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Design and Development of a Web Mapping Prototype for Participatory Water Quality Mapping

Research Article

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Abstract

Citizen science is becoming more and more prominent in everyday life. With this growth in the participation and contribution of scientific research comes an ever-increasing amount of data and findings. The collection of water quality data is just one example out of a plethora that exists. While these types of data are being collected, there are very few open options that allow users to engage with said data. Further, with the continuous evolution of technology and the general public coming to understand how earth feature representations in a spatial format, we see the emergence of web mapping and ways to analyze data through different criteria or methodology. There seems to be a lack of a way for citizens to analyze water quality data in a spatial format that allows them to project either their findings or someone else's that can quickly deliver an idea of what is going on in the world's hydrological ecosystem. Through open-source software and over 40 years of local hydrological data, we have created an easy to use web map that allows for the interpolation of water bodies and the sample characteristics that exist within them. Given our results, this project has the potential to be heavily built upon and expanded through the inclusion of other interpolation methods, key historical data, and an expanding library of sample characteristics. We believe that this research will aid local communities in furthering their knowledge of the health and wellness of their bays, bayous, rivers, and more, and will encourage those people to continue their hard work and encourage others to get involved.

Keywords: Citizen science; web mapping; open-source software; water quality; Web GIS; interpolation

1. Introduction

As the use of geographic information systems (GIS) has continued to grow, it has also integrated with related methods such as machine learning (Bragagnolo et al., 2020; Jacobs & Mitchell, 2020) while also being influenced by evolving architectures such as software-as-a-service (Pegoraro, 2019). Having the ability to access data in an office or on the go easily has provided people further resources in being hyper-connected with each other, and of course, the data that is constantly consumed. This growth in the industry brings further interest and involvement in various areas of study, and one no longer needs to attend years of school and study to participate. Citizen science and web mapping are becoming more accessible (Zhang, 2021), which allows for people to delve into topics that interest them and wish to represent them in a spatial format (González et al., 2020; Granell et al., 2016). By encouraging this growth, there should be a continued push towards better data, science, and increased involvement in the world and the topics that make it up. Citizen science is not necessarily a new branch of the scientific community, and it can be traced back to the mid-1990s, where Alan Irwin defined it as "developing concepts of scientific citizenship which foreground the necessity of opening up science and science policy processes to the public" (Irwin, 1995). He believed that science should be a response to the citizens' concerns and that citizens could have the ability to produce quality scientific studies themselves.

Though the terms "citizen science" and "citizen scientists" did not enter the Oxford English Dictionary until June of 2014, one could argue that the concepts were alive and well long before then, whether it is a child with a telescope looking at the stars or someone with a chemistry set. As humanity learns more about the outside world and how it is affected by everyday human life (e.g., pollution & climate change), it only makes sense for people to get more involved in the scientific realm. Some organizations such as those discussed in this paper perform citizen science while participating in activities that they enjoy so that they can learn more about their surroundings and see how they are affected by humanity, and get ideas on how to change the way people live.

In April of 2016, the creation of the Escambia Water Quality Academy (EWQA) for the university would utilize citizen science data collected by the Bream Fishermen Association (BFA) over the last 50 years was proposed. While the data had been collected, to our knowledge, it was largely not put to use and had been sitting in the Florida Department of Environmental Protection's (FDEP) database STORET. This shortcoming was a motivating factor for our project and led to a collaboration between students, faculty, and local stakeholders with an interest in water quality data collection and dissemination. The goal of the project described in this paper was to integrate professional development opportunities for students into a collaboration with a local NGO (Bream Fishermen Association) to allow Universtion of West Florida (UWF) students to assist with ongoing BFA water monitoring efforts via the EWQA. Internal college funding allowed for two classes of UWF student volunteers to obtain water quality sampling training from the FDEP in exchange for their contributions to BFA sampling efforts.

Our initial investigation of the STORET data revealed that it was not in a standardized format. Further we discovered specific data discrepancies, such as listing items as zeroes or null values when they fell below the minimum detection level instead of leaving them as the true values. Also problematic was that the STORET data was stored in various spatial datums, which complicated the geocoding process. Because of these challenges we early efforts on our project consisted of laborious data cleaning, with only a short amount of time spent the production of cartographic products (e.g., dot-density map comparing the number of stations to watersheds). This paper focuses on the later phase of our project, where we created a web map prototype that will allow for geospatial analysis of water quality sampling data. Based on end-user/stakeholder feedback, the focus of the web map design focused on providing functionality for the interpolation of water quality metrics across defined water bodies. The web map prototype was built with the idea to expand the project in the future for additional geospatial analysis functionality.

2. Background

Water quality testing plays a major role in environmental science study as it allows humans to realize their relationship with the planet (Butler et al., 2016). Knowledge of water quality and how the associated hydrologic system naturally ebbs and flows is vital (Hansen et al., 2015; Seelen et al., 2019). Human interaction with water bodies can directly impact associated chemical levels. Further, water characteristics can vary based on spatial location and the movement of water. Shomar et al. (2009) states "Groundwater contamination can pose serious health and economic threats to the population that relies on this water for drinking, agriculture, and industry uses" (pg. 1). People may often think of water bodies as singular entities that sit dormant. Whatever may be in one body will have no effect on the area around it or neighboring water bodies simply because they see no physical connection/relationship occurring. Unfortunately, this is not true, and the scary reality is that the water is constantly being polluted.

While a simple data table with rows and columns may suffice, or even graphs, by creating a web map, a whole new way of interacting/interpreting the data can be realized. Users of web mapping applications for citizen science have become accustomed to fast performance and user-friendliness (Newman et al., 2010; Lukyanenko et al., 2019). GIS is already quite powerful in that it allows for information to be studied in an understandable manner. However, by combining it with a web map, it now becomes easy to access through the ability to use it on smartphones, tablets, computers, etc. This project's original intention was to create a web map for the user that would show water quality stations and relate a table that would house historical data. We added interpolation functionality to our web application design to facilitate the ability to estimate water quality within the resulting web maps. Using spatial interpolation through a technique called Inverse Distance Weighted (IDW) allows the data to be generated into estimated cell values based on distance from output points with a surface grid (Asadi, 2007).

IDW considers the sampled values and distance to nearby known points, gives each sample point a weight that is the inverse proportion of the distance, and can give the estimated value for the unknown points. To obtain a visual interpretation of these data and how it is spread out over the testing area, a technique called "tessellating" is used. Tessellations are shapes (most commonly squares and triangles) laid out in a grid format and placed over the study area. The grids are clipped to the shape of the study area so that more accurate values may be determined based on how many grid cells there are total and their shape. Values are then linked to the cells via proximity to, in this case, a water quality monitoring station. A cell close to a water quality monitor station has the measured value, while cells further away have an estimated value, a method of which is described by Gold (2016). By estimating water quality across the cells, we attempt to get beyond static representation and provide an interactive map that allows the user to interpret the data. This opens the user's ability to simply select a cell in the grid, covering the water body in question and allow them to obtain a glimpse of the characteristic measurements being identified in the study area. Having access to this technology in the field or even back in the lab gives both citizens and regular scientists more power at their fingertips for research and interpretation.

Roth et al. (2017) argue that cartographers are well-positioned to take on user experience (UX) designers on mapping and GIS projects. An important part of that design process is the utilization of wireframing methods to prototype how a web mapping application (aka Web GIS) should look and function. A common way to work towards web GIS design is through the use of wireframes. Wireframes are "the blueprint for design" (Bank, 2014) of an interface such as a proposed Web GIS. They are illustrative of the proposed structure, content, information hierarchy, functionality, and behavior. A wireframe can be low-fidelity (rough sketch) or high-fidelity (representative with sample data). The low-fidelity wireframe should be useful for providing a more general context of where interface design elements will fit within the information hierarchy, while the high-fidelity examples are more illustrative of how they will look (informed by the previously prepared prototype map scenarios). Roth et al. (2017) provide a useful example of where the process of wireframing can be used within a Web GIS user-centered design process. By using wireframes early in the design stages of a Web GIS, we can reduce uncertainty in the design of the proposed Web GIS.

Further working towards the creation of Web GIS requires a database to hold the information being studied and presented to the end-user. With spatial database design in mind adopting the standard language of database design proposed first by Codd (1970) – who is credited with proposing the relational model that would become the standard for database management systems -- Later this approach of conceptualizing debases would be formalized by Chen (1976) in his entity-relationship(-data) model (or ERD). Noting that current GIS design methodologies do not treat the database design problem with enough detail, Calkins (1996) offered an explicitly spatial extension to ERD modeling. It could be argued that GIS practice still does not treat database design with an appropriate level of detail. One difference between now and when Calkins (1996) proposed this model is that spatial functionality has found its way into more mainstream database software ranging from Microsoft (or MS) SQL Server to the open-source standard of PostgreSQL with its PostGIS extension.

Until recently, desktop GIS software—which was dominated by a small group of commercial enterprises—was primarily used by select professions and specialty groups (Goodchild 2013; Tsou 2011). With the increasing availability of web mapping application programming interfaces (APIs) and free and open-source geospatial software (termed FOSS4G), those tasked with the job of developing and designing web-based geographic information system (Web GIS) applications are faced with the question of how to (re)develop new and existing capabilities. While Web GIS does often reproduce features currently available within desktop GIS, usage requirements often demand it be both easier to use and more specific in its purpose. Interaction as a subject of study within Web GIS builds upon established Window-Icon-Menu-Pointer modes of graphical interaction, such as changing the scale (zoom), location, and the ability to pan the map interface (You et al. 2007; Manson et al. 2012).

Studies that have focused on the map interface as an area of interactivity, or cartographic interaction, are mostly concerned with communicating information from the cartographer to the map user (Crampton 2002). However, a Web GIS often provides interaction methods beyond the map, such as layer toggle checkboxes that are peripherally located on the map itself. HTML5, or the fifth revision of HTML, represents a group of web browser technologies with many goals focused on increasing usability and platform independence by reducing the necessity of plug-ins (Sarris 2012; Taivalsaari & Mikkonen 2011). Leaflet, an open-source mapping API written for JavaScript (the de facto standard scripting language for HTML5), was selected for the interface software architecture in our prototype for participatory water quality mapping. Finally, modern web development techniques offer the ability to do server-side programming with what were traditionally client-side scripting languages. Specifically, Node.js allows for the server-side Node.js applications, operations involving sockets, streams, and files are typically performed in an asynchronous manner, where the execution of listeners is triggered by events (Alimadadi et al. 2016; Madsen et al. 2015).

3. Methods

Through early work on this project and in the initial stages of design, we had an idea of what the final prototype would look like. Specifically, knowing that we would be incorporating as much existing water quality data as we could (e.g., from STORET and other local organizations) was a big part of the mockups. We began this research project in April of 2016 as an undergraduate focus and would meet as needed. When the project shifted focus to that of thesis research, the meetings became more regular, with most as frequently as once a week, sometimes twice a week when deemed necessary. There was constant communication that included messages, phone calls, and video chats. To get an idea of where the project would end up, we began by visualizing the end of the research project and laying it out in UML and wireframe diagrams, as shown below. Having the data early on and knowing what we wanted to focus on (though it became more focused as time went) helped steer us towards the direction that we ended up taking. We had previously done work with a student in which they designed a web map that performed interpolation, so there was some basis of knowledge to go off of; the only caveat was that the previous work was done using COTS (ESRI's ArcMap) while we were attempting to create something similar in open-source software. These early efforts drew feedback from a science teacher who leads a marine science academy at a local high school.

Figure 1 shows a high-fidelity wireframe that was shared with the client, which served as a discussion piece. In prioritizing functionality, it became apparent that a map that showed interpolated sampling values across the water bodies' surface would be of great value. Therefore, it was decided to make the final deliverable in terms of web mapping functionality be a map that could inject new sampling station data and show these data interpolated across a surface. To keep the development of the prototype tractable, we decided to only work for the time being on getting this functionality working across two water bodies (Bayou Texar and Escambia Bay), as well as only focusing on two sample characteristics (dissolved oxygen and nitrogen) which were deemed a top priority by the client.

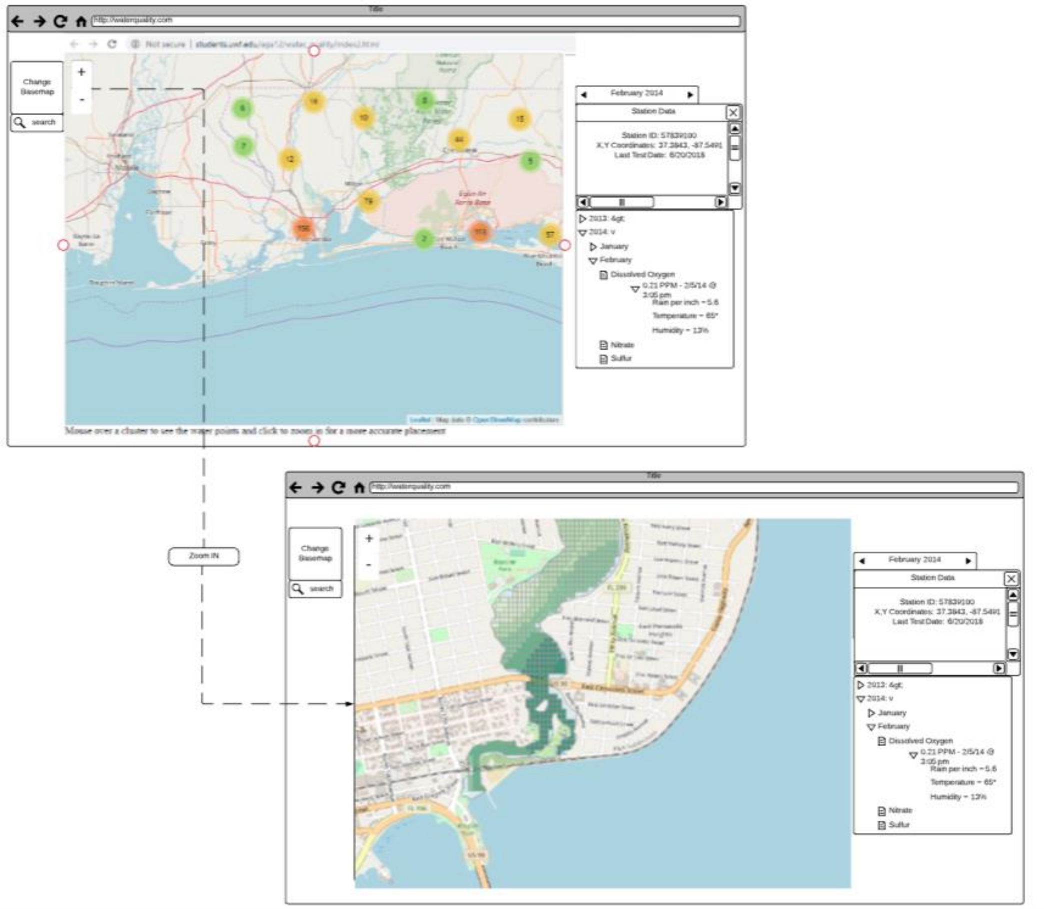

Figure 1. Hi-fidelity wireframe (early design)

Figure 2 is an early use-case diagram that depicts how we thought a fully formed website/web map would have users access it to contribute to data and simply benefit from it. It was imagined that we would have two different methods of "user access." Those who had collected water samples and wished to upload their CSV to either just add data or to create an interpolated map would need to log in with a username and password. By logging into the website in order to contribute, it was thought this would hopefully deter someone from just adding in "garbage data" that would make our product more vetted and desirable for trusted scientific use and analysis by being able to control our database better. Those who did not have data they wished to contribute could simply access the presented data freely and could benefit from what the community had provided to them. While QA/QC is mentioned in this diagram on the right side, it has not yet been built into the product. The idea was to have a script that would run through the uploaded file (which must be a CSV or it will not upload) and determine if the formatting of the data that we would specify in order to keep the database and information clean and in a uniform manner had been met before adding it to be processed. This is still a feature that is under consideration for future development.

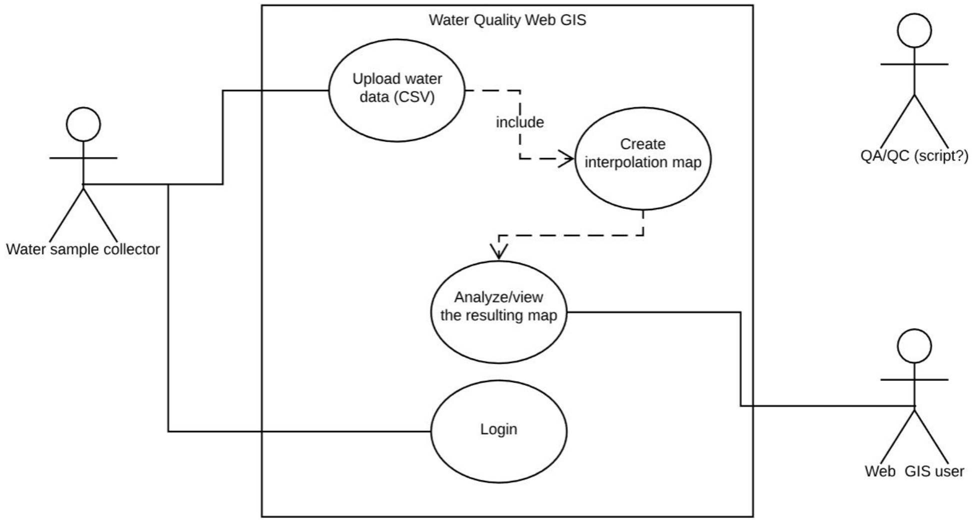

Figure 2. Use-case diagram

Figure 3 is an ERD that gives an example of how we structured our database. By laying it out before the actual database design, we were able to talk through what data would be represented in the final product and discuss how the data is related to one another, what it represents and how it informs the web GIS design. A basic explanation of the tables and how the data relates to one another is this:

1. The table water_bodies has a zero-to-many relationship with the table sample stations because while a water body may exist, it does not explicitly contain a sample station. However, at the same time, it may also contain more than one sample station. Also, the water_bodies table contains a field called "grid_geom," which is the interpolation grid and brings into play the spatial aspect of our data.
2. The table sample_stations has a zero-to-many relationship with water samples because while a station may be present in a water body, it might not necessarily have any data that has yet been recorded. On the other hand, a sample station may have many samples that have been recorded.
3. The table sample_characteristics has a zero-to-many relationship with the samples table because we may define certain characteristics that can be measured (e.g., dissolved oxygen). However, no specific samples of that characteristic may be supplied.

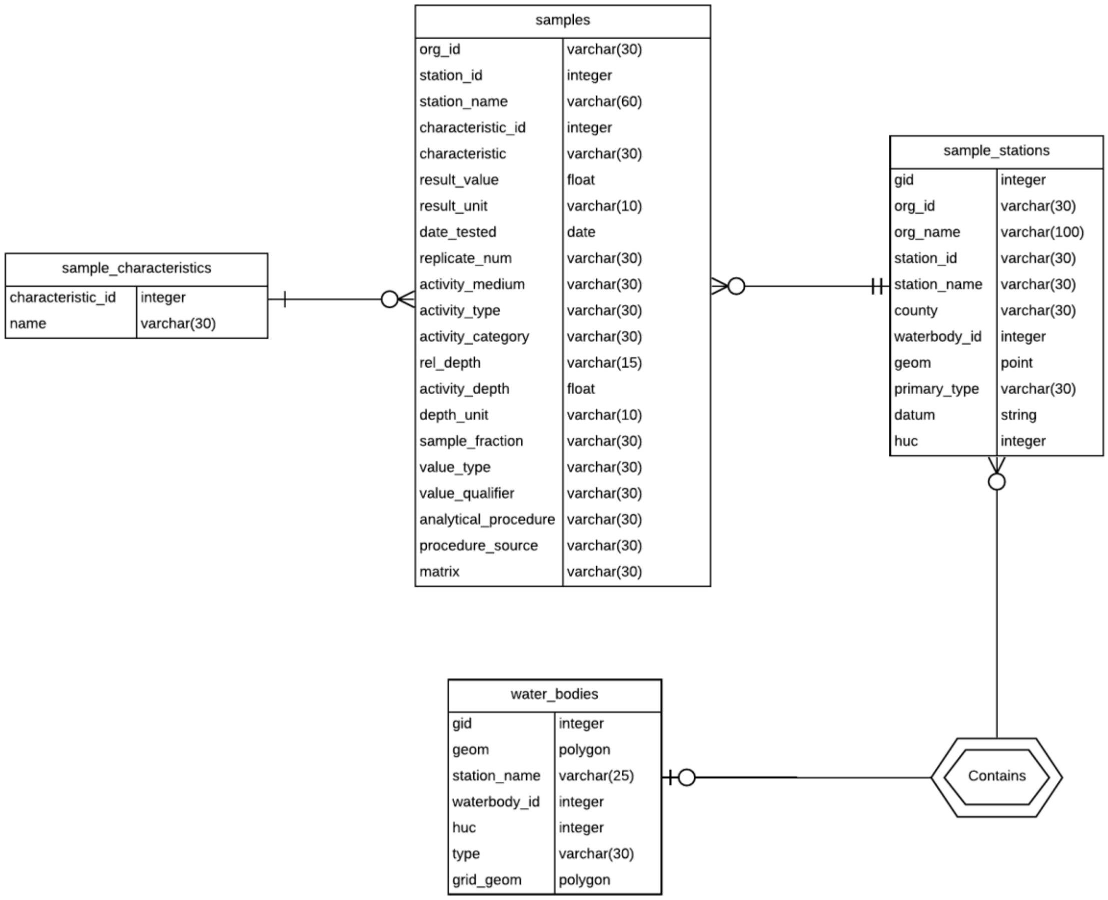

Figure 3. Entity relationship diagram

Finally, the spatial relationship between the interpolation grid and the sample stations was of particular importance in our prototype design. Having a gridded surface to compare to our area under study (e.g., Escambia Bay) was a necessary step in our interpolation, but having the ability to clip the grid to the waterbody was particularly helpful for quantitative and visualization purposes. To accomplish this task, we utilized PostGIS functionality, which allowed for spatial comparison of the water body boundaries to the grid and a resulting clipped surface.

Figure 4 depicts what more in-depth conversations between us about how users and those providing data to the product would interact with it in a technical aspect. The top section shows that of the water sample collector (or "citizen scientist") and how they would log in to their account on the website and select a waterbody to add data to (if a waterbody did not have an existing shapefile, it would need to be requested for us to input it), they would upload their CSV containing sample data which would be run through our script to vet it. If everything was fine, it would be added to the data. They could then log out of their account and interact with the web map. The bottom section depicts the flow of how a normal web user would interact with the product. They would access the website, select a waterbody to map, query the properties/characteristics that they were looking to analyze (such as all dissolved oxygen for Bayou Texar that occurred between 1999 and 2006 that was above 3.4 ug/l), and then be able to analyze/interact with the displayed information. This is something that is still being worked on/built upon and has been an idea for how the web map would be utilized from the start, especially that of the role of the "Web GIS User."

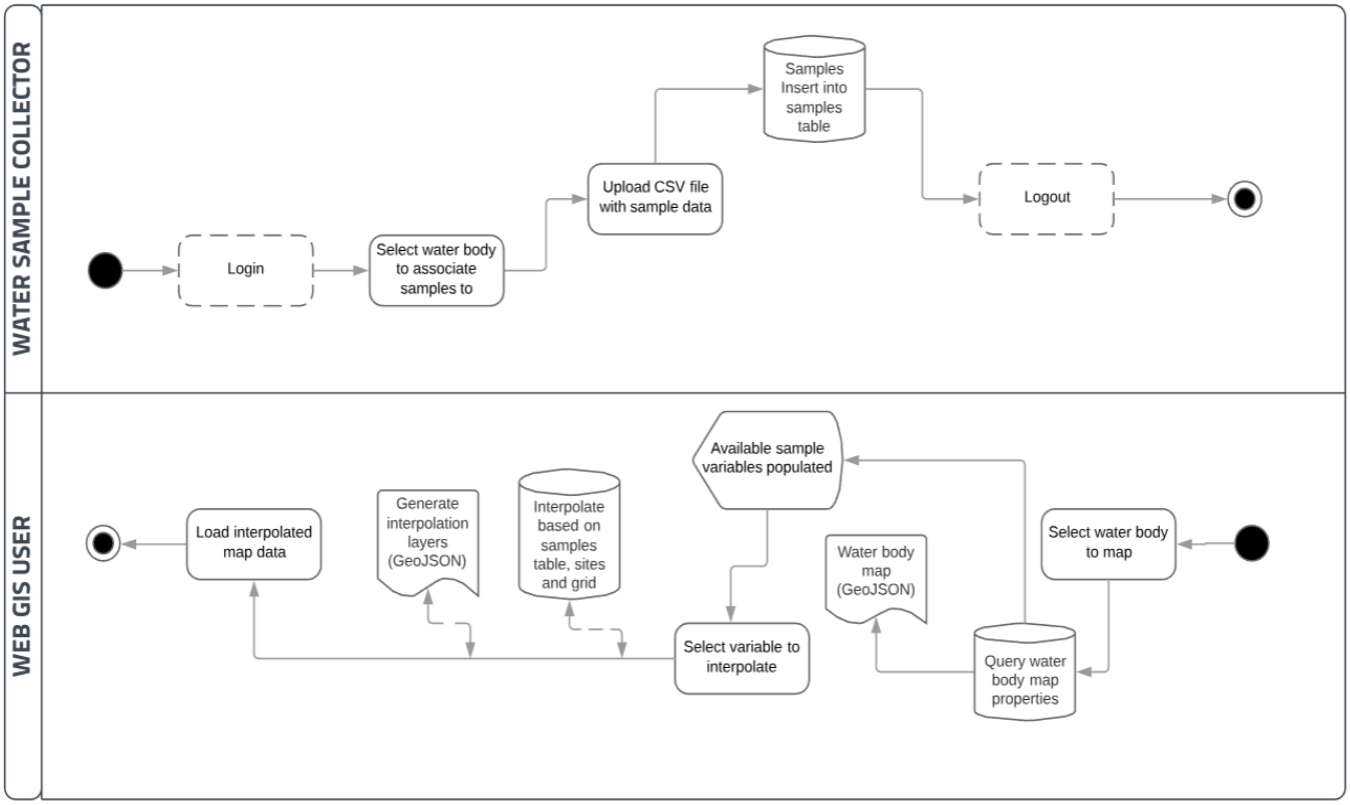

Figure 4. Activity/sequence diagram

Figure 5 is a late-stage design, something that we mocked-up within the last month or so to depict what we think and hope the project's future development will bring along. Currently, the webpage from a front-end development point of view is very plain and lacks creativity with a lack of aesthetically focused design. While it has user-specific functionality that we have imagined, it can be improved upon to be more visually pleasing. On top of that, a better job can be done that allows for a much smoother flow in uploading new data or requesting data from the server to allow the user to analyze records. Based on feedback from conversations had with potential users of the proposed system and questions received during presentations at conferences, we would like to offer several different interpolation options in the future. Rather than just having IDW, we would like to compare to see how the data can be analyzed using Kriging and Spline methods. By offering more than just one method for interpolation, we hope that this would bring interest to our research from more parties who may benefit from what we have built and are trying to provide to the community both in the area and for other populations that may be interested.

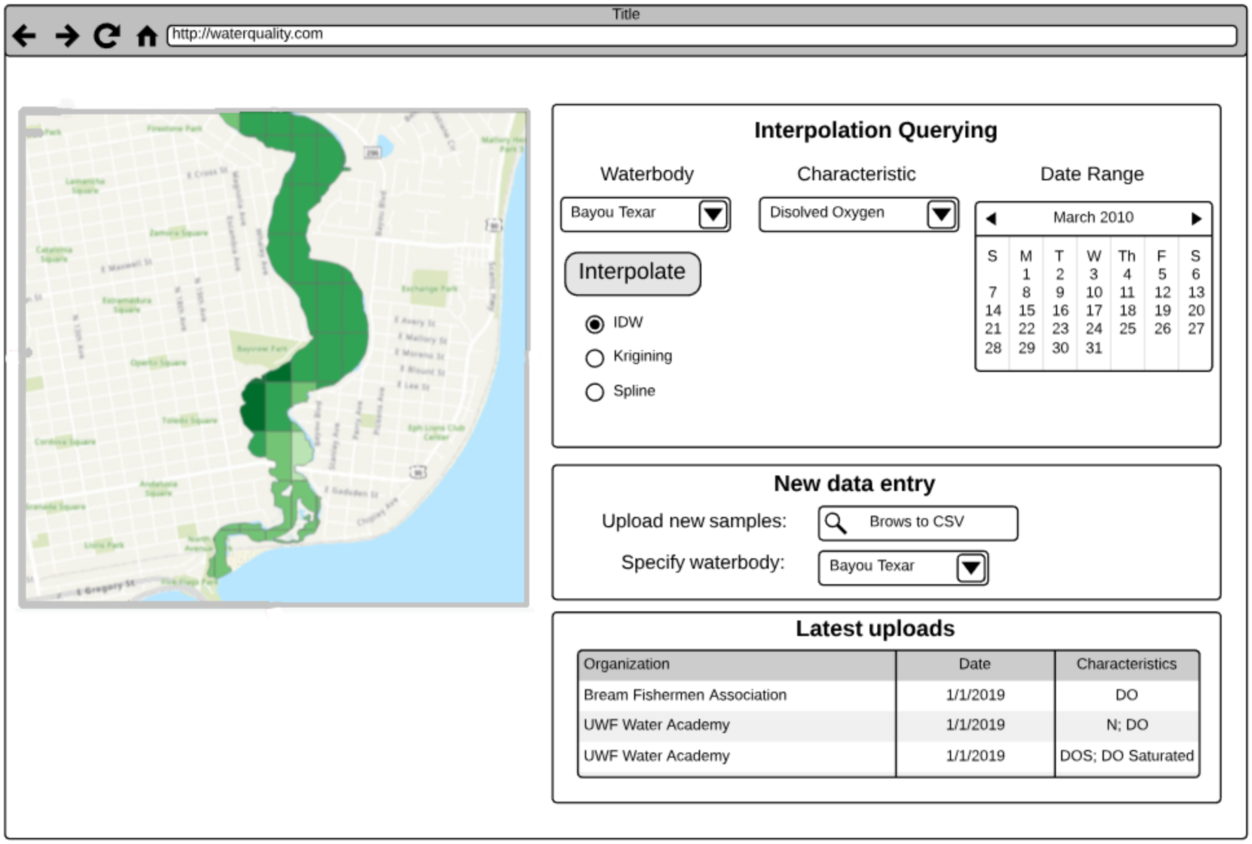

Figure 5. – Hi-fidelity wireframe (late design)

4. Results

After developing the prototype and documenting its functionality and purpose, we were prepared to present its potential to citizen scientists for feedback on its potential usability and usefulness. We presented the prototype at one major national conference (American Association of Geographers 2019, Washington DC) and two regional GIS workshops (GIS of Alabama 2019, Orange Beach & Northwest Florida GIS User Group 2019, Pensacola, Florida). The AAG presentation was well attended, and audience members expressed interest and solicited more information regarding the proposed Web GIS. Specifically, one attendee who serves as a GIS manager at the state agency water research group noted that they would greatly benefit from having a tool to bring together disparate water quality sampling into a single usable web mapping application such as the prototype building.

The functioning prototype source code was maintained in GitHub, which allowed for collaborative development and source control (see https://github.com/orgs/WQWebGIS/). The actual programming language source code consisted of 96% JavaScript, 2.2% SQL, and an additional 2% HTML and related styling syntax. The actual demonstration of the prototype took place in a local web server environment, which was not deployed to a production server environment. However, we did record a demonstration of the functionality for presentation and feedback purposes (see https://youtu.be/T5-UiFkc3jw).

Finally, at a meeting with a key stakeholder for the EWQA, we revisited the three critical pieces of functionality that were prioritized from our earlier meetings on 1) switching between water bodies; 2) the ability to upload water quality sample data; and 3) providing the ability to produce an interpolated web map by way of newly provided water quality data. In this final meeting, we highlighted and covered that the prototype now provided the ability to upload water quality sample data and have a resulting thematic web map based on the estimated values. Due to the scope of time available to this project, we had to focus our efforts on the two agreed-upon functions for the web mapping prototype (upload of sample data and a resulting map interpolation). With additional time and resources, we have considered the following needed functionality to focus on:

- Host the code and website on a dedicated server
- Include other water bodies and possible expand this project to other counties
- Include more sample characteristics, especially those that are vital to the knowledge of water quality (i.e., fecal coliform, DDT, E.coli, etc.)
- Build a history function into the station points
- Build authentication/profile functionality so that users have persistence in sessions
- Adding the functionality to allow users to add data from the field
- Add in the functionality so that users may add in their water bodies rather than waiting for them to be hardcoded into the web map
- Work with a graphics team to design a logo and color scheme for the website
- Meet and present with potential "clients" who may be interested in testing and using our product

5. Conclusion and Discussion

In conclusion, we have shown that it is feasible to build an interactive web map that allows the functionality to perform spatial interpolation on the fly using citizen science data and open-source software. We have seen that it is imperative when creating or using a database that good data maintenance is needed, as many hours were spent just cleaning up records. This taught us through the necessity to have a database in which strict regulations and data formatting should be set by the designer to disallow such errors to exist. We determined that while there is software on the shelf that may perform the tasks that we sought, we could build something similar on our own and give it the functionality that we wished it to have without spending anything other than time. We also determined that there is a severe lack in technology that serves water quality analysis, especially for those who may be in the realm of citizen science, and so we have a potential major gap to fill. This brings me into my next point which is the future of this project and its development.

While this project was initially slated to be just a one-semester undergraduate thesis project, it progressed into a master's degree capstone and resulted in a functioning web map prototype. Future efforts on this project have been discussed and include potentially comparing IDW interpolation to kriging, natural neighbor, etc. Moreover, would be the potential to present this project to other community members such as the BFA to get letters of support showing how this would benefit potential users. This would ultimately be used to help move the project forward and get the financial backing that would allow us to hire people to help the project continue to grow.

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