Development of a Mobile GIS High-Water Mark Data Collection Application for the Mississippi River Basin

by

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To my in-laws, John and Judy Windham, I finally finished my coursework and thesis.
Wish you were here to celebrate with me.

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List of Abbreviations

2D	Two-Dimensional
3D	Three-Dimensional
ADH	Adaptive Hydrology/Hydraulics
API	Application Programming Interface
CHL	Coastal and Hydraulics Laboratory
CSV	Comma-Separated Values
DBMS	Database Management System
DEM	Digital Elevation Model
DoD	Department of Defense
ERDC	US Army Engineer Research and Development Center
Esri	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HEC	USACE Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center’s River Analysis System
HWM	High-Water Mark
HWMDP	High-Water Mark Data Portal
HWMM	High-Water Mark Mobile
MS	Mississippi
NOAA	National Oceanic and Atmospheric Administration

ODK	Open Data Kit
STN	Short-term Network
US	United States
USACE	United States Army Corps of Engineers
USC	University of Southern California
USGS	United States Geological Survey
VM	Virtual Machine

Abstract

A high-water mark (HWM) is a horizontal mark left on a structure or vegetation after floodwaters recede. HWMs provide engineers and floodplain managers insight into flood events because they represent the highest elevation of flooding at peak river stage. Cataloging HWMs after a flood event and referencing them to a corresponding peak river stage, allows an engineer to evaluate the impacts caused by the corresponding river stage. The river stage can be determined by utilizing the national network of streamgages maintained by the United States Geological Survey (USGS). Collecting and cataloging data from a HWM and the corresponding streamgage is valuable because the data provides a reference for engineers to calibrate and validate hydraulic models, and the data provides a reference of the impact elevation for when a future flood event is forecasted to exceed or reach the same river stage.

Currently, collecting and cataloging HWM data involves a manual method where emergency management personnel and engineers fill out paper forms, and then a professional land survey crew surveys the HWM to determine the elevation of the mark. Furthermore, the attribute data collected on the HWM is not standardized, meaning that different federal agencies collect different attributes. This thesis presents a standardized method for cataloging and collecting HWM data using a mobile Geographic Information System (GIS) application for HWM data collection and a standardized digital repository for HWM cataloging and sharing. Both the application and the repository developed in this thesis provide a standardized and automated approach to HWM data collection and dissemination including direct download. Also, this thesis provides a method for the user to reference the HWM to a corresponding river stage by offering the ability to query the USGS streamgage network to find the nearest streamgage to the HWM during the field activities. The application was field tested by hydraulic

engineers and flood operation managers as part of this thesis work, followed by an online survey conducted to collect feedback from the users. The results from the field tests and online user survey will be used for future refinement of the applications, which has been offered as an enhancement to existing HWM data collection, storage, and dissemination strategies currently in use by the US Army Corps of Engineers (USACE) and the USGS.

Chapter 1 Introduction

High-water marks (HWM) collected after flood events provide valuable data that can be used to reduce risk in the event of extreme future floods. Engineers, floodplain managers, and emergency management personnel use the HWM data for planning purposes as well as a preventive measure to reduce or eliminate the risk of property damage or loss of life (USGS 2016). HWMs provide a reference elevation for a corresponding flood stage on a river. Furthermore, cataloging HWMs after a flood event, and referencing them to a corresponding peak river stage allows the engineer to evaluate the impacts caused by the corresponding river elevation. The corresponding river elevation can be determined by utilizing the national network of streamgages maintained by the United States Geological Survey (USGS). Referencing HWMs to corresponding peak river stages by using the streamgage network is very important for two reasons; (1) a reference identifies the impact elevation of areas where waters may overtop the banks should a future flood event be forecasted to reach or exceed the same river elevation, and (2) engineers can use these references to calibrate and validate hydraulic models utilized to develop regulated floodplains and predict frequency and consequences associated with flood events. Engineers and floodplain managers can use HWMs to make informed decisions about how to manage future floods based on the past and current behavior of rivers (National Hydrologic Warning Council 2006).

1.1 Project Objective

Data collected on HWMs is not stored in a standard digital repository and is quickly forgotten after the floodwaters recede, according to Keith Flowers, Hydraulic Engineer with the United States Army Corps of Engineers (2016). Based on this information, a standardized digital repository for capturing, storing, and disseminating HWMs is a necessity. HWM data is needed to provide reliable historical flood information, which can be used to prevent or reduce the loss of life and property damages (The Association of State Floodplain Managers, Inc. 2014). The more extensive the repository to store HWM data, the more valuable it is for the engineers, floodplain managers, and emergency management personnel. It is also important to provide a procedure for collecting the data and seamlessly integrating it into the repository. Therefore, this thesis presents a mobile Geographic Information System (GIS) application called High-Water Mark Mobile (HWMM) specifically designed to automate the collection of HWM data. In addition to documenting the development of HWMM, this thesis also describes the building of a standardized digital repository of HWM data utilizing Esri's ArcGIS geodatabase technology. Also, this thesis presents the creation of the High-Water Mark Data Portal (HWMDP), which utilizes Esri's ArcGIS Online Web Map Application technology to provide end users with a platform independent application for viewing the HWM data and streamgage information (Esri 2016a). The HWMDP is designed to be a straightforward public-facing end-user web interface and data archive, while the HWMM comprises the mobile data collection and back-end data collection and temporary storage system.

In summary, the objectives of this thesis are: (1) to build a standardized digital repository to store HWM data, (2) to develop a mobile GIS data collection solution for collecting HWMs (HWMM), and (3) to provide a common online operating picture of HWM data and streamgage information (HWMDP).

1.2 Study Area

The study area for this thesis project is the Mississippi (MS) River Basin as depicted in Figure 1. This area was chosen due to the proximity of the HWMM and HWMDP application developer, the author. Also, there were a number of historical floods along the MS River. The data from those floods was used to test the HWMM and HWMDP applications. In a future test, the data can also be used to validate hydraulic models. Although the study area is the MS River Basin, the HWMM and HWMDP applications were developed to be location-independent so they can be leveraged for use in any location where HWMs are present.

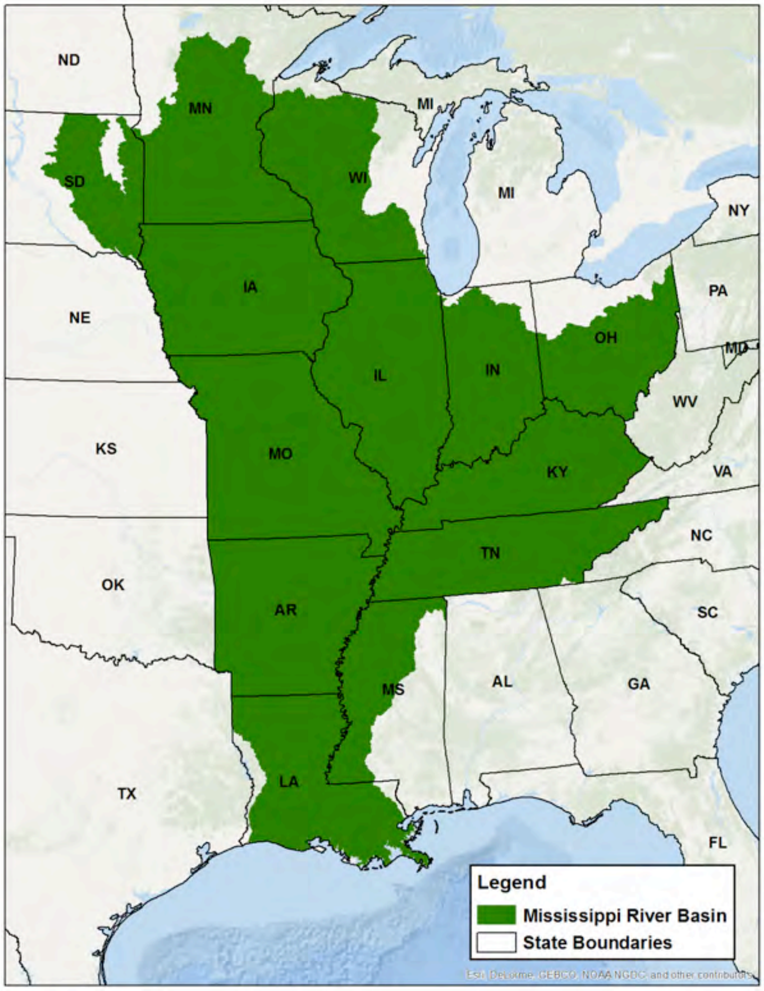


Figure 1 MS River Basin Study Area

1.3 Importance of the US Streamgage Network in Flood Management

There is an extensive network of streamgages in the United States (US) maintained by the federal government that measures river stages at a frequency of 5 to 15-minute intervals (USGS

2016c). This data is currently stored in a database available to both the public and government entities. The streamgage data is used for forecasting river stages associated with a storm event and for estimating return intervals of high river stages. Statistical analysis is typically performed on the streamgage data by the US Army Corps of Engineers (USACE) to produce a frequency or a return interval applied to the river stage. For example, the 100-year floodplain is based on a stage that has a 100-year frequency, meaning on average this stage will not be exceeded but once every 100-years (USGS 2016b). Another way of stating this is a 100-year flood has a 1% chance of occurring in any given year. This is important because a river stage with a corresponding HWM allows an engineer to attribute a frequency or return interval to the HWM. This method is very similar to how the Federal Emergency Management Agency (FEMA) applies its 100-year floodplain to estimate flood insurance costs (FEMA 2016a).

In brief, streamgages establish historical flood flows. Figure 2 shows a USGS streamgage measuring the flow of a river. Streamgages are used to provide two fundamental elements of hydrologic information about a stream or river: stage and discharge (USGS 2016c). The stage is defined as the water depth above some arbitrary datum usually measured in feet. Discharge is the total volume of water that flows past a certain point on the river for a certain amount of time, usually measured in cubic feet per second or gallons per minute (The Association of State Floodplain Managers 2014). At the time of this writing, the USGS operates and maintains over 9000 streamgages nationwide (USGS 2016f). This number fluctuates yearly depending on federal government budget, including cuts or shortfalls in funding.

Figure 2 USGS Streamgage (National Hydrologic Warning Council 2006)

1.4 High-Water Marks and Hydraulic Models

Engineers use hydraulic models to predict future river stages and corresponding inundation extents by calibrating models to past observed events (Mississippi River Commission 2012). It is importation to utilize an extensive network of streamgages in order to calibrate models that can accurately predict river stages resulting from rain events. Furthermore, in order to calibrate these models to predict the extents and depth of inundation accurately, it is important to have an extensive network of HWMs as well as photos of the HWMs correlated with the streamgage network. HWM photos offer the engineer a visual validation. The ability to predict river stages with a verified calibrated model allows for advanced flood risk communication, floodplain management to mitigate loss of life and property damages, community planning such as where and how high a bridge should be built, and evacuation planning in the event of flooding.

1.5 Historic High-Water Mark Photos

A photo associated with the HWM and the river stage from the nearest streamgage is a valuable piece of information for the calibration of hydraulic models (Flowers 2016). Figure 3 provides an example of a visual reference of a flood impact elevation; Chuck and Lydia Leblanc, husband and daughter to Julie LeBlanc, Chief of Hydraulics and Hydrologic Branch at the USACE New Orleans District, are pointing in the photo to the elevations of two flood events, Hurricanes Katrina and Andrew. One of the goals of this thesis research is to provide a mechanism or tool for engineers to easily associate HWM photos like this taken in the field to nearest streamgage readings within the waterbody corresponding to the HWM. The HWMM and HWMDP are purposefully designed to allow the user to query the nearest streamgage and to link it to a HWM point using a streamgage query tool. Thus the user can obtain the river stage from the streamgage and associate it with the HWM. The HWMM geodatabase also has the capability of storing HWM photo files. The photos are thus available as historical references for floods.

Figure 3 HWMs from Two Different Flood Events (Julie LeBlanc, USACE, New Orleans District 2005)

1.6 Smart Devices for Field Data Collection

This thesis proposes that smart mobile devices such as iPads and iPhones be used for GIS-enabled data collection. The smart devices deployed at USACE are iPads and iPhones; therefore, the HWMM application is built upon the iOS platform using Collector for ArcGIS Typically, the position and elevation of HWM data are collected using a Global Positioning System (GPS) device. HWM points are land surveyed to tie the point to an elevation. Mobile GIS data collection using a smart device poses some limitations in this regard, including accuracy and precision. Nevertheless, technological advancements in the GPS and Global Navigation Satellite System (GNSS) chipsets in smartphone devices have allowed Esri to overcome this hurdle. Esri conducted a mobile phone accuracy study in July 2013 using a number of different cellular-enabled smartphones and tablets to test their accuracy for data collection (Esri 2013). All of these devices included an integrated GPS chip-set. Although the chip-sets were manufactured by different companies, they are all are designed for locational accuracy. Esri found through their testing that approximately 90% of all positions collected fell within 3m of their baseline. As part of the same study, they connected the smartphones to a consumer grade external GPS receiver. They found that approximately 99% of all positions collected fell within 3m of their baseline and almost 70% were within 1m of the baseline.

Esri later partnered with Trimble to allow the R1 and R2 GNSS Receivers to work with Collector for ArcGIS (Esri 2016c). The receivers cost about $2,500. The receivers can be paired with Bluetooth technology to a smartphone device to provide 1-centimeter RTK accuracy. Even without a reciever, the accuracy provided by Collector for ArcGIS without the R1 or R2 GNSS receivers were deemed sufficient for this thesis project.

1.7 Thesis Organization

This thesis is divided into five chapters. The project background is described in Chapter 2, which documents various hydraulic models used by USACE, an evaluation of available mobile GIS data collection software, and current HWM data collection methods and applications. Chapter 3 presents the development of the applications, HWMM and HWMDP, for this thesis project. Chapter 4 provides an evaluation of the applications including field test and user survey. Finally, Chapter 5 provides conclusions and recommendations for future improvements of the HWMM and HWMDP applications.

Chapter 2 Background

Smart mobile devices such as smartphones and tablets embed GPS and wireless Internet access together to provide accurate and precise location information. These devices can be applied in the field for mobile field data collection. In addition, Web GIS can be leveraged to provide a platform for creating GIS data collection forms used by the smart device as well as a storage mechanism for the collected data (Lwin 2014). Once the data is collected using the smart device, it is automatically written to the GIS in real-time which eliminates many of the data handling tasks common to field data collection.

Esri's ArcGIS Online is a publically accessible web GIS platform (Esri 2016a). This platform can be used to create, store, analyze, publically or privately share and publish GIS-enabled data. This thesis project uses ArcGIS Online to consume a GIS web-enabled feature service, build a web map, and design and develop a specialized streamgage query tool within a web mapping application. The HWM data collected as a result of this thesis project can be used in validating hydraulic models. Section 2.1 of this chapter documents various hydraulic models used in forecasting future flood events and explains how HWM data is used. Section 2.2 provides an evaluation of ArcGIS Online in it's present state as well as other GIS programming technologies and tools available for mobile GIS data collection. Section 2.3 provides an overview of the two different, commonly used methods of HWM data collection to determine if a standard data collection method already exists. Lastly, Section 2.4 provides a comparison of existing HWM applications compared to the HWMM.

2.1 Hydraulic Models Used in Forecasting Future Flood Events

Hydraulic engineers use HWM data as a validation or calibration tool for hydraulic models. They do not use the actual HWM data points in the model but use them as references.

The HWM data provides a foundation to validate the models after the models are run. The hydraulic modeling packages currently used by the USACE provide guidance on the types of data or attributes required by engineers for these analyses, which in turn can inform the design of the geodatabase developed as part of this project. The types of hydraulic modeling tools in use by USACE include the Hydrologic Engineering Center's River Analysis System (HEC-RAS), Adaptive Hydrology/Hydraulics (ADH), and a model known simply as "FLO-2D."

2.1.1. Hydrologic Engineering Center's River Analysis System (HEC-RAS)

HEC-RAS is a one and two-dimensional (2D) hydraulic modeling tool developed by the USACE Hydrologic Engineering Center (HEC). HEC-RAS provides several river analysis components displayed in Figure 4. These components are (1) steady flow water surface profile computations, (2) one- and two-dimensional unsteady flow simulation, (3) movable boundary sediment transport computations, and (4) water quality analysis (Warner et al. 2009). HEC-RAS allows hydraulic engineers to forecast floods and to establish floodplains. For example, HEC-RAS was used to calibrate a hydraulic model to the historical 2011 MS River flood. This model can now be used to forecast river stages for a potential future event similar to the magnitude of the 2011 flood (Mississippi River Commission 2012). HWM collected after flood waters receded were used in validating the calibration of the model.

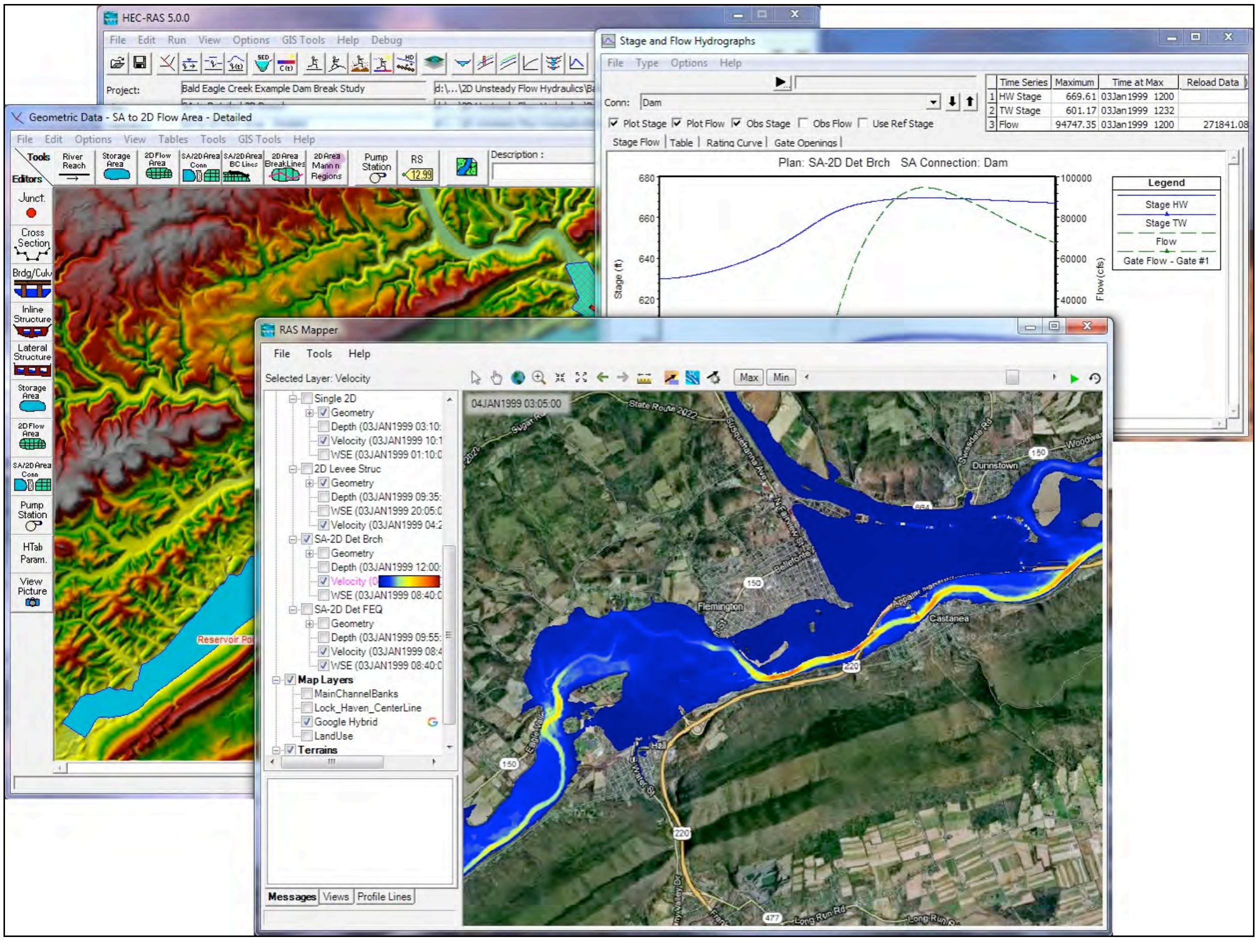


Figure 4 HEC-RAS Tools (Warner et al. 2009)

2.1.2. FLO-2D

FLO-2D is a 2D hydraulic flood routing modeling program displayed in Figure 5. It is used to model flat terrain (FLO-2D Software, Inc 2016). FLO-2D takes into consideration the fact that water does not flow in one direction on flat terrain, but in multiple directions. Before FLO-2D, hydraulic models included the assumption that water flowed in one direction on flat terrain, which is not valid. FLO-2D provides the tools necessary to model 2D flows. This program provides a better overall view of flood routing for flat terrain than one-dimensional models. Engineers use FLO-2D for projects such as modeling floods in the MS Delta which have a land slope of less than 1 foot per mile.

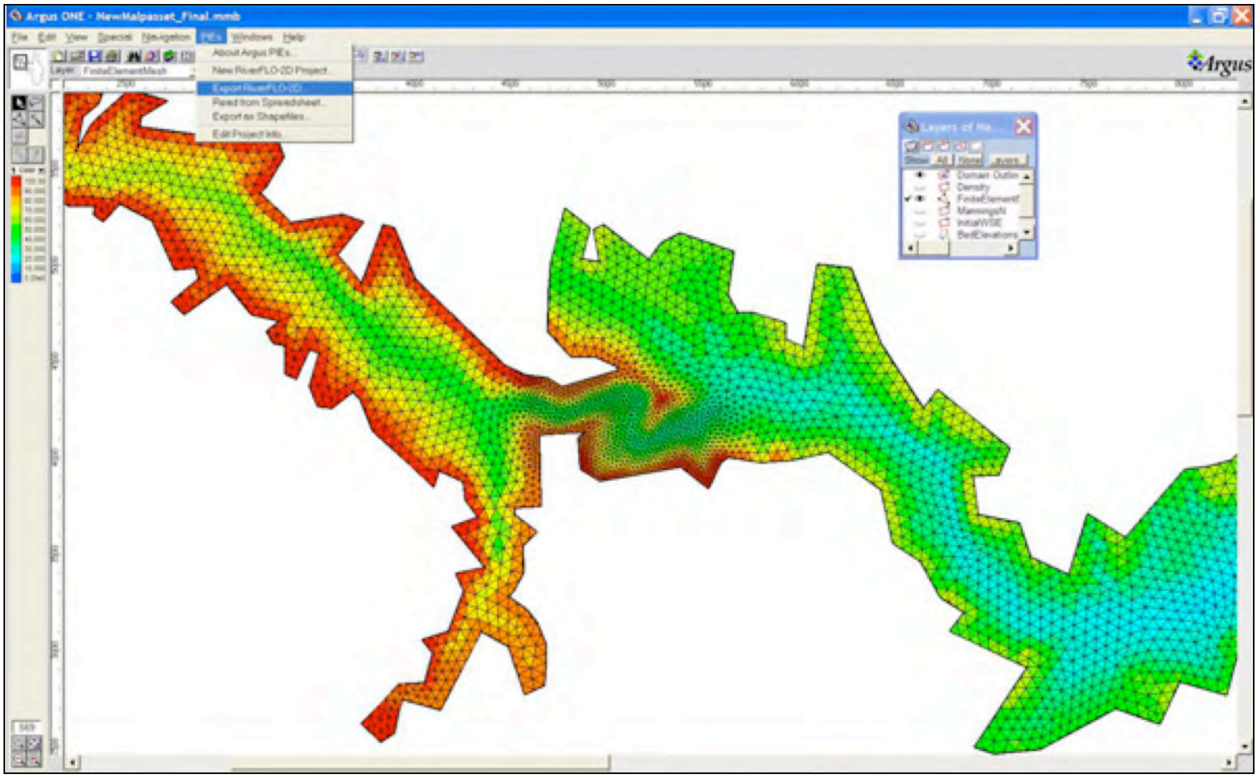


Figure 5 FLO-2D Model of a Portion of the Mississippi River (FLO-2D, Inc. 2016)

2.1.3. Adaptive Hydrology/Hydraulics (ADH)

ADH provides one, two, and three-dimensional (3D) hydraulic modeling capabilities (ERDC CHL 2007). The US Army Engineer Research and Development Center (ERDC) Coastal and Hydraulics Laboratory (CHL) developed ADH to solve the problems of environmental concerns for the Department of Defense (DoD) in estuaries, coastal regions, reservoirs, and river basins. The problems, which may be addressed, include the flow in and out of estuarine environments, the analysis of potential dam breaks, and the study of river stages during flood events. ADH is an adaptive finite-element model for flow and transport of water. Engineers use ADH for very detailed localized modeling, such as the study of river training structures that enhance navigation of large river systems. Figure 6 displays an ADH model output from a portion of the MS River.

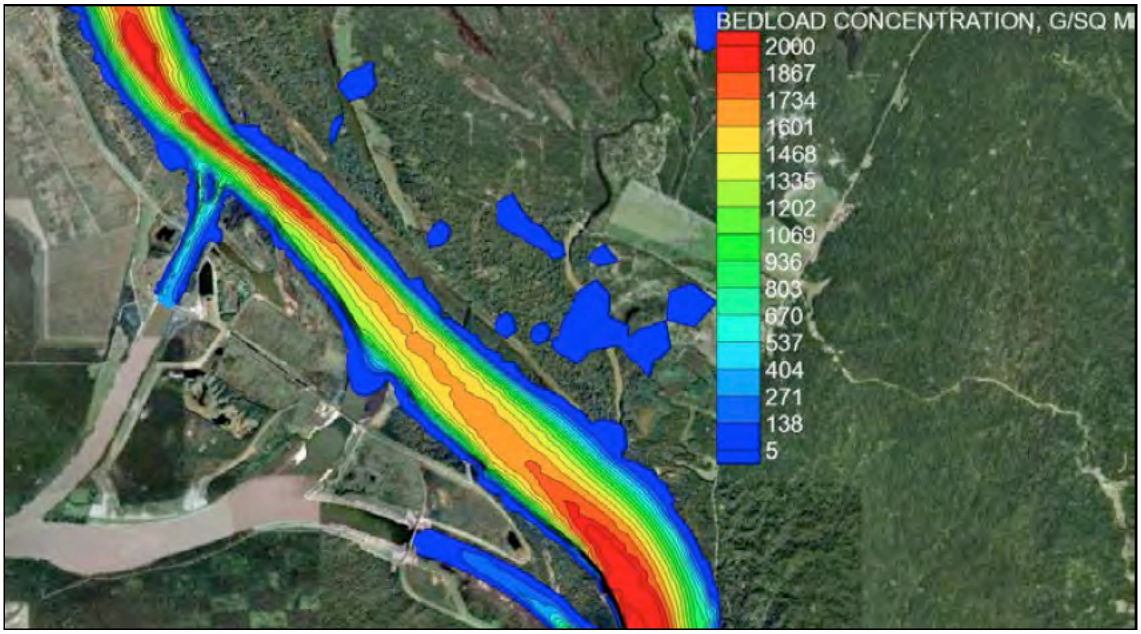


Figure 6 ADH Model of a Portion of the Mississippi River (ERDC CHL 2007)

All of the above models predict a resulting stage from a rain event. HWMs are used to verify the calibration of the hydraulic model as well as validation that the model is correct.

2.2 Mobile GIS Data Collection Software

Research conducted on mobile GIS data collection software discovered a number of formats available: commercially developed software, open source software, and Esri software applications and tools. Many of the commercially developed software applications provide easy, out-of-the-box solutions for non-GIS professionals, but unfortunately, most are costly. While open source software is usually free which provides a cost effective solution, prior programming experience is required. Esri software applications and tools provide many options including easy-to-implement web maps, custom GIS feature services, and easily deployable mobile applications. However, an ArcGIS Online license is required. Each of these formats is compared and contrasted in the following sections.

2.2.1. Commercially Developed Software

An exhaustive search showed no existing commercially developed mobile HWM data collection applications. Therefore, a search was conducted to determine if existing commercially developed software could be modified for HWM data collection use. At the time of this writing, one such software was found, Fulcrum (Fulcrum 2016). It ranked in the top ten mobile data collection applications (Guay 2016). Fulcrum combines geolocation with custom forms. It supports multi-platforms such as the iOS and Android platform. It is easily configurable with no coding required and provides cloud storage. In addition, Fulcrum offers more than just a mobile solution; it also offers an application-programming interface (API). The API can be used to customize the software further for HWM data collection. In addition to cloud storage, Fulcrum includes a custom form builder, multiple data export options, real-time data tracking, and offline data collection. The downside to Fulcrum, however, is cost and data storage limitations. The professional version costs $30/month, which only includes 30 GB of data storage (Mobile Form Builder & Data Collection App 2016). One of the requirements of the HWM mobile data collection application is the ability to store photos. A total of 30 GB of data storage is considered a limitation when multiple photos are captured and stored for each HWM. Also, $30/month is a recurring cost, whereas this project does not have funding to purchase adidtional software. Due to the cost of this software and storage limitation, Fulcrum did not meet the requirements of this thesis project.

2.2.2. Open Source Software

Open source software such as KoBo Toolbox, PhiCollect, and OpenDataKit provides freely available source code for a reasonable price, which meets the cost requirement of this thesis project (KoBo Toolbox, WebFirst, OpenDataKit 2016). In general, open source code can be edited or modified by anyone, as long as applicable licensing rules are followed, such as Creative Commons (Creative Commons 2016). For example, the OpenRosa Consortium is a working group that was developed to focus on providing open source, standard-based tools for mobile data collection (Anokwa et al. 2009). One such open source mobile GIS data collection software is Open Data Kit (ODK). ODK is an Android application for developing forms for mobile data collection based on an OpenRosa Compliant XForm. ODK is comprised of seven different tools: Build, Collect, Aggregate, Form Uploader, Briefcase, Validate, and XLS2XForm. ODK Build offers a drag and drop capability for creating forms. ODK Collect is an android-based application that allows a user to collect data. ODK Aggregate provides an online repository for the data collected. ODK Form Uploader provides a method to upload blank forms and media files to ODK Aggregate. ODK Briefcase provides a method to transfer data between Collect and Aggregate. ODK Validate ensures that the form is an OpenRosa Compliant XForm. ODK XLS2XForm provides a tool to create the XForms from Excel XLS files. While this software is a cost effective solution, it does have some limitations. ODK runs only on the Android OS platform and not the iOS platform. The USACE now uses IPads and IPhones for field data collection, therefore the iOS platform is a requirement. Also, ODK does not provide geodatabase support. It was preferred by the developer that the HWMM support the use of an Esri geodatabase as the digital repository for HWM data. Due to these limitations, ODK also did not meet the requirements of this thesis project.

2.2.3. Esri Software Applications and Tools

The USACE currently has an Esri enterprise license agreement that provides all of the required licenses and tools to USACE. Esri software applications and tools were also reviewed in order to find the best application development solution for this project. Two of the solutions investigated to develop a data collection tool were AppStudio for ArcGIS and Collector for ArcGIS (Esri 2016 and 2016b). AppStudio for ArcGIS requires no previous programming experience, but does require GIS experience. AppStudio supports multiple platforms and is easily configured to run on multiple platforms with no extra coding or programming required. In addition, AppStudio provides customization and programming access for building unique applications, which is a benefit to those that want to customize an application. One limitation, however, is an Esri ArcGIS Online license is required to use AppStudio. A commercial ArcGIS Online account subscription can cost $2,500 for 5 users, and the cost decreases with an increasing number of users. Since the USACE does not incur additional fees for AppStudio and their licensing agreement is anticipated to continue for many years into the future, the cost of the license does not impact the requirements of this thesis project; in fact the existing Esri licensing structure within the USACE supports the goals of this thesis project.

The main benefits of Collector for ArcGIS are that it supports multiple platforms similar to AppStudio, and provides an out-of-the-box data collection tool that requires little programming and customization. However, the requirement of an ArcGIS Online account can be considered a limitation, since the application won't be accessible to those without an enterprise-level account. Another benefit of Collector for ArcGIS is that it provides offline access to maps and data and the ability to create and share interactive web maps (Esri 2016b). Offline access is extremely useful in the field when Internet or Wi-Fi is not available. The user can continue data collection offline and sync the data with the enterprise geodatabase whenever Internet service is available. To use Collector for ArcGIS, a published web map containing a published feature service is required (Esri 2016b). A feature service allows features to be displayed, edited, and deleted on the Internet (Esri 2016d). Publishing a feature service entails developing an enterprise geodatabase, creating a map document for web editing, registering the enterprise geodatabase with ArcGIS Server, publishing the map document with feature access enabled, and building a web map to consume the feature service. The data collection application cannot be developed without either a published web map or feature service. This is not a limitation since the objectives of this thesis project are: (1) to build a digital repository to store HWM data (enterprise geodatabase), (2) to develop a mobile GIS data collection solution for collecting HWMs (HWMM), and (3) to provide an online common operating picture of HWM data and streamgage information (HWMDP), which uses a published feature service and web map). For the above-stated reasons, it was deemed that Collector for ArcGIS proved to be the best option available for the application development phase of this thesis project.

2.3 Current High-Water Mark Data Collection Methods

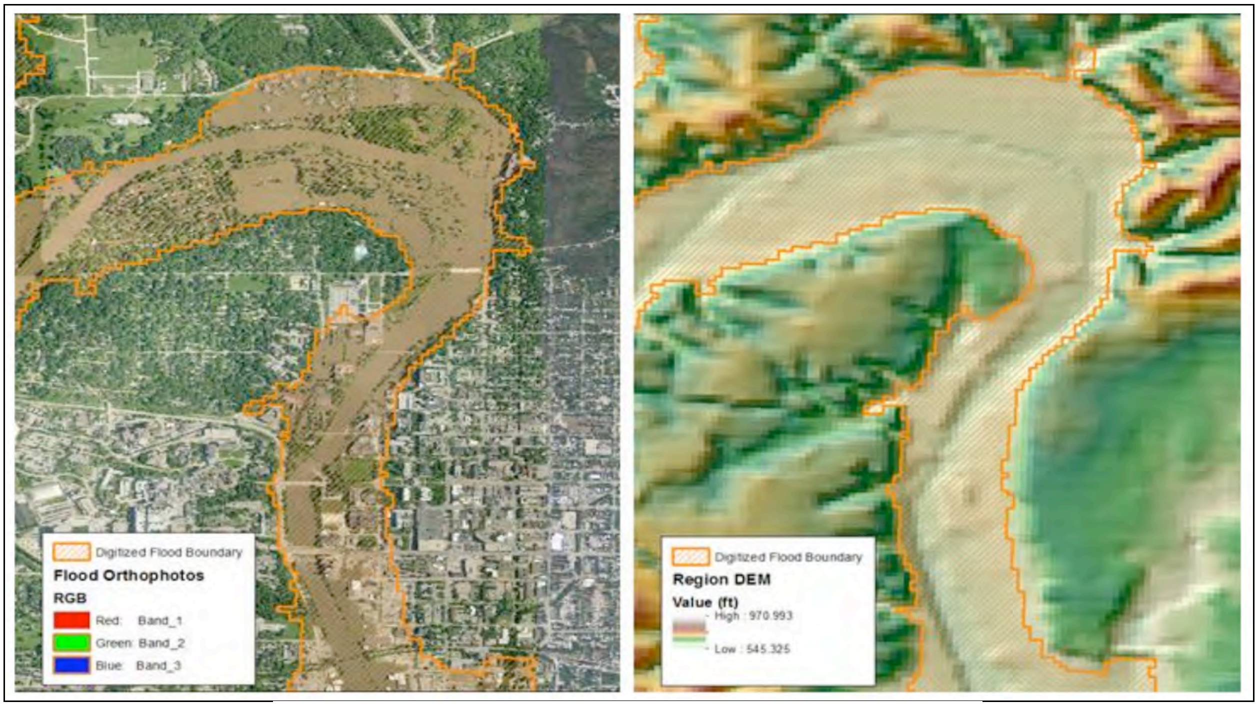
The method of collecting HWM data can be categorized as direct or indirect. The direct method involves collecting HWMs in person with or without a measuring instrument, such as field surveying equipment or a tape measure. The indirect method involves measuring HWMs using computer tools and applications. The USGS and the USACE both use the direct method due to the perishable nature of HWMs, meaning that since HWMs exist in the environment, wind, rain, etc. can distort or remove the HWM soon after the flood event. This thesis project will focus on automating the direct method of HWM data collection.

The current data collection method of the USGS and USACE is the pen and paper method, classified as direct. Data collection is a manual process that starts once the floodwaters recede. The goal is to record the floodwater’s peak, which is when floodwaters reach maximum elevation prior to descending. Field crews are sent to locate and flag HWMs. This method includes first prepping for field data collection in the office. Preparations involve reviewing streamgage information and assembling teams. Reviewing streamgage information provides the field crew with the exact locations of areas that have been flooded. The information is then used to determine routes to the flooded areas. Emergency management personnel are assembled into two-person teams based on their expertise and experience. Once teams are formed, they are assigned a geographic area to search. The teams are sent into the field to flag and collect information on each HWM found. The teams record the HWM information via a paper form located in Appendix A (USACE Wilmington District 1998). The USGS and USACE use different paper forms for data collection. Though the forms are similar, there are some discrepancies. An example of one discrepancy is the USGS collects the owner's name, address, and email. USACE does not collect this information. In March of 2016, the USGS published a manual for HWM collection, titled "Identifying and Preserving HWM Data", in hopes of building a standard for HWM data collection (Koenig et al. 2016, Appendix B). The manual was written for skilled HWM data collectors and lists specific instructions on how to identify and capture HWM data.

Field or land survey is another direct form of HWM data collection (USGS 2016e). Once HWMs are flagged, field crews are sent to land survey the HWM. Surveying provides very precise and accurate measurements, and individuals that conduct land surveys are highly skilled in this area. The resolution of the measurements is usually expected to range between 1 and 2 centimeters depending on the survey equipment used. Land surveyors must choose the appropriate rod heights and GNSS setup depending on the land survey method used (Koenig et al. 2016). In most cases, the federal government contracts the land surveying service to an outside contractor, as was the case with Hurricane Katrina. The USGS contracted the URS Group, Inc. to provide land surveys of the HWM data collected by the USGS (URS Group, Inc.

2006). Not only can contracting to an outside agency be costly, but these arrangements also take up time. Travel and lodging for the land survey field crew have to be arranged, equipment has to be setup, and in some cases, federal governement security clearances for each crew member have to be obtained (URS Group, Inc. 2006). The timeline for collecting HWM is delicate due to the perishable nature of HWMs. Therefore, this kind of outsourcing can cause a delay that poses a risk for accurate data collection.

Remote sensing data is used in the indirect method of collecting HWMs to establish the height of the floodwater. Aerial photos representing the peak flood are georectified then inundation boundaries are manually digitized from the photo. After digitization, the boundary edges are intersected with a terrain model such as a Digital Elevation Model (DEM). Lastly, elevations are calculated along the boundary. This information can be used to reconstruct the exact elevation height of the floodwaters (The Association of State Floodplain Mangers 2014). Figure 7 depicts an example of flood inundation boundaries digitized from orthophotos (a) and the predicted flood elevation after the intersection with terrain data (b). The indirect method is used mostly to provide historic HWM information when land or field surveys were not conducted at the time the HWM was collected. This thesis project provides an alternative to the indirect method described above by providing the user the ability to determine the peak river stage by cross-referencing the nearest streamgage to the HWM, thus capturing this information in a timelier manner immediately following a flood event.



(a) (b)

Figure 7 Flood Orthophotos Depicting Digitized Boundaries Before (a) and After Terrain Data Intersection (b) (The Association of State Floodplain Mangers, Inc. 2014)

2.4 Existing HWM Applications

Several HWM online web mapping applications are available in the federal government including applications developed by Florida Silver Jacket Team, Federal Emergency Management Agency (FEMA) Region 6, and the USGS. The three applications are online web-mapping applications and do not provide a mobile data collection solution; therefore, they do not meet the overall goal of this thesis project.

The Silver Jackets are co-agency developed teams in each state that foster collaboration in an order to reduce flood risk. Members from the USACE, USGS, FEMA and National Weather Services make up most of the teams. The Florida Silver Jacket team is currently developing a pilot data collection application for HWM data. The application is being developed as a pilot due to funding limitations, also using Collector for ArcGIS. The Florida Silver Jacket data collection application differs from HWMM/HWMDP in that it does not and will not incorporate streamgage feeds/data or the ability for the user to cross-reference the nearest streamgage to determine the peak river stage. This limitation does not provide the user a visual reference elevation, meaning the Silver Jackets tool could not be used to validate hydraulic model output nor serve as a historical data capture tool to support forecasting of future floods. Also, compared to the USGS manual on identifying and standardizing HWMs (Appendix B), the Silver Jacket data collection tool only allows for a small subset of the data to be collected. Not all the attributes included in the HWMM/HWMDP are included in their application; therefore, it does not provide a standardized approach for HWM data collection.

FEMA Region 6 and the Oklahoma Water Resources Board joined forces to develop an ArcGIS Online Web Map depicting HWM data collected during a major disaster in Oklahoma (FEMA Region 6 2015). FEMA declared the major disaster as project DR4222. Project DR4222 represented the severe storms, tornadoes, flooding, and straight-line winds during May 5, 2015, to June 22, 2015. This disaster was declared a major disaster, therefore, federal assistance was provided. The online web map was built from the DR4222 data collection effort using the paper and pen method. The data was digitized to build the online web map depicted in Figure 8. The online web map does not provide a mobile data collection application but does provide an online web map viewer. It also does not include streamgage information nor does it provide a query tool for determining the nearest streamgage, considered a critical limitation of the application.

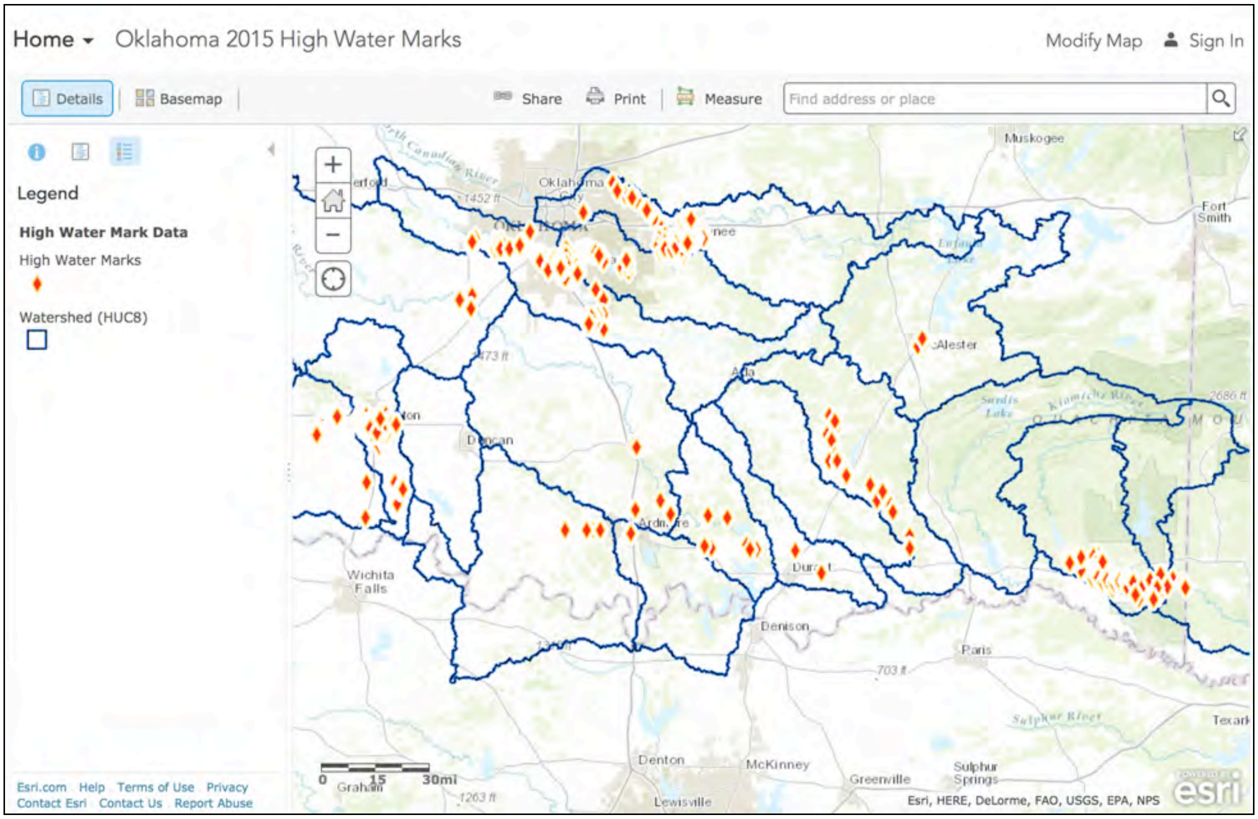


Figure 8 Oklahoma 2015 High Water Marks ArcGIS Online Web Map (FEMA Region 6 2015)

In addition, the USGS developed the Short-term Network (STN) that provides an application and database for the USGS event-based sensor deployments and the USGS High-Water Mark data collection efforts (USGS 2016d). The application supports a Flood Event Viewer displayed in Figure 9, based on Esri ArcGIS Web Map technology, which is also a requirement of the HWMM and HWMDP applications. The main limitation of the STN design is there is no mobile data collection application associated with it. Hans Vraga, USGS WiM Project Manager, asserted, "the USGS STN team does not have a mobile application for HWM data collection. One that integrates into the STN has been on our project wish list for some time" (2016). Based on feedback from Vraga, the HWMM and HWMDP could be easily integrated into the STN since both platforms are based on Esri ArcGIS Web Map technology.

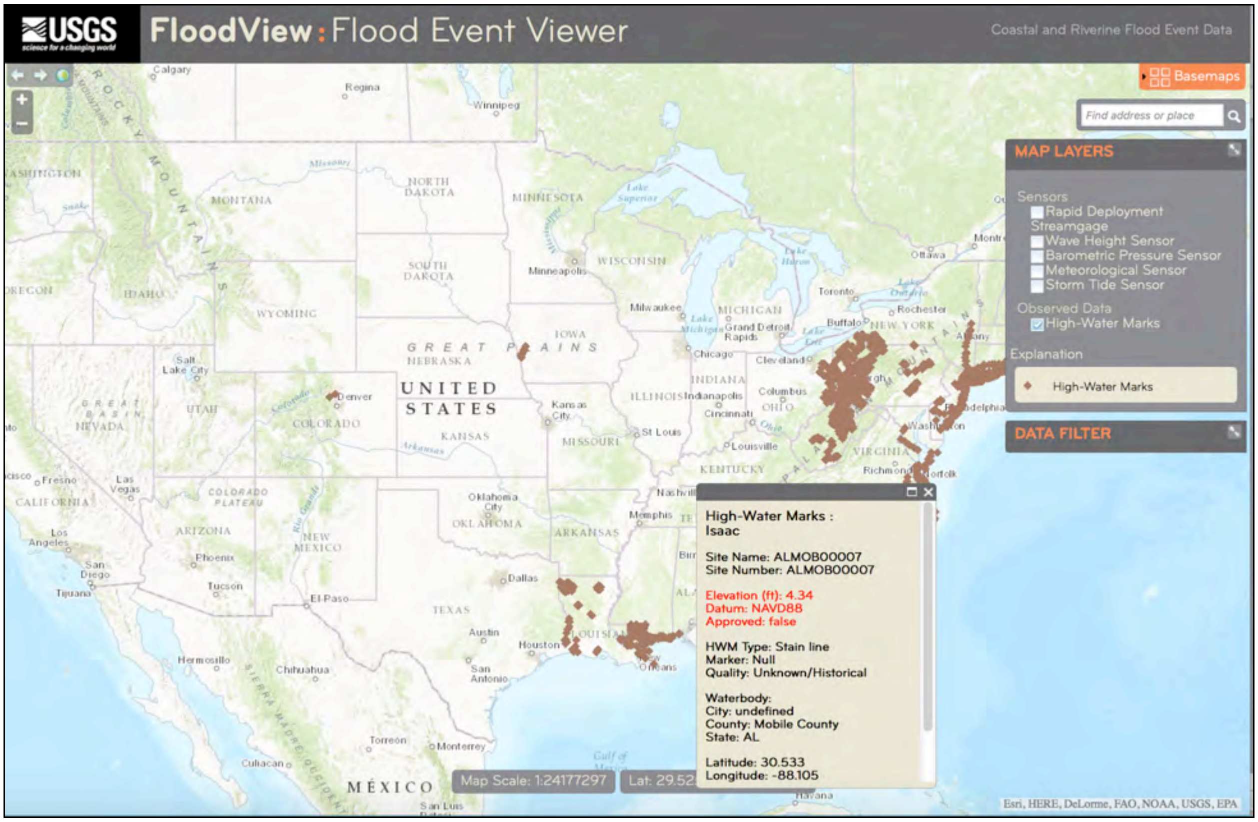


Figure 9 Short-term Network Flood Event Viewer (USGS 2016d)

The applications and tools described above do not meet the objectives of the HWMM and HWMDP applications. All three tools have limitations and shortfalls. By contrast, HWMM provides a mobile data collection solution utilizing Collector for ArcGIS and ArcGIS Online Web Map technology and a digital repository of all HWM data collected. In addition, HWMDP provides an online common operating picture for users to reference HWMs to a corresponding river stage by providing the ability to query the USGS streamgage network to locate the nearest streamgage to the HWM. Thus HWMM combined with HWMDP offer a standardized method of collecting, disseminating, and referencing HWMs to corresponding streamgages, providing engineers and floodplain managers with visual reference (HWM photos) elevations that can be used as a validation tool for hydraulic modeling. Additionally, HWMM and HWMDP provide direct HWM data collected and stored over time in a digital form, which eliminates the time and potential human error in transferring paper field notes to digital form and facilitates access to historical flood information for use in forecasting future floods.

Chapter 3 Development

This chapter provides an overview of the development methods and design of the mobile GIS data collection and web mapping applications for HWMs documented in this thesis. Section 3.1 identifies the scope and objectives of the applications. Section 3.2 describes the overall methodology related to assessing data needs, designing the application workflow, and the programming approach. Section 3.3 explains the data model and the creation of the geodatabase for the mobile and web applications. Section 3.4 describes the development of the mobile data collection tool as well as the web mapping application used for viewing the collected data.

3.1 Scope and Objective of the Application

HWM data collection assists in recovery, mitigation, and response following flood events. This data also accurately documents a flood event in time by providing historical information (URS Group, Inc. 2006). A HWM is an indication of the maximum elevation of water during a flood event. It is typically linear in nature and can occur on various structures in the built environment as well as trees or bushes, as depicted in Figure 10. As previously mentioned, HWMs provide valuable insight into understanding historical as well as recent flood events (Koenig et al 2016). Therefore, it is very important to ensure that documenting the HWM is done accurately. As described in Chapter 2, it was determined through research that no standard or mobile data collection application or tools exist for the collection, storage, or dissemination of HWM data. There is no national repository for HWMs as there is for levees and dams (The Association of State Floodplain Managers 2014). Furthermore, data collection is dependent upon the agency collecting the information proving that there is no standard method for collecting the data or standard for the types of data collected. Therefore, this thesis project developed a standardized digital repository for HWMs and provides a standard, mobile data collection tool, and an online common operating picture.

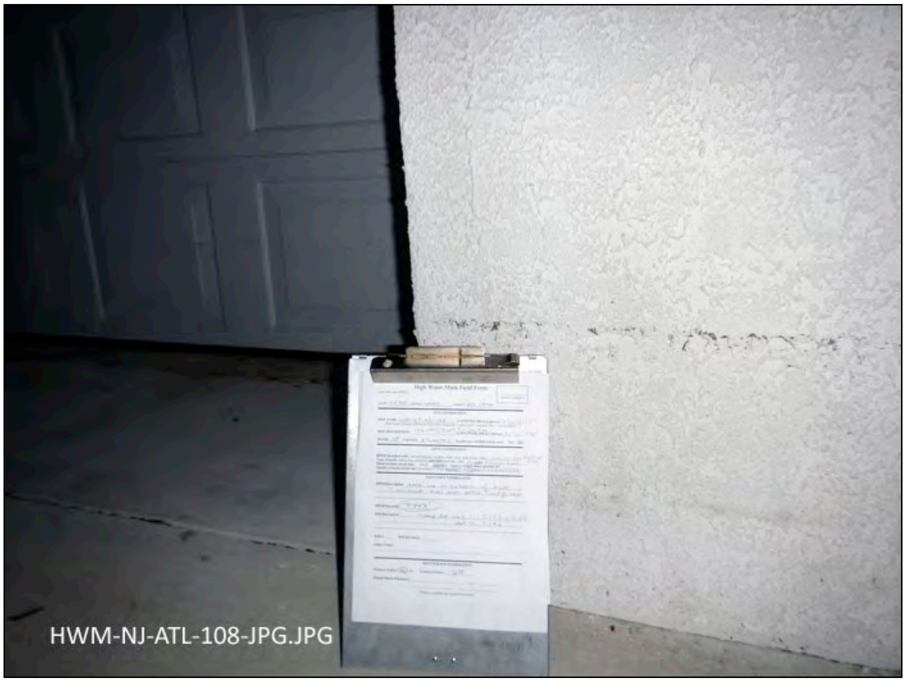


Figure 10 HWM depicted with Paper Data Collection Form (Koeing et al 2016)

The HWM standard digital repository, data collection tool, and common operating picture leverages GIS technology. A GIS is a computerized system for creating, storing and retrieving locational-aware data. GIS data can be viewed on maps and used for the study, analysis, and interpretation in an effort to be able to understand patterns, relationships, and trends (Esri 2016f). Esri is the leading distributor of GIS related software and tools. Esri provides a GIS platform called ArcGIS, which consists of a suite of tools including ArcCatalog, ArcMap, and ArcToolbox. Esri also provides an online GIS platform called ArcGIS Online with configurable web map templates, feature services, the ability to support mobile web mapping applications, and other GIS tools that are available via the Internet (ESRI 2016a).

A preliminary study was conducted during the research phase of this thesis project to determine feasible toolkits for HWM data collection, storage, and dissemination. As previously stated, the preliminary study found in 2016 the USGS published a manual for standardizing the identification and collection of HWMs using a standard paper form found in Appendix B.

The main objectives of this thesis project are to develop a standard digital repository for HWMs that includes critical attributes of interest to hydraulic engineers, a mobile GIS data collection tool using the USGS standardized methods for collecting HWMs, the latter also integrated into a near real-time, interactive web map depicting the HWM data. The secondary objective is to provide the ability for the end user to cross-reference the HWMs to the nearest streamgage using an online method in an effort to facilitate analysis of future flood events and provide a common operating picture for the hydraulic engineers and emergency management personnel.

The USACE has a mission to provide emergency response to natural disasters such as flooding. The USACE sends teams of engineers into the field to collect HWMs as soon as possible after floodwater recedes during a flood event. They have a need for a digital repository to store the HWM data they collect. Much of the historical data collected was not stored in any type of computer or digital format. It has been collected and stored using a paper form. Land surveys are then performed later using the data collected on paper forms to establish the reference elevation of the HWM.

The USACE hydraulic engineers and emergency management personnel will be the main users of the HWM mobile GIS data collection application referred to as HWMM as well as the online common operating picture aka web mapping application referred to as HWMDP. The future goal of this thesis project is to integrate the HWM dataset and the HWMM technology with the USGS STN, so the design of HWMM is intended to take this into account. As previously stated, the STN uses an ArcGIS Online Web Map for the STN Flood Event Viewer (USGS 2016d). Utilizing the same technology, HWMM can be easily integrated into the STN providing a common picture of HWM data between the two agencies.

As previously mentioned in Chapters 1 and 2, the scope of the HWMM application is to provide a mobile GIS solution to automate the data collection of high water marks. The scope of the HWMDP is to provide a web mapping application that can display the HWM data collected with the ability to cross-reference streamgage data to provide engineers and emergency management personnel a common operating picture after a flood event. To accomplish this, a number of ArcGIS tools are used. HWMM consists of a geodatabase for data storage, considered the backend digital data repository of the application. In section 3.2 the features and attributes of the geodatabase are explored. The user interface for HWMM was developed using Collector for ArcGIS. Collector for ArcGIS provides a readily available user-centric data collection application with little programming required to set up, but it does require a published ArcGIS Online Web Map to work. A feature service was developed using a feature class in the geodatabase and then used to build the online web map. HWMDP was also developed using ArcGIS Online Web Mapping technology. The HWMDP was designed to consume the HWMM feature service and a live streamgage feed to provide a common picture of the HWM data and the streamgage information.

3.2 Methodology

The methodology of the thesis project focuses on application development for data collection, dissemination, and storage of HWMs. The case studies evaluated in determining the feasibility of this thesis project investigated the various existing methods of HWM data collection, the types of data collected, the use of HWMs in flood modeling, and the availability of other mobile data applications. The following section explains the data needed to develop the application, the application workflow, and the programming approach implemented to accomplish the thesis project.

3.2.1. Data Needs

Ideally the HWMM application should provide and consume various datasets from the USGS, USACE, Esri, and National Oceanic and Atmospheric Administration (NOAA). The backend of the application is a spatial database management system (DBMS). The DBMS utilized is Microsoft SQL Server, which provides an enterprise geodatabase. The enterprise geodatabase consists of one feature class and two tables which provide the framework for the HWMM application. The enterprise geodatabase is integrated into the HWMM application so that data is automatically collected within the database. The data in the application is then shared, or exposed, by publishing it as a web feature service. The feature service can be used as a feature layer in an ArcGIS Online Web Map. In addition, a live streamgage feed comprised of streamgages monitored and administered by the USGS and NOAA as well as an Esri basemap is also included in the HWMDP application (Esri Observation 2016). The same Esri basemap, World Topographic Map, is used in both the data collection tool and the online web map. Figure 11 provides a visual flow of HWM data collection, storage and dissemination.

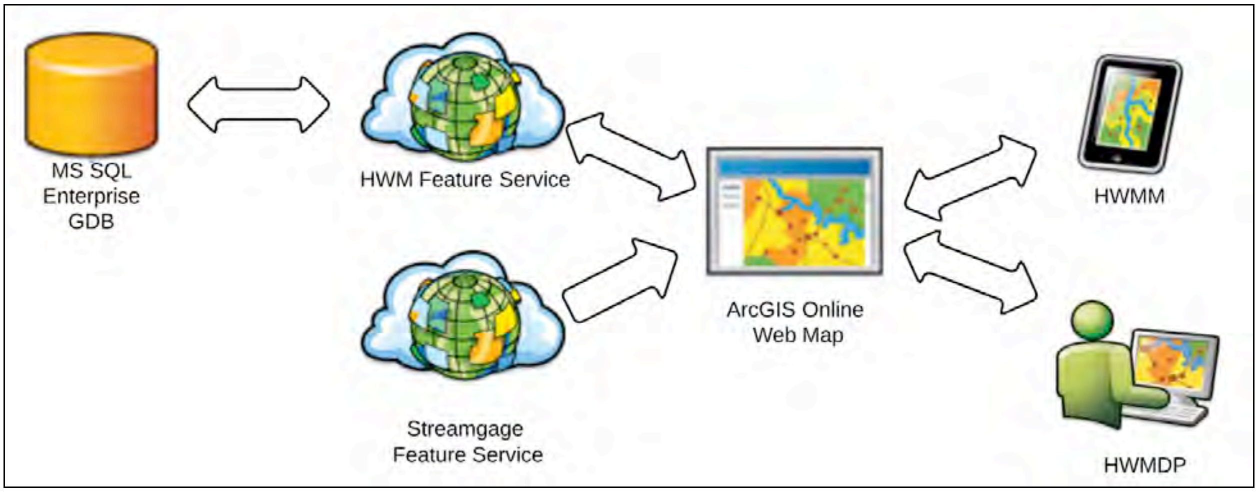


Figure 11 Data Flow Diagram (images by Esri)

3.2.2. Application Workflow

The high level overview of the HWMM application's functionality is displayed in Figure 12. Once the user launches the application, the first step is authentication with a username and password provided by their ArcGIS Online organizational account. Upon successful authentication, the user's current location is determined and the application automatically zooms in to the user's location. Next, the user can enter HWM data by clicking the "+" button. A form then displays on the mobile device for the user to enter the data. Once all the data is entered into the form, and the user has the option of taking a photo. Finally, after the user completes the form and either uploads a photo or takes a new photo, the user will click the submit button. When the user submits the data, HWM attributes and photos are written to the enterprise geodatabase and the HWM point is automatically displayed on the map. At this point in the application, the user can continue to enter more HWM points, save the data entered up to this point and exit the application, or exit the application without saving.

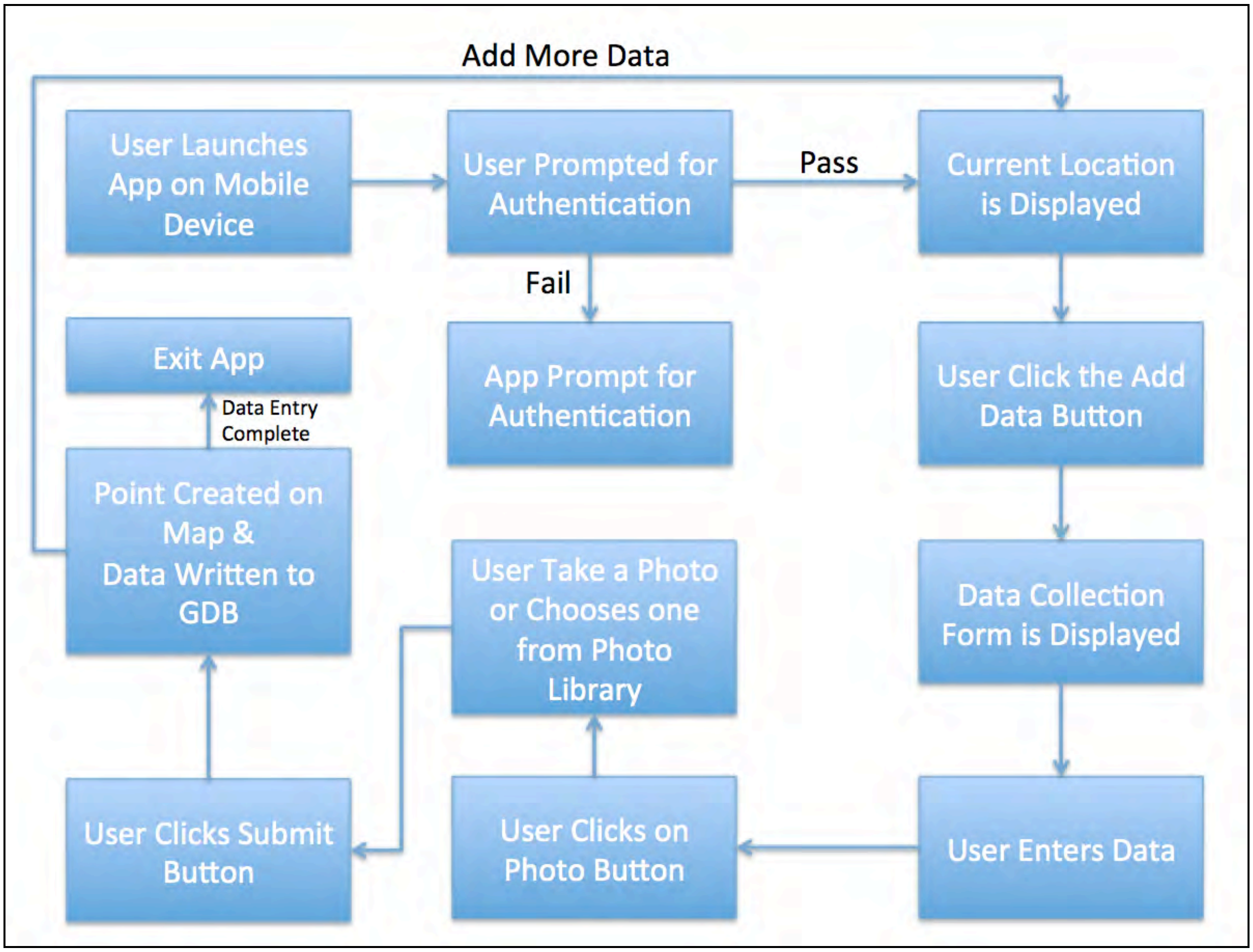


Figure 12 HWMM Application Flowchart from the User's Perspective

3.2.3. Programming Approach

ArcGIS tools were used in the development of the HWMM and HWMDP. Esri's Collector for ArcGIS is a mobile data collection tool developed by Esri (Esri 2016b). Collector for ArcGIS provides a mobile data collection solution with minimal programming required. In general, it was developed to assist field crews in the ability to rapidly deploy a mobile data collection application (Esri 2016b). Rapid deployment was one of the reasons Collector for ArcGIS was chosen as the tool for HWMM development, as previously stated in Chapter 2. The USACE purchased iPads and iPhones in 2015; therefore, the ability for the mobile data collection tool to run on the iOS platform was a requirement of this project. Thus the mobile platform of HWMM is iOS. The version of ArcGIS used for development is 10.4, the latest version at the time of this writing.

The HWMM data is displayed and accessible through the Internet via the ArcGIS Online Web Map. Behind the scenes, Esri's ArcGIS Server provides the functionality to create, publish, and share feature services from an enterprise geodatabase through the Internet. The HWMM feature service is coupled with the live streamgage feature service, or feed, in the ArcGIS Online Web Map. In turn, the online web map was integrated into the ArcGIS Web Mapping Application, HWMDP. The HWMDP provides the end user interface, including a streamgage tool with the ability to query attribute data from the streamgage feed to determine the closest streamgage in the water body associated with the HWM. Providing this information to the engineer allows him or her to reference the HWM to a corresponding peak river stage by using the streamgage network after data has been collected in the field. This is a significant advantage to the engineer because they no longer have to wait until land surveys of the HWMs are complete to determine the elevation of the HWM.

3.3 Geodatabase Creation

In the past, the prep work conducted prior to HWM data collection was a time-consuming and cumbersome task (Lwin et al 2014). Prep work included building maps and location data for the area where HWMs will be collected as well as ensuring all necessary materials and tools (field notebook, cellphone, camera, and GPS) are available. The traditional method of collecting data with a paper form in real-time disaster situations is not efficient especially in emergency response situations. Preparing basemaps and collecting ancillary datasets to aid in field data collection in the immediate aftermath of a disaster is not practical. The rapid pace of GIS technology and the advancement of mobile devices have opened the door for rapid development of mobile data collection applications. And, the ability for the user to acquire precise location information is an advancement that has transformed the geospatial industry (Wang et al. 2006). Today, many mobile applications provide location information with a click of a button and step-by-step directions without the need for advanced instruction. In addition, much of the location information in the mobile device is readily available because it is stored in a spatial DBMS.

A geodatabase is different from traditional databases because it stores spatial information (latitude and longitude). Therefore, point, lines, and polygons can be stored in a geodatabase. Per Esri, the geodatabase is the native data structure format for ArcGIS (2016e). Accordingly, a geodatabase was used for this thesis project, particularly, an enterprise geodatabase. An enterprise geodatabase allows multiple users to perform edits of the features and non-spatial data located in the geodatabase. SQL Server is a DBMS developed by Microsoft. Esri provides SQL Server as one of the options when building an enterprise geodatabase. SQL Server was used for the HWMM geodatabase repository because it does not require separate licenses and it is more intuitive than the other enterprise DBMS options provided by Esri.

3.3.1. Data Features and Attributes

The structure of the HWMM geodatabase consists of one feature class and two tables. A feature class is a collection of common spatial features such as points, lines, or polygons (ESRI 2016e). A feature class is comprised of one type of geometry. For example, the HWMM will contain a High-Water Mark feature class that will only consist of point data. In a geodatabase, tables are non-spatial. They consist of tabular data such as the first or last name of a landowner. Relationship classes can also be part of the geodatabase structure. Relationship classes enable the geodatabase tables and features to be joined by a common attribute or key so that information from one feature can be related to another feature or table. The structure of a geodatabase is similar to a database in that each feature class is a table with columns and rows. The main difference is a shape attribute within the feature class. The shape attribute is used to hold the geometry value of the feature class. This enables ArcGIS to “draw” the feature on the map. The next section will dive deeper into the HWMM geodatabase structure and explore the data model.

3.3.2. Data Model

A data model of the structure of the HWMM geodatabase was designed before HWMM development. Data models provide the ability to visualize the structure of the geodatabase prior to creation. This model is a combination of a physical and logical model. The model allowed the developer a chance to “see” issues and figure them out prior to the start of development. Figure 13 depicts the HWMM data model comprised of two non-spatial tables and one spatial feature class. Site is a non-spatial table in the data model. It contains information about the place where the HWM is being collected. Photo is also a non-spatial table. It stores information about the photo taken of the HWM and will be used by the engineers and emergency management personnel as a historical reference for documenting flood events. High_Water_Mark is a spatial feature in the data model. It is a point feature class that represents the HWM point and the information about the HWM. The High_Water_Mark feature class also contains attributes for the streamgage. Information about the streamgage can be entered into this feature class once the nearest streamgage to the HWM is determined.

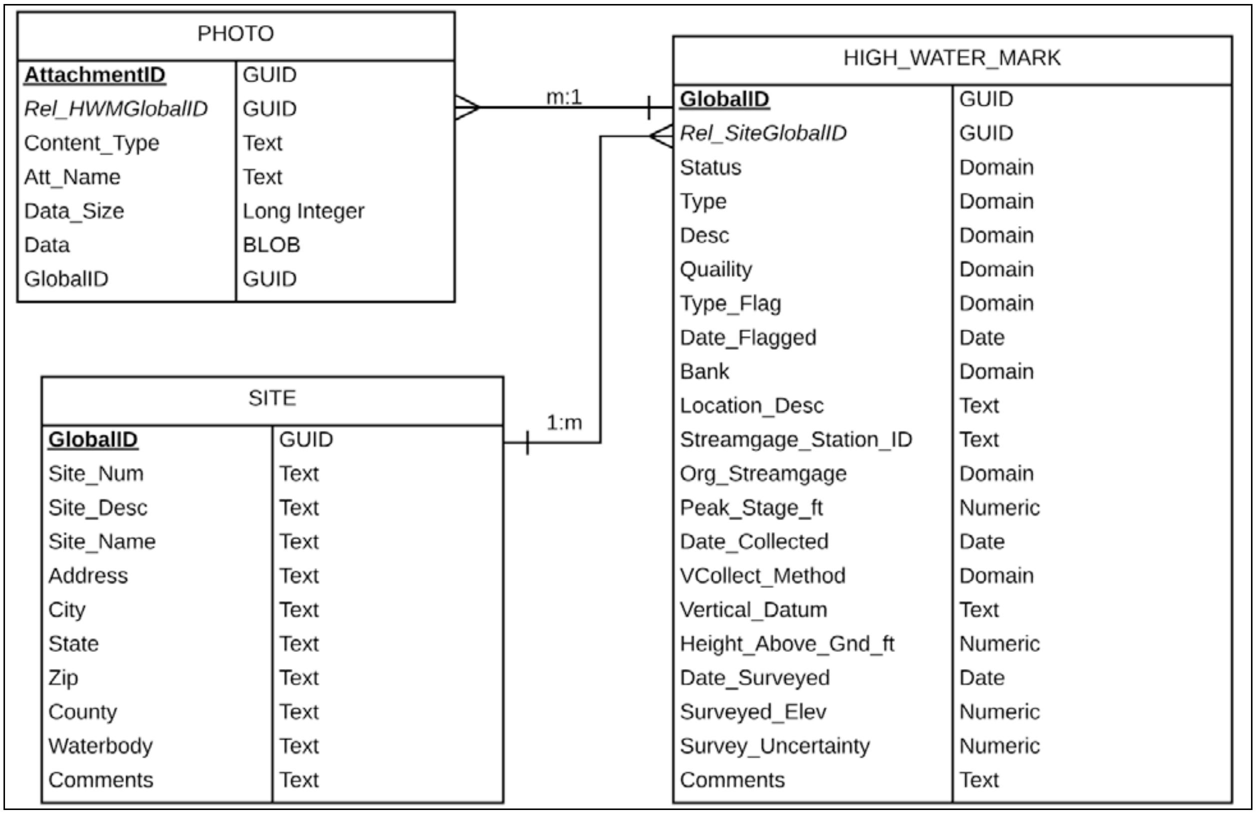


Figure 13 HWMM Data Model

Relationship classes join tables together in the data model. Relationship classes define how origin objects such as feature classes and tables relate to destination objects through the use of primary and foreign keys. Relationship classes can be one of three types: 1:1, 1:M, or M:N. In the HWMM data model, one site can have many HWMs. This relationship is one-to-many, using the GlobalID as the primary key in the Site table relating or joining to the High_Water_Mark feature class through the foreign key, Rel_SiteGlobalID. Similarly, High_Water_Mark can have many photos, thus the relationship type is one-to-many. The primary key in the High_Water_Mark feature class is GlobalID and relates or joins to the foreign key, Rel_HWMGlobalID, in the Photo table. The High_Water_Mark feature class is the focal point in the geodatabase, meaning that without it, the other objects in the data model could not exist. It is the core attribute that links the rest of the tables together through the use of relationship classes.

Within the data model, each feature class and table is made up of a collection of attributes. An attribute represents a single piece of information such as a type of HWM. Users can manually enter data into attributes by typing the information in or they can choose from a pick list of values. This is provided through the use of an attribute domains within the enterprise geodatabase. The HWMM geodatabase contains eight domains. Domains reduce data entry error by providing the user a list of possible values to choose from; therefore, it is considered a good practice to include domains. Appendix C contains the data dictionary for the enterprise geodatabase. The data dictionary explains each feature and table, related attributes, and domains.

3.3.3. Feature Service

The HWMM feature service is the foundation of the HWMM application. It provides the venue for creating, editing, and deleting the HWM points. A feature service is used to serve feature data over the Internet in the same manner that Collector for ArcGIS works (Esri 2016b). Collector for ArcGIS consumes an online web map containing a feature service and provides a template for data collection. The template is constructed from the attributes in the feature service. Furthermore, the feature service allows the client to execute queries and edit non-spatial tables if relationship classes exist between the feature class and non-spatial tables. This is a valuable functionality because it provides the user the ability to edit both the spatial and non-spatial data in the application through the mobile device, rather than having to edit the data directly in the enterprise geodatabase using ArcGIS for Desktop after field data collection is completed. A major benefit of using feature services is the data can be created, edited, and queried on the mobile device, and all of the information is written to the enterprise geodatabase automatically. Figure 14 depicts the dataflow process from the geodatabase to ArcServer and finally to the ArcGIS clients.

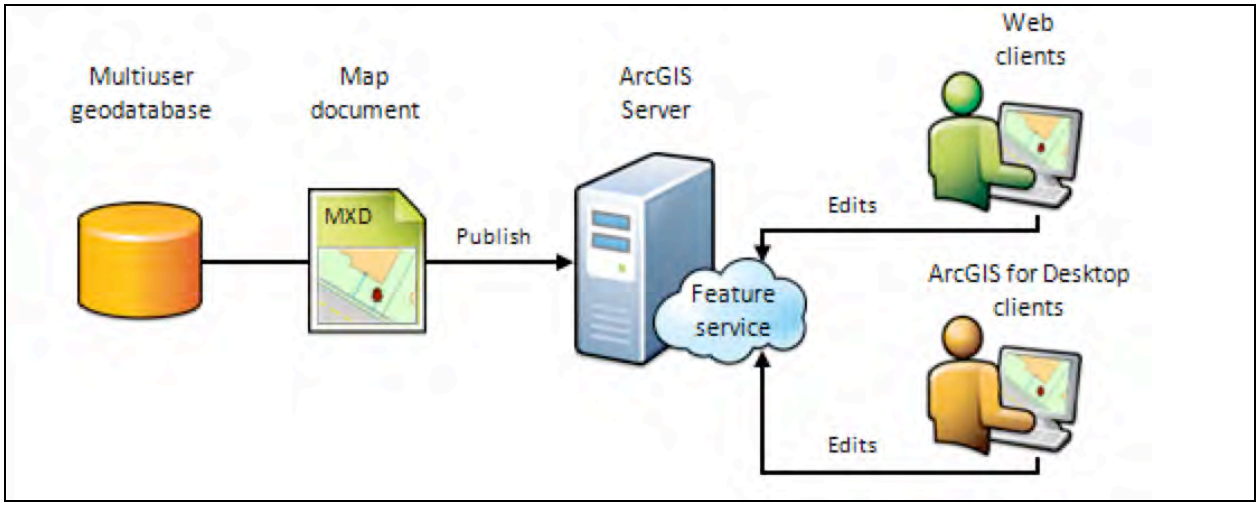


Figure 14 Feature Service Diagram (Esri 2016d)

Esri maintains a live streamgage feature service consisting of the USGS and NOAA network of streamgages (Esri Observation 2016). As previously stated, the streamgage feature service is used in the HWMDP application. Currently, the streamgage attributes, such as streamgage id, streamgage height, and streamgage flow, can be manually entered into the High_Water_Mark feature class via the HWMDP application. The HWMM application does not include this type of editing capability at this time but is explored as a future enhancement in Chapter 5. Figure 15 shows the feature service data integration with the data model to provide a visual of the data model integrated with the feature services.

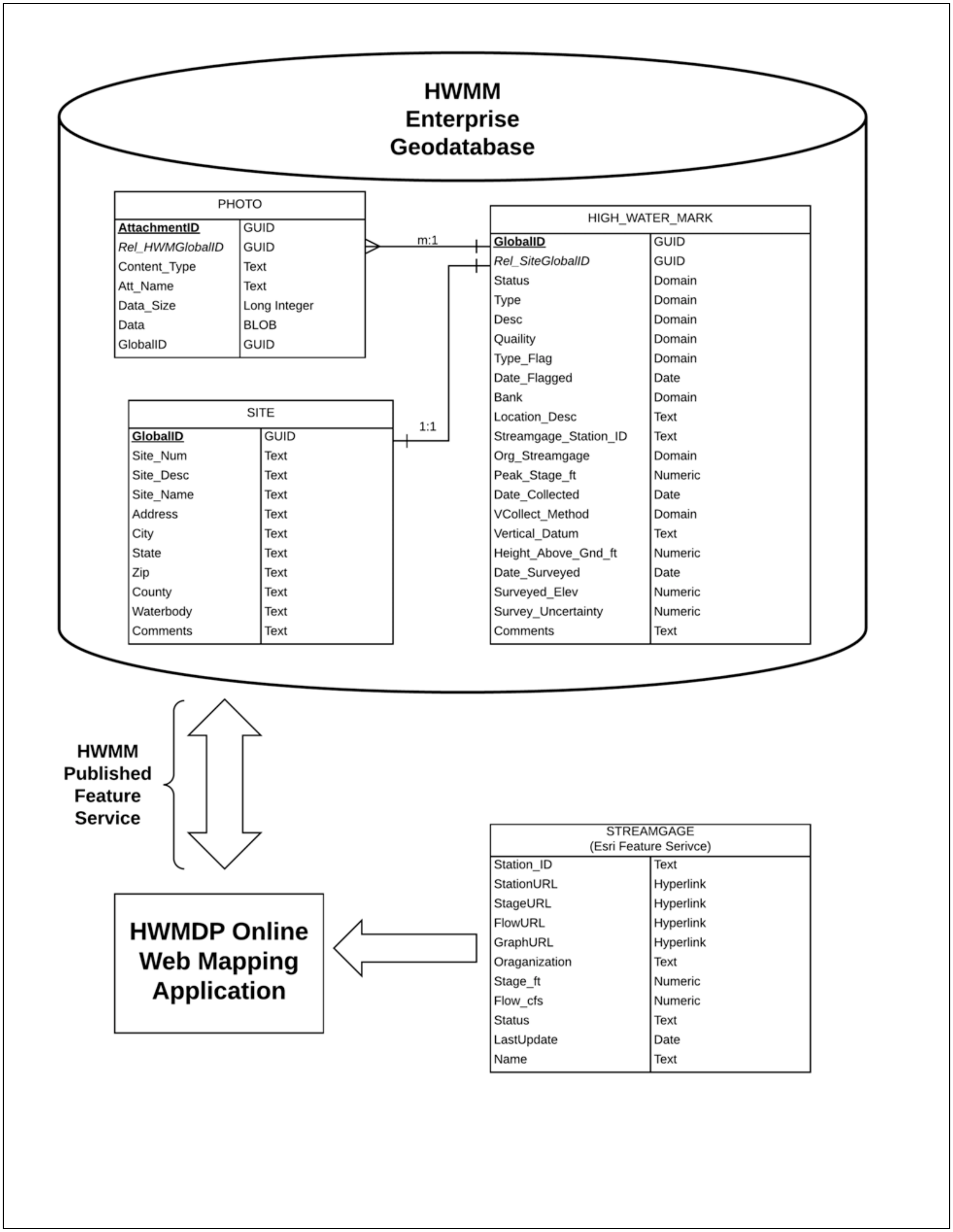


Figure 15 Feature Service Data Integration with Data Model

3.4 Application Development

Developing a mobile GIS data collection tool for HWMs was a significant contribution to the USACE, as this is the first mobile tool available for HWM data collection at the time of this writing. The mobile application uses a standardized HWM data repository based on the USGS's manual, "Identifying and Preserving High-Water Mark Data" (Koenig et al. 2016). The USGS manual presents the idea of using a standardized form for HWM data collection. This manual was used to build the feature class and tables for the geodatabase, therefore, providing a standardized repository for HWM data. The repository will provide historical flood information, which can be used to calibrate and validate hydraulic models.

In addition to the mobile data collection tool and the geodatabase repository, a feature service is used as a method for creating, editing, and querying the data via the Internet. The feature service is also used as input into an ArcGIS Online Web Map. Users can be given the option of editing and querying the feature data via the feature service within the online web map. Data is written to the feature services by users and updated in the geodatabase real-time. This means that as soon as points are submitted to the HWMM application, the same points can be seen in the HWMDP application. The two applications working synchronously is a huge advancement over the paper and pen method, significantly cutting down on the amount of time required to collect the data and then process it.

The following sections provide a thorough explanation of the development of the HWMM and HWMDP applications. Section 3.4.1 provides an overall programming description. This section is broken down further to describe in detail the data collection application and the online web map application.

3.4.1. Programming

A virtual machine (VM) housed at University of Southern California (USC) running Windows 2012 Server provides the development environment for this thesis project. Desktop for ArcGIS 10.4, ArcGIS Server 10.4, Collector for ArcGIS 10.4, and ArcGIS Online are the Esri tools used for development. The end products of the thesis project are a digital repository of HWM data (enterprise SQL Server geodatabase), a mobile GIS data collection application (HWMM) and an online web map application (HWMDP).

3.4.1.1. HWMM

Collector for ArcGIS was used to develop the HWMM data collection application. The enterprise geodatabase, feature service, and online web map provided the foundation for the data collection form in Collector for ArcGIS. The form uses the attributes from the feature services as the data fields for collection. Figure 16 is a screen capture of the HWMM application. On a mobile device, the application loads and zooms to the user's current location as displayed in Figure 16. The user clicks the "+," then, manually enters the information into the form. Figure 17 displays an example of a completed form with all data fields filled in.

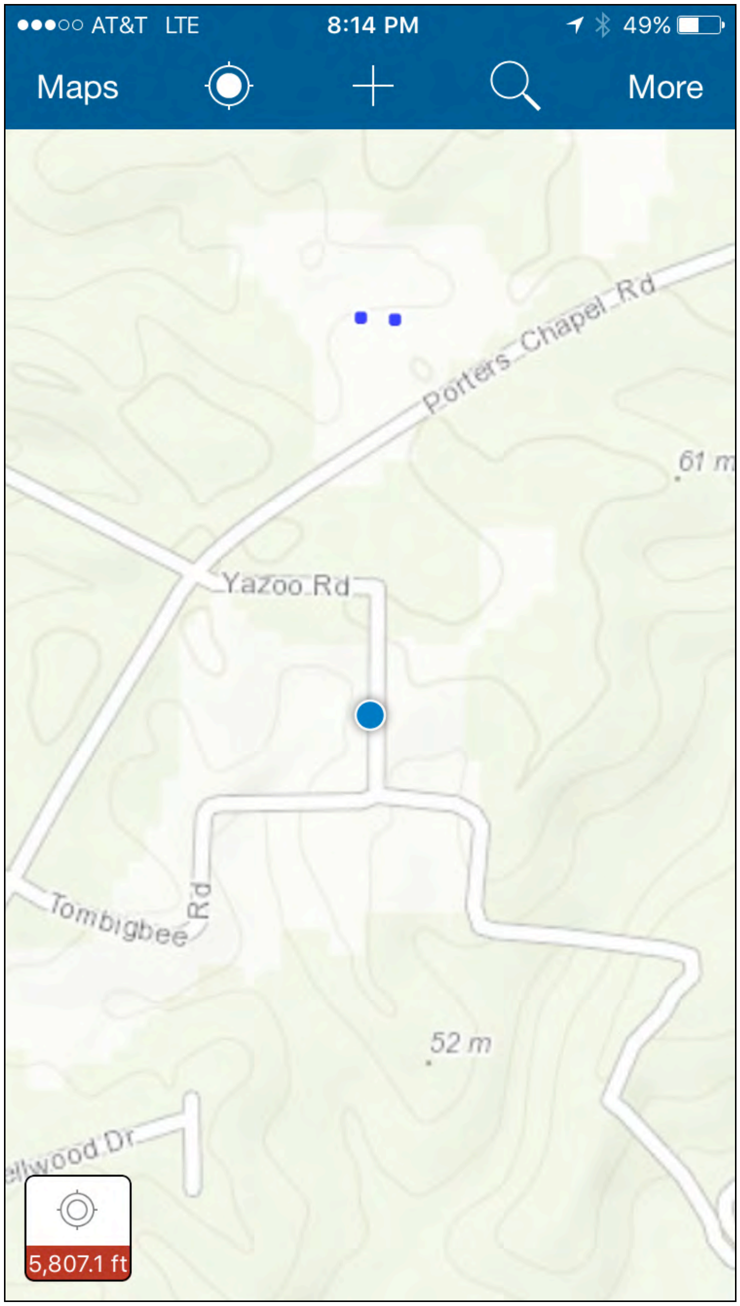


Figure 16 HWMM displaying User's Current Location

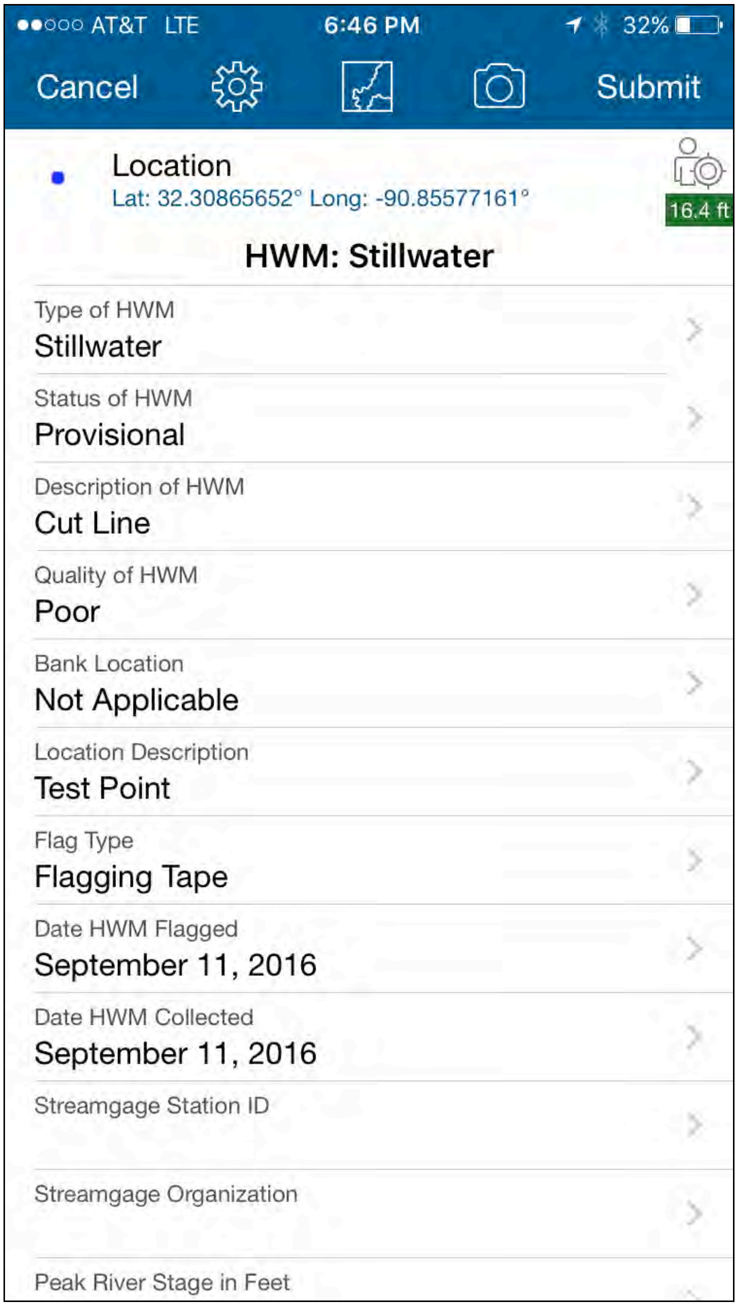


Figure 17 HWMM Form

3.4.1.2. HWMDP

The HWMDP is an ArcGIS Online web mapping application built using the HWMM web map, designed to be used with browsers on desktop computers. The HWMDP is intended to provide a common picture for users to view and download all the data collected in the field with the HWMM mobile app. The bowser-based web map also consumes a live feature service of streamgage data. Esri provides the live streamgage feed consisting of the USGS and NOAA streamgage network (Esri Observation 2016). The web map contains both feature services and thus both are included in the web mapping application, HWMDP. By providing both datasets in a single map, the engineers and emergency management personnel using the application are provided a common operating picture as shown in Figure 18.

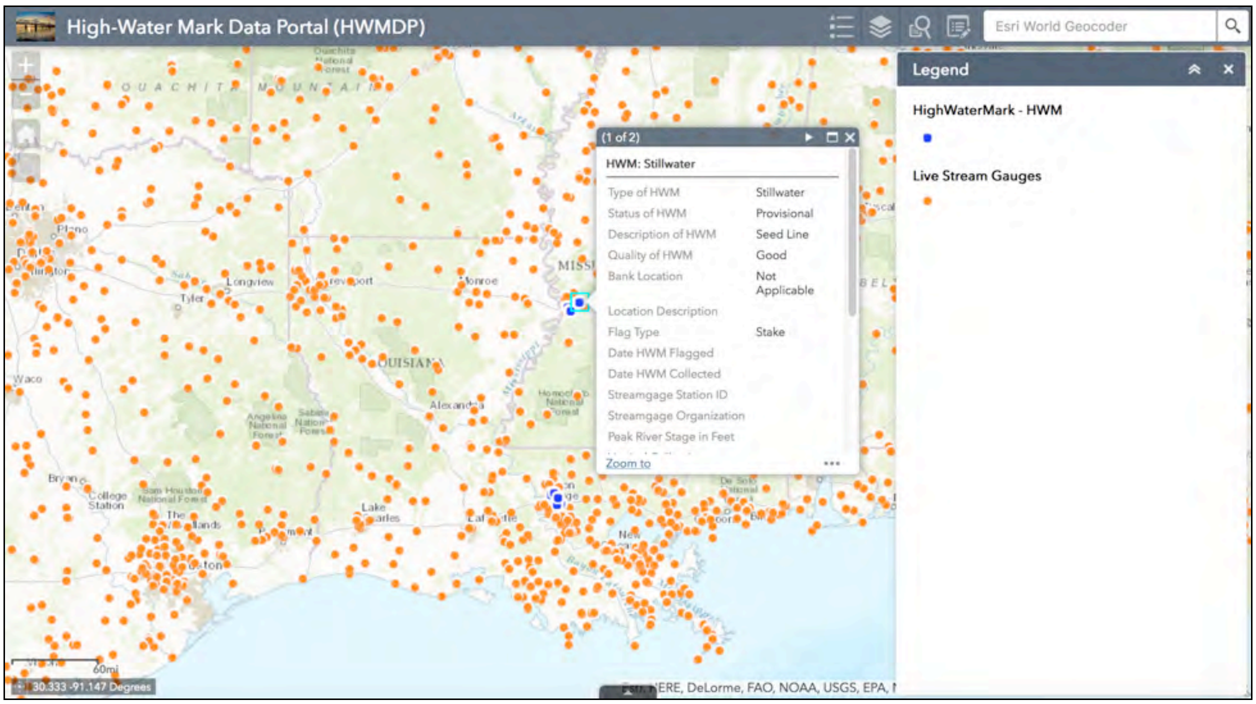


Figure 18 HWMDP ArcGIS Online Web Map

ArcGIS Online provides the ability to share web maps and feature services. Therefore, the maps and feature services created with ArcGIS Online for this project can also be leveraged in an ArcGIS application development environment such as ArcGIS Web AppBuilder. In this project, ArcGIS Web AppBuilder was used to customize the final desktop browser-based application, HWMDP, in order to include the streamgage query tool and the ability to download the data.

3.4.1.3. Data Download

The HWMDP application gives the user the ability to download the HWM data collected with the HWMM application as well as the streamgage data provided by Esri's live feature service (Esri Observation 2016). The user can download all the HWM data or apply a filter to download specific data. The data download tool is available when the user clicks on the down arrow at the bottom of the HWMDP application as shown in Figure 19. The attribute table containing all of the HWM feature data is available. Clicking the "Options" button allows the user the ability to export the data to Common-Separated Values (CSV) format. The user can import the dataset in ArcGIS ArcMap to view the data locally.

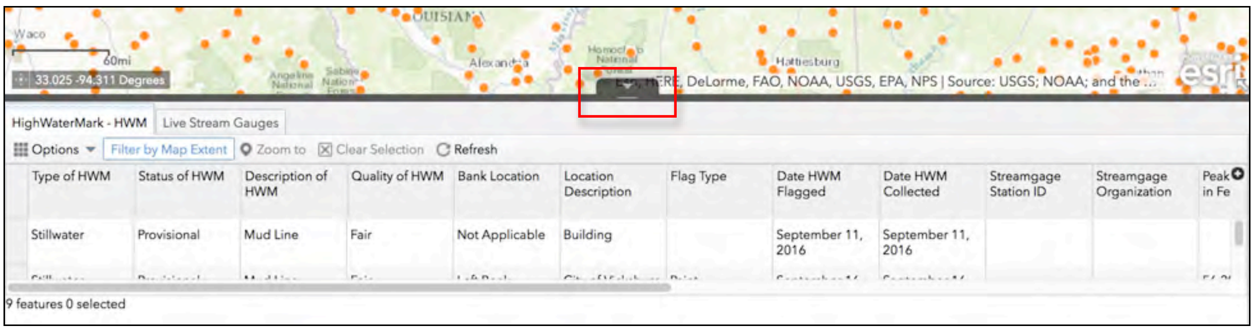


Figure 19 HWMDP Data Download Tool

3.4.2. Programming Challenges

The first programming challenge in the HWMDP development was including the ability to cross-reference the nearest streamgage to the HWMM point. The site table was created to provide a waterbody attribute that is used to determine the waterbody a given HWM is associated with. This information, in turn, is used to determine the nearest streamgage to the HWM. The ability to determine the nearest streamgage then provides a peak river stage that can be referenced to the HWM. The ability to completely automate this task without requiring input from the end user proved unsuccessful, due to the lack of direct access to the Collector for ArcGIS source code and the timeframe to complete the project.

Developing a streamgage query tool using Web AppBuilder circumvented the programming challenge. The query tool deploys a geoprocessing task in the form of a buffer around a HWM point in order to determine the nearest streamgage. When the streamgage query tool is executed, a 5-mile buffer is created around the HWM data point. A 5-mile distance was chosen based on the proximity of streamgages located in the MS River. The streamgages that match the query are highlighted. Figures 20 and 21 display the tools' functionality. While this method does not write the peak river stage of the water into the attribute field of the HWM feature, the user can still manually view the information as well as manually edit the HWM feature to add the peak river stage and streamgage data as needed.

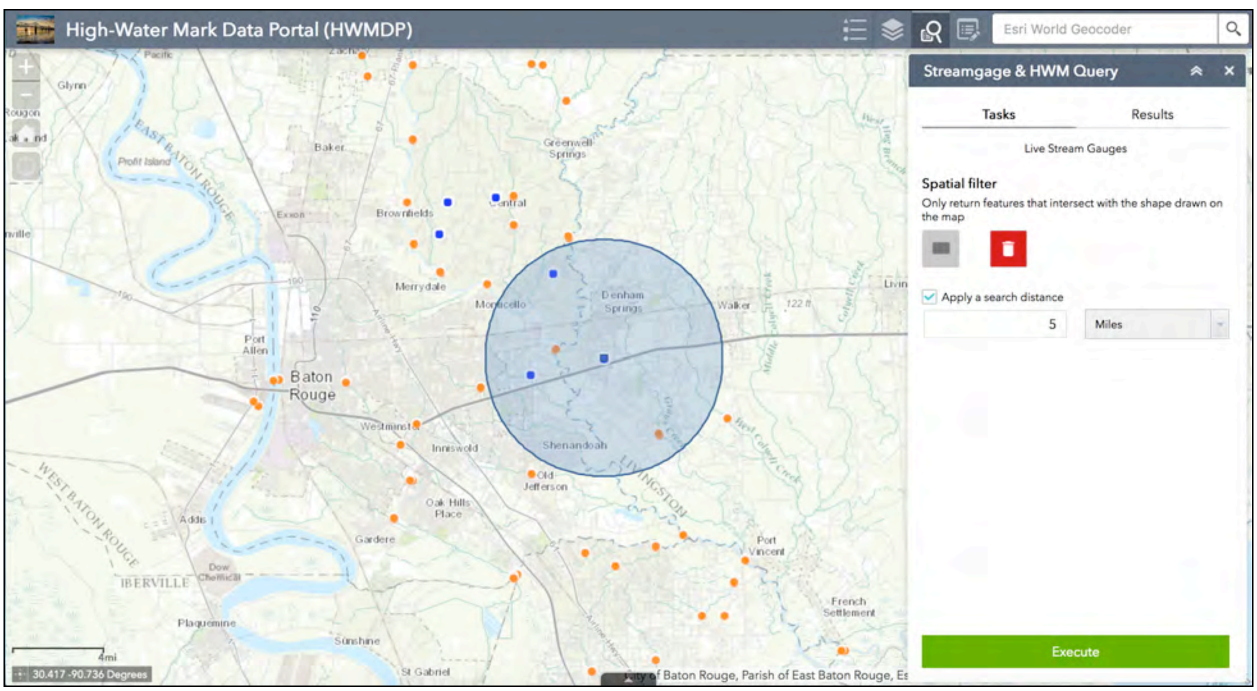


Figure 20 Streamgage and HWM Query

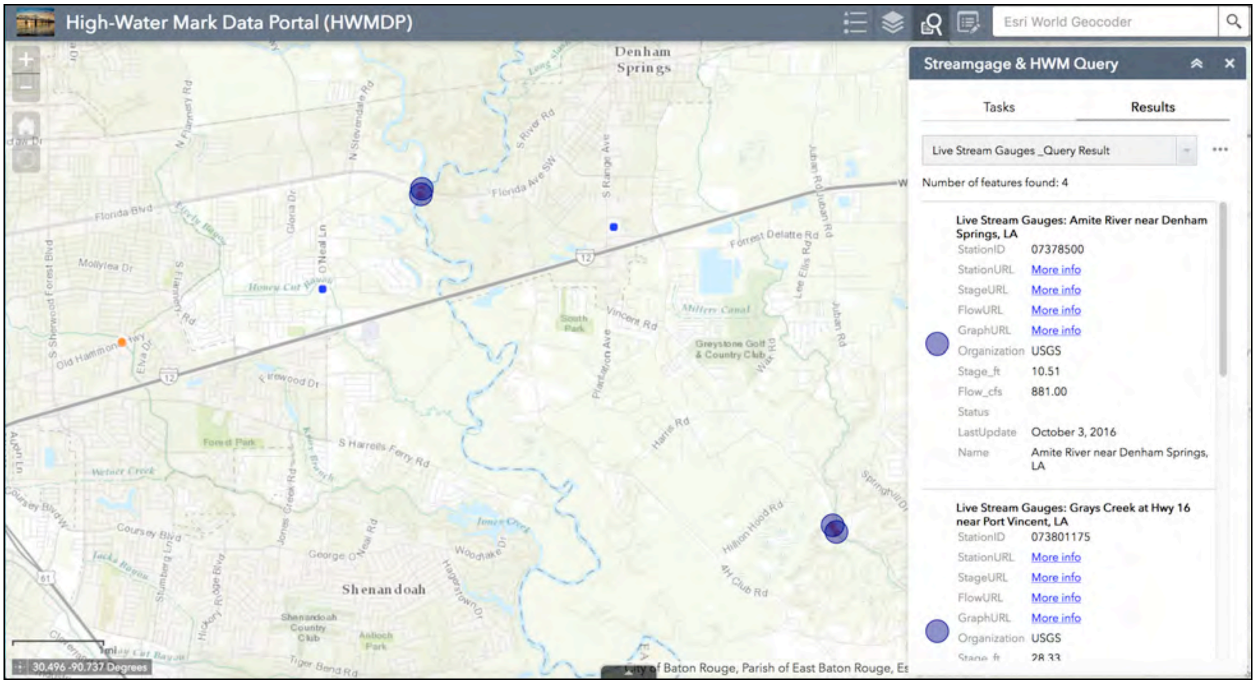


Figure 21 Example Results of Query Displaying Information on Nearest Streamgage

Another programming challenge was the ability to capture the accuracy of the HWMM user's mobile device into the enterprise geodatabase. The ability to capture the accuracy into the geodatabase record for the HWM point would allow data users to know the accuracy of each measured point. Esri does not provide a method to capture the mobile device accuracy information via the Collector for ArcGIS application. However, Esri does provide a workaround. The workaround includes creating a location tracking layer. The location tracking layer is intended to track the location of the Collector for ArcGIS application user (ESRI 2016b). In tracking the location of the user, an accuracy of the location is captured within the layer. Unfortunately, when the location tracking layer was created in the HWMM application, it did not function as intended. A point in the layer had to be created and the accuracy had to be manually entered. Further research and debugging must be performed to determine if the lack of functionality is a bug or developer error.

Chapter 4 Application Evaluation

This chapter provides an overview of the evaluation of the applications, HWMM and HWMDP. Section 4.1 describes the evolution of application design and how the design changed to overcome initial application development programming challenges. Section 4.2 describes the results of the field tests conducted as well as the audience selected to field test the applications. Section 4.3 provides an overview of the user survey form.

4.1 Evolution of Application Design

The initial enterprise geodatabase design for this thesis project changed throughout the project development process. The first change was to accommodate survey information in the form of multiple attributes such as survey date, survey uncertainty, survey elevation in feet, and vertical datum. An attribute was also added for the vertical collection method. This attribute is used as an indicator to describe what type of method was used to collect the height of the HWM. If the peak streamgage reading from neither the nearest streamgage nor the land survey is conducted, the design of the geodatabase allows for entry of a manual measurement of the HWM using a tape or other measuring device to determine the ground height of the HWM. Although measuring with a tape measure will not provide a true elevation, the height above ground provides the user a reference point for flooding, since the height of the ground can later be determined from a digital elevation model using the indirect method.

The relationship class between the HWM feature class and the Site table was modified from the original data model design as well. This was due to a limitation with Collector for ArcGIS as provided by Esri. The initial enterprise geodatabase design contained a 1:M relationship class between the Site table, which was the parent table, and the HWM feature class, which was the child table. The data model and thus geodatabase were designed to allow multiple

HWMs to reference one site since many HWMs are normally collected in a given flood event area or a single location. The Collector for ArcGIS application cannot interpret the geodatabase relationship since the parent is the non-graphic table and not a feature class. Therefore, the application presented the error message "No editable layers available." Per ArcGIS Blog article, "Related Tables – Exploring New Ways to Use Collector for ArcGIS," 1:1, 1:M, and M:1 relationships are supported by Collector for ArcGIS (Shaner 2015). Therefore, an Esri technical support ticket was submitted to determine if this was a bug in the Collector for ArcGIS application or a developer error. According to Esri Support Services, the 1:M relationship originating from a non-graphic table to a feature class is not supported by the Collector for ArcGIS application (Rashan W. 2016). In an effort to mitigate this geodatabase relationship limitation, the relationship class between the HWM feature class and Site table was changed to a 1:1 relationship class. Once this was modified in the geodatabase, the HWMM functioned properly, allowing the user to enter a point for the HWM feature as well as site information. Figure 22 displays the revised data model.

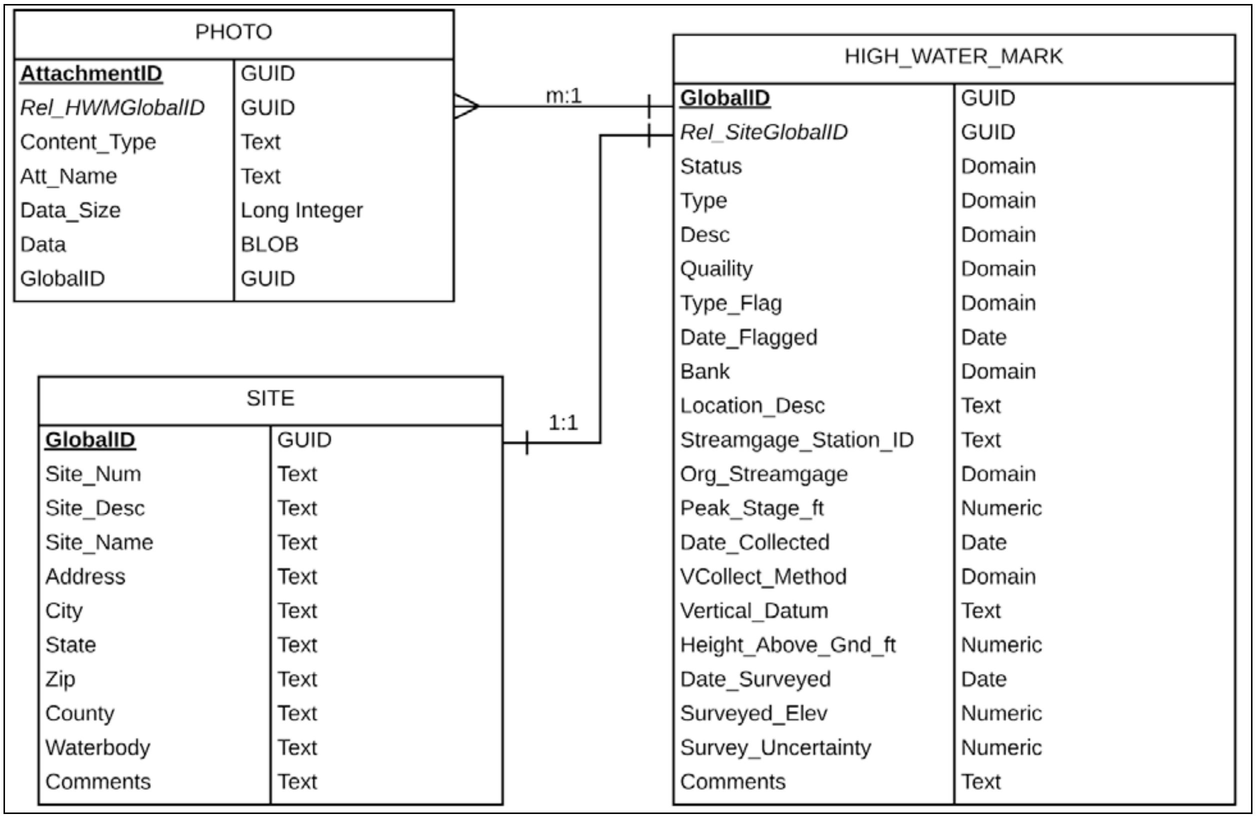


Figure 22 Revised Data Model

Changing the relationship class between the site and HWM feature class essentially de-normalized the geodatabase, meaning that duplicate site records can exist. A user will have to manually enter the Site information for each HWM that is collected. The user will not be allowed to choose from a previous site record due to 1:1 relationship class between the HWM feature class and Site table. Changing the relationship class also means there can be duplicate site records for a single Site with different primary keys. From a geodatabase perspective, this is allowed as long as two records do not have the same primary key. From a user perspective, there will be duplication of effort when entering Site-specific data in the field, and from a database administration perspective, multiple HWM records pertaining to the same Site will need to be managed. For example, if two users are collecting HWMs at the same Site, they both will enter information about the site location creating two records for the same Site.

4.2 Results of Field Tests

An initial field test was conduced in Baton Rouge, LA the weekend of August 26 – 28, 2016. Baton Rouge experienced historical flooding from excessive rainfall between August 12 and August 14, 2016. Many areas in East Baton Rouge Parish, Livingston Parish, and Ascension Parish flooded. After the floodwaters had receded, the author conducted a field test using the HWMM application. During the field test, it was determined that the user was not able to enter Site information, due to the previously described issue of the non-graphic Site table having a 1:many relationship to the HWM feature class (see Section 4.1). The field test was still conducted despite the issue. Six HWMs were collected during the field test, and the site information was hand written for documentation purposes. The limited number of HWMs collected was due to inclement weather conditions and the timeframe of data collection. Many homes and buildings did not have any HWMs remaining because of the perishable nature of the HWM and the amount of rainfall the area received after the floodwaters receded.

After the data model had been modified as described in Section 4.1, a second field test was conducted in Vicksburg, Mississippi (MS) on September 16, 2016. Vicksburg is located on the MS River and has experienced historical flooding over time. HWMs were captured on the floodwall in downtown Vicksburg along the MS River waterfront as well as around the ERDC. Two hydraulic engineers from the USACE Mississippi Valley Division and one emergency management personnel from ERDC field-tested the HWMM and HWMDP applications. A HWM collected during the Vicksburg, MS field test is shown in Figure 23.

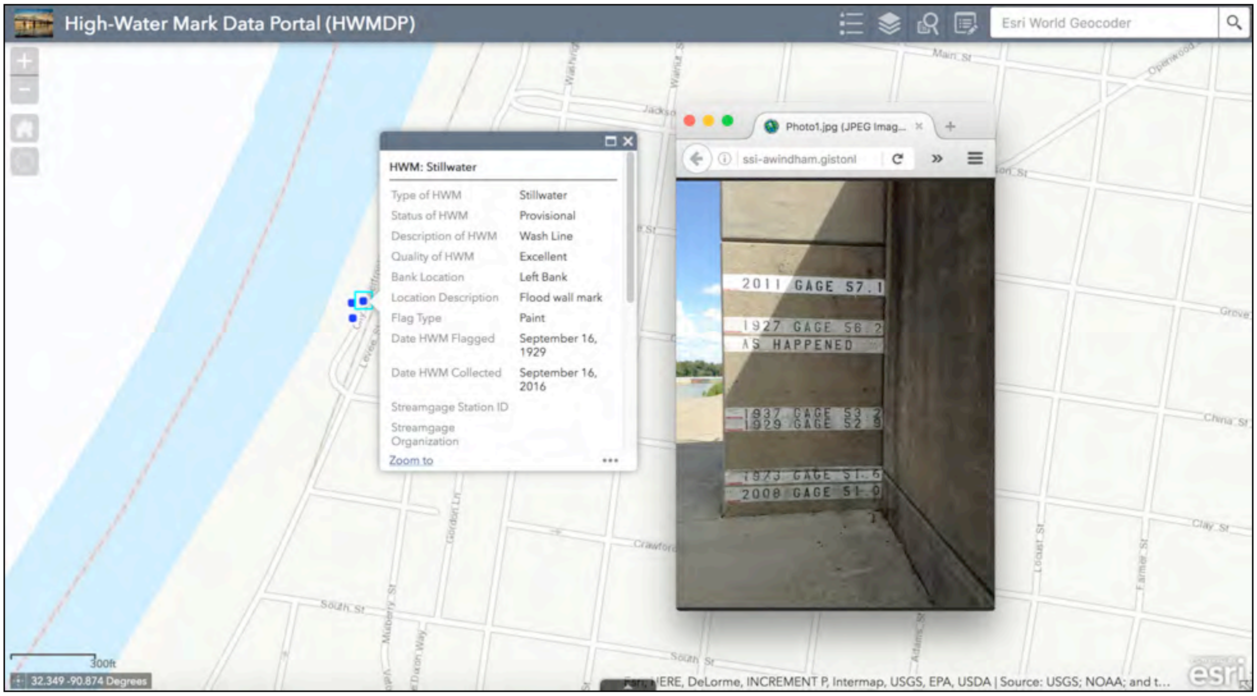


Figure 23 Data Collected during Vicksburg, MS Field Test

Prior to the field test in Vicksburg, the field testers were briefed on the overview of each application which included the objective of this thesis project, the differences between both applications, and instructions on how to use the applications. User guides for each application are found in Appendix D. Providing information prior to conducting the field test allowed the individuals to become familiar with the applications before going into the field. After the field test were complete, the users were asked to complete an online user survey to gather feedback. The results of the user survey are described in Section 4.3.1.

The mobile devices used during the field test included two Apple iPads and one iPhone. The USACE bought a few iPads to use for development and testing purposes. Unfortunately, other USACE personnel checked out the iPads during the time the HWMM field test was conducted. Therefore, personal iPad and iPhone devices were used. The two iPads used for the field test were an iPad Air and an iPad Mini. The iPhone used for the field test was an iPhone

6s. Despite different Apple iOS versions, all of these devices worked properly for field data collection using the HWMM application. A USACE Dell workstation was also used to test the HWMDP application by the two hydraulic engineers shortly after the field test were conducted. The HWMDP successfully provided a common operating picture of the HWM data collected in the field, therefore, it will be used in the office and not on a mobile device.

The HWMM application has a default accuracy of 30 feet set by the Collector for ArcGIS application. Accuracy is a global setting in the Collector for ArcGIS application, therefore, if accuracy is increased or decreased it is applied to all Collector for ArcGIS applications on the mobile device. 30 feet accuracy was used during the field test. The accuracy setting was deemed appropriate and not changed during the field test. Figure 24 shows the default accuracy set by the device using during the field test. If the user increases the accuracy so that the mobile device cannot determine the device's location, an error message will be displayed as depicted in Figure 25.

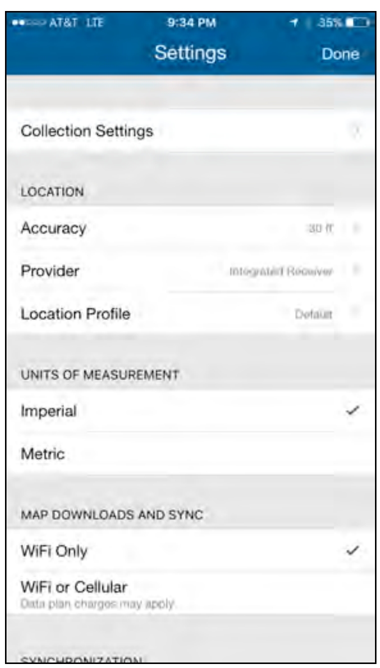


Figure 24 Default High-Water Mark Mobile Accuracy

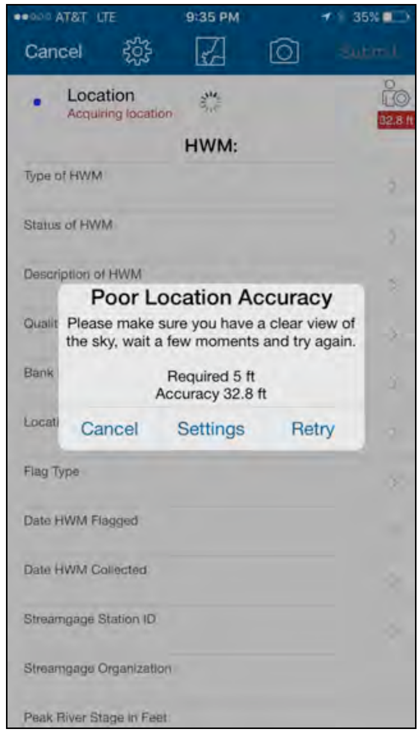


Figure 25 Collector for ArcGIS Accuracy Error

4.3 User Survey Form

A user survey was developed for this thesis project to ensure the HWMM and HWMDP met the objectives of the thesis outlined in Chapter 1. The user survey also provided an avenue for the user to provide feedback to the developer. This valuable information is used to gauge the overall user experience and interest in using the applications. The user survey form was developed using Google Forms. Google Forms was used because it is cost effective, easy to use, and requires no programming for the survey to work on mobile devices. At the time of this writing, the live survey form can be found at the following link: https://goo.gl/forms/65uTuFzbOC8WRJh82. The survey was sent via email to the three field tester on September 16, 2016, shortly after the Vicksburg, MS field test was conducted.

The survey is divided into four sections. Each section pertains to an occupational audience (hydraulic engineer, emergency management/operations personnel, surveyor, and other) as depicted in Figure 26. Each occupation may or may not use both applications, therefore, the survey questions change based upon the occupation chosen by the user.

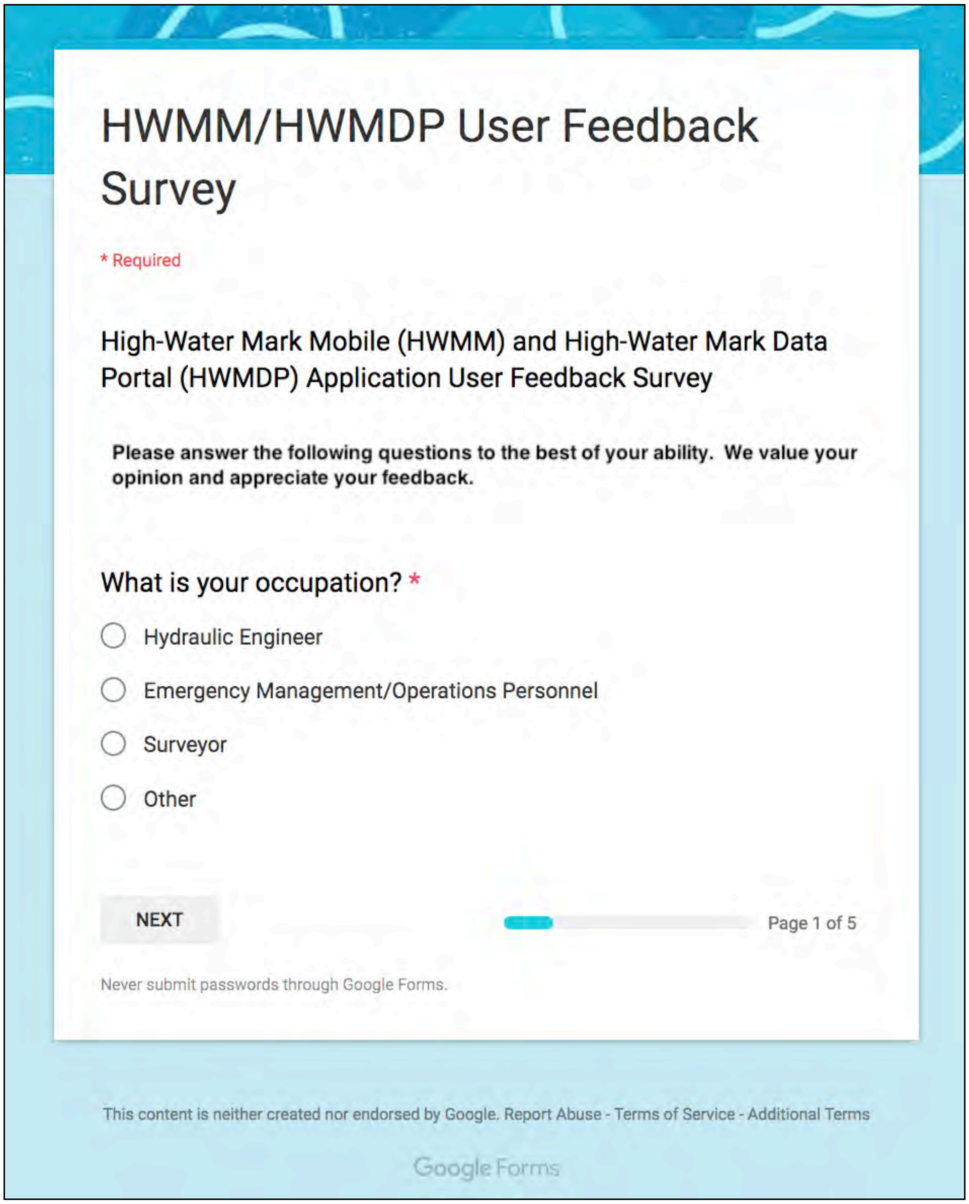


Figure 26 HWMM/HWMDP User Feedback Survey

The questions asked, and available answers are as follows:

Hydraulic Engineer Survey Questions:

Question: In regards to the HWMM application, how much time did the mobile application save you entering one HWM vs. the current pen/paper method? (The time includes collecting and processing the data)

Possible Answers: More than 20 minutes, 10 – 20 minutes, Less than 20 minutes

Question: How many HWM did you collect?

Possible Answers: More than 20, 15 – 19, 10 – 14, 5 – 9, Less than 5

Question: When using the HWMM application was it easy to create, edit or delete HWM points and enter Site information?

Possible Answers: Yes, No

Question: If you chose "No," can you please explain?

Possible Answers: (Free Form Text)

Question: When using the HWMDP application did you have any issues using the query tool to find the nearest streamgage?

Possible Answers: Yes, No

Question: If you chose "Yes," can you please explain?

Possible Answers: (Free Form Text)

Question: When using the HWMDP application, was it easy to edit and/or delete HWM points?

Possible Answers: Yes, No

Question: If you chose "No," can you please explain?

Possible Answers: (Free Form Text)

Question: Which feature of the HWMM/HWMDP did you find most useful?

Possible Answers: (Free Form Text)

Question: Please provide any suggestions, improvements, or feedback below.

Possible Answers: (Free Form Text)

Emergency Operations/Management Survey Questions:

Question: In regards to the HWMM application, how much time did the mobile application save you entering one HWM vs the current pen/paper method? (The time includes collecting and processing the data)

Possible Answers: More than 20 minutes, 10 – 20 minutes, Less than 20 minutes

Question: How many HWM did you collect?

Possible Answers: More than 20, 15 – 19, 10 – 14, 5 – 9, Less than 5

Question: When using the HWMM application was it easy to create, edit or delete HWM points and enter Site information?

Possible Answers: Yes, No

Question: If you chose "No," can you please explain?

Possible Answers: (Free Form Text)

Question: *Did you use the HWMDP application?*

Possible Answers: *Yes, No*

Question: Which feature of the HWMM/HWMDP did you find most useful?

Possible Answers: (Free Form Text)

Question: Please provide any suggestions, improvements, or feedback below.

Possible Answers: (Free Form Text)

Surveyor Survey Questions:

Question: Using the HWMM, were you able to easily locate the HWM that needed to be surveyed?

Possible Answers: Yes, No

Question: How many HWM were you able to update with survey information?

Possible Answers: More than 20, 15 – 19, 10 – 14, 5 – 9, Less than 5

Question: What type of survey information, if any, is missing from the HWM data collection form?

Possible Answers: (Free Form Text)

Question: Which feature of the HWMM did you find most useful?

Possible Answers: (Free Form Text)

Question: Please provide any suggestions, improvements, or feedback below.

Possible Answers: (Free Form Text)

Other Survey Questions:

Question: What is your occupation?

Possible Answers: (Free Form Text)

Question: Which application did you use?

Possible Answers: HWMM, HWMDP, Both

Question: Which feature of the HWMM/HWMDP did you find most useful?

Possible Answers: (Free Form Text)

Question: Please provide any suggestions, improvements, or feedback below.

Possible Answers: (Free Form Text)

4.3.1. Summary of Survey Results

The survey results for the HWMM/HWMDP User Feedback Survey provided valuable feedback on the usefulness of the applications and areas that need improvement. The first survey question results are shown in Figure 27. This question provides valuable information on the type of users most interested in the HWMM and HWMDP application. Although the applications were developed for a specific user group, in the future other users with differing occupations in the USGS or USACE could use the application.

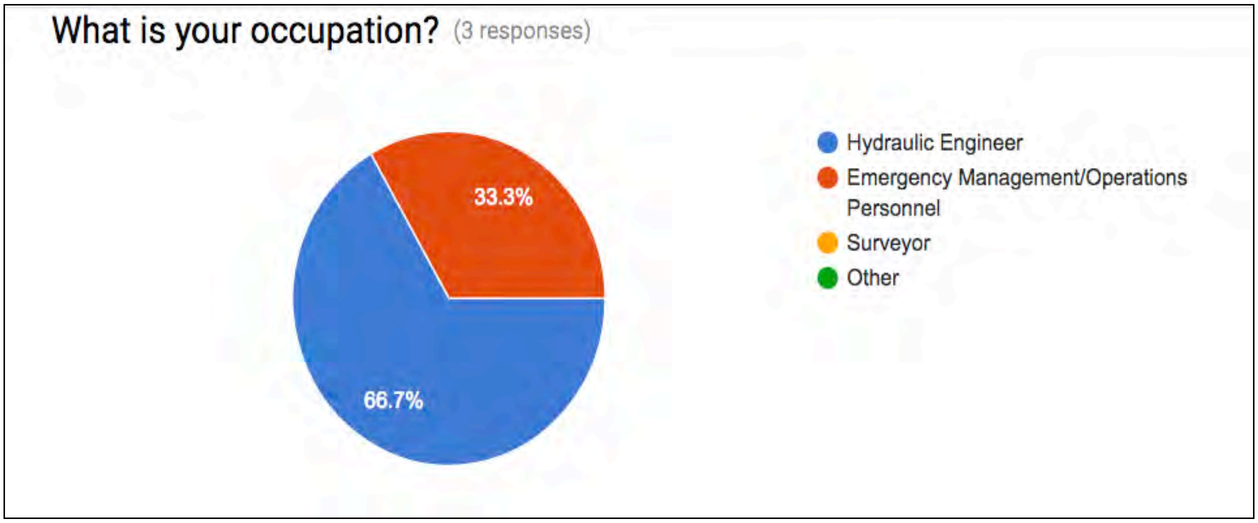


Figure 27 Summarize responses of first survey question

The survey also includes two questions common to all audiences. These questions are "Which feature of the HWMM/HWMDP did you find most useful?" and "Please provide any suggestions, improvements, or feedback below." Both of the answers to the questions are free form text. The responses to these questions are found in Table 1. These responses pertaining to improvements will be used to refine the applications in future development efforts.

Table 1 Survey Results

Question: Which feature of the HWMM/HWMDP did you find most useful?	
Hydraulic Engineer 1	"The ability to find the nearest streamgage."
Hydraulic Engineer 2	"Entering data on the iPad. Much better than using paper form."
Emergency Ops	"Zoom to location and pick list to enter information."
Question: Please provide any suggestions, improvements, or feedback below.	
Hydraulic Engineer 1	"This is a very useful tool that would save time and increase accuracy and productivity when collecting HWM."
Hydraulic Engineer 2	"Date for the collecting and flagging the HWM. I can chose a date, but can't clear it if I don't want to enter a date."
Emergency Ops	"Make more pick list for the site entry."

The overall feedback from the survey was positive and proved the two applications to be beneficial to the users surveyed. Based on the survey results, two out of three users stated that the HWMM application saved them more than 20 minutes collecting and processing one HWM compared to the current paper/pen method. These results are shown in Figure 28. All participants stated that the HWMM application provided an easy way to create, edit and delete HWM and site data. The hydraulic engineers who used the HWMDP application stated that they had no issue using the query tool to find the nearest streamgage. They also stated that the streamgage query tool provided a cost-effective and fast solution to the current survey method. Based on the user's feedback, the HWMM and HWMDP met the objectives of this thesis.

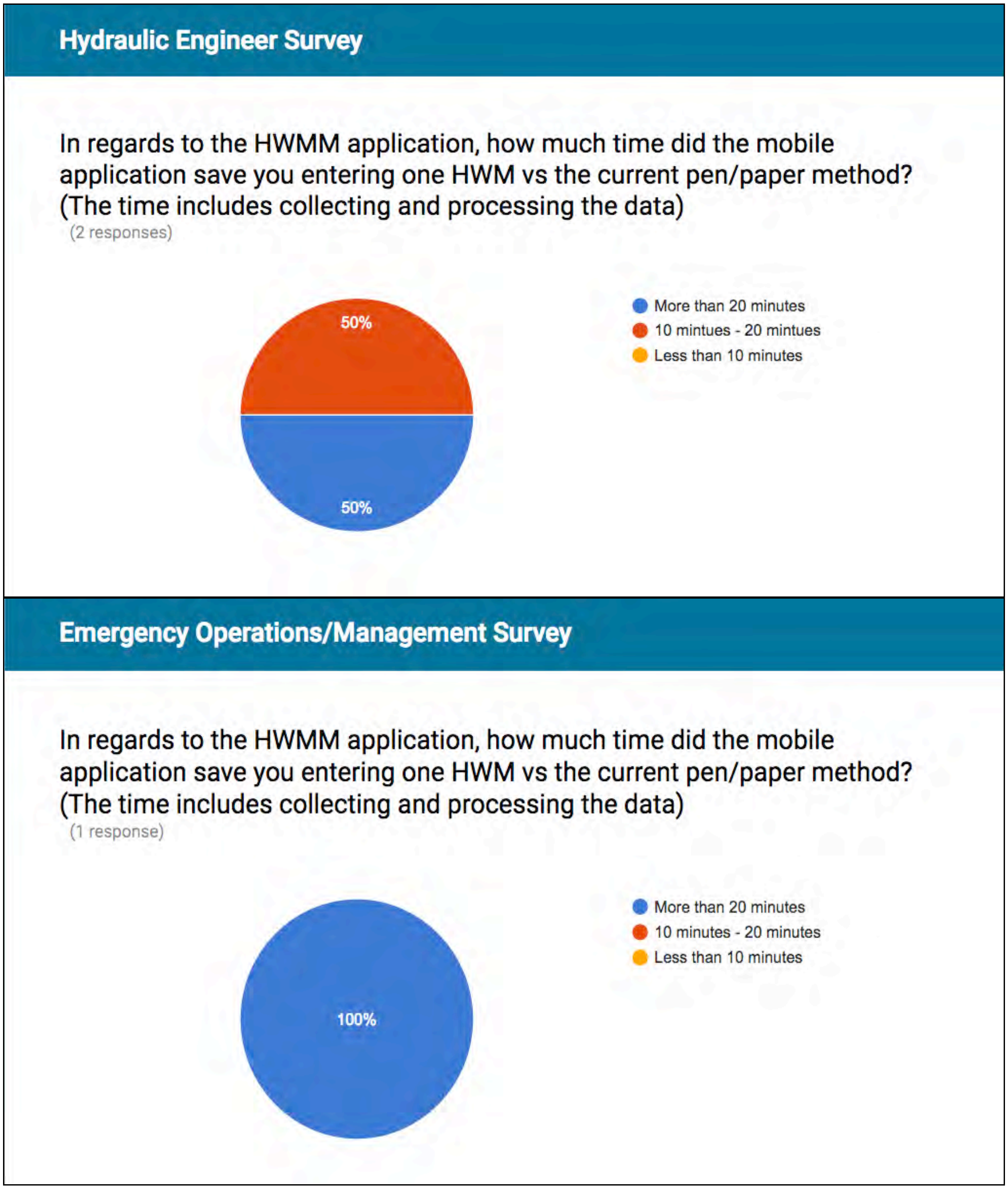


Figure 28 Summarized Responses to Question on Time Savings

Chapter 5 Conclusions

This chapter concludes this thesis by reviewing the results of this project and providing information on future enhancements and intended technology transfer activities. Section 5.1 describes the goals achieved with this thesis project by summarizing the outcomes of the original thesis project objectives. Section 5.2 discusses future improvements that may be made to the HWMM and HWPP applications. Lastly, Section 5.3 describes a transition path for the HWMM and HWMDP for implementation within the USACE.

5.1 Goals Achieved

The objectives of this thesis were: (1) to build a standardized digital repository to store HWM data, (2) to develop a mobile GIS data collection solution for collecting HWMs (HWMM), and (3) to provide an online common operating picture of HWM data and streamgage information (HWMDP). These objectives were accomplished through the development of the HWMM and HWMDP. A standardized digital repository, mobile application, and the ability to locate streamgages near HWMs were developed and tested.

The field test conducted in Baton Rouge and Vicksburg proved to be beneficial. The hydraulic engineers who tested the applications in the field were able to successfully collect HWM data, and then use the HWMDP to review the repository of HWM data. Specifically, they were able to view the HWMs captured after the flood event in Baton Rouge and reference these to a corresponding peak river stage. This allowed the engineers to evaluate the impacts caused by the corresponding river stage elsewhere in the Baton Rouge area.

In addition to field tests, feedback from user survey responses indicated that the applications also met the thesis objective outlined in Chapter 1. The HWMM application proved to be useful in collecting HWM data. The HWMDP provided the engineers a desktop, browser-based online interface, which makes the HWM data readily available at any the time. Any user with an ArcGIS Online Organization account can log into the HWMDP and view HWMs and streamgage data, providing a common operating picture to the user.

5.2 Future Improvements

There are a few future improvements that would be beneficial. The first improvement is incorporating more domain values into the Site table. Domain values provide a list of possible values for an attribute field. Providing the user a list of permissible values saves on the amount of time required for a user to enter data as well as the amount of time validating the attribute field.

The second improvement would be to programmatically incorporate the streamgage query into the HWMM application. The level of effort to incorporate this improvement would involve developing and incorporating the code into the HWMM application. Esri AppStudio could be used to develop the functionality. This improvement could take a significant amount of time to develop code and to test.

The third improvement would be to develop a method for normalizing the Site information/records in the enterprise geodatabase. Due to the relationship class change between the HWM feature class and Site table as described in Section 4.1, the Site table may contain multiple records for one site. A potential fix for this issue is to build a script to determine the duplicate records. The Find Identical ArcGIS tool can be used to find the duplicate records within the Site table. This improvement will need to be developed and tested to ensure it works properly.

The fourth improvement would be to expand upon the user survey to gather more feedback from the users. The first survey question for the Hydraulic Engineer and Emergency

Management/Operations Personnel ask the user how much time they saved entering one HWM using the HWMM application. This question can be expanded to ask exactly how much time was saved. Also, it would be useful to understand exactly what HWMM functionality saved them time (less prep work before data collection, collecting the HWM, taking the photo, associating the photo to the HWM, etc.).

The fifth improvement would be to automatically collect device accuracy in the enterprise geodatabase with each record. This improvement would include working with the Esri Collector for ArcGIS development team on the source code, if possible.

The final improvement would be to capture information on the user into the HWMM application. The user information could be captured when the user authenticates in ArcGIS Online to order to use the Collector for ArcGIS application. According to Esri Support Services, capturing the authenticated user in a feature class (geodatabase) Site record is not an available option in the Collector for ArcGIS application at this time (Daniel, Esri Support Services, October 18, 2016, e-mail message). Daniel recommended creating a domain list with all the HWMM users and linking the domain to an attribute within the HWM feature class. At the time of this writing, this is a feasible solution if the number of HWMM users is small. However this could potentially be an issue when the number of HWM users grow during an emergency situation unless sufficient prep time is available to customize the domain list to include all known users prior to the land survey to collect HWMs.

5.3 Technology Transfer

The USACE hydraulic engineers and emergency management/operations personnel served as mentors throughout the development of the HWMM and HWMDP applications. During the field test, the engineer expressed interest in having other members of their team test the HWMM and HWMDP. They were very excited about the potential to collect HWM in a timely and cost-effective manner. This section explores the process of transitioning the HWMM and HWMDP from the USC SSI's ArcGIS Online Organization account to the USACE. The USACE's ArcGIS Online instance is called the USACE Geospatial Platform.

It is anticipated that the enterprise geodatabase for the HWMM and HWMDP applications will be migrated first to the USACE within the fiscal year 2017. The USACE currently has numerous instances of SQL Server deployed within the USACE. The geodatabase would reside in the USACE Central Processing Center. Once migrated, accounts/users will need to be created. This will be performed in collaboration with a USACE database administrator.

The next step would be to rebuild and publish the feature service described in Chapter 3. The feature service is used to develop the web map, which is used by the Collector for ArcGIS application. Once the feature service is published, the web map can be created. The web map will consume the HWM feature service as well as the streamgage feature service. The web map will be used to develop the HWMM and the HWMDP applications. Once the HWMDP is created, the streamgage query tool will be developed. Finally, training and end-user testing should be conducted using the HWMM and HWMDP user guides (Appendix D). After a successful pilot and deployment, USACE hopes to partner with the USGS to associate the HWMM data with the USGS STN. The STN uses an ArcGIS Online Web Map for the STN Flood Event Viewer. Utilizing the same technology, HWMM can be easily integrated into the STN providing a common picture of HWM data between the agencies. It is also anticipated that the USACE IT personnel will assist with implementing the improvements to the applications described in Section 5.2 as soon as the technology transfer is completed.

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Appendix A: USACE Wilmington District HWM Data Collection Form

USACE High-Water Mark Data Collection Form

Event:

HWM Number:	Taken By:
HWM Elevation (ft, msl):	Date Taken:
Latitude:	Longitude:
HWM Type:	Outside or Inside:
USGS 7.5 minute Quadrangle Sheet:	
Nearest Town:	
Address:	
Remarks:	

US Army Corps of Engineers
Wilmington District

Appendix B: USGS Data Collection Form

USGS science for a changing world

U.S. DEPARTMENT OF THE INTERIOR
U.S. Geological Survey

HIGH WATER MARK FORM

Collection Team: HowDo FL
Event: SANDY
Date: 6/30/2015

Site Visit Summary

STATION ID: ____ STATION NAME: ____
SITE DESCRIPTION: ____ WATERBODY: ____
LAND OWNER: ____ PHONE: ____ EMAIL: ____
ADDRESS: ____
Party: RDH Start Time(UTC): 1200 End Time(UTC): 1400 Weather: Partly Cloudy, warm

Site Visit Tasks

☐ Flagging HWMs only ☑ Retrieving flagged HWMs ☑ Levels Ran ☑ Pictures Taken ☑ Site Sketch

Comments: Home-owner granted access for today only.

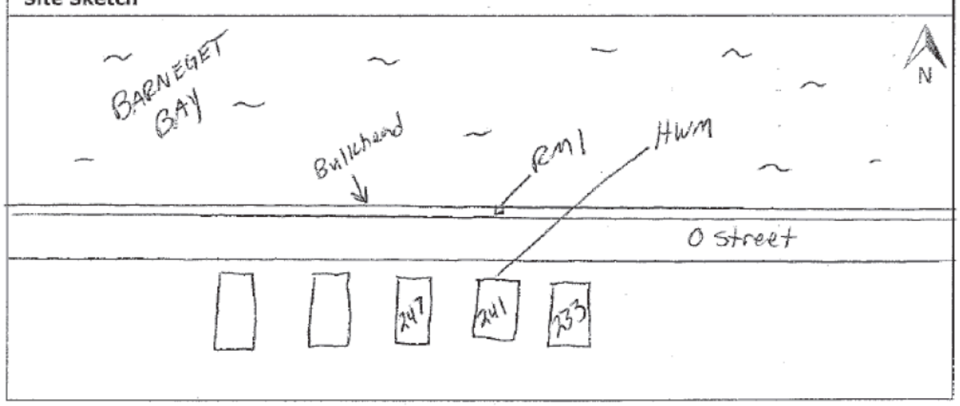
Datum

Horizontal datum: WGS 84 How was it determined: Handheld GPS Vertical datum: NAVD88
How was it determined: GNSS campaign performed and RM installed near home.
Type of "on-site" Objective Point used to determine HWM elevation(NGSBM, RM, RP): RM Elevation: 5.100 ft
Name(If NGSBM, PID/DES): RM1 Description: Chiseled sq. on seawall located
Comments: approx. 30 ft North of front door of home.

HIGH WATER MARK

HWM Elevation: 7.256 (+/-): 0.05 Rated: GOOD Environment (coastal, riverine): COASTAL
Type (runup, wave, stillwater): Stillwater Location (lat/long): N 39° 56′ 4.38″, W 074° 4′ 52.3″
How was elevation determined: GNSS campaign performed to establish RM1. Levels ran from RM1 to HWM.
Description (seed line, debris, mud): Seed line acrossed front face of home located ~3.2 ft above land surface.
Height above ground: 3.2 ft Date Flagged: N/A Date Surveyed: 6/30/2015
Comments: See associated station levels file, pictures, and GNSS campaign spreadsheet

Site Sketch



Appendix C: Data Dictionary

Feature Class Name	HighWaterMark				
Alias	HWM				
FC Definition	This feature class contains information about High-Water Marks				
Attribute Name	**Data Type**	**Char Length**	**Domain Table**	**Common Name**	**Definition**
OBJECTID				OBJECTID	A unique, not null integer field used to uniquely identify rows in tables. ESRI generated
GlobalID	Global ID			HWM Primary Key	Primary Key. A uniquely generated identifier for each HWM
HWM_Type	Text	15	HWM_Type	Type of HWM	The type of HWM
Status	Text	15	HWM_Status	Status of HWM	The status of the HWM
Description	Text	20	HWM_Desc	Description of HWM	The description of the HWM
Quality	Text	15	HWM_Quality	Quality of HWM	The quality of the HWM
Bank	Text	20	Bank	Bank Location	The bank location of the HWM
Loc_Desc	Text	100		Location Description	The location description of where the HWM was found
Flag_Type	Text	20	Flag_Type	Flag Type	The type of flag used
Date_Flagged	Date			Date HWM Flagged	The date the HWM was flagged
Date_Collected	Date			Date HWM Collected	The date the HWM data was collected
Streamgage_Stn_ID	Text	25		Streamgage Station ID	The unique identifier for the Streamgage
Streamgage_Org	Text	50	Streamgage_Org	Streamgage Organization	The organization responsible for the streamgage
Peak_Stage_FT	Double			Peak River Stage in Feet	The peak river stage in feet that caused the HWM
VCollect_Method	Text	25	VCollect_Mthd	Vertical Collection Method	The vertical collection method used to determine the height of the HWM
Vertical_Datum	Text	75		Vertical Datum	The vertical datum used for the survey or vertical collection method
Height_Above_Gnd_FT	Double			Ground Height in Feet	The ground height of the HWM when measured with a tape measure
Survey_Date	Date			Survey Date	The date the HWM was surveyed
Surveyed_Elev	Double			Surveyed Elevation	The elevation of the HWM survey
Survey_Uncertainty	Double			Survey Uncertainty	The survey uncertainty
Notes	Text	150		Notes	A description or other unique information concerning the HWM, limited to 150 characters
Relationship(s):					
This table contains a 1:1 relationship with the Site table and a 1:M relationship to the Photos table					

Table Name	SITE				
Alias	Site				
Table Definition	The site description of where the HWM was collected/found				
Attribute Name	**Data Type**	**Char Length**	**Domain Table**	**Common Name**	**Definition**
OBJECTID	Object ID			OBJECTID	A unique, not null integer field used to uniquely identify rows in tables. ESRI generated
GlobalID	Global ID			Site Primary Key	Primary Key. A uniquely generated identifier for each Site
REL_HWMGLOBALID	GUID			HWM Foreign Key	Foreign Key to join HWM to the Site table
Site_Number	Text	25		Site Number	The unique identifier for the site
Site_Name	Text	50		Site Name	The common name of the Site
Site_Desc	Text	150		Site Description	A description or other unique information concerning the site, limited to 150 characters
Address	Text	100		Address	The address of the site
City	Text	60		City	The city the site is located in
State	Text	50		State	The state the site is located in
Zip	Text	5		Zip Code	The zip code the site is located in
County	Text	50		County	The county the site is located in
WaterBody	Text	150		Water Body	The nearest water body to the site
Relationship(s):					
This table contains a 1:1 relationship with the HWM table					

Table Name	HighWaterMark_ATTACH				
Alias	Photo				
Table Definition	The attachment table to contain the photo's of the HWMs				
Attribute Name	**Data Type**	**Char Length**	**Domain Table**	**Common Name**	**Definition**
AttachmentID	OBJECTID			Attachment ID	A unique, not null integer field used to uniquely identify rows in tables. ESRI generated
GLOBALID	Global ID			Photo Primary Key	Primary Key. A uniquely generated identifier for each Photo
REL_GLOBALID	Guid			HWM Foreign Key	Foreign Key to join HWM to the Photo table
Content_Type	Text	150		Content Type	The type of content - Photo
Att_Name	Text	250		Attachment Name	The name of the photo
Data_Size	Long Integer			Data Size	The size of the photo
Data	Blob			Data	The photo attachment
Relationship(s):					
This table contains a 1:M relationship with the HWM table					

Domains		
Table Name	**Code Value**	**Description**
Bank		
	Left	Left Bank
	Right	Right Bank
	N/A	Not Applicable
Flag_Type		
	ST	Stake
	NL	Nail
	FT	Flagging Tape
	WF	Wire Flag
	USGS_MT	USGS Marking Tabs
	PT	Paint
	PIM	Permanent Ink Marker
	CM	Chiseled Mark
	TP	Tape
HWM_Desc		
	SL	Seed Line
	DL	Debris Line
	ML	Mud Line
	IR	Ice Ring
	CL	Cut Line
	WL	Wash Line
HWM_Quality		
	0.05	Excellent
	0.1	Good
	0.2	Fair
	0.4	Poor
	>0.4	Very Poor
HWM_Status		
	PV	Provisional
	AP	Approved
HWM_Type		
	RU	Runup
	WV	Wave
	SW	Stillwater
Streamgage_Org		
	NOAA	National Oceanic and Atmospheric Administration
	USGS	United States Geological Survey
VCollect_Mthd		
	HL	Hand Level
	LG	Level Gun
	RT-GNSS	RT-GNSS
	Static-GNSS	Static GNSS
	Tape	Tape Measure
	GPS	Handheld GPS
	TS	Total Station

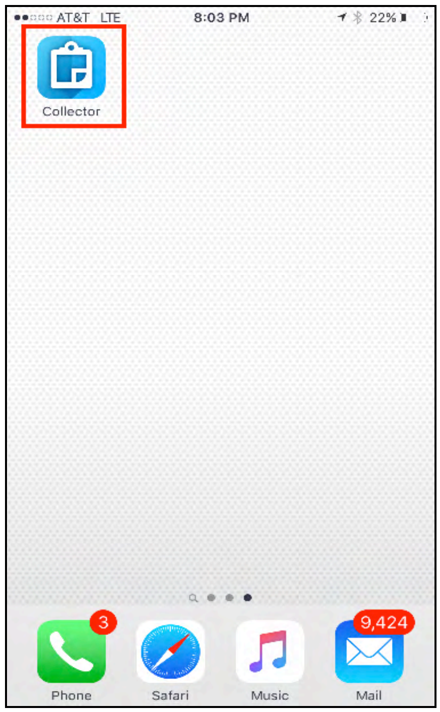
Appendix D: User Guides

High-Water Mark Mobile (HWMM) Application User Guide

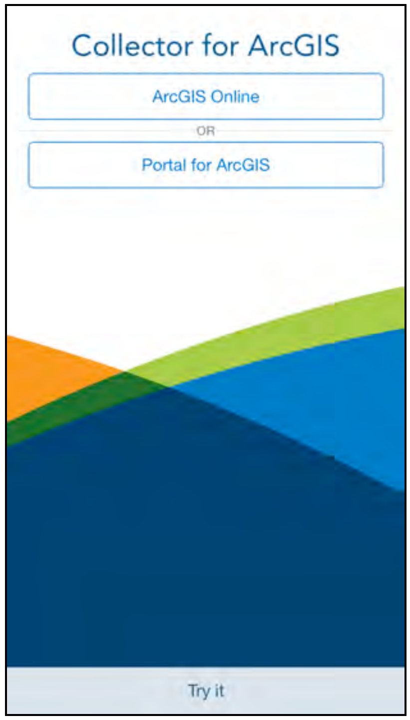
The High-Water Mark Mobile (HWMM) application is used to enter high-water mark data. The HWMM application is compatible with the iOS platform. The application uses Collector for ArcGIS, which requires an ArcGIS Online account.

1. If not already installed, install Collector for ArcGIS from the App Store.

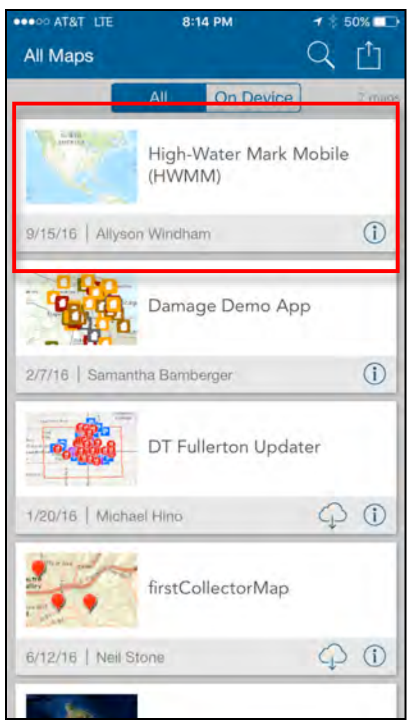
2. Double click the Collector for ArcGIS application to start the application:



3. Log into the application by clicking on the appropriate account and enter the user name and password:

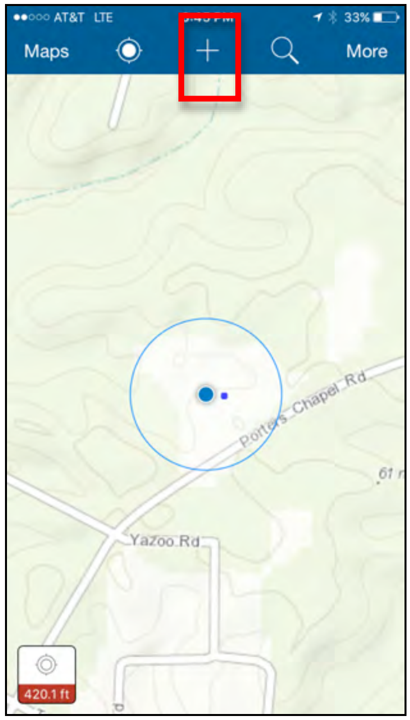


4. Click the High-Water Mark Data Collection to launch the app:

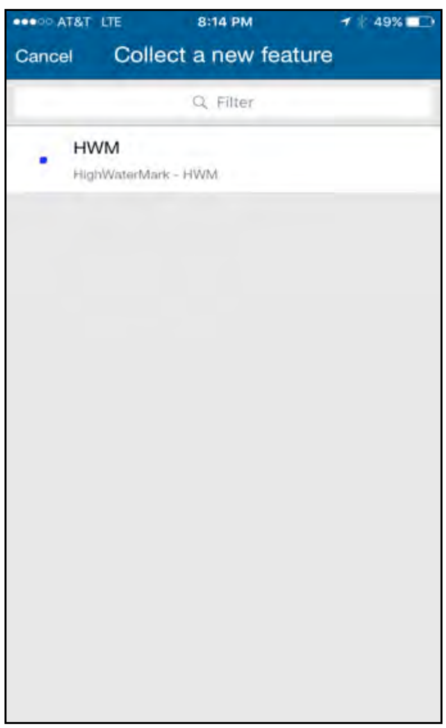


5. The application will load the user's current location.

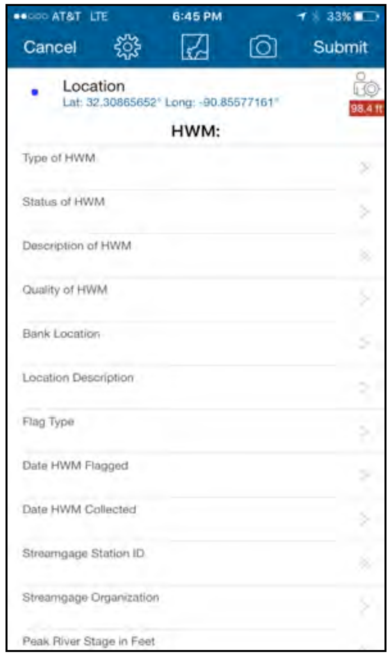
6. Click the plus sign at the top of the application if using an iPhone. Click the plus sign on the right side if using an iPad:



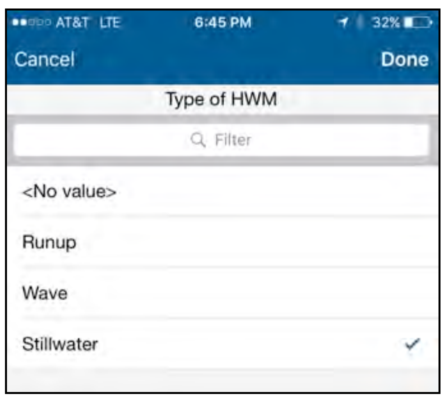
7. Click on HWM to start collecting the data:



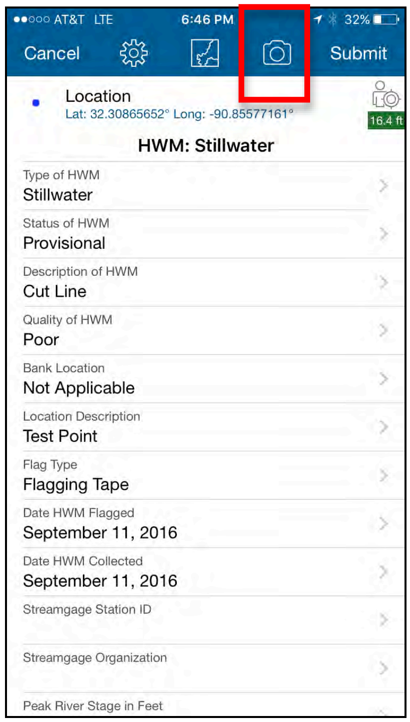
8. Enter the information listed in the data entry form:



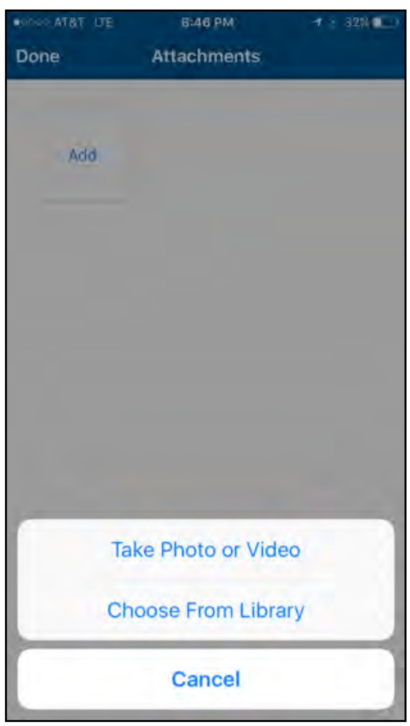
***Multiple fields have a list of predefined data to choose from:



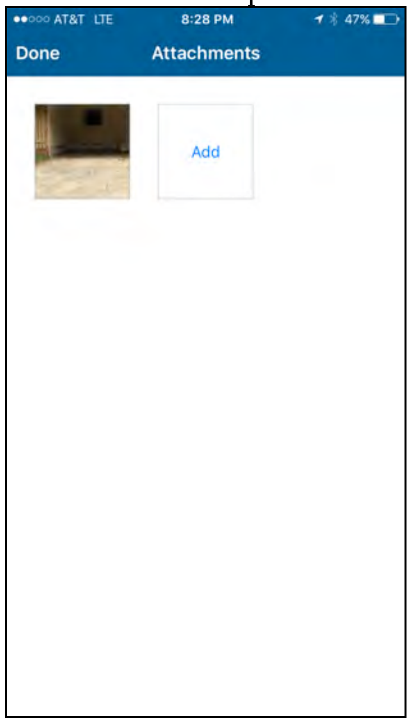
9. Once all the data has been entered, click on the camera icon:



10. Click Add – the camera options display. Choose either “Take Photo or Video” or “Choose From Library”



11. Click Done once the photo has been taken and uploaded:

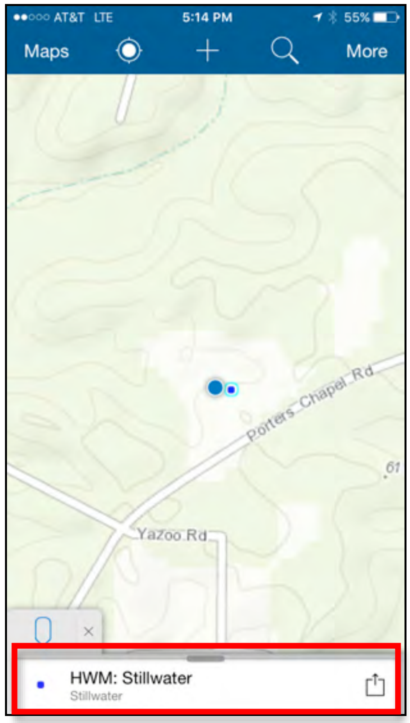


12. Click the submit button at the top of the form to submit the HWM:

13. Continue to enter a new HWM, enter Site data (Continue to Step 14) or Exit the Application (Continue to Step 20).

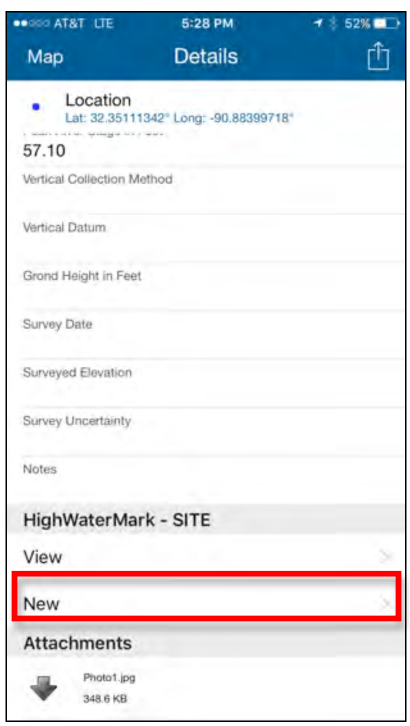
14. To enter Site data, click on the HWM point on the map.

15. Click the HWM:XXXX at the bottom of the map. The HWM form will open:

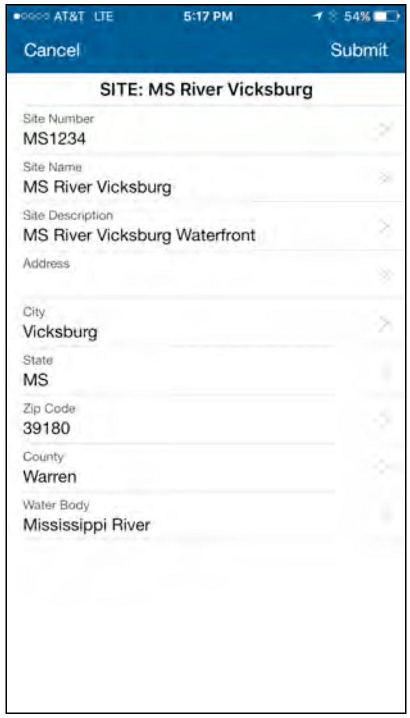


16. Scroll to the bottom of the HWM form.

17. Click New:

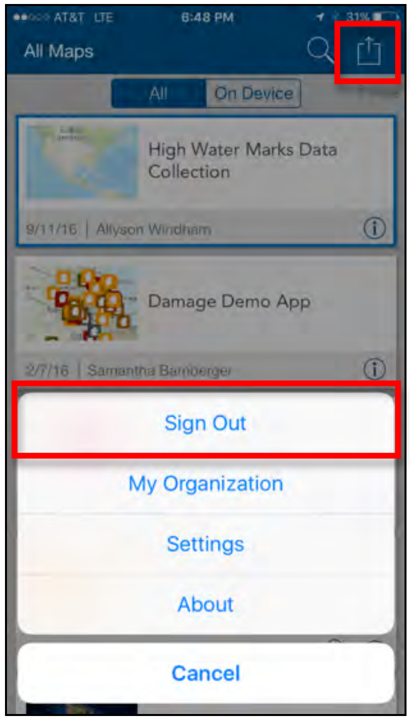


18. Enter the site information:



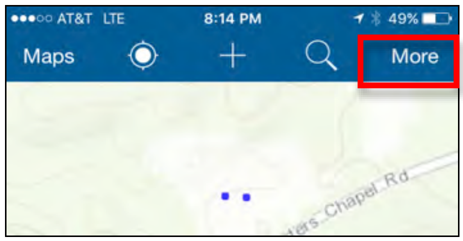
19. Click the Submit Button

20. Exit the application by clicking the Maps button to return to the homepage of the app. Then click on the exit button and choose the "Sign Out" option.

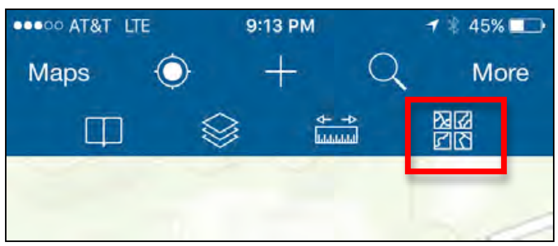

AT&T LTE
6:48 PM
31%
All Maps
All
On Device
High Water Marks Data Collection
9/11/16 | Allyson Windham
Damage Demo App
2/7/16 | Samantha Bamberger
Sign Out
My Organization
Settings
About
Cancel

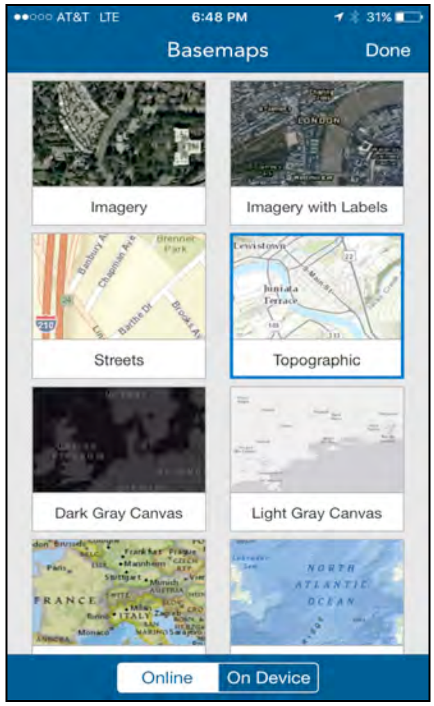
Additional Functionality of the HWMM Application

Additional functionality is available by clicking the **More** option on an iPhone. If using an iPad these features are listed on the main toolbar:

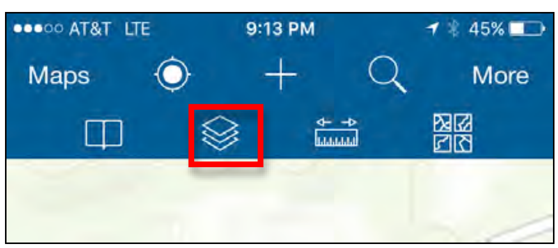


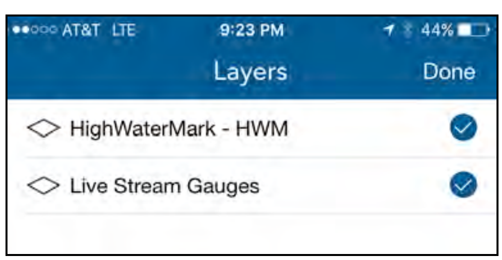
Basemap Option



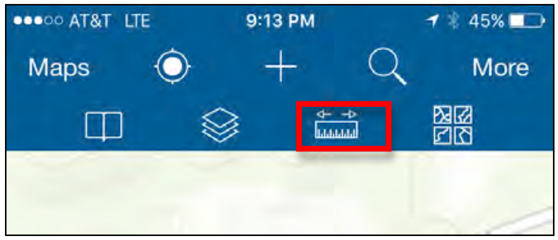

AT&T LTE
6:48 PM
31%
Basemaps
Done
Imagery
Imagery with Labels
Streets
Topographic
Dark Gray Canvas
Light Gray Canvas
Online
On Device

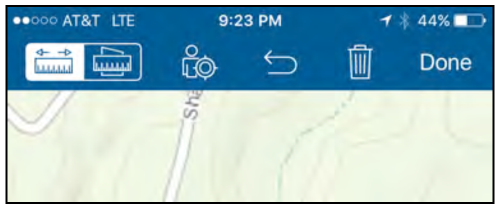
Layers


AT&T LTE
9:13 PM
45%
Maps
More

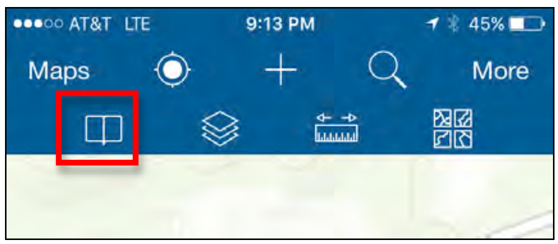

AT&T LTE
9:23 PM
44%
Layers
Done
HighWaterMark - HWM
Live Stream Gauges

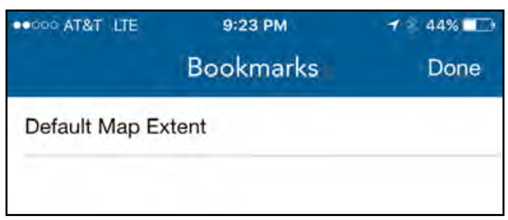
Measurement





Bookmarks



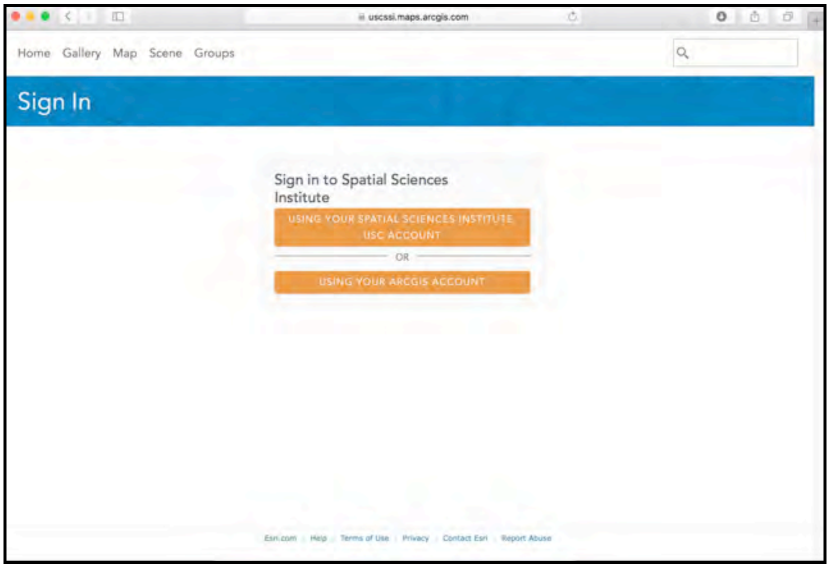


High-Water Mark Data Portal (HWMDP) Application User Guide

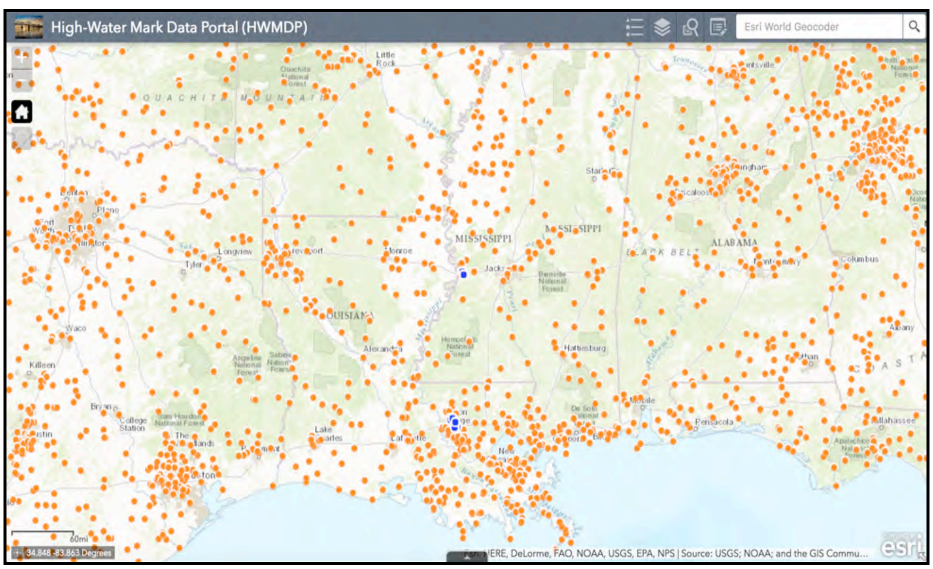
The High-Water Mark Data Portal (HWMDP) application is used to run the streamgage query tool, edit, or delete HWM points collected by the HWMM. The HWMDP is an online web application that requires an ArcGIS Online account. It provides a common operating picture of all HWM points and Streamgages.

1. Open a web browser and navigate to:
   http://uscssi.maps.arcgis.com/apps/webappviewer/index.html?id=e995422ae96e4987ad566d0ae0cf7780

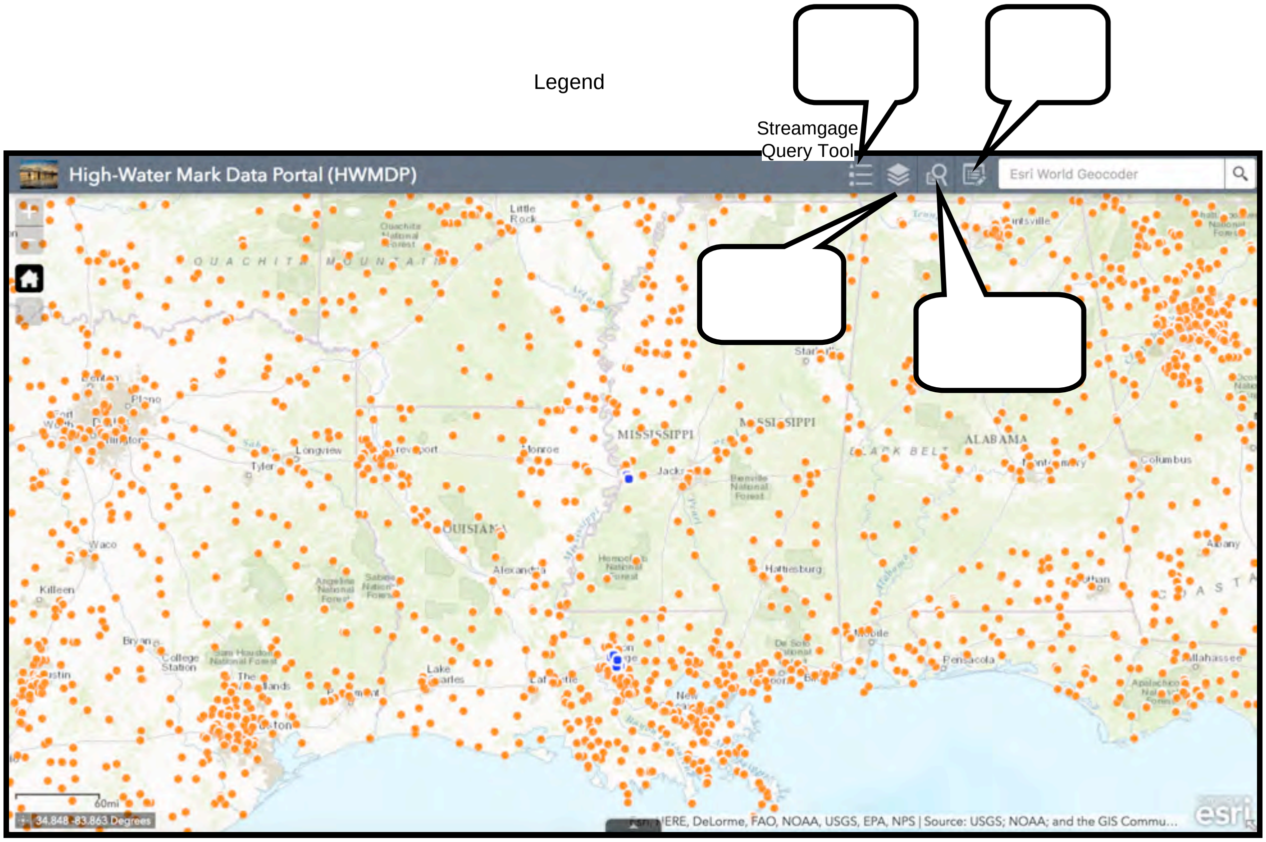
2. Sign in using an ArcGIS Online Account:



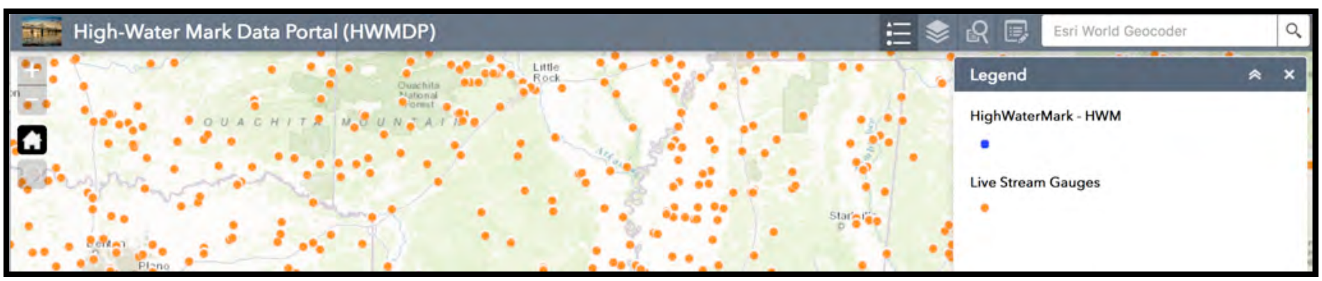
3. The HWMDP application opens:



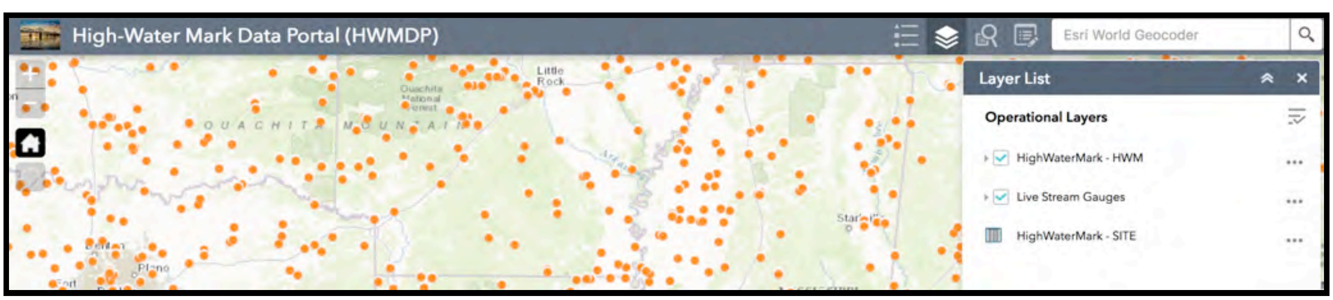
❖ HWMDP has various tools available:



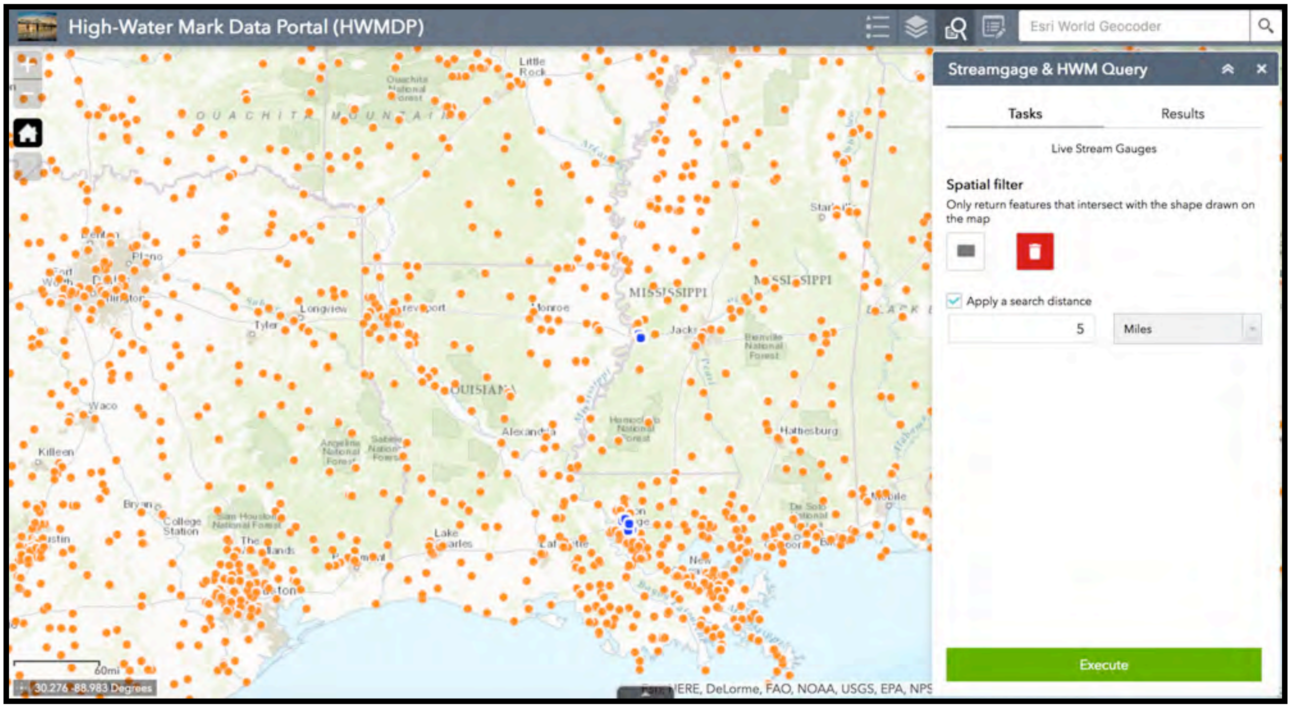
❖ Legend – Displays symbology and description of layers in the map:



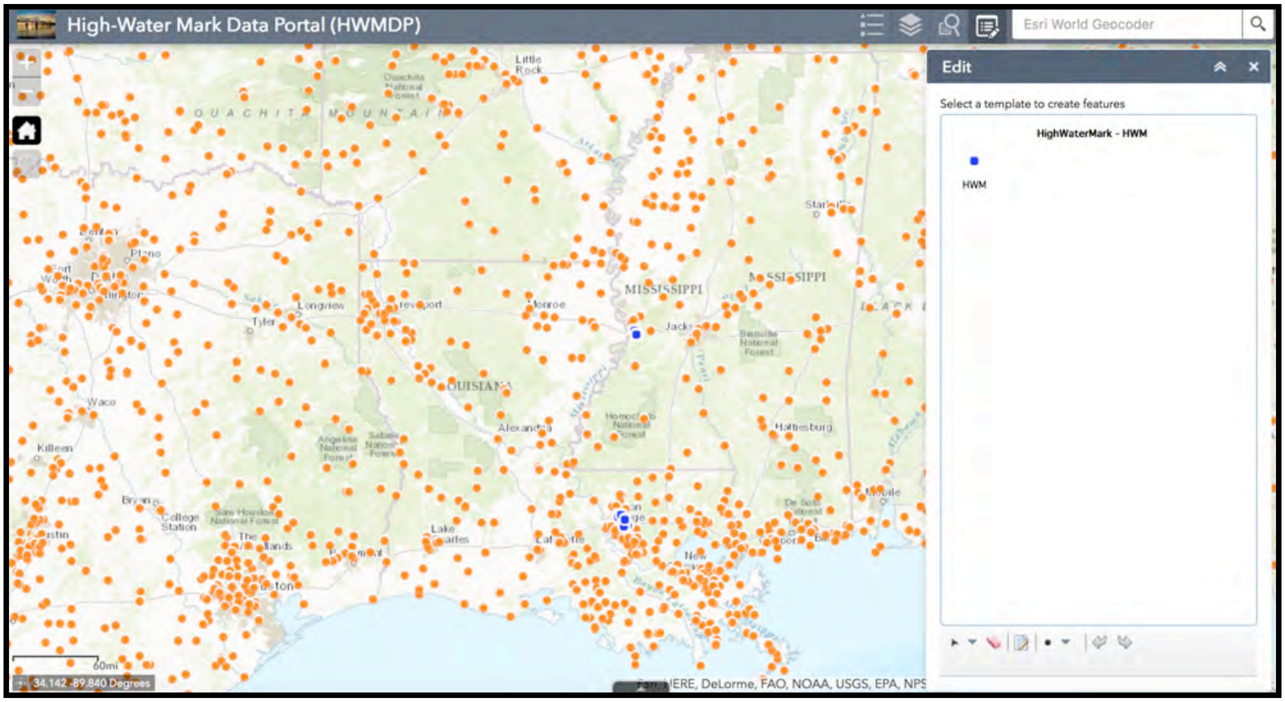
❖ Layers – Displays the different operational layers in the map:



❖ Streamgage Query Tool – Query tool to find the nearest streamgage to the HWM:



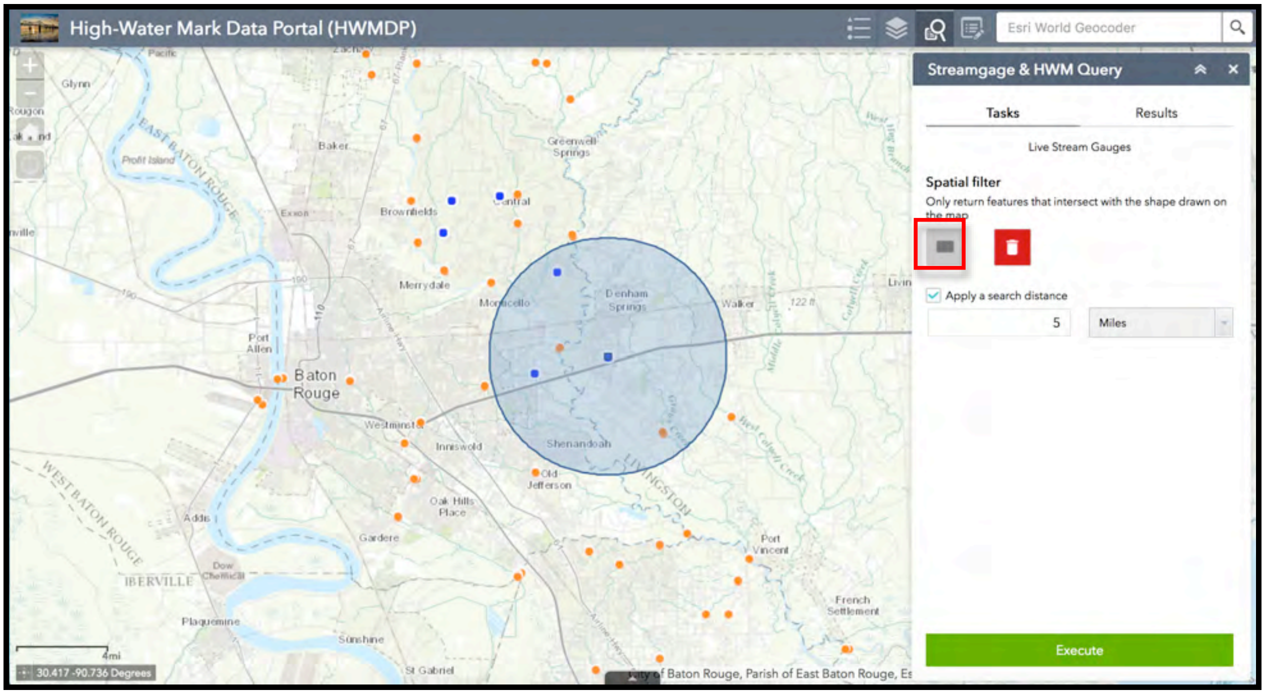
❖ Edit Tool – Allows the user to edit the HWM record to add the streamgage information:



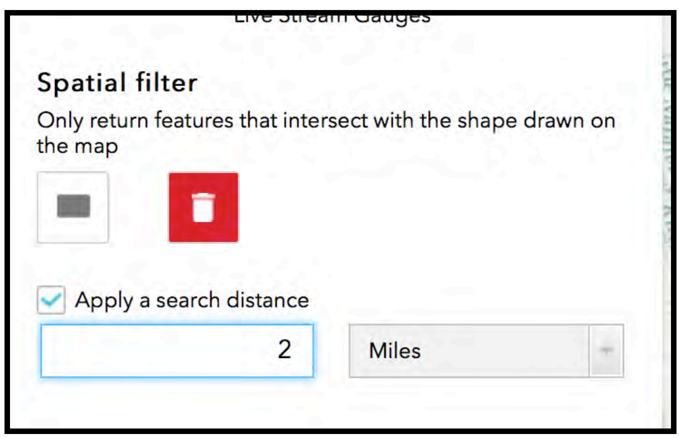
How to use the Streamgage Query Tool

1. Zoom to the area of the HWM to find the nearest streamgage

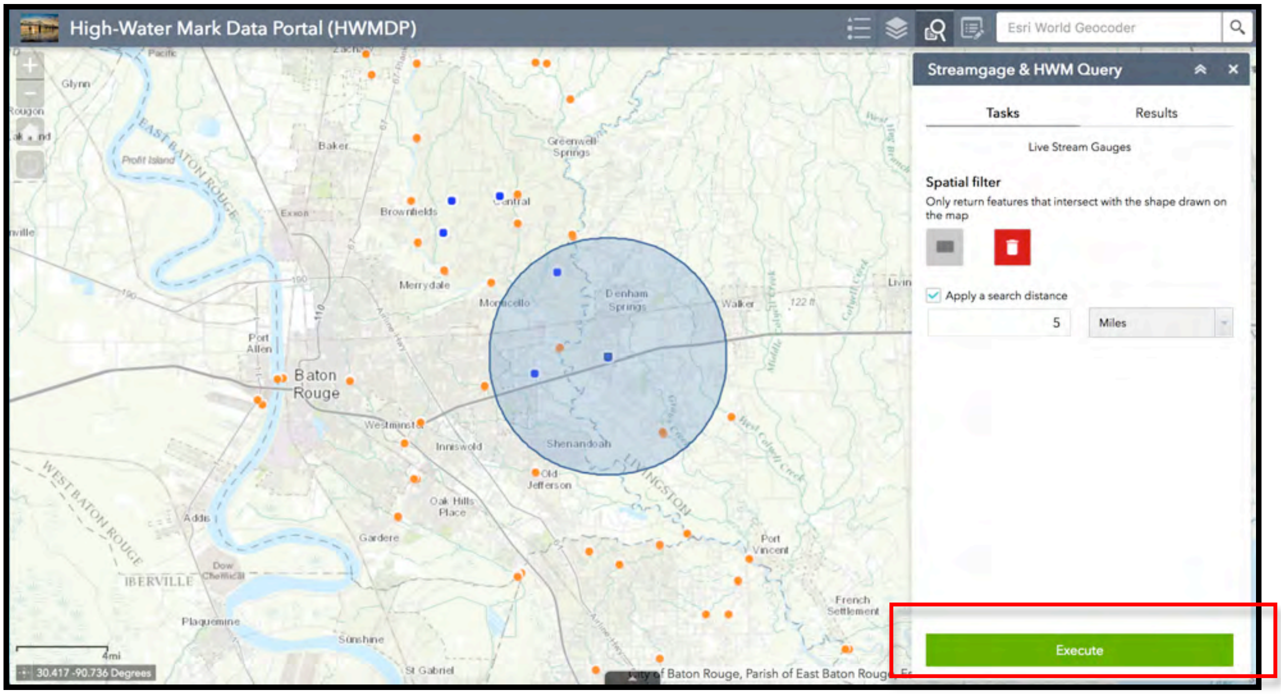
2. Click on the rectangle drawing tool to draw a rectangle around the HWM:



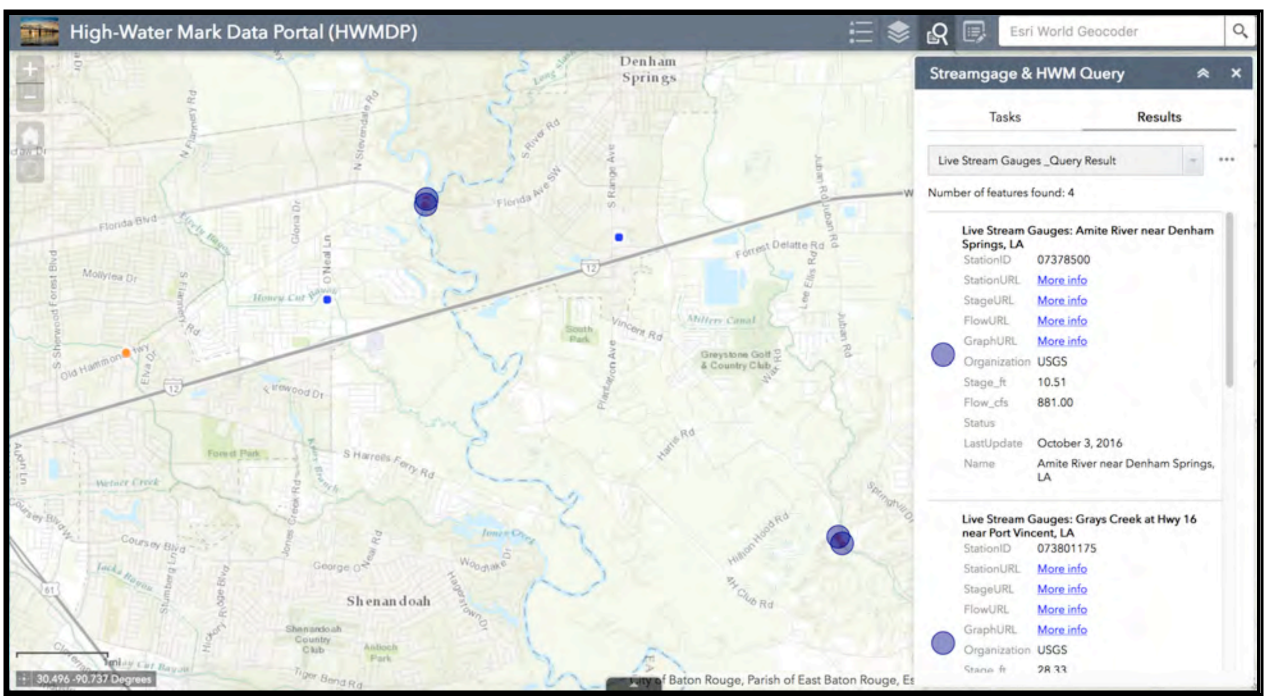
3. Enter buffer distance. *The default is a 5-mile buffer. This can be increased or decreased depending on the area and the number of streamgages found:



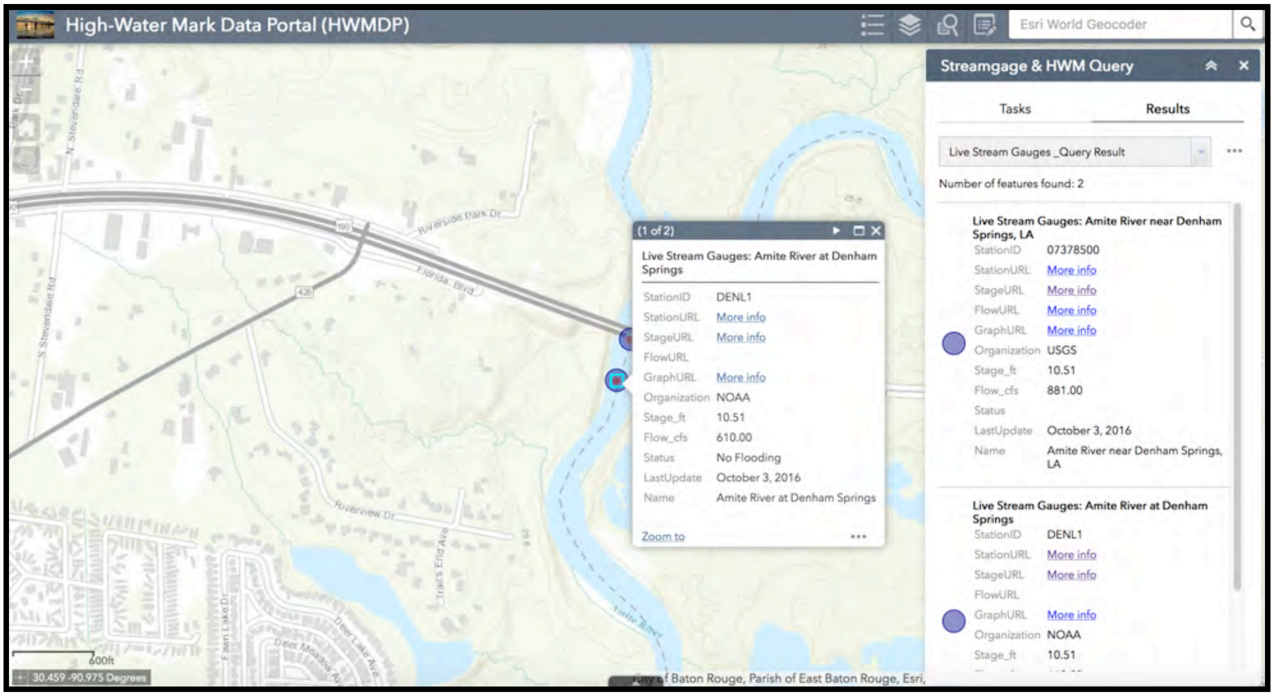
4. Click on the Execute button:

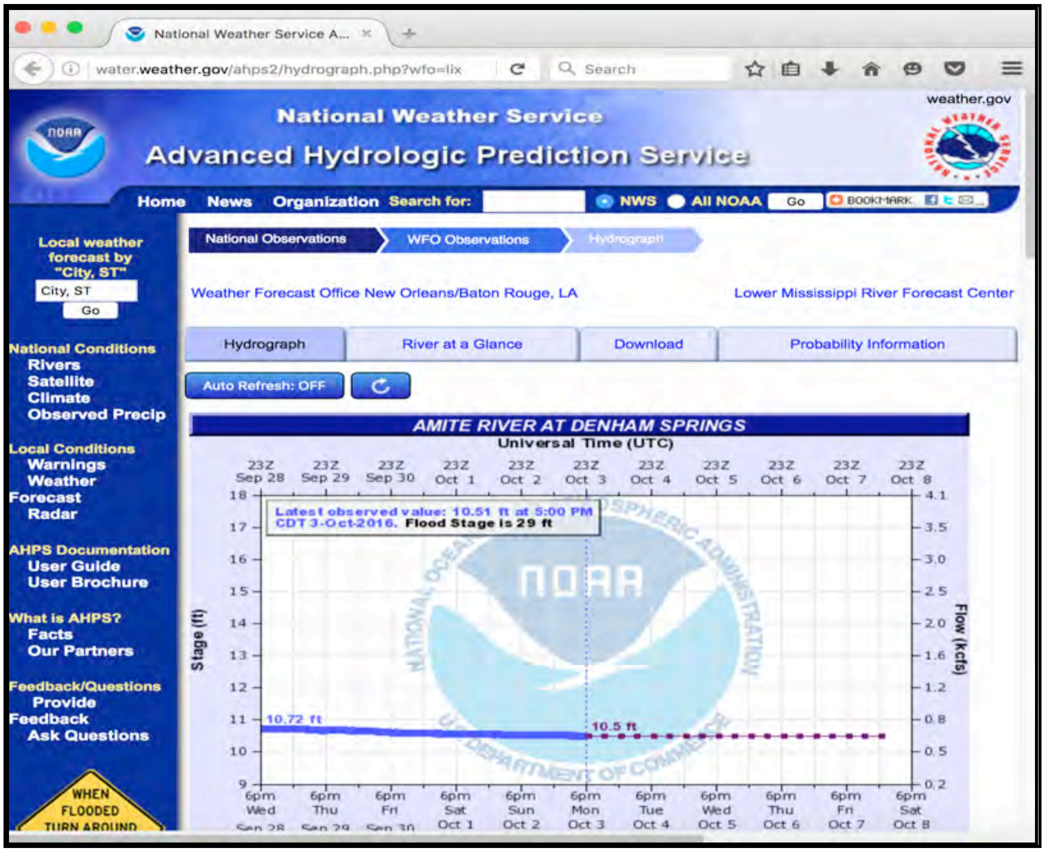


5. The streamgages that meet the buffer query are highlighted with a blue circle, and the results are displayed on the right:

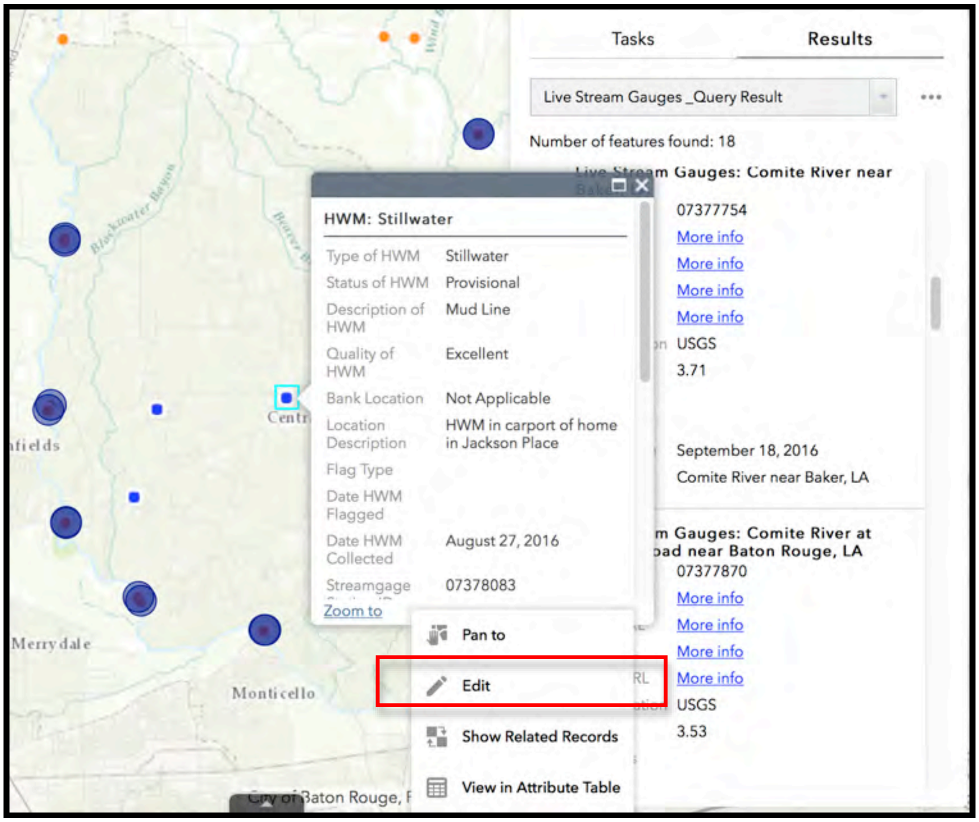


6. Find the nearest streamgage from the results list or using the map. Click on the streamgage point to view the attribute information or click on the "More info" link to open the streamgage information page in the web browser. Information about the streamgage including streamgage id, streamgage owner, and peak river stage can be found:

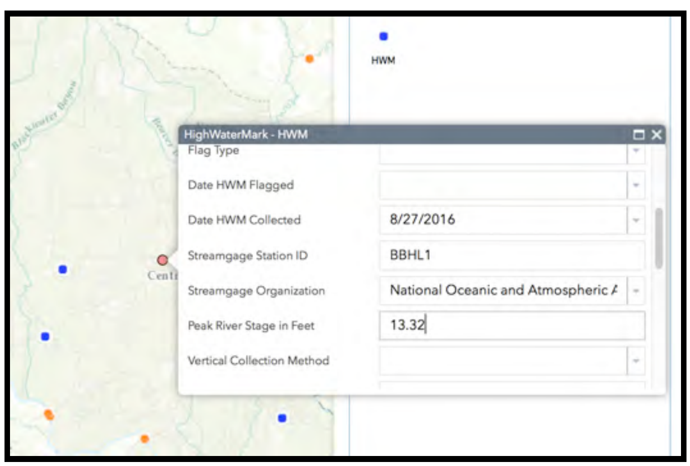




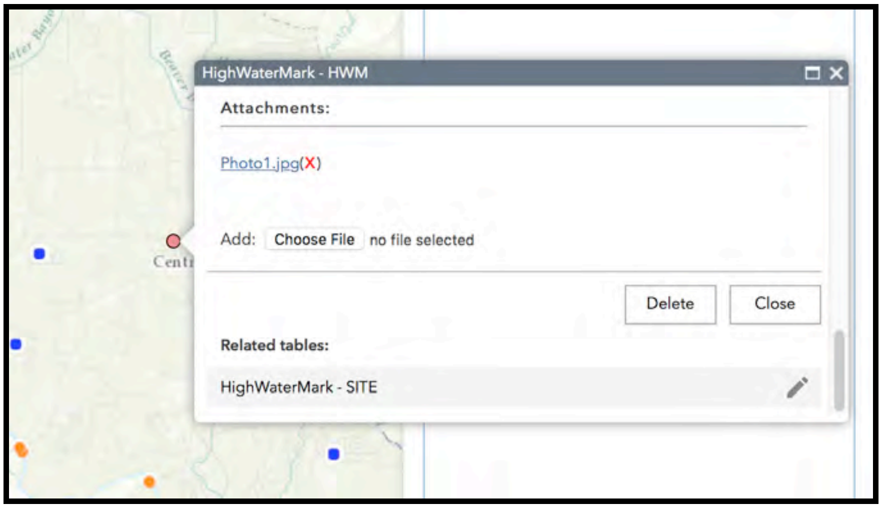
7. Click on the HWM point to open the HWM attributes. Click on the … at the bottom of the attribute window, then click Edit:



8. Enter the streamgage id, streamgage organization, and peak river stage:



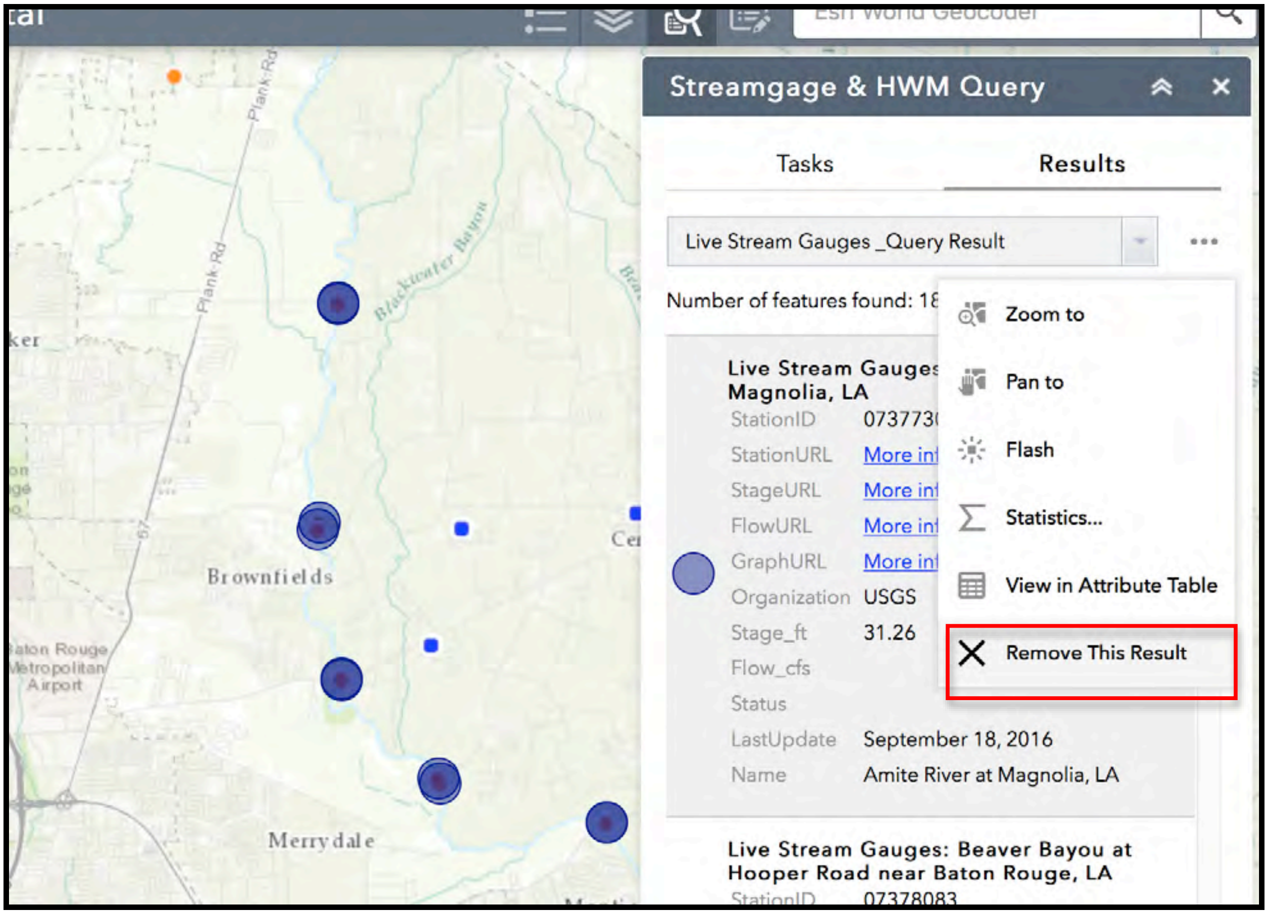
9. Scroll to the end of the HWM attribute window. Click Close:



10. The HWM is updated with the nearest streamgage information.

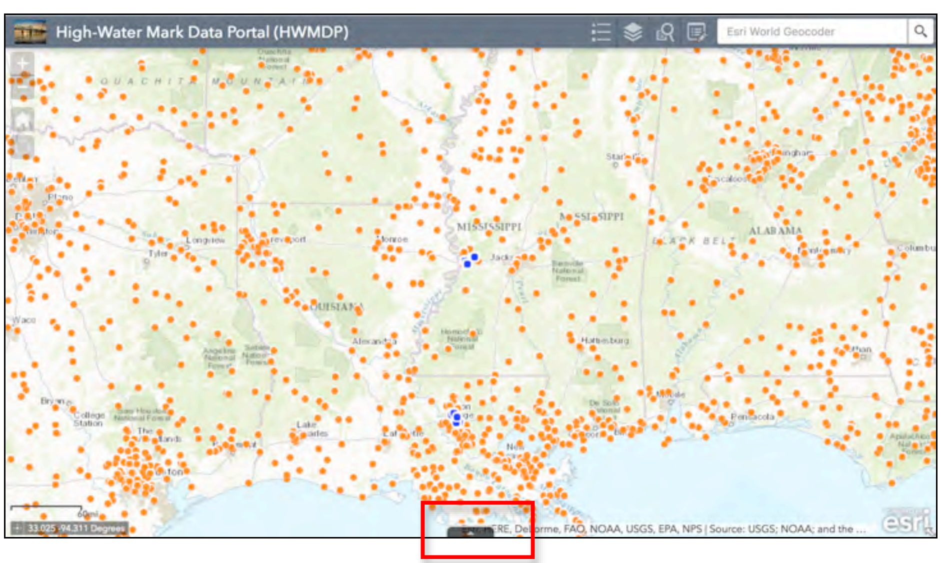
11. Continue to run the streamgage query tool to edit more HWMs.

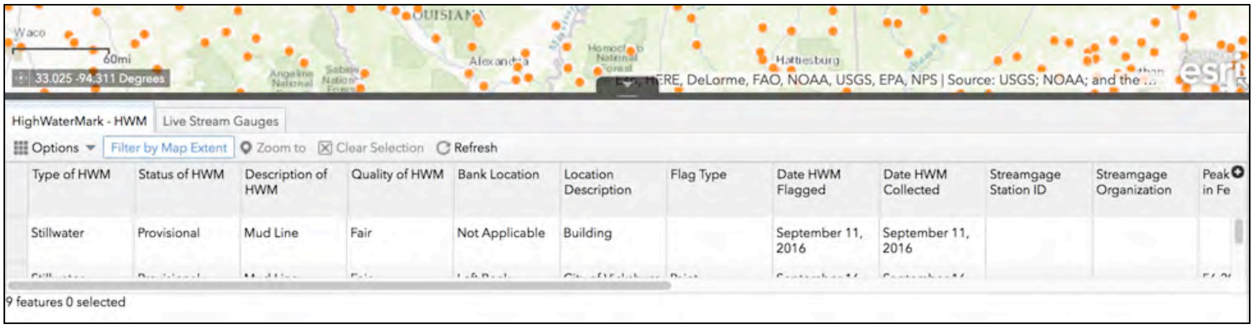
12. If the previous query results are displayed when the Streamgage Query Tool button is clicked, those will need to be removed. To remove the results, click on the …, then Remove this Result:



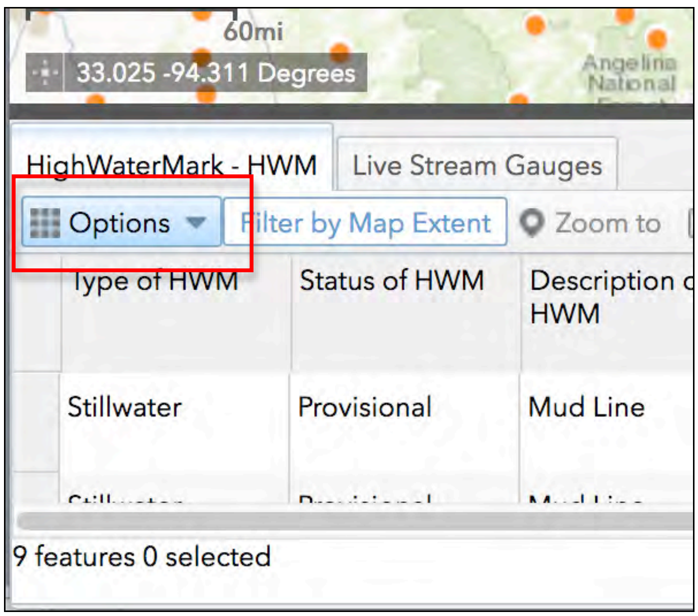
How to download the data:

1. Click the up arrow button to open the attribute table.

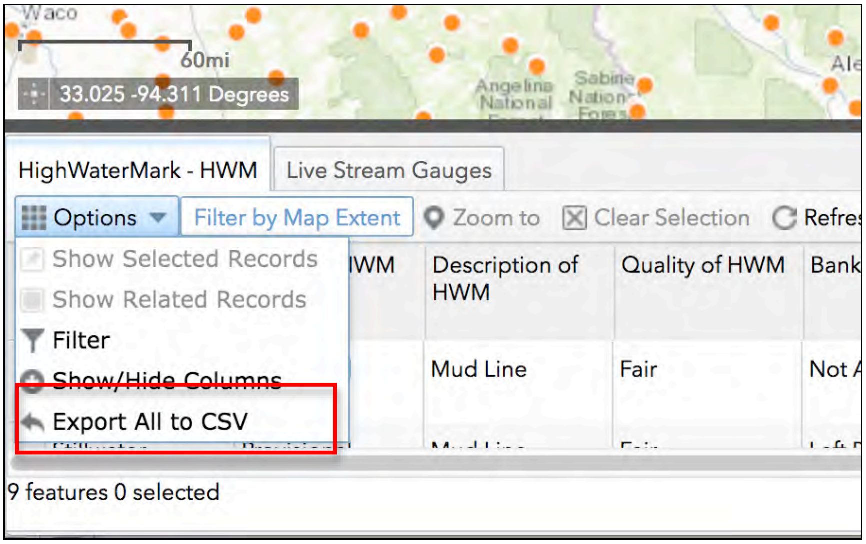




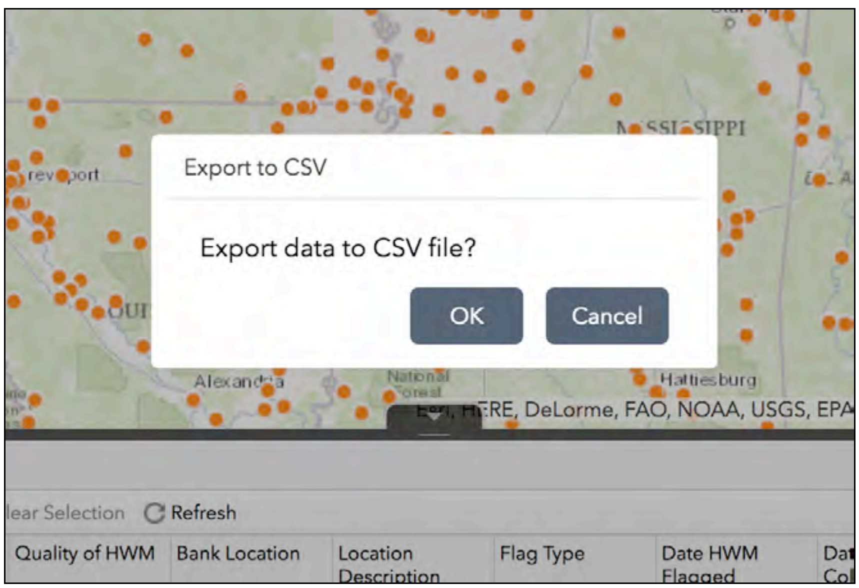
2. Choose the Options menu item



3. Choose Export All to CSV



4. Choose OK to export data to CSV



5. Choose location to save data when prompted
6. Data will be saved in CSV format and can be opened with Microsoft Excel or imported into ArcMap