Creating a framework to develop an effective GIS web application for public consumption

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I certify that I have read this thesis and that, in my opinion, it is satisfactory in scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

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DEDICATION

For all the people who believed in me, you helped me persevere.

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ABSTRACT

The popularity of using GIS web applications has risen, and is likely to be a staple tool in the future of science communication, public engagement, and outreach. In this paper, I will evaluate one of the GIS web tools the State of Hawaiʻi is planning to use, and determine its effectiveness. The Hawaiʻi Department of Health, authorized by Act 132, established the Cesspool Conversion Working Group (CCWG) to research and develop an extensive plan to tackle the conversion of cesspools statewide by 2050. While adopting an updated cesspool prioritization framework, the CCWG decided to create a GIS web application that would be a visual representation of cesspool prioritization. To measure the functionality of the web application, we evaluated the user experience through a combination of qualitative observations and survey. This study contributes to the body of evidence that creating a GIS web application with an excellent user experience requires an iterative process. Scientists can enhance their GIS web applications by considering the diverse users which are bound to utilize their tool.

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1.0 INTRODUCTION

1.1 History of Cartography and GIS

The history of cartography is long, with the oldest route recorded in history as a 9ft long painting found in Anatolia dated to 6100-6300 BC (Dempsey, 2014). In contrast, the history of geographic information systems (GIS) is relatively short. The first application of the concept was in 1832 when Charles Picquet created a map showing the density of the population stricken with cholera in Paris (Tate, 2018). His map was what we would call a voronoi diagram today. Almost twenty years after Picquet, the English doctor John Snow, created a similar map of cholera in London. However, he also included the information of well documented water supplies in his map which gave public health investigators the ability to see which well sites were contaminated (USC, 2010).

Digital GIS came about in the 1960's when computers were being rapidly improved upon. In the mid-sixties, the Harvard Laboratory for Computer Graphics was founded in order to create software that could help landscape architects and urban planners. These roles utilize maps on a daily basis and digital GIS allows them to modify maps more easily in comparison to paper ones. One of the students from the lab was Jack Dangermond, who in 1969 founded the Environmental Systems Research Institute (ESRI). ESRI is now the largest GIS software developed in the world. Due to its popularity, the company has developed many different GIS products, one being the web appbuilder which the study is centered around. Web appbuilder allows people to create fully featured HTML apps without coding. We decided to use the developer edition of web appbuilder to add a custom widget that did require coding.

1.2 Cesspools in Hawai‘i

An environmental health problem Hawai‘i faces is the usage of cesspools which are substandard waste disposal methods. Cesspools are open pits that allow for wastewater to leech into the surrounding environment. The untreated sewage discharge allows for contamination and degradation of water and land by pathogens and nitrates. There are an estimated 88,000 cesspools in Hawai‘i which is estimated to release 53 million gallons of untreated sewage every day (Department of Health, 2017). The Hawaiian Islands depend on groundwater for drinking water, and cesspools threaten the security of its water resources. Therefore, during the 2017 state legislative session, Act 125 was passed which declared that all cesspools will need to be converted to an upgraded treatment method by 2050. The Hawaii Department of Health (DOH) drafted an earlier prioritization method to determine which cesspools were most harmful to human and environmental health. Act 132 tasked the CCWG with evaluating the previous cesspool prioritization methods. DOH awarded the team at the University of Hawai‘i Water Resources Research Center and Hawaii Sea Grant College program (UH team) to research and develop new and improved cesspool prioritization rankings. The group identified that a critical tool in conveying the results of their findings was through using ArcGIS maps. Through consultation with DOH and the CCWG, the team at UH decided that creating a web application through web app builder would be beneficial to the project since it would allow the public to explore and learn more about cesspool rankings distributed throughout the state.

There is a need to improve the usability of environmental data, especially information that pertains to human health. Besides displaying the cause of an environmental problem; a user-friendly web map application can convey the importance of solving environmental problems through a more visual approach in comparison to pure writing. The UH team aimed to design a web map application that prioritizes user experience (UX) to better support cesspool owners. However, there are limited case studies in academic literature that provide guidance on how to design a user-friendly GIS web application (Goodspeed C., 2016). The results of this study are focused on bridging the gap between best user centered design practices and the usefulness of GIS web applications in science communication. For the web app to be considered successful, the application needs to be usable which is what this experiment was designed to quantify.

1.3 Approach

As more GIS web application products became available, we knew that it was more important to focus on usability rather than innovation and creation. In order for the web app to be deemed successful it needs to be usable, accessible, and useful. Prioritizing these values led us to selecting a user-centered process. User-centered design is a methodology that focuses on understanding the needs of the user and ensuring that all needs are met (UCD USGS Workshop, 2021) . The research in this study follows a user-centered design approach to empathize with the user as much as possible.

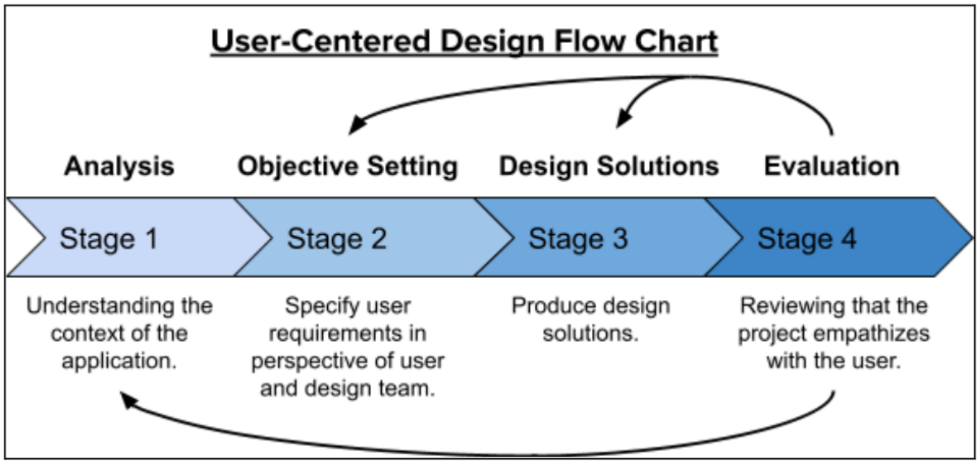

Figure 1: The figure is a visual representation of the user-centered design process.

User-centered design is an iterative process. The first stage in the process is to understand the context of when the user uses the product. During this stage we recognized that this product will be used mostly by people who live in homes located in Hawaiʻi that have a cesspool. Another likely demographic to utilize the web application are grassroots organizations and interest groups with a special interest in environmental health. Government officials, including planners and engineers, are another set of users that would possibly want to use the web app to help them determine policies and procedures that could help solve the issue.

After understanding the use and different priorities of the users, we had to specify what user requirements the web application needed to include. Users would need to be able to search for their individual cesspool by using an address or parcel identification number and conceptualize how their cesspool fits with the larger issue of wastewater pollution. This would satisfy the needs of affected residents, NGOs with ties to environmental health issues, and public officials who are in charge of policy that directly impacts the conversion plan.

Once the user requirements were specified the team started to discuss the other aspects of usability for the designing solutions stage. Usability includes effectiveness, efficiency, engagement, error tolerance, and ease of learning. The team tried to brainstorm potential obstacles to the application in succeeding in each of these categories. The first challenge for the team was ensuring the app was accessible for visually impaired users. Another obstacle the team thought of was a language barrier. Hawaiʻi is the only state in the United States to have two official languages, Hawaiian and English. The last challenge the team thought users could face would be poor internet connection. Once all the obstacles were listed the next step in the process was to research tests that would determine whether or not the app overcame the obstacles once the design was finished.

The last stage in the user-centered design process was to determine which user experience methods the study would use to evaluate the app in its success of allowing users to accomplish the goals set in the second stage. We decided to conduct a single survey designed to take participants less than twenty minutes to complete. This would allow similar working groups to follow the guidance in the study since time constraints are a common issue for small teams with limited funding. The study could be easily replicated and adapted to other projects DOH might face in the future.

2.0 METHODS

2.1 Inclusivity

During the designing solutions stage, the team brainstormed obstacles users could face. This was to ensure that the web application was as inclusive as possible. Instead of modifying the application at the end, the team decided to consistently evaluate the accessibility of the app throughout the design process.

2.1.1 Visual Accessibility

The first obstacle was to verify whether people with visual impairments would be able to use the app. Visual impairments fall on a broad spectrum from color blindness to low vision and blindness. The team conducted an internet and academic search for different techniques, assistive technology, and assessments to determine whether or not the app was accessible to all visual impairments. To test accessibility for color blindness images of the app were put through a color blind simulator. To test accessibility for blind users a screen reader was downloaded to understand what it could and could not read. Best practices were incorporated into the app in terms of low vision accessibility. Best practices include: making markers large, using simple fonts, and using contrasting colors.

2.1.2 Language Accessibility

Due to the time constraints and limited language resources the team was unable to directly evaluate the web app's language accessibility in Hawaiian. However, the team did reach out to the State of Hawaiʻi Office of Language Access to learn more about how the app could be evaluated in the future once the working group has more resources available.

2.2 SURVEY

Before the survey was public, a pilot study of the survey itself was conducted. The other members who helped design the app were given the survey and later gave feedback verbally during a one on one meeting. This ensured that the participants would be able to first answer the questions and then answer in a way that could be quantified.

The survey was anonymous and gathered both quantitative and qualitative information (see Table 1). Participants were told that the study was designed to evaluate the usability of a cesspool app which was specific to Hawaiʻi. The first section of the survey reemphasized this point, so participants would be certain that they were not the focal point of the experiment. The purpose of this was to create a low stress environment.

The second section consisted of three demographic questions. These questions were used to gain insight to the participants' experience with GIS, cesspools issues, and Hawaiʻi. The third section had participants going through tasks that were goals set in the specified requirements stage. In addition to understanding the displayed information, we wanted to test if participants could manipulate and share the information presented. The results would let us know if the tasks were manageable and if the participant was comprehending the data. The fourth section consisted of questions rating the ease of navigating the web app and evaluating it overall. Participants generally completed the survey within ten minutes.

Table 1: The table consists of the introduction and list of questions used in the survey.

SECTION 1		
Welcome to the Draft Hawai‘i Cesspool Prioritization Tool Evaluation (HCPT) Survey! This survey is to determine the usability of the HCPT App. This application is expected to be a public resource for Hawai‘i residents to determine their cesspool prioritization rank. The HCPT ranks which cesspools are most likely to cause harm to people and the environment. Each colored dot on the map is a cesspool. The colored areas that match the cesspool colors are US Census Bureau tracts. All cesspools within their census tracts are ranked together. Please open a new tab with the following link url to complete the tasks: https://cshuler.net/results2/		
SECTION 2		
Question #	Question	Answer Options
1	What would you rate your experience with geographic information systems (map applications)?	1-5 1= None, 5= Expert
2	How knowledgeable are you about cesspools in Hawai‘i?	1-5 1= No knowledge, 5= Very Knowledgeable
3	How long have you lived in Hawai‘i?	0-1 year 2-4 years 5-9 years 10+ years
SECTION 3		
4	1st task: Please open the layer list and determine which category the cesspools in Diamond Head mostly fall in?	Low, Medium, High
5	2nd Task: Please search for Haleiwa, Hawai‘i. What category	Low, Medium, High

	do the cesspools mostly fall in?	
6	3rd Task: Please turn off the Census Tracts layer in the layer list. Navigate the print function. Select an answer that describes which step you were last able to complete of this task.	• Able to complete both tasks • Only able to complete first task • Only able to complete second task • Unable to complete both tasks
7	4th Task- Part A: Locate Maui Island. What do you notice about the cesspool category distributions around the island?	Free Response
8	4th Task- Part B: Which cesspools on Maui do you think have the greatest impact on the health of the human environment?	• Hana, Hawaiʻi • Kanahena, Hawaiʻi • Mopua, Hawaiʻi
SECTION 4		
9	How would you rate the ease of completing the tasks given?	1-5 1= Very Difficult, 5= Very Easy
10	How intuitive did the web application feel?	1-5 1= Questionable and Clunky, 5= Instinctive and Natural
11	How useful was the app in understanding cesspools in Hawaiʻi?	1-5 1= Not Useful, 5= Very Useful
12	Estimate how long it took you to complete all of the tasks in the previous section. (Using minutes)	1-20 minutes
13	What do you think the web application could improve on?	Free Response
14	Would informational pop ups help you?	Yes, No, Maybe
15	Do you have any additional	Free Response

	feedback you would like to provide?	

2.3 Demographics of Participants

The recruited participants were colleagues, faculty, and UH Mānoa students. Participants were told the anonymous survey would take a maximum of twenty minutes to complete and that they would need access to a device with browser access. Participants were also told about the purpose of the web app that is also the same verbiage as Section 1 of Table 1. Since the focus of the study was on evaluating the usability of an app and not the participants, we did not think it would be appropriate to have an extensive section of our survey dedicated to demographics. However, we did ask three questions that were pertinent to our understanding of the usability of the app in general for the general population. This let us know the group had spent a few years living in Hawaiʻi and had some understanding of GIS, but low knowledge of cesspool pollution in the state.

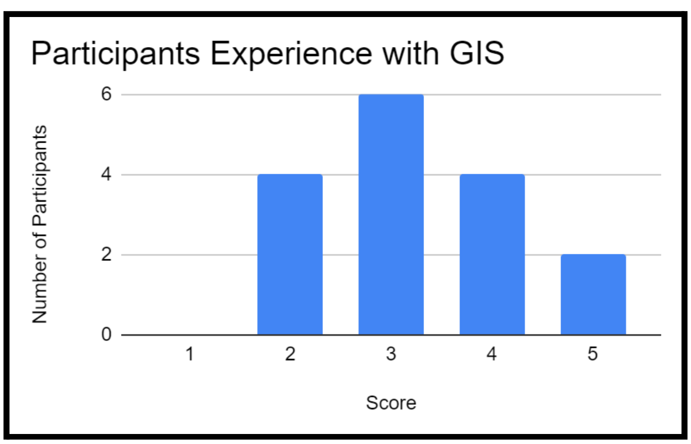

Figure 2: The graph shows how participants scored their experience with GIS prior to the experiment.

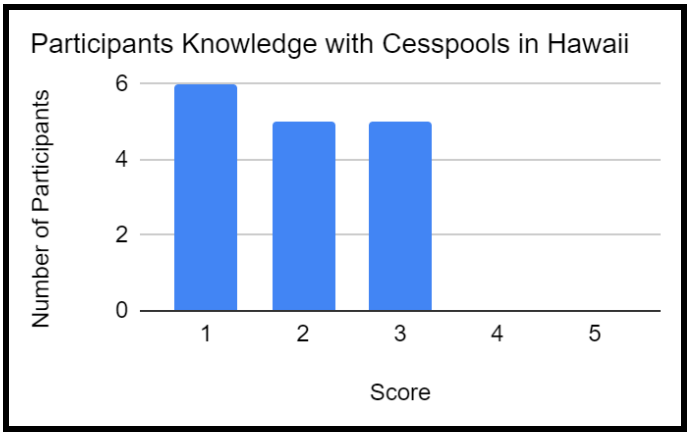

Figure 3: The graph shows how participants scored their knowledge of cesspools in Hawai'i prior to the experiment.

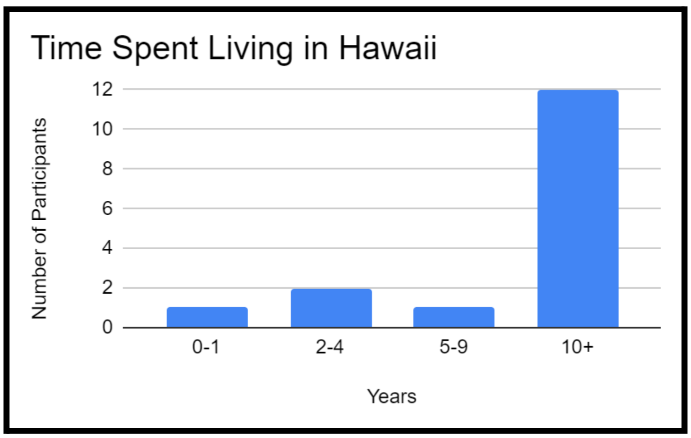

Figure 4: The bar graph shows the time participants spent living in Hawaii in years.

3.0 RESULTS

3.1 Survey

To evaluate the usability of the web application we created an anonymous survey that asked participants both quantitative and qualitative questions. Overall the survey revealed positive results and helped us understand ways to improve the web application. The results have been separated into four categories depending on whether it was a quantitative or qualitative question and if it was asked in the second or third section of the survey. Please refer to Table 1 for the list of questions and its corresponding section number.

3.1.1 Quantitative Results: Task Questions

All participants correctly characterized the cesspools in Diamond Head as medium risk. This allowed us to understand that participants were able, find the layer list and then read the legend to determine which priority ranking Diamond Head fell within.

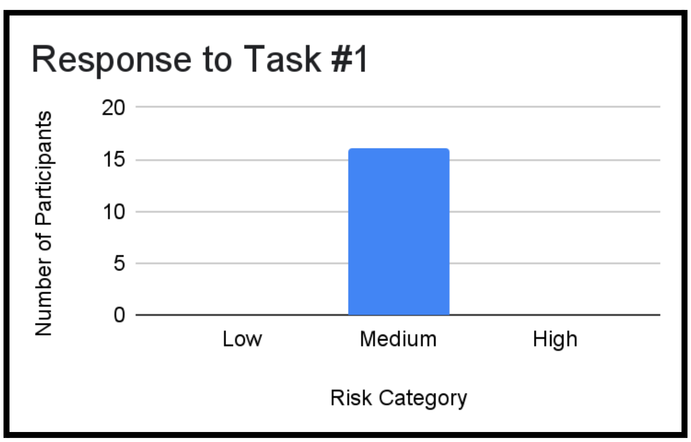

Figure 5: Participants' responses to opening the layer list and deciding which category the majority of cesspools located at Diamond Head are ranked.

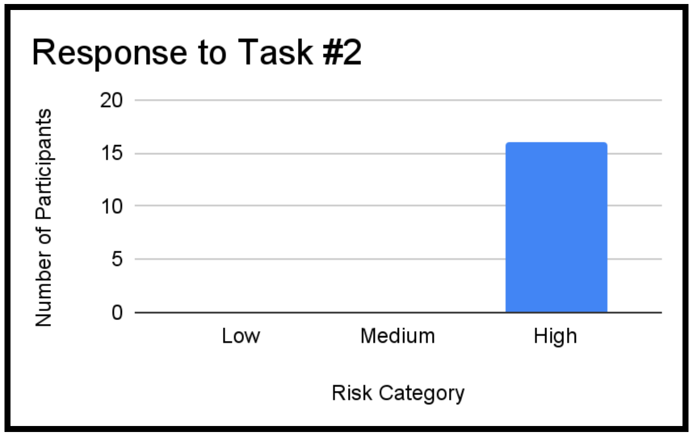

Figure 6: Participant’s responses to locating Haleiwa, Hawai‘i and deciding which category the majority of cesspools are ranked.

All of the participants categorized the majority of cesspools in Haleiwa as high risk. The high option was the proper response for the question. Since the participants were able to successfully complete task two, we knew that participants were able to once again find a selected location and use the legend to find the correct ranking of cesspools in the area.

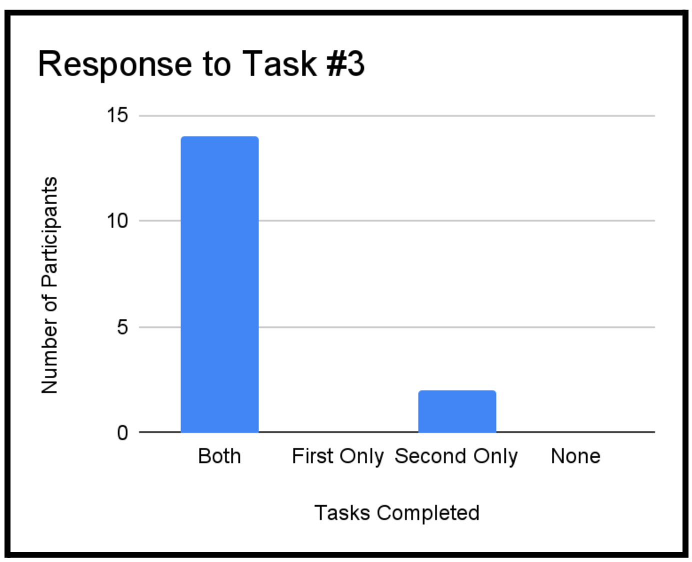

Figure 7: The bar graph shows the participants abilities to complete two tasks. The first task was to turn off the census tracts layer. The second task was to find the print button.

Majority of the participants were able to successfully complete both tasks. All participants were able to find the print button. Two participants were unable to complete the first task, which was to turn off the census tracts layer.

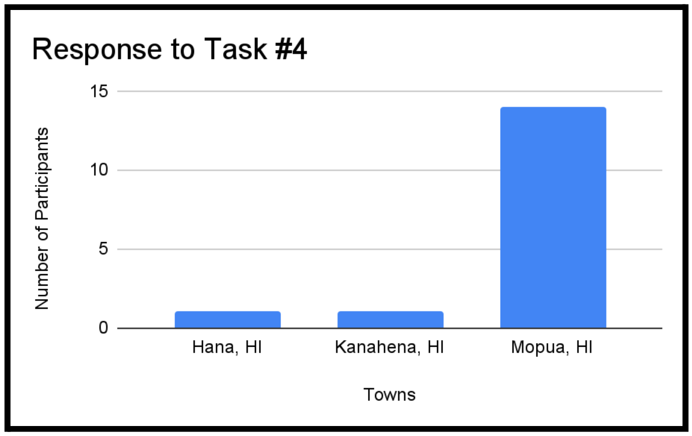

Figure 8: The graph shows which towns cesspools located on Maui island, they think have the greatest impact on the health of the human environment.

The fourth task had two parts; the second part was a quantitative question testing the success of the app in conveying impacts on health to the human environment. Majority of the participants selected Mopua, HI, as the town with the greatest impact on health to the human environment. One participant each chose the towns Hana and Kanahena.

3.1.2 Qualitative Results: Task Questions

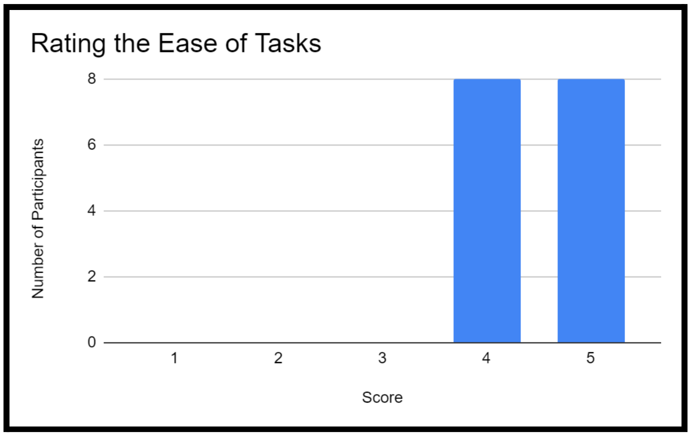

Figure 9: The graph shows the participants rating of the ease of the tasks.

The participants were evenly split when rating the ease of completing the tasks. On a scale of 1 to 5, with one being "Very Difficult" and 5 being "Very Easy", participants chose either 4 or 5.

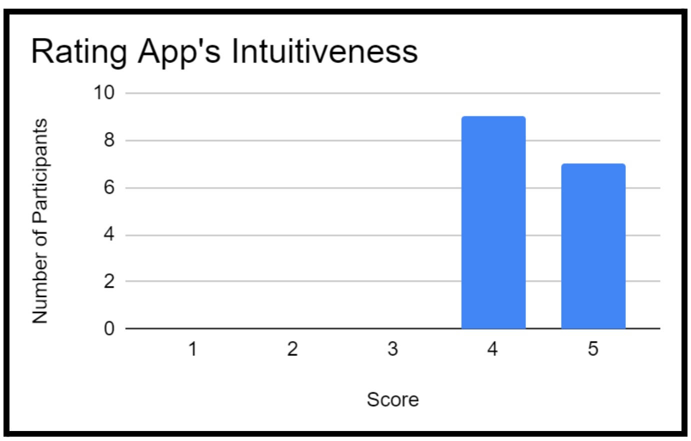

Figure 10: The graph shows the participants view on the web apps intuitiveness.

Participants were asked to rate the web app's intuitiveness on a scale of 1 to 5. One describing the app as "Questionable and Clunky" and five describing the app as

“Instinctive and Natural.” Nine participants chose to give the app a four rating and seven chose to give the app a five rating.

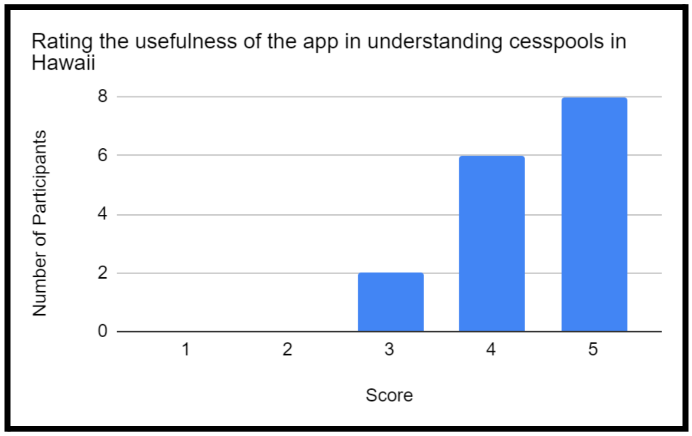

Figure 11: The graph shows whether or not the web app was useful in terms of understanding the issue of cesspools in Hawai‘i.

The third question asked participants to rate the usefulness of the app in understanding cesspools in Hawai‘i on a scale of 1 to 5. One being “Not Useful” and five being “Very Useful.” Two participants responded with a 3, six participants responded with a 4, and eight participants responded with a 5.

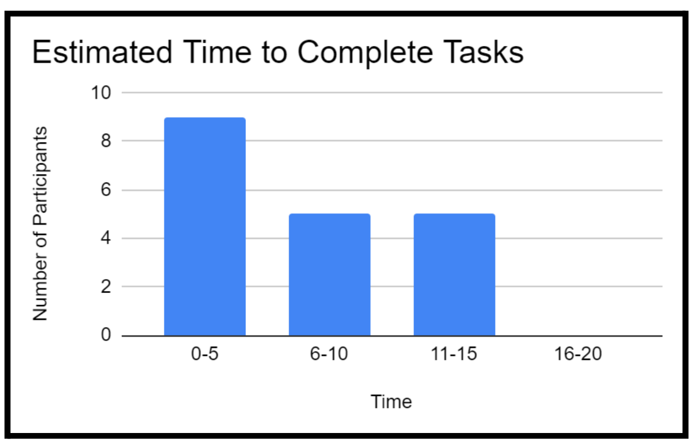

Figure 12: The graph shows the time it took to complete the tasks in the previous section estimated by participants.

The next question asked participants to estimate how long it took them to complete the previous section of the survey in minutes. Nine participants estimated it took them five minutes to complete. Five participants said it took them anywhere between six and ten minutes while five more participants estimated it took them eleven to fifteen minutes to finish the tasks.

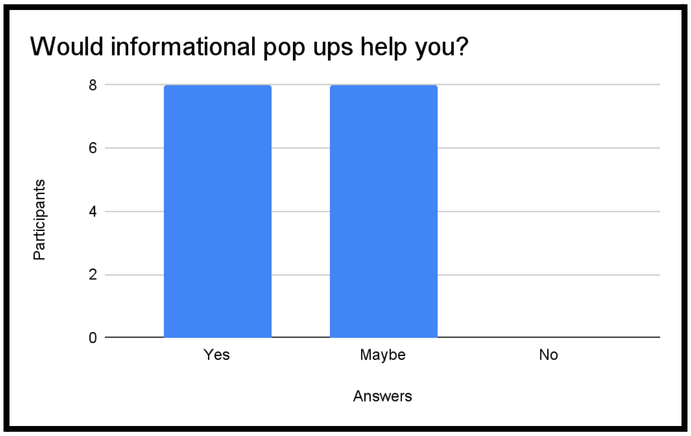

Figure 13: The graph shows the participants responses when asked whether or not they think informational pop ups would have helped them.

The last quantitative question participants responded to was whether or not they thought informational pop ups would have helped them. The participants were once again evenly divided between two of the three options. Eight said yes and the other half said maybe.

3.1.3 Qualitative Results: Post Task Questions

The fourth task, Part A, asked participants to first locate Maui Island. Then they described what they noticed about the cesspool category distributions around the island. Two participants compared Maui's cesspool distribution to other islands. A participant compared Maui to Oahu, noticing that there were more yellow cesspools and fewer orange and red on Maui relative to Oahu. A different participant compared Maui to all the other islands in Hawaiʻi, describing that the majority of the cesspools were in the center of the island.

Half the participants noted that central Maui seemed to be ranked moderately. Four of those participants were able to go into more detail. Four participants noticed that the cesspools in the northwestern portion of Maui and along the west coast were ranked at a higher risk. They then went on to describe that the cesspools in central northern Maui and along the east coast were at the lowest risk. The rest of the participants also commented that the northwestern portion of Maui had high risk ranked cesspools but did not write about anything regarding the other parts of the island.

3.1.4 Qualitative Results: Post Task Questions

In the survey, participants were asked about what they thought the web application could improve upon. Three participants reported that they would like the names of areas to be shown in front of the points on the maps, saying that it was a little difficult to read the labels. A few participants requested that the information be explained a bit more. Two specifically wanted the explanation of the terms to be available even after users read the splash page. A participant suggested that the layer list widget be set to automatically display rather than have participants open it. Four participants commented that they would have liked it if the tool included a tutorial that explained how to navigate the web app.

The survey also asked participants if they had any additional feedback they would like to share. Seven participants had no additional comments while six commented that they thought the tool worked well and would be able to use it. Three participants wrote more on how they would have liked to have seen additional information about the low, medium and high rankings.

3.2 Visual Accessibility

To test that best practices for color blindness were followed, images of the web application were put through a color blind simulator. This revealed to us that the colors chosen were appropriate. A screen reader was downloaded to test the accessibility of the web app for low to no vision users. Even though the widgets were readable, the map itself was not which does not make this web app truly accessible.

4.0 DISCUSSION

The results of this survey are not groundbreaking, but rather evidence that the best practices in user experience are easily applicable and beneficial to GIS web based tools. The majority of user experience case studies have centered around web applications that do not feature map services. However, we were able to successfully design an app that allows users to learn more about cesspool prioritization in Hawai'i. Guidance proposed by outside case studies [Kumar, 2017 and Matera, 2006] emphasized the importance of empathizing with the user. Even though we tried our best to always put the needs of the user first, our results showed that there were still some instances where we made assumptions of the user that were preventing our app from being "perfect". This proved the value in evaluating the usability of the web application and allows us to make the recommendation that other projects should seek human feedback on their own GIS web applications.

4.1 Additional Context

When building the app we tried to simplify the information we needed to convey which led to some oversimplification. The participants wrote comments asking about the reasoning behind priority ranking and recommended that we include more background information. We concluded that there needs to be an informational widget that would allow users to reference once they exit the splash page which will be added in the next generation of the web application. Another factor that might have changed the participants' responses was if they had learned the tool will be attached to a website which will have more written information. We think that the tool combined with the web page will result in higher usability ratings. It was encouraging to see the public interested in wanting to learn more about the prioritization and helped us realize that we might have underestimated public interest.

4.2 Adjustment of Layout

In the survey, participants completed tasks one and two as expected. Participants were able to search for a location and then use the legend to determine the priority ranking for that area. Task three was created to test whether or not participants would be able to manipulate the map and share a printed version of the map. Every participant was able to find the print function, most likely since the button uses the common print icon. Two participants were unable to figure out how to manipulate the map.

The web app builder has two widgets that both display the datasets and their corresponding legends. One is placed in the top right corner while the other is next to the print function. Only one of the widgets allows the user to turn off and on the datasets which let us know which widget people were accessing to read the legend. Even though most of the participants were able to find the widget that would allow them to manipulate the map, we decided to change the layout. Now, the widget we want users to use will be in both the top right corner and next to the print widget.

4.3 Visual Accessibility

This study evaluated the usability of a GIS web application made for the public to learn more about cesspool prioritization in Hawaiʻi. Users with low to no vision ability will most likely not be able to access the web application due to lack of visual descriptors. Therefore, the recommendation for DOH, is to instead create a database that is visual disability friendly. One that includes all of the information presented in our web map but without the actual map, since that is the largest reason why our application was inaccessible. Users with color blindness will be able to use the maps since we use a red to yellow color gradient to differentiate levels of priority.

5.0 CONCLUSION

The web application is another tool designed by the CCWG for the Department of Health as one of the solutions to the cesspool problem in Hawaiʻi. Cesspools allow for raw, untreated sewage to leech into the environment releasing pathogens and nitrates which presents a human health risk as the discharge could enter drinking water or recreational waters. In addition, the discharge could damage nearby land and aquatic ecosystems. Therefore evaluating the usability of the web application is critical to the overall success in the mission to convert all cesspools by 2050 in the State of Hawaiʻi.

The survey used to evaluate the app revealed that users were able to navigate through and understand the majority of the information being presented. However, the survey uncovered two areas that could be improved within the app: context and layout. The commentary from the survey was primarily related to context. Participants wrote they needed more information to draw the connection between the priority ranking and impact of cesspools on human health easier. Our solution after reading such comments was to embed an information section in the web application rather than rely on the temporary splash page. The quantitative data showed that participants had some difficulty manipulating the data which let us know the layout of the web application could also be improved. Our solution to this problem was to put the widget that allows users to turn on and off the layers in two corners of the screen rather than one.

Knowing there are still opportunities to improve the app reconfirms the fact that a user-centered approach is an iterative process. This study is also evidence that regardless of following best practices, human feedback is necessary to ensure the usability of a tool. This lesson will be communicated with DOH so that in the future they may use this study to guide them when evaluating similar applications. Now we can publish the web application for public usage since we have implemented the changes needed for the application to be as user friendly as possible.

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