Creating a Web GIS to Support Field Operations and Enhance Data Collection for the Animal and Plant Health Inspection Service (APHIS)

by

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To my parents Bill & Carolyn Farhat, for all their continued support

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Abbreviations

USDA	United States Department of Agriculture
APHIS	Animal and Plant Health Inspection Service
PPQ	Plant Protection and Quarantine
EWBB	Exotic Wood-boring Beetles
AGM	Asian Gypsy Moth
GIS	Geographic Information System
AGOL	ArcGIS Online

Abstract

Invasive insects are damaging to the environment and economy. Early detection of these pests is important to prevent their establishment before their populations grow and cause extensive damage. In the United States, the Animal and Plant Health Inspection Service (APHIS) safeguards natural resources and agriculture through their Plant Protection and Quarantine (PPQ) program by preventing the establishment and entry of forest pests into the United States. APHIS traps exotic wood-boring beetles (EWBB) and other pests. Throughout all the APHIS offices across the United States, there is no unified field data collection method. As of 2019, the APHIS office in Chicago, IL uses Microsoft Access for all their field data collection. The main objective of this thesis is to build a Web GIS with mobile data collection capabilities and an operations dashboard to further monitor data collection in the field. Collector for ArcGIS can be used for mobile data collection in the field and an operations dashboard can help supervisors monitor field operations more effectively. This project utilized a user needs interview with members of the APHIS team in Chicago to guide application development. The developed Web GIS application, which includes an operations dashboard and Collector for ArcGIS, was then tested by users of APHIS to determine whether their workflows would benefit. The application was well received by users and the feedback helped to uncover a few notions that could guide further development of this application in the future. These enhance APHIS's current workflow through real-time data collection as well as more accurate data collection. The completed application could also be used in rural areas where less high-risk importers are present through customization. Approximately 80% of the application would remain the same, though there would be changes in the symbology and data collection layers. This could benefit APHIS offices, as well as other organizations monitoring invasive pest control.

Chapter 1 Introduction

The Animal and Plant Health Inspection Service (APHIS) conducts various surveys for forest pests that are known to cause extensive damage to the agricultural industry and forested areas. Many of their field operation surveys involve trapping of these forest pests for early detection. As of 2019, current data collection methods involve pen and paper field records and entering data into Microsoft Access. Connecting their database structure to a Web GIS (Geographic Information System) could enable more efficient field data collection as well as more thorough monitoring of trapping and pest detection. Field technicians could enhance their daily workflows with a data collection app with more automated field collection and field supervisors could more effectively manage their teams using an operations dashboard. Using a data collection app with datasets of forested areas and canopy cover type, technicians could more effectively place traps for more efficient early detection of forest pests. Storing APHIS's database in Microsoft's SQL Server could streamline data collection with the use of ArcGIS Server and ArcGIS Online (AGOL).

The main objective of this project is to build a Web GIS that enables the use of an operations dashboard and Collector for ArcGIS. These applications can enhance 2019methods used for field data collection as well as having more practical data storage. A Web GIS could also provide many opportunities such as data analysis, story maps, data collection, and data sharing between agencies through AGOL.

The rest of Chapter 1 is divided into three different sections. Section 1.1 gives a general statement of need for the application. Section 1.2 describes the overall motivation for this application. Finally, Section 1.3 discusses the general overview of the application.

1.1. General Statement of Need

APHIS's duties include plant pest management of invasive species, early detection of exotic pests, and protecting American agriculture from pests (Lance 2003). APHIS conducts several types of surveys for presence of forest pests near high-risk areas such as industrial areas or railroads that contain wood packing material. The most common pathways for introduction of exotic pests is through trade of live plants and wood material (Liebhold et al. 2012). Wood material mainly includes pallets, which invasive pests can bore into and be transported into the United States. Surveys for pest detection involve setting up numerous traps with target-specific lures to attract pests in high-risk areas. Traps baited with lures assist in early detection of exotic wood-boring pests (Brockerhoff et al. 2006). Forested areas are common places for traps as pests are attracted to a wide variety of tree species.

As of 2019, APHIS stores all their data in a Microsoft Access database which contains addresses of high-risk importers, and past trap locations. Entering trap information into the database involves writing down coordinates along with other information in the field and entering them into Access in the office. The APHIS workflow could benefit from a database format that supports AGOL functionality. Connecting their Access database to a Web GIS (Geographic Information System) can provide more efficient data collection and better management of field operations. ArcGIS Online can provide many opportunities for more efficient data collection in the field with the use of an Operations Dashboard and Esri's Collector for ArcGIS (to be referred to as "Collector" from here on).

1.2. Motivation

This section discusses the general motivation for creating this application and is divided into two different subsections. First, Subsection 1.2.1 discusses the impact of invasive species in the environment. Subsection 1.2.2 further discusses the need for a Web GIS.

1.2.1. Invasive Species and Pest Surveys

In the United States, invasive species cause almost $120 billion in damages every year (Pimentel, Zuniga, and Morrison 2004). Invasive species incur great damage in the environment as well as the economy due to the costs of managing them. Invasive species are hard to manage once they become established due to lack of natural predators to control them (Pimental, Zuniga, and Morrison 2004).

Early detection is often the most cost-effective management solution to keeping invasive species under control. Epanchin-Niell et al. (2016) concluded that a trapping program for early detection is very cost-effective and can provide net present benefits over a 30-year plan. By putting up traps in high risk areas, APHIS can prevent establishment of forest pests. A trap allows for APHIS to become aware of the presence of pests so that they can respond appropriately and potentially mitigate the spread of forest pests.

Once established, forest pests cause destruction in the environment and economy because they are very costly to manage. Therefore, early detection is very important. A Web GIS that combines pest surveys can provide for more efficient data collection with less errors. More time can be spent doing surveys, which could lead to more effective management and early detection of these pests. The following sections discuss the different types of invasive species that APHIS monitors through surveys in further detail.

1.2.1.1. Exotic Wood-boring Beetles Survey

Exotic wood-boring beetle (EWBB) trapping is one of the main surveys that APHIS conducts for early detection of these pests. Trade between countries leads to the spread of EWBB through wood packing material such as pallets (Haack 2006). Wood packing material is the vector of travel for many EWBB such as bark beetles and longhorn beetles, the main target taxa of APHIS EWBB Surveys. APHIS is made aware of their presence through a reporting system. Emergency Action Notifications (EANs) are issued in this system which provides addresses of high-risk importers (Magarey, Colunga-Garcia, and Fieselmann 2009). These are issued based on importers not following proper regulations such as fumigation protocol and other treatments. Surveying for EWBB is important because it can help APHIS understand which importers are not following proper protocols and mitigate the spread of EWBB.

1.2.1.2. Asian Gypsy Moth Survey

The Asian Gypsy Moth (AGM) is another forest pest that APHIS conducts surveys for. AGM is a defoliator that attacks oak tree species. Unlike the European Gypsy Moth (EGM), AGM can fly further distances and attack a wider range of host trees (Gibbons 1992). As with EWBB, early detection is also important. Surveying is required to develop an understanding of the distribution of AGM, as well as EGM. Trapping involves setting up a delta trap with a lure that attracts AGM. Going unchecked, AGM can cause extensive damage in forests and cause a loss of biodiversity due to the many organisms that rely on oak species.

1.2.1.3. Cerceris Survey

The last main survey is for Buprestid beetles, such as the Emerald Ash Borer (EAB). EAB is a very destructive EWBB that attacks Ash trees and has destroyed millions of ash trees in North America (Herms and McCullough 2014). Traditional trapping methods are not used for monitoring of buprestids. Instead, the Cerceris Fumipennis wasp, a natural predator, is used to monitor buprestid populations. Cerceris wasps prefer hard sandy soil such as baseball diamonds to make their nests and they often drop their prey next to their nests (Swink, Paiero, and Nalepa 2013). This technique is known as biosurveillance and can be an excellent tool to monitor early detection and establishment of buprestids.

1.2.2. Web GIS Needs

This section discusses the need for a Web GIS for APHIS and the potential benefits. It is divided into three sections which include connection to Web GIS, data collection, and operations dashboards.

1.2.2.1. Connection to a Web GIS

APHIS's Access database does not have a connection to ArcGIS. If any analyzing or viewing of the data needs to be done, it must be exported as a table and opened in ArcMap or Google Earth. This would be problematic if there were ever a new forest pest introduced into Illinois, as no real-time system would be in place to monitor a huge operation. The normal field operations would have to be scaled up to include more trap locations and more technicians during an emergency. Having an organized system already in place can avoid inefficiencies and confusion. Without Web GIS, the alternative would be paper maps and manually entering data into the Access database.

1.2.2.2. Data Collection

Data collection in the field using Collector can allow for more accurate data collection as well as saving time. Recording data manually is often labor-intensive and can introduce errors (Vivoni and Camilli 2003). Pen and paper methods often result in errors when copying down coordinates. Coordinates may be written down wrong and entered into the database incorrectly back in the office. There is also a lot of information that is needed depending on the survey type. The Cerceris survey requires information about the baseball diamonds and nest count. A technician may check over a dozen baseball fields in one day and the information about each field may be written down incorrectly or forgotten about.

Once pest detection traps are installed, they are serviced every two weeks. Collector has the capability to allow records of related tables to be linked to a feature class. This could allow for field technicians to view a recent history of work performed on the trap such as a lure change or a sample being taken. This could cut out a lot of time that is spent writing down all this information. It could also ensure that a lure is changed when it has expired. With more information available, fewer mistakes would be made.

The availability of real-time data is especially important for the Cerceris Biosurveillance survey. This survey involves going out to different baseball diamonds in search of Buprestid drops from the Cerceris wasp. If more than one technician is in an area, it is possible that they could have crossed paths and visited diamonds that have already been checked that day. This can quickly turn into a very inefficient and redundant process. Without an application that shows real time site visits performed, field technicians are at the mercy of a log of visits only available in the office and relying on their coworkers to enter visits in a timely manner. A more automated, real-time collection could eliminate these inefficiencies.

1.2.2.3. Operations Dashboard

Monitoring of traps could be more effective with real-time data, allowing for supervisors to better assess the spread of the infestation. Operations dashboards can give supervisors a better idea of the day-to-day operations and identify problems or concerns (Edwards et al. 2015). An operations dashboard would be useful for showing statistics on traps that have been serviced and information about positive identifications of the pest. This would allow more time for supervisors to react to information and reformulate operations. Even on a small scale of regular operations, it can provide information that operations are going smoothly.

Overall, manually entering data into a database with no connection to ArcGIS Online (AGOL) is inefficient and allows for more user errors. A GIS with a similar database structure to APHIS's Access database and AGOL allows for real-time data collection and a better portrayal of field operations. Using Web GIS, specifically an operations dashboard and Collector, these goals could be achieved.

1.3. Application Overview

This section is divided into four different sections. Section 1.3.1 discusses the intended users of the application. Section 1.3.2 provides the study area of the application. Section 1.3.3. describes the use of the application. Finally, section 1.3.4 discusses the design of the application.

1.3.1. Intended Users

Testing will be required for data collection and the web application to demonstrate a fully functioning Web GIS. The users of this Web GIS include APHIS Field Technicians, the state Pest Survey Specialist (PSS), and the Field Operations Supervisor. The operations dashboard will be utilized by all three of these positions and the data collection will be conducted by technicians and the PSS. Technicians will use iPhones and iPads for data collection through Collector. As of 2019, data collected in the field is entered manually once technicians have returned to the office, so using Web GIS would allow for more efficient data collection by removing extra steps from the current workflow. Mobile data collection is more cost-effective, reduces database errors, and keeps the users more informed. (Poorazizi 2008). There are many potential advantages to implementing Web GIS for APHIS.

1.3.2. Study Area

The study area for this application is Cook County, Illinois. Datasets that will be included in the application will cover the extent of this county. Synthetic data will need to be created in this county in order to demonstrate a functioning database design for collection. Sites and traps will be created in Cook County because the intended users are from the Chicago APHIS office and majority of their surveys take place there.

1.3.3. Application Use

This section is divided into two different sections. Section 1.3.3.1. discusses the use of Collector for field data collection. Section 1.3.3.2. describes the use of an operations dashboard to monitor field operations.

1.3.3.1. Collector for ArcGIS

APHIS field technicians can utilize Collector to gather data in the field. Using a web map created in AGOL, data can be entered and viewed real-time. Datasets such as land cover and boundaries of forest preserves can aid in more effective trap placement.

The main focus of data collection will be the subsites (which are the traps) and activities (the services associated with the traps). A data collection layer can be used to help gather data in the field. A point can be dropped for each trap and appropriate information can be entered. Dropdowns for each attribute of the site can be loaded in eliminating the need for typing in information for each subsite. A related table, activities, can be joined to the subsite layer allowing for easier viewing of service history.

Certain symbology can be used to distinguish between different types of surveys. It can also be used to inform the technician if there is a trap due for a service, or if a lure needs to be changed. Labels can also help provide important information without clicking on a site and checking the services associated with it.

1.3.3.2. Operations Dashboard

An operations dashboard can be utilized in order to help monitor field operations. The same web map that is used for data collection can be used for this dashboard. Real time data collection can be viewed from the dashboard as well as providing important information in the form of charts.

Charts can include information such as the distribution of different lure being used for traps, how many traps need to be serviced, and how many samples were collected from each survey. This dashboard can be used by the field operations supervisor and the PSS to quickly check and see how smoothly field operations are going.

1.3.4. Application Design

APHIS's Access database can be imported to a SQL Server enterprise geodatabase. The tables and relationships will need to be created in a SQL Server enterprise geodatabase, which will then be connected to ArcGIS Server. The tables will reside in SQL Server which can be exported easily to Access. Data collected in the field can be entered through AGOL using Collector. APHIS's database design is provided with tables and relationships, but the high-risk importer data and past trap locations are not provided as it is confidential information. Synthetic data will need to be created using their Access front end file, as well as within the application after it is built to ensure a fully working database.

For the web application, it will have to be built in a way that will not cause errors in the original database design, and that will easily integrate with Collector. Codes are used for traps based on the location, lure type, and date which are linked to a collection sample. For example, CO-WAL-ET1-190605 would be a trap in Cook County at a Walmart site with an ethanol trap that was collected on June 5th, 2019. This code is tied to a collection sample for more organized sample processing. An operations dashboard will also be utilized to provide a summary of current field operations with charts and meters showing current traps that are up to date, lure expirations, and types of lures used.

Certain datasets to supplement field data collection will be utilized to provide for more efficient trap placements. A dataset that will be used in the web map is the Illinois Protected Lands dataset which includes all the natural areas in Illinois owned by state agencies, federal agencies, non-governmental organizations, and municipalities. Many of these areas contain forests and trees which is ideal for trap placement because these areas are targets for certain invasive species. A Gap Analysis Project (GAP) Land Cover dataset can also be used to supplement these polygons with dominant tree species to allow for even more efficient trap placement. All of these additional datasets can provide the user with an overview of potential trap locations for their sites.

Chapter 2 Related Research

This chapter is divided into five different sections which reviews research related to Web GIS, database design, forest pests, and related applications. These sections can help direct the features being built within the application and provide information on how this application adds to value to forest pest management and field operations. The final section gives a summary of the research and applicability to the application being built.

2.1. Web GIS

Web GIS can be a powerful tool for many organizations to facilitate data collection and analysis. Its functionality can extend to users who are not familiar with GIS programs such as ArcMap or ArcGIS Pro. It can also transform data in a way that is more manageable for users across an organization or government agency. It can bring data in tables to life using web maps which can be distributed to a wider audience.

2.1.1. Operations Dashboard

With more readily available data created by the Web GIS, an operations dashboard could be used to actively monitor field operations and make them more efficient. Edwards et al. (2015) concludes that dashboards increase supervisor efficiency and reduce costs. Dashboards can provide a lot of information based on current field operation efficiency. With respect to pest management and trapping, it can provide readily available information such as traps that need to be serviced, lure lifespan status, and counts on different traps and lures. All this information could be provided in a dashboard and viewed with the simple click of a button. It can also provide information on how smoothly the operation is going. Lee et al. (2015) states that real-time data allows for quicker reaction time to events and a swifter operation of services. This would be a necessity if there was ever an emergency operation set into motion based on the establishment of a new forest pest. The number of traps and technicians working in the field would increase significantly and a dashboard could properly organize and help oversee operations.

2.1.2. Data Collection

Web GIS coupled with data collection apps can be a powerful tool. Esri's Collector for ArcGIS facilitates data collection in the field and can be synced directly to feature layers in ArcGIS Online (AGOL). Godfrey and Stoddart (2019) evaluate some advantages and limitations of Web GIS which include user friendly data collection and lack of visualization of data that lies in related tables, respectively. User friendliness is an important feature because it allows for an application that does not require extensive training. A data collector can drop a point at a location, record the attributes, and move on to the next site. APHIS's database contains many related tables and AGOL's issue with lack of visualization of these tables will need to be properly addressed in the methods in order to conform to the database design while allowing relevant information to be shown to a field technician. Windham (2016) built a database for use with Collector and ran into issues with the relationships between tables and with duplicate data entries. Duplicate entries may occur in this project especially with the Cerceris Biosurveillance Survey and will need to be addressed.

2.2. Database Design

APHIS has all its information stored in Microsoft Access, so it will need to be stored in a different database for easier access to the data with a Web GIS. Nourjou and Thomas (2016) utilize a database that stores all its data in an enterprise database which is connected to a GIS server which then administers web services to different applications, such as mobile apps and web maps. The enterprise geodatabase they use is Microsoft SQL Server 2016. Windham (2016) also uses a similar database structure in conjunction with her Collector application. Research shows that this may be the standardized format for efficient data storage for a Web GIS.

SQL Server could provide many advantages over an Access database. SQL Server can provide access to many different users at once as well as retrieving data in different tables using relationships and joins (Amirian, Basari, and Winstanley 2014). This would be a good backbone structure for administering web services for data collection and visualization. The database would also be capable of being queried for information. McGuire et al. (2008) utilized Esri ArcGIS Server to query different information for visualization. ArcGIS Server has the capability to connect to SQL Server to pull information for web services.

2.3. Forest Pests

Section 2.3.1 discusses the role of GIS in forest pest management and Section 2.3.2 discusses trap placement for forest pests.

2.3.1. Role of GIS

GIS can be integral to understanding the distribution of forests pests, as well as discovering patterns and trends. Sabtu, Idris, and Ishak (2018) discuss the importance of GIS and forest pests and concluded that advances in GIS make managing forest pests more effective. More efficient data collection of trap locations could include more information such as the tree the trap is hung on, ground cover density, etc. All this information could advance scientific knowledge of forest pests to help understand factors that contribute to their spread.

2.3.2. Trapping

Trapping for forest pests can be a complex process due to the numerous types of traps and lures that can be used. Certain lures and traps attract certain pests and these traps must be hung near host material, or trees that the pest would be attracted to. Sheehan et al. (2019) determined that traps placed at different horizontal distributions made no effect on the catch rate of certain taxa. This is important because trap height and proximity to host material may play a bigger role. The knowledge of host material in the area through a land cover dataset may aid in trap placement. Dodds, Dubois, and Hoebeke (2010) studied the effect of trap placement in a few different scenarios including disturbed areas with closed canopy and found that traps contained more beetles. A type of dataset that would portray this information would be advantageous to have in the field when placing traps.

2.4. Related Applications

This section discusses related applications that can show how the application being built adds to current applications. It also provides insight on how the application can be enhanced for more effective field collection. Section 2.4.1. describes APHIS Access database. Section 2.4.2 discusses TrapView which is an application that can automatically take pictures of samples from traps. Lastly, Section 2.4.3 describes EDDMapS, which is a Web GIS for invasive species.

2.4.1. APHIS Access Database

As of 2019, APHIS uses an in-house Access database for field data collection. Figure 1 shows one of the first forms of the database where you can add and view data.

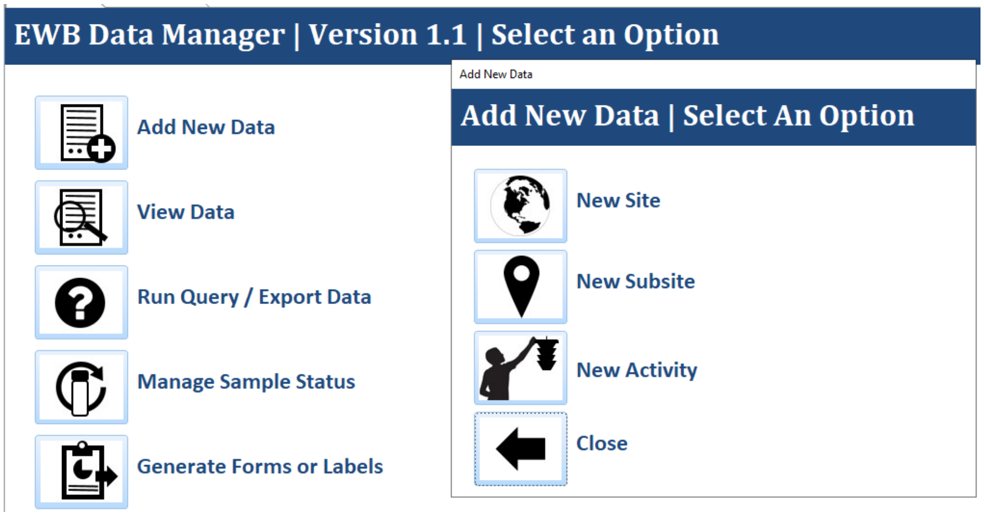

Figure 1. APHIS Access Database Form

This is the primary method for entering data that was collected in the field. There are a few important tables in this database regarding field data collection. These tables are site, subsite, and activity. The site table contains locations of high-risk importers. The subsite table contains locations of individual traps. The traps can be from a variety of surveys such as wood-boring beetles and gypsy moth. For the Cerceris survey, the subsite is a baseball diamond which is the primary survey locations. The activity table contains services associated with each subsite. These can range from installing a trap, removing a trap, collecting a sample from a trap, or collecting a sample from a baseball diamond.

The APHIS workflow in 2019 for exporting data involves converting an access table to a shapefile and emailing out the shapefile to be used in an iPhone application to view current traps. Not only is this inefficient, but it requires the Pest Survey Specialist to email out new shapefiles every week. Information is not real-time and there are no capabilities to collect data digitally in the field.

2.4.2. Trapview

Trapview is a company that provides resources for trapping moths and uploading data to the cloud. With Trapview Mobile, their mobile application, you view pictures taken from the sticky plates of the traps on their cloud where they help identify the moths (Trapview 2019). The use of cloud and pictures enables their system to be real-time which makes trapping more efficient. This can help with early detection and eliminating the need to check traps frequently as pictures are automatically taken.

While real-time pictures may seem out of the realm of possibility for this project, it brings up the importance of photo capabilities for traps. Having the capability to take a picture of the delta trap sticky plate (used for Asian Gypsy Moth Survey) provides a safety net incase the sample is lost or misplaced.

2.4.3. EDDMapS Pro

EDDMapS, also known as the early detection and distribution mapping system, is a web mapping system for the early detection and management of invasive species (EDDMapS 2019). Their mobile application is called EDDMapS Pro and allows the user to take a picture of an invasive species and record information associated with it such as infestation size and density. Data is uploaded to their website where it can be reviewed for accuracy. Their website allows for treatment information to be added to existing observations to facilitate management.

2.5. Summary

The related research of Web GIS, database design, and forest pests helps direct the development of this thesis. This research helps solidify the need for a Web GIS for APHIS because it can be more efficient for data collection and provide more real-time information using Collector and an operations dashboard. The architecture of the Web GIS is important because it needs to conform to APHIS's Access database format. There are certain datasets that can aid in field data collection based on the research done on forest pests. Host material, such as trees, can help with trap placement in the field. Having a dataset that contains this information can allow for more efficient trap placement.

Section 2.4 discusses related applications. This research helps identify how this application will add to current applications. The APHIS Access database has no mechanism for automated data collection in the field nor a map to view the data. This application will build upon the Access database and enhance the current workflow. It will provide real-time data collection and a more effective means of data collection in the field using Collector and datasets to enhance trap placement. The other applications researched provide insight on how the application can be enhanced such as providing photo capabilities.

Chapter 3 Application Development

The main goals of this thesis are to provide the Animal and Plant Health Inspection Service (APHIS) with a more efficient means of data collection and the capability to better oversee field operations. These goals can be accomplished by evaluating the user needs of the Web GIS and implementing a system that works with their database format. This chapter is divided into application requirements, data, database design, collector and operations dashboard design, and user feedback.

3.1. Requirements

This section is divided into goals of the application, user requirements, and functional requirements. The User Needs Interview is detailed in Section 3.1.2. and Appendix A and dictates the overall need for this application as well as guiding the development.

3.1.1. Application Goals

The main goal of this application was to enhance the workflow of data collection for APHIS. This involves facilitating data collection in the field, enhancing data processing, and allowing better visualization of data in the field via Collector as well as through an operations dashboard.

3.1.2. User Requirements

A user needs interview was conducted with four different users to explore methods for field data collection and monitoring during the 2019 field season. It was also used to uncover the need for supplemental datasets and additional functionality for field data collection and monitoring. Users included field technicians, a pest survey specialist, and a field operations supervisor within APHIS. Based on the interview, additional datasets were requested such as precipitation, dominant tree species in natural areas, floodplains, roads, and boundaries of forest preserves and other natural areas. Some requested features included a barcode system for traps, visual notification of overdue traps on a map, different symbols for surveys, real time data entry, and real time visualization of surveys. The user needs interview is detailed further in Appendix A. Based on time constraints and data availability, only some of these requested features and datasets were implemented into the application. Omitted features can be detailed in section 5.6., Future Work.

3.1.3. Functional Requirements

There were a few different capabilities that the application required in order to be functional for data collection and monitoring. The primary requirement was to have a web map that could integrate with Collector in order to facilitate data collection. The same web map also needed to be able to function with an operations dashboard in order to help monitor ongoing field operations for upper management as well as the technicians. For some of the features of an operations dashboard to function correctly, such as filtering of data, relationships between feature classes and tables needed to be set up properly.

The secondary requirement was to have a database that would maintain the same format as APHIS's Access database. This was especially important because it would allow data collected in the field to be used directly in queries within the Access database. When data is collected in the field, a sample from a trap is collected. The status of that sample is more easily updated through Access, which as of 2019, is how the pest survey specialist manages samples.

3.1.4. Interagency Operations and the Public

Natural resource management is a diverse field composed of many different facets. A large makeup of this field is invasive species management which is often an interagency effort to control them. Web GIS applications provide more user interaction through querying and data gathering tools, and easier access to data via the Internet. (Kearns, Kelly, and Tuxen 2003). With data ready for distribution, the Animal and Plant Health Inspection Service (APHIS) can work together with agencies such as the Illinois Department of Agriculture and the Illinois Department of Natural Resources to control forest pests. Kearns, Kelly, and Tuxen (2003) also mention that Web GIS can allow for more public participation. Outreach is especially important in invasive species management because the public can also be viewed as "boots on the ground" in terms of early detection. Through a Web GIS, data can be used to create story maps and volunteered geographic information (VGI) maps, which the public could actively participate in.

3.2. Data

Based on the User Needs Interview detailed in Section 3.1.2. and Appendix A, datasets were acquired to enhance data collection in the field. Datasets can be viewed in Table 1 and are described in detail in following sections.

Table 1. Datasets

Data Set	Spatial Reference	Source	Year	Format
Illinois Protected Lands	GCS_North_American_1983	Prairie State Conservation Coalition	2016	Vector
GAP Land Cover	GCS_North_American_1983	Illinois Natural History Survey	2000	Raster
APHIS Access Database	N/A	APHIS	2019	.accdb
Illinois County	GCS_North_American_1983	Illinois Geospatial Data Clearinghouse	2003	Vector

3.2.1. Illinois Protected Lands

Data from protected lands in Illinois was gathered into a web map and dataset by the Prairie State Conservation Coalition. This dataset contains polygons of all the protected areas in Illinois such as nature preserves, forest preserves, municipal parks, and state parks. Each polygon contains an ownership attribute as well as the acreage. Figure 2 shows a visualization of the dataset in the southern portion of Cook County in Illinois.

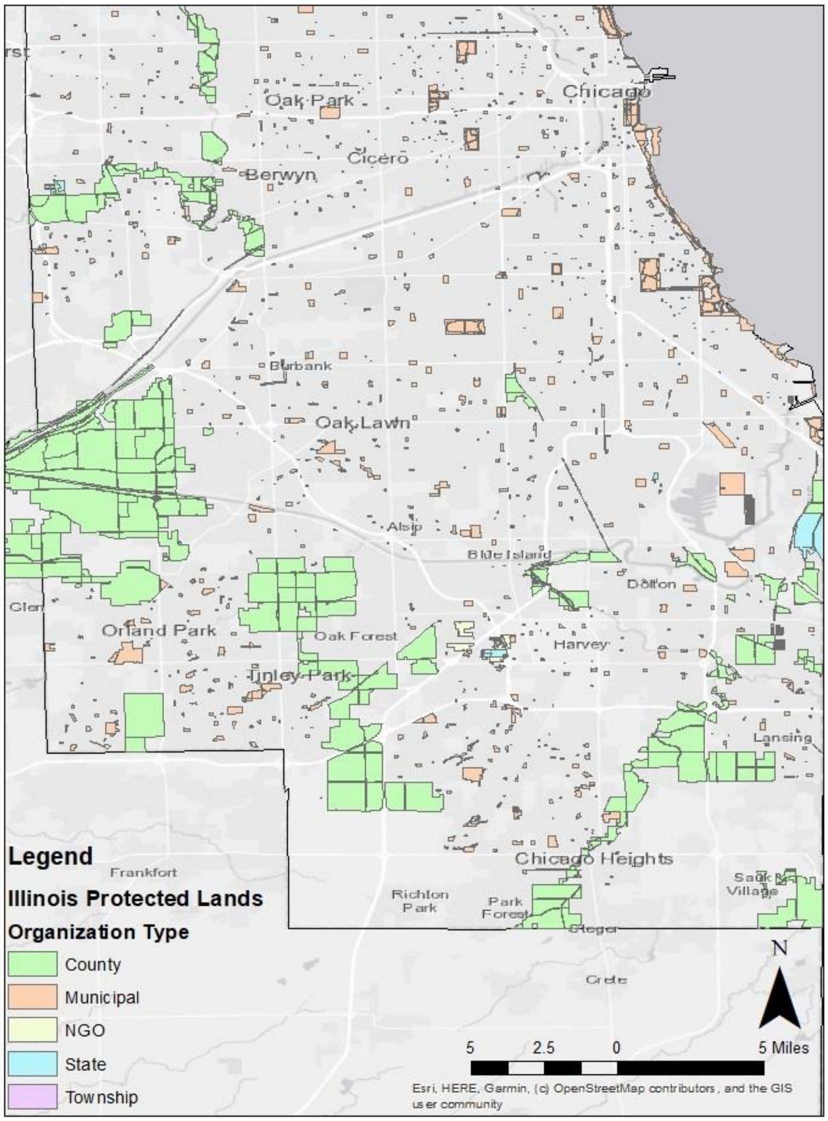

Figure 2. Illinois Protected Lands in Cook County

This map shows the different ownership types by organization. Majority of the protected lands in Cook County fall within the jurisdiction of the County, which is one of the primary locations for trap placement. Also included in this dataset was locations of Illinois Nature Preserves (INP). INP are locations where traps are not allowed to be placed. These locations were extracted from the main dataset to its own shapefile.

3.2.2. Gap Land Cover

The GAP Land Cover dataset contains land cover types throughout Illinois. The resolution of this dataset is 30x30 meters. This dataset includes a corresponding code list detailing each grid type based on descriptions in a table. These table descriptions were joined to the raster dataset in order to better visualize the data. The visualization of the dataset within Cook County, IL can be viewed in Figure 3.

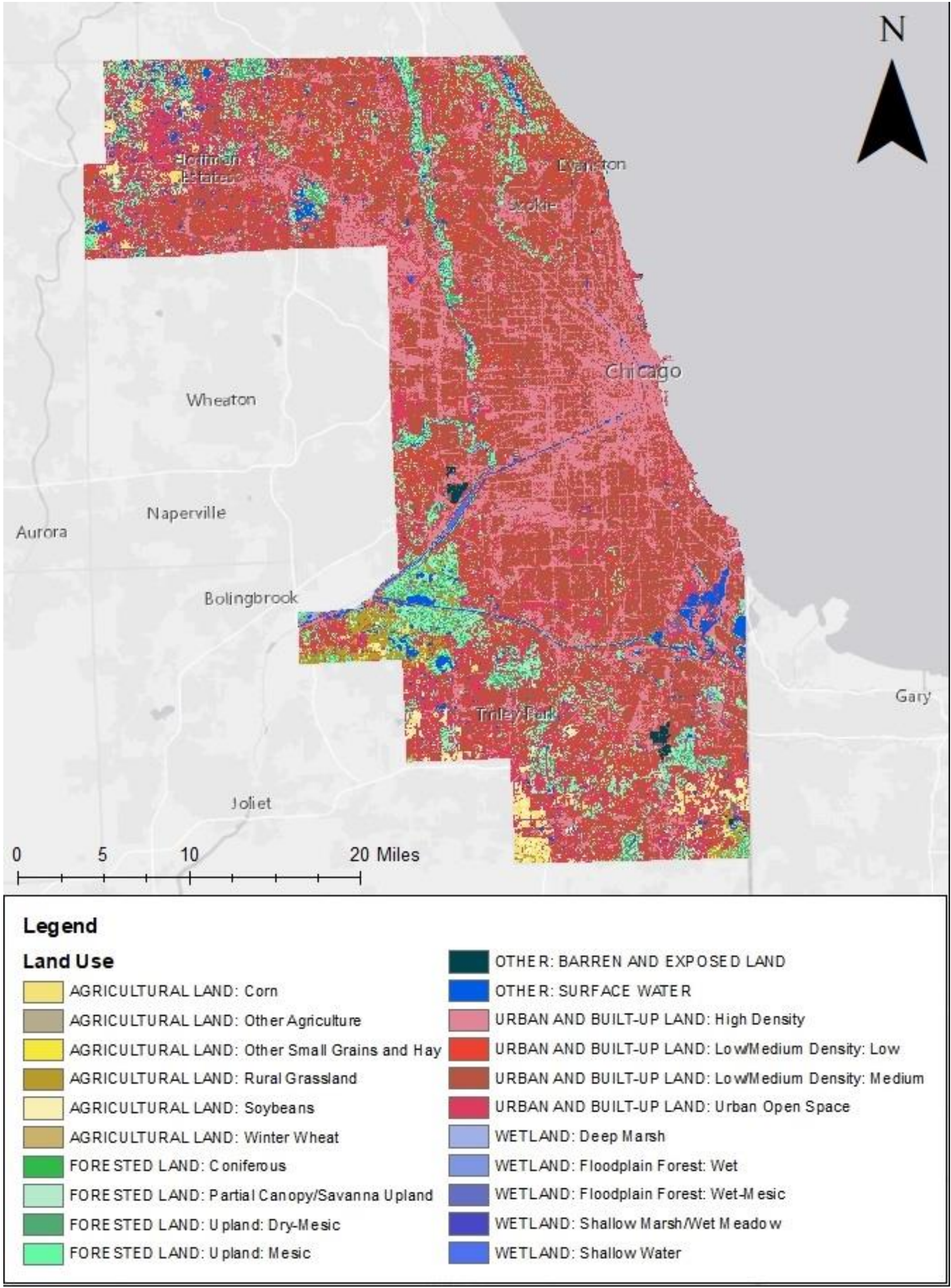

Figure 3. Land Uses in Cook County, IL

Majority of Cook county is densely populated due to it falling within the realm of the Chicagoland area. However, this dataset contains numerous areas which are classified as forest or wetland which contain tree canopy.

The GAP Land Cover dataset on its own provides no real benefit in a field data collection application. For this reason, a model was used to combine GAP Land Cover with the Illinois Protected Lands Dataset. Figure 4 shows the model that was used to add a field to the Illinois Protected Lands Dataset for canopy cover type.

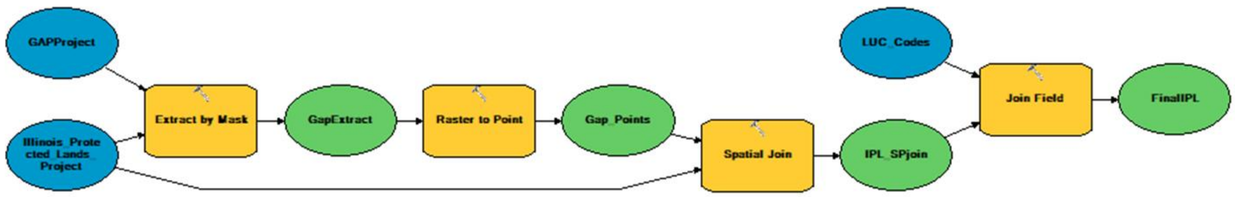

Figure 4. Land Cover Polygon Model

This model converted the raster values from GAP Land Cover to points and determined the majority land cover type within each protected land polygon. It assigned the majority land cover code to the polygon dataset. For each of the protected lands in Cook County, a field describing the majority land cover type was added. Tree canopy cover can be inferred from the land cover type.

3.2.3. APHIS Access Database and Synthetic Data Creation

This database was acquired directly from the APHIS Pest Survey Specialist in Illinois who manages it. It is a stripped-down database containing no actual data, as the real data contains actual addresses of high-risk importers and locations of previous traps. This data was omitted for security reasons.

The relationships between tables and the front-end forms for data entry were included. Figure 5 shows an example of the front-end forms of the database.

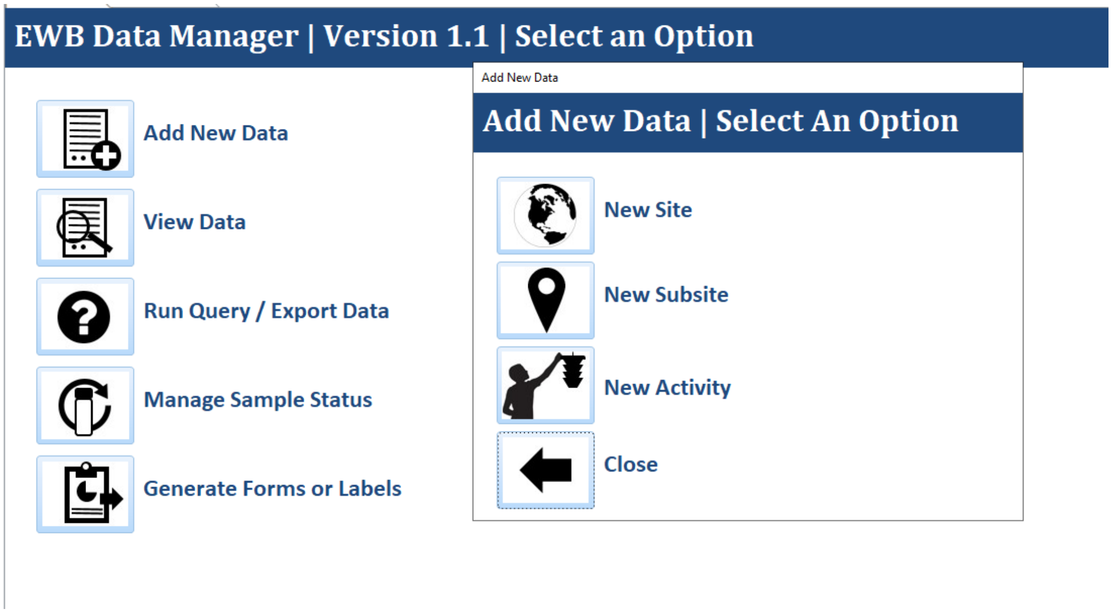

Figure 5. Front-end forms in APHIS Database

Data that can be entered into the database includes sites, subsites, and activities. Sites are the high-risk importer sites. Subsites are the traps that need to be placed within a certain range of the 'Site'. Activities are the services are associated with each subsite or trap. Activities include installation of a trap, removal of a trap, and taking a sample from a trap. The database diagram of the APHIS database can be viewed in Figure 6. It contains table and relationships with primary keys.

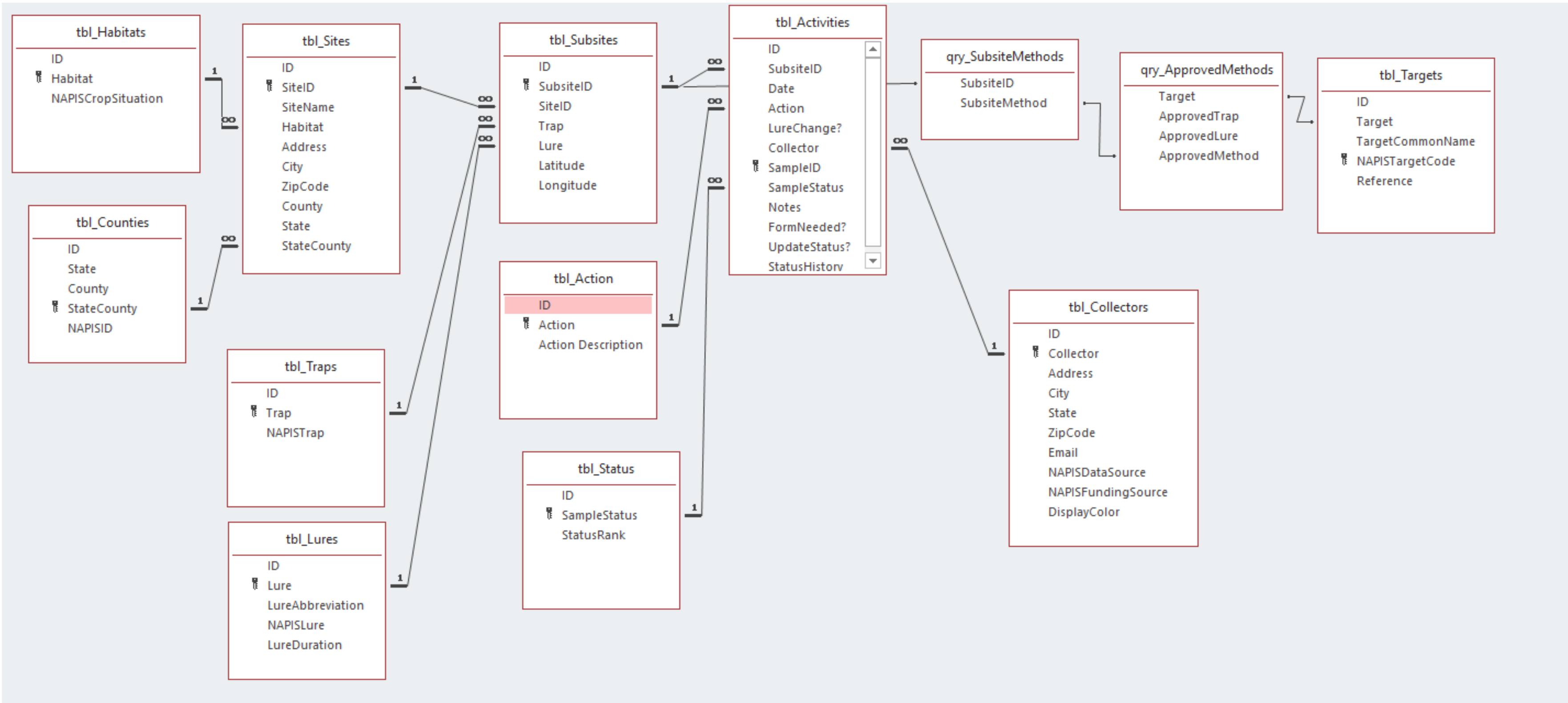

Figure 6. APHIS Access database diagram

Of these tables in the database diagram, sites, subsites, and activities are the main tables that are used in this application. An entity-relationship diagram of these tables can be viewed in Figure 7.

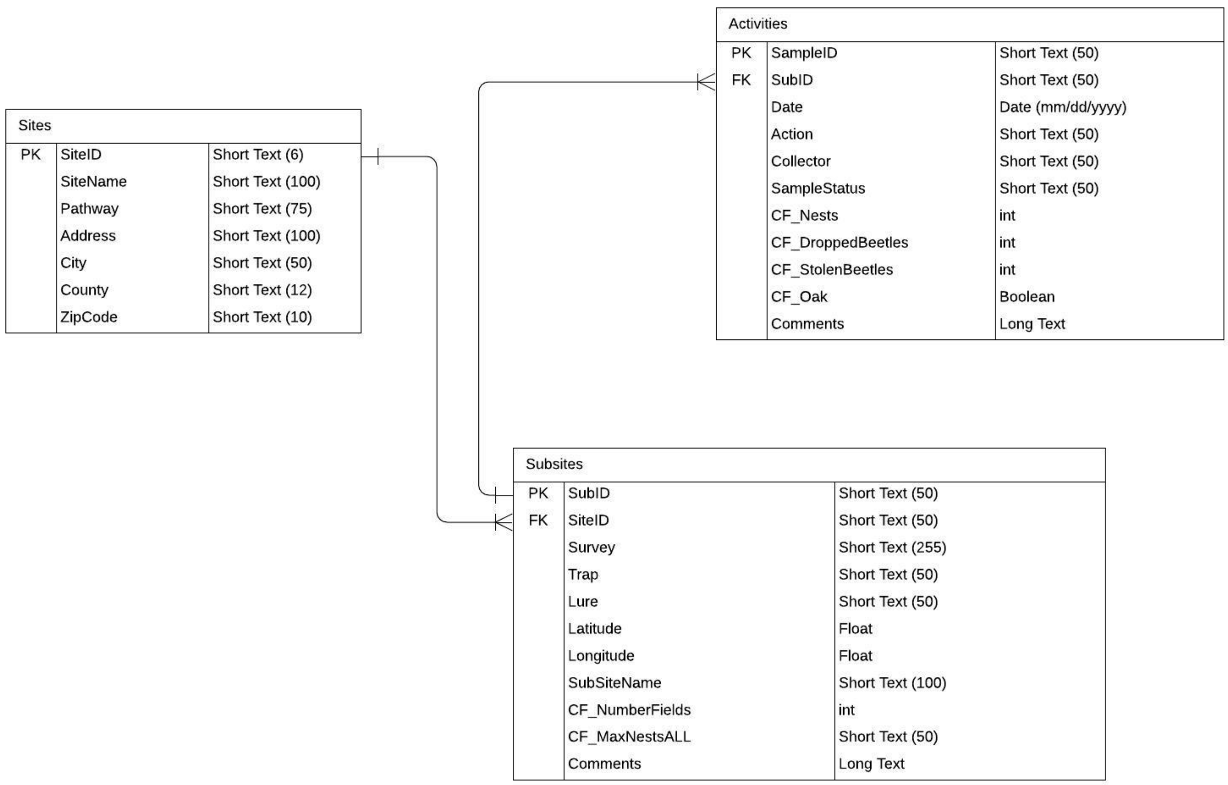

Figure 7. Entity-Relationship Diagram of Relevant Tables in Application

Of these tables, synthetic data entry was performed using the "New Site" access form in order to maintain the same format that is currently being used within field operations in 2019. Synthetic data entry was created for sites in Cook county as this is the area where the users conducted user testing. Sites were chosen at random and can be viewed in Table 2.

Table 2. Site Table

SiteID	SiteName	Habitat	Address	City	ZipCode	County	State
CO-WAL	Walmart Supercenter	Swpm [Solid Wood Packing Material Site]	930 Mt Prospect Plaza	Mt. Prospect	60056	Cook	IL
CO-LOW	Lowe's Home Improvement Center	Swpm [Solid Wood Packing Material Site]	7971 S Cicero Ave	Chicago	60652	Cook	IL
CO-INT	Intermodal Sales Corporation	Railroad Yard/Siding	15601 S Cicero Ave # 104,	Oak Forest	60452	Cook	IL
CO-CFP	Chicago Floral Planters	Nursery - General	5037 W 127th St	Alsip	60803	Cook	IL
CO-DES	Des Plaines	Municipal (City) Park	<null>	Des Plaines	60018	Cook	IL
CO-AMZ	Amazon Warehouse	Warehouse	1925 Busse Rd	Elk Grove Village	60007	Cook	IL

In APHIS's Access database, the site table contains addresses of high-risk importers. In this Web GIS, sites were geocoded and buffered with a 2-mile radius. This allowed for easier visualization of the site to see potential locations where subsite or traps can be placed. A model was used to prepare these sites for use in the Web GIS, which can be viewed in Figure 8.

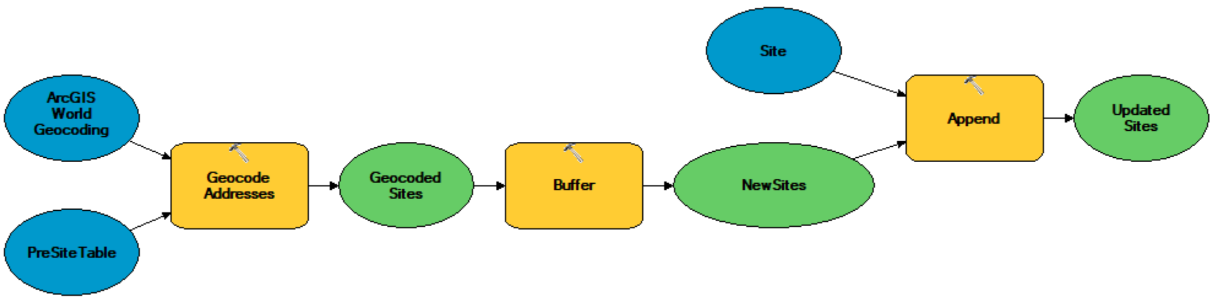

Figure 8. Geocoding and Buffer Model

This model utilized the ArcGIS World Geocoding Service in which the first operation is free and does not require credits. The PreSite table contains the addresses and sites that were entered into APHIS's Access database. This model geocoded the addresses from the PreSite table and placed a 2-mile buffer around each site. These buffered sites were then appended to the Site table. Anytime a new site needs to be added, it can be entered into the PreSite table and will be geocoded and buffered. There is no mechanism to add new sites in the field as adding new sites is something that should be done with backend processing due to the additional geoprocessing required. APHIS's workflow, as of 2019, involved adding new sites in the beginning of survey season and additional sites are added as needed based on reports of high-risk importers.

Synthetic subsites and activities were also created for this Web GIS. Subsites were placed nearby appropriate sites and appropriate activities were added to each subsite, such as a trap installation or sample being taken. These subsites, as well as sites can be viewed in the map in Figure 9 and 10.

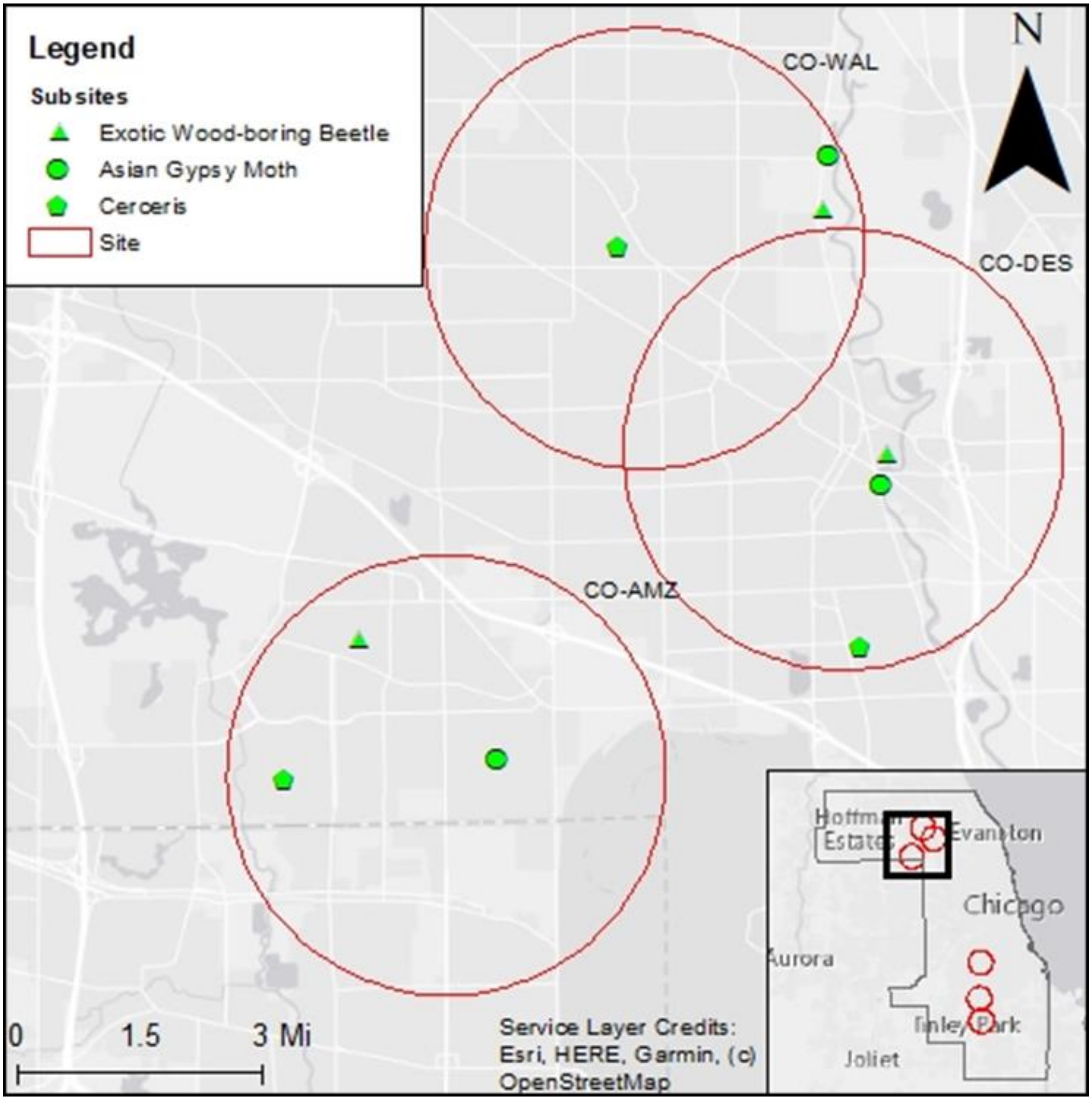

Figure 9. Sites and Subsites in Northern Cook County

This figure shows the sites and subsites in northern Cook county. The sites are labeled by SiteID and include CO-AMZ, CO-DES, and CO-WAL. The subsites are symbolized by the three different survey types which include Exotic Wood-boring Beetle, Asian Gypsy Moth, and Cerceris.

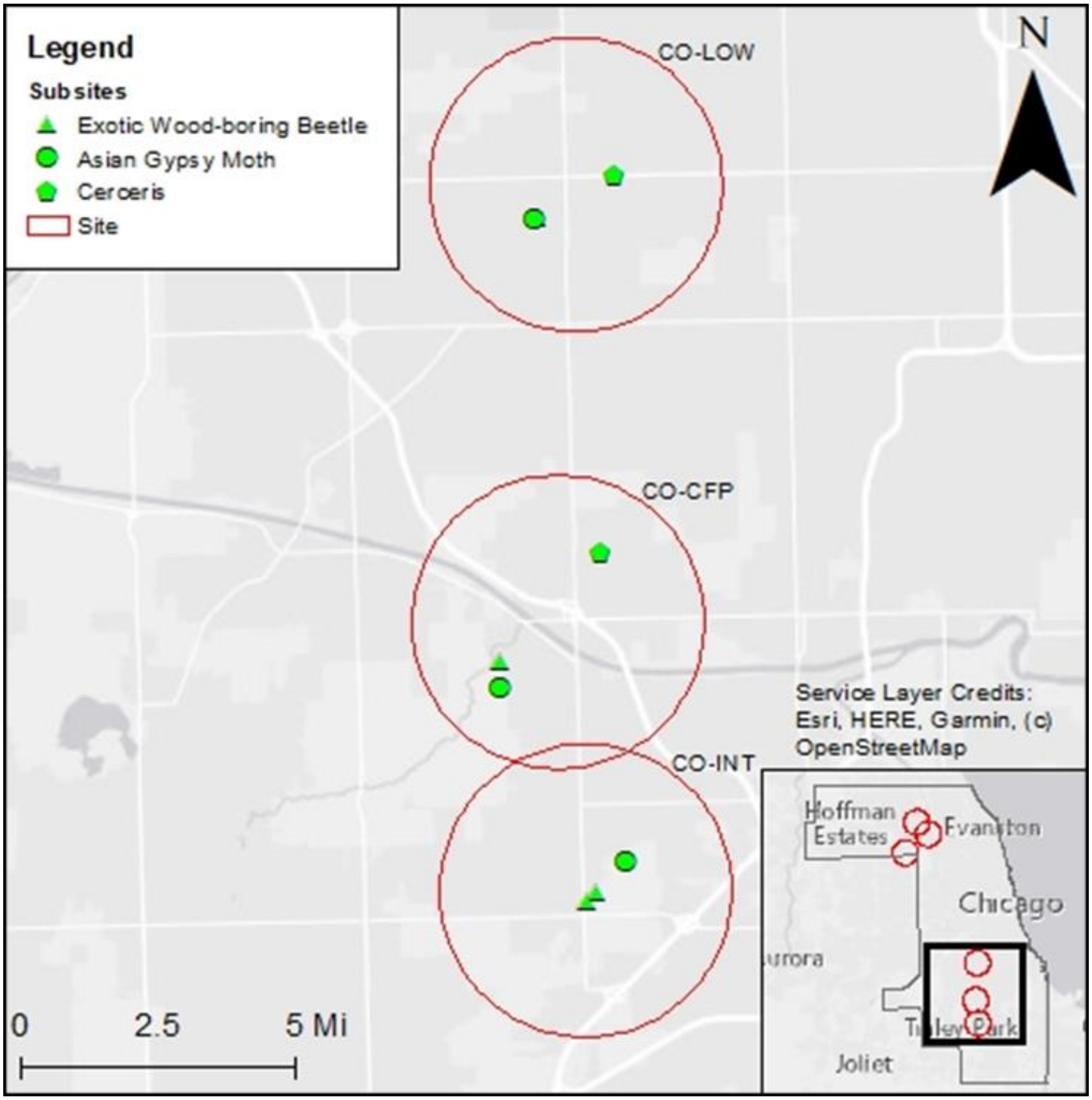

Figure 10. Sites and Subsites in Southern Cook County

This figure shows the sites and subsites in southern Cook county. The sites are CO-LOW, CO-CFP, and CO-INT. The synthetic activities that were created are non-spatial and are related to the subsite's shapefile through the primary key SubsiteID. The activities that were created are trap installations and samples being taken from a subsite. A table of the subsites and activities can be viewed in Appendices B and C, respectively.

3.3. Database Design

This section discusses how the database was designed and how the feature services were created. It goes into depth on the transition of APHIS's Access database to an enterprise geodatabase. It also discusses domains, relationships, and symbology.

3.3.1. Creating an Enterprise Geodatabase

The first step in building this Web GIS was to create an enterprise geodatabase. This geodatabase was stored in SQL Server which allows for feature classes to be published as feature services. These feature services can then be consumed in web maps to allow for data collection for multiple users. Figure 11 shows the tool dialog box that is used to create the enterprise geodatabase.

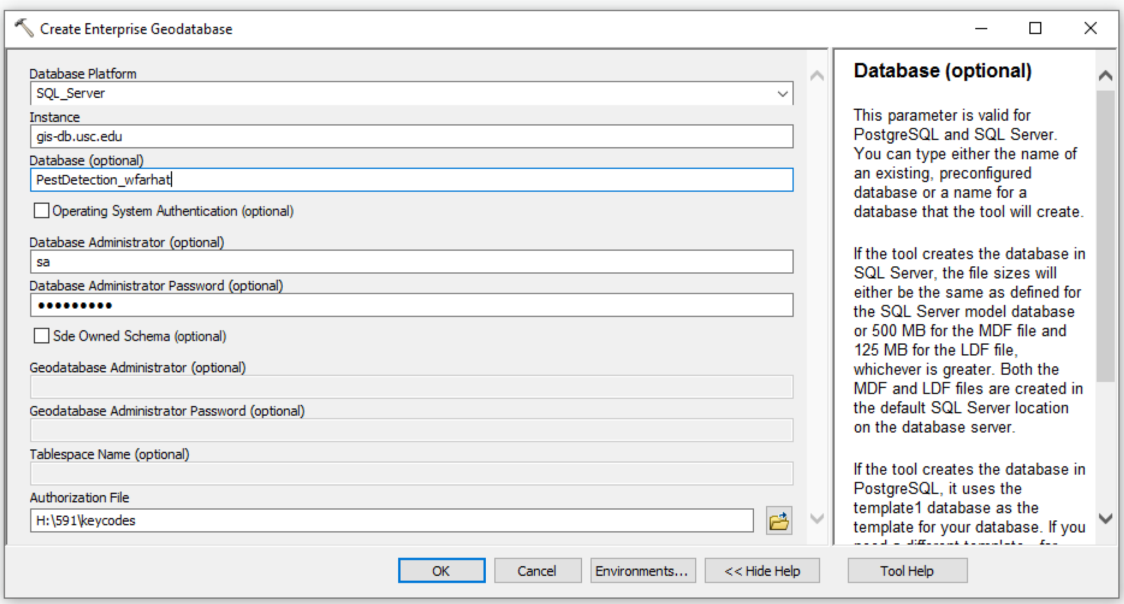

Figure 11. Create Enterpise Geodatabase Tool

After the enterprise geodatabase was created, a user was created in order to publish feature services. Figure 12 shows the tool dialog box to create a new database user.

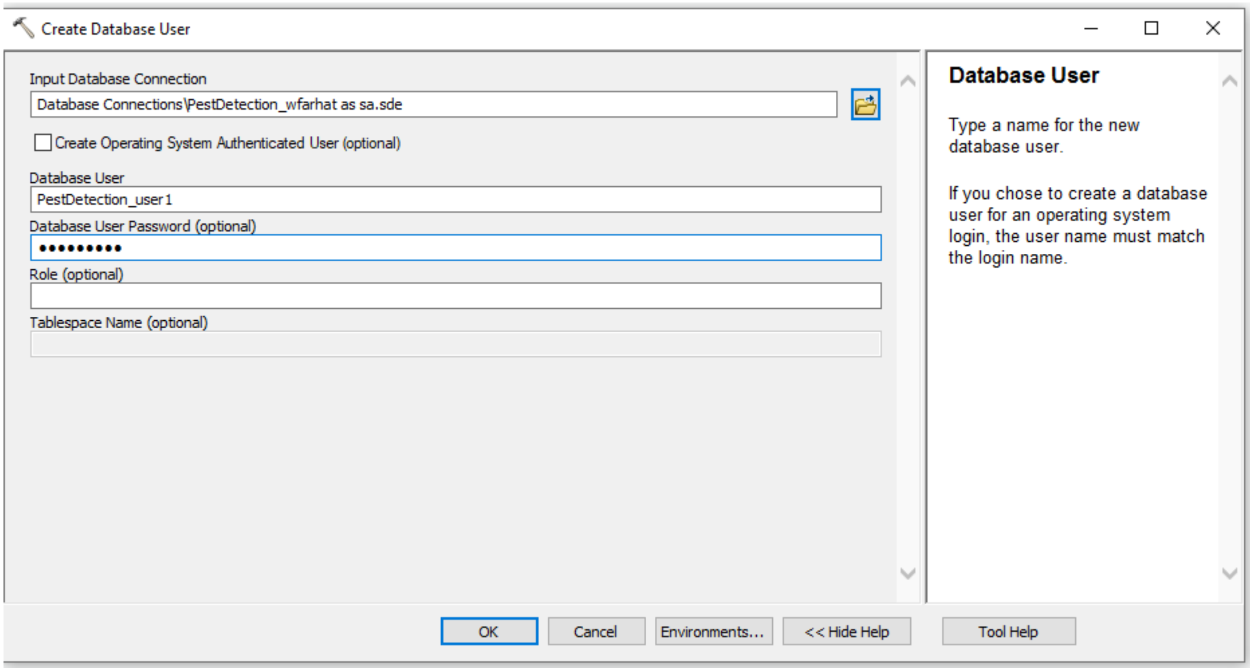

Figure 12. Create Database User Tool

After the geodatabase and database user is created, the geodatabase can then be registered with ArcGIS Server. Registering the geodatabase with ArcGIS Server allows for feature services to be stored there and called upon in web maps.

3.3.2. Creating Feature Classes and Tables

The sites and subsites shapefiles, and the activities table that were synthetically created in Section 3.2.3 were used in this Web GIS for data collection layers. These shapefiles were converted to feature classes in the enterprise geodatabase. Attachments were added to the Subsite feature class which allows for pictures to be uploaded via Collector. The activities table was added to the enterprise geodatabase through the Table to Table tool. For the subsite table, an additional field was added called "SurveyStatus" which indicates whether a trap or baseball diamond is due for a service based on the most recent activity or visit. A python script was required to populate this field and will be further discussed in Section 3.3.6. All these feature classes were created using the Projected Coordinate System: WGS_1984_Web_Mercator_Auxiliary_Sphere, which is the same coordinate system that AGOL uses.

The additional datasets discussed in Section 3.2, Cook County Boundary, Illinois Nature Preserves (INP), and Illinois Protected Lands (IPL) were projected to WGS_1984_Web_Mercator_Auxiliary_Sphere to match the projection of the data collection layers and imported into the enterprise geodatabase. Further geoprocessing was required to clip INP and IPL to the extent of Cook county.

3.3.3. Creating Relationships between Feature Classes and Tables

In order to have a proper functioning database, as well as more efficient data collection, relationships were added between data collection feature classes and tables. Relationships were built based on the Entity-Relationship diagram shown in Figure 8. Two relationship classes were created using the Create Relationship Class tool. The first relationship class was built between Site and Subsite using the SiteID primary key. It is a one-to-many relationship, meaning that many subsites can be contained within each site. The second relationship class was created between Subsite and the Activities table using the SubsiteID primary key. This is also a one-to-many relationship, meaning that each subsite can have many activities associated with it. The creation of these relationships allows for easier querying of data as well as accessing related activities within Collector and the operations dashboard. For example, subsites associated with the site “CO-WAL” can easily be viewed, as well as the activities associated with each subsite.

3.3.4. Adding Domains and Subtypes

In order to facilitate data entry and collection in the field, domains were added to each feature class and table in the enterprise geodatabase. This enables dropdowns for each field containing multiple options when entering a new site, subsite, or activity. The domains were constructed using the Table to Domain tool. This tool enabled adding domains from the additional tables that were provided in the APHIS Access Database. An example of some of the domains and coded values for the "Action" domain can be viewed in Figure 13.

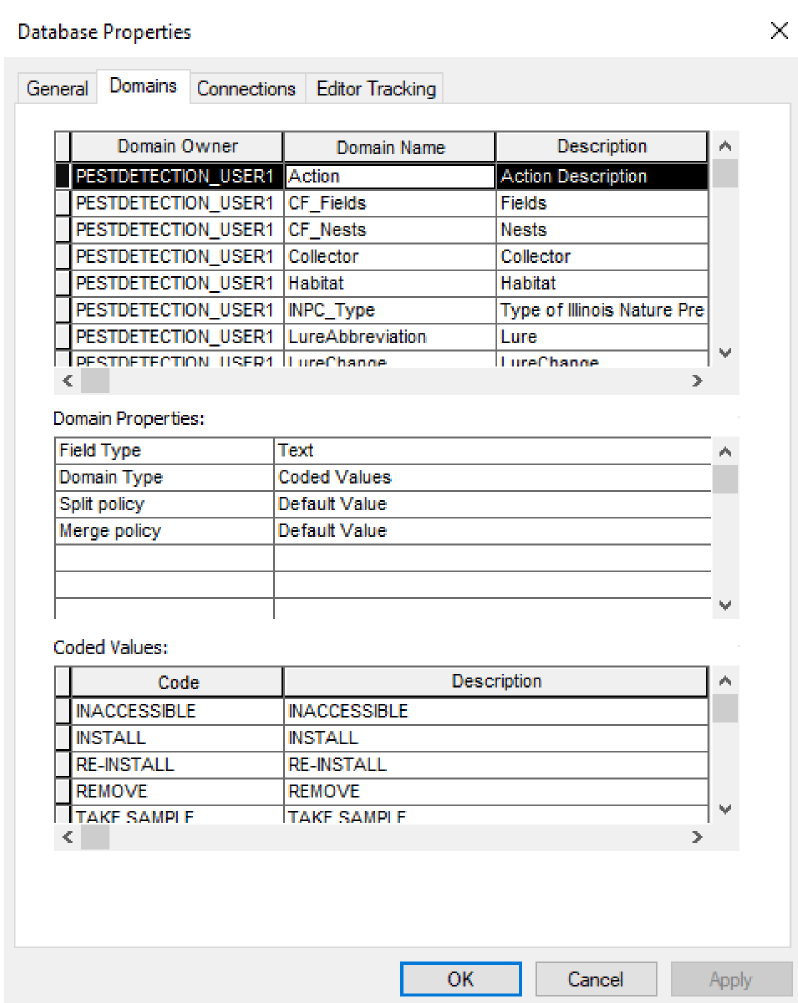

Figure 13. Database Properties dialog showing Domain Values

In this figure, the "Action" domain provides different codes when it is applied to a field in a feature class or table. When entering an Action in the activities table, the coded values will be available in a dropdown for easier data collection. Domains were applied to their appropriate fields in feature classes and tables.

Subtypes were created for the Subsite table based on the three different types of surveys that are conducted—Exotic Wood-boring Beetle Trapping, Asian Gypsy Moth Trapping, and the Cerceris Survey. These different subtypes can be viewed in Figure 14.

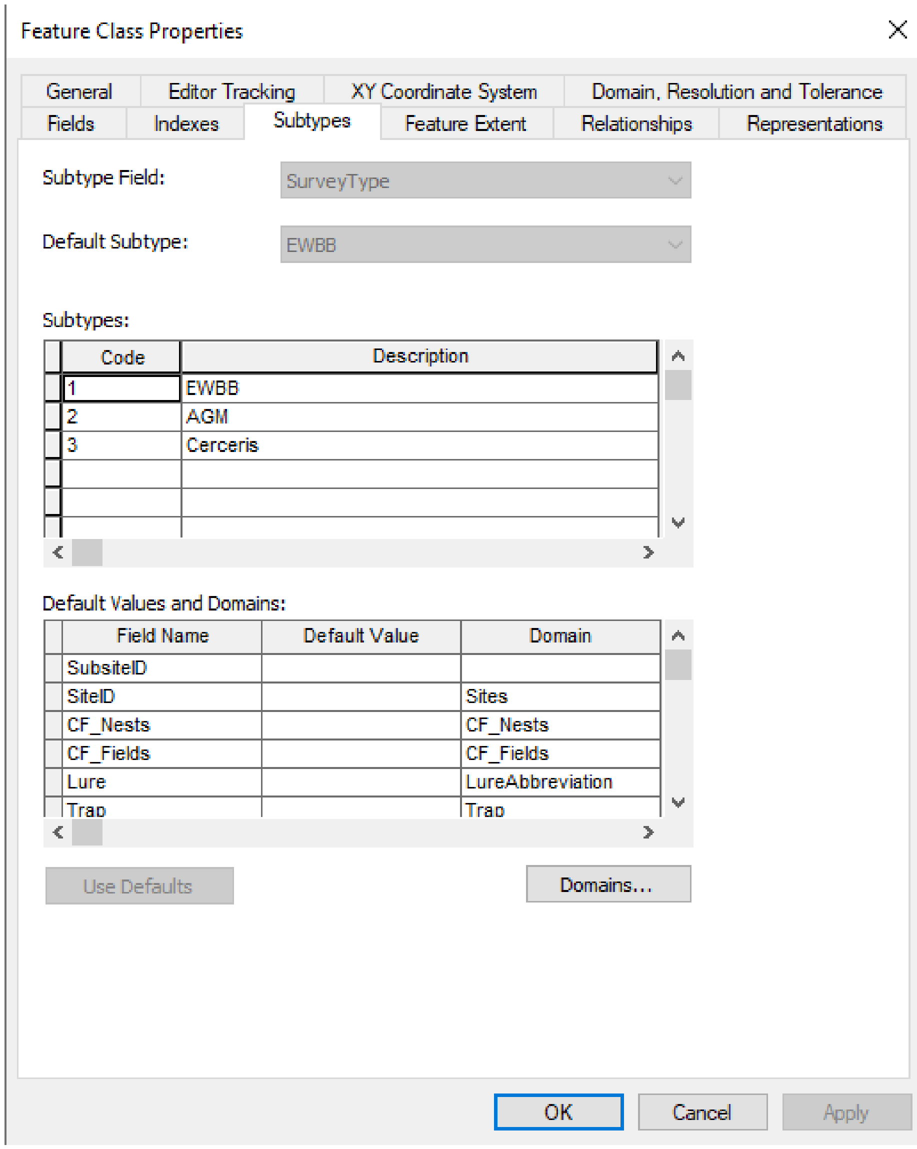

Figure 14. Subtypes for Subsite Feature Class

Subtypes were created in order to better organize the different types of surveys and to more easily apply appropriate symbology based on the survey type when adding a new subsite.

3.3.5. Symbology

Symbology for the site and subsite feature class was created in ArcMap. Symbology was specifically chosen to help technicians easily view on the map which types of subsites were in view. The symbology was further evaluated by users in a feedback survey in Chapter 4. A map showing symbology for these classes can be viewed in Figure 15.

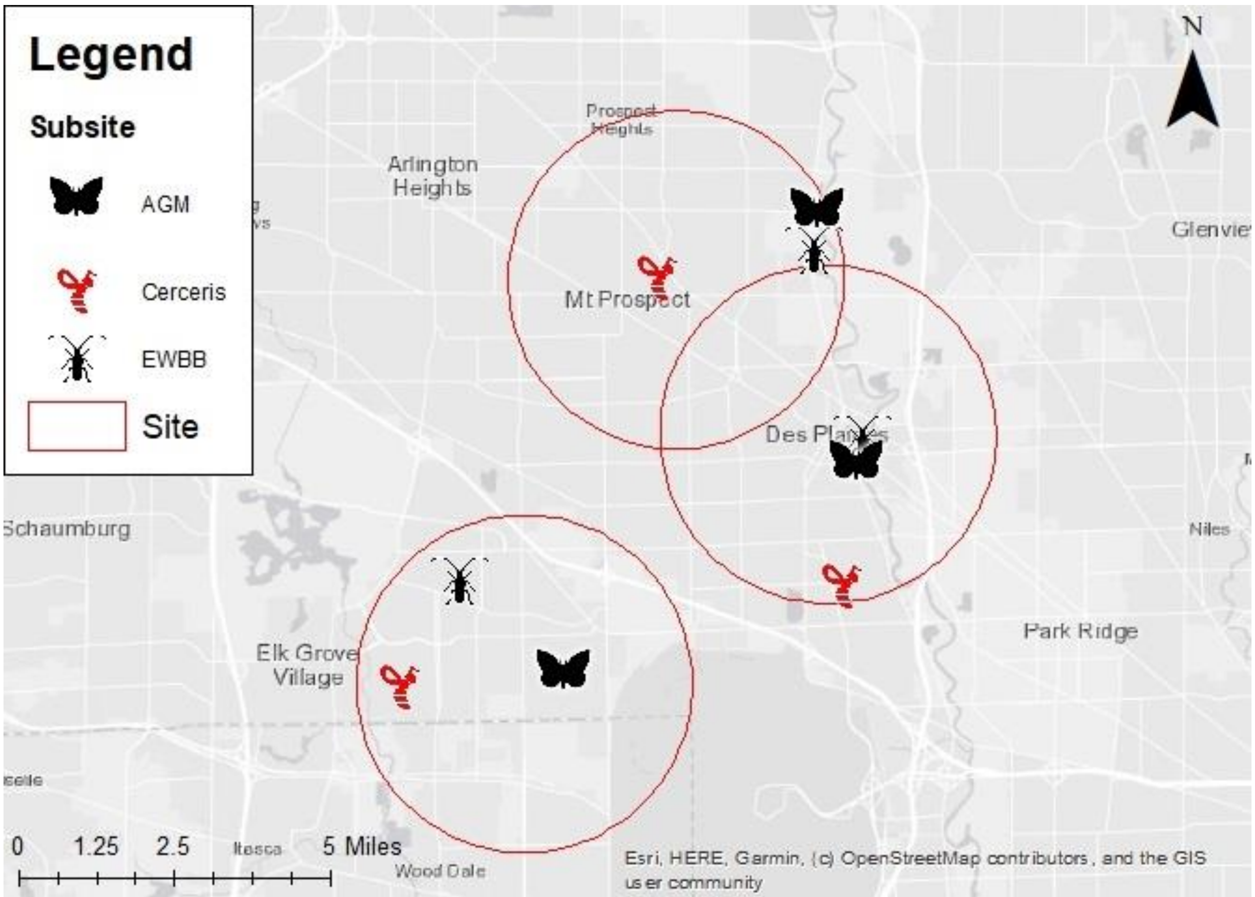

Figure 15. Symbology for Subsites and Sites in Cook County, IL

Symbology for the subsites contained three different symbols, one for each type of survey. The moth symbol was for the Asian gypsy moth survey, the wasp was for the Cerceris survey, and the beetle was for the exotic wood-boring beetle survey. The symbology was based on the different subtypes for the subsite feature class. The black symbols indicated a subsite that is currently up-to-date or did not yet require a service. A backend script was run to update subsites based on recent activities and updated symbology accordingly which is discussed in Section 3.3.7. Since these feature classes were published in a feature service, labeling is not supported. Labeling was completed using AGOL which will be discussed further in Section 3.4.3.

Base layers that will not be used for collecting data include Illinois Protected Lands, Illinois Nature Preserves, and Cook County Boundary. These base layers can help enhance data collection by providing locations where traps can be placed. The symbology of the layers is shown in Figure 16.

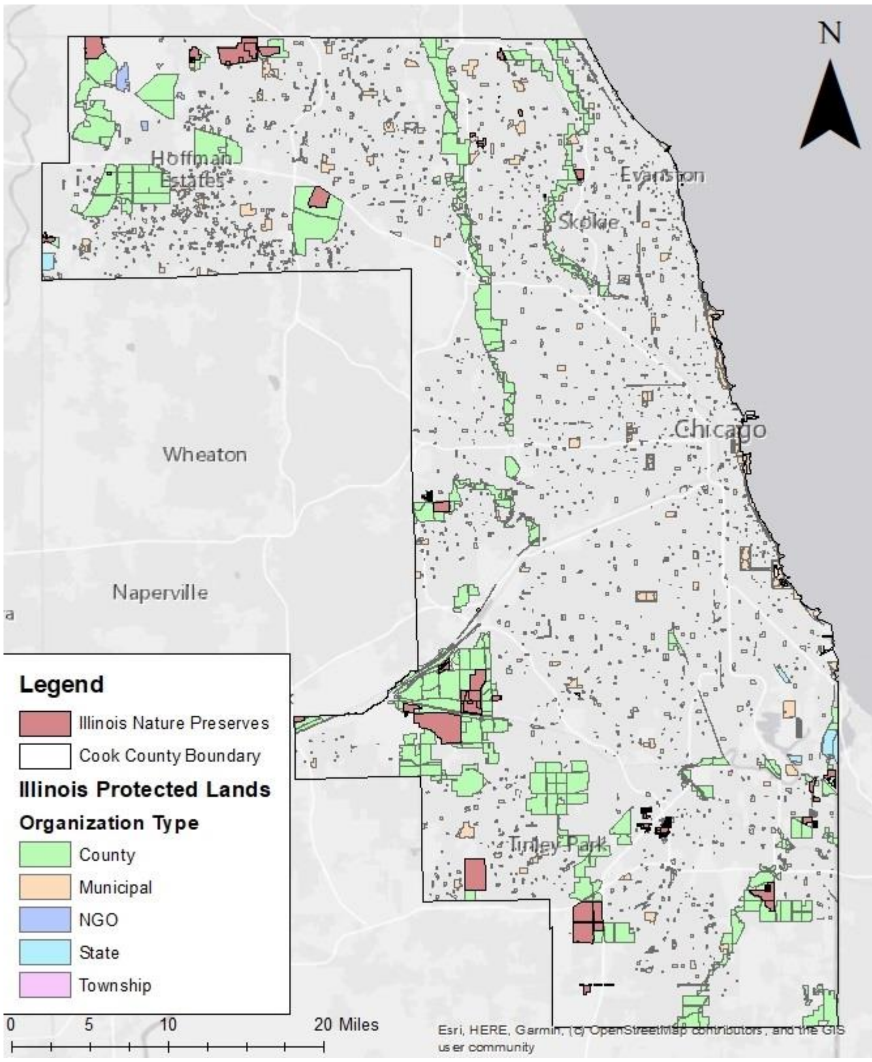

Figure 16. Symbology for Base Layers

In Figure 16, the symbology shown was chosen in order to show a different color for each different type of organization that the land may be owned by. Illinois Nature Preserves are areas where surveys cannot be conducted, so a darker red color was chosen for these polygons. Transparency was not used in these layers as it can be easily adjusted in a web map on AGOL.

3.3.6. Backend Data Processing

AGOL doesn't have much support for working with related tables in a web map. For instance, updating the subsite table based on a recent activity is unachievable in AGOL. A script was built to help address this issue.

The script utilized ArcPy cursors to update the subsite table based on the most recent activity associated with each subsite. It stored this date in a field in the subsites table. The field calculator was then used to calculate the number of days between the most recent activity and the current data. If the amount of days exceeded 14, then the "SurveyStatus" field of the subsite table is updated. A snippet of the code and associated code values can be viewed in Figure 17.

```
# Code Values
# 1 = EWBB
# 2 = AGM
# 3 = Cerceris
# 4 = EWBB Due
# 5 = AGM Due
# 6 = Cerceris Visited

if ((SurveyStatus == 1) and (Days > 14)):
    return 4
elif((SurveyStatus == 2) and (Days > 14)):
    return 5
elif((SurveyStatus == 3) and (Days > 0)):
    return 6
elif((SurveyStatus == 4) and (Days < 14)):
    return 1
elif((SurveyStatus == 5) and (Days < 14)):
    return 2
else:
    return SurveyStatus
```

Figure 17. Code Values and Code Snippet

This code is used as the expression in the field calculator tool which updates the SurveyStatus field based on days since the last subsite activity. This field can be symbolized once consumed as a feature service in a web map in order to provide a visual notification of due traps or subsites to survey.

3.3.7. Publishing Services to ArcGIS Server

After the feature classes, tables, and symbology were complete, the layers were ready to be published as a feature service to ArcGIS Server. Two different feature services were created. The first service contains the data collection layers which includes Site, Subsite, and Activities. These layers were published with feature access allowing data collection and editing of the data except for the Site feature class. Sites still need to be entered through ArcMap due to additional geoprocessing of buffers and geocoding. The second feature service that was created contains all the base layers which include Illinois Protected lands, Illinois Nature Preserves, and Cook County Boundary. This allows for the first feature service to be stopped while running backend scripts without stopping all the base layers.

3.4. Collector and Operations Dashboard Design

This section describes the creation of the web map in AGOL which can be used in Collector and the operations dashboard. Both applications are available through Esri. Collector uses the web map directly to facilitate data collection in the field and the operations dashboard uses the web map to filter and query data. This section also discusses symbology that needed to be changed in the web map, as the feature service did not support such functions.

3.4.1. Creation of Web Map and Consuming Feature Services

After the feature services were published to ArcGIS Server, they were ready to be consumed in a web map. In AGOL, a new web map was created, and the feature services were entered into the map from the REST endpoints on ArcGIS Server. This allowed the layers that were published through the feature service to be consumed into the map.

3.4.2. Symbology and Pop-ups

Symbology changes were needed once the layers were consumed in the web map and after the synthetic data was created for subsites and activities. Transparency was set to 50% for the base layer polygons to allow for easier viewing of what's underneath such as a forest on a land cover basemap. For the Subsite table, symbology needed to be changed based on the "SurveyStatus" which provides a visual notification of whether a trap needs service or if a baseball diamond has not yet been visited. This symbology can be viewed in Figure 17.

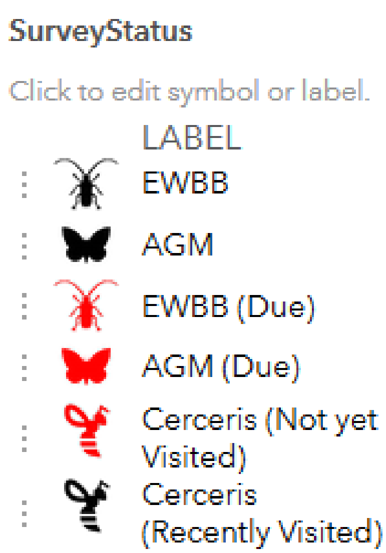

Figure 18. Symbology for Subsite layer based on SurveyStatus

This symbology allows the user to quickly glance at the map and see which traps are due for service and which baseball diamonds have not yet been visited.

Since feature services do not support labels, labels had to be added once the feature services were consumed in the web map. A web map portraying labels can be viewed in Figure 19 on the following page.

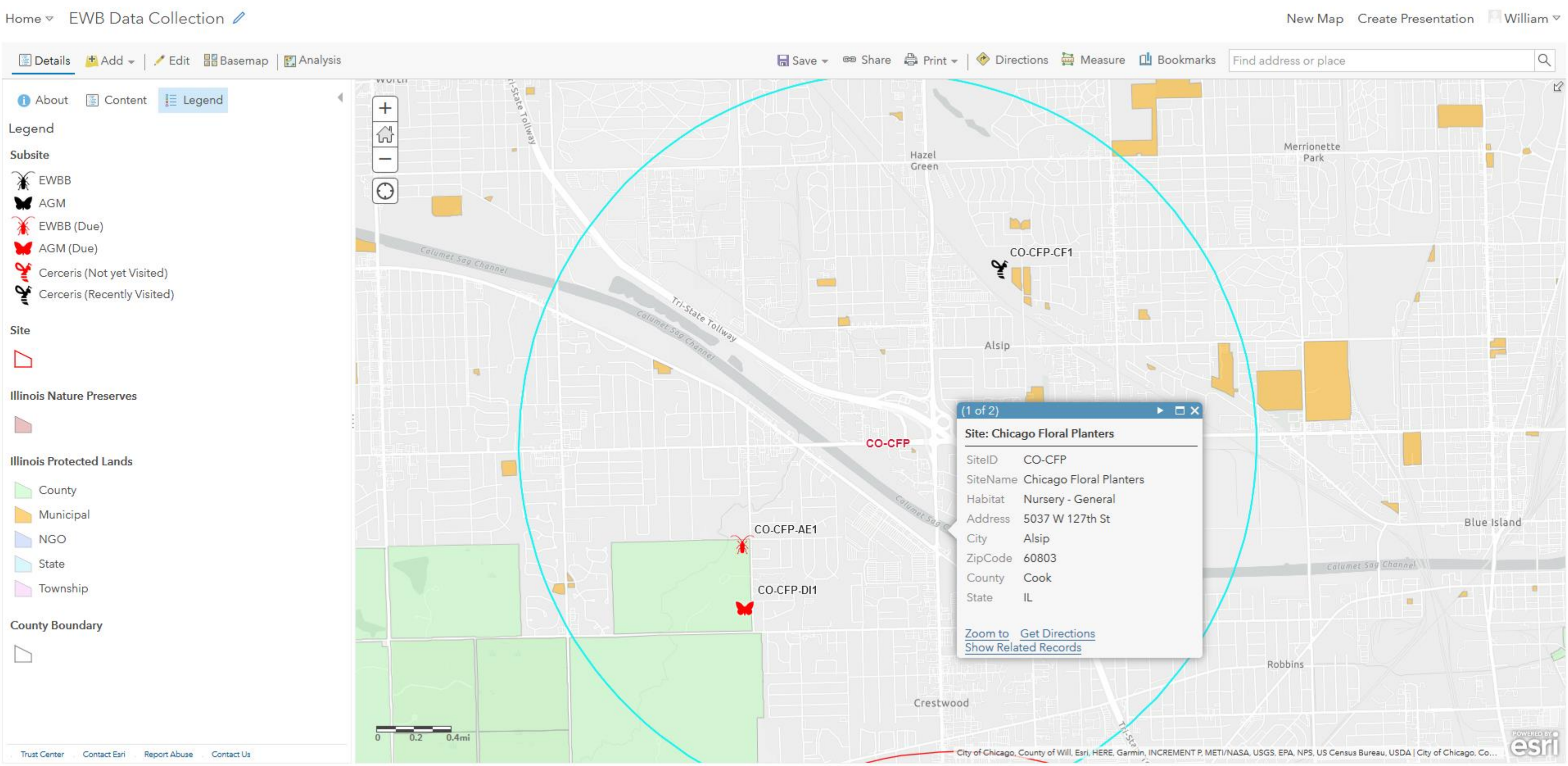

Figure 19. Web Map displaying labels for sites and subsites

The SiteID is utilized for the labels for the Site layer. The SubsiteID is used for the labels for the Subsite Layer. APHIS uses specific site codes for each site and specific codes for each subsite. The subsite is concatenated based on the SiteID, and the lure abbreviation or survey type. For example, CO-CFP-DI1 means Chicago Floral Planters in Cook County, with a Disparlure lure. The CF1 in CO-CFP-CF1 means Cerceris field #1 at that site. Visible labels allow for the user to glance at the map and quickly see which subsite is which.

One change was needed for the information displayed on pop-ups for subsites. The backend script that runs updates subsites based on the most recent activity. It provides the date of the latest activity. A new field was constructed using an Arcade expression to display how many days it has been since the last visit. This is important because unless the backend script is ran every day, subsites might not contain accurate symbology. It is also important because although a baseball diamond is visited, it may not have been visited in a while. The user can decide to visit that subsite, or baseball diamond, based on how many days have passed. This pop-up can be seen in Figure 20.

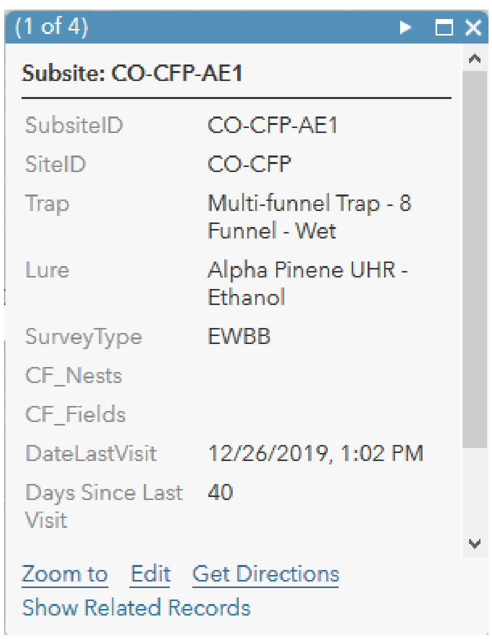

Figure 20. Pop-up displaying days since last visit

The days since last visit field can provide the user with how many days have been since the last visit without having to do the calculation themselves.

With the final changes to symbology, the web map was ready to be used with Collector and an operations dashboard. With an operations dashboard, the web map can be referenced and input directly into the dashboard. With Collector, the same web map can be used directly for data collection.

3.4.3. Collector

In order to use the web map in Collector, the web map needs to be shared with appropriate users. Once they have access, they can begin using the web map for data collection. Since the data collection layers are all related through primary keys, there is a setting in Collector which needs to be toggled in order to collect data. Figure 21 shows the setting that needs to be toggled.

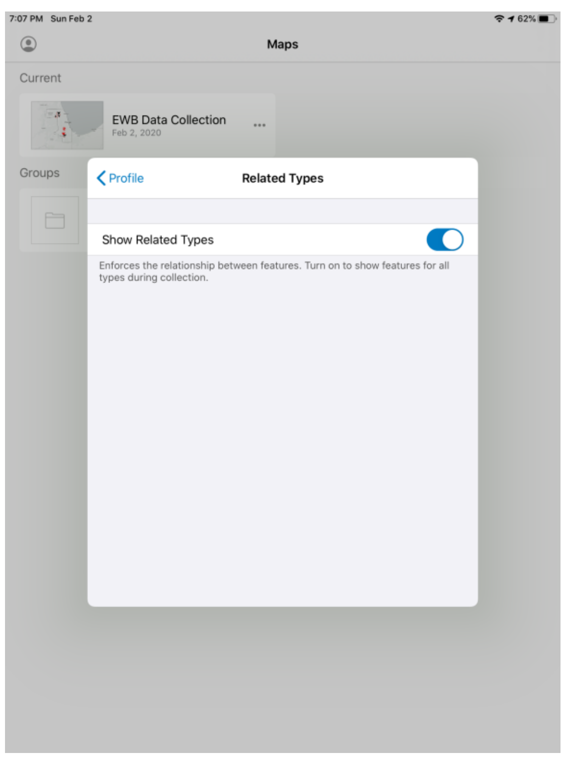

Figure 21. Collector Setting for Related Types

The setting in Figure 21 needs to be turned on in order to view related types. Once it is toggled, Collector is ready to be used for data collection.

3.4.4. Operations Dashboard

The same web map that was created for Collector was used in the operations dashboard. A dashboard can provide functionality that can be used with filtering selections and displaying graphs. Four sidebars were added to the dashboard showing the sites, subsites, activities, and attributes for activities. Figure 22 shows the sidebars that were utilized.

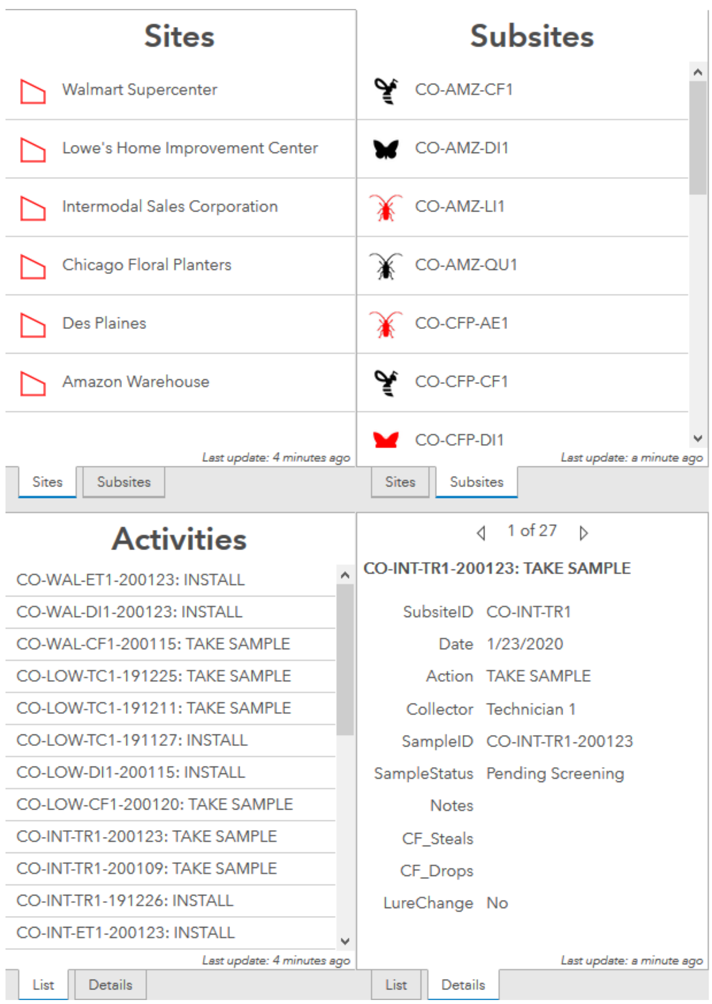

Figure 22. Operations Dashboard Sidebars

In Figure 22, the sites and activities sidebar are displayed from top to bottom with the subsites and details sidebar being underneath. The subsites and details can be viewed by clicking the appropriate tab at the bottom of the sidebar. Selecting a site from the ‘sites’ sidebar will filter the subsites in the subsites sidebar, as well as zooming to the corresponding site on the map. Selecting a subsite will filter the activities list, as well as the details list. It will also zoom to that area on the map.

On the web map, a selection can be made using the selection tool to also filter sites and subsites on the sidebar. Zooming in and out of the map will also filter sidebar results, except for activities since it is only a table.

Two charts were added to the dashboard to provide even more information. The first chart shows the distribution of lures across all subsites. Zooming in and out on the map will change what is displayed. Clicking on a piece of the pie chart will filter all subsites on the map that are using that specific lure. The other chart displays the survey status of subsites. Clicking on a specific status will filter all the subsites with the corresponding status.

Since the web map that was used in the operations dashboard did not allow data editing capabilities, a web app was created using Esri’s Web App Builder to allow for the editing of data in the dashboard. This web app can be selected by clicking the tab at the bottom of the dashboard under the map as the web maps are stacked on top of each other. Any selections made in the web app will not change any of the charts or sidebars.

3.5. User Feedback

Users tested the application and had access to iPhones, and AGOL in order to test data collection via Collector and the operations dashboard. A survey was conducted in order to gauge user satisfaction with the application as well as identify issues that needed to be addressed for future work. Results from the survey are displayed in the following chapter.

Chapter 4 Results

This chapter gives an overview of the application that was developed, examines end user workflows, assesses how the application was evaluated by users, and gives a discussion of the results. The application was composed of two parts- (1) data collection using Collector for ArcGIS, and (2) monitoring using an operations dashboard. The application can be used to collect data in the field for multiple surveys that APHIS in Chicago manages which include the Cerceris survey (biosurveillance of EWBB using wasps), Exotic Wood-boring Beetle trapping, and Asian Gypsy Moth trapping. The data collected in the field can be viewed in real-time using the operations dashboard which gives an overview of all the surveys as well as providing information on traps or surveys that require a technician’s attention. User testing involved subjects testing out the functionality of the application and completing a survey.

4.1. Application Overview

This section is divided into two subsections. Section 4.1.1. gives an overview of the functionality of Collector for collecting data in the field. Section 4.1.2. provides an overview of the operations dashboard and how it can be used to monitor survey operations as well as add or change data. Application development was guided by a user needs interview to shape an application in ways that would be beneficial to APHIS and improve data collection and monitoring workflows. This section also provides an overview for users on how to use certain features of the application.

4.1.1. Collector for ArcGIS

Collector for ArcGIS was the first component of the application. A web map was built in ArcGIS Online that used feature services for the data collection layers and background layers.

Synthetic data was created for sites, subsites, and activities. An overview of the Collector application can be viewed in Figure 23.

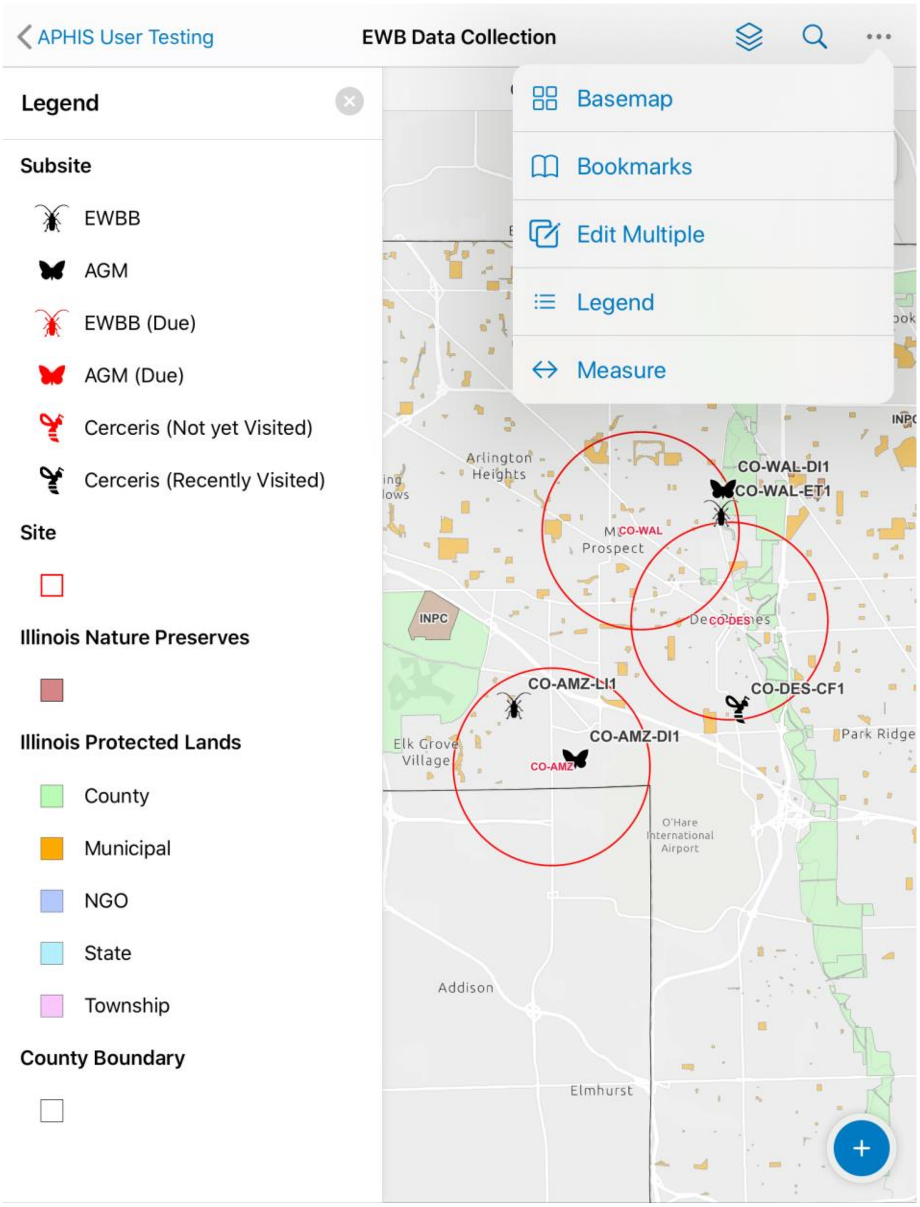

Figure 23. Collector Overview

This figure shows the map, legend, and how to access other features. The legend displays the symbology that was chosen for this application. The color of the symbol that was chosen for the subsites reflects whether further maintenance was needed for that subsite. A black symbol represents a subsite that has had a recent activity or visit within the past two weeks. Most surveys require a trap to be checked every two weeks. A symbol that is red reflects a subsite that is due for a service. This symbology change required a python script that can be viewed in Section 3.3.6. Sites were symbolized using a red outline for the 2-mile buffer and a label containing the SiteID. Through using the "…" button in the top right, the basemap can be changed and the legend can be toggled. In the bottom right, the blue plus sign can be used to add new subsites. This process can be viewed in Figure 24.

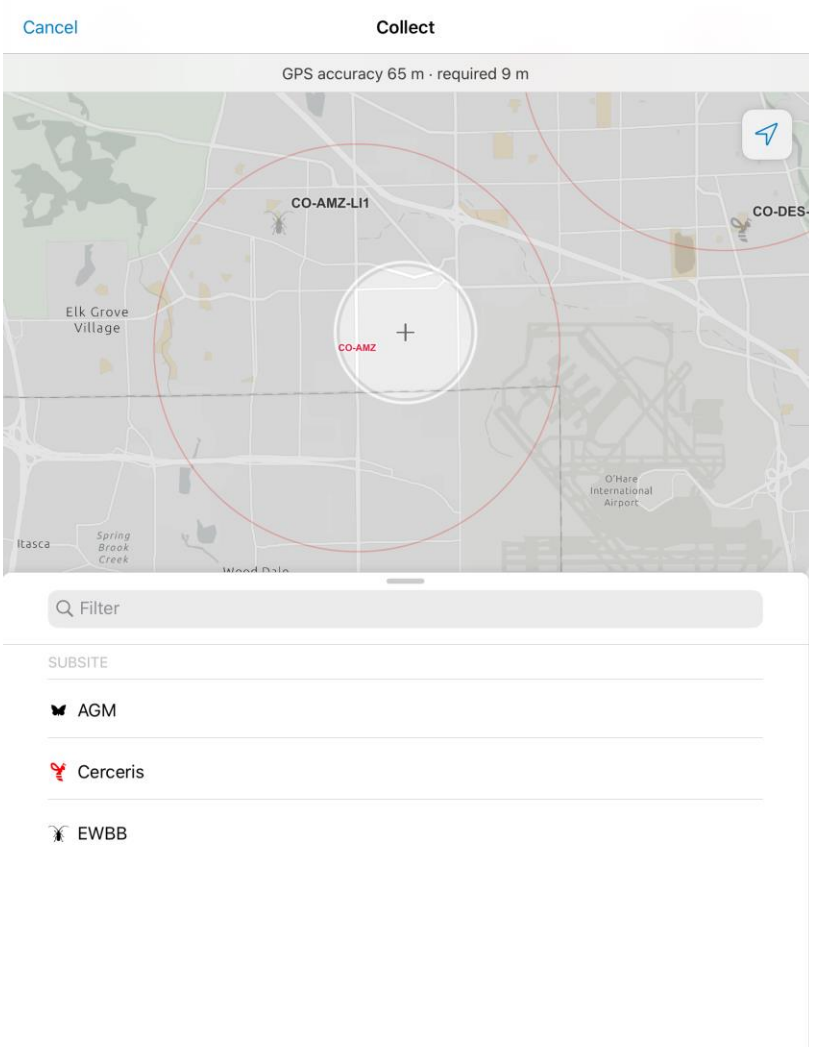

Figure 24. Adding Data in Collector

Subsites and activities are the only types of data that can be collected in the field. After a subsite type is selected, data can be filled in for that specific subsite. Figure 25 shows a subsite being entered for an Asian Gypsy Moth subsite. When adding a new subsite, the symbology color reflects a trap or survey that does not require maintenance for an additional 14 days.

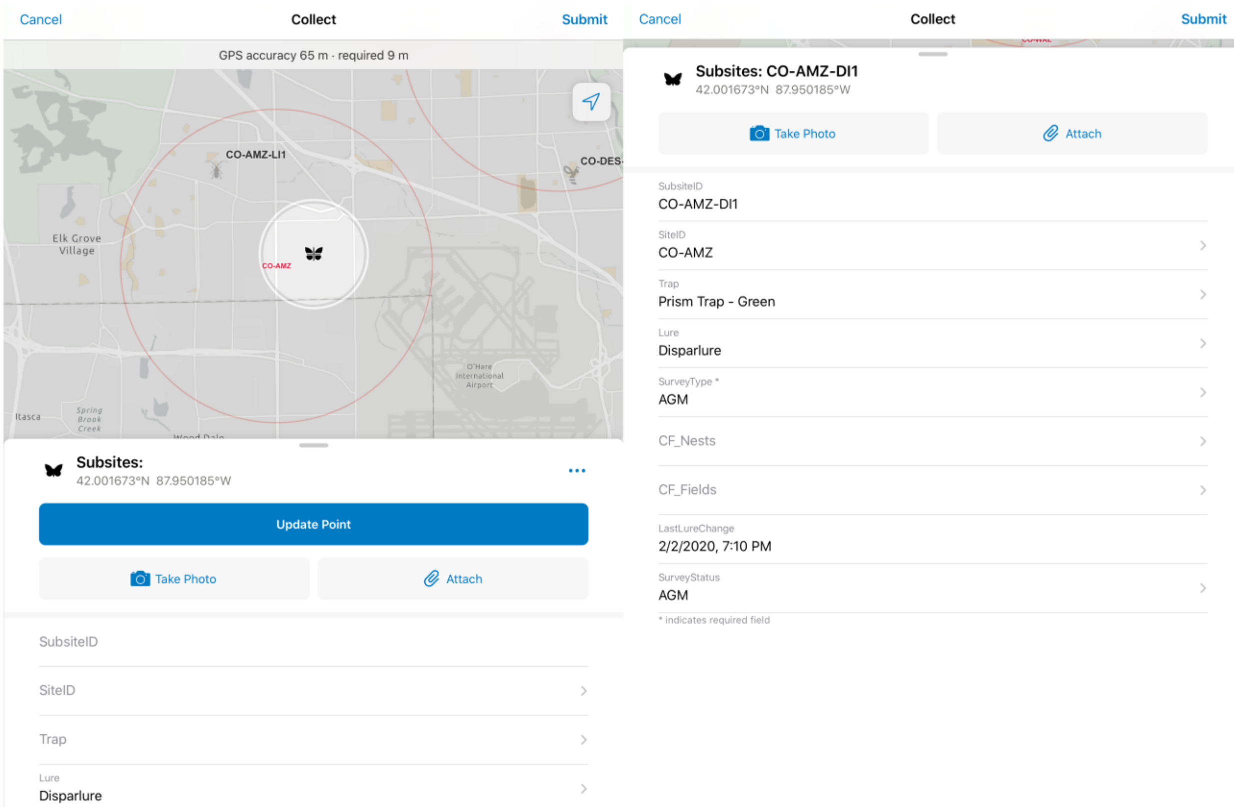

Figure 25. Adding an Asian Gypsy Moth Subsite

Photos can also be added to each subsite using the "Take Photo" button. This can provide additional information for technicians to help find their trap. Surveys usually take place over a couple months and areas can be overgrown and look entirely different during the next visit. After a subsite is created, activities can be added. This process is shown in Figure 26.

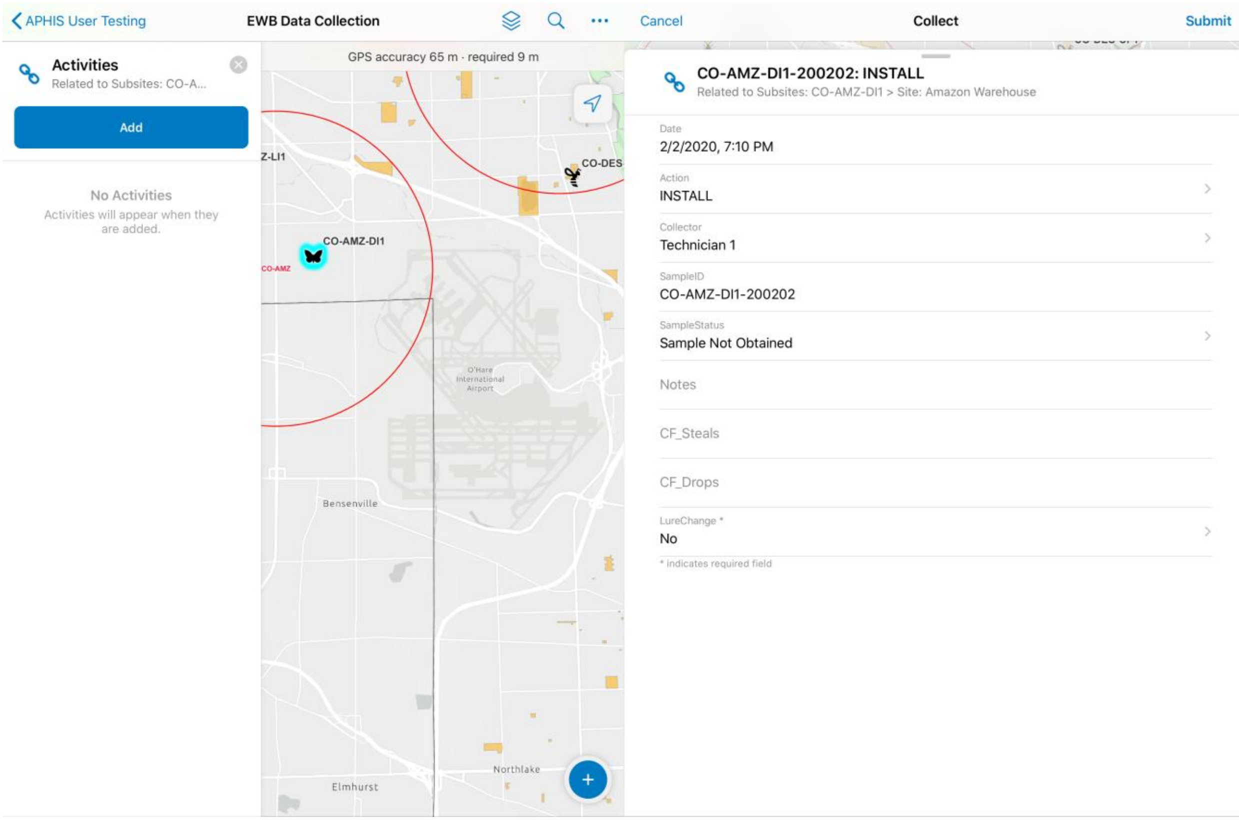

Figure 26. Adding a New Asian Gypsy Moth Activity

When a subsite is selected, an option in the sidebar appears to add a new activity to the subsite. If the subsite is an AGM or EWBB subsite, the first activity is usually installing the trap, which is this action that is selected in this figure. Other activities involve taking a sample or taking the trap down. In this case, a sample is not obtained because the trap was recently setup. After 14 days, the backend script will update the symbology of the subsite to red based on this recent activity.

4.1.2. Operations Dashboard

The operations dashboard provides an overview of survey operations. It displays all the sites and subsites on a map and associated activities can be viewed for each subsite. The operations dashboard updates data in real-time as it utilizes the same AGOL web map that is used in Collector. An overview of the dashboard can be viewed in Figure 27.

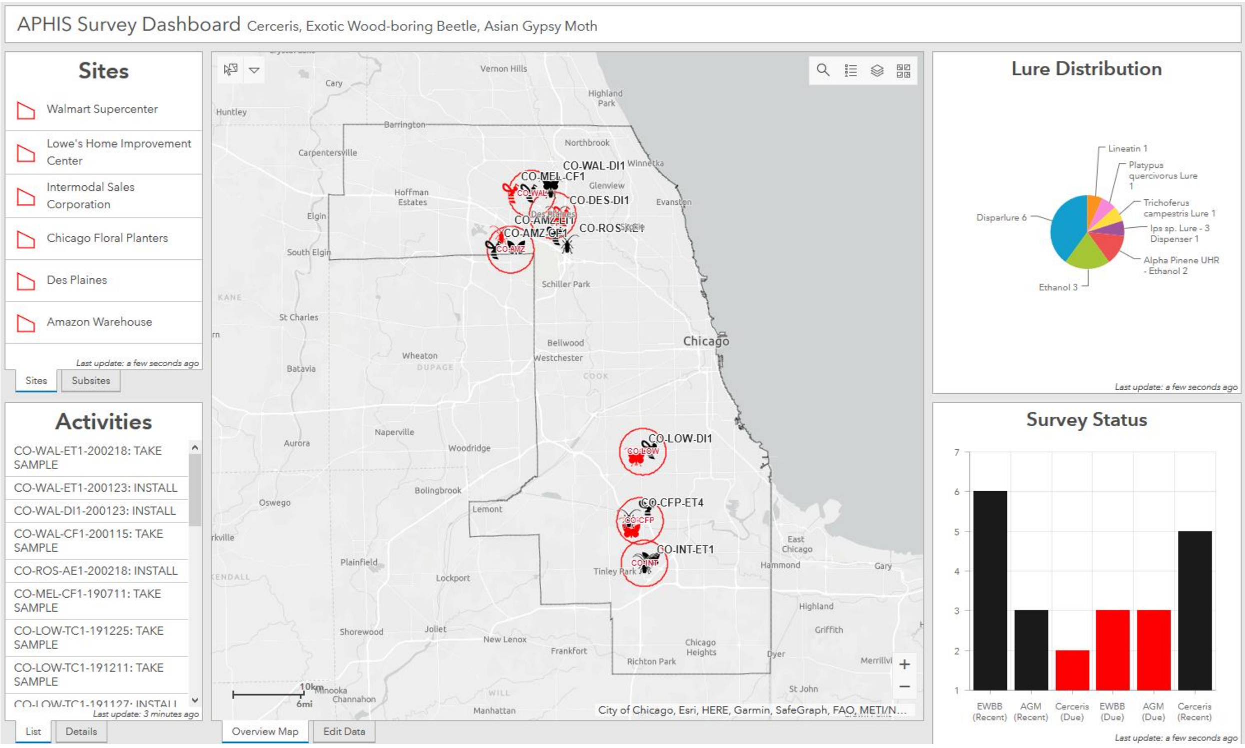

Figure 27. Operations Dashboard Overview

The map shown is an overview map that can be used for seeing different information about the sites and subsites. Zooming in and out and panning the map can change the pie chart and bar chart depending on which subsites are shown on the map. The pie chart shows the distribution of different lures that are currently being used for surveys. The bar chart shows which subsites are due for a service and ones that have been recently visited or are up to date.

Figure 28 shows the selector that can also be used to toggle which subsites or sites are selected. Selected sites or subsites will be reflected in the side bars on the left. The activities sidebar does not update unless a subsite is selected in the sidebar.

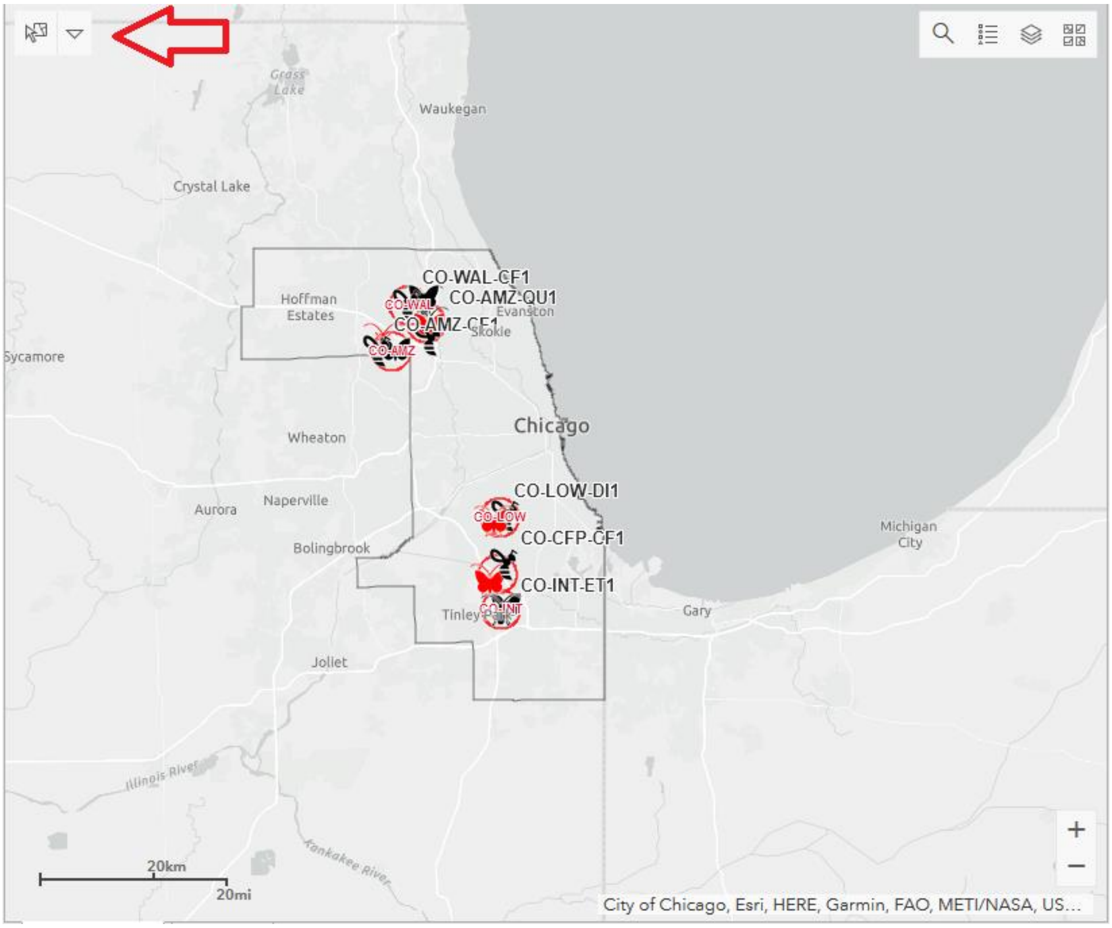

Figure 28. Making a Selection in the Dashboard

The purpose of this feature is to be able to reduce the number of subsites or sites that appear in the sidebar. Multiple technicians each have their own routes and subsites that they manage. This tool can be used to select their specific subsites or sites to appear in the sidebars.

Clicking on a site in the sidebar on the left of the dashboard will filter corresponding subsites in the subsites tab. It will also zoom to that area of the map. In Figure 29, it shows the subsites tab being updated after clicking on the "CO-CFP" site in the sidebar. Clicking on a subsite in the subsites tab filters the activities list showing all the activities associated with a subsite. Clicking the details tab will give further information about each individual activity. The purpose of this is to provide a history of what has been done to each subsite during its lifetime.

Some information that can be inferred from this is when the last sample has been taken, when the trap was installed, and when it last had a lure change.

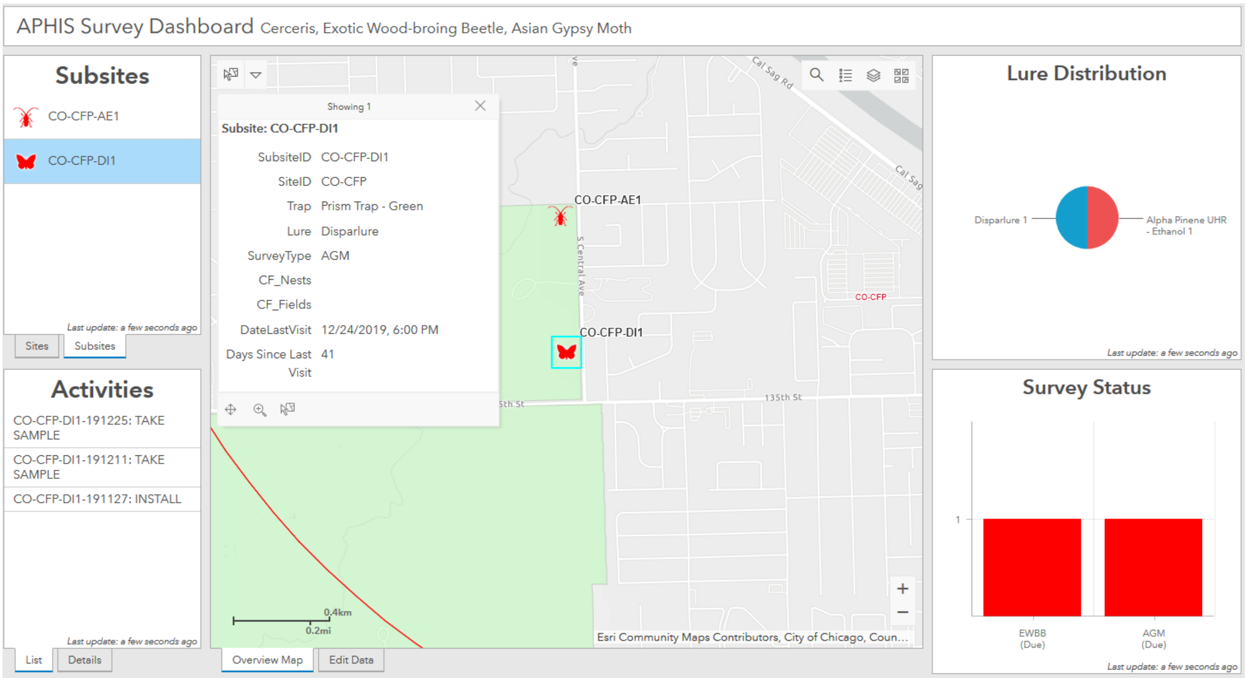

Figure 29. Dashboard Sidebar for Sites and Subsites

This figure also shows how the sidebars on the right, which include the pie chart of lure distributions and a bar chart showing current survey status, update based on which subsites are currently in view. Since both subsites have not been visited in the last 14 days, they are both due for maintenance.

The overview map within the operations dashboard does not provide the option of editing data. It is merely for viewing and filtering data, as well as providing additional information contained in graphs and charts. For this reason, an additional web app was created to provide data editing capabilities.

Figure 30 shows how to access the additional map in order to edit data. By clicking on the tab at the bottom of the map that says “Edit Data”, it pulls up the web map that allows editing of data.

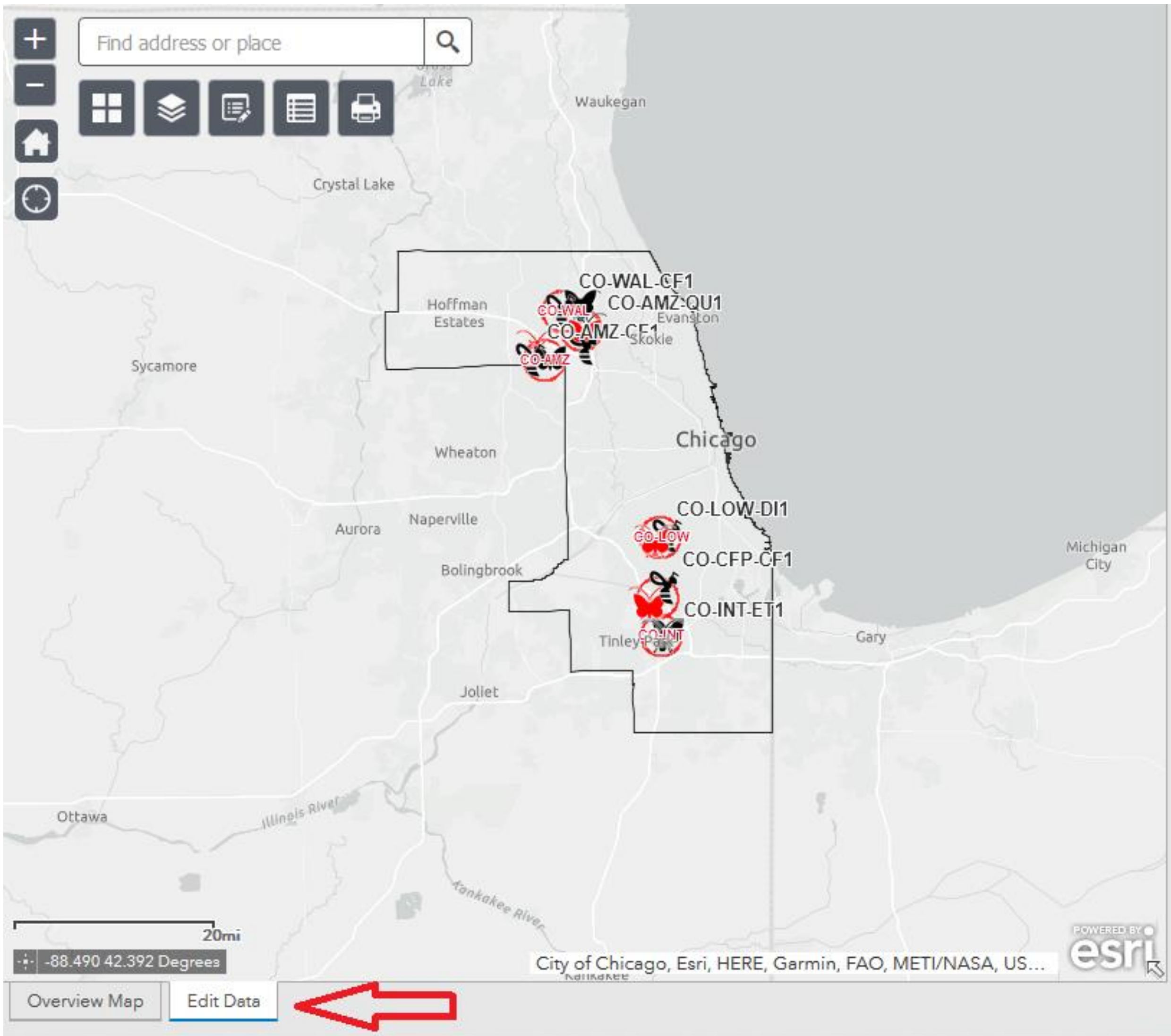

Figure 30. Web Map with Data Editing Capabilities

In this web map, sidebars are not updated based on selections made, zooming in and out, or panning the map. These capabilities are not possible when creating the operations dashboard. Clicking on a subsite will allow one to edit it and add additional activities. The purpose for this is to correct errors that were made in the field or to add activities that may not have been added when in the field. There are buttons on this map that allow you to change the basemap, toggle layers, edit data, view the attribute table, and print out a map.

Clicking on a subsite will allow you to edit it by clicking the "…" symbol on the button right of the popup. This process can be viewed in Figure 31.

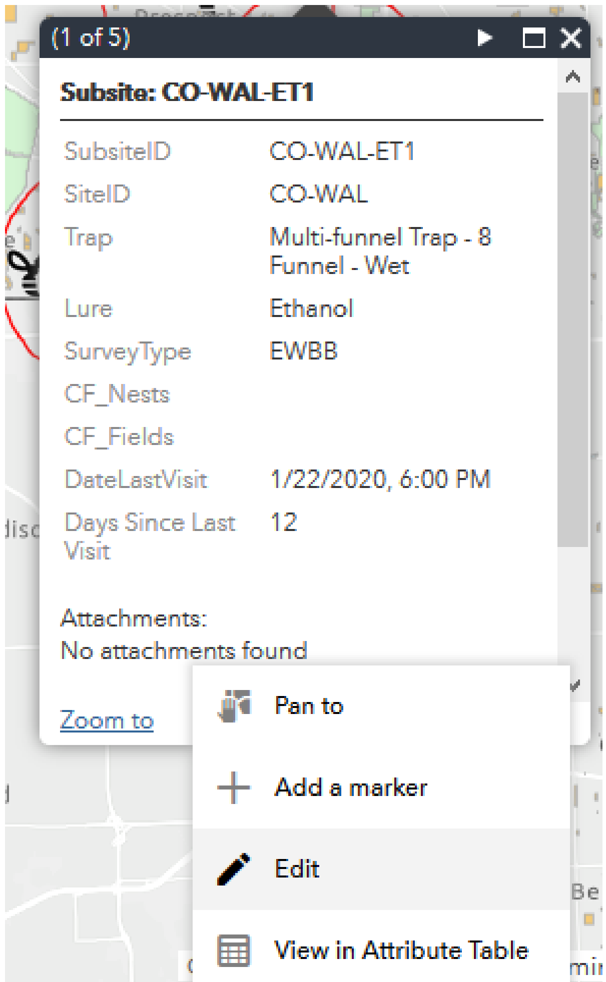

Figure 31. Editing Data within Subsite Popup

After clicking "Edit", activities for each site can also be editing by scrolling down to the bottom of the popup and clicking on "Activities" which will pull up related records for the subsite. In this additional web map on the dashboard, data can also be exported from the attribute table. In Figure 32, clicking the attribute button below the search bar will bring up the attribute table.

Clicking on options in the attribute table gives the option of exporting all the data to CSV. The purpose of this is to have a mechanism to easily add data back to APHIS's Access database for sample processing.

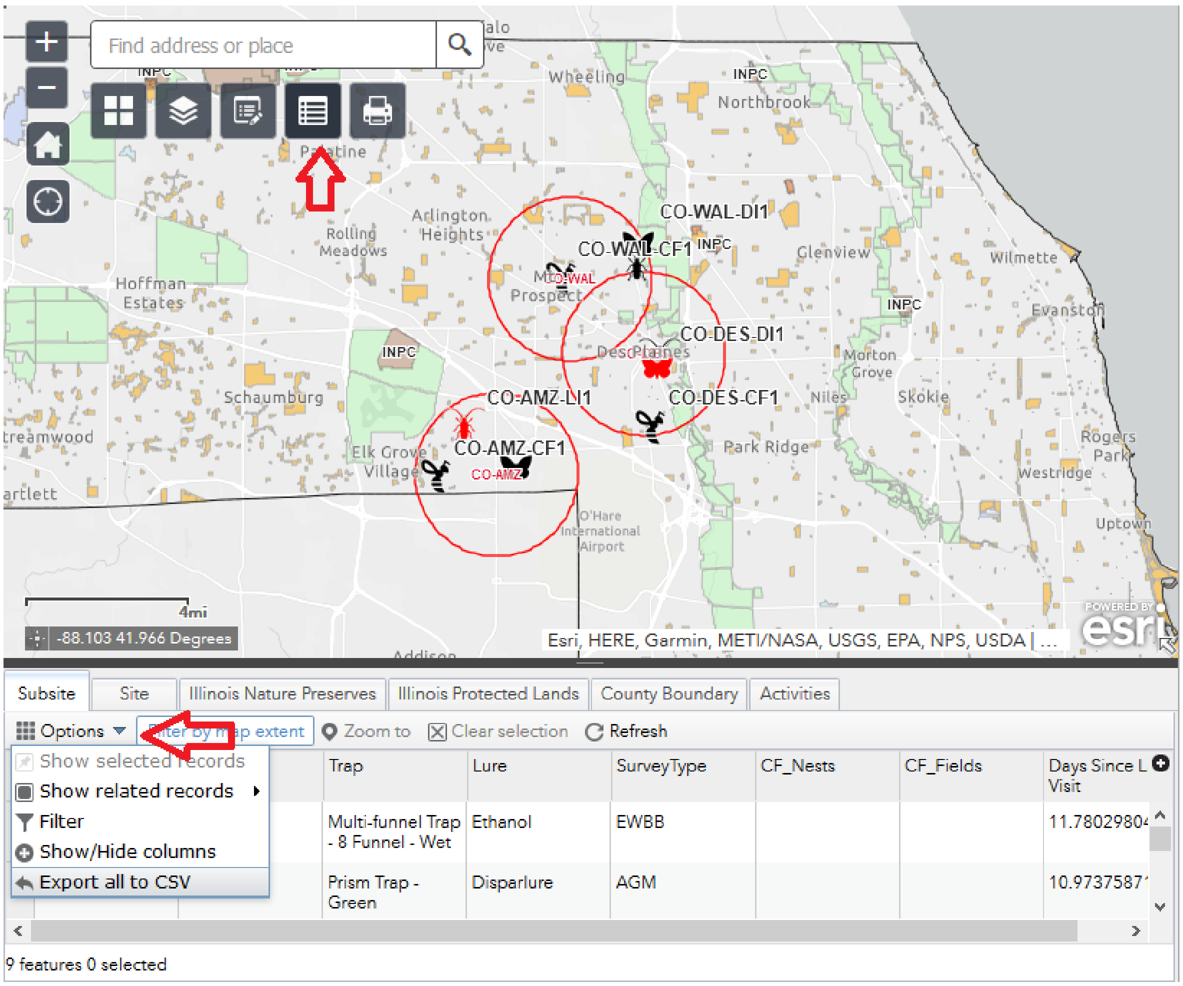

Figure 32. Exporting Data from the Dashboard

Each trap or survey involves collecting a sample with a unique SampleID. Access is the preferred method for managing and updating samples.

4.2. End User Workflows

Using a Web GIS instead of APHIS's 2019 methods would be quite different. The following sections discuss how the workflow would change for certain users. The first section discusses how it would change for the Pest Survey Specialist as well as the Field Operations Supervisor, who both work together to find suitable sites to trap.

4.2.1. Pest Survey Specialist (PSS) and Field Operations Supervisor (FOP)

The PSS and FOP are responsible for getting sites approved in the beginning of the field season. This involves reaching out to nearby forest preserve managers to get approval for setting up traps in their areas. A workflow diagram can be viewed in Figure 33 which details steps that a PSS or FOP would take using the Web GIS application that was developed.

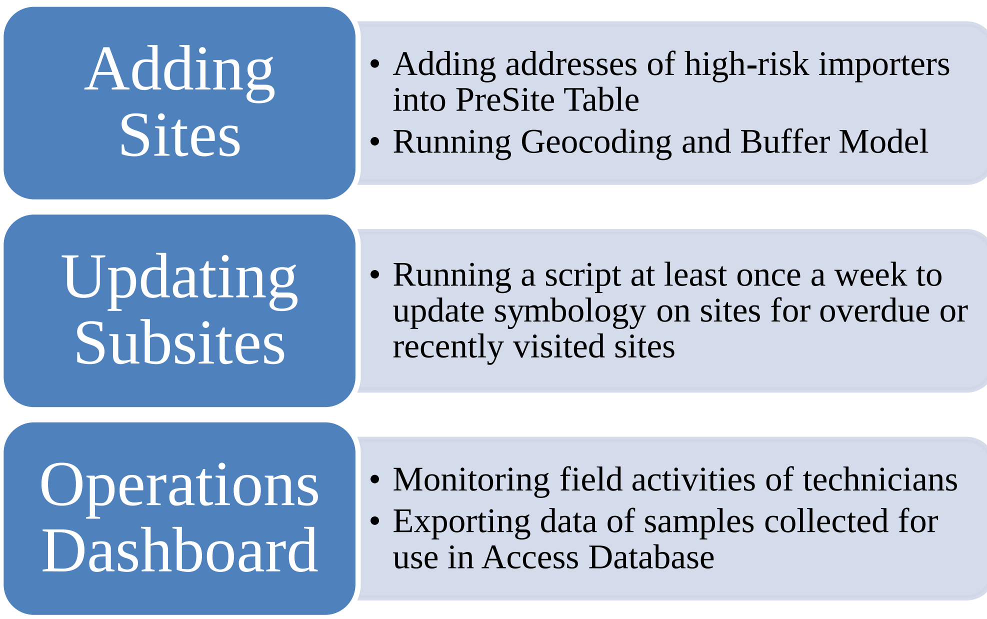

Figure 33. Web GIS Workflow for PSS and FOP

Adding sites would take a more digital form using a Web GIS. 2019 methods involved compiling a list of sites in APHIS's access database and determining where suitable sites to trap would be using either Google Maps or Google Earth. With this Web GIS, sites would be automatically geocoded from the Site table in access and buffered accordingly. This would provide technicians with the sites being visible in the operations dashboard and Collector. From here, the responsibility of setting up subsites is the field technicians.

These subsites would need to be updated to facilitate smoother field operations for the technicians. A script can be run which updates the subsite symbology based on recent activities. The operations dashboard would reflect these changes to the subsites and show which subsites are due for a service or ones that have been recently visited. It would provide a general picture of the current field operations and whether work is getting done punctually. Data can also be exported from the dashboard and tied into the MS Access database to better handle samples and their unique codes that have been collected from traps.

4.2.2. Field Technicians

The field technicians are responsible for data that is collected in the field and making sure it is without error and accurate. This data is usually written down on pen and paper and entered into MS Access at the end of the workday. With a Web GIS, it would allow data to be collected while in the field and a way to view it on the map in the office with an operations dashboard.

In Figure 34, it shows an example workflow for a technician utilizing a Web GIS. Instead of writing down coordinates for subsites, coordinates are automatically taken when creating a subsite using Collector.

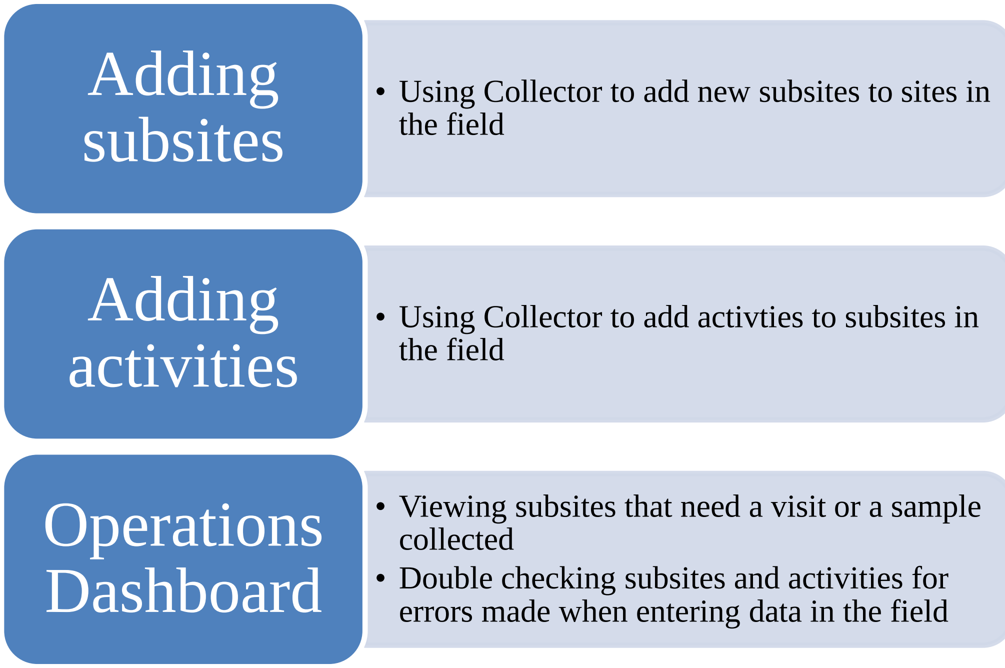

Figure 34. Web GIS Workflow for Field Technicians

Collector also gives the user appropriate attributes about each subsite to fill in with dropdowns to speed up data collection and reduce errors. Activities are also able to be added in Collector using relationships to relate tables and feature classes. Many activities can be added to each subsite showing the history of what was done at each subsite. 2019 methods involved entering all this data into Access after transcribing this information in the field. This process involves going through multiple forms in Access just to add one new subsite and a new activity.

The operations dashboard provides a new way to view and visualize the data in a web map. Technicians can click a subsite on the map to view its attributes such as trap type or survey type and view related activities. In Access, this was all done by viewing the data in tables and not being able to visualize the data.

4.3. Application Evaluation and Testing

The operations dashboard and collector were each used in application testing. The users were provided with a guide similar to what was discussed in Section 4.1. This section is divided into three sub-sections. The first section discusses the subjects who were involved in the user testing. The second section discusses the design of the survey that was used for feedback. The third section discusses the results of the survey.

4.3.1. Subjects

The subjects that were used to evaluate the application were the same users who were interviewed in the user needs interview which was discussed in Section 3.1.2. The field operations supervisor was not available during the time of testing. These interviews can also be viewed in Appendix A. These users include two field technicians and the pest survey specialist (PSS). The technicians tested Collector and the operations dashboard while the PSS only tested the operations dashboard due to the PSS mainly working from the office and not in the field.

The user needs interview was conducted via email. Participants filled out a word-processing document with answers to questions to gauge overall satisfaction with 2019 methods for data collection and monitoring as well as additional datasets or methods that could enhance their 2019 methods. Users were asked to perform testing and were provided with a guide on how to access and use the data collection map in Collector and how to use the features of the operations dashboard. Testing was conducted from February 3rd, 2020 to February 27th, 2020 and users were instructed to fill out a survey upon completion. The survey was distributed to five members of APHIS, ranging from field technicians to supervisors.

4.3.2. Survey Design

The survey that was used for feedback was designed using Google Forms. Questions were in the format of a multiple-choice grid, a linear scale and long answer. Likert scale questions were created with a five-point response scale based on difficulty, adequacy, satisfaction, and usefulness of the application. Users were told that results would be anonymized. The survey involved answering questions based on if the subject preferred the dashboard and Collector over older methods such as using pen and paper to transcribe data and entering it into Microsoft Access. It also contained questions that gauged satisfaction of using the application and difficulty of the application. A few questions about the usefulness of the symbology were also asked. If a low rating was given on any aspect of the application, a long answer question was provided for an explanation why. Screenshots of the entire survey can be viewed in Appendix D and are examined in the following section.

4.3.3. User Feedback

The users that participated in testing were asked what part of the application that they tested. Two of the users tested both the operations dashboard and Collector while one user only tested out the dashboard. This distinction is important because the operations dashboard and Collector are two different methods for achieving daily tasks for APHIS. Since only one user tested part of it, their responses needed to be interpreted differently. The Collector element of the application is only beneficial for technicians to use as they are the ones collecting data in the field.

The next question on the survey asked whether the tester preferred the application that was built for this project or the 2019 methods for accomplishing daily tasks. 2019 methods included using MS Access, iGIS (an iPhone application for viewing subsites), and writing down information with pen and paper. Daily tasks included viewing sites, viewing subsites, adding/editing/exporting data, identifying potential trap locations, checking day-to-day operations, and monitoring the status of traps. Of the users that tested both aspects of the application, both testers chose the application over 2019 methods for daily tasks. The one user who only tested the operations dashboard chose the application over 2019 methods for most tasks expect adding/editing/exporting data. The results from this question can be viewed in Figure 35.

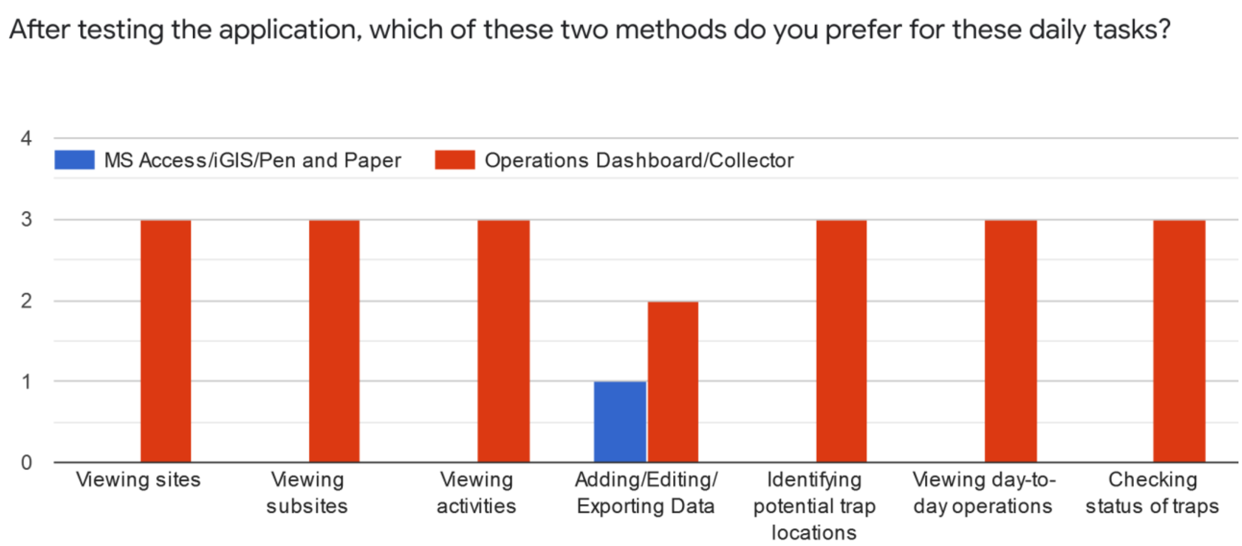

Figure 35. Daily Task Responses

A follow-up question was asked if the 2019 methods was chosen for one of the daily tasks asking why this method was superior to the other. The tester stated that APHIS's MS Access database was "built with high specificity to our unique workflow and the forms in particular help immensely with data fidelity - correct subsite and sample IDs, for instance".

The next question asked testers how satisfied they were with using the operations dashboard for daily tasks. The results of this question can be viewed in Figure 36. This question was asked on a five-point Likert scale with 1 being unsatisfied and 5 being very satisfied.

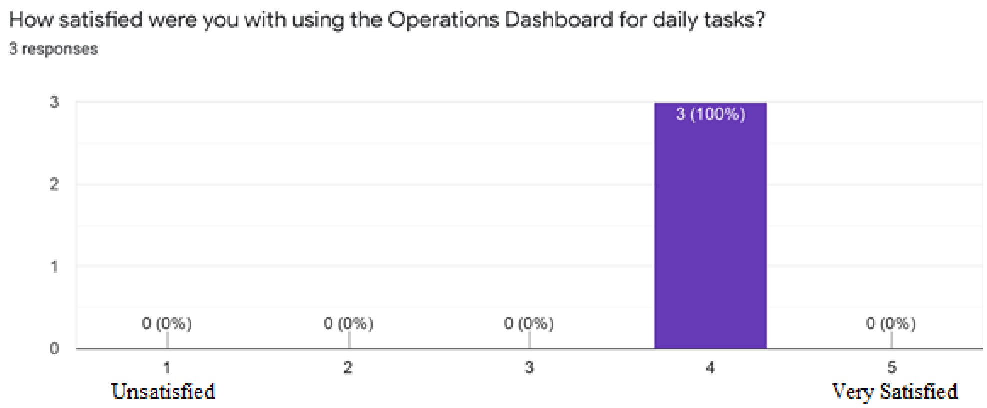

Figure 36. User Satisfaction of the Operations Dashboard

All testers responded with a value of 4 which can be interpreted as largely satisfied. The following questions asked how satisfied the tester was with using Collector for daily tasks. These results can be viewed in Figure 37.

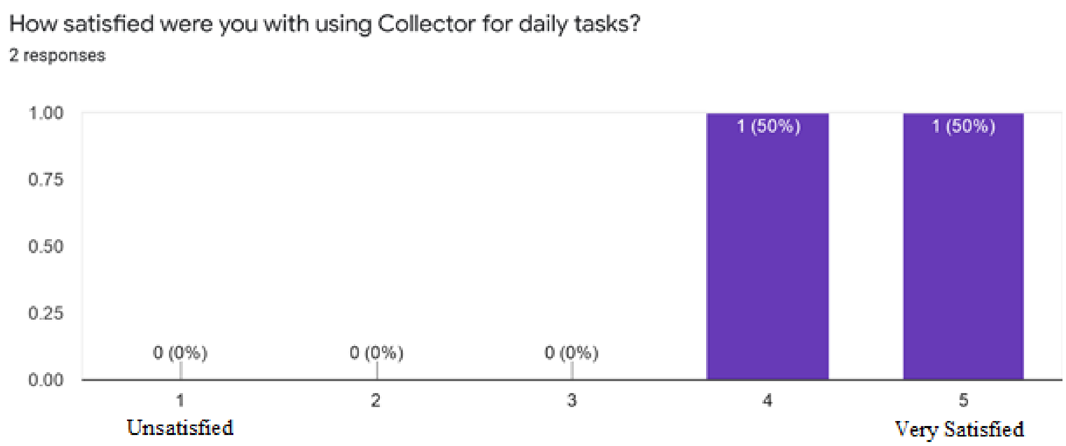

Figure 37. User Satisfaction of Collector

Of the two testers who tested Collector, one user was largely satisfied and the other was very satisfied.

The next question asked about the difficulty of using the application. The results from this question can be viewed in Figure 38.

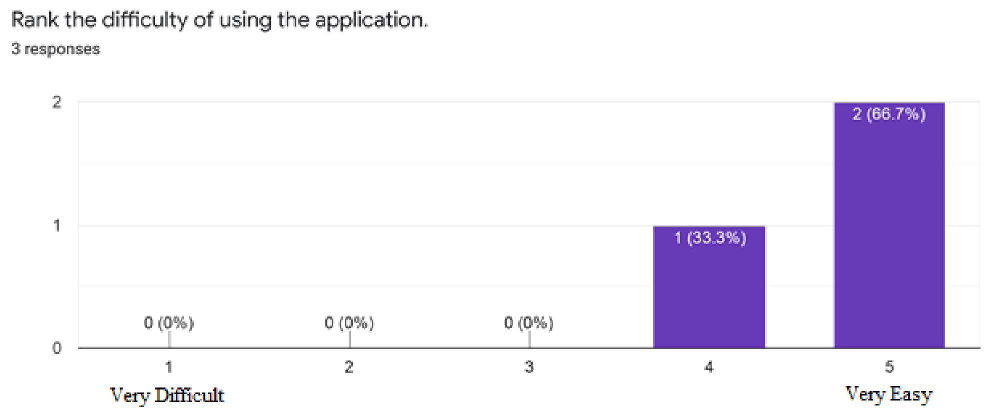

Figure 38. Difficulty of the Application

Two testers responded that the application was very easy to use and one selected that it was easy to use. A follow-up question was asked to this question if the user thought the application was difficult to use. One user responded and stated that more training would be required to effectively use the operations dashboard. This user also stated that Collector was easier to use than the dashboard.

The next question asked about the adequacy of the datasets that were used for the application. These datasets included the Illinois Nature Preserves Commission (INPC) land, Cook county boundary, and the Illinois Protected Lands datasets which includes forest preserves, municipal parks, federal land, and state parks. The results from this question can be viewed in Figure 39.

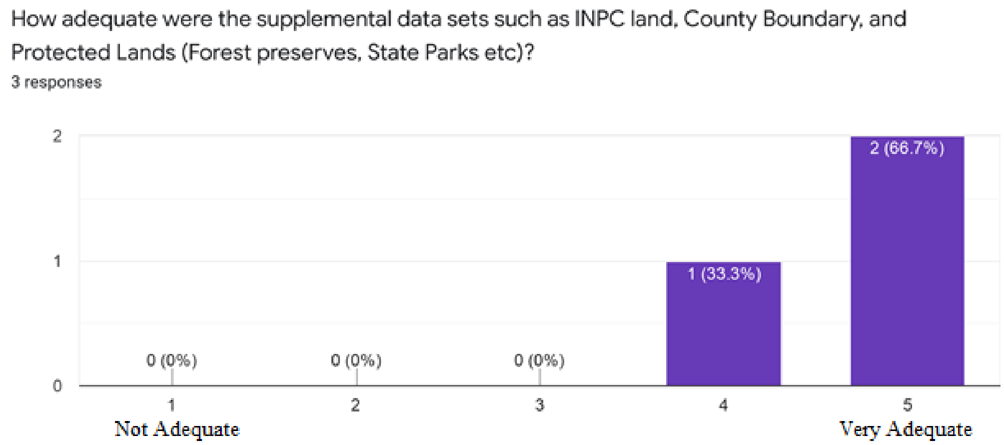

Figure 39. Adequacy of Supplemental Datasets

Two testers responded that the datasets were very adequate for the application and one said that they were largely adequate. A follow-up question was asked if there were any datasets that could be added in the future. One user asked if there was any way to add contact information to the sites feature class such as a phone number and name of the land manager of where traps would be setup.

The following question asked testers to rate the symbology that was used for sites. The symbology that was chosen was a 2-mile buffer of sites, a red circle, and a site label containing the SiteID. The results from this question can be viewed in Figure 40.

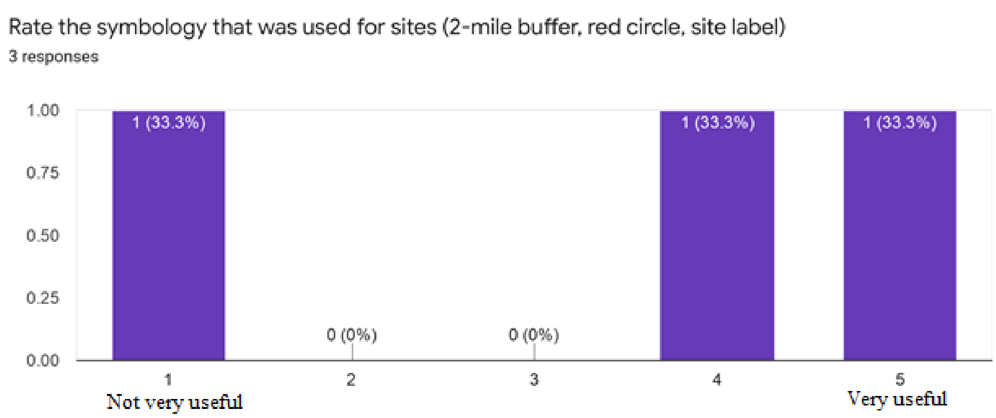

Figure 40. Usefulness of Site Symbology

Results from this question were mixed. One tester said that the symbology was very useful while another said it was not very useful at all. The other tester said it was largely useful. A couple follow-up questions were asked to this question. The first question was whether the site symbology could be improved upon. Responses from this question are displayed in Table 3.

Table 3. Site Symbology Question #1

Can site symbology be improved upon in anyway? Please elaborate.	
Response 1	I think that it would be best if only cerceris sites had the appropriate buffer around them instead of a 2-mile buffer around the entire site. The buffer line clutters the map more than it help me to associate different sites.
Response 2	I think the symbology is great. Very clear and concise.

One tester suggested that the buffers only be placed around Cerceris subsites instead of around sites. The other tester thought that the symbology was very useful. The other follow-up question can be viewed in Table 4.

Table 4. Site Symbology Question #2

The researcher chose a 2-mile buffer radius for sites based on availability of nearby locations to place traps. Is there a more optimal radius for sites? Please explain why or why not.	
Response 1	I think if having a buffer is useful for looking for optimal subsites then 2-miles is appropriate because any further away may just warrant creating a different site.
Response 2	This is tricky. I think that site size really varies with each site. The radius feature would be great for the Cerceris survey, but for EWBB the size may only be as large as the property the traps are on. I think the survey type would have to indicate the radius size. The idea that the radius can be changed would be beneficial for a couple of reasons; it could indicate the strength of lures for EWBB and AGM, it could also clarify survey SOPs for Cerceris (like, there has to be an Oak tree within 500ft of the baseball diamond).
Response 3	While the two-mile buffer could be a useful guideline, trap location selection is often more reliant on accessibility... which is usually best assessed through ground-truthing. Regarding buffers, a 200-meter buffer around each Cerceris site would be a useful tool for determining host tree proximity - currently, the targets for that survey are oak pests, and a surveyed Cerceris colony technically shouldn't be considered negative for those taxa unless there are oak species within 200 meters of the site.

One tester thought that the buffer was useful because it could help deem whether a subsite would be able to be adequately setup. The other users preferred the buffer to be used with Cerceris subsites or dependent on the strength of the lure that was being use for a subsite.

The subsequent question focused on evaluating the symbology that was used for subsites. Subsites include AGM traps, EWB traps, and Cerceris surveys. The results can be viewed in the chart in Figure 41.

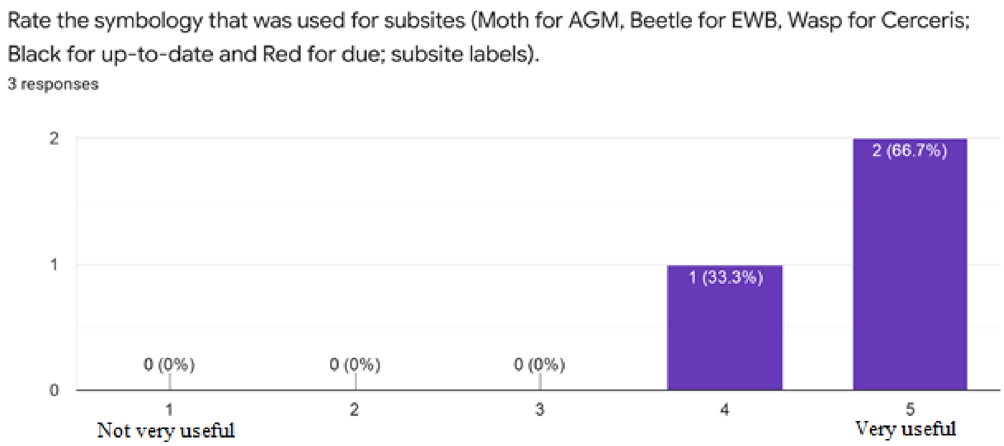

Figure 41. Usefulness of Subsite Symbology

Two testers reported that the symbology was very useful while one tester reported that it was largely useful. A follow-up question was asked based on responses to this question. These results can be viewed in Table 5.

Table 5. Subsite Symbology Question #1

Can subsite symbology be improved upon in anyway? Please elaborate.	
Response 1	I enjoy having clearly different symbols to demonstrate which type of trapping is being done. I also appreciate that symbol color changes as traps become overdue.
Response 2	It's perfect.
Response 3	You may want to consider adding another trap status category; the lure status is certainly important, but survey guidelines mandate that traps should be checked every two weeks. Basically, a trap could be "overdue" in three ways: its lure is expired, it hasn't been checked recently enough, or both.

All testers were moderately satisfied with the usefulness of the subsite symbology. One user brought up the point of how lures should be somehow incorporated into the symbology of overdue subsites.

At the end of the survey there was one final question providing an opportunity to provide feedback upon testing the application. All testers responded and their responses can be viewed in Table 6.

Table 6. Additional feedback

Provide any additional feedback here.	
Response 1	I could not access the map on my collector app due to untrusted certificates. I did however get to test the app on someone else devise. Error message as follows: Domain: NSURLErrorDomain Code: -1202 Description: The server’s certificate is invalid. You might be connecting to a server that is pretending to be 'gis-server-02.usc.edu', which could put your confidential information at risk. One thing I that maybe nice to add to improve the efficiency of the app would be to have auto populating data for subsite and site information when you are entering in an activity for subsite. It would also be useful to have the ability to add sites to the map. This ability would come in handy when discovering a new baseball diamond in a new county, or in a area not being surveyed. I think that this map would be very useful for conducting Cerceris surveys because it would allow you to have real time data on which diamonds have been surveyed.
Response 2	Overall I think the entire setup is great. As mentioned before, I'd want the researcher to provide some one on one training with the dashboard, but that would be necessary with any given data collection mechanism. Personally I love the app. As long as the GPS signal was clear (can also be a problem with a number of other data collection tools), I think having all the information at your fingertips in such a portable tool like a cell phone is great all around. I think there would be less data entry errors and I think it would be easier to keep track of your sites in the 'big picture' frame of mind (like lure changes). Having the site editing locked makes complete sense and also lessens the chance for errors. One feature that would be amazing; if when you went to enter a subsite; the site ID was pre-filled in with the site information OR give an error message if the Site ID and Subsite ID's first characters don't match. Of course, I don't know if that's technically possible, and there may be a reason why it's not a good idea. I just think that would be another way to decrease data errors.
Response 3	Great work! The dashboard provides a really excellent snapshot of ongoing survey work and the mapping element is pretty slick. I'm really interested in how these data could be exported into other formats (Excel, Access, etc.). Combined with our existing database structure, we could rig up an impressive system. Again, really great work!

The first tester ran into issues with opening the map within Collector and provided the error message. This tester also suggested that it would be beneficial if the app could auto-populate subsite and site information when entering an activity for a subsite. They would also like to be able to add a site from Collector. The second tester would have liked more training with the dashboard and thought that the overall application would help reduce errors in the field. They also mentioned auto-populating data for sites and subsites. The third tester mentioned how it would be beneficial to export data directly to Access or somehow tie a Web GIS in with their existing database.

Chapter 5 Conclusions

This chapter is divided into six different sections. The first section gives a summary of the application as well as discussing the overall objectives of this application. The second section interprets the results of the feedback survey. The third section discusses challenges in development. The fourth section notes some of the limitations of this project. The fifth section discusses the applicability of this application for other projects and APHIS surveys. The last section mentions future work for further development of the application.

5.1. Application Summary

This Web GIS was built to enhance field operations for APHIS. Older methods included a Microsoft Access database to store data as well as the manual collection of data in the field using pen and paper. Using APHIS's Access database as a framework for a Web GIS, data collection layers were built to be used in an operations dashboard and a web map for Collector. Additional datasets were added to enhance field operations such as boundaries of state parks, forest preserves, and municipal parks in Illinois. Tree canopy cover can also be inferred from these boundaries using a GAP land cover dataset. Traps or surveys can be added in the field with coordinates automatically recorded and activities associated with the traps were possible with relationships between feature classes and tables.

The general objective of this application was to improve the workflow of APHIS technicians as well as supervisors and survey specialists using a Web GIS. With an operations dashboard and Collector, data can be more effectively recorded and the workflow of APHIS technicians and managers is made more efficient. The operations dashboard provides a better general overview of survey operations than an Access database and Collector provides a more efficient method for collecting data while in the field and not transferring data in Access at the office. Based on feedback from the testers, the Web GIS was the preferred method for most daily work tasks.

5.2. Discussion

Overall, the application was well-received. Satisfaction levels were high for both the operations dashboard and Collector for daily work tasks, especially in comparison to 2019 methods. One tester mentioned that the dashboard and collector would help reduce errors in transcribing data in the field. Additional training could also help in regard to using the dashboard because one tester had difficulties understanding what everything did.

The datasets that were prepped and chosen for this Web GIS were rated as very adequate. One tester asked if there would be any way to add contact information for sites. This is something that can be easily changed in the attributes of the site feature class. Two additional fields can be added to include and name and phone number of staff that manage the land where traps are being placed.

The symbology that was chosen for sites had mixed reviews. The consensus was that the buffers that were used for sites cluttered the map too much and would be more beneficial for the subsites of the Cerceris survey. Perhaps sites could not be buffered in any way and use a different symbol to easily distinguish sites on the map. The goal is to find trapping subsites that are nearest to the site. If sites are not buffered, technicians and managers will not have to add sites through ArcMap, and it could be done online or in the field. This would be beneficial for the Cerceris survey because it can be done at any baseball diamond and technicians could easily add a new site while in the field.

The symbology that was chosen for subsites was deemed useful. The different symbols such as wasps, beetles, and moths helped testers easily distinguish between subsites. The script that changes the color of the symbols was also beneficial to users. One tester mentioned that it would be valuable to include the duration of lures into the symbology. This could be done by having an additional calculation in the script that changes subsites to due after a certain amount of time has passed. An alternative and perhaps easier solution to this would be to have the date of the last lure change added to the subsite feature class from the activity table. Arcade expressions could be used to include an additional field that has a countdown for when the lure would expire. This field could be used to label subsites even further. For example, 'CO-WAL-ET1' could then read 'CO-WAL-ET1 - Lure: 12 days'.

Testers agreed that the dashboard and collector provided a general overview of survey work and could help reduce errors when transcribing data in the field. A few changes could be made to help data collection and monitoring go more smoothly such as better symbology for sites and including lure duration in subsites symbology. These changes are mentioned further in Section 5.6 Future Work.

5.3. Challenges in Development

There were a few challenges during the development phase. These issues include minimal support from AGOL for working with related tables, parts of a script not working in ArcMap, and data not being able to be edited in the operations dashboard.

With APHIS data collection, subsites are created that contain information about the trap or survey and a related table, activities, is used to store services associated with that subsite. These services include a sample being collected, and a trap being installed or removed. This information is unable to be stored in a popup for the subsite feature class in AGOL. To circumvent this issue, a script was developed to update subsites based on the most recent activity. The script added a new field to the subsite feature class containing the date of the most recent activity or visit. With this script, symbology was able to be updated to show which subsites were due for a service or activity.

Lure duration was not able to be incorporated into the symbology for subsites. A script was built that calculated the dates of the last lure changes for the subsites with respect to lure durations to provide a number of days that the lure would be effective. During this analysis, ArcMap crashed numerous times and was unable to run this script. An alternative method is discussed in Section 5.6.

In the operations dashboard map that is provided when creating a dashboard in AGOL, data is unable to be edited. The web app builder in AGOL was used to address this issue. In web apps, data can be edited freely with the correct settings. The web app was linked into the operations dashboard as an additional map to allow users to edit data. The web app does not work with certain functionality of the dashboard such as filtering of data and the informational graphs. For this reason, the dashboard contained both maps.

5.4. Limitations of Project

Some of the main limitations of this project were the sensitivity of APHIS data, issues with the testing phase, and the incorporation of lures into the subsite symbology. APHIS was not able to provide data for development and testing purposes, rather, just the framework of their Access database was provided. Their sites, which contain high-risk importer locations are sensitive data that cannot be shared with the public. Access to this information requires security clearance. Also, past locations of their subsites such as traps or baseball diamonds (for Cerceris survey) are also sensitive data. For this reason, synthetic data was created to demonstrate an overall functioning Web GIS for data collection and monitoring. With real data, testing could have provided a better picture as to whether a Web GIS would be more beneficial. Users were only able to test Collector and the operations dashboard based on the features and data collection layers.

There were also some issues during the testing phase of this project. Due to the timing of testing, this application was not able to be tested in the field. Surveys usually run from late spring to early fall and testing took place during the month of February. Also, due to the sensitivity of APHIS's data, real data would not have been able to be collected anyways. Some users were also not available for testing due to unforeseen circumstances. More users could have swayed the results in a different direction. One user also ran into an error when trying to gather data in Collector. The error message was provided in the feedback survey and can be described as a certificate issue. Only one user ran into this error message and this user was able to test out the application on another user's iPhone. Government phones and computers have certain firewalls and applications in place that control what comes in and out. Since the web map was hosted on USC's web server, it is possible that this issue would not occur if the information was coming from an APHIS web server. Although other users were able to access Collector, this is possibly an explanation as to why one user could not.

The incorporation of lure duration into the subsite symbology was also a limitation. As one tester mentioned in the survey, subsites are due based on a sample needed to be taken or a lure expiring. With this application, a user would have to look through the activities table to figure out when the next lure change would be needed. This issue was mentioned in the previous section as a challenge in development.

5.5. Applicability for Other Projects

In terms of data collection, this application could serve useful for other APHIS surveys and projects, as well as other organizations doing similar work. Most APHIS surveys involve trapping, which comprises returning to traps to collect samples and replace lures every so often. Also, other projects can benefit from this project through some of the issues that were encountered in AGOL.

In terms of scale, this application can easily be used for other APHIS surveys, or other surveys being undertaken with similar objectives. Around 80% of the application would remain the same. The parts that would need to be changed include the supplemental datasets, such as Illinois Protected Lands dataset, which provides locations where traps can be placed. This dataset extensively covers all of Illinois, but in different states, a similar dataset may or may not be available. Symbology would also need to be updated based on the types of surveys that are included in the application, which could include different icons for each survey. More conventional symbology could also be used and can easily be changed in the web map without updating the actual feature class on the backend. With this application's structure, it would be easy to incorporate different types of drop-down menus and surveys. One of the core benefits of this application is the ability to update symbology automatically with a script based on subsites that are due for a visit. Many capabilities are possible within AGOL web maps, as long as a script can be run on the backend. Different traps or surveys may have different lengths of time before they need to be checked for another service. This length of time could be easily incorporated into the script as well to update symbology accordingly.

The database design would remain the same as the site, subsite, and activity tables in the database provide an excellent structure for survey data collection. The dashboard would also remain the same, as the relationships between tables were already set-up and would not need to be altered.

Majority of APHIS surveys involve using trapping to monitor high-risk importers, but sites could also be more natural areas as well. For example, a site could be a state park where trapping is conducted even if there is no high-risk importer in the area. APHIS tries to spread out their traps, even in rural counties, to get a handle on what types of species are present in that area. Although the study area for this application was Cook County, IL, where high-risk importers are more present, the same application can also be used for rural or natural areas where there are no high-risk importers present.

Other projects may benefit by viewing how this application was built. There are certain capabilities that are not provided in AGOL dashboard builder and web maps. One example is how data cannot be edited in the map provided in dashboard builder. This issue was circumvented by linking a web app builder map into the dashboard to allow for data collection. Also, relationships between feature classes and tables allowed for data to be collected in an efficient way. The relationship between the subsite feature class and activities table allowed for data to be linked which provided more capabilities to filter data in the dashboard. Python scripting helped address this issue by enabling the ability to show information between related feature classes in tables in a web map popup.

5.6. Future Work

Although the application that was built was well received, it remains a work in progress. There were some issues encountered during the application development that left parts unfinished. Also, not everything was included in the application based on suggestions from the User Needs Interview. Feedback from the User Testing Survey also uncovered additional features that could be implemented.

First, incorporating lure durations into subsite symbology is important to include in a future iteration of this application. Lures are also a determinant of whether a site is due for inspection or not, not just if it hasn't been visited in the last two weeks. If a lure is expired, it would not be as effective at catching insects. Including this lure duration calculation into symbology would provide a technician with additional information about the lure without having to check through all the activities for a subsite.

Second, weather data could improve the Cerceris survey. This was requested in the User Needs Interview. The APHIS team in Chicago covers over a dozen counties for surveys. Incorporating rainfall or precipitation would allow users to glance at the map and view rainfall in different counties and plan their day accordingly. Rainfall inhibits Cerceris activity, so visiting sites in a county where there has been a lot of rainfall in the past few days would not be beneficial.

Lastly, barcodes for traps was a feature that was also requested in the User Needs Interview. Having a barcode on a trap would provide more efficient data collection when entering activities for a subsite. The activities table utilizes a SampleID that is generated based on the SubsiteID and the date. For example, a sample collected at 'CO-WAL-ET1' would be 'CO-WAL-ET1-200215' would be a sample collected on February 15th, 2020 at the 'CO-WAL-ET1' subsite. A barcode could provide the means for scanning the barcode on the trap instead of manually entering the code. The web maps that Collector utilizes do not offer the capability of auto-entering information based on related tables. This is, however, something that Survey123 may offer and would be worth looking into for a future development of this application.

The goal of this application was to improve APHIS's workflow for daily tasks and to provide a system for more efficient data collection and monitoring. A user needs interview was conducted to examine 2019 methods and to identify areas in where their system could benefit from using a Web GIS. This interview guided application development and was tested by the users to gauge overall satisfaction and identify strengths and weaknesses in the application. The completed application can provide a framework for APHIS to use in their data collection and monitoring paradigm. This application can help to streamline data flows through improved efficiency and accuracy of data collection. The dashboard can also help visualize data as well as providing the capability to double-check accuracy of data collected in the field. Although this framework is specific to Chicago surveys, it can also be easily modified for use in other offices where similar surveys take place.

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Appendices

Appendix A User Needs Interview

Interview 1: Field Operations Supervisor

<u>Data Collection</u>

1. What current methods are used for EWBB, AGM, and Cerceris data collection? Is there a need for more efficient methods, especially in the field?

We use a one-directional system to provide detailed trap / survey site information. Shapefiles are emailed to field staff and an iPhone app is used to open and display the shapefiles on maps. Currently there is no capability for data capture to move in the other direction. For trap surveys staff consensus is that this works well; it's preferred to enter survey records into Access DB when back at the desk at the end of the day / first thing next day. For Cerceris, a bidirectional (data go out to staff and data captured digitally in field sync with or are eventually migrated to database) and real-time (activities captured in field are immediately visible to other field staff) system would be ideal and preferred.

2. What sort of datasets could help with trap placement in the field (canopy cover, boundaries, etc.)?

Land ownership/management, dominant tree species, flood potential, county boundaries, State Nature Preserve designated areas

3. Is it hard keeping track of which traps need to be updated and what has been done to it last?

Current workflow works well. There is some work involved with pulling queries from Access and creating shapefiles biweekly. Rarely situations could arise where real-time (as opposed to biweekly) update of these maps would be helpful.

4. What sort of symbology could help in a data collection app to more efficiently carry out field operations (traps having a certain symbol, such as a moth for AGM traps, a beetle for EWBB traps, etc.)?

The symbology you mentioned would be good, also possibly different colors to indicate what lure the trap is currently set with.

5. Feel free to provide additional comments or feedback on what needs improvement or what could help field data collection/entry go more smoothly.

Random thought but it might be cool… maybe a button to initiate a text message to the most recent person to check the trap? Sometimes trap can't be found, can't figure out best route to get to trap, not sure if lure changed, etc. Not critical, but why not.

<u>Operations Dashboard</u>

1. What current methods are used for monitoring EWBB, AGM, and Cerceris field operations? Is there a need for more efficient ways of keeping track of operations?

Access DB is very functional at this point and works well for QC purposes. Not sure if that can be improved.

2. What methods would be used for managing forest pest emergencies in Illinois (i.e. the spotted lanternfly entering Illinois)? Is it organized? Is there a need for improvement? What would be needed?
Case by case. With SLF there is a working group and an emergency response plan for Illinois. In general, we'd want to map highest priority areas for visual and/or trapping survey (as well as outreach efforts) based on host plant distribution and pathway locations. Pathways are highly specific to the situation, information we have at the moment, and type of pest.

3. How important would real-time data collection be for field operations, especially for larger operations? Is there a need for a supervisor or PSS to keep track of operations in a simple way? Can it save time that could be delegated to focusing on other tasks?
It depends. See above. However, it should be noted that upper management do seem to want real-time visualization of survey work nationally and across programs. So the situation can be easily envisioned where we are at some point required to get data into a national database near-real-time. If that came down the pike we would want a tool to help achieve that while simultaneously maintaining control of our data through primary use of a local database. Yes, if something like that were to occur, it would save a lot of time for the PSS.

4. Is there any specific information you would want to be visualized as a graph, chart, or graphic for field operations (such as a chart showing the counts of different lures being used) in an operations dashboard?
Actually yes, that is a good idea (lures currently deployed). Location-specific degree day accumulation (current to maybe the previous day or week) would also be helpful to time the install/removal of traps, timing of lure changes through the season, timing of visual surveys and Cerceris phenology. Also precipitation records (current to the previous day) on a map would help with Cerceris. If an area got a lot of rain yesterday it will likely be useless for Cerceris survey today. Sites that haven't had rain for 3+ days will be best to focus on.

5. Feel free to provide additional comments or feedback on what needs improvement or what could help field operations go more smoothly.
If the trapping survey app were created, a barcode system could be cool. I think Oregon Dept of Ag developed an app with this capability. Each trap gets a barcode taped onto it and when you check the trap, you scan the barcode on your phone.
I think I heard insect collections are now using tiny QR codes on specimen labels as well. On the screening, ID, and entry of specimens end of the workflow, it could be great to be able to print vial labels with QR, scan QR when you're screening and update the sample status that way. May be beyond the scope of what you're looking to do here but just a thought.

Interview 2: Pest Survey Specialist (PSS)

Position/Title: Pest Survey Specialist
<u>Data Collection</u>
1. What current methods are used for EWBB, AGM, and Cerceris data collection? Is there a need for more efficient methods, especially in the field?

While in the field, most trapping personnel utilize a combination of pen/paper and smartphone notetaking apps to record pertinent survey data. The data are then entered into an in-house Access database (ILID) when they return to the office. AGM and EWB trap locations are relatively stable throughout the course of the survey season, but the *Cerceris* survey in particular would benefit from a mobile data collection interface; survey locations are constantly in flux and real-time updates to the map would allow personnel to make more informed decisions while out in the field, ultimately maximizing their productivity.

2. What sort of datasets could help with trap placement in the field (canopy cover, boundaries, etc.)?
Satellite imagery with canopy cover is useful when checking the accuracy of GPS points (landmark location) as well as trap placement – technicians can locate nearby forested areas if a trapping site doesn't have enough suitable host material. Parcel/property ownership information would be advantageous for initial survey planning, as the PSS needs to obtain permission/permits for site access and trapping activities – county forest preserve districts, municipal parks districts, state parks, private property, etc.

3. Is it hard keeping track of which traps need to be updated and what has been done to it last?
While there are queries that calculate a trap's lure duration and scheduled change date, this information often has to be looked up on a trap-by-trap basis. Our current system designates a trap "OVERDUE" if it hasn't been checked in 14 days or more. It would be great if the map was able to flag these traps with some sort of symbol, color change, etc. That way the user would be able to spot the overdue traps at a glance and plan accordingly.

4. What sort of symbology could help in a data collection app to more efficiently carry out field operations (traps having a certain symbol, such as a moth for AGM traps, a beetle for EWBB traps, etc.)?
We currently use an iPhone application for mobile mapping capability out in the field and are somewhat limited by its capabilities – many apps reserve their more impressive bells and whistles for users who purchase the premium version. Symbology in particular has been a challenge; there are only so many ways to differentiate traps/sites when we're only allowed to use the circle symbol. More descriptive symbols would certainly be helpful, though not necessarily required.

5. Feel free to provide additional comments or feedback on what needs improvement or what could help field data collection/entry go more smoothly.
Generally speaking, data collectors using the application may not be local. One of my biggest issues has been working with our downstate offices to ensure that their data are accurate and entered on a regular basis – tricky when they're downstate. I've implemented some safeguards that allow me to QC and correct their entries before I append them into the back-end database, but it's an imperfect system. I don't anticipate that this application will solve this sort of user issue - it's inherent to all data collection/entry systems - but I've found it very important to thoroughly assess where user errors or misunderstandings will cause problems.

<u>Operations Dashboard</u>

1. What current methods are used for monitoring EWBB, AGM, and Cerceris field operations? Is there a need for more efficient ways of keeping track of operations?
I monitor survey operations and data with a variety of queries and reports built into the ILID database. It's the only "system" that I've ever used and thus, I don't have much to compare it against… but I imagine that a dashboard listing all of the important highlights at one glance would be useful. I've been fortunate to have technicians that don't need extensive supervision or micro-managing once they've been trained, but other supervisors might like to have that information handy for distribution to technicians on a regular basis - making sure that traps are being checked, their lures changed, and samples collected on the appropriate schedule.

2. What methods would be used for managing forest pest emergencies in Illinois (i.e. the spotted lanternfly entering Illinois)? Is it organized? Is there a need for improvement? What would be needed?
Our most pressing concern is certainly SLF, which at this point is detected primarily through visual survey efforts. Useful data sets would include host presence/absence data, high-risk pathways (rail lines, proximity to cargo airports receiving flights from quarantine zones out east, stone importers, etc). Someone overseeing such a survey would surely want an up-to-date accounting of survey activities so that personnel could inspect hot spots without duplication of effort. Similar to the *Cerceris* survey, it would be easy for multiple technicians to check the same patch of TOH in the same day simply because they didn't know that someone had already done it.

3. How important would real-time data collection be for field operations, especially for larger operations? Is there a need for a supervisor or PSS to keep track of operations in a simple way? Can it save time that could be delegated to focusing on other tasks?
As previously mentioned, real-time data collection would be most useful for the *Cerceris* survey. It's not something that I would be keeping tabs on personally, but would be useful for technicians.

4. Is there any specific information you would want to be visualized as a graph, chart, or graphic for field operations (such as a chart showing the counts of different lures being used) in an operations dashboard?
I can't think of anything specifically, but I'm curious about what kind of visualizations would be possible. It's very likely that there's something that would be really informative, but that I just haven't imagined it yet.

5. Feel free to provide additional comments or feedback on what needs improvement or what could help field operations go more smoothly.
Really looking forward to keeping tabs on this project!

Interview 3: Plant Protection Quarantine Technician #1

<u>Data Collection</u>
1. What current methods are used for EWBB, AGM, and Cerceris data collection? Is there a need for more efficient methods, especially in the field?

Currently I use paper datasheets to capture what my field work activities. In the morning before heading out for the day I use the Access database to copy down the information I need. Then, when I get back to the office, I use my notes to input the day's data back into Access. The process can be a bit tedious and I've found that there are many chances for errors, just because you're writing coordinates/sample IDs, sites, etc., repeatedly. I think there would be a real benefit to some kind of real-time data entry.

Cerceris work in particular. The possibility of having a map with all the data in front of you, knowing when the field was last checked (without having to look in Access before you left for the office for the day) could result in more efficient trapping. Technicians would be able to see what fields/general areas had already been covered that week and then avoid those areas to survey new fields.

Having dataset access in the field would also be helpful for the times when employees are out of the office and others are managing their traps. To have the information (location, lure change dates, trap type, etc.) easily accessible in the field would be much better than the current system of looking through Access database for the information needed

2. What sort of datasets could help with trap placement in the field (canopy cover, boundaries, etc.)?

Personally I think a boundary layer with ownership information would be extremely helpful. In previous years I've had to search the web for county forest preserve maps, which can range from an interactive map with great information to a simple PDF. This information could also allow us to trap in areas we hadn't thought of before…or gain access to new areas with different ownership groups.

I like using satellite aerial maps that show the landscape, but having a road map is also really useful. Some of our trapping sites have odd locations and it's necessary to know how to get there! Ultimately I think having a few options to switch between would be necessary for the best functioning tool.

3. Is it hard keeping track of which traps need to be updated and what has been done to it last?

I pretty much rely on what I've entered into Access in the previous weeks. As the season progresses and different lures have different longevity rates, it becomes really hard to keep track of. It would be great to have a function where I can click on the sites I'm visiting that day and it tells me which lures need changed. Right now, having to scroll through Access or look through my paper notes is a waste of time and I can easily make mistakes.

4. What sort of symbology could help in a data collection app to more efficiently carry out field operations (traps having a certain symbol, such as a moth for AGM traps, a beetle for EWBB traps, etc.)?

I think the simple stuff, like different symbols for the different surveys (one for EWBB, one for AGM, one for *Cerceris*, etc.) Having a specific symbol, moth or beetle, doesn't seem like a necessity to me but if it can be done…why not! Anything that makes the map easier to read.

Having each of the surveys have their own color would be good (think all AGM are purple moths, EWBB are green beetles, etc).

5. Feel free to provide additional comments or feedback on what needs improvement or what could help field data collection/entry go more smoothly.
I don't have much to say about the dashboard idea, other than do it. It's great for the technicians to see the summary information too.

Interview 4: Plant Protection Quarantine Technician #2

Data Collection
1. What current methods are used for EWBB, AGM, and Cerceris data collection? Is there a need for more efficient methods, especially in the field?
There is no standardized method for collecting data in the field. There is a pilot arc collector map available for EWBB and Cerceris. I believe that it would be a much more efficient if there was a way to collect data in the field. It would reduce error when entering data and assure that sample are collected.

2. What sort of datasets could help with trap placement in the field (canopy cover, boundaries, etc.)?
I believe it would be very useful to have to know boundaries, cover types, restricted use areas, and being able to access historic and seasonal base maps.

3. Is it hard keeping track of which traps need to be updated and what has been done to it last?
No it is not hard to tell with the system I have set up. My method is writing down when I make visit and making notes in my calendar for when the next lure change is. If there was the ability to keep track of this through one app platform it would be much more efficient.

4. What sort of symbology could help in a data collection app to more efficiently carry out field operations (traps having a certain symbol, such as a moth for AGM traps, a beetle for EWBB traps, etc.)?
I would like to able to denote the different types of traps. It would be helpful to have different color symbology to distinguish ball diamonds with higher rates of Cerceris. It would be useful if the map could have symbols change color when a trap is due for a lure change or collecting.

5. Feel free to provide additional comments or feedback on what needs improvement or what could help field data collection/entry go more smoothly.
To help find traps that have been placed it would be useful if you could take a picture of the trap once they have been placed.

Appendix B Subsites and Synthetic Data

SubsiteID	SiteID	CF_Nests	CF_Fields	Lure	Trap	POINT_X	POINT_Y
CO-INT-DI1	CO-INT			DI	Prism Trap - Green	-87.72506841	41.61423973
CO-INT-TR1	CO-INT			TR	Multi-funnel Trap - 8 Funnel - Wet	-87.73340809	41.60816154
CO-INT-ET1	CO-INT			ET	Multi-funnel Trap - 8 Funnel - Wet	-87.73551075	41.60639867
CO-CFP-AE1	CO-CFP			AE	Multi-funnel Trap - 8 Funnel - Wet	-87.75874507	41.65369826
CO-WAL-ET1	CO-WAL			ET	Multi-funnel Trap - 8 Funnel - Wet	-87.89256928	42.0738568
CO-WAL-DI1	CO-WAL			DI	Prism Trap - Green	-87.89176907	42.08079714
CO-DES-CF1	CO-DES	3	2			-87.88586316	42.01624872
CO-AMZ-LI1	CO-AMZ			LI	Multi-funnel Trap - 8 Funnel - Wet	-87.97441286	42.01726166
CO-CFP-DI1	CO-CFP			DI	Prism Trap - Green	-87.75845045	41.64870216
CO-LOW-CF1	CO-LOW	4	4			-87.72808906	41.74990054
CO-LOW-TC1	CO-LOW			TC	Cross Vane Panel Trap - Black	-87.7490849	41.74112589
CO-AMZ-DI1	CO-AMZ			DI	Prism Trap - Green	-87.95018487	42.00167294

CO-AMZ-QU1	CO-AMZ			QU	Multi-funnel Trap - 8 Funnel - Wet	-87.88128442	42.04156903
CO-AMZ-CF1	CO-AMZ	3	1			-87.98811602	41.99877
CO-LOW-DI1	CO-LOW			DI	Prism Trap - Green	-87.74940013	41.74113329
CO-CFP-CF1	CO-CFP	5	3			-87.73177719	41.6752351
CO-DES-DI1	CO-DES			DI	Prism Trap - Green	-87.88241307	42.03771027
CO-WAL-CF1	CO-WAL	4	2			-87.92885715	42.06896644

Appendix C Activities Synthetic Data

SubsiteID	Date	Action	LureChange	Collector	SampleID	SampleStatus	CF_Steals	CF_Drops
CO-INT-TR1	1/23/2020	TAKE SAMPLE	No	Technician 1	CO-INT-TR1-200123	Pending Screening		
CO-CFP-DI1	11/27/2019	INSTALL	No	Technician 1	CO-CFP-DI1-191127	Sample Not Obtained		
CO-CFP-DI1	12/11/2019	TAKE SAMPLE	No	Technician 1	CO-CFP-DI1-191211	Forward for Diagnostics		
CO-CFP-DI1	12/25/2019	TAKE SAMPLE	No	Technician 1	CO-CFP-DI1-191225	Sample Not Obtained		
CO-LOW-TC1	11/27/2019	INSTALL	No	Technician 1	CO-LOW-TC1-191127	Sample Not Obtained		
CO-LOW-TC1	12/11/2019	TAKE SAMPLE	No	Technician 1	CO-LOW-TC1-191211	Pending Screening		
CO-LOW-TC1	12/25/2019	TAKE SAMPLE	No	Technician 1	CO-LOW-TC1-191225	Pending Screening		
CO-DES-CF1	1/27/2020	TAKE SAMPLE	No	Technician 1	CO-DES-CF1-200127	Forward for Diagnostics	3	5
CO-INT-ET1	1/23/2020	INSTALL	No	Technician 1	CO-INT-ET1-200123	Sample Not Obtained		

CO-INT-ET1	1/23/2020	INSTALL	No	Technician 1	CO-INT-ET1-200123	Sample Not Obtained		
CO-INT-TR1	12/26/2019	INSTALL	No	Technician 1	CO-INT-TR1-191226	Sample Not Obtained		
CO-INT-TR1	1/9/2020	TAKE SAMPLE	No	Technician 1	CO-INT-TR1-200109	Pending Screening		
CO-INT-DI1	1/9/2020	INSTALL	No	Technician 1	CO-INT-DI1-200109	Sample Not Obtained		
CO-INT-DI1	1/23/2020	TAKE SAMPLE	No	Technician 1	CO-INT-DI1-200123	Pending Screening		
CO-CFP-AE1	12/12/2019	INSTALL	No	Technician 1	CO-CFP-AE1-191212	Sample Not Obtained		
CO-CFP-AE1	12/26/2019	TAKE SAMPLE	No	Technician 1	CO-CFP-AE1-191226	Pending Screening		
CO-DES-ARN	1/23/2020	TAKE SAMPLE	No	Technician 1	CO-DES-ARN-200123	Pending Screening	2	5
CO-WAL-DI1	1/23/2020	INSTALL	No	Technician 1	CO-WAL-DI1-200123	Sample Not Obtained		
CO-WAL-ET1	1/23/2020	INSTALL	No	Technician 1	CO-WAL-ET1-200123	Sample Not Obtained		

CO-AMZ-DI1	2/3/2020	INSTALL	No	Technician 1	CO-AMZ-DI1-200202	Sample Not Obtained		
CO-AMZ-LI1	1/7/2020	INSTALL	No	Technician 1	CO-AMZ-LI1-200107	Sample Not Obtained		
CO-AMZ-QU1	1/22/2020	INSTALL	No	Technician 1	CO-AMZ-QU1-200122	Sample Not Obtained		
CO-AMZ-CF1	1/15/2020	TAKE SAMPLE	No	Technician 1	CO-AMZ-CF1-200115	Forward for Diagnostics	5	2
CO-LOW-DI1	1/15/2020	INSTALL	No	Technician 1	CO-LOW-DI1-200115	Sample Not Obtained		
CO-CFP-CF1	1/22/2020	TAKE SAMPLE	No	Technician 1	CO-CFP-CF1-200122	Forward for Diagnostics	3	4
CO-DES-DI1	1/15/2020	INSTALL	No	Technician 1	CO-DES-DI1-200115	Sample Not Obtained		
CO-WAL-CF1	1/15/2020	TAKE SAMPLE	No	Technician 1	CO-WAL-CF1-200115	Forward for Diagnostics	4	2
CO-LOW-CF1	1/20/2020	TAKE SAMPLE	No	Technician 1	CO-LOW-CF1-200120	Negative		2

Appendix D User Testing Survey

Evaluation Survey for APHIS Web GIS

My name is Will Farhat, and I am a Graduate Student at the University of Southern California's Dornsife Spatial Sciences Institute in Los Angeles, California.

This project intends to better understand the advantages of using Web GIS, primarily Collector for ArcGIS and an Operations Dashboard versus more traditional methods. Your participation will help the researcher better understand how daily workflow can be improved using Web GIS. Your response would be fully anonymized. Your participation in this project would involve a short survey, which would take 5-10 minutes to complete.

Benefits and Risks: The benefit of your participation in this research project is that you will help us better understand user needs for pest detection field data collection and monitoring. There is no cost to you for taking part in this research project. We believe there is little risk to you participating in this research project. However, if you are ever uncomfortable answering the questions, you can stop and withdraw at any time.

Confidentiality and Privacy: During the research project, all data will be kept in a secure location. Study staff will have access to the data, although legally authorized agencies, including the University of Southern California Office for the Protection of Research Subjects, have the right to review research records. In the data set, your response will be anonymized.

Voluntary Participation: Participation in this research project is voluntary. At any point during this project, you can withdraw your permission.

Questions: If you have any questions about this project, please contact me at [redacted] or e-mail wfarhat@usc.edu.

* Required

Which part of the application did you test?

- ◯ Operations Dashboard
- ◯ Collector for ArcGIS
- ◯ Both

After testing the application, which of these two methods do you prefer for these daily tasks?

	MS Access/iGIS/Pen and Paper	Operations Dashboard/Collector
Viewing sites	○	○
Viewing subsites	○	○
Viewing activities	○	○
Adding/Editing/Exporting Data	○	○
Identifying potential trap locations	○	○
Viewing day-to-day operations	○	○
Checking status of traps	○	○

If you answered MS Access/iGIS/Pen and Paper above, would you please elaborate on the potential advantages for using this method for this task? Please specify for each task.

Your answer

How satisfied were you with using the Operations Dashboard for daily tasks?

	1	2	3	4	5	
Unsatisfied	○	○	○	○	○	Very satisfied

How satisfied were you with using Collector for daily tasks?

	1	2	3	4	5	
Unsatisfied	○	○	○	○	○	Very satisfied

Rank the difficulty of using the application.

	1	2	3	4	5	
Very hard	○	○	○	○	○	Very easy

If you thought the application was difficult to use, please elaborate, specifying which part (Collector or Dashboard).

Your answer

How adequate were the supplemental data sets such as INPC land, County Boundary, and Protected Lands (Forest preserves, State Parks etc)?

	1	2	3	4	5	
Not adequate	○	○	○	○	○	Very adequate

Were there any additional data sets that should be included?

Your answer

Rate the symbology that was used for sites (2-mile buffer, red circle, site label)

	1	2	3	4	5	
Not very useful	○	○	○	○	○	Very useful

Can site symbology be improved upon in anyway? Please elaborate.

Your answer

The researcher chose a 2-mile buffer radius for sites based on availability of nearby locations to place traps. Is there a more optimal radius for sites? Please explain why or why not.

Your answer

Rate the symbology that was used for subsites (Moth for AGM, Beetle for EWB, Wasp for Cerceris; Black for up-to-date and Red for due; subsite labels).

	1	2	3	4	5	
Not very useful	○	○	○	○	○	Very useful

Can subsite symbology be improved upon in anyway? Please elaborate.

Your answer

Provide any additional feedback here.

Your answer

By typing your name in the text box below, you understand and agree to the above. Your responses will be anonymized in advance of analysis. *

Your answer