Fluid: a Mobile Application for Communicating Water Quality Information to Recreational Water Users in the Hudson River

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The presence of contaminants in our rivers, streams, lakes, and oceans pose a threat to the health and safety of recreational water users such as people who swim, paddle, boat, or fish. Though monitoring the quality of these bodies of water is technologically feasible, it is not practiced effectively enough to protect the people it affects. Communicating the quality of water to the people who interact with water is crucial, especially in today's billion dollar market for water sports [1]. In this study, we evaluated people's motivations, wants, and pain points related to water quality information and communication, specifically along the Hudson River. The target groups of the study included people in New York and New Jersey who partake in recreational river activities such as swimming, paddling, boating, and fishing on the Hudson River. We used several research methods including literature reviews, competitive analysis, interviews, usability tests, and field studies. From our research, we designed a mobile application that effectively communicates water quality information to people who use the Hudson River so they can stay safe and healthy while partaking in the river activities they enjoy.

CCS CONCEPTS • Human Centered Design • User Research • Usability Testing • User Interviews • Field Study

Additional Keywords and Phrases: Water quality data, Mobile application, User experience

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1. INTRODUCTION

In the US, an estimated 4 billion water recreation events take place annually, resulting in an estimated 90 million illnesses [2]. These waterborne illnesses include gastrointestinal and respiratory illnesses, ear infections, and skin manifestations [3] and are caused by a variety of agents including bacteria, viruses, and parasites [3]. Chemicals are also a source of waterborne illnesses; severe water pollution, often centralized in urban cities, is one of the major problems affecting the environment [4].

1.1 Problem space

Between the 1940s and 1980s, General Electric (GE) dumped millions of pounds of polychlorinated biphenyls (PCBs) into the Hudson River [5]. PCBs are extremely dangerous; they can cause liver, kidney, and nervous system disorders, as well as developmental and reproductive abnormalities [5]. PCBs are known as “forever chemicals” because they do not break down over time; a significant amount of PCBs still remain in the Hudson River. [5]

In this study, we collaborated with Blue CoLab, a training, innovation, and research program for Water Quality Monitoring (WQM) technologies [6], to design a solution to communicate water quality information to Hudson River users. Our goal was to provide the river user community with the information they need to make informed decisions for their health and safety, while partaking in river activities such as swimming, paddling, boating, and fishing.

2. LITERATURE REVIEW

2.1 Water quality monitoring technology

In our aim to report accurate water quality information to the community, we considered the Water Quality Monitoring (WQM) technology available. In Choate Pond in New York, Blue CoLab's solar-panel powered water monitoring stations "Ada" and "Alan" measure Water Quality Index (WQI) parameters, including temperature, pH, dissolved oxygen, turbidity, and salinity, every fifteen minutes [6]. This is just one example of the water quality monitoring technology available. Additional Wireless Sensor Networks (WSN) have been instrumented for Water Quality Monitoring (WQM) in the past decade, and other WQM techniques exist in practice such as artificial sampling, automatic and continuous monitoring, and environment monitoring with remote technology [7]. These techniques overcome the challenges of manual

WQM, including human error and equipment error [8]. While this WQM technology is available for implementation, largely WSN, data security during water quality transmissions remains a major issue [7].

2.2 Data communication

In our aim to report water quality information to the community, including numerical measurements of contaminants, we considered the interaction between numerical data and people. Numerical measurements without familiarity or appropriate contextual clues are un-relatable to people, and consequently become incomprehensible, and therefore irrelevant [9]. According to Nsiah-Kumi [10], data reported to the community must be understandable, relevant, and relatable, in order to successfully communicate potential health or safety risks. To make data understandable, relevant, and relatable, visual interpretations of data prove useful even when dealing with complex problems such as environmental changes [11]. Effectively communicating environmental data, such as water quality, can be done visually to help bridge the gap between scientific data and personal comprehension [12]. Kaufmann [13] mentioned that data recall is also a barrier associated with traditional data communication, and that art and visualization can tackle this barrier by helping people recall data more accurately.

3. METHODS

3.1 Generative Research

To get a deeper understanding of the relationship between recreational water users and water quality, we conducted generative research to uncover user motivations, wants, and pain points relating to water quality and water data. Our research helped us answer the following questions: Why do recreational water users want information about water quality? What do recreational water users want to know about water quality? What frustrations or concerns do recreational water users have with finding information about water quality?

3.1.1 Competitive analysis

We looked at existing platforms in the same or similar field, namely Swim Guide, Riverkeeper, Edeya, Paddle Ways, and Air Visual, to help answer these questions, and get an idea of market gaps or potential areas of improvement. Our insights helped us understand what we want to achieve and what we want to avoid when aiming to improve the interaction between water quality data and people.

3.1.2 Interviews

We gathered qualitative data through 12 semi-structured interviews, so that we could address our main research questions on user motivations, wants, and pain points relating to water quality, leaving room for follow up questions to gain deeper insights. Our target group for these interviews were people in New York and New Jersey who partake in recreational river activities such as swimming, paddling, boating, and fishing. In our research, we included vulnerable communities such as older individuals and immunocompromised individuals, who are at high risk of infection by serious waterborne illnesses [3]. We also included a mix of genders and ethnicities in our participant pool to ensure accurate representation of our potential users. Our screener survey helped us recruit participants in our target group.

Some of the questions from our interviews involving user motivations: What recreational water activities do you partake in? Tell me about how and when you do this activity. Is water quality a concern when you do (that activity)?

Some of the questions from our interviews involving user wants: What would you want to know about the water you are interacting with? Why would you want to know that? How often would you want access to that information (about water quality)? If you could access this information in any way imaginable, how would you want the information communicated to you?

Some of the questions from our interviews involving user pain points: Have you ever tried to find information about water quality? Were you successful? If yes, what helped you reach your goal? If not, what prevented you from reaching your goal? What would have improved this experience for you? Have you ever had a negative experience with (activity) because of the water quality? Would anything have helped you avoid or better navigate this situation?

We conducted thematic analysis on our qualitative data in an affinity diagram, shown in Figure 1.

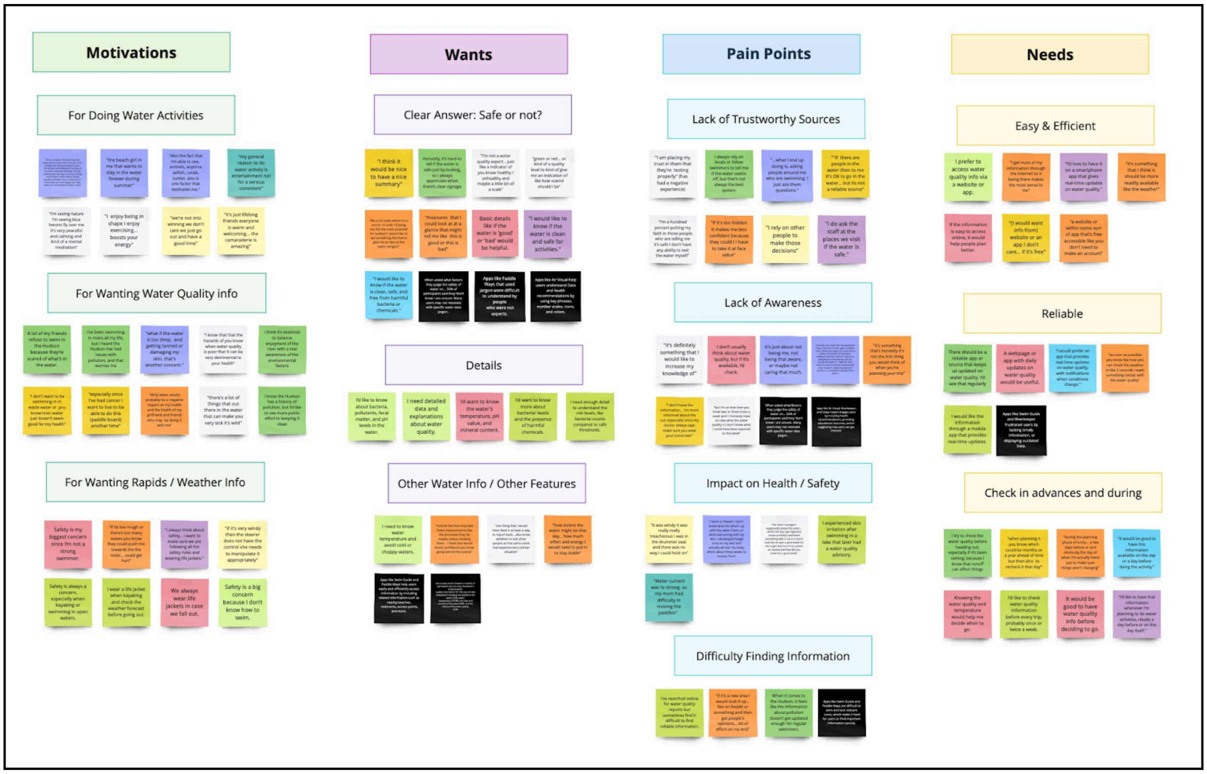


Figure 1: Affinity diagram from user interviews.

3.1.3 Findings

Users want a clear answer to whether or not the water is safe, as expressed in the following interview quotes: “I could look at a glance that might tell me like this is good or this is bad." “Basic details like if the water is 'good' or 'bad' would be helpful.” “I would like to know if the water is clean and safe for activities." “Green or red... give me an indication of like how scared should I be." Clarity of information was also a key finding from our competitive analysis. Apps like Air Visual helped users understand Data and health recommendations by using key phrases, number scales, icons, and colors.

Users want relevant water information including temperature and rapid class, as expressed in the following interview quotes: “I need to know water temperature and avoid cold or choppy water.” “If it's too rough or there's too many waves... could get hurt." “Safety is my biggest concern since I’m not a strong swimmer.” Relevant information was also an added value to some applications found in our competitive analysis. Apps like Swim Guide and Paddle Ways helped users easily and efficiently access information by including related information such as nearby beaches, restrooms, access points, and more.

Users want detailed information about water quality components, as expressed in the following interview quotes: “I need enough detail to understand the risk levels.” “I need detailed data and explanations about water quality.” “I’d want to know the water's temperature, pH value, and mineral content.” Users also want to be more informed and aware of water quality information, as expressed in the following interview quote: “It's definitely something that I would like to increase my knowledge of."

Users want to check expected water quality information in advanced / while planning activities, as expressed in the following interview quotes: “During the planning phase of a trip... a few days before.” “It would be good to have water quality info before deciding to go.” “Whenever I’m planning to do water activities, ideally a day before.”

Users want to know how the water is tested, as expressed in the following interview quote: “Include like how they take these measurements, like the processes... I think that would boost confidence you know going behind the scenes." Apps like Swim Guide build user trust by showing information about how the water is tested.

Users want to report water quality conditions to others and read other people’s experiences, as expressed in the following interview quote: “I would have liked at least a way to report back... also know whether or not other people at that same event had experienced a similar situation."

Things to avoid included jargon, data gaps, and long text. Apps like Paddle Ways that used jargon were difficult to understand by people who were not experts. Apps like Swim Guide and Riverkeeper frustrated users by lacking timely information, or displaying outdated Data. Apps like Swim Guide and Paddle Ways are difficult to skim and lack relevant icons, which make it hard for users to find important information quickly.

3.2 Usability Test

After our first iteration of the design for a mobile application that communicates water quality information to Hudson River users, we conducted 8 usability tests. Our participants had a mix of technology proficiency, and were all people who participate in river activities such as swimming, paddling, boating, and fishing.

3.2.1 Task selection and measurements

Our first usability task: find out the pH level of the water at your location. Our research found that some users were interested in knowing details about water quality so they can stay informed, so this would be a common use case. On our home screen we did not want to overload users with detailed information (like pH levels), so users had to click to 'view details' for this task. During our usability testing, we hoped to find out if this information was easily accessible to users.

Our second usability task: find out the water quality forecast for next Monday. Our research found that some users were interested in checking water quality estimates in advance so they can plan their trip, so this would be a common use case. Since we didn't list every day of the week on the homepage, finding the forecast for Monday could be a tricky part of the design. During our usability testing, we hoped to find out if the path to this information was intuitive to users.

Our third usability task: find out how water was tested at your location. Our research found that some users were interested in knowing how the water is tested so they can build trust with the company, so this would be a common use case. We had designed this information under an "awareness" tab where users can learn more about the water testing process and the history of water quality in their area. During our usability testing, we hoped to find out if the navigational tabs and corresponding icons lead users to the information they were looking for.

We used quantitative measurements including SUS survey, success rate, number of confusions, and time on task, as well as qualitative measurements including notating quotes from the participant, and notating expressions, gestures, and body language from the participant.

We conducted thematic analysis on our qualitative data in an affinity diagram, shown in Figure 2.

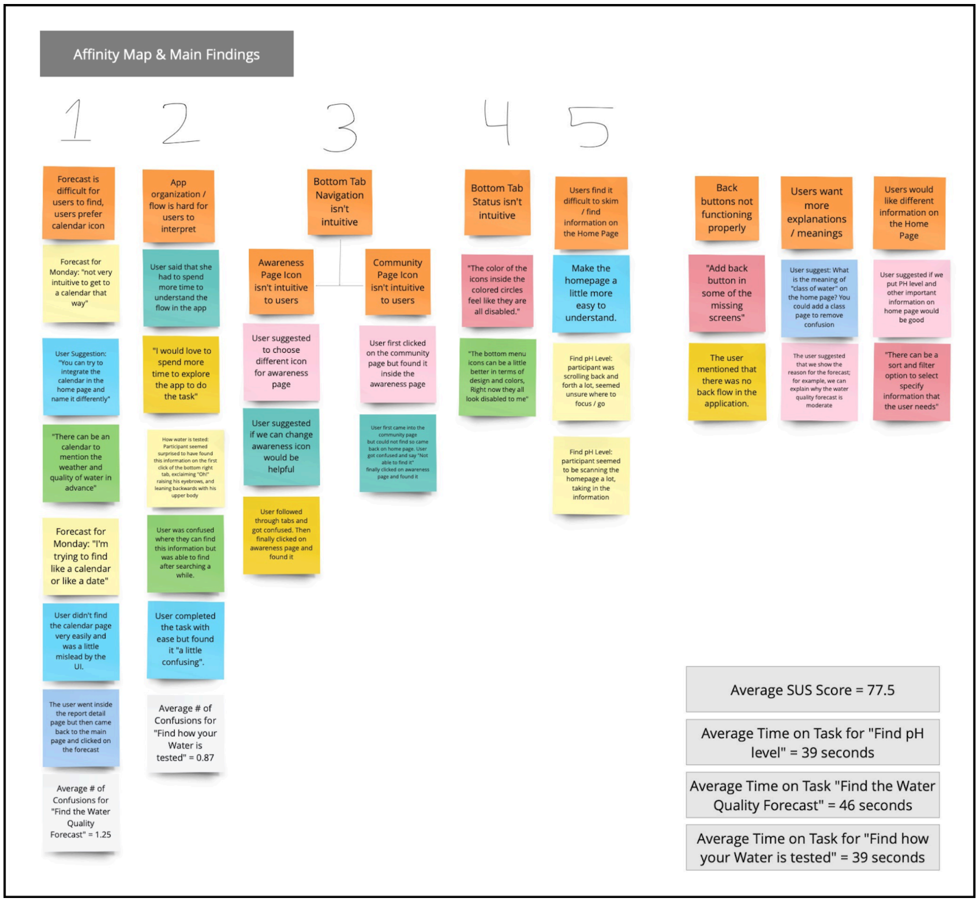


Figure 2: Affinity diagram from usability tests.

3.2.2 Findings

Our first finding was that the forecast was difficult for users to find, and users prefer a calendar icon. The average number of confusions for the task "Find the water quality forecast" was 1.25, which tells us that most users were confused about how to find this information. One user went inside the details page first, but then came back to the main page and clicked on the forecast. One user was scrolling around a lot and mentioned, “I'm trying to find like a calendar or like a date." Other users who had difficulty finding the forecast suggested a calendar icon would be more intuitive to them as well: “There can be a calendar to mention the weather and quality of water in advance" and “You can try to integrate the calendar in the home page and name it differently."

Our second finding was that the app organization was hard for users to interpret. Two users mentioned needing more time to understand the app: "I would love to spend more time exploring the app to do the task" and “(I) had to spend more time to understand the flow in the app.” While completing the task “Find out how water is tested,” one participant seemed surprised to have found this information on the first click, exclaiming "Oh!" raising his eyebrows, and leaning backwards with his upper body. One user mentioned “it was a little confusing” while trying to complete the tasks.

Our third finding was that the bottom tab navigation wasn’t intuitive for users. Many users struggled with the icons on the bottom tabs that represent the “Awareness” page and the “Community” page. While completing the task “Find out how water is tested,” (in which users must navigate to the “Awareness” page) users spent an average of 46 seconds, which implies hesitation or confusion. On this task, one user went through all the tabs and got confused, then lastly clicked on the awareness page and found it. Another user first clicked on the community page but then found it inside the awareness page. A third user went into the community page but could not find it so came back to the home page. The user then got confused and said they couldn’t complete the task. Two users expressed that using a different icon for the “Awareness” page would be helpful to them.

Our fourth finding was that the bottom tab status wasn't intuitive for users. Two users mentioned that the coloring on the bottom navigation bar was confusing to them. One of these users said, “The color of the icons feel like they are all disabled." The second user said, "The bottom menu icons can be a little better in terms of design and colors, Right now they all look disabled to me.”

Our fifth finding was that users found it difficult to quickly find information on the home page. One participant seemed to be scanning the homepage a lot, taking in the information slowly. When one participant was completing the task “find pH level,” they were scrolling back and forth a lot, and seemed unsure where to focus. Another participant suggested we “make the homepage a little more easy to understand.”

3.3 Field Study

After our second iteration of the design for a mobile application that communicates water quality information to Hudson River users, we conducted a field study with 9 participants who partake in river activities such as swimming, paddling, boating, and fishing. Our participants had a mix of technology proficiency. We asked these participants to use our mobile application over 5 days in their natural environment.

3.3.1 Measurements

We used quantitative measurements including overall system usage, key feature usage, and funnels of key interaction flows, as well as qualitative measurements including interviews and thematic analysis with affinity diagramming shown in Figure 3.

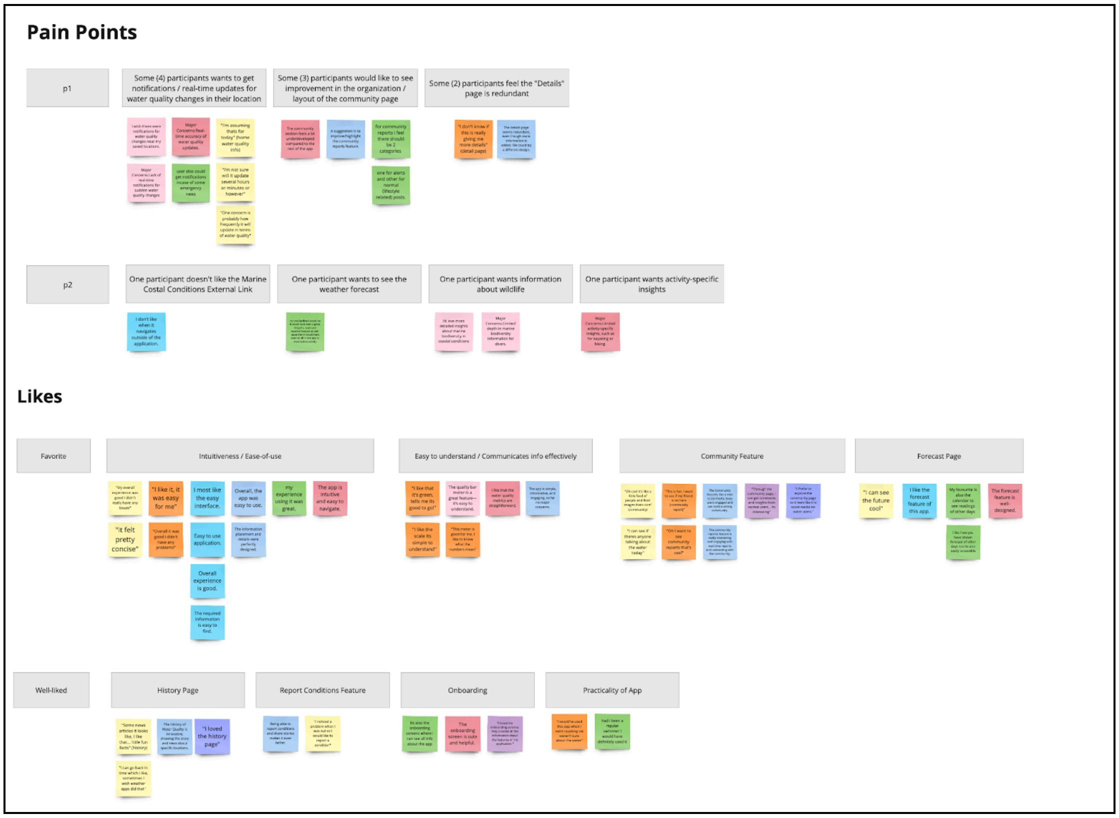


Figure 3: Affinity diagram from field study.

3.3.2. What worked well

Most (6) participants thought the app was intuitive and easy to use. One participant said, "The app is intuitive and easy to navigate." Another mentioned, "The information is easy to find." Other participants explained that the app was easy to use, and that they had a positive experience with it. Our quantitative data in Figure 4 supports this insight as well, showing most participants spent only 5-8 minutes on the app over 5 days, which could suggest it did not take a lot of time to learn how to use the app.

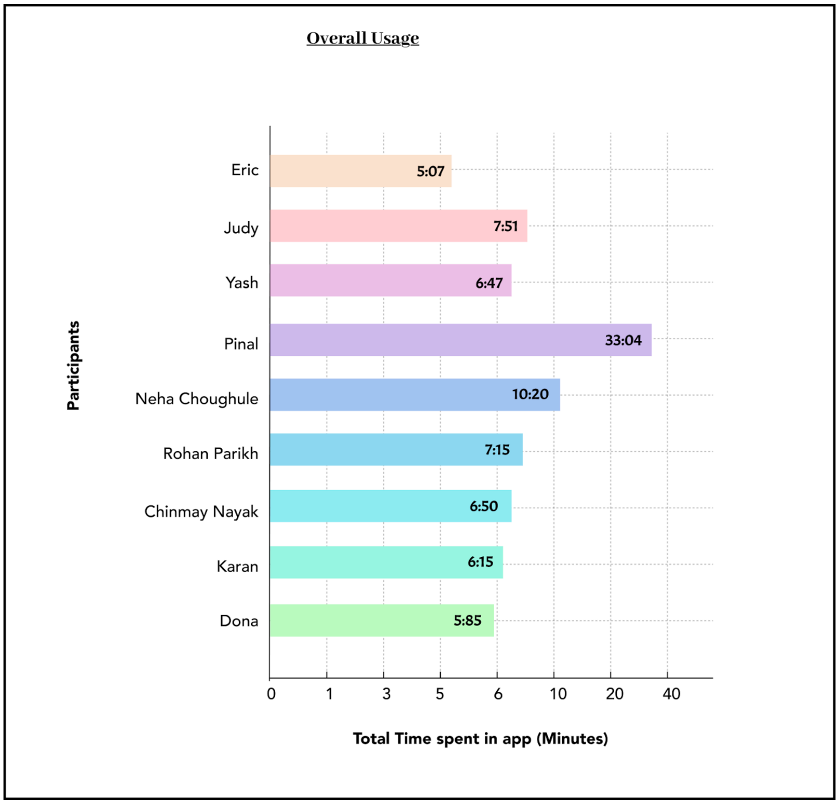


Figure 4: Overall Usage chart from field study.

Most (5) participants valued the community feature, and (4) participants valued the forecast feature. In reference to the community feature, one participant exclaimed, “This is fun, I want to see if my friend is on here!” Another participant mentioned, “The community reports feature is really interesting and engaging.” Other participants expressed that they would use this feature. In reference to the forecast page, one participant mentioned it was their favorite feature. Other users mentioned it was “cool” and “well-designed.” This insight was also supported by our quantitative data in Figure 5, in which we found that checking the forecast and community posts were the most used flows, aside from reading water quality information on the homepage and details page. Participants also spent a greater average of time on the forecast page than any other page except for the homepage.

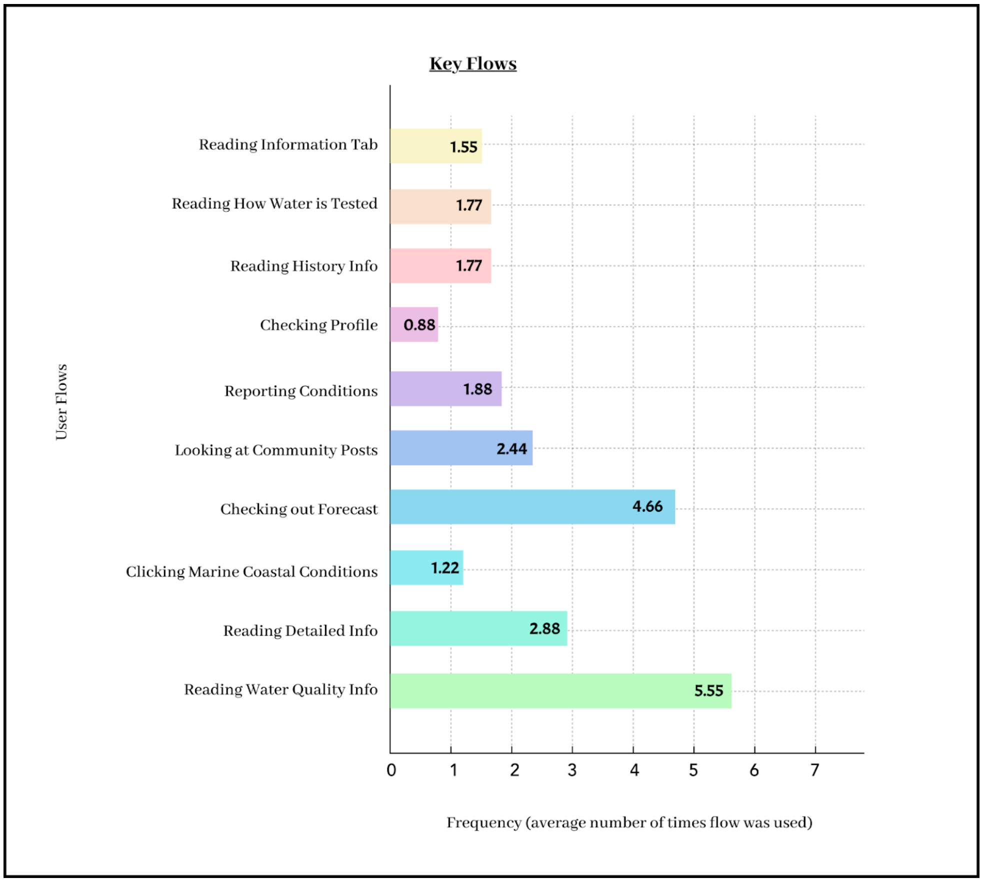


Figure 5: Key Flows chart from field study.

Some (4) participants felt the information was easy to understand. Two participants mentioned the water quality meter made it easy for them to understand the water data. One participant mentioned the color-coding of the meter was helpful to them. Other participants said the app / metrics were “simple” and “straightforward.”

Other well-liked features mentioned by some (2-3) participants: history of water quality, report conditions, onboarding, practicality of the app. One participant mentioned liking the history page because it felt like “little fun facts.” Another mentioned “being able to report conditions and share stories makes it (the app) even better.” Others mentioned they enjoyed the onboarding screens, and some mentioned occasions where they would have used the app. Our quantitative data in Figure 6 showed these pages and features had moderate usage, which agrees with the moderate amount of positive comments we received.

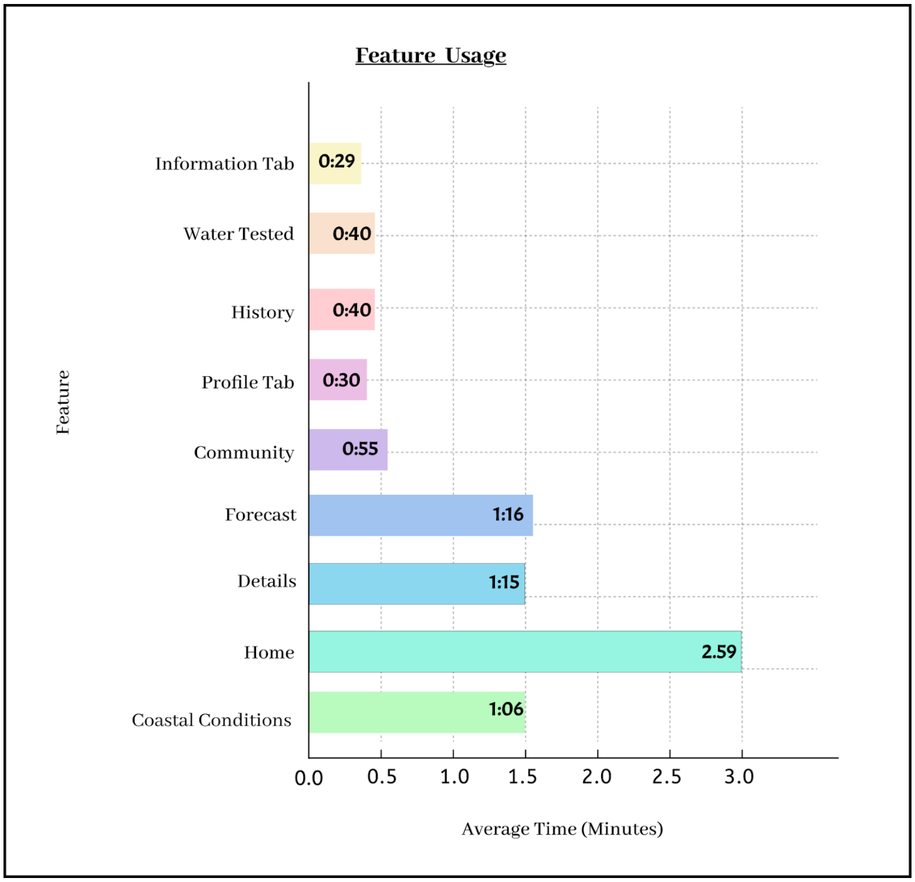


Figure 6: Key Flows chart from field study.

3.3.3. Room for improvement

Some (4) participants wanted to get notifications / real-time updates for water quality changes in their location. One participant mentioned "I wish there were notifications for water quality changes." Another mentioned their major concern about the app is "real time accuracy of water quality updates." A third participant seemed unsure about when the information was last updated, and was concerned about how frequently it would be updated. A fourth participant wanted "notifications in case of some emergency news."

Some (3) participants would like to see improvement in the organization / layout of the community page. One participant mentioned the community page seemed "underdeveloped," and others recommended organizational changes for the community page.

Some (2) participants felt the "Details" page was redundant. One participant expressed, "I don't know if this is really giving me more details" when looking at the details page. Another participant mentioned "the details page seems redundant."

4. SOLUTION

4.1 First iteration

Based on existing technology, we made assumptions that water would be tested at different locations along the Hudson River, and data would be fed to the cloud for our mobile app's functionality.

The main features of our application, as follows, reflected our generative research findings.

- A color-coded "Good," "Bad," or "Moderate" water quality display on the home screen with a recommended action i.e. "Swimmable" or "Avoid swallowing water." This feature is based on the insight that users want a clear answer to whether or not the water is safe.
- Water temperature and tides display on the home screen. This feature is based on the insight that users want relevant water information including temperature and tides.
- Easy-to-interpret details about water quality information. This feature is based on the insight that users want detailed information about water quality components.
- Water quality forecast. This feature is based on the insight that users want to check expected water quality information in advanced / while planning activities.
- Water quality testing information. This feature is based on the insight that users want to know how the water is tested.
- Water quality community forum. This feature is based on the insight that users want to report water quality conditions to others and read other people's experiences.
- History of water quality information. This feature is based on the insight that users want to be more informed and aware of water quality information.

The main color in our design was blue. We chose this color to help users associate our app with their experiences in the water. Blue is the color most people associate with water, and it's also a color that promotes calmness, serenity, and peace, according to Mental Health America [13]. Our users associate their water activities with these peaceful feelings as well, such as an interview participant who said, "To just float in water without doing actually anything is also so relaxing," and another participant who mentioned, "It's very peaceful and calming and kind of a mental meditation." Additionally, according to ColorPsycology.org blue is also the color of trust, loyalty, and integrity [14]. Trust is important to our users as well, as expressed in the following interview quotes: “I'm a hundred percent putting my faith in those people who are telling me it's safe I don't have any ability to test the water myself," and “I have to take it at face value.”

We used bottom tab navigation for our interaction design because it makes our app easy for users to navigate with only one hand, making it accessible and user friendly [15] shown in Figure 7.

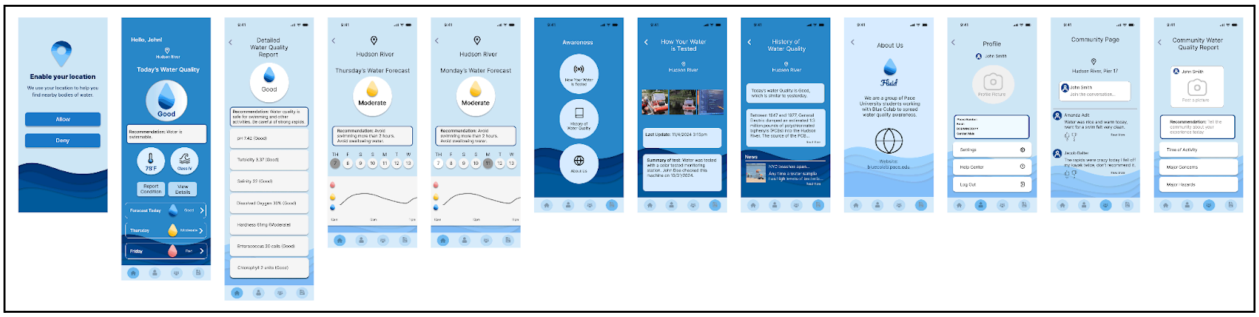


Figure 7: First iteration of the Fluid mobile application design.

4.2 Second iteration

After usability testing, we iterated on our mobile application design by making the following improvements, shown in Figure 8. These improvements were based on key findings from our qualitative and quantitative data.

- Based on the finding that users found it difficult to skim the home page and find information, we improved the visual hierarchy on the homescreen to help guide users' eyes to the most important information on the screen [16]. We also added a color-coded water quality meter and color-coded safety advice to the homescreen to improve the contextualization of the data display, which helps improve data communication [8].
- Based on the finding that the app organization was hard for users to interpret, we redesigned the home page to improve consistency and make navigation more intuitive, implementing usability heuristic number four [17]. We also added more buttons to the homescreen to allow easy access to information with less navigation, and made these buttons intuitive by improving iconography and consistency.
- Based on the findings that the bottom tab navigation and status were both not intuitive, we rearranged and simplified the bottom tab navigation, and improved iconography. We also changed icon colors to improve the visibility of the system status, implementing usability heuristic number one [18].

- Based on the finding that the forecast was difficult for users to find, and that users prefer a calendar icon, we created a new "forecast" button, utilizing a calendar icon and a consistent button design to make the button more intuitive.

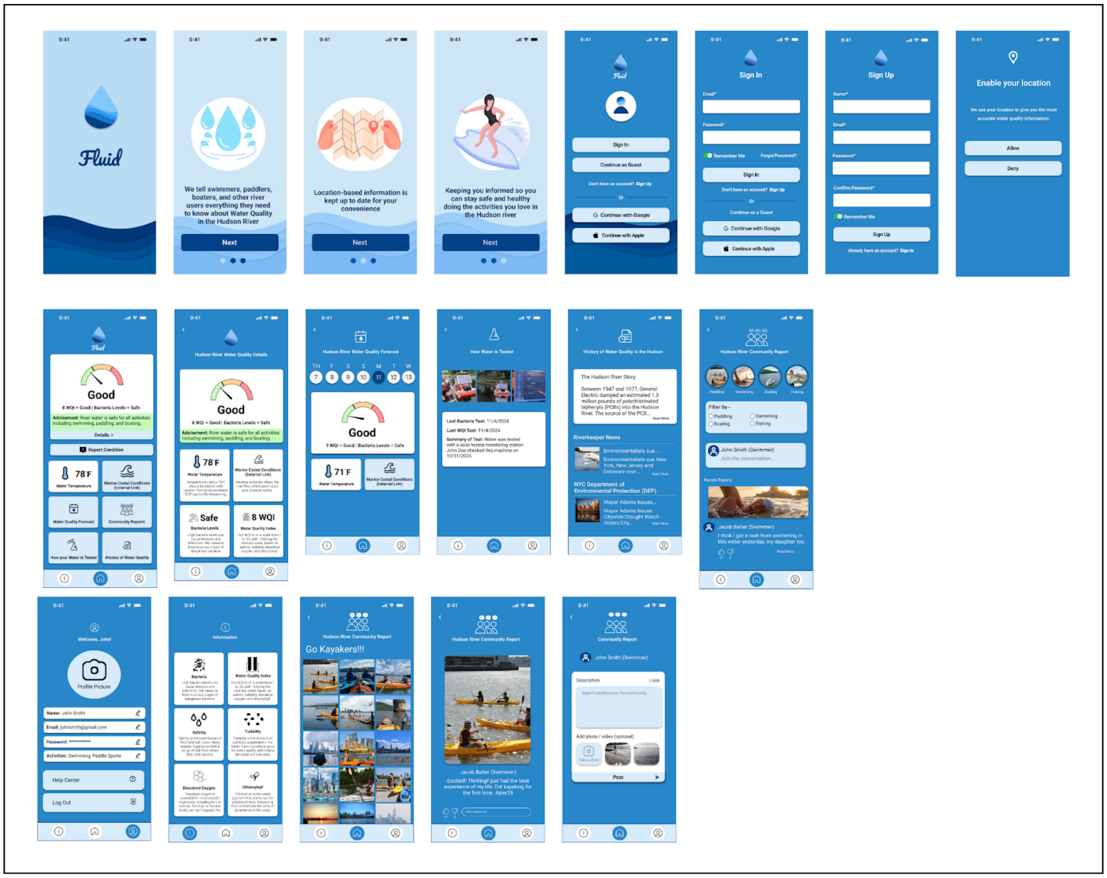


Figure 8: Second iteration of the Fluid mobile application design.

4.3 Future Recommendations

After our field study, we created a prioritized list of the following improvements to our mobile application design for future iteration. These improvements were based on key findings from our qualitative and quantitative data.

- Based on the finding that some participants wanted to get notifications for water quality changes in their locations, we recommend implementing push notifications for water quality changes, and adding a clear timestamp of the most recent water quality test.
- Based on the finding that some participants would like to see improvement in the organization of the community page, we recommend redesigning the community page layout to create distinct sections for official reports and alerts and casual posts from users.

- Based on the finding that some participants felt the "details" page was redundant, we recommend removing the "details" page, and consolidate information on the homepage and information tab.

CONCLUSION

Every year in the US alone, an estimated 90 million illnesses occur from water recreation events [2]. People who participate in recreational water activities, such as swimming, paddling, boating, and fishing, have a right to know about contaminants in water that pose a threat to their health and safety. With Water Quality Monitoring (WQM) technology available, water quality data should be accessible to all water users.

Our mobile application design, shown in Figure 9, demonstrated a feasible solution in this problem space by effectively communicating water quality information to people who use the Hudson River so they can stay safe and healthy while partaking in the river activities they enjoy. Our design fulfilled user needs by communicating data in a clear, easy-to-interpret, and efficient way. We met user pain points by creating a platform that was trustworthy, accessible, and reliable. Additionally, we addressed user motivations and aspirations by increasing knowledge and awareness around water quality.

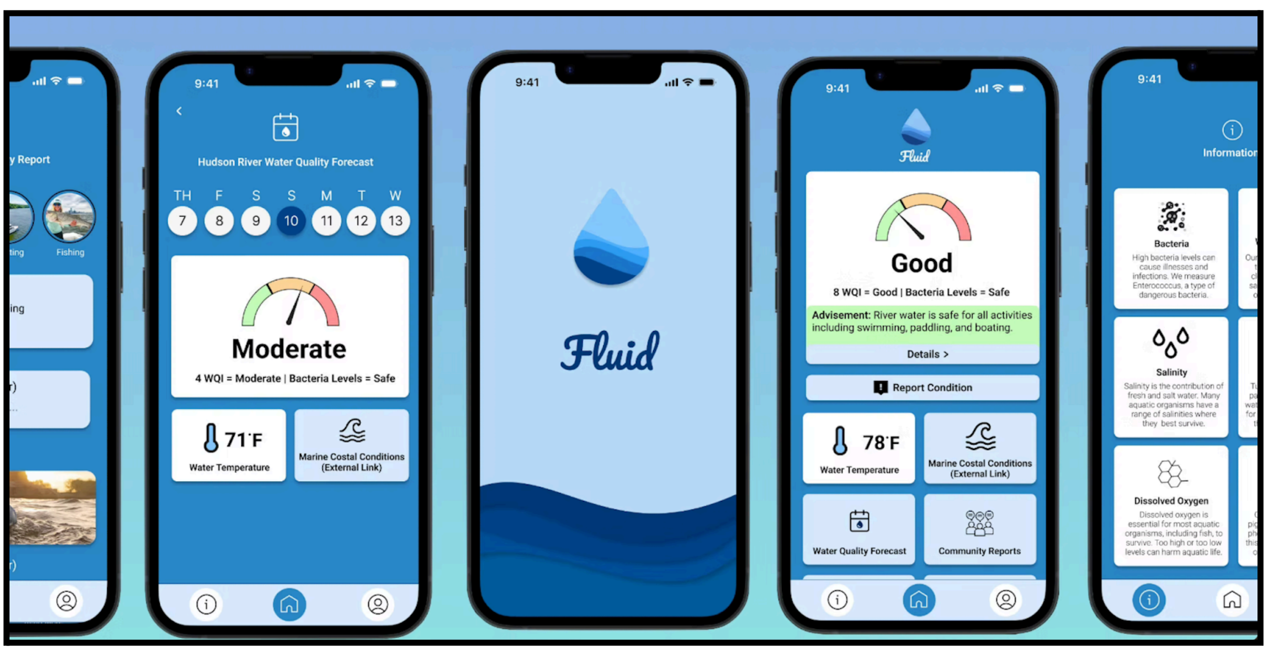


Figure 9: Final Fluid mobile application design.

For future iteration, we recommend adding push notifications for water quality changes, and a clear timestamp of the most recent water quality test. We also recommend redesigning the community page layout to separate alerts from casual posts, and merging the “details” page with the homepage and information tab.

Though our study focused on the Hudson River, similar applications could be applied across the US to address other bodies of water. Implications could even be made for a location-based mobile application that communicates water quality information to recreational water users wherever they are.

5. LIMITATIONS

We recognize that data security during water quality transmissions with Wireless Sensor Networks (WSN) remains an issue in Water Quality Monitoring (WQM) technologies. It was beyond the scope of our research project to look into feasible solutions to this challenge.

We were unable to include youth in our participant pool for interviews, usability testing, and field studies, which could have resulted in a sampling bias. This limitation was due to a time constraint and ethical considerations on doing research with minors.

Some of our participants were not actively partaking in water activities during the time of the field study because of the season. To meet this limitation challenge, we set up appointments with users in locations comfortable to them or locations that felt relevant to their usual water activity. While we were not able to have participants use our mobile application directly before engaging in water activities because of the weather, most participants felt confident imagining their usual habits and surroundings while interacting with our app.

6. APPENDIX

We used the following personas to guide our research and design decisions, ensuring our process stayed human-centered / user-centered [20].

About:

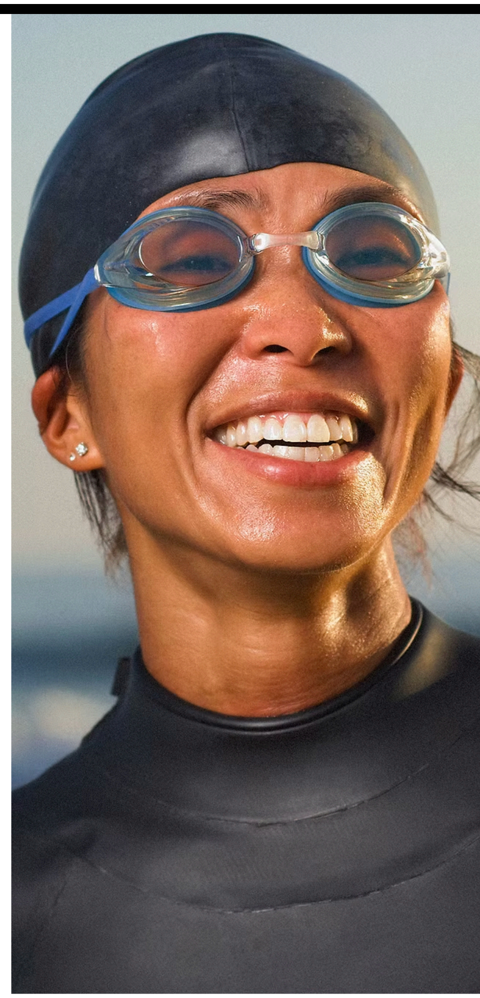
Amanda is a professional swimmer who competes in events around the country. She loves swimming because it helps keep her in shape and she feels like she can relax her mind while she's in the water.

Frustrations:

Amanda ended up sick for a week after her last swimming event, and thinks it was because she swallowed some river water with bacteria in it. The event managers supposedly tested the water that day, but Amanda wishes she could have seen the water information for herself that day, and the estimated conditions before deciding to attend the event. She wonders if anyone else got sick from the event, and wishing there was a way to connect with other river users about it.

Needs:

- A quick way to check water quality and water temperate the day of, and in advanced
- A way to report conditions to other swimmers, and read reports from other river users



Amanda

About:

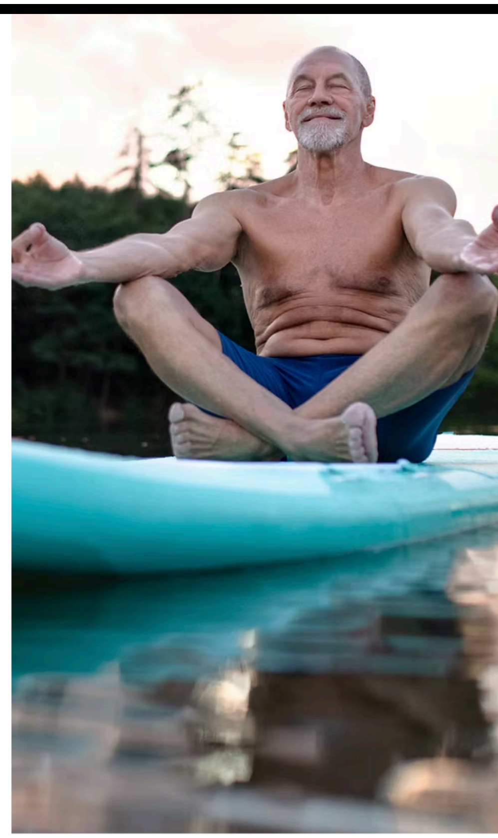
Ronald likes to Kayak for fun as a way to connect with nature and make new friends. As a cancer survivor, Ronald is cautious about his health and safety. He always wears sunscreen, especially when the UV index is high, and will wear a mask or stay inside when the air quality is bad.

Frustrations:

Ronald tries to make sure he doesn't go kayaking in rough conditions, like when it's windy and he could get knocked over, but it's hard for him to find the information he needs to keep himself safe. He doesn't know anything about water quality information, but would like to be more aware of it to protect his health.

Needs:

- A clear answer to if the water is safe or not
- A way to check water tides
- Easy-to-understand water quality details



Ronald

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