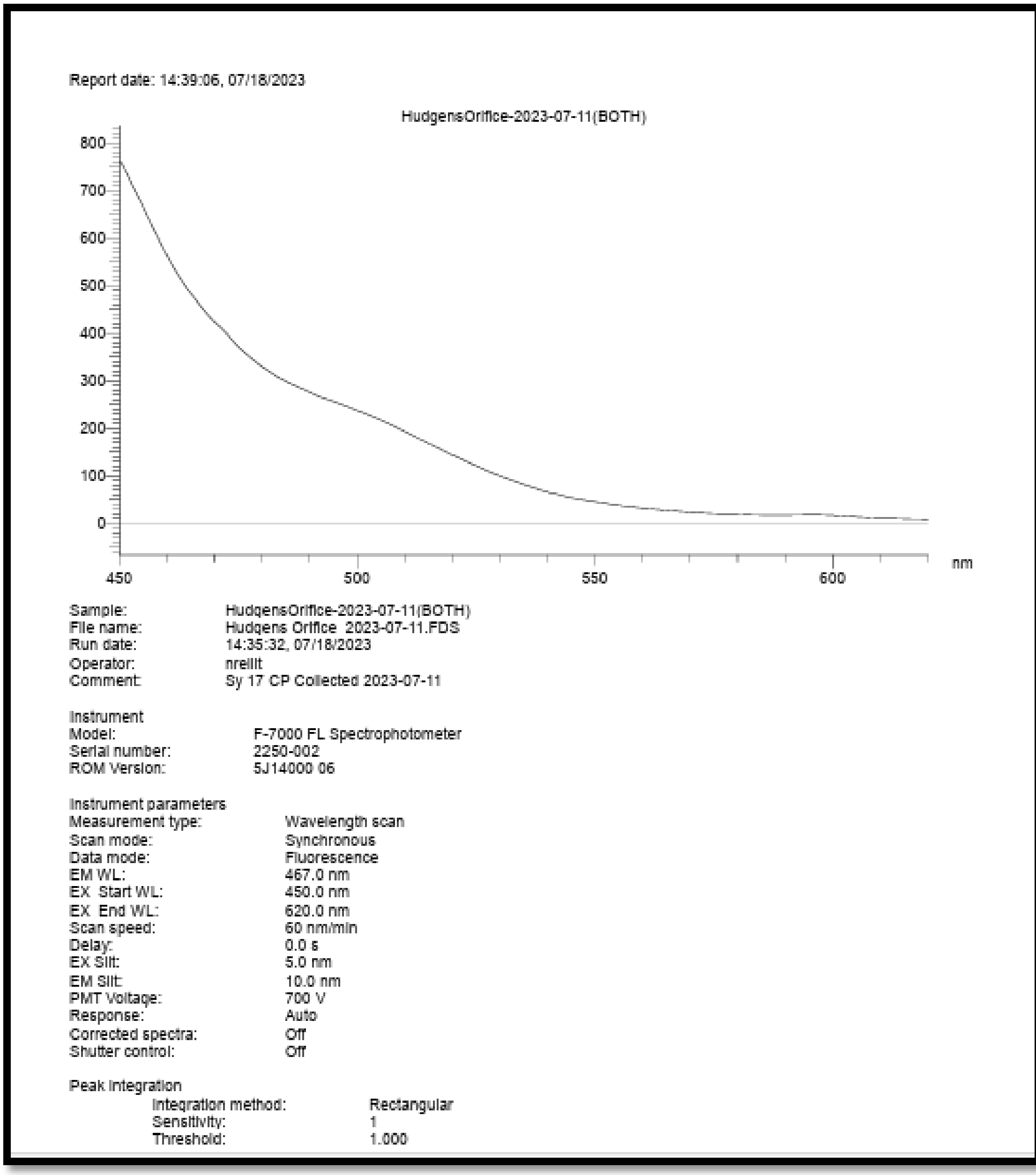


Figure 4.24 Sample Test Spectrum of Hudgens Spring 8 Days Before Dye Injection 07/11/23.

4.1.10. Hudgens Spring After Fluorescein Tracer. It was recovered at 100 % charcoal packets in the five opportunities of fieldtrip to Hudgens Spring. The result of dye analysis in all times did not show up dye under spectrometer analysis as seen in Figure 4.25, Figure 4.26, Figure 4.27, Figure 4.28, and Figure 4.29 respectively.

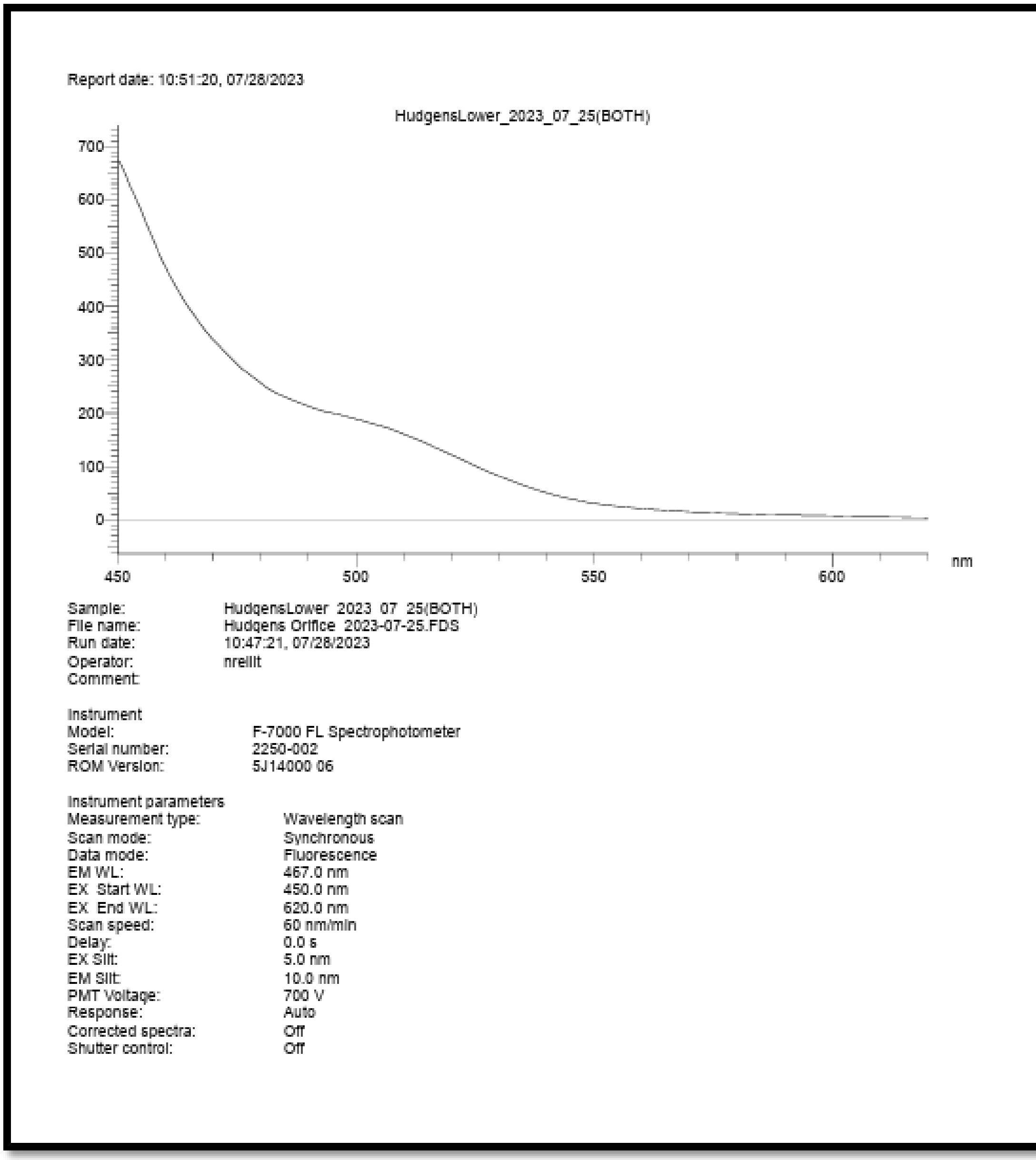
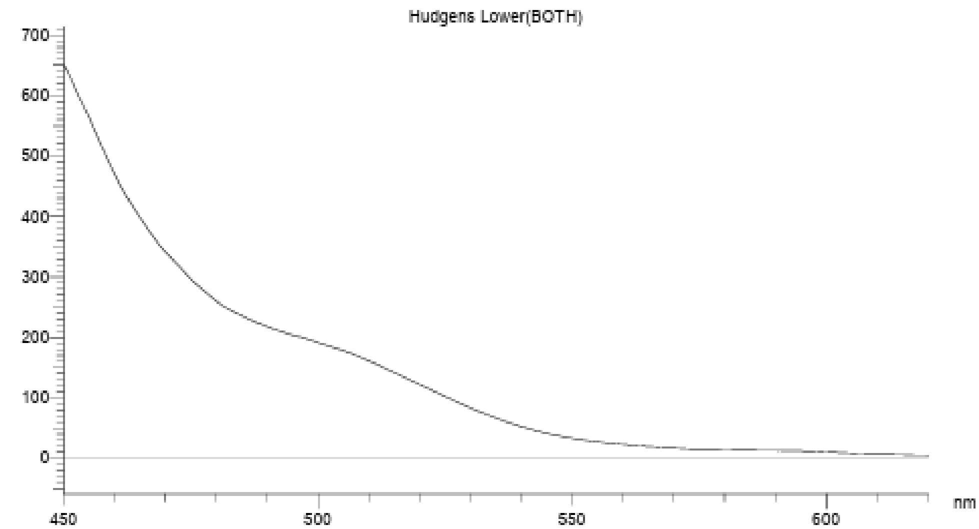


Figure 4.25 Sample Test Spectrum of Hudgens Spring 6 Days After Dye Injection 07/25/23.

Report date: 12:41:54, 08/03/2023



Sample: Hudgens Lower(BOTH)
File name: Hudgens Orifice 2023-08-02.FDS
Run date: 12:37:13, 08/03/2023
Operator: nrcorlj
Comment:

Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Figure 4.26 Sample Test Spectrum of Hudgens Spring 14 Days After Dye Injection 08/2/23.

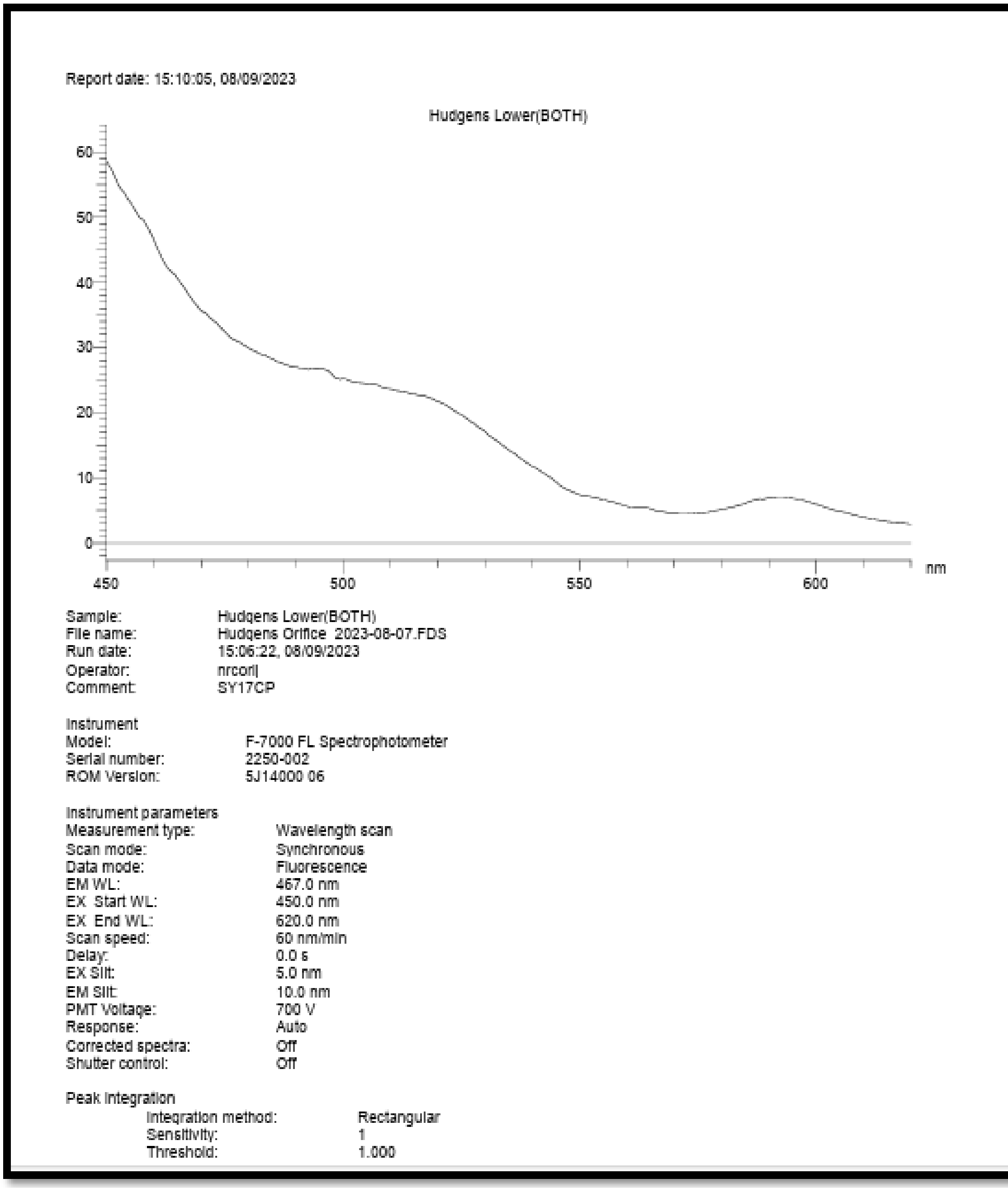
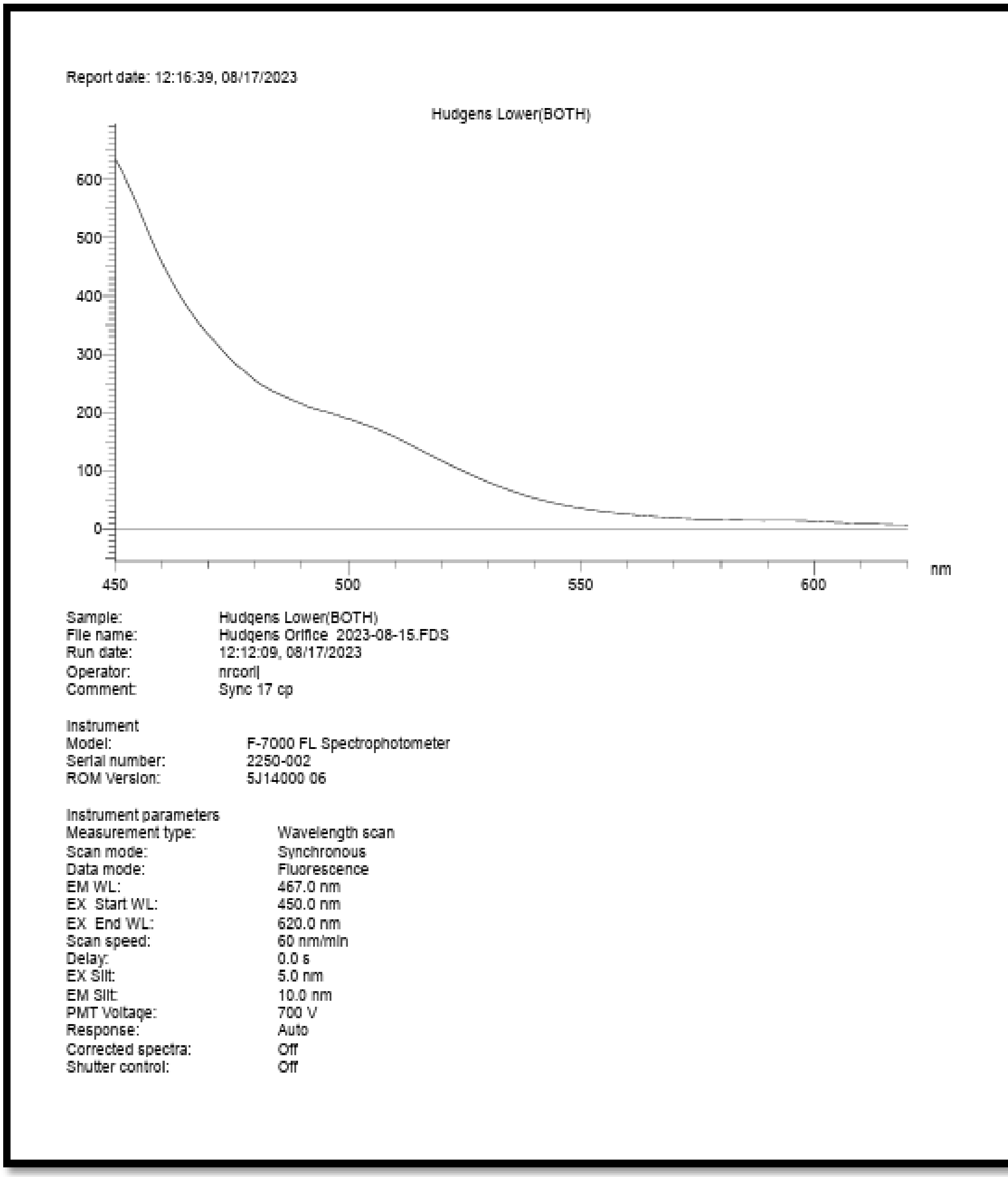


Figure 4.27 Sample Test Spectrum of Hudgens Spring 19 Days After Dye Injection 08/7/23.


Report date: 12:16:39, 08/17/2023

Sample:	Hudgens Lower(BOTH)
File name:	Hudgens Orifice 2023-08-15.FDS
Run date:	12:12:09, 08/17/2023
Operator:	nrcorl|
Comment:	Sync 17 cp

Instrument

Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Figure 4.28 Sample Test Spectrum of Hudgens Spring 27 Days After Dye Injection 08/15/23.

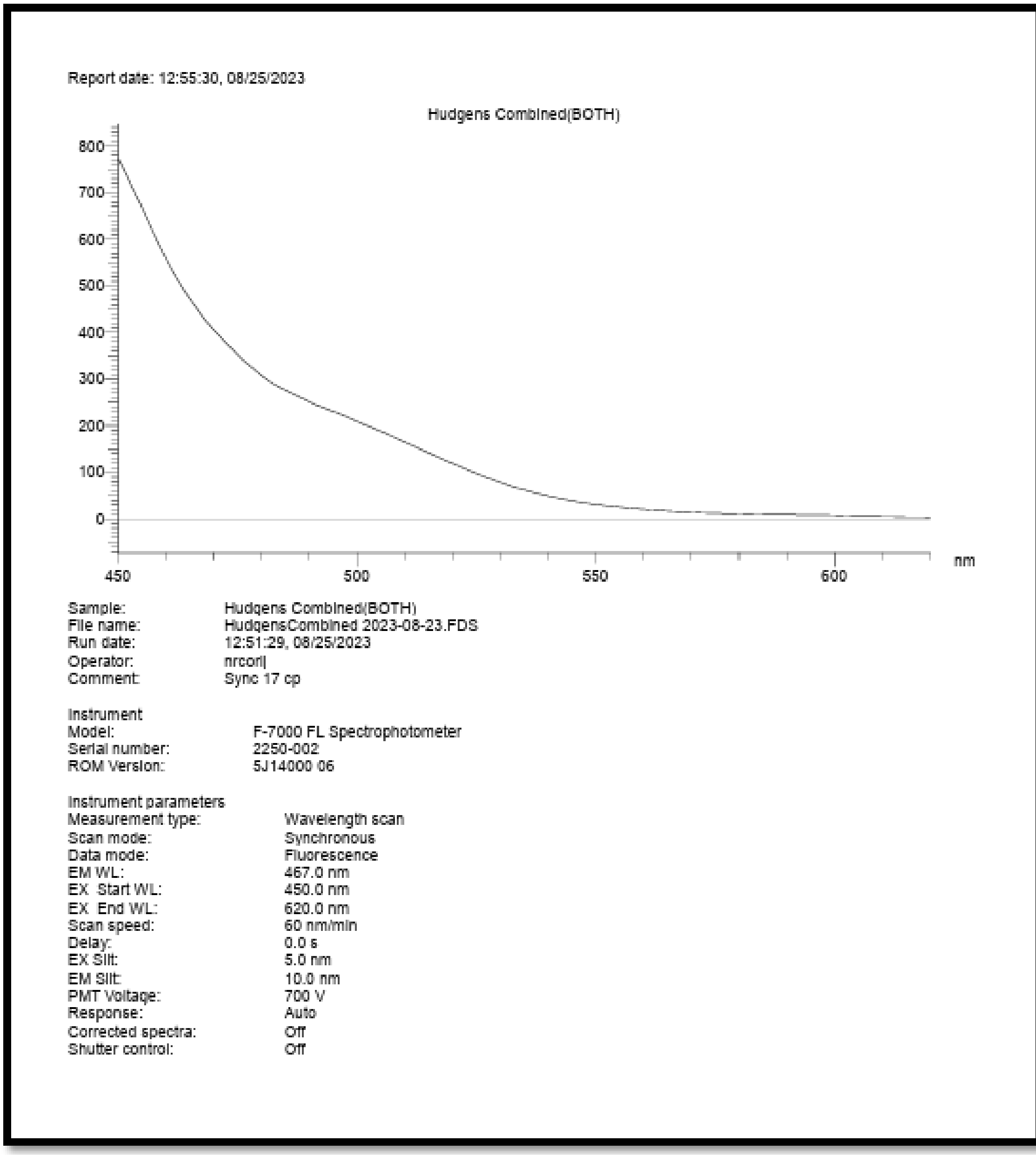


Figure 4.29 Sample Test Spectrum of Hudgens Spring 35 Days After Dye Injection 08/23/23.

4.1.11. Background of Natural Spring Before Fluorescein Tracer. From Spectrometer 7000 F 1 profile was created accordingly before date of dye injection. In

Figure 4.30 as it is seen there is no fluorescein peak between range 514.4 nm to 519.6 nm, then water is without that tracer.

The sample that was collected for fluorescent tracer dye analysis was recovered in a charcoal packet on July 11, 2023.

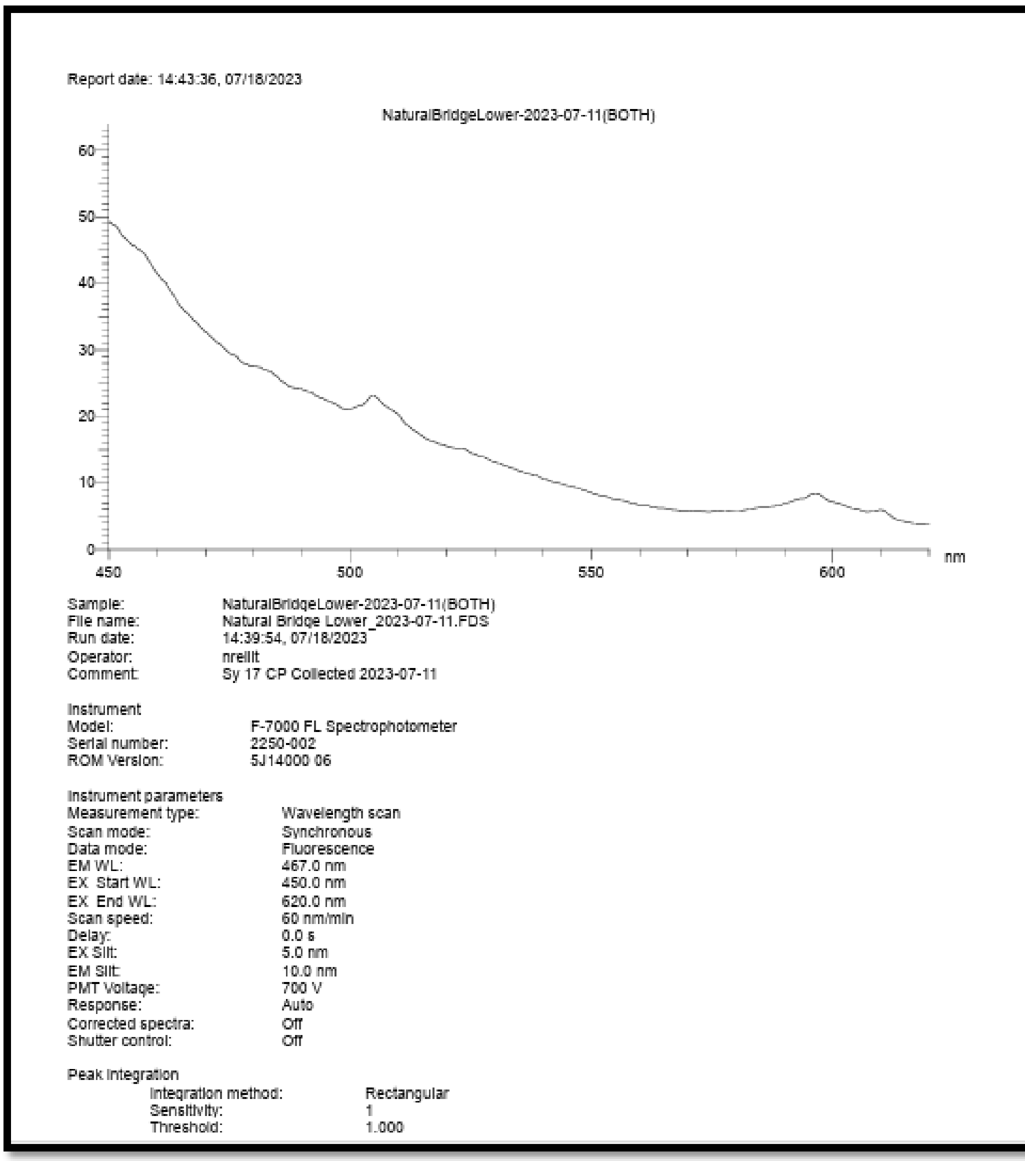


Figure 4.30 Sample Test Spectrum of Natural Spring 8 Days Before Dye Injection 07/11/23.

4.1.12. Natural Bridge Spring After Fluorescein Tracer. It was recovered at 100 % charcoal packets in the five opportunities of fieldtrip to Natural Bridge Spring. The result of dye analysis in all times did not show up dye under spectrometer analysis as seen in Figure 4.31, Figure 4.32, Figure 4.33, Figure 4.34, and Figure 4.35 respectively.

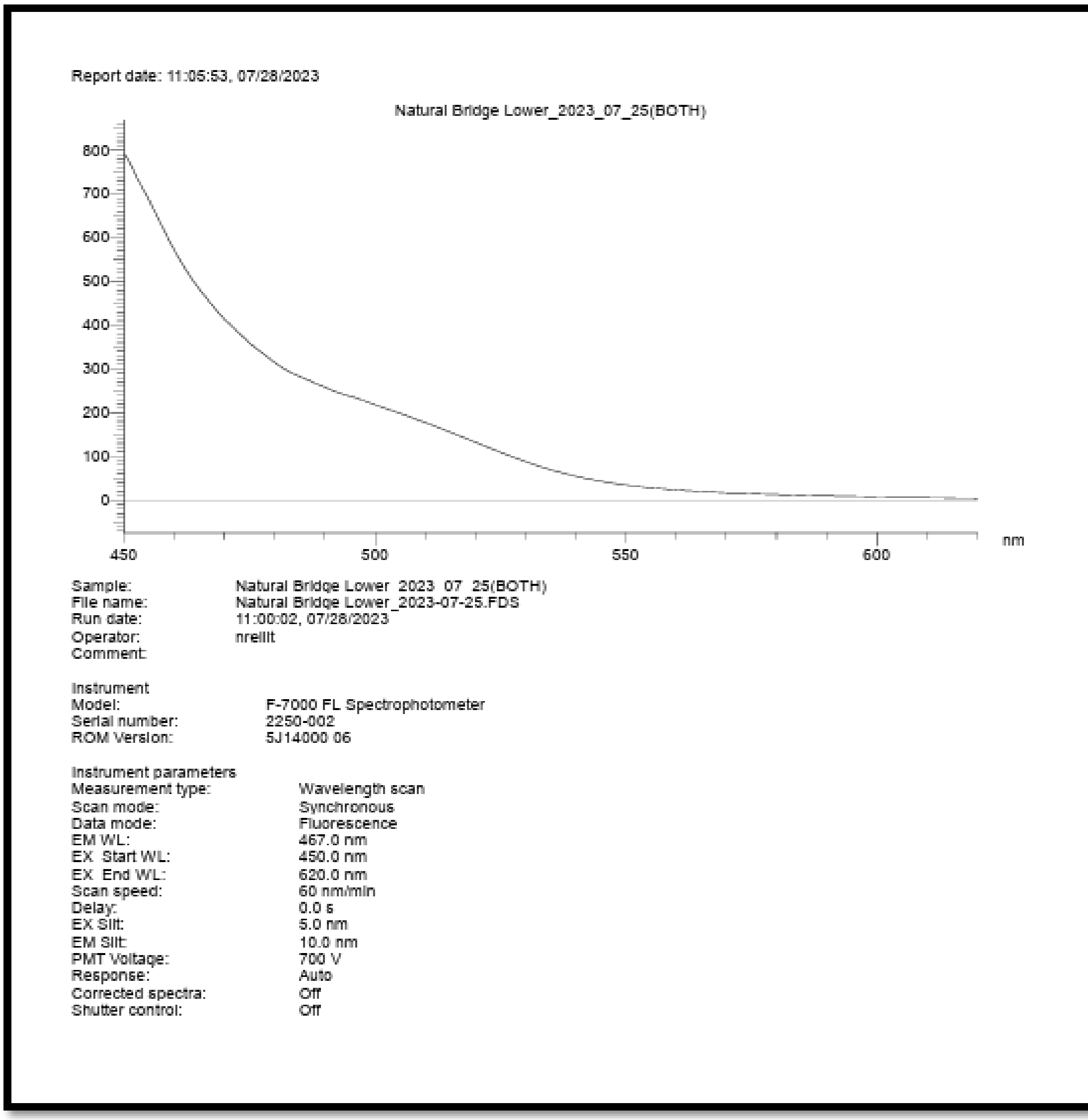


Figure 4.31 Sample Test Spectrum of Natural Spring 6 Days After Dye Injection 07/25/23.

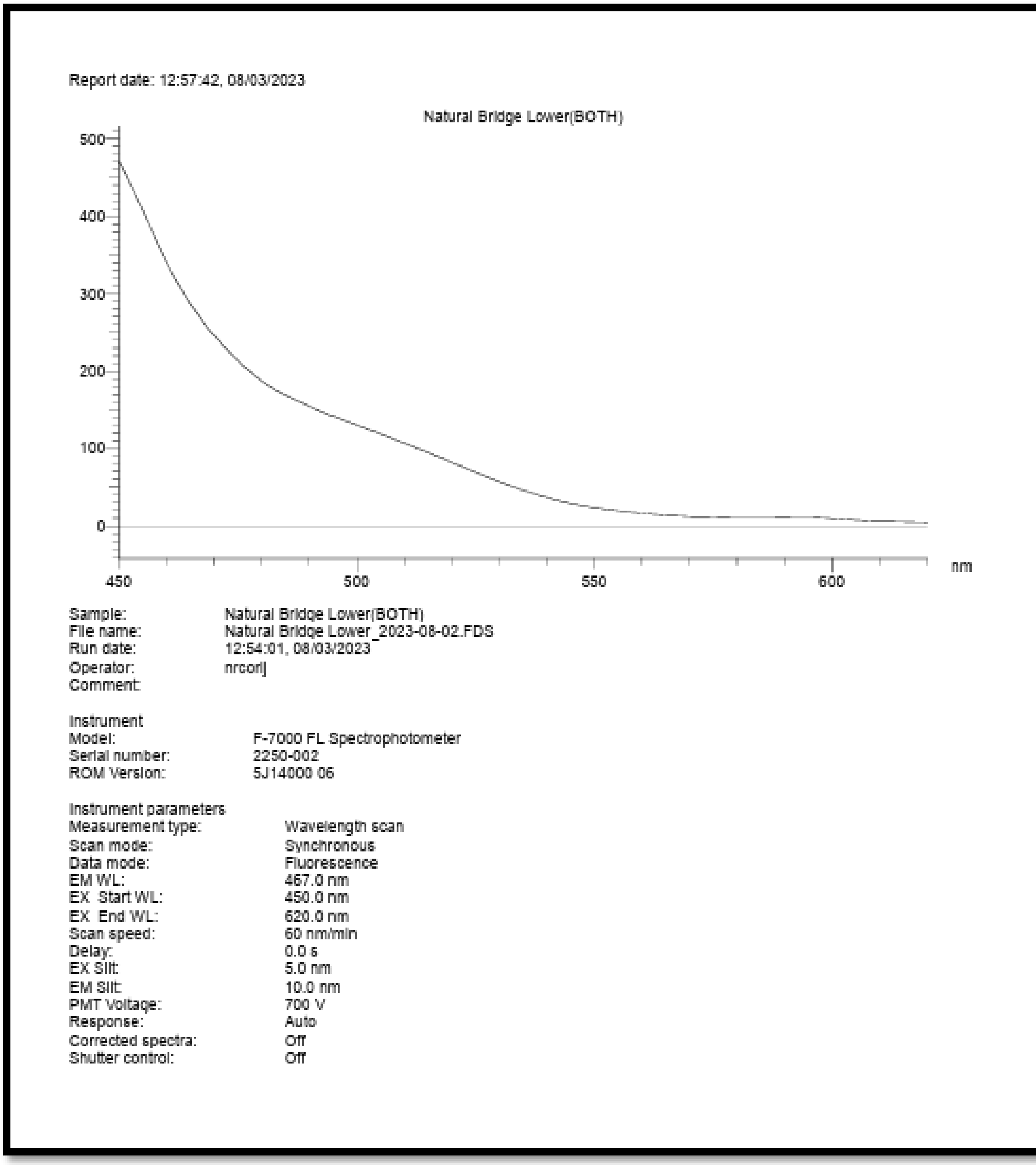
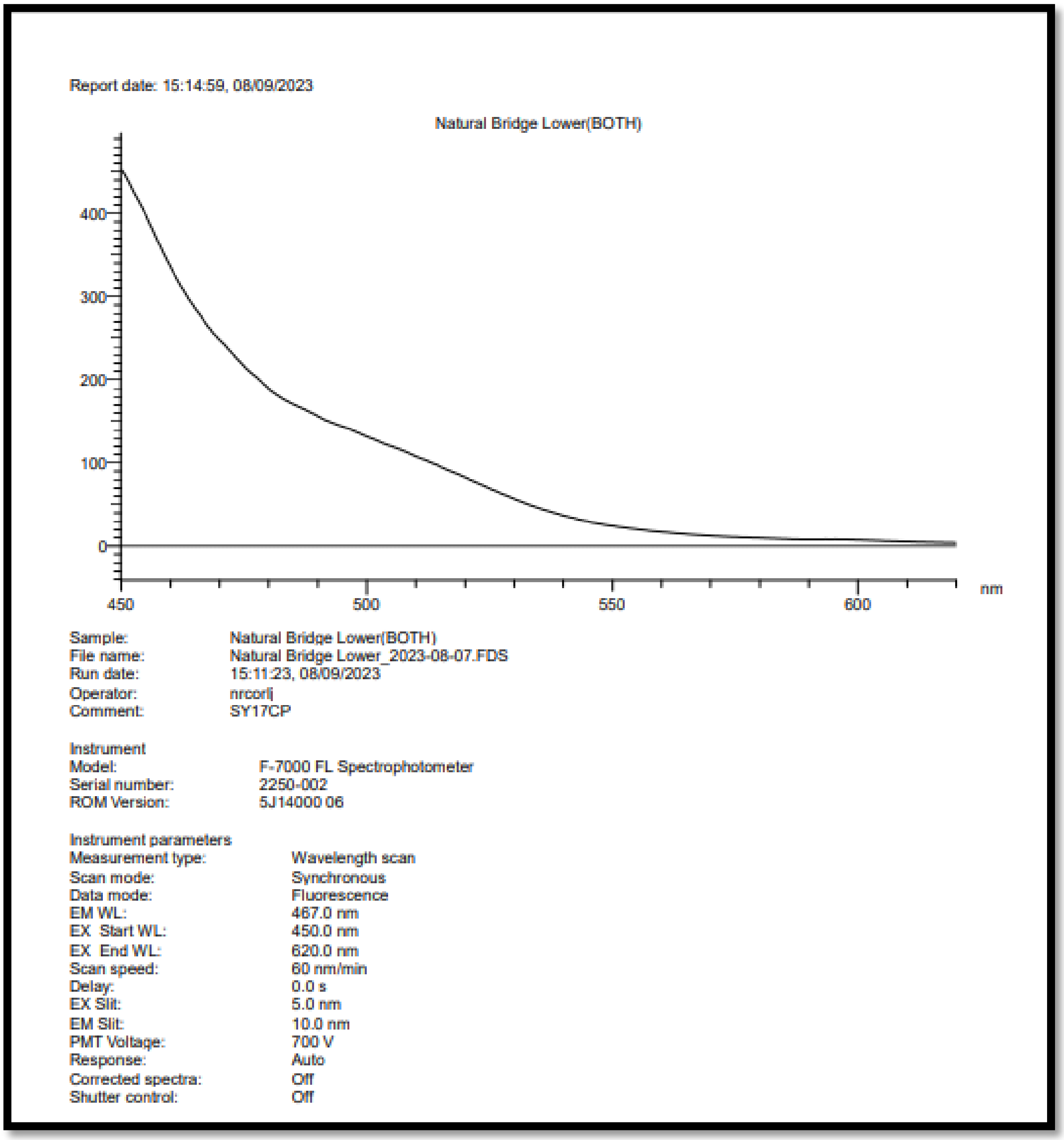


Figure 4.32 Sample Test Spectrum of Natural Spring 14 Days After Dye Injection 07/25/23.



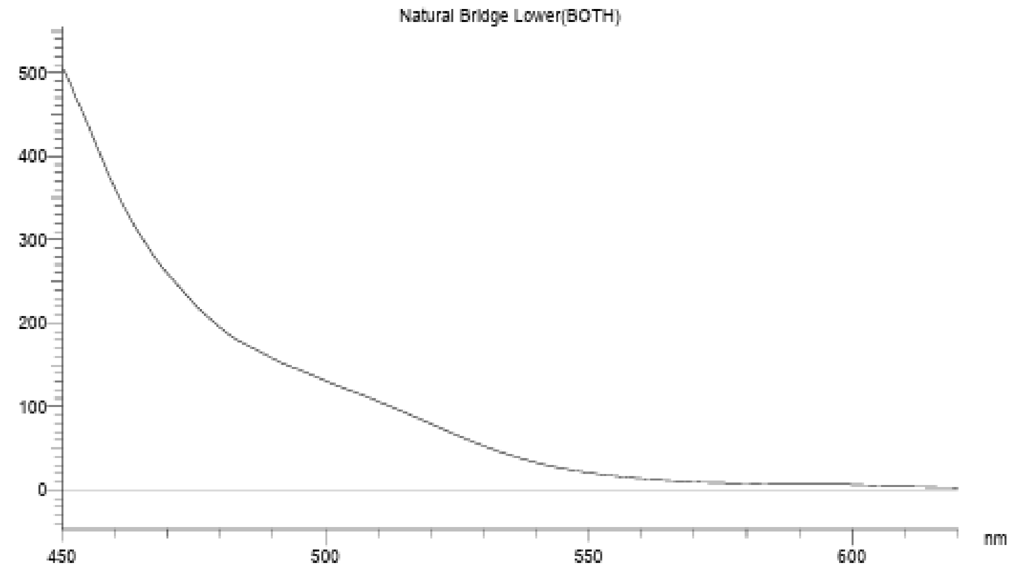
Sample: Natural Bridge Lower(BOTH)
File name: Natural Bridge Lower_2023-08-07.FDS
Run date: 15:11:23, 08/09/2023
Operator: nrcorlj
Comment: SY17CP

Instrument
Model: F-7000 FL Spectrophotometer
Serial number: 2250-002
ROM Version: 5J14000 06

Instrument parameters
Measurement type: Wavelength scan
Scan mode: Synchronous
Data mode: Fluorescence
EM WL: 467.0 nm
EX Start WL: 450.0 nm
EX End WL: 620.0 nm
Scan speed: 60 nm/min
Delay: 0.0 s
EX Slit: 5.0 nm
EM Slit: 10.0 nm
PMT Voltage: 700 V
Response: Auto
Corrected spectra: Off
Shutter control: Off

Figure 4.33 Sample Test Spectrum of Natural Spring 19 Days After Dye Injection 08/7/23.

Report date: 12:21:24, 08/17/2023



Sample:	Natural Bridge Lower(BOTH)
File name:	Natural Bridge Lower_2023-08-15.FDS
Run date:	12:17:54, 08/17/2023
Operator:	nrcorij
Comment:	Sync 17 cp

Instrument

Model:	F-7000 FL Spectrophotometer
Serial number:	2250-002
ROM Version:	5J14000 06

Instrument parameters

Measurement type:	Wavelength scan
Scan mode:	Synchronous
Data mode:	Fluorescence
EM WL:	467.0 nm
EX Start WL:	450.0 nm
EX End WL:	620.0 nm
Scan speed:	60 nm/min
Delay:	0.0 s
EX Slit:	5.0 nm
EM Slit:	10.0 nm
PMT Voltage:	700 V
Response:	Auto
Corrected spectra:	Off
Shutter control:	Off

Figure 4.34 Sample Test Spectrum of Natural Spring 26 Days After Dye Injection 08/15/23.

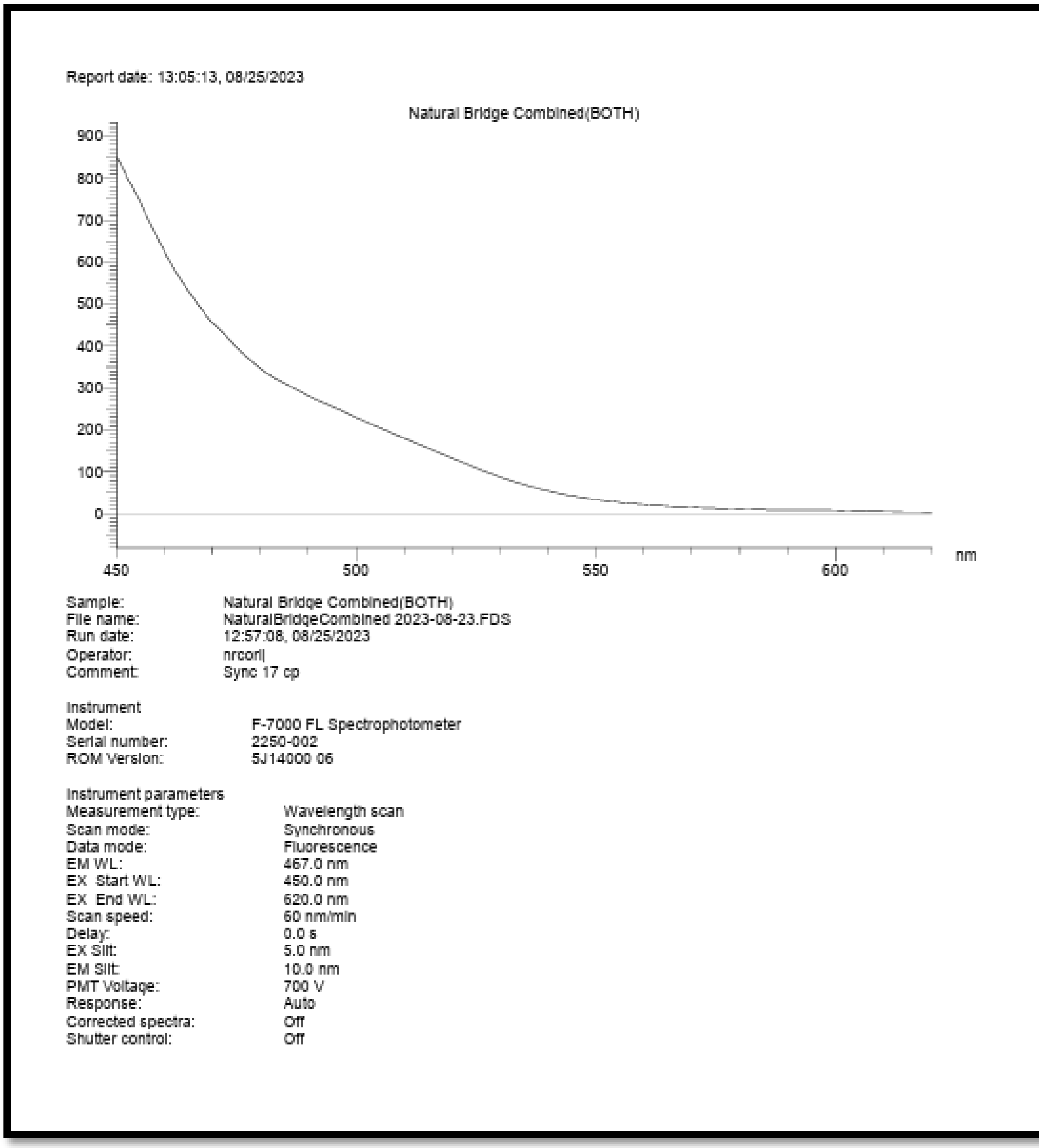


Figure 4.35 Sample Test Spectrum of Natural Spring 35 Days After Dye Injection 08/23/23.

4.2. SUMMARY OF FLUORESCEIN TIME TRAVEL

From the six locations the charcoal packets were gathered as seen in Figure 4.36. Yelton and Wilkins Spring presented Fluorescein peak after 14 days followed by Boiling after 27 days.

1) Boiling Spring: 27 days.

2) Onyx Spring: not dye recovered.

3) Yelton Spring: 14 days.

4) Wilkins Spring: 14 days.

5) Hudgens Spring: not dye recovered.

6) Natural Bridge Spring: Not dye recovered.

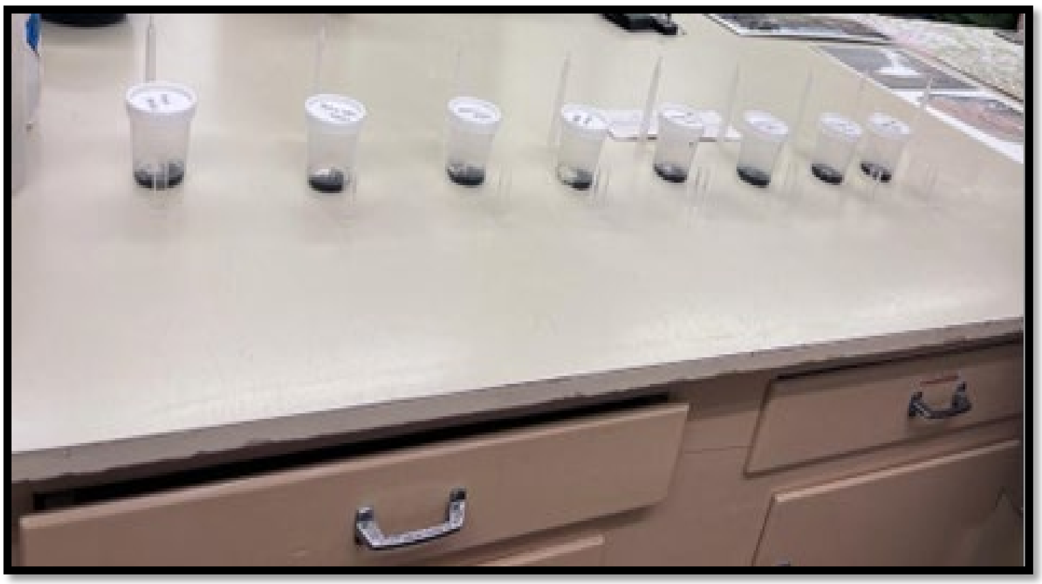


Figure 4.36 Charcoal Samples at the Laboratory of MDNR.

4.3. WATER CHEMESTRY

To analyze water samples were collected weekly between May. 3, 2023, to August 28, 2023.

4.3.1. Monitoring Results in Boiling Spring. During investigation of this spring, we analyzed eight main chemistry parameters in nine times as seen in Table 4.1. Nine field trips were necessary to accomplish this goal. In average the temperature was 60.9 Fahrenheits, the pressure 744.09 mmHg, dissolved oxygen 8.06 mg/L, specific conductance 223.75 uS /cm, total dissolved solids 210.60 mg/L, Salinity 0.13 ppt, PH 7.47 and oxidation-reduction potential 139.04 mV. Boiling Spring discharges in two clear points as seen in Figure 4.37. The one selected for analysis is the one that is closest to the edge of the Gasconade River. Fishes was seen around discharge point. Water was transparent and often cold. Fishes were seen around the spring.

Table 4.1 Chemistry Parameters in Boiling Spring.

Date	Temperature (Fahrenheit)	Pressure (Millimeters per mercury)	Dissolved Oxygen (Milligrams per liter)	Specific Conductance (Microsiemens per centimeter)	Total Dissolved Solids (Milligrams per liter)	Salinity (Parts per trillion)	Potential of Hydrogen	Oxidation Reduction Potential (Millivolts)
5/3/2023	55.94	744.2	8.92	263.1	170.95	0.13	7.56	168.2
5/24/2023	60.62	746.3	6.84	319	208	0.15	7.31	67.2
5/31/2023	61.34	743.3	8.5	320.6	208.65	0.15	7.43	90.5
6/7/2023	60.98	740.6	8.29	317	206.7	0.15	7.39	151.2
7/11/2023	63.68	743.2	7.94	352.3		0.18	7.5	180
8/2/2023	62.42	745.3	7.93	345.9	224.25	0.17	7.52	178.8
8/7/2023	59.72	743	8.46	320.8	208.65	0.15	7.62	166.3
8/15/2023	59.9	746.6	8.32	335.6	217.75	0.16	7.44	145
8/28/2023	60.08	744.3	8.32	368.7	239.85	0.18	7.44	104.2
Average	60.52	744.09	8.17	327.00	210.60	0.16	7.47	139.04

Figure 4.37 View of Boiling Spring Discharging in Gasconade River.

4.3.2. Monitoring Results in Onyx Spring. During investigation of this spring, there were found eight parameters in two contrasting times of fieldtrip as seen in Table 4.2. In average the temperature was 54.32 Fahrenheits, the pressure 741.9 mmHg, dissolved oxygen 13.37 mg/L, specific conductance is 223.05 uS /cm, total dissolved solids 177.125 mg/L, Salinity 0.13 ppt, PH 8.33 and oxidation-reduction potential 177.75 mV. Onyx Spring discharges next to a big bluff in a clear canal as seen in Figure 4.38.

Table 4.2 Chemistry Parameters in Onyx Spring.

Date	Temperature (Fahrenheit)	Pressure (Millimeters per mercury)	Dissolved Oxygen (Milligrams per liter)	Specific Conductance (Microsiemens per centimeter)	Total Dissolved Solids (Milligrams per liter)	Salinity (Parts per trillion)	Potential of Hydrogen	Oxidation Reduction Potential (Millivolts)
5/3/2023	50.54	740.6	13.7	270.7	240.5	0.18	8.65	188.7
8/15/2023	58.1	743.2	13.04	175.4	113.75	0.08	8.02	166.8
Average	54.32	741.9	13.37	223.05	177.125	0.13	8.335	177.75

Figure 4.38 Side View of Onyx Spring.

4.3.3. Monitoring Results in Yelton Spring. During investigation of this spring, we found out there were eight chemistry parameters in seven times of fieldtrip as seen in Table 4.3. In average the temperature was 61.82 Fahrenheits, the pressure 739.88 mmHg, dissolved oxygen 7.26 mg/L, specific conductance 334.1 uS /cm, total dissolved solids 221.2 mg/L, Salinity 0.16 ppt, PH 7.38 and oxidation-reduction potential 136.35 mV. This Spring discharges in a small pond as seen in Figure 4.39.

Table 4.3 Chemistry Parameters in Yelton Spring.

Date	Temperature (Fahrenheit)	Pressure (Millimeters per mercury)	Dissolved Oxygen (Milligrams per liter)	Specific Conductance (Microsiemens per centimeter)	Total Dissolved Solids (Milligrams per liter)	Salinity (Parts per trillion)	Potential of Hydrogen	Oxidation Reduction Potential (Millivolts)
5/3/2023	58.28	739.6	8.56	258.6	168.3	0.12	7.36	167.5
5/24/2023	60.44	741.9	8.49	297.2	193.7	0.14	7.27	73.9
5/31/2023	59	739	8.26	291.4	189.8	0.14	7.29	86.9
6/7/2023	61.7	735.6	6.92	301.1	195.65	0.14	7.35	146
7/11/2023	63.14	739.4	7.68	359.2	233.3	0.17	7.5	182.2
8/2/2023	66.2	741.8	4.96	409.1	265.8	0.2	7.42	170.6
8/7/2023	62.96	738.9	9.46	234.9	211.25	0.16	7.41	165.1
8/15/2023	59	742.5	7.98	334.1	217.75	0.16	7.39	-
8/28/2023	65.66	740.2	3.05	485.3	315.25	0.23	7.41	98.6
Average	61.82	739.88	7.2622	330.1	221.2	0.1622	7.378	136.35

Figure 4.39 View of Yelton Spring.

4.3.4. Monitoring Results in Wilkins Spring. During investigation of this spring, we found out there were eight chemistry parameters in seven times of fieldtrip as seen in Table 4.4. In average the temperature was 59 Fahrenheits, the pressure 743 mmHg, dissolved oxygen 7.82 mg/L, specific conductance 329.9 uS /cm, total dissolved solids 214.5 mg/L, Salinity 0.16 ppt, PH 7.38 and oxidation-reduction potential 144.1 mV. This spring discharges in a cemented pond as seen in Figure 4.40.

Table 4.4 Chemistry Parameters in Wilkins Spring.

Date	Temperature (Fahrenheit)	Pressure (Millimeters per mercury)	Dissolved Oxygen (Milligrams per liter)	Specific Conductance (Microsiemens per centimeter)	Total Dissolved Solids (Milligrams per liter)	Salinity (Parts per trillion)	Potential of Hydrogen	Oxidation Reduction Potential (Millivolts)
5/3/2023	60.08	739.9	8.2	280.1	182	0.13	7.37	176.9
5/24/2023	59	742.5	8.94	322.4	209.95	0.16	7.36	73
5/31/2023	60.62	739.5	7.42	301.3	195.5	0.14	7.33	87.1
6/7/2023	58.64	736.2	7.47	318.5	206.7	0.15	7.45	140.4
7/11/2023	63.14	740.1	6.3	367.9	239.2	0.18	7.4	176.3
8/2/2023	59	742.1	6.56	354.5	230.7	0.17	7.42	164.2
8/7/2023	58.64	739.5	8.05	331	215.8	0.16	7.38	163.8
8/15/2023	59	743	7.82	329.9	214.5	0.16	7.38	144.1
8/28/2023	59	740.9	6.92	356.6	232	0.17	7.35	97
Average	59.68	740.41	7.52	329.13	214.04	0.16	7.38	135.87

Figure 4.40 View of Wilkins Spring.

4.3.5. Monitoring Results in Hudgens Spring. During investigation of this spring, we found out the main chemistry parameters of this spring in 7 opportunities as seen in Table 4.5. In average the temperature was 60.8 Fahrenheits, the pressure 743.8 mmHg, dissolved oxygen 6.49 mg/L, specific conductance 363.7 uS /cm, total dissolved solids 235.9 mg/L, Salinity 0.17 ppt, PH 7.56 and oxidation-reduction potential 142 mV. This spring has multiple points of discharges as seen in Figure 4.41.

Table 4.5 Chemistry Parameters in Hudgens Spring.

Date	Temperature (Fahrenheit)	Pressure (Millimeters per mercury)	Dissolved Oxygen (Milligrams per liter)	Specific Conductance (Microsiemens per centimeter)	Total Dissolved Solids (Milligrams per liter)	Salinity (Parts per trillion)	Potential of Hydrogen	Oxidation Reduction Potential (Millivolts)
5/3/2023	60.44	740.3	8.28	310	202.15	0.16	7.57	127.6
5/24/2023	58.28	743	8.75	299.6	195	0.14	7.46	74.7
5/31/2023	61.88	740.3	7.77	309	200	0.15	7.43	87.5
6/7/2023	61.34	736.3	7.08	322.2	209.3	0.15	7.5	144.2
7/11/2023	65.3	740.7	6.72	381.9	247.6	0.18	7.6	166.5
8/2/2023	61.52	742.2	6.17	378.3	245.7	0.18	7.51	164
8/7/2023	60.8	740.2	7.15	358.2	233.35	0.17	7.46	164.6
8/15/2023	60.08	743.8	6.49	363.7	235.9	0.17	7.56	142
8/28/2023	61.88	741.6	6.93	354.1	230.1	0.17	7.38	93.4
Average	61.28	740.93	7.26	341.89	222.12	0.16	7.50	129.39

Figure 4.40 View of Hudgens Spring.

4.3.6. Monitoring Results in Natural Bridge Spring. During investigation of this spring, we found out the main chemistry parameters of this spring in 7 opportunities as seen in Table 4.6. In average the temperature was 60.8 Fahrenheits, the pressure 741 mmHg, dissolved oxygen 8.11 mg/L, specific conductance 294.7 mV, total dissolved solids 191.7 mg/L, Salinity 0.14 ppt, PH 7.24 and oxidation-reduction potential 139 mV. This spring discharges in a clear point as seen in Figure 4.42.

Table 4.6 Chemistry Parameters in Natural Bridge Spring.

Date	Temperature (Fahrenheit)	Pressure (Millimeters per mercury)	Dissolved Oxygen (Milligrams per liter)	Specific Conductance (Microsiemens per centimeter)	Total Dissolved Solids (Milligrams per liter)	Salinity (Parts per trillion)	Potential of Hydrogen	Oxidation Reduction Potential (Millivolts)
5/3/2023	60.44	737.5	10.68	480	312	0.23	7.55	181.3
5/24/2023	56.66	740.3	11.92	431.2	280.15	0.21	7.73	72.9
5/31/2023	59.9	738.5	10.84	463.3	300.95	0.22	7.81	84.4
6/7/2023	59.9	733.5	9.94	468	304.2	0.23	7.84	142.9
8/2/2023	63.32	739.2	8.68	449.4	291.85	0.22	7.55	164.7
8/7/2023	62.96	737.7	94.5	463.2	300.3	0.22	7.57	164.5
8/15/2023	62.42	741	8.11	294.7	191.7	0.14	7.24	139.6
8/28/2023	59.9	738.9	10.15	478.8	311.35	0.23	7.46	90.3
Average	60.69	738.33	20.60	441.08	286.56	0.21	7.59	130.08

Figure 4.41 View of Natural Bridge Spring.

4.4. SIMILARITIES BETWEEN SPRINGS CONNECTED

4.4.1. Temperature. From the springs connected we can characterize that the highest temperature belongs to Yelton Spring, secondly Boiling Spring, and finally Wilkins Spring as seen in Figure 4.43.

Yelton: 61.82 Fahrenheit.

Boiling: 60.49 Fahrenheit.

Wilkins: 59 Fahrenheit.

Water temperature should be 59 F to 68 F to be consumed (Safe Drinking Water Foundation, 2024).

The average temperature of the springs that are connected is 60.67 F. Boiling is -0.15 F below the average temperature. Yelton is 1.15 above the average temperature.

Wilkins is 0.99 below the average temperature. During the time of study temperature in springs connected does not have significant variations as seen in Figure 4.44.

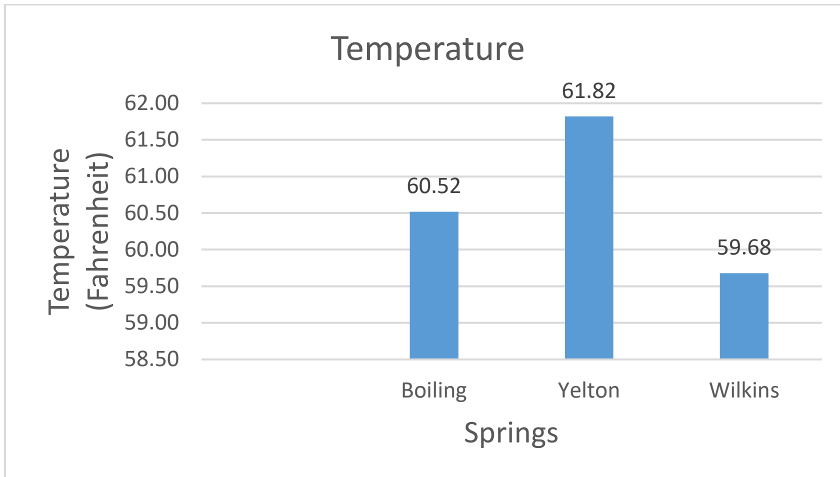


Figure 4.42 Average of Temperature of Springs.

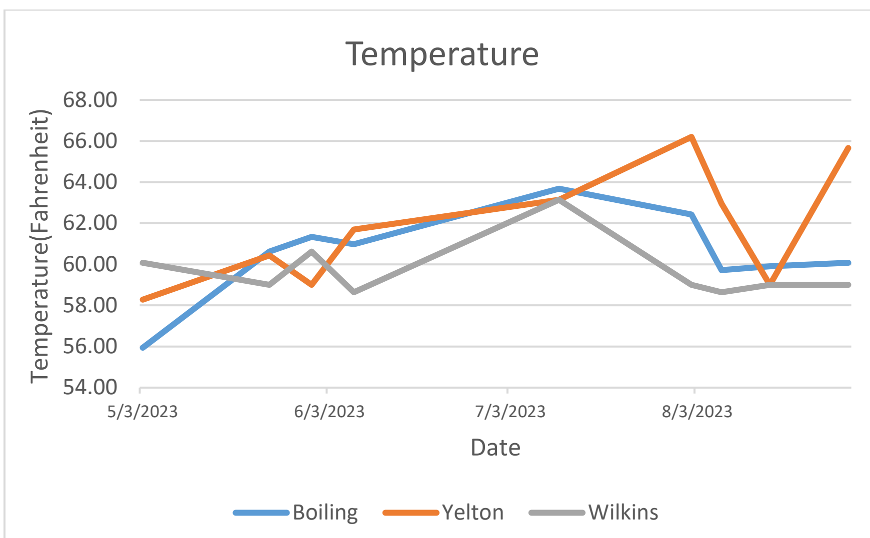


Figure 4.43 Trendline of Temperature of Springs.

4.4.2. Pressure. From the springs connected we can characterize that the highest pressure belongs to Boiling Spring, secondly Wilkins Spring, and finally Yelton Spring.

Yelton: 739.88 mm/Hg as seen in Figure 4.45.

Boiling: 744.09 mm/Hg.

Wilkins: 740.41 mm/Hg.

Water pressure should not be a guideline for water quality (Safe Drinking Water Foundation, 2024). During the time of study pressure in springs connected does not have significant variations as seen in Figure 4.46.

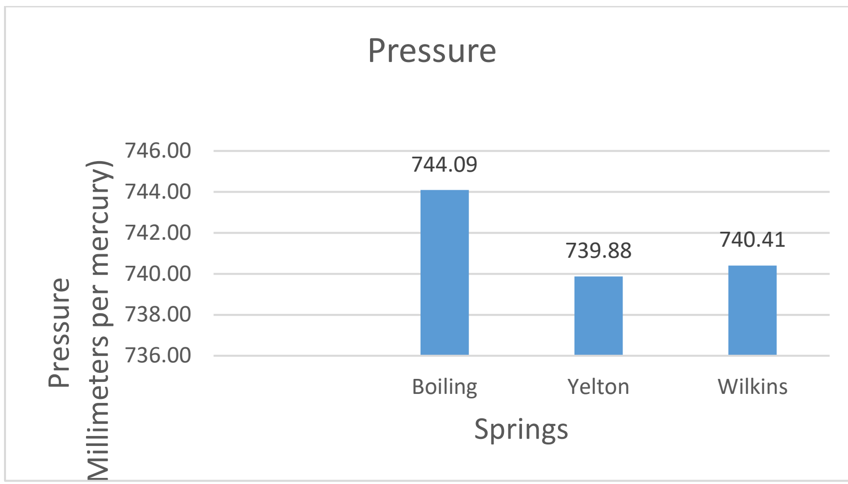


Figure 4.44. Average of Pressure of Springs.

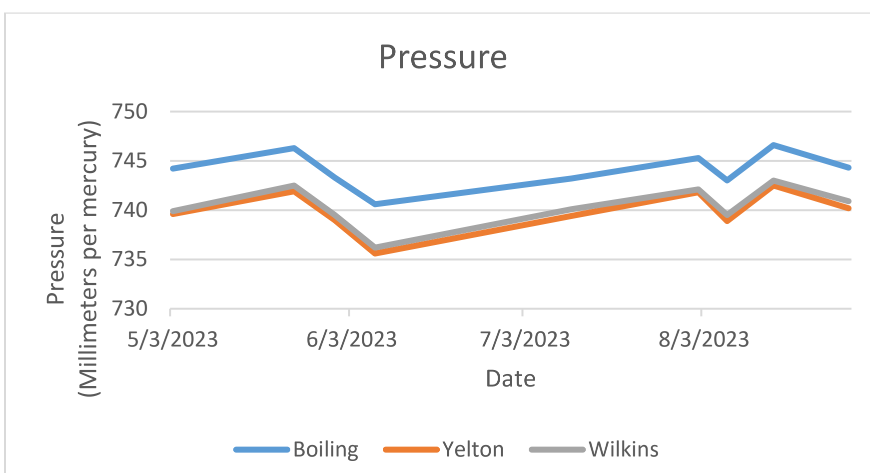


Figure 4.45. Trendline of Pressure of Springs.

4.4.3. Dissolved Oxygen (DO). From the springs connected we can characterize that the highest DO belongs to Boiling Spring, secondly Wilkins Spring, and finally Yelton Spring as seen in Figure 4.47.

Yelton: 7.26 mg/L.

Boiling: 8.17 mg/L.

Wilkins: 7.52 mg/L.

Dissolved Oxygen should be from 5 ppm to 15 ppm for fishes (Missouri Stream Team , 2017).Thus all three spring are capable to grow fishes.

During the time of study DO in springs connected does not have significant variations as seen in Figure 4.48.

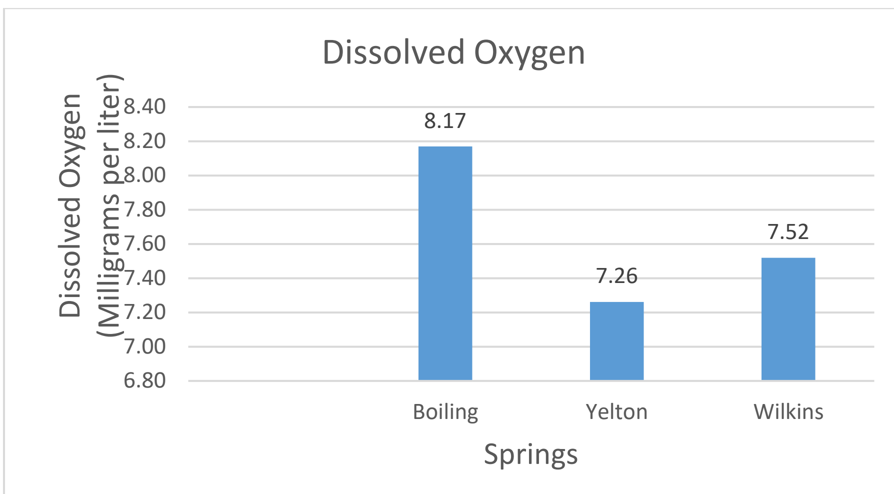


Figure 4.46 Average of Dissolved Oxygen of Springs.

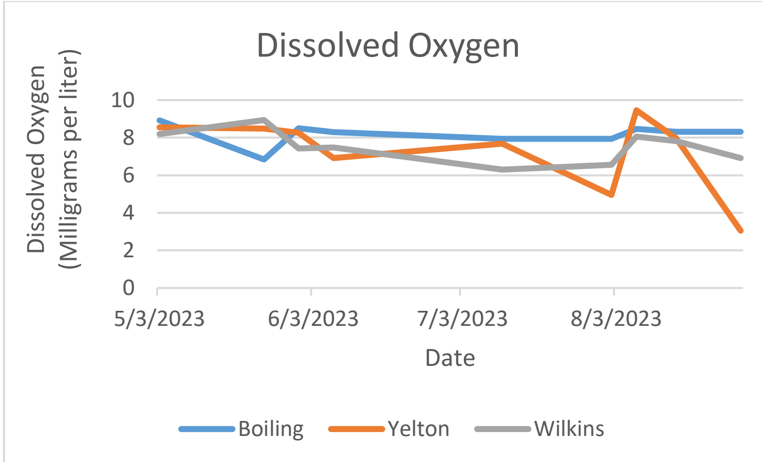


Figure 4.47 Trendline of Dissolved Oxygen of Springs.

4.4.4. Specific Conductance (SC). From the springs connected we can characterize that the highest SC belongs to Yelton Spring, secondly Wilkins Spring, and finally Yelton Spring as seen in Figure 4.49.

Yelton: 330.10 mS/cm.

Boiling:327 mS/cm.

Wilkins:329.13 mS/cm.

Water SC should be less than 2000 mS/cm to be consumed (Missouri Stream Team , 2017). All springs belong to this range. During the time of study SC in springs connected does not have significant variations as seen in Figure 4.50.

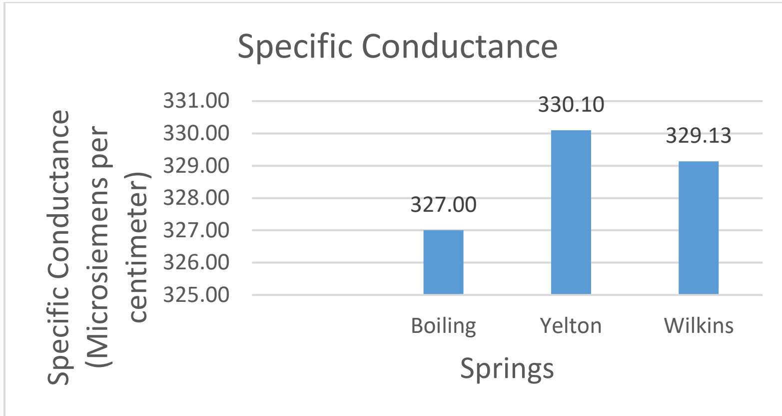


Figure 4.48 Average of Specific Conductance of Springs.

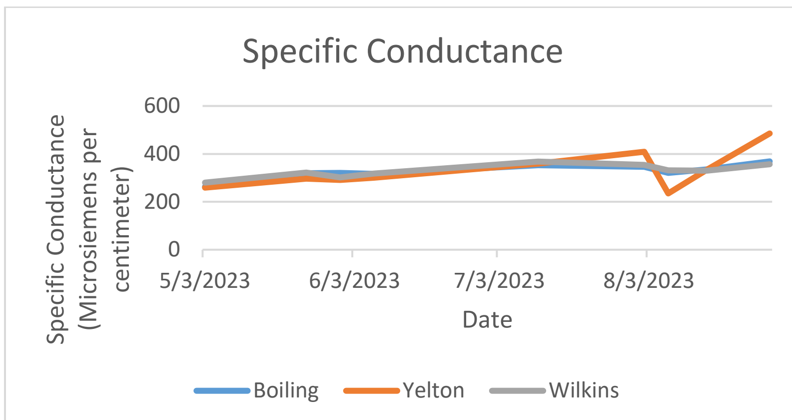


Figure 4.49 Trendline of Specific Conductance of Springs.

4.4.5. Total Dissolved Solids (TDS). From the springs connected we can characterize that the highest TDS belongs to Wilkins Spring, secondly Boiling Spring, and finally Wilkins Spring as seen in Figure 4.51.

Yelton: 221.2 mg/L.

Boiling: 210.6 mg/L.

Wilkins: 214.04 mg/L.

Water TDS should be less than 500 mg/L as recommended parameter for water quality (Missouri Stream Team , 2017). During the time of study TDS in springs connected does not have significant variations as seen in Figure 4.52.

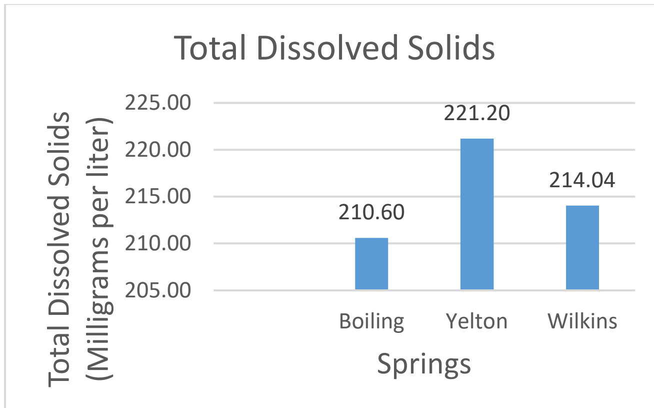


Figure 4.50 Average of Total Dissolved Solids of Springs.

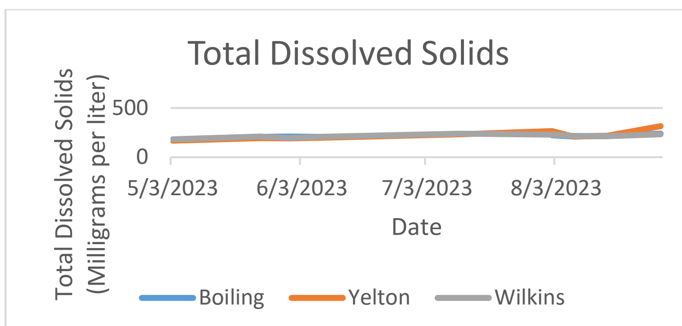


Figure 4.51 Trendline of Total Dissolved Solids of Springs.

4.4.6. Salinity (Sal). From the springs connected we can characterize that the highest Salinity belongs to Yelton Spring, secondly together Boiling Spring and Wilkins Spring as seen in Figure 4.53.

Yelton: 0.162 ppt.

Boiling: 0.158 ppt.

Wilkins: 0.158 ppt.

Water salinity is best if less than 1ppm to be consumed (Missouri Stream Team , 2017). Therefore, salinity is not a hazard in the springs examined. During the time of study Sal in springs connected does not have significant variations as seen in Figure 4.44.

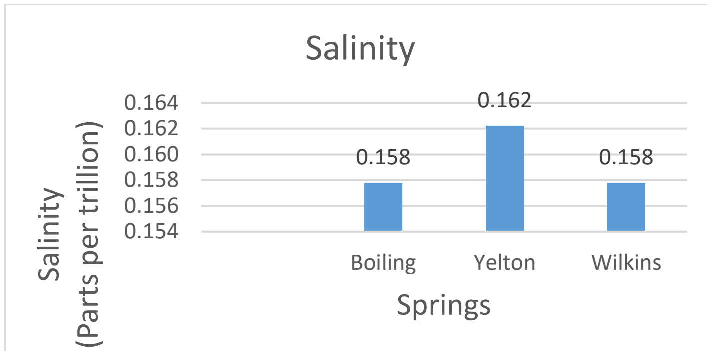


Figure 4.52 Average of Salinity in Springs.

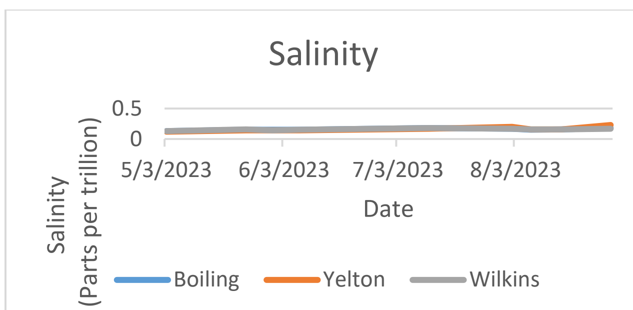


Figure 4.53 Trendline of Salinity in Springs.

4.4.7. Potential of Hydrogen (PH) From the springs connected we can characterize that the highest PH belongs to Boiling Spring, secondly together Yelton Spring and Wilkins Spring as seen in Figure 4.55.

Yelton: 7.38.

Boiling: 7.47.

Wilkins: 7.38.

Water PH should be 6.5 to 9 to be consumed (Missouri Stream Team , 2017). During the time of study PH in springs connected does not have significant variations as seen in Figure 4.56.

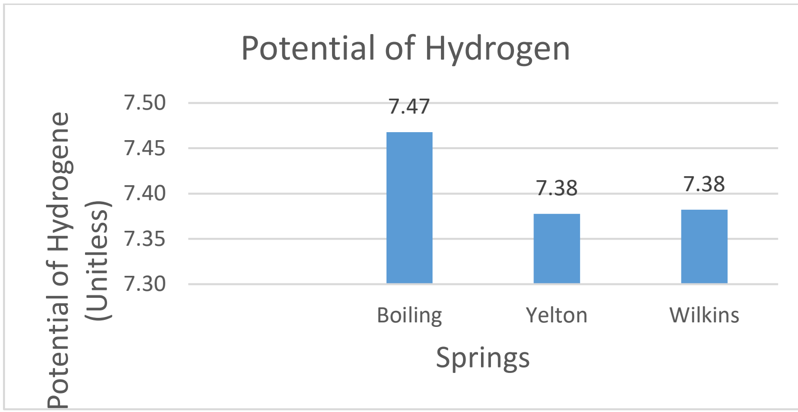


Figure 4.54 Average of Potential of Hydrogen of Springs.

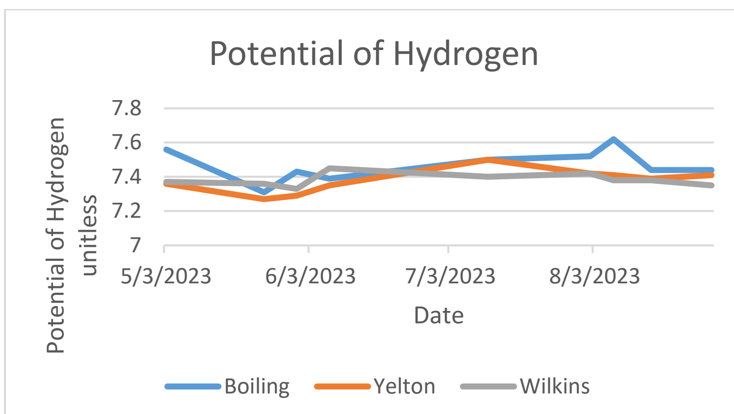


Figure 4.55 Trendline of Potential of Hydrogen of Springs.

4.4.8. Oxidation-Reduction Potential (ORP). From the springs connected we can characterize that the highest ORP belongs to Wilkins Spring, secondly Boiling Spring, and finally Yelton Spring as seen in Figure 4.57.

Yelton: 136.35 millivolts.

Boiling: 139.04 millivolts.

Wilkins: 135.87 millivolts.

Water ORP should be at the range of 650 mV-750 mV. (Missouri Stream Team , 2017). During the time of study ORP in springs connected does not have significant variations as seen in Figure 4.58.

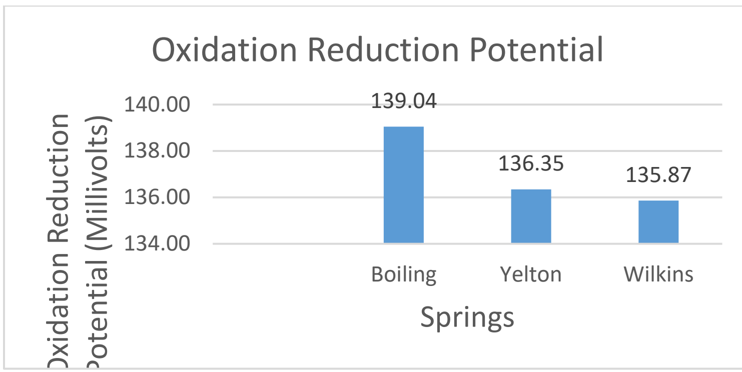


Figure 4.56 Average of Oxidation-Reduction of Springs.

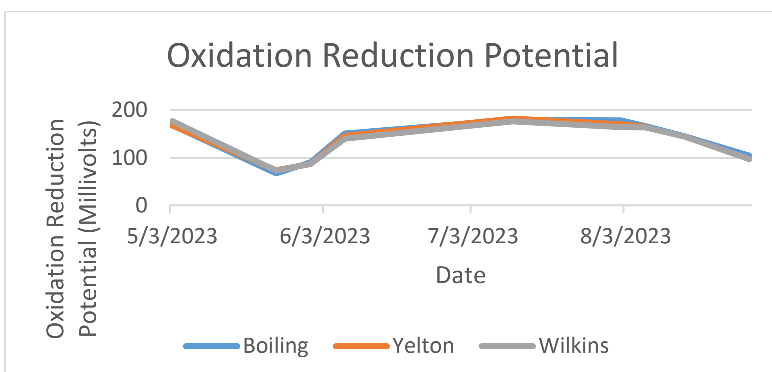


Figure 4.57 Trendline of Oxidation-Reduction of Springs.

5. CONCLUSIONS

1. Determining the groundwater movement in karst system is complicated. Dye tracing is a powerful tool required to understand this type of water system.
2. The springs that are connected are Yelton Spring and Wilkins Spring, that discharge to Boiling Spring.
3. Hudgens Spring does not connect with Wilkins Spring even though they are closer (Dye recovery negative).
4. Onyx Spring does have little discharge in summer season, so it provides less measurements to analyze data.
5. The average temperature of springs connected is 60.67 F with a deviation of +-1.8%
6. The average pressure of springs connected is 741.46 mm Hg with a deviation of +-0.4%.
7. The average dissolved oxygen of springs connected is 7.65 mg/L with a deviation of +-6%
8. The average specific conductance of springs connected is 328 uS/cm with a deviation of +-0.53%.
9. The average total dissolved solids of springs connected is 215 mg/L with a deviation of +-2.7%.
10. The average salinity of springs connected is 0.16 ppt with a deviation of +-1.8%.
11. The average potential of hydrogen of springs connected is 7.41 with a deviation of +-0.42%.
12. The average oxidation-conductance of springs connected is 137.09 Mv with a deviation of +-1.43%.

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VITA

Katherin Roxana Montes Chamorro received her B.S. in Mining Engineering in September 2015 from Universidad Nacional del Centro del Peru and received her M.S. in Geological Engineering from the Missouri University of Science and Technology in May 2024.

Katherin was born in Icuiza, a small village in the mountains of Peru. After a brief time of experience in Mining Engineering field she was a Fulbright Program recipient with the mission to teach her indigenous language “Quechua” at the University of Oregon for one academic year. After that special opportunity she appreciated more her love to nature and decided to pursue studies in hydrogeology at the Geological Engineering department at the Missouri University of Science and Technology.

In her free time, she served as treasurer and fund-raising chair I at the International Student Club and Katherin also volunteered as Quechua teacher at Organización Mundial de Apoyo a la Educación.