STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

UNDERSTANDING GROUNDWATER-SURFACE WATER INTERCHANGE IN THE F-AREA WETLANDS OF FOURMILE BRANCH WATERSHED

DOE-FIU SCIENCE & TECHNOLOGY
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EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Development Initiative, an innovative program developed by the U.S. Department of Energy's Office of Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2022, DOE Fellow intern, Stevens Charles, spent 10 weeks doing a summer internship at Savannah River National Laboratory (SRNL) under the supervision and guidance of Dr. Hansell Gonzalez-Raymat. The intern's project was initiated on June 01, 2022, and continued through August 12, 2022, with the objective of understanding and possibly creating a conceptual model of the groundwater and surface water interchange in the F-area wetlands of the Fourmile Branch Watershed.

From 1955 to 1988, low-level radioactive waste solutions were disposed of in three unlined basins known as the F-Area Seepage Basins. Some contaminants seep through the soil and became sequestered while others continued their migration through the vadose zone and into the saturated zone, creating a groundwater plume that extends approximately 1 square kilometer. As a result, these contaminants contaminated the groundwater and migrated downstream, resurfacing at outcrops (seep lines) in the adjacent wetlands where some of the contaminants were then able to enter the Fourmile Branch stream system. Groundwater-surface water interfaces are the regions where contaminated groundwater emerges to the surface, which is often one of the major ecological and human health risk pathways. In the F-Area, contaminants such as I-129 appear at these outcrops/seep lines throughout the year. To understand the contaminant transport from subsurface to surface an understanding of the groundwater - surface water interchange must be made.

The groundwater and surface water interchange are a difficult topic to comprehend. There have been many techniques and technologies developed to attempt to understand this phenomenon. Some techniques that have been used include thermal imaging, distributed temperature sensors, seepage meters, and a distributed temperature profiling system, which is the strategy that was deployed in the F-area wetlands during summer 2022. Each of these strategies were researched, and the distributed temperature profiling system was selected to help aid in understanding the groundwater and surface water interchange in the wetlands.

Platforms such as GIS and pylenM, a package that uses machine learning functions to perform soil and groundwater analysis were also used to analyze the relationship between groundwater and surface water.

1. INTRODUCTION

Savannah River Site (SRS) is a 310 square mile area located in west central South Carolina near the boundary of Georgia that was developed during the middle of the 1950's for use in the production of materials such as tritium, plutonium, and special nuclear materials for national defense, medicine, and space programs. These processes resulted in the release and spread of radiological and other chemical contaminants across the SRS.

From 1955 to 1988, the F-Area Seepage Basins received low level acidic waste solutions that contained nitrate, metals, and several radionuclides. Some of these contaminants including tritium, uranium isotopes, strontium-90, and iodine-129, over a period, were able to pass through the soils at the bottom of the basins, through the vadose zone and into the saturated zone. Once in the groundwater, these contaminants migrated downstream and resurfaced at seeps in wetland areas associated with Fourmile Branch. Specifically, Fourmile Branch and its associated wetlands have been impacted for more than thirty years by the outcropping of contaminated groundwater coming from the F-Area Seepage Basins.

Since the basins were closed in 1991, several groundwater remedial actions, such as the pump and treat system, were used to lessen contaminants in the groundwater. The groundwater pump and treat system eventually became expensive to maintain and operate and generated secondary waste that needed to be disposed. As a result, the pump-and-treat was replaced with a more passive attenuation-based remedy in 2004.This passive attenuation-based remedy uses subsurface barriers installed across flow paths in the upper aquifer, forming a funnel and gate system that allow contaminants to be treated within the gates. Base injections are done periodically at the gates to remove U-238 and Sr-90 while silver chloride injection campaigns have been performed just upgradient of the central gate to treat I-129. In the F-Area wetlands, an enhanced monitored natural attenuation (MNA) approach has been implemented, periodically injecting a base solution to increase the sorption of cationic contaminants, making them less bioavailable. While these strategies are successful in sequestering the contaminants of concern, a long-term monitoring strategy is necessary at locations where remediation have left residual contamination in the subsurface known as zones of vulnerabilities where there is potential for contaminant remobilization if environmental conditions change. Currently there are three major zones of vulnerability: 1) the soils directly beneath the former seepage basins and the underlying vadose zone, 2) the gates where in situ treatments enhance attenuation of contaminants, and 3) the wetlands where contaminants are attenuated by primarily natural processes. Specifically in the F-area wetlands, where contaminants can resurface, understanding the groundwater and surface water interactions is important. The main objective of this project was to complete literature review of the many techniques that can be used to understand the groundwater interchange. After completing the literature review, some of these strategies were tested such as the temperature profiling system. The temperature profiling system was initiated in the F-area to improve the understanding of the relationship between groundwater and surface water by collecting continuous temperature data spatially and temporally in the wetlands.

2. RESEARCH DESCRIPTION

Long Term Monitoring

For sites like the F-area Seepage Basins, where the risk of environmental contamination from heavy metals and radionuclides continues to exist, long-term monitoring is essential. With long-term monitoring, there will be an emphasis on the measure of hydrological and geochemical parameters that control the remobilization of contaminants. By focusing more on the controlling variables, there can be less of an emphasis on the contaminant concentration. This strategy can aid in predicting any changes in concentration of contaminants as well as predicting their mobility. Moreover, monitoring those controlling variables (leading indicators) would provide greater opportunity to take proactive measures to prevent the remobilization of attenuated contaminants rather than focusing on contaminant concentration (lagging indicators) which can only indicate when contaminants have become remobilized.

Techniques used to understand the relationship between Groundwater and Surface Water Interactions

Some techniques used to find and understand the groundwater and surface water exchange are given below:

Temperature is the most popular indicator of the movement of groundwater. The temperature recorded at the surface varies based on the air temperature, while the groundwater temperature remains constant throughout the year since it is less affected by the atmosphere. During warm and cold month, it is expected that there will be a high discrepancy between the variable temperatures recorded on the surface and the constant temperatures in the subsurface. In the summer, the recorded temperature at the surface is usually warmer than the constant temperatures recorded in the subsurface. Vice versa occurs during winter months where the groundwater is warmer than the surface water. By using the difference in temperatures throughout the year, areas where the groundwater is resurfacing can be located. For example, during the summer when the surface temperature is usually warm, an area of cooler water could possibly mean that the cooler groundwater is resurfacing at this location. The following techniques use temperature to aid in understanding the groundwater surface water interchange.

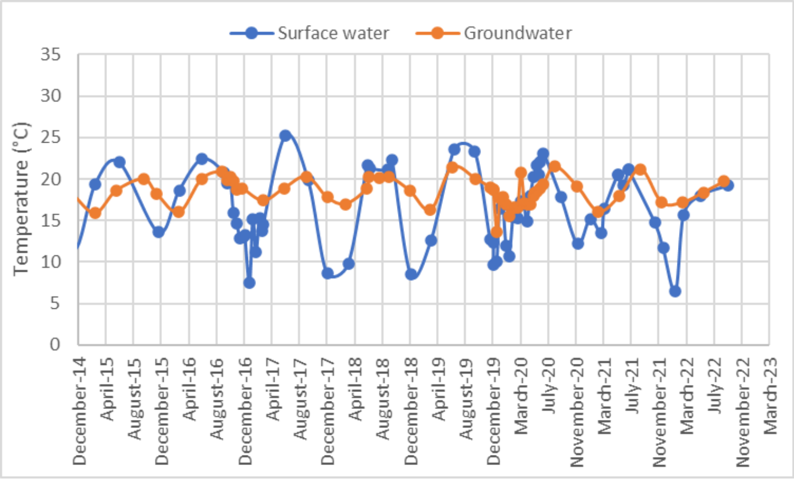

Figure 1. Temperatures Recorded at varying groundwater and surface water gauges

Based off the monitoring data in Figure 1, the best times to use temperature as an indicator to help understand groundwater and surface water interchange is between December and March. This period shows the most variability between groundwater and surface water and this can aid in predicting areas where groundwater is possibly resurfacing.

Thermal Imaging

Thermal Imaging provides a faster response when compared to the conventional method of installing equipment. This technique converts infrared heat to an electric signal. (Forward Looking Infrared) FLIR UAV/planes are commonly used to conduct this analysis. These planes usually fly over the study area and create images that differentiate temperature. Unfortunately, in the case of the F-area wetlands, the canopy and overgrown vegetation makes it hard to use UAV planes to collect thermal images. Besides flyovers, it has been considered the use of handheld thermal imaging cameras to perform walkover surveys and located areas where there is a groundwater and surface water interchange. These handheld cameras would be able to get under the vegetation cover, however these cameras would not be able to collect continuous data. Scientists will have to manually go into the field to capture pictures that will be able to gather information on the temperature discrepancy of surface water. Another problem with thermal imaging is that it only calculates temperature data at the surface and not in the subsurface, meaning scientist will not be able to understand how water is moving at the subsurface until after groundwater seeps onto the surface.

Figure 2 shows an example of what a thermal imaging camera can capture. The image above was taken during the winter where the surface water is cooler. The warmer temperatures indicate areas where the warmer groundwater temperature is resurfacing. Thermal imaging is an effective strategy during the summer and winter months due to the differences in groundwater and surface temperatures. During times when the temperatures between the subsurface and surface are very similar, thermal imaging would not be as successful. An example would be the period between April 2018 and August 2018 shown in figure 1. There is minimal difference between groundwater and surface water and as a result, it may be harder to use thermal imaging or other temperature-based techniques.

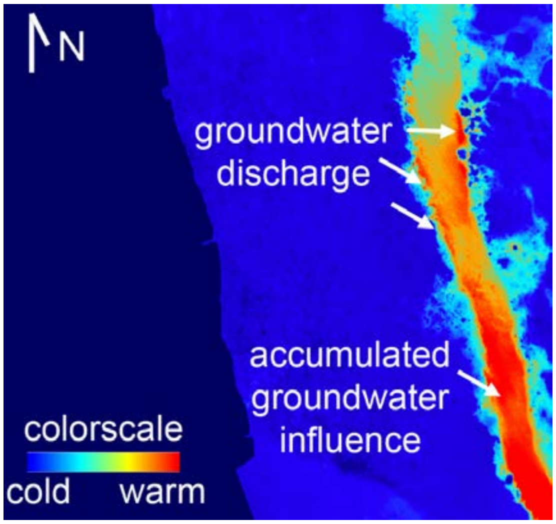

Figure 2. An example of how Thermal Imaging can capture groundwater seepage(Briggs,2022)

Distributed Temperature Sensor

Distributed Temperature sensors measure temperatures by means of fiber-optic. This technique can be used at a lake bottom, in a mine shaft, air-snow interface, air-water interface, and in a first order stream. Contrary of thermal imaging, this technique is continuous and can measure the temperature at different depths. Distributed temperature sensors are very fragile, and at times are difficult to place due to the debris on the surface.

Figure 3 shows an example of a team installing distributed temperature sensors (DTS) in a stream. For this strategy a cable is used to provide a continuous measurement of temperature both spatially and continuously. This strategy is similar to the distributed temperature profiling system that was initiated into the F-area wetlands during the summer.

Figure 3 Distributed Temperature Sensor

Seepage Meter

Seepage meters measures the flux between the groundwater and surface water. The two techniques above only observed the temperature difference between the subsurface and surface. Seepage meters allow the collection of the groundwater that seeps onto the surface. A seepage meter is a drum like figure with an open end pressed into sediments with a clear bag attached (Figure 4). Exchange between surface water and ground water is calculated by change of volume in bag over area. A seepage meter can be used in stream channels, lakes, wetlands, and near ocean shorelines

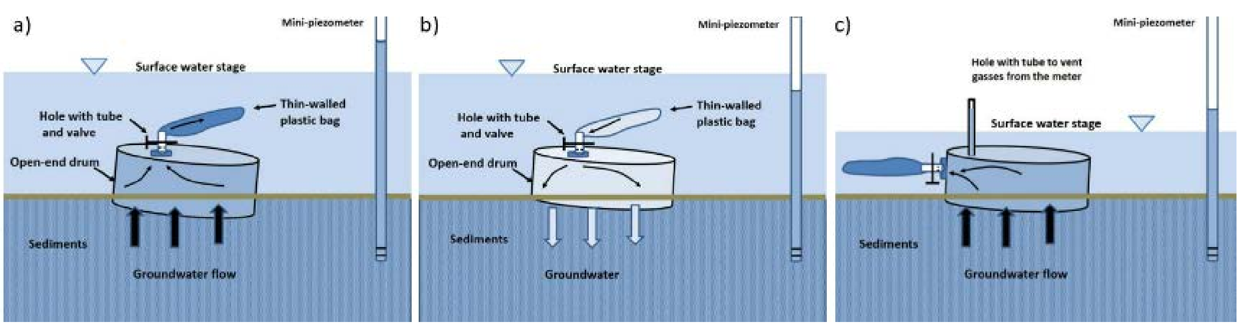

Figure 4.Process of Installing a seepage meter (Woessner,2020)

In areas where there is very low seepage, interconnected ganged meter setups can be used. This will allow seepage from multiple locations to be collected at one location. An example of this is shown below in 5.

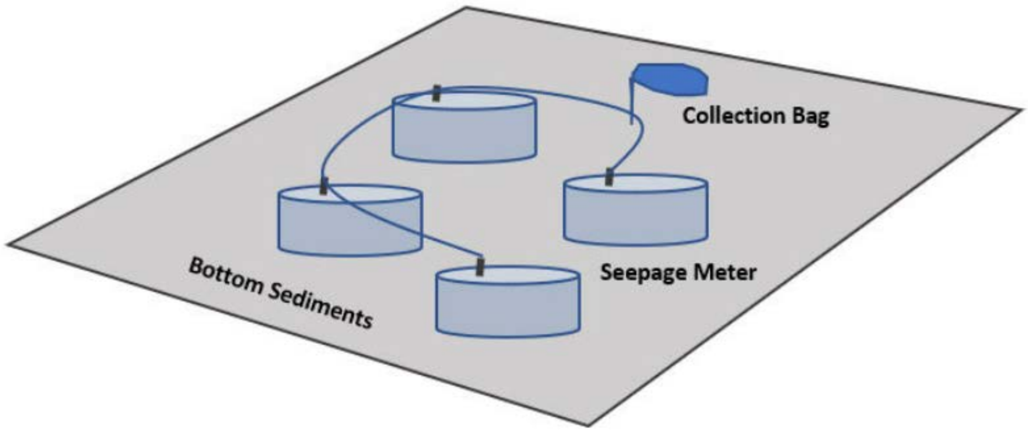

Figure 5. An example of an interconnected ganged meter (Woessner,2020)

Seepage meters are useful but like other techniques there are some weaknesses. One of the problems comes with placing the meters in the study area. In areas such as the F-area wetlands where the ground is covered with vegetation and other debris, securely placing the meter would be very difficult.

Composition

Understanding the difference in the minerals and composition found in the subsurface compared to those found at the surface can also help identify areas where the groundwater seeps to the surface. If a mineral that is usually found in the upper aquifer is found on the surface, then it can be predicted that groundwater is seeping into that area. Examples of tracers that have been used to study interactions between groundwater and surface water include alkalinity, electrical conductivity, isotopes of radon, chlorofluorocarbons, strontium, and radium isotopes. Radium is currently the only isotope that has been collected in the F-area for an extended period. Like many other parameters the data on radium isotopes was only collected quarterly in the F-area wetlands and not much information was found from the data. Also, much of the information that was found did not deal with sites that have been contaminated.

Distributed Temperature Profiling

The distributed temperature profiling system is currently being tested at the F-Area wetlands to try to understand the groundwater and surface water interchange. This strategy provides temperature data spatially and temporally like distributed temperature sensors. A difference between these two are that DTS are continuous spatially, as it is usually collecting data along a cable. With distributed temperature profiling, probes that can collect temperature data are installed at multiple points in the wetlands. In the summer of 2022, probes were installed in 97 locations. These probes contain temperature sensors located every 5 or 10 cm (Figure 6) allowing temperature to be collected at different depths. By using temperature as a tracer, the stored data will help researchers understand the groundwater surface water interactions as well as biogeochemical processes that occur in the wetlands.

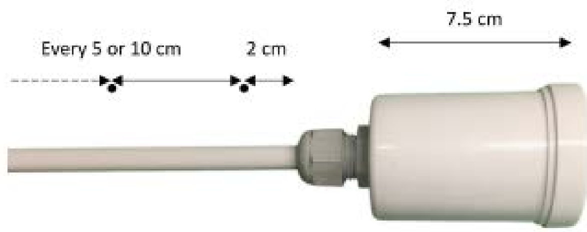

Figure 6. The figure on the left represents an image of the temperature probes, and the location of each of the sensors, which are a couple centimeters apart. (Dafflon et al. 2022)

Information is collected on these probes and can be retrieved via Bluetooth by researchers. To retrieve all the data, the researcher must travel to each of the locations that the temperature probes are placed.

<u>Installation of In-situ sensors at shallow piezometer wells</u>

In situ sensors that measure temperature as well as other parameters could be installed deployed in shallow piezometer wells at different stream locations to monitor groundwater surface water interactions. The continuous data collected could help to understand whether the location where the sensor is placed is gaining or losing. If it is gaining, the groundwater is moving up to the surface, and if the location is losing, the surface water is moving into the groundwater. A location that is losing would be ideal for the F-area wetlands since the surface water has a possibility of diluting the possibly contaminated groundwater.

Examples of gaining and losing streams shown in Figure 7 would serve as a guide to help understand the time series data that is collected from the temperature probes. A gaining stream would have near constant temperatures in the groundwater, A losing stream would show that groundwater temperatures have higher temperature fluctuations.

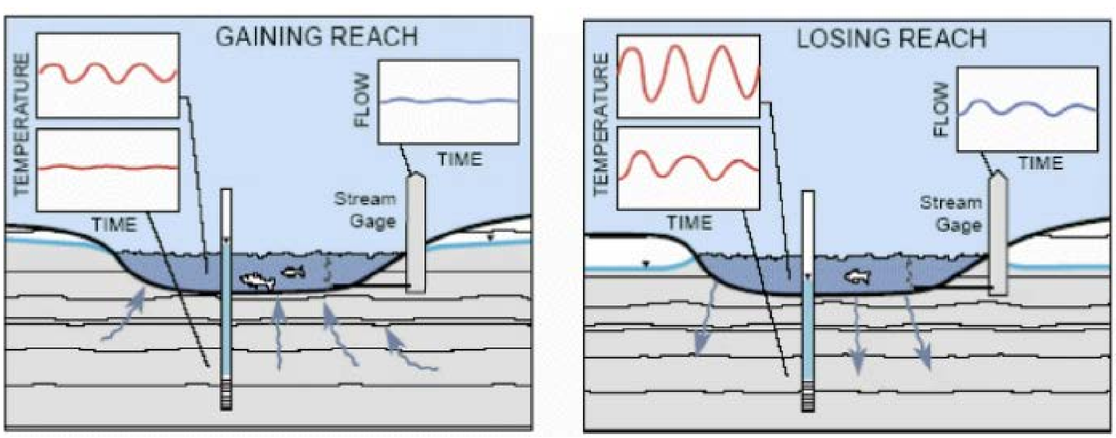

Figure 7. Examples of what a time series for losing/gaining streams might look like (Stonestrom,2004)

3. RESULTS AND ANALYSIS

Heat is the main tracer used when attempting to understand the groundwater and surface water interchange. After the installation of the temperature probes in the wetlands, continuous temperature data will be available to researchers. Previously, temperature data was only collected quarterly. The lack of data caused many problems for researchers when attempting to analyze and better understand the wetlands. Even with the lack of data, there were still attempts to understand the groundwater and surface water interchange by creating an Inverse distance weighting (IDW) interpolated GIS map from the temperatures recorded at each station located in the upper aquifer. IDW is an interpolation method that uses a known scattered set of points. to assign values to unknown points. The values of the unknown points are created by averaging out the values of a known point.

Figure 8 shows the difference in temperatures recorded during different times of the year. Some of the things that should be observed is how during Q1, temperatures recorded near the seepage basins are warmer than the temperatures recorded near the seepage lines. Since the groundwater below the wetlands and Fourmile Branch is closer to the surface, groundwater temperature tends to be more affected by changes in temperature occurring in the surface. Figure 9 shows the topography of the F-Area. Upstream areas closer to the basins have a thicker vadose zone and this provides an extra layer that decreases the impact of the surface temperature on the groundwater below. Near the seep lines areas where the vadose zone is thinner, groundwater temperatures are more impacted by changes in the surface temperature due to the smaller layer above the upper aquifer.

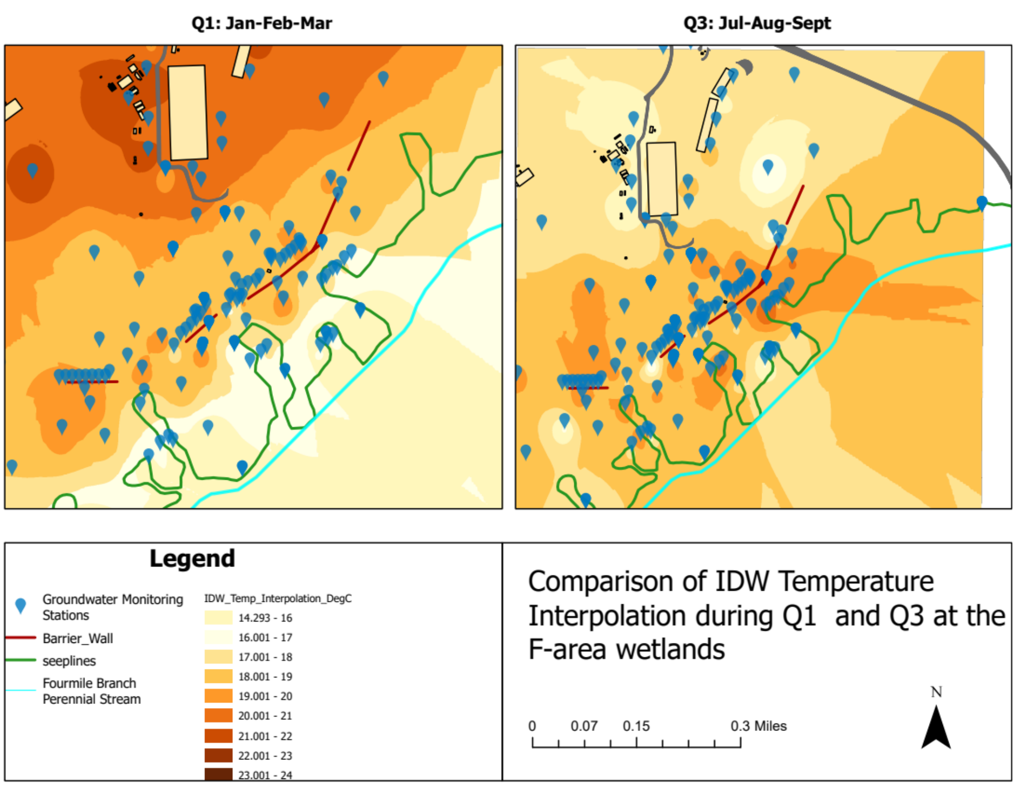

Figure 8.Compares the Temperature recorded during Q1 and Q3 at the Fourmile Branch Watershed in 2020

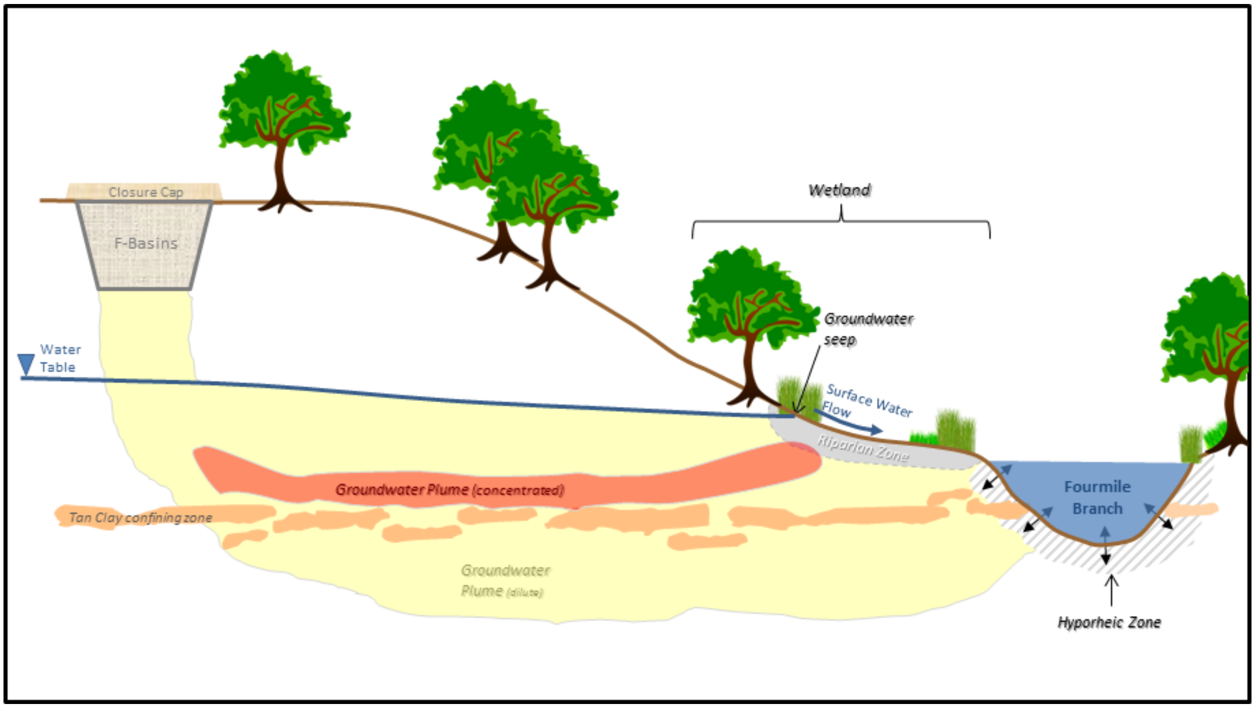

Figure 9. The makeup of Fourmile Branch watershed from the basins to the stream

Figure 9 also shows how the topography of the Fourmile Branch Watershed affects the temperatures recorded at different locations. From the monitoring data we can observe that in a groundwater well close to the basin (FSB95DR), there is minimal temperature fluctuations due to the thick layer separating the surface temperature and the groundwater temperature. On the other hand, we can see that for shallow wells (FPZ6A) and surface water monitoring points that are closer to the wetlands experience more temperature variations as seen in Figure 10. The surface water station FAS093 shows the most variation due to its exposure to surface temperature.

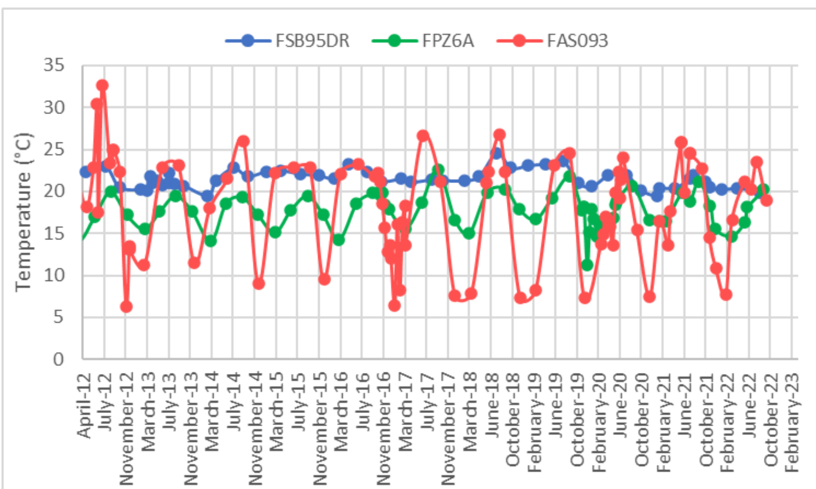

Figure 10.Temperature variations shown in relation to location in the Fourmile Branch Watershed

It needs to be stated that the temperatures used for the interpolations in figure 8 were not collected on the same day, simply the same quarter. The data was only used to understand how the temperature changes during different times of the year, but more information can be learned from the continuous spatially and temporally data that will be recorded after the installation of the temperature probes (Figure 11).

Figure 11. Images of the installation of the temperature probes

These probes were installed in 97 locations and will help researchers understand the biogeochemical processes that occur in the wetlands at the end of June 2022. After a few days of the probes being in the field, senior scientist Hansell Gonzalez-Raymat was able to extract temperature data from one of the probes. The results are shown in Figure 12.

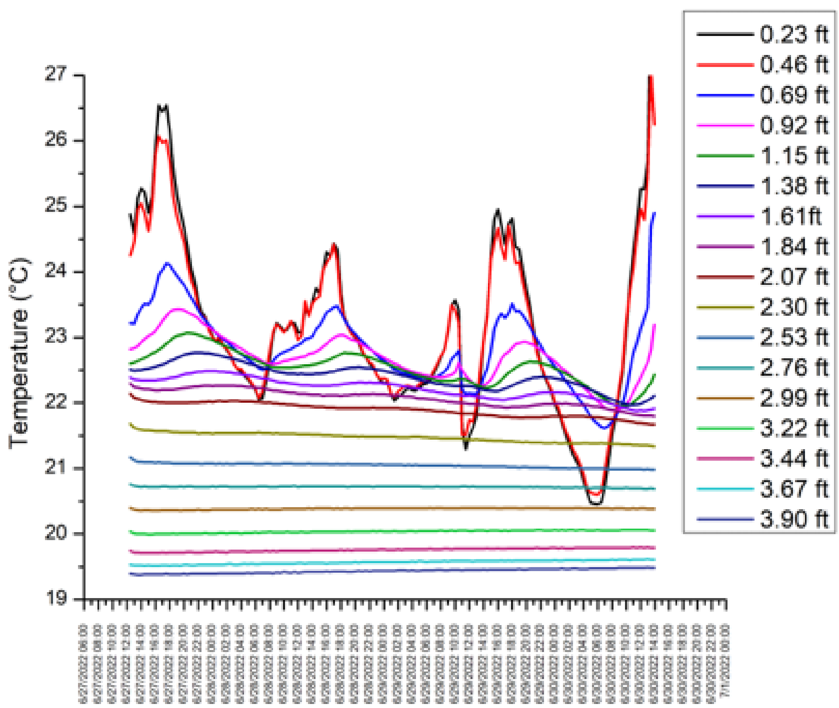

Figure 12. A time series of the temperature recorded a different depth at one of the locations where a temperature probe was installed

This data is over a span of three days and from the small-time span, more information is available to the researchers when compared to the previous quarterly data. By observing the data above, it proves that the temperatures near the surface have a higher variability. It also shows that as the depth increases, the temperature values have less variability due to it not being affected by the surface temperature as much. The results from this probe were collected in the summer so as the depth increases the temperatures recorded are cooler then the temperatures at the surface since the warmer atmosphere has less of an impact on the groundwater that is located at deeper depths. During the winter months, the opposite should occur. The temperatures at the surface should be cooler than the temperatures recorded at deeper depths.

The previous quarterly data and the continuous temperature data provided by the temperature sensors all help further understand the groundwater and surface water relationships in the F-area wetlands. During the internship, machine learning and GIS also aided in understanding the conditions of the wetlands.

<u>Pylenm</u>

PylenM provides machine learning functions for performing soil and groundwater data analysis, and for supporting effective long-term monitoring. This development is a part of the Advanced Long-Term Monitoring Systems (ALTEMIS) project. With PylenM we will be able to visualize the temperature at the different monitoring stations (Figure 13).

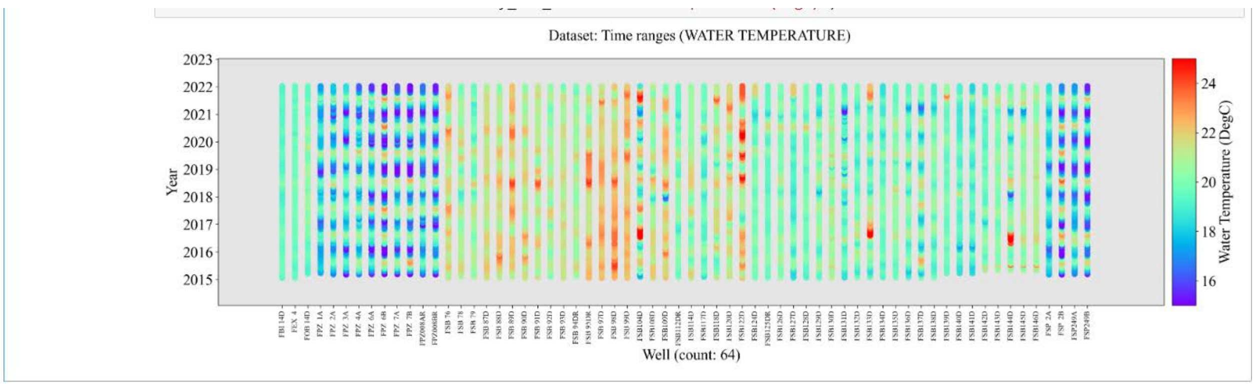

Figure 13. The temperature data from 2015 to 2022 shown on a color map

By creating this color map for all the monitoring stations, relationships can be seen. For example, stations starting with FPZ, which monitor shallow wells are located closer to the surface. Due to its proximity to the surface, the temperatures have higher variations since the atmosphere has a higher impact on the groundwater. For the shallow wells, the temperatures change in relation to the season, cooler temperatures during the winter and warmer temperatures in the summer. Similar patterns are shown with stations labeled with FAS, which monitor groundwater seeps. Stations labeled FSB are groundwater stations located in the upper aquifer. Those stations mostly show similar behavior in temperature between 2015 to 2022 throughout the year since there is not as much effect from the atmosphere. To sum up, from the heat map it might be possible to predict how the temperatures will react at different areas in the F-area.

<u>GIS</u>

GIS was also used to aid in understanding the F-area wetlands. Specifically, the F-Area is a braided stream which consists of a network of river channels separated by small, often temporary islands. Due to the tree cover it is hard to find and understand this braided stream system. A strategy was developed to use the LIDAR data which has the ground elevation for the F-area and subtract that from the water level records at each monitoring station. The water level data again was not spatially or temporally continuous and as a result, an IDW interpolation was done for the water level data during Q1 of 2021. By conducting an IDW interpolation a raster was created to interpolate the water level for the entirety of the F-area. By subtracting the ground elevation from the water level, areas where the water level is higher than the ground elevation can be identified. In the figure below, these areas are shown to be negative as the water level has a greater value then the ground elevation. In addition, in these areas, groundwater seepage possibly occurs.

The map shown in Figure 14 is simply an estimation since the water level is only an interpolation, however, this map does back up the information that is known about the F-area wetlands. For example, the water table moves closer to the surface the further downstream. The map demonstrates that perfectly as the shade of red becomes lighter demonstrating a smaller difference between ground elevation and the water table.

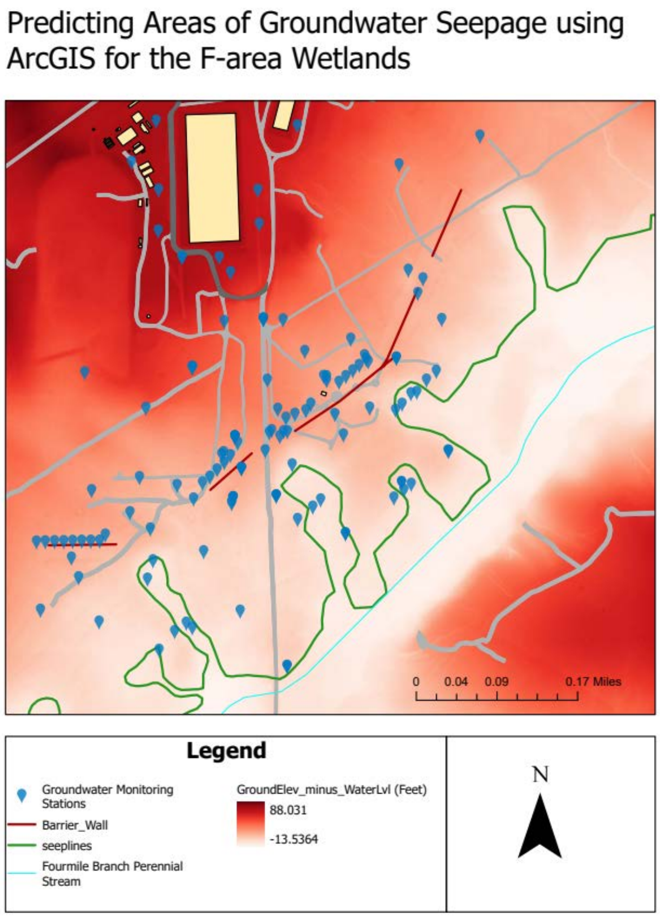

Figure 14. Raster Subtraction to help understand the braided streams in the F-area

A weakness in this map is that it only focuses on groundwater wells since the water level has not been recorded at surface water wells. During the end of year, continuous sensors will be placed in the wetlands which will then be able to collect continuous water level data at surface water wells. Another weakness in the map is that the resolution is too low. It is possible to see areas where the water level may be higher than the ground elevation, it is not possible to locate the braided streams in the wetlands. If more data is available and the resolution increases, a raster subtraction between the ground elevation and the water level can be done to find braided streams and areas where groundwater resurfaces.

4. CONCLUSION

The purpose of this research was to understand the nature of the interface between the emerging groundwater and the surface water which is a key regulatory compliance point. The nature of the flow from the subsurface to the surface stream water is poorly understood. Moreover, the geochemical behavior of contaminants at this interface over the long-term is dynamic and poorly understood. The lack of data that was collected made it difficult for researchers to understand the wetlands. Fortunately, in the summer of 2022, a distributed temperature profiling strategy was initiated in the wetlands. This strategy involved installing 97 temperature probes throughout the F-area. These probes have sensors that will be able to provide researchers continuous temperature data spatially and temporally.

Along with using temperature probes for the distributed temperature profiling strategy, other techniques were also researched. Examples of the techniques that were researched included thermal imaging, distributed temperature sensors, seepage meters, and by analyzing the presence of different isotopes. Different programs were also used to understand the relationship with the groundwater and surface water. PylenM, a program that provides machine learning, and GIS both helped aid in understanding the nature of groundwater seepage. The lack of data does make understanding the F-area harder while using these programs, but they do provide a strategy when more data is available. By the end of the year sensors will be installed which will be able to collect continuous data for different parameters such as temperature, pH, and water level which will all help understand the groundwater and surface water interaction. The goal of understanding the Groundwater-Surface water interphase is to eventually use the information to start building a conceptual model of the braided stream system in the F-area wetlands.

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