Design before you code: Using wireframes in support of interactive and web-based mapping

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Abstract: In this paper, we explore the potential of wireframe design and evaluation for interactive and web-based mapping through a case study on water level visualization. Specifically, our research informed development of the National Oceanic & Atmospheric Administration's (NOAA) Lake Level Viewer (http://www.csc.noaa.gov/digitalcoast/tools/llv), an interactive and web-based geovisualization application supporting adaptive management of coastal hazards related to future water levels in response to climate change in the Great Lakes region of North America. Eighteen (n=18) target users completed cognitive walkthroughs with Lake Level Viewer wireframes, with the sessions audio recorded for subsequent transcription and qualitative data analysis. We took a balanced approach to the wireframe design based on two fundamental aspects of the user experience (UX): high-fidelity wireframes to illustrate the proposed representation solution using real data and low-fidelity wireframes to provide a rough sketch of the proposed interaction solution. The pair of wireframe evaluations led to a series of revisions to the functional scope and visual design of the Lake Level Viewer. The wireframe evaluations also generated multiple recommendations for leveraging wireframes in support of large-scale mapping and GIS projects as well as for designing water level visualizations supporting adaptive management in response to climate change.

Keywords: user-centered design, user-experience design (UX design), wireframes, cognitive walkthrough, water level visualization, uncertainty visualization, adaptive management, climate change

1. Introduction

Cartography and coding increasingly are intertwined. Unprecedented demand for interactive and web-based mapping applications has left many cartographers scrambling to update their coding skills in order to remain relevant on such projects. While coding indubitably is essential to today's mapping workflow, cartographers can continue to make substantial contributions to interactive and web-based mapping projects without writing a line of code. We argue that cartographers are well-positioned to take on the role of *user experience* (UX) designers on large-scale mapping and GIS projects. Rather than (or in addition to) contributing to the *development* (coding) of these applications, cartographers should be enrolled to complete the user-centered *design* and *evaluation* of prototypes in order to streamline the development workflow, and ultimately to promote a positive user experience with the application. Such a user-centered design approach, in which cartographers solicit input and feedback on prototypes from target users throughout the project, increasingly is recommended as the best approach to interactive and web mapping (e.g., MacEachren and Kraak, 2001, Fuhrmann and Pike, 2005, Nivala et al., 2007, Haklay and Zafiri, 2008, Tsou, 2011).

Prototyping describes the creation of visual mockups and early marks of a proposed application for discussion and evaluation by the project team, expert consultants, and, most importantly, a representative set of target users (Snyder, 2003). Therefore, prototyping has been identified as essential for effective user-centered design, both broadly in Usability Engineering (e.g., Nielsen, 1992, Nielsen, 1993) and specifically in Cartography and GIScience (e.g., Slocum et al., 2003, Robinson et al., 2005). In most cases, prototyping is described as a highly iterative process, in which prototypes begin as early hand-drawn sketches of the proposed application, are formalized into static wireframes and mockups using productivity and graphic design software, and ultimately are developed into partially-functional alpha releases and fully-functional, but unstable beta releases (Roth and Harrower, 2008). Through this iterative user-centered design process, the utility (i.e., usefulness) and usability (i.e., ease-of-use) of the prototypes incrementally are improved, ultimately leading to successful transition of the full release of the application. There are a growing number of useful examples in Cartography and GIScience regarding the formative evaluation of alpha and beta prototypes to improve a specific interactive and web-based mapping application (e.g., Gabbard et al., 1999, Andrienko et al., 2002, Haklay and Tobón, 2003, Chung et al., 2005, Elzakker et al., 2008, Kramers, 2008). However, few of these studies report on the design and evaluation of earlier, static prototypes, and their usefulness in the overall user-centered design process (see Lloyd and Dykes, 2011, for a notable example in the context of geovisualization).

This paper contributes to Cartography and GIScience in two ways. First, we report on the use of wireframes as part of a user-centered design process. A *wireframe* is a rough visual outline of a proposed application, created early in the user-centered design process after completing a needs assessment with target users and formalizing the functional requirements of the application (Lloyd, 2009). Therefore, wireframes are most closely related to Tsou and Curran's (2008: 313) "skeleton" stage of user-centered design. Introduced by Tullis (1998: 323) as "web page templates," wireframes are useful for presenting the functional scope of the proposed application to target users, for structuring the procedure by which target users will work through the application, and for troubleshooting potential issues target users may have in parsing the information and controls presented to them. Wireframes typically are produced in a digital environment (i.e., are one step beyond early, hand-drawn sketches), but are not interactive (compared to more robust alpha and beta releases).

Second, we demonstrate the usefulness of wireframing through an in-depth case study on water level visualization. Specifically, our research informed design and development of the National Oceanic & Atmospheric Administration's (NOAA) *Lake Level Viewer* (http://www.csc.noaa.gov/digitalcoast/tools/llv), an interactive and web-based geovisualization application supporting adaptive management of coastal hazards related to future water levels in response to climate change in the Great Lakes region of North America (Figure 1). The Great Lakes are a chain of interconnected freshwater lakes (from west-to-east: Lakes Superior, Michigan, Huron, Erie, and Ontario) that constitute a portion of the international border between Canada and the United States. Our focus is on the U.S. coast, which spans eight U.S. states: Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio, Pennsylvania, and New York (again west-to-east). The Lake Level Viewer is a sibling application to the NOAA Sea Level Rise and Coastal Impacts Viewer, a geovisualization application supporting adaptive management along the Atlantic, Gulf, and Pacific coasts in the U.S. (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer). As described below, a fundamental redesign of the Lake Level Viewer was necessary due to the unique adaptive management context along the Great Lakes. The wireframe evaluation led to a series of revisions to the functional scope and visual design of the Lake Level Viewer, and identified numerous design insights that may be useful for similar interactive and web-based mapping applications that visualize future water levels under alternative climate change scenarios.

This paper proceeds with four additional sections. In the follow section, the case study is introduced, including background on adaptive management on the Great Lakes and prior work on the Lake Level Viewer leading to the design of the wireframes. The third section details our method design for evaluating the wireframes. We completed a series of cognitive walkthroughs using the wireframes with eighteen (n=18) target users across the Great Lakes. The fourth section reports on the feedback we received on the wireframe designs during the cognitive walkthroughs, and discusses key revisions to the Lake Level Viewer concept and design following the wireframe evaluation. The fifth and final section offers concluding remarks about wireframing for Cartography and GIScience.

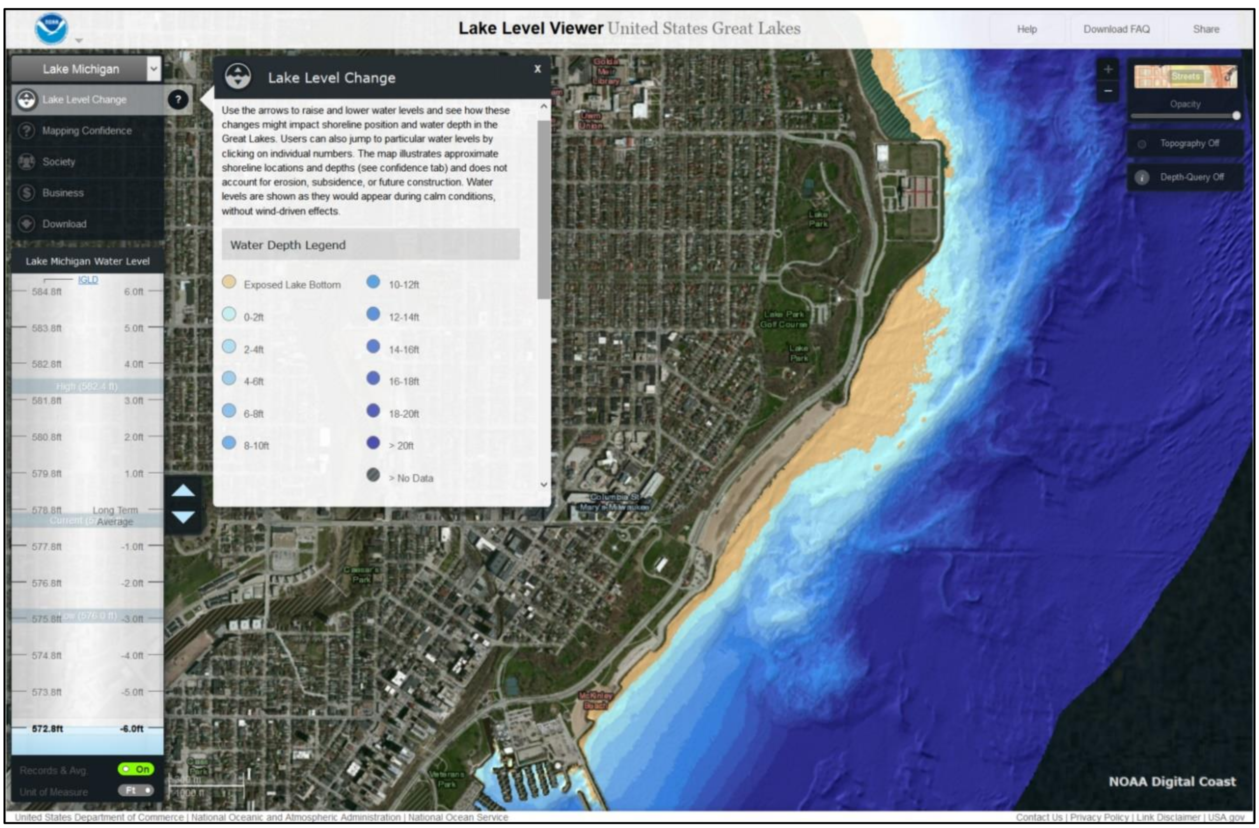

*Figure 1. **The National Oceanic & Atmospheric Administration's (NOAA) Lake Level Viewer.** The Lake Level Viewer is an interactive and web-based geovisualization application supporting adaptive management of coastal hazards related to future water levels in response to climate change in the Great Lakes region of North America. The Lake Level Viewer was developed in collaboration of the NOAA Coastal Services Center, the University of Wisconsin Sea Grant Institute, and the University of Wisconsin–Madison Department of Geography. The Lake Level Viewer is available for public use at: http://www.csc.noaa.gov/digitalcoast/tools/llv.*

2. Background: The Lake Level Viewer Case Study

2.1 Adaptive Management on the Great Lakes

The Lake Level Viewer concept aligns broadly with tenets of adaptive management. *Adaptive management* describes the application of a structured, iterative process of decision making under high levels of information uncertainty, allowing for incremental action to be taken as new information is generated (Holling, 1978, Lee, 1982, Walters, 1986). Adaptive management techniques have been applied for the management of renewable resources, such as forestry, fishing, water, and wildlife, and recently have been extended for management of coastal hazards as way to promote resilient Great Lakes communities (Hart and Hamilton, 2012). Adaptive management is particularly applicable for mitigation of coastal hazards related to climate change, which include coastal bluff erosion, habitat destruction, storm flooding, and water quality degradation, among others (Moy et al., 2011).

A pressing issue along the Great Lakes related to climate change is the prediction of, and response to, future water levels. Modeling of climate-related changes to the oceans suggests a marked increase in global sea levels over the next century under a variety of emissions scenarios (IPCC, 2007). In contrast, recent modeling of climate-related changes to the Great Lakes water levels suggests a possible decrease in lake levels, but an increase in the annual variation of water levels (Angel and Kunkel, 2010, Hayhoe et al., 2010). Prevailing thought in the scientific community is that warmer temperatures and decreased ice cover will drive a trend toward lower water levels, although the overall effect of climate change on lake levels remains unclear (Croley, 2007, Lofgren and Hunter, 2010, DiMarchi and Dai, 2011). The water levels across the Great Lakes already set or approached record lows in 2012-2013. Such significant and unprecedented lake levels require careful consideration of an array of new coastal hazards with no historical analog. Further, the potential decreases in lake levels requires different adaptive coastal management solutions compared to those applied for increasing sea levels.

Effective adaptive management of Great Lakes coastal areas in response to climate change relies upon the availability and accessibility of *water level visualizations*, or interactive and web-based mapping applications depicting the exposure or flooding of land as a result of historical and current storm events or future climate change predictions (Kostelnick et al., 2009). Such visualizations directly serve municipalities and local communities, state and federal government agencies, and universities or other research institutions. Such visualizations also are invaluable to the industries upon which Great Lakes communities are reliant, as lake level changes may negatively impact agriculture, energy, manufacturing, shipping, and tourism (Bosello et al., 2007). However, water level visualizations derived from future climate models are not readily available to stakeholder groups in the Great Lakes (Greene and Hart, 2011) and the visualizations that are publicly available vary greatly across models and are wrought with uncertainties (Nicholls and Cazenave, 2010, Moy et al., 2011).

2.2 Target Users and Functional Requirements for the Lake Level Viewer

The NOAA Lake Level Viewer application was proposed to address the above adaptive management needs along the Great Lakes. The wireframe evaluation that we report in this paper was part of a larger user-centered design process for the Lake Level Viewer, completed in partnership with the NOAA Coastal Services Center, the University of Wisconsin Sea Grant Institute, and the University of Wisconsin–Madison Department of Geography; use of the first person 'we' in the following refers collectively to this team. Notably, the portion of the team at the University of Wisconsin was involved in the design and evaluation of the Lake Level Viewer only—with developers at the NOAA Coastal Services Center responsible for all coding—demonstrating the potential for cartographers to contribute to large interactive and web-based mapping projects as UX designers, rather than developers. Prior stages of the user-centered design process included a pair of focus groups with target users and a competitive analysis of 25 existing water level visualization tools found online (see Roth et al., 2014).

Feedback from the focus groups allowed us to formalize target user profiles and use case scenarios for the Lake Level Viewer concept. The target user group for the Lake Level Viewer was diverse, and included decision makers and planners along the Great Lakes working in all levels of government, academic researchers studying regional climate change on the Great Lakes, and industries whose essential infrastructure and operations may be impacted by changing water levels on the Great Lakes. From this diverse target user group, we identified nine user profiles and associated use case scenarios guiding the design and evaluation of the Lake Level Viewer wireframes (Table 1).

#	Target User Profile	Hypothetical Organization	Hypothetical Sector	Hypothetical Use Case Scenario
1	Community Planner	City Public Works Department	Government, Municipal	I need the Lake Level Viewer to track changes in lake levels, illustrate impacts of these changes to our city's infrastructure, and encourage coastal sustainability.
2	Grant Officer	County Planning Commission	Government, County	I need the Lake Level Viewer to help me review grant applications and supervise funded programs designed to promote resilient and sustainable use of our coasts.
3	Program Manager	State Coastal Management Program	Government, State	I need the Lake Level Viewer to select land conservation and restoration locations that could increase in size or richness of habitat.
3	Natural Resource Manager	State Department of Natural Resources	Government, State	I need the Lake Level Viewer to identify locations that may become susceptible to invasive species as water levels change.
4	Engineer	U.S. Army Corps of Engineers	Government, Federal	I need the Lake Level Viewer to study and model hydrological processes and hazards across the Great Lakes.
5	Director	International Joint Commission	Government, International	I need the Lake Level Viewer to inform our adaptive management strategy for regulating coastal activities across the Great Lakes.
6	Outreach Specialist	Sea Grant Institute	University	I need the Lake Level Viewer to disseminate the state of climate change science on the Great Lakes to the community through public workshops.
7	Researcher	Research University	University	I need the Lake Level Viewer to collect geospatial data on water levels under different climate change scenarios to inform my research on resiliency and sustainability.
8	Engineer	Power Company	Industry	I need the Lake Level Viewer to develop low water scenarios for determining impacts to underwater infrastructure (e.g., water intake pipes) used in our business operations.
9	Owner	Marina	Industry	I need the Lake Level Viewer to understand impacts of changing water levels on dredging and infrastructure at and around my marina.

Table 1. Target User Profiles and Use Case Scenarios for the Lake Level Viewer. *These user profiles and use case scenarios were developed through earlier stages in the user-centered design process and were used to inform design and evaluation of the Lake Level Viewer wireframes.*

Next, insights from the focus groups and competitive analysis allowed us to establish a set of functional requirements for inclusion in the Lake Level Viewer wireframes, organized according to *representation requirements* (i.e., data and services needed to render the visualization onscreen) and *interaction requirements* (i.e., the interface controls for manipulating the resulting visualization). Table 2 provides a summary of these requirements. First, the Lake Level Viewer required a high quality digital elevation model (DEM) with detail on both sides of the coastline to account for possible increases or decreases in lake levels, a requirement not needed for the flood-centric Sea Level Rise and Coastal Impacts Viewer. We built a seamless DEM from the U.S. Army Corps of Engineers topo-bathy LIDAR dataset, although issues with water turbidity limited the completeness of the surface-penetrating topo-bathy LIDAR dataset across the five lakes, particularly for high traffic areas such as marinas and ports. We therefore designed the visualization architecture as a series of pre-processed web map services (one for each water level, see http://www.csc.noaa.gov/arcgis/rest/services/LakeLevels), allowing for straightforward maintenance as improvements are made to the topo-bathy dataset.

We then conceived the map visualization as a series of user-selected overlays atop a 'slippy' (i.e., browsable) raster tileset. Interestingly, none of the 25 water level visualizations surveyed in the competitive analysis supported both a positive and negative change in water levels, and therefore represented the 'flood extent' rather than the 'waterline' or 'water extent'. Accordingly, we proposed a novel representation solution for the default map overlay using a diverging color scheme, with blue representing 'water depth' and brown representing 'exposed lake bottom'. Based on feedback from the focus groups, we planned on a water level range of +/-6ft using the International Great Lakes Datum (IGLD) as a 0ft baseline. Following the Sea Level Rise and Coastal Impacts Viewer, we included an optional uncertainty overlay in the Lake Level Viewer, indicating areas with an 80% 'confidence' of being inundated in blue and areas beneath this threshold, but above 50% 'confidence', in orange. We also included a second uncertainty representation to depict LIDAR completeness, using a texture fill to represent areas with 'no data'. Following conventions of the other reviewed water level visualizations, we included four basemap tileset options ('imagery', 'streets', 'topography', and an additional 'bathymetry' to account for decreased water levels), two context overlays ('population density' and 'business' density, based on readily available information sets), map legends, and supplementary information about background assumptions, data lineage, and our visualization techniques.

#	Requirement	Description
Representation		
1	DEM	Derived from Army Corps topo-bathy lidar
2	Water Depth	Depicted in a blue color ramp; registered to the International Great Lakes Datum (1985)
3	Exposed Lake Bottom	Depicted in a brown color ramp; registered to the International Great Lakes Datum (1985)
4	Confidence	Depicted in orange; registered to the International Great Lakes Datum (1985)
5	No Data	Depicted using a hatched texture
6	Basemaps	Four multiscale tilesets for use as the basemap: Imagery, Streets, Bathymetry, and Topography
7	Context Layers	Restricted to Population Density (Census Bureau) and Business density (Bureau of Labor)
8	Legend	Visual description of Water Depth, Exposed Lake Bottom, Confidence, No Data, and context layers
9	Supporting Information	Documentation on the background assumptions, data lineage, and visualization techniques
Interaction		
1	Lake Level Slider	Ability to change water level, with a range of +/- 6ft
2	Lake Level Benchmarks	Change the water level to past benchmarks, including historic High, Low, and Average
3	Lake Selection	Inset map for switching between lakes
4	Accordion Panel	Organize functionality, legends, and supplementary information by overlay
5	Depth Query Tool	Click on the map and activate a histogram of flooding scenarios for that location
6	CanVis Overlay	Overlay photo simulations of flooding or exposure at specific sites, created using NOAA CanVis software
7	Map Transparency Tool	Adjust transparency of the Water Depth, Exposed Lake Bottom, and Confidence representations
8	Basemap Toggle	Switch between basemaps
9	Map Browsing	Panning and zooming through direct manipulation of the map and buttons
10	Share	Create a RESTful hyperlink to share the current configuration
11	Download	Download the DEM dataset
12	Minimize	Collapse the interface panels to dedicate more screen real-estate to the map

Table 2. The Functional Requirements of the Lake Level Viewer. *Earlier stages in the user-centered were used to establish a core set of functional requirements for the Lake Level Viewer, which then informed design and evaluation of the wireframes.*

Following the majority of water level visualization tools, the primary interface control for the Lake Level Viewer was a persistent 'lake level slider', allowing the user to change the depicted water level (in 1ft increments) on the map as well as select key benchmarks, such as the historic 'high', 'low', and 'long term average'. Importantly, the Great Lakes have different baseline water levels according to the IGLD (Lakes Michigan and Huron are one continuous body of water, and therefore have the same baseline water level). To account for this variation, we proposed inclusion of a 'lake selection' inset map, with selection of a new lake updating both the map centering and the 0ft value used in the lake level slider. In order to organize interface functionality and supplementary information by map overlay, we planned on using an accordion interface panel with five expandable options: 'lake level change', 'mapping confidence', 'socioeconomic', 'download', and 'supporting info'. Additional interaction functionality specific to the lake level change overlay included a 'depth query' tool presenting a bar chart of +/-6ft water depths for a selected location and a 'CanVis' feature presenting a photo simulation of flooding or exposure at specific locations, created using NOAA CanVis software (http://www.csc.noaa.gov/digitalcoast/tools/canvis). Interface controls for manipulating the basemap remained persistent at the top of this accordion panel, which included the ability to toggle the different basemap options, tools for zooming, and a 'map transparency' tool for adjusting the opacity of the overlay layers. Additional interaction requirements included the ability to 'share' the current map configuration using a RESTful hyperlink and the ability to minimize the accordion panel and lake selection inset to dedicate a larger portion of the screen real-estate to the map.

3. Methods

The Lake Level Viewer wireframes were evaluated using the *cognitive walkthrough* method. In a cognitive walkthrough, target users 'walk through' a prototype—in this case the wireframe designs—from the perspective of their user profiles to achieve the cognitive goals associated with their use case scenarios (Allendoerfer et al., 2005, Blackmon et al., 2002). The cognitive walkthrough provides a useful proxy for first time use of a proposed application, giving designers insight into the likely entry point of the application (i.e., the 'first click'), the subsequent sequence in which interface controls are used, bottlenecks or breakdowns in this interaction workflow, potentially confusing or misleading controls, and significant gaps in functionality (Polson et al., 1992, Riemen et al., 1995). Unlike many other usability evaluation methods, the cognitive walkthrough is suitable for evaluating rough wireframes outlining proposed functionality, assuming sufficient explanation of the wireframes is provided such that the participant can envision how the application will work—even if this vision is incorrect, which may reveal design issues—and respond to prompts accordingly.

3.1 Participants

Eighteen (n=18) target users participated in the cognitive walkthrough of the Lake Level Viewer wireframes. Participants were purposefully sampled to represent the target user profiles and use case scenarios described in Table 1, capturing the range of user goals and tasks that the Lake Level Viewer is intended to support. Participants also were purposefully sampled across the Great Lakes region: four (n=4) participants were from the State of Michigan, three (n=3) from New York, three (n=3) from Ohio, three (n=3) from Wisconsin, two (n=2) from Pennsylvania, one (n=1) from Indiana, one (n=1) from Minnesota, and one (n=1) from Canada, leaving Illinois the only unrepresented Great Lakes state. All eighteen participants had earned a Bachelor's degree or higher, with ten (n=10) holding a Masters degree. Participants held degrees in a wide range of disciplines—a reflection of the diverse user profiles and use case scenarios—including Atmospheric Science, Aquaculture, Civil and/or Environmental Engineering, Economics, Environmental Studies, Forestry Geography, Geology, Historic Preservation, Journalism & Mass Communication, Marine Science, and Water Resource Management. The average amount of work experience within the domain was approximately eleven (11) years, with a range of one to thirty-three years (1-33).

3.2 Materials

Design of the Lake Level Viewer wireframes was informed directly by the user profiles, use case scenarios, and functional requirements formalized in prior stages of the user-centered design process. In practice, two forms of wireframes exist: low-fidelity and high-fidelity. *Fidelity* refers to the degree to which a prototype, wireframe or otherwise, accurately represents the functional scope and visual design of the proposed application (Tullis, 1990). Rudd et al. (1996) provide a summary of the various considerations for using low-fidelity versus high-fidelity prototypes in user-centered design. Low-fidelity prototypes hold the advantage of a lower development cost, and thus can be leveraged earlier in the user-centered design process and allow for evaluation of multiple prototype designs. However, low-fidelity prototypes cannot be evaluated in a controlled study using benchmark tasks, as they do not include the actual text and multimedia to be included on the page. This latter issue is particularly a concern when wireframing interactive and web-based map applications, as the inclusion of real data and map representations is essential for understanding how the proposed design matches the needs of target users (Lloyd and Dykes, 2011). Roth and Harrower (2008) describe placeholder representations included in low-fidelity wireframes as *lorem ipsum maps*, and warn about the negative implications this design practice can have on the look and feel of the mapping application. In contrast, high-fidelity prototypes make use of real data and representations—allowing for simulated use of the prototype in controlled evaluations— but are expensive to develop and time consuming to create.

Given the above discussion, we completed a balanced approach to wireframing based on the distinction between representation and interaction requirements introduced above (Table 2). For the representation requirements, we designed a series of high-fidelity wireframes that used a small strip of the processed DEM and showing the proposed representation solution in seven different visual states of the Lake Level Viewer: (1) water depth at 0ft (baseline) atop satellite basemap, (2) water depth at +6ft atop satellite basemap, (3) water depth + exposed lake bottom at -6ft atop satellite basemap, (4) water depth at 0ft atop topography basemap, (5) confidence at 0ft atop satellite basemap, (6) confidence at +6ft atop satellite basemap, and (7) confidence + exposed lake bottom at -6ft atop satellite basemap. Figure 2 shows the high-fidelity representation wireframes. We did not evaluate the streets tileset in the cognitive walkthroughs due to the anticipated familiarity with slippy web mapping services like Google Maps and overall time constraints.

We then designed a series of six low-fidelity wireframes showing the Lake Level Viewer interaction requirements based on the proposed organization of the accordion panel: (1) lake level change menu activated, (2) mapping confidence menu activated, (3) socioeconomic menu activated, (4) download menu activated, (5) supporting info menu activated, and (6) minimized view. The low-fidelity interaction wireframes did not include an example map representation and included placeholder informational text. Figure 3 shows the low-fidelity interaction wireframes. The balanced approach allowed target users to gain an understanding of the type of datasets and map representations that would be included in the Lake Level Viewer through the high-fidelity representation wireframes, but did not require our team to have operational web services mapping the entire Great Lakes coast at the time of wireframe evaluation, nor require us to have complete, high-fidelity wireframes for the interface controls.

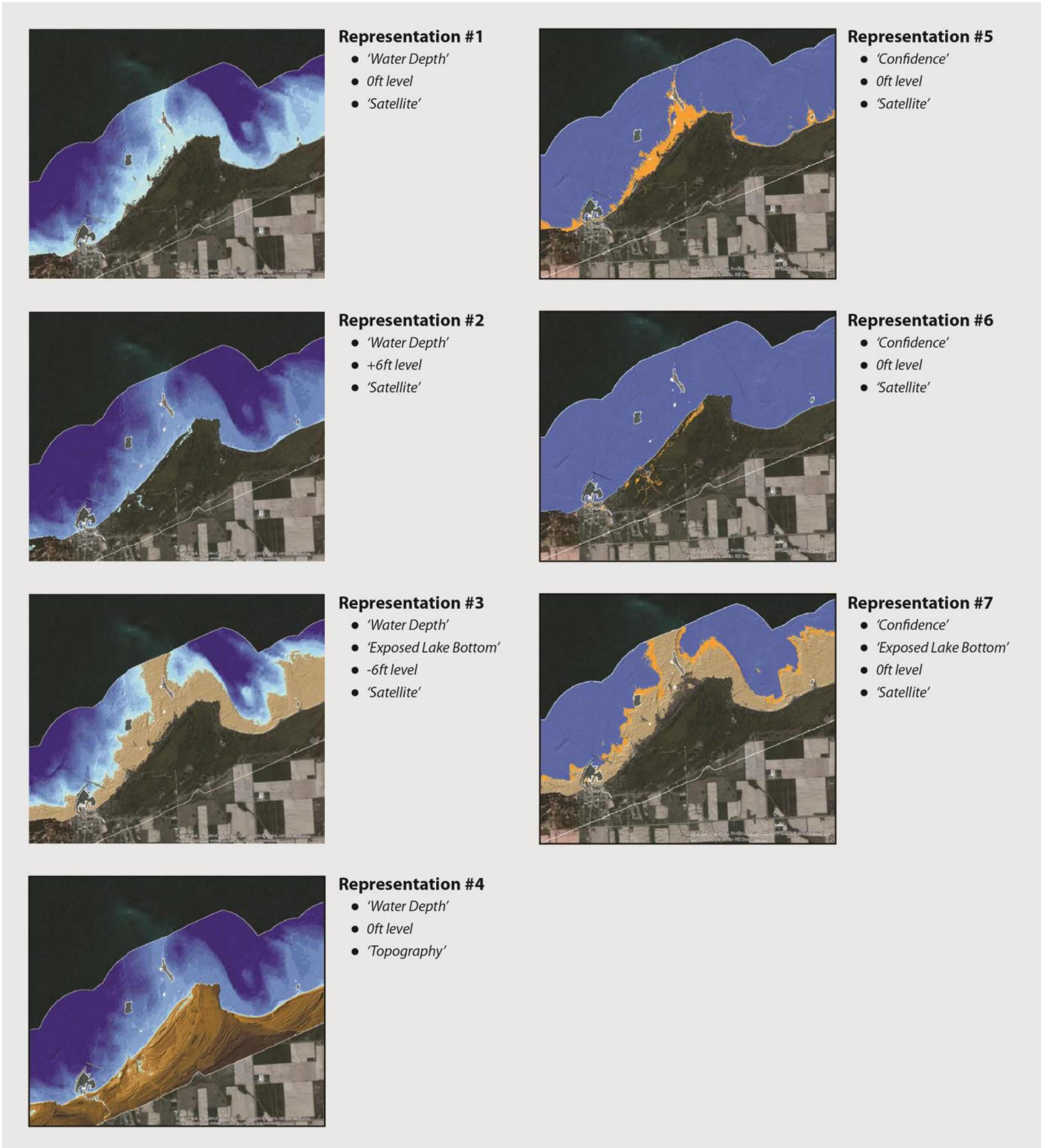

Figure 2. High-fidelity Representation Wireframes for the Lake Level Viewer. *We created seven high-fidelity wireframes using a small strip of the processed DEM to illustrate several visual states of the proposed Lake Level Viewer*.

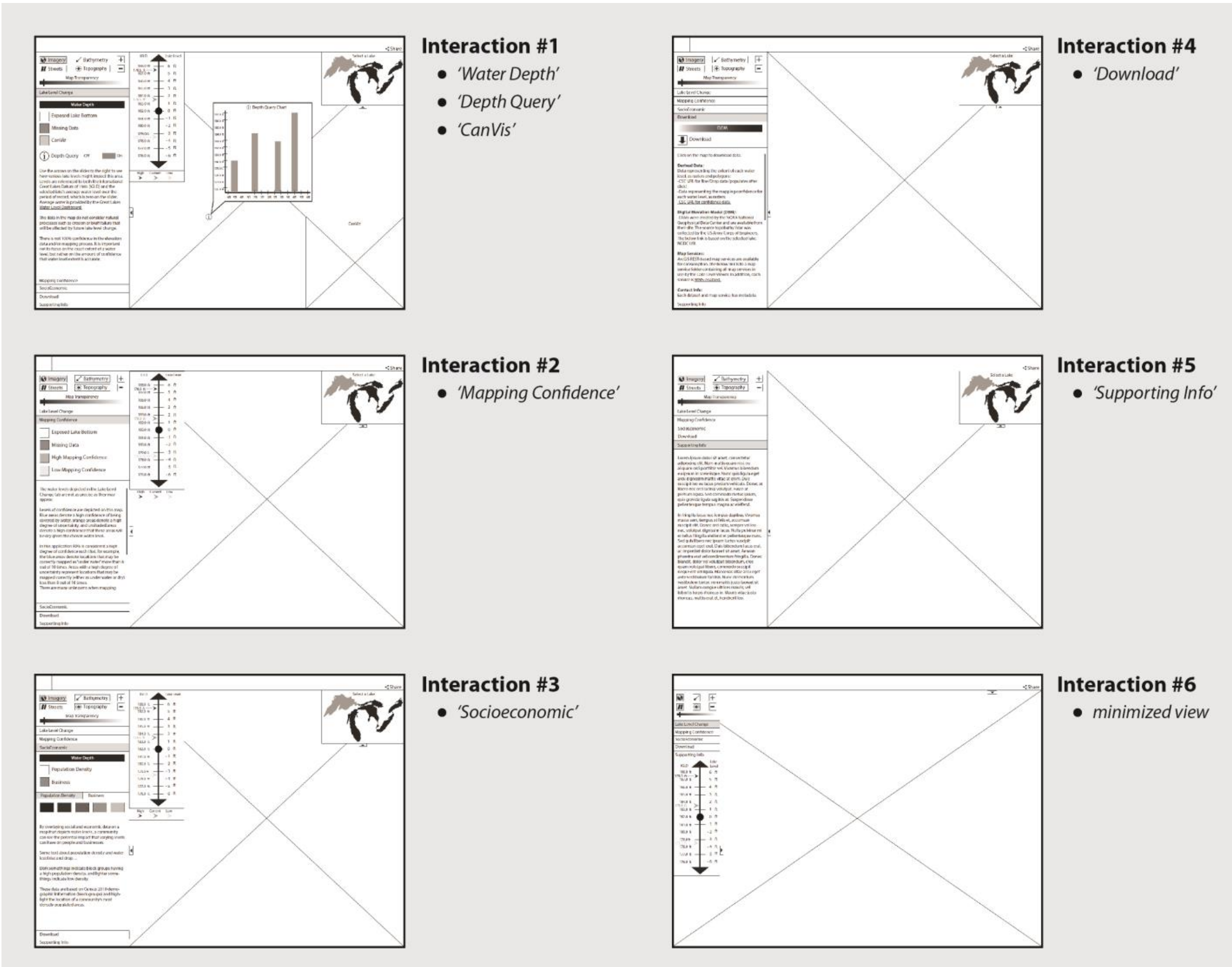

Figure 3. Low-fidelity Interaction Wireframes for the Lake Level Viewer. *We created five high-fidelity wireframes based on the five menu options in the proposed accordion interface panel and a sixth to show the minimized view*.

3.3 Procedure

The wireframe evaluation procedure was divided into four sections. In the initial section, we collected background information and discussed the participant's professional interests and responsibilities in order to contextualize the subsequent cognitive walkthroughs with the his or her real world cognitive goals and work tasks. The middle sections comprised the cognitive walkthroughs, first with the high-fidelity representation wireframes and then with the low-fidelity interaction wireframes. Before the cognitive walkthrough stages, we played a two-minute video about the sibling Sea Level Rise and Coastal Impacts Viewer in order to help the participant envision how the subsequent Lake Level Viewer wireframes could work. We concluded the wireframe evaluation with a debriefing discussion about additional opinions about and ideas for the Lake Level Viewer.

A procedural modification of the cognitive walkthrough method was required for the middle sections of the wireframe evaluation, as the use of interactive and web-based mapping applications for critical thinking and decision making often is unstructured, exploratory, and open-ended (Roth, 2011). Rather than imposing a set of simplified benchmark tasks upon the participant to complete in the cognitive walkthrough, we first allowed each participant to openly explore individual wireframes and then discuss how the outlined functionality could support his or her cognitive goals and work tasks. Following this open-ended discussion, we then asked follow-up probes in order to interrogate specific functionality outlined in the wireframe and to drill deeper into the potential for the Lake Level Viewer to support the participant's goals and tasks. This modification was justified further by our decision to use low-fidelity wireframes to evaluate the interaction functionality, as insufficient detail was provided in these wireframes to complete benchmark tasks (a limitation of low-fidelity wireframes introduced above).

We conducted the walkthroughs in person, at the participant's work location, using full color prints of the high-fidelity representation wireframes and black-and-white prints of the low-fidelity interaction wireframes. We designed the wireframe evaluation to last no longer than sixty minutes. The eighteen evaluations were completed in February and March of 2014.The wireframe evaluations were audio recorded for subsequent transcription and analysis.

3.4 Analysis

Our anlaysis of the wireframe evaluation followed tenets of *qualitative data analysis*, or the systematic interpretation of non-numerical information such as text, images, and maps (Dey, 1993, Miles and Huberman, 1994). The audio recordings were transcribed by our university transcription service and segmented, or unitized, at the statement level for subsequent margin coding (Bertrand et al., 1992). We developed a coding scheme based on the functional requirements outline in Table 2, as well as several of our general questions or concerns about the UX design that were unresolved in earlier stages of the user-centered design process. A total of twenty-eight (n=28) codes were identified, organized by five broader themes: (1) statements about the representation of inundated vs. exposed areas, (2) statements about the representation of uncertainty, (3) statements about the basemap or context overlay representations, (4) statements about the proposed interaction controls, and (5) statements about the overall interaction design. For reliability, two coders applied the twenty-eight part coding scheme to the eighteen transcripts, with discrepancies resolved by a third member of the project team (Robinson, 2008). Table 3 lists the twenty-eight codes and summarizes the frequencies of participant statements by code.

A total of 910 codes were applied across the eigthteen transcripts, an average of 50.56 codes per transcript. Participant reaction was more positive than negative, with 495 positively coded statements (average of 27.50) and 415 negatively coded statements (avg=23.06). Participants discussed the representation and interaction functionality almost evenly, with 454 statements about the representation wireframes (avg=25.22) and 456 statements about the interaction wireframes (average=25.33). Discussion of the high-fidelity representation wireframes was overall negative (diff=-62; avg=-3.44), while discussion of the low-fidelity interaction wireframes was overall positive (diff=142; avg=7.89). Each category of codes is treated individually in the following results section following the synoptic style of reporting described by Monmonier and Gluck (1994).

4. Results and Discussion

4.1 Representing Water Levels

The first three categories of codes primarily related to the high-fidelity representation requirements, although did spark redesigns to the interface controls in several important ways. The first category of codes indicated statements about our solution for depicting the changing water levels (W: total=177; avg=9.83). Six codes were included under the water levels category: (W1) water depth symbolization, (W2) exposed lake bottom symbolization, (W3) shoreline symbolization, (W4) datum choice, (W5) legend design, and (W6) lake level range. The overall valence of this discussion was nearly neutral (diff=5; avg=0.28). The greatest amount of discussion about the water level representation was generated about the appropriate datum choice (W4: total=53; avg=2.94), followed by the included lake level range (W6: total=38; avg=2.11) and exposed lake bottom symbolization (W2: total=34; avg=1.89). Participants discussed the water depth symbolization (W1: total=24; avg=1.33) and shoreline symbolization (W3:

total=24; avg=1.33) evenly. Minimal feedback was offered on the legend design (W5: 4 statements; average=0.22).

Reaction to the water depth symbolization (W1: diff=20; avg=1.11) and exposed lake bottom symbolization (W2: diff=12; avg=0.67) overall was positive. All participants (18/18) correctly guessed the meaning of the blue color ramp during the cognitive walkthrough without a legend, while half (9/18) of the participants correctly guessed the meaning of the brown color ramp without a legend. Upon walkthrough of representation wireframes #1-3, one participate stated “It looks very straightforward actually…It’s easy to pick up on,” and a second stating that “The [color] ramp is appropriate, I think.” The most common misinterpretation of the brown color ramp was shallow water, such as an “inundated sandbar” or a “mudflat.” Nearly all participants (17/18) agreed that the representation would be improved by depicting a 0ft shoreline benchmark (W3) to aid interpretation of flooded versus exposed areas, as well as aid comparison across all water level scenarios. One participant stated “If you wanted to really make it clear, you may be able to outline [the shoreline] with some sort of line symbol,” while a second stated “Personally, I think illustrating the original shoreline would be useful because you can always use that as a perimeter of what people are familiar with presently.”

The one participant stating that the 0ft shoreline should not be included in the visualization was concerned about the dynamic nature of the shore, stating “If you put in a vector shoreline, it's got to be based on one snapshot at a time, and that shoreline, any shoreline, it's going to change…because every body of water is going to change.” This concern directly relates to our choice of IGLD as the datum or 0ft line (W4), a topic that elicited the most negative discussion regarding water level representation (diff=-19; avg=-1.06). Participants discussed the tendency to think of the 0ft baseline as the “current level” or how the lakes “look now”, rather than the 25-30 long-term average on which the IGLD is based. One participant stated “The zero being current…I would think of that as the most recent gauge water level,” while a second stated “Is that supposed to be right now, present day based on some kind of data that's taken frequently?” Only half (9/18) of the participants knew what the IGLD acronym meant, with participants agreeing that it would be clearer to describe the baseline as the “long term average” in the lake level slider rather than, or in addition to, the IGLD acronym.

This discussion about the datum choice (W4) also highlighted the potential utility of converting the baseline datum for different regulatory and management use case scenarios; recommended alternatives included: the “current” or “real-time” shoreline (n=7), the ordinary high water mark (n=6), the ordinary low water mark (n=3), the North American Vertical Datum (NAVD88; n=3), seasonal averages (n=2), the 100-year floodplain (n=2), future projections based on climate change scenarios (n=1), the IGLD55 precursor (n=1), and the vegetation line (n=1). One participant noted that industrial firms along the lake were likely to make use of a “local datum” based on their own surveys, which are unlikely to align with authoritative, government datum definitions. Flexible conversion of the baseline datum was outside of the project scope for the initial Lake Level Viewer release given the technical solution of pre-processing each foot increment as a different overlay layer. However, we did modify the design of the lake level slider to indicate both water level change relative to the long term average (i.e., the IGLD baseline) as well as elevation above sea level (supporting simpler conversion to alternatives), and included supporting information about the IGLD and the associated meaning of 0ft (Figure 4). Two participants also noted the importance of converting between standard and metric units of measurement for international use, an interface control we added subsequently to the Lake Level Viewer functional requirements.

ID	Code	Positive		Negative		Difference		Overall	
Representation		**Total**	**Avg**	**Total**	**Avg**	**Total**	**Avg**	**Total**	**Avg**
Water Levels		*91*	*5.06*	*86*	*4.78*	*5*	*0.28*	*177*	*9.83*
W1	Water Depth Symbolization	22	1.22	2	0.11	20	1.11	24	1.33
W2	Exposed Lake Bottom Symbolization	23	1.28	11	0.61	12	0.67	34	1.89
W3	Shoreline Symbolization	11	0.61	13	0.72	-2	-0.11	24	1.33
W4	Datum Choice	17	0.94	36	2.00	-19	-1.06	53	2.94
W5	Legend Design	3	0.17	1	0.06	2	0.11	4	0.22
W6	Lake Level Range	15	0.83	23	1.28	-8	-0.44	38	2.11
Uncertainty		*29*	*1.61*	*91*	*5.06*	*-62*	*-3.44*	*120*	*6.67*
C1	Confidence Symbolization	2	0.11	34	1.89	-32	-1.78	36	2.00
C2	No Data Symbolization	1	0.06	34	1.89	-33	-1.83	35	1.94
C3	Uncertainty Comprehension	26	1.44	23	1.28	3	0.17	49	2.72
Basemaps/Overlays		*76*	*4.22*	*81*	*4.50*	*-5*	*-0.28*	*157*	*8.72*
B1	Imagery Tileset	19	1.06	0	0.00	19	1.06	19	1.06
B2	Topography Tilest	28	1.56	13	0.72	15	0.83	41	2.28
B3	Context Layers	20	1.11	54	3.00	-34	-1.89	74	4.11
B4	Supporting Information	9	0.50	14	0.78	-5	-0.28	23	1.28
Interaction		**Total**	**Avg**	**Total**	**Avg**	**Total**	**Avg**	**Total**	**Avg**
Interface Functionality (Utility)		*227*	*12.61*	*126*	*7.00*	*101*	*5.61*	*353*	*19.61*
I1	Lake Selection	33	1.83	4	0.22	29	1.61	37	2.06
I2	Lake Level Slider	30	1.67	11	0.61	19	1.06	41	2.28
I3	Lake Level Benchmarks	15	0.83	27	1.50	-12	-0.67	42	2.33
I4	Depth Query Tool	30	1.67	28	1.56	2	0.11	58	3.22
I5	CanVis Overlay	50	2.78	14	0.78	36	2.00	64	3.56
I6	Map Transparency Tool	7	0.39	13	0.72	-6	-0.33	20	1.11
I7	Basemap Toggle	16	0.89	7	0.39	9	0.50	23	1.28
I8	Map Browsing	21	1.17	5	0.28	16	0.89	26	1.44
I9	Share	12	0.67	7	0.39	5	0.28	19	1.06
I10	Download	13	0.72	10	0.56	3	0.17	23	1.28
Interface Design (Usability)		*72*	*4*	*32*	*1.78*	*40*	*2.22*	*104*	*5.78*
U1	Layout Design	17	0.94	11	0.61	6	0.33	28	1.56
U2	Minimized Layout Design	11	0.61	1	0.06	10	0.56	12	0.67
U3	Interface Aesthetics	1	0.06	4	0.22	-3	-0.17	5	0.28
U4	Learnability	2	0.11	7	0.39	-5	-0.28	9	0.50
U5	Subjective Satisfaction	41	2.28	8	0.44	33	1.83	49	2.72
Representation Overall		**196**	**10.89**	**258**	**14.33**	**-62**	**-3.44**	**454**	**25.22**
Interaction Overall		**299**	**16.61**	**157**	**8.72**	**142**	**7.89**	**456**	**25.33**
All Statements		**495**	**27.50**	**415**	**23.06**	**80**	**4.44**	**910**	**50.56**

Table 3. Coding Results of the Wireframe Evaluation of the Lake Level Viewer. A twenty-eight part coding scheme was applied to analyze and interpret the transcripts, following tenets of qualitative data analysis (QDA). This table summarizes the total and average (out of 18 participants) frequencies of both positive and negative statements regarding the given code, as well as the difference between positive and negative frequencies and the overall frequency of each code.

Opinion about our suggested water level range of +/-6ft (W6) was divided evenly between participants suggesting that the range should be constrained by actual historic observations (9/18) and those wanting as wide of a range as possible (9/18). Representing the former perspective, one participant stated “I mean what's the likelihood of a minus six and how does that happen? Has it ever happened?” While envisioning how a citizen may react to a wider range, a second participant stated “[he or she] would think, oh my God, we're going to see a rise of 20 feet!” This first camp therefore was concerned with public reaction to the Lake Level Viewer, recommending the depicted range be constrained to +/-3 feet. Representing the latter perspective, one participant stated that when “forecasting or simulating longer-term scenarios, I would say a doubling of the natural range might be a good start,” and a second stating that if “the ultimate objective is to visualize the changing sea level or water levels down the road, I wonder if [+/-6ft] is going to be enough.” This second camp saw +/-6ft as appropriate, with three (3/18) participants recommending up to +/-10ft to explore extreme future climate change scenarios.

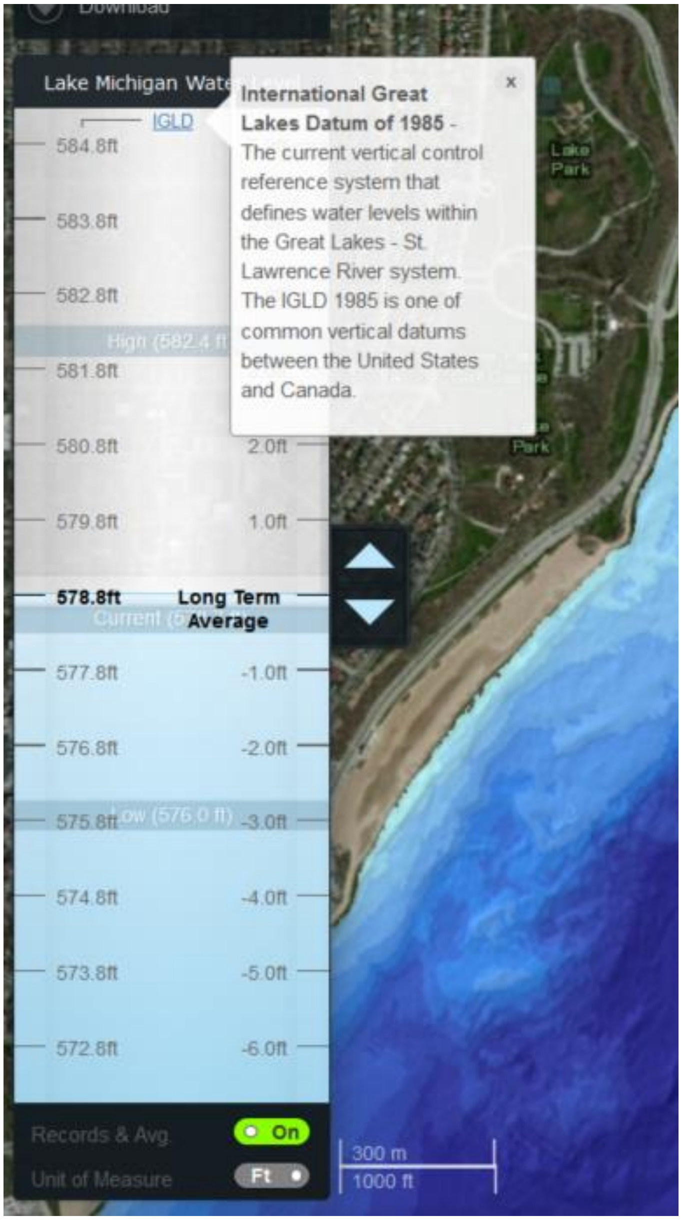

Figure 4. The Redesigned Lake Level Slider. *Based on feedback to the wireframes, we redesigned the lake level slider to include indications of both elevation above sea level and departure from the "long term average." We also provided supporting information about the meaning of the IGLD as an information window and an interface control to change between standard and metric units of measurement. Finally, the visual design of the lake level slider was refined to appear as a vessel that can be filled or drained, rather than a simple slider bar widget, to avoid confusion with a zoom slider and to evoke a metaphor of inundation and exposure.*

Discussion around the appropriate water level range also revealed the importance of considering the specific adaptive management context for each of the five Great Lakes. The constraint of +/-6ft was seen as most problematic for Lake Erie, where storm-related seiches can cause fluctuations in water levels up to +/-8ft from the long term average, although typically these events fall within the proposed +/-6ft range. The constraint of +/-6ft was seen as least problematic on Lake Superior, which does not see fluctuation beyond +/-3ft from the long term average. However, because Lake Superior is used to moderate the water levels of the lower lakes, having a broader range of +/-6ft on Lake Superior allows for exploration of different adaptive management solutions across the five lakes. Ultimately, we decided to maintain the +/-6ft range across lakes given our target user profiles comprising educated and experienced professionals (Table 1), but not to extend beyond this range to allay concerns about public misinterpretation. We also decided to maintain the same +/-6ft level across lakes—despite different adaptive management contexts—to improve navigation between lakes in the Lake Level Viewer (see additional details below).

4.2 Representing Uncertainty

The second category of codes indicated statements about representing uncertainty in the Lake Level Viewer (C: total=120; avg=6.67). Three codes were included under this category: (C1) confidence symbolization, (C2) no data (completeness) symbolization, and (C3) uncertainty comprehension. Overall, discussion regarding uncertainty symbolization and comprehension explained the largely negative opinion towards the representation wireframes (diff=-62; avg=-3.44), as the proposed uncertainty solutions garnered 91 negative statements (avg=5.06) but only 29 positive statements (avg=1.61). Issues related to uncertainty comprehension yielded the most discussion (C3: total=49; avg=2.72), followed by the confidence symbolization (C1: total=36; avg=2.00) and the no data symbolization (C2: total=35; avg=1.94).

Participants were not as successful walking through representation wireframes #5-7 depicting confidence (C1) as they were using representation wireframes #1-3 showing the water depth and exposed lake bottom. In total, participants offered 34 negative statements about the confidence symbolization and only 2 positive statements (diff=32; avg=-1.78). Further, only five participants (5/18) correctly identified the orange shading as a depiction of low confidence or uncertainty without a legend, despite introducing the concept of confidence in the introductory video of the sibling Sea Level Rise and Coastal Impacts Viewer. Alternative interpretations included: shallow areas (n=6), recently changed areas (n=3), wetlands (n=2), the worst case flooding scenario (n=2), danger/unnavigable (n=1), land cover category (n=1), offshore sandbars (n=1), and toxic waste (n=1).

Responses to prompts about uncertainty comprehension (C3) identified a major point of confusion with the orange and blue confidence symbolization. Many participants misinterpreted ‘confidence’ as ‘risk’, and thus interpreted the orange color to have the highest risk of flooding, even though the blue color denoted the areas most likely to become inundated. As one participant explained, “I see warm colors as being, you know, high risk…to me, it's like flip-flopped. You're having low confidence but it's in orange, which is kind of, I wouldn't see it that way.” Two participants were wise to note that there are risks with both flooding and exposure, and that the use of orange as a warning of low confidence in the delineation between land and water is appropriate. Both of these participants went on to note that the confusion between confidence and risk can be alleviated through proper messaging in the legend and supporting information. As one participant stated, “Going back to the risk versus confidence thing, I think it would be very important to clearly delineate what these colors generally mean, and then have an option, again, to click on to see, okay what does this really get at?” Fourteen of the participants (14/18) indicated that the confidence legend needed to be accompanied by a clear, well-written supporting information (B4) explaining the meaning of confidence. Further, thirteen of the participants (13/18) stated that the confidence explanation explicitly should use the term “likelihood” and included information about the 80% and 50% likelihood thresholds to communicate what actually is meant by confidence to improve comprehension. As a result of this feedback, we fundamentally redesigned the accordion panel containing the included overlays to instead consist of a series of menu items, removing the supporting info panel as a menu option. Instead, each of the overlay options includes an associated ‘help’ button that, when clicked, activates an information panel providing comprehensive visual and text-based supporting information based on the above recommendations (Figure 5).

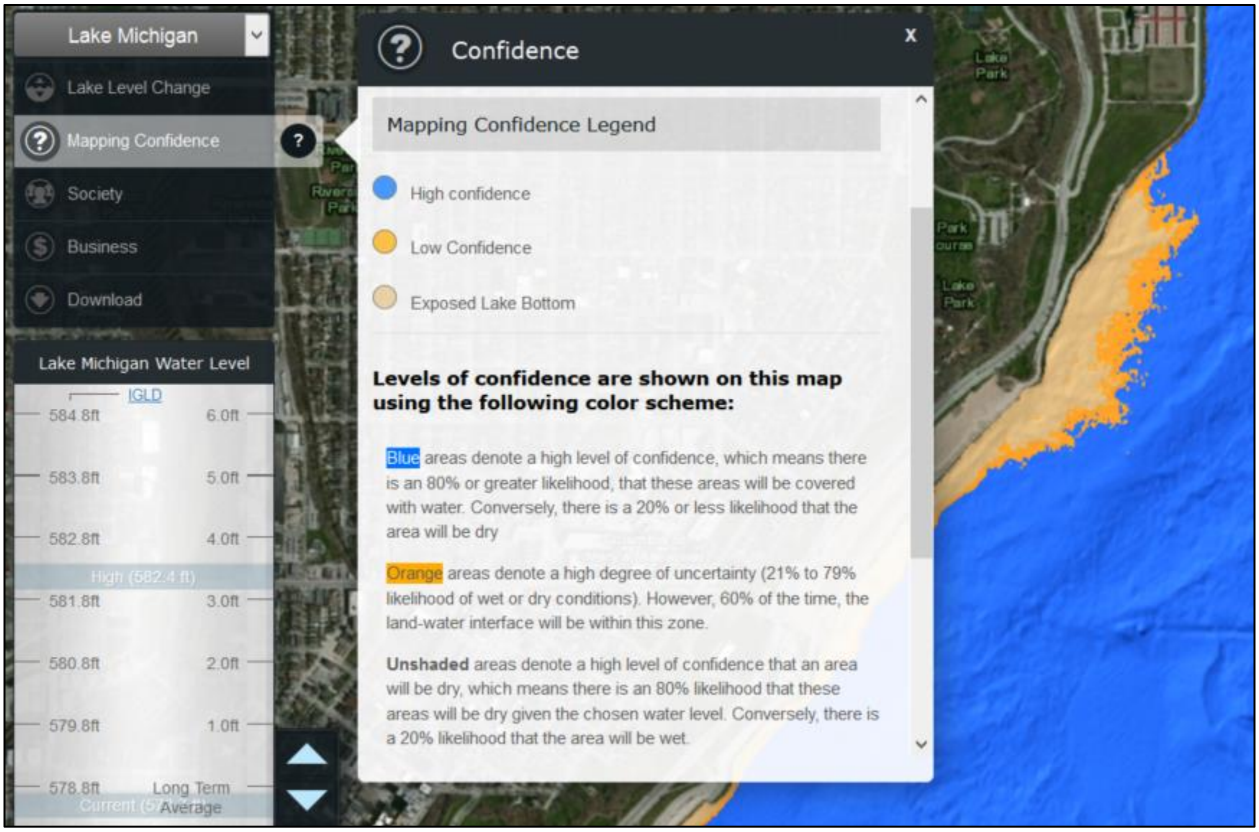

Figure 5. The Redesigned Lake Selection and Overlay Menu of the Lake Level Viewer. The original lake selection inset map and accordion panel design in the interaction wireframes was replaced with a set of persistent menu options. Further, each overlay option has a 'help' button providing comprehensive visual and text-based supporting information about the given overlay, rather than providing this information as a single menu item. The figure shows the redesign to the mapping confidence overlay based on recommendations from the wireframe evaluation.

Interpretation of the no data texture fill (C2) also was problematic across all seven representation wireframes, garnering 34 negative statements (avg=1.89) but only 1 positive statement (avg=0.06). None (0/18) of the participants correctly guessed the meaning of the texture fill without use of a legend, with the no data symbolization most commonly confused as offshore islands. One participant offered insight as to why he or she believed the texture represented islands, indicating that the white hatching "contrasts with the orthoimage", causing the texture fill to stand out against the dark water surface in the imagery tileset. Because of this contrast, areas with no data rose to the figure in the visual hierarchy, and thus led participants to interpret these areas as important features in the map (i.e., high on the intellectual hierarchy) rather than gaps in the dataset. As a result, we made the no data symbolization partially transparent in the full release of the Lake Level Viewer, suppressing these areas to ground in the visual hierarchy so that they can be read more easily as data gaps.

4.3 Basemap/Overlay Representations

The third category of codes addressed the various basemap tilesets and context layers viewed in concert with the water level and confidence visualizations (B: total=157; avg=8.72). Four codes were included to capture statements about the basemap or context overlays: (B1) imagery tileset, (B2) topography tileset, (B3) context layers, and (B4) supporting information, already reviewed above regarding the importance of supporting information for clarifying the uncertainty representations. Interestingly, context layers were the most frequently discussed topic across the transcripts (B3: total=74; average=4.11). Discussion of context layers was followed by feedback on the topography tileset (B2: total=41; avg=2.28), supporting information (B4: total=23; avg=1.28), and the imagery tileset (B1: total=19; avg=1.06).

Participant reaction to the imagery (diff=19; avg=1.06) and topography (diff=15; avg=0.83) tilesets was largely positive. When probed, nine participants (9/18) preferred the imagery tileset, while nine participants (9/18) preferred the topography tileset (shown in representation wireframe #4). Participant discussion indicated different use case scenarios for the imagery versus topography tilesets: Those preferring the imagery tileset needed to interpret land use in the context of the exposed or flooded land, while those preferring the topography tilset primarily needed to interpret landforms when viewing exposed or flooded land. When prompted about all four proposed tilesets, all participants (18/18) agreed that the imagery tileset was the best default for initial exploration of the Lake Level Viewer. Notably, six participants (6/18) were confused about the meaning of the white line showing the extent of the LIDAR data when using the imagery tileset. The most common misinterpretations were administrative boundaries or roads. As a result, this boundary line was replaced by an opacity mask over areas not included in the LIDAR swath, a third form of uncertainty representation included in the final Lake Level Viewer.

The discussion about context layers was largely negative (diff=-34; avg=-1.89), and primarily constituted requests for additional context layers beyond the proposed population and business layers. Context layer requests primarily were divided between aspects of the human or built environment and aspects of the physical or natural environment. Requested human/built context layers included: parcels (n=7), critical infrastructure (n=5), breakwalls/seawalls (n=4), marinas/ports (n=4), public access (n=4), land use (n=3), bridges (n=2), parks (n=2), permitted structures (n=2), slip layouts (n=2), zoning (n=2), hazardous facilities (n=1), navigation channels (n=1), poverty rates/socioeconomic status (n=1), reservations (n=1), and water uses (n=1). This feedback prompted replacement of the simple socioeconomic panel with a pair of menu options indicating the vulnerability of the built environment: 'society' (including the Hazards & Vulnerability Research Institute's (HVRI) social vulnerability index for 2006-2010: http://webra.cas.sc.edu/hvri/products/sovi.aspx) and 'business' (showing the originally planned density of employees along the lakes). Requested physical/natural context layers included wetlands/marshes (n=9), erosion rates (n=6), floodplain maps (n=6), sedimentation/sandbars (n=5), habitat types (n=4), flood frequency (n=3), flood hazards (n=3), lake bottom (n=3), rivers/stream (n=3), fisheries (n=2), ice cover (n=2), land cover (n=2), soil type (n=2), wind direction/speed (n=2), beaches (n=1), currents (n=1), evaporation scenarios (n=1), and weather conditions (n=1). Other requested context layers included historic water level gauges (n=3), historical imagery (n=1), locator maps (n=1), oblique photos (n=1), and offshore surveys (n=1). While we were unable to accommodate this variety of requests in the initial release of the Lake Level Viewer, we anticipate integrating a subset of these context layers into future generations of both the Lake Level Viewer and the Sea Level Rise and Coastal Impacts Viewer.

4.4 Interface Functionality (Utility)

The fourth and fifth categories of codes primarily related to the low-fidelity interaction requirements. The fourth category of codes marked statements about the interface functionality included in the Lake Level Viewer, directly addressing its perceived utility for the use case scenarios outlined in Table 1. The interface functionality proposed in the low-fidelity wireframes by far garnered the most discussion during the cognitive walkthroughs (I: total=353; avg=19.61), but also included the largest number of unique codes. Ten codes in total were included under this category: (I1) lake selection inset map, (I2) lake level slider, (I3) lake level benchmarks, (I4) depth query tool, (I5) CanVis photo simulations, (I6) map transparency tool, (I7) basemap tileset toggle, (I8) map browsing functionality (panning + zooming), (I9) share function, and (I10) download function. The CanVis overlays received the most discussion (I5: total=64; avg=3.56), followed by the depth query tool (I4: total=58; avg=3.22), the lake level benchmarks (I3: total=42; avg=2.33), the lake level slider (I2: total=41; avg=2.28), and the lake selection inset map (I1: total=37; avg=2.06). Discussion was spread relatively evenly across the remaining interface functionality codes: map browsing (I8: total=26; avg=1.44), basemap toggle (I7: total=23; avg=1.28), download (I10: total=23; avg=1.28), map transparency tool (I6: total=20; avg=1.11), and share (I9: total=19; avg=10.6). This discussion was overwhelmingly positive (diff=101; avg=5.61), with only the lake level benchmarks (I3: diff=-12; avg=-0.67) and map transparency tool (I6: diff=-6; avg=-0.33) having a slightly negative valence.

The cognitive walkthrough of interaction wireframes required participants to indicate where they would click first, and then how they would continue to navigate the system. Ten participants (10/18) indicated they first would use the lake selection inset map (I1)—the intended entry point in the interaction wireframes—while five participants (5/18) first using the lake level slider (I2), two (2/18) the map browsing tools (I8), and one (1/18) reviewing the supporting info panel (B4). This initial prompt in the cognitive walkthrough generated discussion about how the Lake Level Viewer should look upon first entry, as the 0ft baseline in the lake level slider is relative to only one of the Great Lakes. Several participants suggested having a splash screen for the Lake Level Viewer that required the users to first select one of the five lakes. One participant stated "there are people who work Great Lakes wide, but I think most people actually care about a single lake," and a second stating "there'd be nothing wrong with having the select a lake, just a map of all of the Great Lakes there [to start] ." Finally, a third envisioned the initial navigation of the splash page, stating "It could even be like the first dialogue box that you see when you open up the viewer, select the lake, and then once you select the lake, that dialogue box goes away [and] it zooms in to your lake…almost as if like the select a lake is, you know, the ignition key." As a result, we added an opening splash page requiring users to select one of the five Great Lakes (Figure 6), with the map then opening to an overview of the selected lake and the lake level slider adjusting the long term average baseline accordingly. We then replaced the lake selection inset map with a simple drop down menu for toggling between the lakes (Figure 5). Overall, this discussion and subsequent revisions demonstrated one of the primary advantages of using low-fidelity wireframes: critical evaluation of the entry point of a proposed application.

The majority of participants (17/18) viewed the vertical design of the lake level slider (I2)—a change from the horizontal design in the Sea Level Rise and Coastal Impacts Viewer—as intuitive. Interestingly, the one (1/18) dissenting participant was concerned that the lake level slider might be confused as a zoom slider due to the vertical orientation and its position in the top-left corner of the application. Explaining this concern, the participant stated "I kind of like it in the left panel area only because I think so many people are familiar with this being your zoom level tool…without really reading the content, that's kind of what I assumed also." As a result, we repositioned the lake level slider in the bottom-left corner of the application and refined its designed to appear as a vessel that can be filled or drained—and thus evoking a visual metaphor of water inundation and land exposure—rather than a common slider bar widget (Figure 4). All participants (18/18) interpreted the lake level benchmarks correctly during the cognitive walkthroughs (I3).

The initial reaction to the CanVis photo simulations was overwhelming positive (I5). Twelve (12/18) of the participants were visibly intrigued during demonstration of the CanVis photo simulations in the opening video of the Sea Level Rise and Coastal Impacts Viewer. Participants thought the photo simulations would be particularly useful for public outreach, with one participant stating "I think for presentations…I think that's really useful, especially for presenting it to more of a general public…I think that really brings it to light, and like, holy cow, that's what it would look like!" When probed, however, nine participants (9/18) said they appreciated the "wow factor," but that they were unlikely to use the CanVis photo simulations themselves. One participant stated "I can't think of anytime when I would actually ever need it," and a second stated "But for us personally, I don't think it'd be to have a lot of relevance as far as…our personal use as well." During the cognitive walkthroughs, participants helped us to brainstorm the kinds of locations that should be included in the CanVis photo simulations on the Great Lakes. Types of locations for depicting an increased water levels included: major urban areas (n=7), marinas/harbors (n=3), national/state parks (n=3), bays/inlets (n=2), beaches (n=2), infrastructure (n=2), dams (n=1), docks (n=1), estuaries (n=1), historical places (n=1), lighthouses (n=1), places with historical flooding issues (n=1), public utilities (n=1), recreation (n=1), sea walls (n=1), shallow areas or sensitive shorelines (n=1), and wetlands (n=1). Identifying types of locations appropriate for depicting decreased water levels was a more difficult question for participants to answer, and included: lighthouse (n=1), marinas (n=1), mud flats (n=1), and sea walls (n=1).

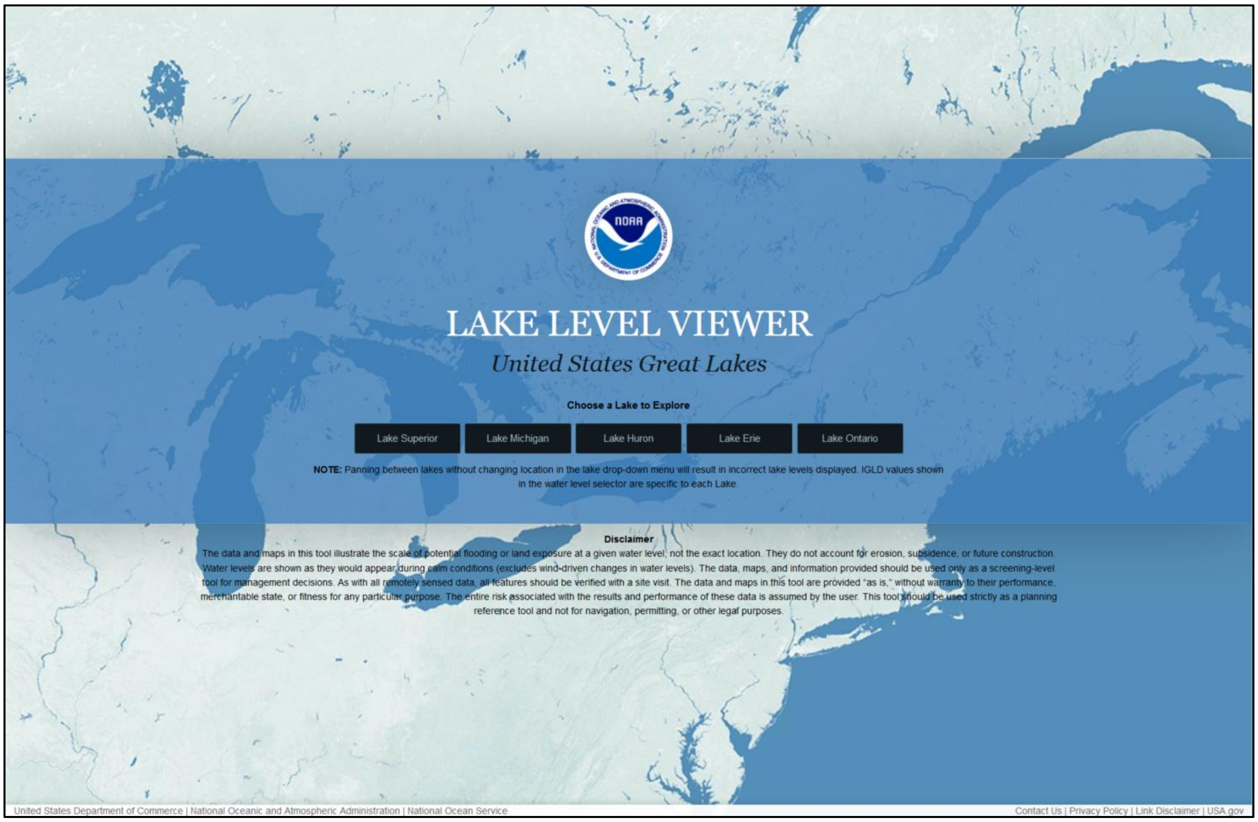

Figure 6. The Splash Page of the Lake Level Viewer. The cognitive walkthrough of the low-fidelity interaction wireframes generated discussion about the entry point of the Lake Level Viewer. Because the 0ft baseline of the lake level slider must be relative to one of the Great Lakes, it was unclear how the application would look upon first loading of the page. Based on participant feedback, we added a splash page requiring users to choose a lake, which then configured the map and the lake level slider.

Overall, participants were content with the map transparency tool (I6), map browsing tools (I8), the share function (I9), and the download function (I10), having no noteworthy suggestions for improving their position or design. There were minor confusions regarding the depth query (I4) and basemap toggle (I7) functionally. First, participants were confused by the bar chart included in the information window activated when using the depth query tool, correctly identifying that the chart always would display an incremental increase and thus not provide interesting or unexpected information. Several participants continued to critique the bar chart even after we noted to ignore it during the cognitive walkthroughs. Upon probing, all participants (18/18) indicated they only wanted to retrieve the water depth upon use of the depth query tool. Twelve (12/18) of the participants wanted the depth query tool to be 'off' by default to avoid issues with panning.

Second, participants were confused with the topography and bathymetry basemap options in the basemap toggle interface. Seven of the participants (7/18) were unsure how the map would update when toggling the topography and bathymetry layers. Because all four options were given as radio buttons, participants expected all tilesets to cover the entire map. However, the LIDAR topo-bathy dataset only covered a small swath along the coast, meaning that the topography and bathymetry layers really were overlays that would be placed above the imagery or streets tilesets. Further, six of the participants (6/18) stated that the bathymetry overlay should remain on at all times, given the purpose of the Lake Level Viewer, and noted that this toggle essentially was redundant with the map transparency tool. As a result of the above feedback on the depth query and basemap toggle functionality, we revised the Lake Level Viewer concept to include a 'map tools' panel to contain these tools, located in the top-right corner of the application in the position vacated by the lake selection inset map (Figure 7). The imagery and streets tilesets were provided as radio buttons that replace one other when selected, with the typography and depth query tools provided as checkboxes, both set to 'off' by default.

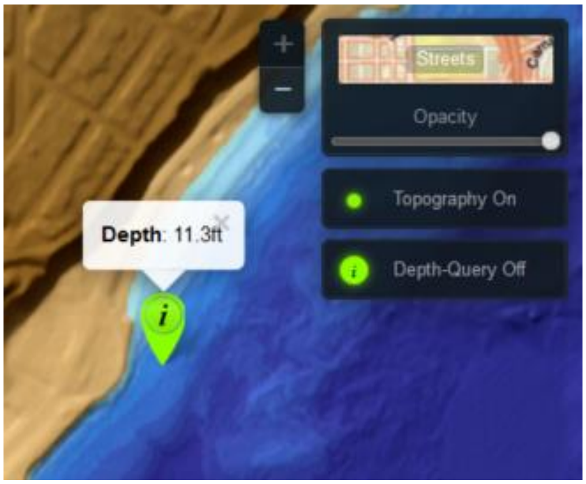

Figure 7. The Depth Query Information Window and the Map Tools Panel. Based on feedback from the cognitive walkthroughs, the depth query information window content was revised to include only the water depth at the selected location. Further, the interface widgets for toggling the basemap tilesets were clarified to indicate that the imagery and streets options were complete tilesets, while the topography option was an overlay only available along the coast. These tools then were grouped with the map transparency and depth query tools in a map tools panel.

4.5 Interface Design (Usability)

The final category of codes identified broader issues in interface design, signaling potential usability problems with the Lake Level Viewer. The interface design was the least discussed of the five categories (U: total=104; avg=5.78), with the depth of feedback constrained by the rough design of the low-fidelity interaction wireframes. Thus, we suspect that low-fidelity wireframes generally are better purposed for garnering input about the utility, rather than the usability of a proposed interactive and web-based mapping application. If understanding usability is the priority, high-fidelity wireframes and partially functional prototypes should be used instead. This category included five codes: (U1) layout design, (U2) minimized layout design, (U3) interface aesthetics, (U4) learnability, and (U5) subjective satisfaction. The most frequently applied code regarded statements about subjective satisfaction with the proposed Lake Level Viewer (U5: total=49; avg=2.72), followed by the layout design (U1: total=28; avg=1.56) and the minimized layout design (U2: total=12; avg=0.67). Discussion regarding learnability (U4: total=9; avg=0.50) and interface aesthetics (U3: total=5; avg=0.28) was sparse.

The main suggestions for improving the layout design (U1) were mentioned above, including placing the lake level slider beneath the lake selection and overlay tools along the left side of the application as well as moving the map tools to the vacated position in the top-right of the application. In addition to the above discussion, participants justified such layout recommendations as a way of improving navigation, with the user starting with the lake selection on the top-left, moving down vertically to the overlay options, then adjusting the water level in the lake level slider, and ultimately moving to explore the map. All participants (18/18) agreed that the minimized layout design would be a benefit for repeated use (U2).

Statements regarding subjective satisfaction helped us to understand two important use case scenarios for the Lake Level Viewer (U5). First, participants were eager to integrate the Lake Level Viewer into their outreach efforts, with one participant stating "we could include a lot of this information in some of those outreach events that we do, we could use the visualization aspect of this in our telling of the story of why the Great Lakes do what they do," and a second stating "We get a lot of questions from people…[it would be a] useful tool to have our workers take a look at it each day to help answer questions." Participants also were eager to use the tool to regularly collect the updated LIDAR-based DEM for integration into their own analytical workflows, with one participant stating "the idea of being able to download is wonderful" and a second stating "I would mostly be downloading the data set for other uses…downloading the GIS information, that would be great." Statements regarding subjective satisfaction also made it evident that wireframe evaluation helped to promote buy-in with participants and their respective agencies. One participant stated "I barely looked at it before, but now I think it's cool…I'm anxious for it to come out, actually [laughter] because I know it will be used for sure," while a second stated "It's got a lot of nice features, I think, from what I see from the wireframes…looks like an excellent start and I can tell you based on these, I'm much more eager to see the digital product than I was going into [the wireframe evaluation]."

5. Conclusion

In this paper, we demonstrate the relevance and utility of wireframing for interactive and web-based mapping applications. Specifically, we describe the design and evaluation of wireframes as part of the user-centered design of the NOAA Lake Level Viewer (Figure 1), an interactive and web-based water level visualization supporting adaptive management on the Great Lakes in the face of shifting water levels due to climate change. Eighteen target users completed cognitive walkthroughs with the Lake Level Viewer wireframes, with the sessions audio recorded for subsequent transcription and qualitative data analysis. To maximize project resources, we completed a balanced approach to wireframing based on the fundamental user experience distinction of representation versus interaction, using high-fidelity wireframes to show the proposed representation solution using real data and low-fidelity wireframes to provide a rough outline of the proposed interaction solution. The wireframe evaluation resulted in a variety of insights regarding the design of water level visualizations, spanning the representation of inundated vs. exposed areas, the communciation of uncertainty about this representation, appropriate basemap tilests and context overlays to pair with the water level visualization, as well as essential interface functionality for manipulating the visualization, and their optimal layout for straightforward entry and navigation of the visualization.

The wireframe evaluation led to fundamental changes to the Lake Level Viewer concept, including its functional scope and visual design. Through the Lake Level Viewer case study, we were able to identify numerous benefits to wireframing early in an interactive and web-based mapping project, including: relating functional requirements to user profiles and use case scenarios, brainstorming novel symbolization solutions, identifying probable alternative interpretations of proposed symbolization solutions, determining aspects of the representation that require clarification through visual and text-based supporting information, enumerating additional context layers for inclusion in the application, clarify the entry point to the visualization in the interface design, streamlining navigation across the supported functionality, and promoting buy-in among targeted users and stakeholders. The NOAA Lake Level Viewer was launched successfully in August of 2014 after 12 months of user-centered design and development, and is publicly available for use in adaptive management and decision making at http://www.csc.noaa.gov/digitalcoast/tools/llv.

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