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APPLYING USER CENTERED DESIGN PRINCIPLES TO DELIVER SURFACE WATER DATA TO DIVERSE AUDIENCES

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APPLYING USER CENTERED DESIGN PRINCIPLES TO DELIVER SURFACE WATER DATA TO DIVERSE AUDIENCES

by

Luke Buckley

A meta-document submitted in partial fulfillment of the requirements for the degree of

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Abstract

User-Centered Design (UCD) is an iterative process that allows designers and developers to create useful products. Using a combination of brainstorming, in-person interviews, usability testing, and design evaluation, the Montana Bureau of Mines and Geology (MBMG) is building a web portal to deliver Montana’s Surface Water Assessment and Monitoring Program (SWAMP) data in an efficient manner.

Data from the MBMG and the Department of Natural Resources and Conservation (DNRC) are currently being collected and stored. The MBMG has more than 100 surface-water monitoring sites in its Ground Water Information Center (GWIC) database. In addition, the DNRC has stream stage (ft), discharge (cfs), and water temperature (deg C) data for 34 real-time stations and more than 130 seasonally downloaded stations across Montana. Working together with the Water Management Bureau and Information Technology staff at DNRC, the MBMG developed a database to import an automatic data feed from Aquatic Informatics’ AQUARIUS software. The surface-water data are imported into the system every 30 minutes using a combination of the AQUARIUS API, FTP, Microsoft SQL Server Integration Services, and custom software.

The SWAMP database and website are recent additions to the MBMG Data Center at http://mbmg.mtech.edu/datacenter.

Keywords: Surface Water Assessment and Monitoring Program, SWAMP, User Centered Design, User Experience, Usability Testing, Web Design, Montana Bureau of Mines and Geology
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1 Introduction

The number of surface-water bodies located in the state defines Montana’s hydrological significance as a headwaters state. Many states downstream of Montana depend on the waters that originate within the state. According to the National Hydrography Dataset (NHD) (“Watershed Boundary Dataset for Montana [Online WWW],” n.d.), Montana has more than 7,500 named surface-water bodies which, when laid end-to-end, would stretch for 180,542 miles. The Missouri River, one of the nation’s biggest rivers and a tributary of the Mississippi River, begins with the confluence of the Jefferson, Madison, and Gallatin Rivers near Three Forks, Montana. To better understand and manage surface water, state agencies developed a monitoring network to collect stream stage and discharge data. My Master’s project designs the data-driven website that allows users to retrieve the collected data in a usable and useful manner.

My project serves to answer two main exigencies. First, to satisfy the mandate of the Legislature and execute the law to disseminate surface-water data to the public. Second, to provide the data using online publication methods. An online data system is the most efficient and widely usable solution for making data available.

We live in a world where science and data gathering happens all around us. Scientific research projects (e.g., weather, stream flow, tsunami tracking), because of high-tech measurement devices, generate large volumes of data points in a short period of time (Liew et al., 2011). These data not only need to be accurately stored and managed during the research and data-analysis process, but also for years after the project has completed. This challenge of long-term data management is simplified when the scientist identifies and groups the data and project components (Duerr et al., 2011) using unique record and location metadata. Additionally, this
challenge is overcome by developing a well-designed relational database management system (RDBMS).

The Montana Bureau of Mines and Geology (MBMG) has designed a database management system to store and deliver surface-water data to the public. As part of its obligations to the new Surface Water Assessment and Monitoring Program (SWAMP), created by the 2017 Montana Legislature, the MBMG is mandated to collect information about surface water and perform assessments to determine water availability by sub-basin. The following section describes the background of SWAMP.

1.1 Project Background

According to the USGS Water Science School website (Perlman, 2016), the amount of fresh water available on the planet is around 2.5 percent (Figure 1). The majority of fresh water (98.8 percent) is located in glaciers, ice caps, and groundwater, with the remaining located in

![Figure 1. Distribution of Earth’s water. Downloaded from USGS.](source)
surface-water/other freshwater. Of this amount, only about 24 percent is surface water (i.e., rivers, swamps, marshes, and lakes). Therefore, of all the water available on the planet, approximately 0.007 percent exists as usable surface water. Water is a precious natural resource and Aldus Leopold suggests we all have a moral obligation to protect it (Leopold, 1949). To protect a resource, we must understand the resource.

The early efforts to collect surface-water data came from the Federal government. In the late 1800s, the United States Geological Survey (USGS) began a program to monitor the surface waters of Montana through a stream gaging network. In 1889, USGS staff installed the very first gage on the Missouri River near Fort Benton, Montana. They expanded their monitoring network gradually and, to date, have more than 200 active gages. The agency, however, is adjusting to declining funding. As a result, USGS’s stream-gaging network is declining.

Citizens of Montana have the basic need of knowing that scientific data is collected and available to understand the State’s water resources and to support regulatory decisions and the legitimate expectations that their public employees are up to the task. Many branches of surface water research support citizen’s lives, either directly or indirectly. Water right adjudication depends on knowing how much water is available in a stream and the amount each landowner is using. Climate research requires knowing not only how much water falls in a given area, but also how much runs off, evaporates, or soaks into the ground. In order to understand groundwater—surface-water interaction one needs to understand the relationship between these two sources and, mostly, the elevation of these areas in a particular location. All of these issues have some ethical or moral components that ultimately point to responsible management of the State’s most precious resource.
Beginning in 2012, Montana officials started brainstorming a solution to the declining Federal support of surface-water monitoring. A mix of surface-water experts, administrative officials, and information technology experts were brought together to discuss how to best develop, monitor, and maintain a surface-water network. The group focused on areas of high population growth, irrigation, and/or lack of existing monitoring. Next, the group wrote a proposal for the 2015 Montana Legislature to:

1. install real-time stream gages in these areas (10 per year);

2. contract with satellite services to provide access to the data;

3. install and learn AQUARIUS (surface-water processing software);

4. transmit data to MBMG for storage;

5. build a web-delivery system for the data; and

6. develop a program to assess surface-water data through data interpretation, water budget, and modeling

By the end of the 2015 Legislative Session, the legislators appropriated money to the DNRC for parts (1) through (3) of the proposal. This included the installation of gages from July 1, 2015–June 30, 2017. However, parts (4) through (6) of the proposal were not funded. MBMG needed to find other resources to support database development and interagency communications. By late-summer 2016, the following tasks were either completed or in-progress:

1. Several real-time gages were installed at agreed upon sites in Montana.
2. Satellite data connections were established through the National Oceanographic and Atmospheric Administration (NOAA) and the data were successfully delivered from gage stations to the DNRC offices in Helena, MT.

3. AQUARIUS software was installed and training taken to use software to process the data.

4. IT staff at MBMG and DNRC collaborated to transfer data from DNRC database to MBMG database in Butte, MT. Data are transferred every 60 minutes and processed into existing system.

5. Preliminary website is built and unveiled to the Water Policy Interim Committee (WPIC) of the Legislature. (July 2016)

For the 2017 Legislative Session, the members of WPIC proposed a bill to create the Surface Water Assessment and Monitoring Program (SWAMP) at the MBMG (House Bill 360). The bill passed and the Governor signed it into law. The bill created SWAMP, however, there were no monies appropriated for the program from state funds.

I worked on building the digital infrastructure to support SWAMP throughout the multiyear process. In the following literature review, I discuss some of the existing research done not only building online data systems, but also adhering to usability and user centered design principles.

2 Literature Review

2.1 Online Publication of Scientific Data

The internet provides a consistent and useful research tool. Scientists during the course of a research project must not only store and preserve their data, but also locate additional data to support continued analysis. Scientists, through the course of their research, gather and store
highly detailed measurements and data sets. Mark Costello (Costello, 2009) suggests the internet provides the perfect medium for long-term storage of data that supports a research publication (report, journal article). In addition, he argues that all data should be preserved in a professionally designed data center, accessible to all.

As a particular example of a data center, a group of researchers at the Centre for eResearch and Digital Innovation (CeRDI) designed and built a web-based portal. The portal’s purpose is to disseminate groundwater data collected in Victoria, Australia (Dahlhaus et al., 2016). Throughout many decades (1884-present), data about groundwater in Victoria has been collected by various entities and sent to a wide variety of public agencies. As these agencies evolved, many of them created their own disparate web applications. Once the researchers at CeRDI completed their project, they surveyed their user groups. They found that the internet “one-stop shop” offered the perfect means of providing data from multiple sources through a single easy-to-use interface.

Sweden also provides a modern solution to the question of collecting and preserving data in support of a monitoring network (Fölster, Johnson, Futter, & Wilander, 2014). The initial data collection started as a way to investigate and remediate eutrophication issues in lakes due to wastewater discharges. This lead to the initial creation and subsequent modification of a monitoring program and database over the course of 50 years.

Researchers in Armenia examined economic and environmental issues around Lake Sevan (Astsatryan, Narsisian, & Asmaryan, 2016). They determined that digital access to data for modeling was critical to the success of the model. Robert Guralnick and Heather Constable, in their efforts to investigate vertebrate biodiversity, suggest that data should be made available online to encourage data sharing and simplify the publications process (Guralnick & Constable,
2010). David Neufeld, et al., suggest that land managers, researchers, and the public are hindered in determining important biological diversity without abundant online geospatial data (Neufeld, Guralnick, Glaubitz, & Allen, 2003).

2.2 Usability and the User Experience

My development of the SWAMP website has a few major goals. First, gain the trust of the users who will rely on the data. Carol Ou and Choon Sia (Ou & Sia, 2010) studied the relationship between trust and distrust when evaluating website design. They found that trust is controlled by the caudate nucleus and medial frontal cortex while the amygdala and right insular cortex controls distrust. These studies suggest levels of trust and distrust can coexist in the user’s brain. Ethically, designing to increase user’s trust levels and decreasing distrust levels will lead to positive user experience and interactions with the website. Second, if the users trust your website they will be willing to immerse themselves in it. A study conducted by two universities in Taiwan (Huang, Chiu, Sung, & Farn, 2011) shows that well-designed, thoughtful interfaces encourage repeated and positive experiences for users. In addition, system response times also directly affect the user’s experience. The faster the response, the easier user engagement happens.

A major component of providing useful digital access to data is the design of an effective website. Jesse James Garrett (Garrett, 2011) explains that the user’s experience should be the main focus of a web designer. There are several sections or “planes” that make up a website and each is critical to the overall success of the design. Garrett defines five planes, each plane having a functionality component and an information component. The five design planes are Strategy (objectives and needs), Scope (specifications and requirements), Structure (interaction design and information architecture), Skeleton (interface, navigation, and information design), and
Surface (sensory design). In design, it is critical to build each plane in order and important to consider user needs and experience.

Tharon Howard (Howard, 2010) suggests that there are four major components to consider when designing lasting internet sites. He suggests that people need remuneration, or to believe they will obtain some positive return on their investment (ROI) of time and energy in order to be attracted to participate online. Users need to feel like they have some influence and control over their online participation. Users need to feel like they belong to the online community by developing some strong emotional attachment. Finally, users need to feel like they are significant to be successful.

The main topics discussed in this section all support the two main exigencies of fulfilling Legislative intent and publishing data online. In an effort to support my users, I not only keep these exigencies in mind, I choose to operate under a few basic ethical principles.

### 3 Project and the Moral Universe

It is important for a publicly funded project to provide data that is truthful, accurate, and usable. The following sections outline the ethical system I followed for my project and the Constitutional guidance I followed working for a state agency.

**Ethical System.** Building on a working definition from Weston (Weston, 2013) for this section, I will say that ethics is “taking care for the basic needs and legitimate expectations of others and self” and “a general set of principles that guide the actions of decent human beings.” Many agencies and organizations have standards or published codes of ethical conduct by which they operate. According to the Usability Professionals Association website (“UXPA Code of Professional Conduct,” 2016), usability professionals should: (a) act in the best interest of
everyone; (b) be honest with everyone; (c) do no harm and if possible provide benefits; (d) act with integrity; (e) avoid conflicts of interest; (f) respect privacy, confidentiality, and anonymity; and (g) provide all resultant data.

**Moral Universe.** In analyzing the players of the moral universe related to my project, I occupy the center sphere in the model. My work involves building systems that store and deliver natural resources data. As such, several claimants exert some sort of ethical pull from my research. One of the main goals of creating the program is to publish a series of watershed studies or basin reports. Some of the biggest claimants using this point-of-view are landowners, government researchers, IT staff, and the public at large.

The landowner’s role in this project must be considered carefully. In many cases, the stream to be monitored runs through property owned by private individual. To remain ethical, the agency must negotiate a land-use agreement in good faith. Following both parties signing the agreement, the land must be protected as much as possible while installing the equipment in the stream. Some digging is required and semi-permanent equipment is added to the environment, but care is taken to make sure that the process is not harmful.

The government researcher, an expert in his or her field of study, is employed to gather data in a timely fashion, compile and analyze the data, and publish their findings. Once formally published, the data are available for aiding in local to regional decision making. My project is critical in the data-publishing phase. As all money funding the project comes from state government appropriations, I have an obligation to store the data and make it available to the public (Constitutional rights).
A companion sphere to the government researcher is the IT staff with whom I collaborate. We (IT group) have an obligation to the rest of the moral universe to conduct our tasks effectively and efficiently to not cause tensions and slow others’ productivity.

The public occupies a very large sphere with lots of ethical pull on the project. As mentioned below in the Constitutional Influences section, the public has the right to expect a healthful environment to live in. They also have the right to access public data. I am designing my project in a way that will help promote both of these Constitutional rights. The data system stores the raw data, but the website is such that the data are easy-to-understand and easily accessible. As the monitoring program builds and grows, the data provided will help support the environment in such areas as disaster response, climate research, and aquatic living environments (temperature-sensitive fish population or low-flow conditions).

3.1  Constitutional Influences

Ratified in 1972, the Montana Constitution guarantees citizens the right to 1) a clean and healthful environment (Montana Const. art. II. § 3., n.d.); 2) expect governmental agencies to provide opportunities for citizen participation (Montana Const. art. II. §8., n.d.); and 3) examine documents and observe state government agencies (Montana Const. art. II. §9., n.d.).

The MBMG is a particularly interesting state agency. Non-regulatory, MBMG is one of five standalone Montana State Agencies placed on university campuses. Established in 1919 and incorporated with the Montana School of Mines, MBMG staff research and report on the natural resources of Montana. As all research is funded with public monies (State or Federal dollars), the agency is required to provide access to their data so as not to infringe on the citizens’ rights mentioned above.
Using the Internet coupled with modern database systems and web applications, I am able to accomplish the goal of widely available data access for this project. In an ethical frame of mind, this acts in the best interest of all groups involved (UPA a) since data are available from a single source. Data are provided without bias, which provide integrity (UPA d). The data are generally provided free of charge, which avoids harm and provides benefits (UPA e).

One of the major advancements to the MBMG Data Center has been the ability to add scanned images. As the citizens have a right to examine documents, this functionality helps me accomplish this right-fulfillment. Starting the process in 2005, the Document Manager now delivers over 300,000 PDF documents of natural resources data stored at the MBMG. SWAMP delivers data and the documents generated through the same system. This not only satisfies my ethical obligation, but also allows the user view the documents from any Internet-connected device.

4 Content Analysis

To aid in the design and development of the SWAMP website, I evaluated three different agency websites that conduct similar tasks and deliver surface-water data: Oregon’s Water Resources Department (http://www.oregon.gov/owrd/Pages/sw/index.aspx), The United States Geological Survey (https://waterdata.usgs.gov/nwis/sw), and British Columbia Ministry of Forests, Lands, and Natural Resource Operations (http://cariboo.bcwatertool.ca/stream). Below, I provide a discussion of each website.

4.1 Oregon Water Resources

4.1.1 Design

The main page for the Oregon Water Resources Department is very simple. The page contains a standard header containing the agency/state logo, a brief infographic, a Google search
The page contains a left-hand navigation menu that occupies roughly 20% of the viewable space, leaving the rest of the page for body content. The designer uses a general blue/gray color palette, likely to mimic the water nature of the content delivered. The text’s font size overall is a bit small at 11 pixels (px), but the controls at the top of the page allow user adjustment.

### 4.1.2 Content

The Oregon website divides the content into six main areas:

1) Surface Water Data,
2) Surface Water Availability,
3) Estimation of Peak Stream flows,
4) Dam and Hydroelectric Site Information,
5) Access Data with the Interactive Mapping Server, and
6) Surface Water Data Links.

Under the Surface Water Data option, I was able to view and evaluate both real-time and historic stations and could select stations based on standard form-based queries (e.g., name, geographic location, date range). In addition to the query, I could also browse a list of stations or select one based on a web-mapping application.

Each site reported the site’s geographic location, most recent measurements in text, a chart of most recent measurements (default view is the last 10 days), and options to download the data. The main chart (Figure 2) displayed reports values of Mean Daily Flow and categorizes the data based on five data-quality codes (Raw, Preliminary, Provisional, Published, and Missing). The options are available to change from the calculated average to actual measurements as well as Instantaneous State, Instantaneous Flow, Discharge Measurements.
4.1.3 Conclusions

While the data were easy to retrieve and use, the overall website operation was not designed using responsive technology so it was not easy to use on my iPad or phone.

4.2 United States Geological Survey (USGS)

4.2.1 Design

The main page for the USGS surface water website also has a very simple layout. A general selection menu occupies the top of the page with the standard branding and logos. Below that area, they present a simple two-column layout to briefly describe the options available for searching data. Lastly, an informative footer with links to useful links is placed at the bottom of the page. The designers selected a theme of blues and whites to correspond to the theme of water.
as an identification device. The text displayed appears to adhere to the current suggestions of a
font size ranging between 14-16 px.

4.2.2 Content

The USGS site offers six options for data selection:

1) Current Conditions,

2) Historical Observations,

3) Daily Data,

4) Statistics (Daily, Monthly, Annual),

5) Peak-Flow Data, and

6) Field Measurements.

The total number of gaging stations included in the options listed above are shown to
inform the user about the population of the dataset. After selecting Current Conditions, I was
presented with a map to select a State to investigate. Next, a map provided a glimpse at current
conditions by color coding sites based on their current streamflow conditions as a percentile.

After selecting Montana, I was presented with a list of query options.
I had the opportunity to either select a site from a map or use a form-based query by selecting a site by name, geographic location, or data attributes (number of observations, etc.).

The site report (Figure 3) represented the name and identification number, period of record, and two different graphs (discharge and stage). The discharge and stage graphs presented data for the previous seven days with options to change both the date range and type of graphs or data displayed. The most recent recorded value is shown in the header area of each graph.

### 4.2.3 Conclusions

The website response times were excellent and the pages were all responsive. When browsing on my iPad or phone, I was asked if I wanted to switch to a site designed specifically for mobile devices. I tried this option and was redirected to a map-based interface. Within seconds, I was able to zoom to Montana and repeat the tasks I had performed earlier.
4.3 British Columbia

4.3.1 Design

Locating data for British Columbia surface water was a bit more challenging. It appears that most of the text-based queries are hosted at the Federal level (http://wateroffice.ec.gc.ca/index_e.html). This site contained a general selection menu, which occupies the top of the page with the standard branding and logos. Below this area, they present a simple two-column layout with distinct headings and hyperlinks showing the options available to search data. Lastly, the designers placed an informative footer with useful links. The designers selected a theme of reds, blues, and whites to correspond to the natural resources theme of water as well as national colors as an identification device. The text displayed also appears to adhere to the current suggestions of a font size ranging between 14-16 px.

The provincial government hosts the web-mapping application for surface-water data (http://cariboo.bcwatertool.ca/stream). To view the website, I first had to read and agree to a disclaimer. As a test of usability, I clicked “Disagree” and was redirected to the British Columbia homepage. The map itself occupied the whole page with a standard header bar with no branding or sense of where I was across the top. The website displayed available sites using brightly distinctive colorations and I found that even though it was developed in an unknown platform, I was able to use the site easily.

4.3.2 Content

The text-based British Columbia site offers the following six options for data selection:

1) Real-time hydrometric data,

2) Historical hydrometric data,

3) Hydrometric Station,

4) Network Data,
5) Tools, and

6) Downloads.

After selecting the real-time option, I was able to query the data by station name, location, ID number, drainage basin, or region. I entered some selection criteria (e.g., “Fraser River”) and was asked to read and agree to a disclaimer before viewing the graph.

![Real-Time Hydrometric Data Graph for FRASER RIVER ABOVE TEXAS CREEK (08MF040) [BC]](https://wateroffice.ec.gc.ca/)

**Figure 4.** Output from British Columbia. Downloaded from https://wateroffice.ec.gc.ca/.

The site report (Figure 4) contained options for changing the data type displayed (real-time or historical), view “timeliness” of the data, adjust the date range (default display is seven days), and apply statistics. Further down, the page displayed (not visible in Figure 4) the site’s location information and most recent measurements. Unique to this website, the discharge and stage data were displayed on the same chart. An option is available to view the data in a table instead of the chart. However, I saw no option for downloading the data.
4.3.3 Conclusions

The map-based interface offered a slightly different site report showing seven-day flow, flow-duration tool, monthly-mean flow, and flow metrics. Both sites are responsive as well as viewable and easily usable on my iPad and phone screens.

4.4 Summary

All three websites provide some historical background on their respective programs as well as addressing site operation, frequently asked questions, data disclaimers, and addressing accessibility options. Interestingly, the USGS was the only one to address a social media component. A summary of my findings is available in Table 1.

*Table 1. Summary of Content Analysis*

<table>
<thead>
<tr>
<th>Website</th>
<th>Positive Aspects</th>
<th>Negative Aspects</th>
</tr>
</thead>
</table>
| Oregon Water Resources           | 1. Contained a mix of state and federal sites.  
                                        2. Data are easy to retrieve. | 1. Not responsive to screen size.                     |
                                        2. Response times were excellent. | 1. Complex query system.                              |
| British Columbia                 | 1. Comprehensive site list.  
                                        2. Easy-to-use interface | 1. Differing report types based on interface.  
                                        2. No obvious data download option. |
The exercise of performing content analysis was extremely beneficial as I learned that my development efforts have mirrored other efforts in North America to collect, store, and deliver surface-water data. Some improvements to my site will be: 1) increase information about how and when the data is collected and available, 2) update, and make more visible, a Frequently Asked Questions (FAQ) section, 3) investigate a method to provide rating curves, and 4) improve site documentation (e.g., photos, travel notes, etc.).

5 Methodology

5.1 The SWAMP Website

At the beginning of my project, the SWAMP website consisted of the following pages:

1. The main SWAMP page (Figure 5) provides the introduction and overview of the program and provides navigation options for text- and map-based queries.

2. The SWAMP web mapping application (Figure 6) provides the map-based query system.

3. The stream-gage list view (Figure 7) provides the text-based query system.

4. The DNRC stream-gage report (Figure 8) provides the data summary for all DNRC stream gages.

5. The MBMG stream-gage report (Figure 9) provides the data summary for all MBMG stream gages.
Figure 5. The SWAMP website prior to round one of usability testing.
Figure 6. The SWAMP mapper prior to round one of usability testing.
Figure 7. SWAMP gage listing prior to round one usability testing.
Figure 8. DNRC gage report prior to round one usability testing.
5.2 Usability Testing

One of the main User Centered Design methods I used to develop the SWAMP website was Usability Testing. According to usability.gov (“Usability Testing,” 2018):

“Usability testing refers to evaluating a product or service by testing it with representative users. Typically, during a test, participants will try to complete typical tasks while observers watch, listen and takes notes. The goal is to identify any usability problems, collect qualitative and quantitative data and determine the participant's satisfaction with the product.”
Specifically, I used a combination of iterative design, recorded usability test (audio, video, screen capture), task analysis, surveys, field studies, and an informal interview with the users (Vredenburg, Mao, Smith, & Carey, 2002) to conduct my usability tests.

To meet my goal of identifying usability problems, I selected a group of six people, called Power Users, to test the SWAMP website. Each Power User has some interest in using surface-water data and represents both government and non-government interests. The users are:

- John LaFave, Research Professor, Montana Bureau of Mines and Geology
- Tom Michalek, Research Professor, Montana Bureau of Mines and Geology
- Aaron Fiaschetti, Hydrologist, Montana Department of Natural Resources and Conservation
- Matt Norberg, Hydrologist, Montana Department of Natural Resources and Conservation
- Victoria Haraldson, Water Quality Tech Specialist, Gallatin Local Water Quality Protection District
- Katelyn Vennie, Program Coordinator, Bitter Root Water Forum

I designed my project to incorporate two rounds of usability testing. The first round established a baseline of the website’s operation and discovered existing usability issues. After I analyzed the first round and made improvements to the website, round two evaluated any improvements in usability.

To provide continuity for the usability tests, I developed test session outline for the test session to guide each Power User through the process. Each session began with a brief introduction where I introduced myself and explained some of the SWAMP project background. Following the introduction, I explained that the scope of work for this Master’s project would be the website they would use for the testing (http://mbmg.mtech.edu/swamp/) and that the timeline
for this project would require effort from the tester for this round and an additional round in late-October—early-November 2017. Next, I explained the main points of the usability test and the laptop operation to perform the test.

Each usability test was conducted using Morae® from TechSmith. Morae® is a program that records the user’s screen movements, records their audio, and captures video of their facial expressions and body movements. The user was given the opportunity to examine the laptop and ask any questions.

Before proceeding, each user was presented with the IRB-approved consent form. I went through each section of the form thoroughly and explained each item. A copy of the consent form is provided in Appendix B. Every user agreed to remain in the study as a participant and provided consent to be identified in any literature developed from this study.

I employed several elements of the usability methodology defined by Albert and Tullis (2013) employed for this study: time-on-task, think-aloud protocol (demonstrated with a sample video), task-level success surveys, and system-success survey upon completion. Since this type of testing was either new or foreign to the participants, I developed a brief example video of a usability exercise. In the video, I demonstrated how a user should talk through the task while performing it and the task chosen was unrelated to the coming test. At this point each user watched the video and was invited to ask clarification questions.

Prior to arriving at the user’s locations, I defined the parameters of the test within the Morae® software. The test had three sections: a pre-test survey, the usability test consisting of four questions, and a post-test survey. The general outline and content of the test is as follows:
1. For each participant I observed as they completed the test and provided any procedural guidance as needed. There were very few procedural questions asked, and the tests were conducted without incident.

2. As each participant completed their test, I scored them on task success (success, partial success, or failure), initial impressions of usability based on observation, and my overall interpretations of their comments.

3. I used these notes when reviewing the material to coordinate what I saw and heard and identify issues.

5.3 Data Analysis

I designed each task in the usability test to evaluate the four main things users would likely do when browsing the SWAMP website: (1) look for recent measurements, (2) read about the program and data-delivery system, (3) download and use surface-water data, and (4) use other data available at a site. To determine a participant’s (and therefore website) level of success, I evaluated all video, audio, screen capture, and written notes collected for each participant.

5.4 Definitions and Conventions

To better understand the following analysis, here are some definitions of the methods I used to evaluate the test. First, each user was timed to see how long they took to complete the task. I refer and present this as “time on task” in seconds. Second, each user was evaluated as to their level of success in completing the task. I refer and present this as “task success” and score as success (0), partial success (1), or failure (2). Third, each user was asked to evaluate the ease to complete each task. I refer and present this as “ease of use” on a five-point Likert scale where “1” represents hard-to-use and “5” represents easy-to-use. And last, each user was compared to my operation of the site as a subject-matter expert (SME). I refer and present this as the “SME
ratio” in percent longer (e.g., 45% means the user took 45% longer to complete the task than did the SME).

In addition to these methods, each user was evaluated based on whether they used the map-based or text-based interface to complete the task. I refer to this as the “interface usage” and report the data as a percentage. As part of the evaluation of verbal communications, some common insights were present and I will discuss those in each task section.

5.5 Usability Issues

Summarizing a methodology from Albert and Tullis (2013), a usability issue is anything that either prevents the user from completing their task or makes the task harder to complete. When I analyzed the usability test results, I recorded anything within the website that caused users frustration, confusion, or a false sense of accomplishment. Generally, an issue was labeled if the user’s speech, facial expressions, or on-screen interactions indicated to me that they were struggling. The group of Power Users provided 73 total usability issues during the first test. I analyzed and refined these 73 issues into the 12 updates I made to the website between the first and second usability tests.

5.6 Improvements

I identified 12 improvements, in seven major areas, as part of the first round of user testing. I will summarize the improvements in this section.

1) **The website is not responsive.** To be responsive, a website must display pages that are easily viewable on any size screen (e.g., desktop, tablet, phone). To aid in the look and responsiveness, I upgraded the whole website to operate using the Bootstrap Framework™ designed by Twitter, Inc. Bootstrap is a set of Cascading Style Sheets (CSS) and Javascript (JS) files engineered to allow mobile-friendly development of websites. Using Bootstrap I was able to present a series of pages that looks and performs well on all screen sizes.
2) **The large blocks of text were troublesome.** Research into the influence of line spacing and textual elements on the page (Ling & van Schaik, 2007; Redish, 2014) shows that short, left-justified text blocks with informative headings are easiest to scan. The SWAMP homepage (Figure 10) was improved to include only key pieces of information. In addition, prominent section headings were added to increase the user’s ability to scan text for content.

3) **Social media integration.** The website was updated to include social media share links for Facebook™ and Twitter™.

4) **The website navigation was occasionally confusing.** A consistent header navigation bar was added to allow easy navigation among sections of the website.

5) **The website was slow to respond to user queries.** The production database contains tables and views that provide content to the website. The indexes on these tables were reviewed and optimized. In cases where long-running queries could not be optimized to an acceptable level (e.g., measurement summaries), temporary tables were used to increase performance.

6) **The content and look of the one-page site reports were not consistent.** I reorganized the page content to present a consistent layout and moved any download and other important options to the top of the page.

7) **Date range selection was inadequate.** From the informal interviews following the test, I determined that users would need to have more control over the range of dates displayed in the report. I upgraded the scripting and display options to allow users to view the last seven days (default view), the last 30 days, the entire record, or select a specific date range using standard HTML5 date selection elements.
5.7 The Improved SWAMP Website

As part of the iterative nature of User Centered Design, I updated the website to address the changes listed above. The resulting versions of the websites are shown in the following figures:

1. The main SWAMP page (Figure 10) provides the updated introduction and overview of the program and provides navigation options for text- and map-based queries.
2. The SWAMP web mapping application (Figure 11) provides the map-based query system.
3. The stream gage list view (Figure 12) provides the text-based query system.
4. The DNRC stream gage report (Figure 13) provides the data summary for all DNRC stream gages.
5. The MBMG stream gage report (Figure 14) provides the data summary for all MBMG stream gages.
6. The responsive version of the website (Figure 15) shown on the iPhone 6.
Figure 10. The SWAMP website after improvements.

INTRODUCTION

SWAMP is a joint program initiated by the Department of Natural Resources and Conservation (DNRC) and the Montana Bureau of Mines and Geology to collect real-time streamflow data and conduct watershed assessments to aid decision making and policy development in Montana. While data collection, compilation, and dissemination are critical in the short term, these data provide important information to support watershed studies aimed at constructing predictive models of surface-water and groundwater resources subject to development and climate change. Watershed studies conducted under this program will provide opportunities for applied research and training for students of the Montana University System.

TARGET AUDIENCE

The information is needed by a wide range of consumers, including but not limited to: Water Commissioners, water right holders, reservoir operators, irrigation districts, recreationalists, local watershed groups and conservation districts (drought management planning), MBMG (groundwater studies), Department of Fish, Wildlife and Parks (instream flows), and the Department of Environmental Quality (water quality monitoring), Department of Transportation, and other State and Federal agencies.
Figure 11. SWAMP mapper after improvements.
SWAMP Gage List

The following lists include the stream gages that are currently available in the Surface Water Assessment and Monitoring Program (SWAMP) database. The top section of the page lists the gages that are sending data continuously via satellite. The bottom section lists the gages that have been that are either currently monitored and downloaded manually or have been monitored at some time in the past.

**Real-Time Gaging Station Details**

<table>
<thead>
<tr>
<th>Station Id</th>
<th>Station Name</th>
<th>Last Measured</th>
<th>Last Discharge (cfs)</th>
<th>Last Stage (ft)</th>
<th>Last Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7SLJ 09900</td>
<td>Ashley Creek at Kalispell WTP</td>
<td>10/28/2017 10:00:00 AM</td>
<td>26.47</td>
<td>1.65</td>
<td>6.83</td>
</tr>
<tr>
<td>49A 10000</td>
<td>Barber Canal</td>
<td>10/28/2017 10:15:00 AM</td>
<td>0</td>
<td>.1</td>
<td></td>
</tr>
<tr>
<td>49R 65000</td>
<td>Big Muddy Canal abv Medicine Lake</td>
<td>7/26/2017 4:15:00 AM</td>
<td></td>
<td>4.53</td>
<td></td>
</tr>
<tr>
<td>411 2060</td>
<td>Broadwater East Canal Blw HG</td>
<td>10/28/2017 10:15:00 AM</td>
<td>0</td>
<td>0.65</td>
<td></td>
</tr>
<tr>
<td>43Q 05900</td>
<td>Canyon Creek @ ZooMontana</td>
<td>10/28/2017 10:00:00 AM</td>
<td>126.74</td>
<td>3.04</td>
<td>7.97</td>
</tr>
</tbody>
</table>

*Figure 12. SWAMP gage list after improvements.*
Figure 13. DNRC report after improvements.
Figure 14. MBMG report after improvements.
Figure 15. DNRC report viewed on iPhone 6.
5.8 Usability Task One

For the first task, I asked all participants to locate the real-time stream gage near Lolo, Montana and report the last available stage reading.

5.8.1 Round One

One hundred percent of the participants were able to complete the task; 67% selected the map interface while 33% selected the text interface. On average, the group performed the task in
133.33 seconds with an SME ratio of 108% and assigned an ease of use of 4.5 (on a 5-point scale). Analysis of the think-aloud protocol indicated that most users felt the task was easy due to layout of selection options, but the system was slow to respond when queried.

5.8.2 Round Two

One hundred percent of the participants were able to complete the task; 67% selected the map interface while 33% selected the text interface. On average, the group performed the task in 58.83 seconds with an SME ratio of 55% and assigned an ease of use of 5.0 (on a 5-point scale). Participants noted that the task seemed easier and suggested turning off the geology layer provided in the map and adding scrolling table headers for the text interface.
5.9 Usability Task Two

For the second task, I asked all participants to find and report how often new data are made available on the SWAMP website.

5.9.1 Round One

Sixty-seven percent of the participants were able to complete the task; 100% selected the text interface. On average, the group performed the task in 160.50 seconds with an SME ratio of...
312% and assigned an ease of use of 3.33 (on a 5-point scale). Analysis of the think-aloud protocol and screen capture indicated the text elements containing the answer were poorly designed and organized, thus obscuring the answer.

5.9.2 Round Two

One hundred percent of the participants were able to complete the task; 100% selected the text interface. On average, the group performed the task in 30.17 seconds with an SME ratio of 151% and assigned an ease of use of 4.67 (on a 5-point scale). One participant suggested including the information on all pages while the remaining participants reported no issues.
5.10 Usability Task Three

For the third task, I asked all participants to download the data available for the Ashley Creek gage and review it in Microsoft Excel.

5.10.1 Round One

One hundred percent of the participants were able to complete the task; 100% selected the text interface. On average, the group performed the task in 158.50 seconds with an SME ratio
of 45% and assigned an ease of use of 4.33 (on a 5-point scale). Analysis of the think-aloud protocol and screen capture indicated the download buttons were poorly located and slowed their progress. All users who found and select the Microsoft Excel download encountered an “incompatible format” error that raised questions as to whether the site was trustworthy.

5.10.2 Round Two

One hundred percent of the participants were able to complete the task; 100% selected the text interface. On average, the group performed the task in 111.83 seconds with an SME ratio of 20% and assigned an ease of use of 4.50 (on a 5-point scale). Participants reported no issues other than the “trust” error upon opening the Microsoft Excel option from the website. This option was removed from the website after round two.
5.11 Usability Task Four

![Task Four: Ease of Use](image1.png)

*Figure 22. Ease of use rating for task four.*

![Task Four: Completion Time](image2.png)

*Figure 23. Completion time for task four.*

For the final task, I asked the participants to determine how many water-quality samples are available online at the MBMG stream gage site near Big Sky, Montana.

5.11.1 Round One

Sixty-seven percent of the participants were able to complete the task successfully, 17% completed the task with difficulty, 16% failed to complete the task; 100% selected the map
interface. On average, the group performed the task in 216.00 seconds with an SME ratio of 170% and assigned an ease of use of 3.67 (on a 5-point scale). Analysis of the think-aloud protocol and screen capture indicated in some cases the map interface was “too busy”, the one-page report formats were inconsistent, and the site naming conventions were confusing.

5.11.2 Round Two

Seventeen percent of the participants were able to complete the task successfully, 83% completed the task with difficulty, and nobody failed to complete the task; 100% selected the map interface. On average, the group performed the task in 171.67 seconds with an SME ratio of 207% and assigned an ease of use of 3.50 (on a 5-point scale).

5.12 System Usability Survey

5.12.1 Round One

The analysis of the System Usability Survey (SUS) shows that overall the application scored a 3.95 (on a 5-point scale) for ease of use and a 4.29 (on a 5-point scale) for overall usability. In general, the participants took an average of 668 seconds (11.1 minutes) to complete all for tasks and displayed an overall sense of enjoyment while doing it.

5.12.2 Round Two

The analysis of the System Usability Survey (SUS) shows that overall the application scored a 4.42 (on a 5-point scale) for ease of use and a 4.17 (on a 5-point scale) for overall usability. In general, the participants took an average of 372.50 seconds (6.2 minutes) to complete all for tasks and, again, displayed an overall sense of enjoyment while doing it.

5.13 Technological Challenges

I encountered a few technological challenges in designing the website. The greatest challenge was upgrading the site to operate in a responsive fashion. Downloading and learning the Bootstrap Framework took longer than I had expected, but the overall look and operation of
the site was well worth the effort. The second greatest challenge was designing the indexing scheme to allow the databases powering the website to operate in the most efficient manner.

6 Conclusions

The SWAMP website was created to satisfy the Legislative intent (assess and monitor Montana’s surface water) and MBMG Data Center standards (provide useful, usable, and accurate data). Review of three existing systems (Oregon, British Columbia, and USGS) provided me with some insight into techniques and methodologies already in practice. Although there are not many existing systems, I created a website that stores and delivers surface-water data to the public and tested its usefulness with the public, incorporating their feedback to make the website better.

The usability testing methods I used to refine the website were useful, but it is ultimately an uncertain technology. It was easy to identify the issues discovered by the Power Users; however, the number of existing issues is unknown. The usability community continues to debate the number of testers needed to uncover all the issues (Bevan et al., 2003; Nielsen, 2012; Nielsen & Landauer, 1993). I followed guidance from Albert and Tullis who assert that six users can determine approximately 80-85% of a product’s issues.

The issues uncovered and iteratively addressed during both rounds of usability testing resulted in a 44% reduction in the time needed to complete the tasks (reduced from 11.1 to 6.2 minutes). Based on the volume of traffic on the website this equates to significant time savings for repeat users. Based on the improvements in efficiency observed during the second round of usability testing, users are saving valuable time in locating and downloading Montana’s surface-water data.
The SWAMP website has been online since July 2016. Since its initial release, the website has seen steady growth. During 2017, users performed 119,558 data queries and downloaded 4.98 billion data records.

The popularity of the SWAMP site is increasing. Analysis of MBMG Data Center analytics for the site shows that, in January 2017, seven outside entities referred traffic to the site. By the end of 2017, 49 different outside entities regularly refer traffic to the site. The top eight referrers are Facebook, the DNRC, Nevada Creek Water Users Association, Lolo Watershed Group, Teton River Distribution Project, Big Hole Watershed Committee, Google, and the Bitterroot Water Forum.

7 Future Directions

I will continue to maintain and iteratively work with the SWAMP website. Based on the second round of usability testing, some future updates planned include daily average charts, more granular query ability, and improved social media integration. I have also had initial interest from several additional research groups in Montana to store their data in SWAMP. A pilot project is currently underway with two Water Quality Protection Districts (Gallatin; Lewis and Clark Counties) to develop a methodology to store non-real-time data.

The SWAMP website is a successful project and product that is now a permanent part of the MBMG Data Center. The surface-water data will be served alongside the other natural resources data offered by MBMG: geology, earthquakes, groundwater, abandoned mines, coal, geothermal, and water quality at http://mbmg.mtech.edu/datacenter.
References


Howard, T. (2010). *Design to Thrive: Creating Social Networks and Online Communities that Last.*


Montana Const. art. II. §8.
Montana Const. art. II. §9.

Montana Const. art. II. § 3.


Appendix A—Usability Test Questions

Pre-Test Survey

1. The user was asked for their sex/gender with options of Male, Female, or Other
2. The user was asked for their age range with options of 18-29, 30-39, 40-49, 50-59, or 60+
3. The user was asked for their level of completed education with options of B.S., M.S., or Ph.D.

Usability Test Tasks

1. Locate the real-time stream gage at Lolo Creek and report the last measurement for stage (gage height) and the date (and time) the measurement was recorded.
2. Find and report how often that new data are made available on the SWAMP website.
3. Download the data available for the Ashley Creek gage and review it in Microsoft Excel.
4. How many water quality samples are available online at the MBMG stream gage near Big Sky, Montana?

Post-Task Questions

1. Overall, this task was [5-point Likert scale, very difficult→very easy]
2. Which interface did you use to find the information? [Single choice, Map or Text]
3. Please list any issues you encountered while completing the task. [Open-ended text]

Post-Test Questions

1. I am satisfied with how easy it is to use the SWAMP website. [5-point Likert scale]
2. I could complete the tasks and scenarios effectively using the SWAMP website. [5-point Likert scale]
3. I could complete the tasks and scenarios quickly using the SWAMP website. [5-point Likert scale]
4. I found the SWAMP website unnecessarily complex. [5-point Likert scale]
5. I think it was easy to learn to use the SWAMP website. [5-point Likert scale]
6. I think I would like to use this system frequently. [5-point Likert scale]
7. The system gave error messages that clearly told me how to fix problems. [5-point Likert scale]
8. If I made a mistake, I could recover easily and quickly. [5-point Likert scale]
9. It was easy to find the information I needed. [5-point Likert scale]
10. The system had all the information I expected to find. [5-point Likert scale]
11. The information on the screen was well organized. [5-point Likert scale]
12. The information on the screen was easy to read. [5-point Likert scale]
13. The website navigation links were useful. [5-point Likert scale]
14. Please describe the parts of the website you thought worked well. [Open-ended text]
15. Please describe improvements that would help the website function better. [Open-ended text]
Appendix B—Consent Form

SUBJECT INFORMATION AND INFORMED CONSENT

Study Title: Applying User Centered Design Best Practices to Effectively Deliver Surface Water Assessment and Monitoring Program Data to Diverse Audiences

Investigators:

Luke Buckley
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1300 West Park Street
Butte, MT 59701
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Glen Southergill, Advisor
Montana Tech
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Butte, MT 59701
(406) 496-4777

Purpose:

You are being asked to take part in a usability study evaluating the ability of the Surface Water Assessment and Monitoring Program (SWAMP) website to effectively and efficiently deliver data to end users.

You have been invited to participate because you have an interest in collecting and using surface water data collected on one or more of Montana’s streams and rivers.

The results will be used to identify major or minor functionality issues. Issues identified will be provided to the graduate student to modify the website.

You must be 18 or older to participate in this research.

Procedures:

If you agree to take part in this research study, you will be working on a laptop containing a usability test. An investigator will be present to explain the study and observe you while you complete the test.

You will be asked to perform four specific tasks associated with the test. Each section of the test contains a pre-test set of questions, the task completion, and a post-test set of questions. During the test you will be asked to talk through your thought processes out loud as you complete each task. At the beginning of the usability test your screen actions will be recorded. Additionally, video of your face and audio recordings will be taken for
review and analysis. The recording will begin at the start of the test and stop when you have completed the test.

The study will take place at a desk and should take no longer than 30 minutes.

**Risks/Discomforts:**

There is no anticipated discomfort for those contributing to this study, so risk to participants is minimal.

**Benefits:**

There is no promise that you will receive any benefit from taking part in this study.

**Confidentiality:**

Your records will be kept confidential and will not be released without your consent except as required by law.

Your initials ______ indicate your permission to be identified by name in any publications or presentations.

If you do not want to be acknowledged by name in any publications or presentations, please initial here ________.

The data will be stored in a locked file cabinet. Your signed consent form will be stored in a cabinet separate from the data.

**Voluntary Participation/Withdrawal:**

Your decision to take part in this usability study is voluntary. You may refuse to take part in or you may withdraw from the study at any time without penalty.

**Questions:**

If you have any questions about the research now or during the study, please contact: [Glen Southergill at (406) 496-4777]. If you have any questions regarding your rights as a research subject, you may contact the UM Institutional Review Board (IRB) at (406) 243-6672.

**Statement of Your Consent:**

I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that any future questions I may have will also be answered by a member of the research team. I voluntarily agree to take part in this study. I understand I will receive a copy of this consent form.
Statement of Consent to be Photographed [and/or Audiotaped, Videotaped, etc., if applicable]:

I understand that photographs (audio/video recordings) will be taken during the study.
I consent to having my photograph taken. (being audio/video recorded)
I consent to use of my photograph (audio/video) in presentations related to this study.
I understand that if photographs (audio/video recordings) are used for presentations of any kind, names or other identifying information will not be associated with them.