CREATING SPATIAL DATA INFRASTRUCTURE TO FACILITATE THE COLLECTION AND DISSEMINATION OF GEOSPATIAL DATA TO AID IN DISASTER MANAGEMENT

by

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STATEMENT OF THESIS APPROVAL

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ABSTRACT

The 2012 Great Utah Shakeout highlighted the necessity for increased coordination in the collection and sharing of spatial data related to disaster response during an event. Multiple agencies must quickly relay scientific and damage observations between teams in the field and command centers. Spatial Data Infrastructure (SDI) is a framework that directly supports information discovery and access and use of the data in decision making processes. An SDI contains five core components: policies, access networks, data handling facilities, standards, and human resources needed for the effective collection, management, access, delivery, and utilization of spatial data for a specific area. Implementation of an SDI will increase communication between agencies, field-based reconnaissance teams, first responders, and individuals in the event of a disaster. The increasing popularity of location-based mobile social networks has led to spatial data from these sources being used in the context of managing disaster response and recovery. Spatial data acquired from social networks, or Volunteer Geographic Information (VGI), could potentially contribute thousands of low-cost observations to aid in damage assessment and recovery efforts that may otherwise be unreported. The objective of this research is to design and develop an SDI to allow the incorporation of VGI, professional Geographic Information System (GIS) layers, a mobile application, and scientific reports to aid in the disaster management process. A secondary goal is to assess the utility of the resulting SDI. The end result of combining

the three systems (e.g., SDE, a mobile application, and VGI), along with the network of relevant users, is an SDI that improves the volume, quality, currency, accuracy, and access to vital spatial and scientific information following a hazard event.

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CHAPTER 1

INTRODUCTION

1.1 Background

On April 16, 2012, the state of Utah participated in the Great ShakeOut series of earthquake drills (“The Great Utah ShakeOut”). During this event there was no clear coordination in collection and sharing of spatial data between government agencies. Some agencies and utility groups worked independently, making mock observations and collecting spatial data that would be relevant to the response process following a disaster. However, many agencies could assist each other with damage assessment if standards and infrastructure were in place to share observational as well as other data pertinent to disaster response. Citizens with cellphones and computers could potentially add thousands of relevant spatial data observations, or Volunteer Geographic Information (VGI), to a Spatial Data Infrastructure (SDI) that could aid in the recovery efforts (Goodchild 2007). While VGI is a very promising source of data for disaster management, it comes with many challenges including the volume of data, the absence of structure surrounding this data, and the lack of quality control (Osterman, 2011).

1.2 Problem Statement

SDI is a framework designed to support information discovery, access, and use of data in decision making (Norbert, 2004). It is difficult for one organization to collect and manage all of the spatial information required for effective disaster management (Mansourian, 2006). The incorporation of VGI has the potential to allow agencies and the public to better share spatial information. However, the usefulness of VGI as a means for observation, assessment, and long-term study of an event has yet to be determined within the structure of a disaster specific SDI. Modern smartphones have the capability to contribute location-based data through VGI or custom designed mobile applications. The objective of this research is to design and develop an SDI to allow the incorporation of VGI, professional Geographic Information System (GIS) layers, a mobile application, and scientific reports to aid in the disaster management process. A secondary goal is to assess the utility of the resulting SDI.

1.3 Research Questions

The research questions for this thesis are designed to advance both our understanding and application of SDI and VGI as they relate to disaster response and recovery. They are as follows:

1) How can the SDI model be improved to better facilitate the sharing of spatial information in the disaster management process?

Four ways in which this research will improve the disaster response process are 1) capturing information on an event that scientific or emergency response teams may miss, 2) providing information in near real-time, 3) providing more spatially located information than traditionally possible, and 4) reducing the cost for collecting and managing data. This research will focus on how to improve the disaster-response process through the development of an SDI with four core components: web feature services and enterprise geodatabase, VGI, mobile applications, and an online interface.

2) How can VGI be combined with professional GIS data to improve disaster management and response following an earthquake?

VGI has been shown to be beneficial in coordination efforts during the response phase of disaster management (Zook, 2010). This research seeks to ask how VGI may be used for observations and assessment of damage following an event. The question will be pursued by combining VGI and professionally collected GIS data within a geodatabase. VGI reporting damage related to the disaster will be analyzed alongside existing GIS layers. There data can then be further explored by professionals, thus increasing the number of observations and reducing the amount of time spent in damage assessment.

CHAPTER 2

LITERATURE REVIEW

2.1 Disaster Management

Hazards are potential threats to people and the things they value, and they exist where natural processes and technological systems interact with people. A disaster can be defined as a singular large-scale, high-impact event that causes widespread damage and loss-of-life that overwhelms society's ability to cope (Cutter, 2003). Drabek and Hoetmer (1990) define four steps to comprehensive emergency management: mitigation, preparedness, response, and recovery. Mitigation is deciding what to do where a risk has been determined, while preparedness involves developing a response plan and training personnel. Response is the phase immediately following a disaster where emergency aid and assistance is given. Recovery includes providing immediate support during early recovery to "return vital life support systems to minimum operation levels, and continuing to provide support until the community returns to normal" (Petak, 1985, p. 3).

Geographic Information Systems (GIS) are computer based applications designed to perform a wide range of operations on geographic information (Goodchild, 2009). GIS are well designed to handle the aspects of disaster management (Cova, 1999; Cutter, 2003; Goodchild, 2006; Gunes 2000; Johnson, 2000; Van Oosterom, 2005). Some of the challenges in applying GIS in emergency management have been defined as spatial data acquisition and integration; distributed computing; dynamic representation; modeling coupled physical and human processes; cognition of geographic information; interoperability, scale, spatial analysis, and uncertainty; and decision support systems (Cutter, 2003).

2.2 Volunteer Geographic Information (VGI)

As locationally-aware technologies have advanced, more people are voluntarily contributing personal geographic information to various systems. In 2007, Goodchild coined the term Volunteer Geographic Information (VGI) to describe the general web phenomenon of this user generated content. There are many promising uses for this data, but it comes with many challenges. Osterman et al. (2011) defines three main VGI challenges: the volume of the data, the absence of structure surrounding this data, and the lack of quality control. Current solutions require a combination of computer-based algorithms and human oversight (Qian, 2009).

Many current computer devices have at least one positioning technology built in. Global positioning systems (GPS) are now widely available and come integrated into everyday devices like cameras and cell phones. Even without a GPS connection, a cell phone can determine its location to within 600 meters by triangulating with cell towers (Zandbergen, 2009). Connecting to a Wireless Local Area Network (WLAN) can also provide a device with an approximate location. This technology has led to a proliferation of location-based social-networking applications, including Facebook, Twitter, Instagram, Flickr, and YouTube. A status update is a feature of social-networking sites that allow a user to share information, such as text or photos, usually about their surroundings, thoughts, feelings, or other information. Facebook and Twitter are both popular social-networking applications that allow status updates, though Twitter was designed to only allow status updates of 140 characters (or Tweets). Instagram and Flickr allow users to upload photos that can then be viewed directly within the app or shared through email or a social media site. YouTube allows users to post and view videos.

Rapid utilization of information and data from multiple sources is an integral part of effective disaster management. Local citizens can be an important source of information through computer-based systems such as text, web logs (blogs), video, pictures, and maps (Laituri, 2008). Figure 1 displays an example of a Tweet associated with damage from the 2014 South Napa Earthquake. VGI has seen increasing use in disaster response and recovery. Twitter has been examined as a method of earthquake detection (Earle, 2010, 2012; Sakaki, 2010). Guy et al. (2010) examine the integration of VGI with scientifically-derived seismic information in order to augment earthquake response, and they found that the main advantage of VGI is the speed of available information, especially in areas sparsely instrumented with seismometers. Public Participatory GIS (PPGIS) aims to provide GIS technology to support public participation for various applications, such as community mapping (Brown, 2012). Tools, such as Ushahidi ("FAQ – Ushahidi," 2014), have been developed to facilitate crisis management by utilizing PPGIS by gathering and disseminating VGI through text messages or online sites, such as Twitter.

Two major benefits of VGI with regard to the 2010 Haitian earthquake defined by Zook et al. (2010) are 1) it allowed a greater number of maps to be produced more rapidly, thus freeing scarce technical resources, and 2) it allowed individuals to report on local and specific conditions, providing additional data that could not be matched by traditional means of data collection. Twitter, emails, status updates, and other sources of VGI allowed information about opportunities to spread quickly (Zook, 2010). Although VGI has been used as an aide in disaster response, as well as a tool for early detection of earthquakes, previous systems have not examined its role within a disaster-specific SDI in contributing observations in the immediate aftermath of an event, as well as the longer term scientific study of that hazard.

2.3 Spatial Data Infrastructure (SDI)

As noted, Spatial Data Infrastructure (SDI) is a framework of data that supports the decision-making process by providing the structure for information discovery, access, and use (Norbert, 2004). SDI is developed to facilitate the access and availability to spatial data across government, commercial, academia, and citizens (Alders, 2001). SDI contains five core components: 1) policies, 2) access networks, 3) data handling facilities, 4) standards, and 5) human resources needed for the effective collection, management, access, delivery and utilization of spatial data for a specific area (Rajabifard, 2004). It can be considered a linked network of spatial information within the private and public sector. By creating secure and direct linkages, those responsible for disaster management are ensured to have the most accurate and up-to-date information that is available (Tait, 2003). Many regional, national, and local SDIs have been created because of the importance of supporting and managing geospatial data, including the National Spatial Database Infrastructure (NSDI) in 1994 (Tait, 2003).

Incorporating VGI within an SDI has recently received considerable attention (Budhathoki, 2008; Coleman, 2010; Elwood, 2008; Goodchild, 2007; McDougall, 2009), and the concept of disaster specific SDIs has gained more attention in the last decade (Herold, 2005; Köhler, 2006; Mansourian, 2006). One example of this is in Iran where Mansourian et al. (2006) developed a nationwide web-based SDI that involves multiple agencies collecting and sharing data through a distributed system. Development of this system requires the cooperation of many agencies, which has the potential to improve the quality of decision making and increase effectiveness in all levels of disaster management (Mansourian, 2006). The developers of this system introduce the idea of including mobile GIS, but stop short of incorporating it into their design. This system was also developed before modern smart phones and custom-built applications became popular. It also does not take into consideration the use of VGI as a potential tool in the disaster management process, specifically in the response and planning phases. The overarching goal of this thesis is to develop a next-generation SDI for disaster response and recovery that relies on mobile locationally-aware devices as a source of VGI and data collection.

Figure 1 A Tweet from the South Napa Earthquake showing damage from falling debris.

CHAPTER 3

METHODS

As noted, the objective of this research is to design an SDI to support disaster management that includes VGI. The SDI Cookbook (Norbert, 2003) states that an SDI contains 1) spatial data and attributes, 2) metadata or other sufficient documentation, 3) a way to discover, visualize, and evaluate the data, and 4) a method of access. The design for this SDI is a three step process:

1. Define Users and System Structure
2. System Development
3. System Testing and Analysis

3.1 Define Users and System Structure

Understanding and addressing the needs and roles of users who will be accessing the system is an important part of system design (Lily, 1999). By developing use-cases for each type of user, we can define who can do what with the SDI. Use-cases are designed to describe the behavior of a system under different situations and conditions as the system responds to requests from the system users (Cockburn, 2001). There are potentially six types of users who will be accessing this SDI: the public, the scientific community, emergency operations center (EOC) operators, field responders, GIS analysts from the participating agencies, and the administrators of the SDI. The use-cases will cover the policies and human resources components of the SDI. Table 1 shows a list of the users that will be involved with the system, as well as a brief profile explaining their background as it relates to an SDI. Table 2 lists the interfaces the users will use to accomplish tasks within the system.

3.2 System Development

3.2.1 Relational Database and Feature Services

SDI requires a system that is capable of storing and managing large quantities of spatial and nonspatial data. This system must support multiple users that will access this data simultaneously. Spatially enabled relational databases can provide this functionality. According to Environmental Systems Research Institute (Esri; Esri, 2004) some of the benefits that relational databases provide to GIS are

- A single data store for attribute and spatial data
- Concurrency management in a multiuser environment
- Standard data management practices, such as backup, recovery, and replication
- Scalable data volumes with no size limitations
- Centralized system wide access to data
- Data maintenance over long time periods
- System failure and recovery mechanisms
- Industry-standard client/server and Internet architectures (e.g., Web services)

The data for the SDI will be stored in a relational database using ERSI's ArcSDE technology. This software leverages the utilities of a traditional Relational Database

Management System (RDBMS), such as Microsoft SQL Server or Oracle, and adds a spatial component. This thesis will refer to this technology simply as SDE (Spatial Database Engine). Figure 2 shows a diagram of how the SDE architecture fits within a RDBMS.

In addition to a relational database, the SDI will also require the data to be accessible through a web interface. This can be done with web feature services. A web feature service is defined by the Open Geospatial Consortium (OGC) as a web service standard for vector-based (e.g., point, linear, and polygonal) geographic feature requests on the web. A service can contain multiple geometry types as well as attribute information (Jones, 2014). Feature services allow for the display, querying, and editing of map-based SDE data from a web browser or mobile device (Esri, 2014). Since users of the SDI require the ability to query the data as well as edit and add observations, it makes sense to utilize feature service technology. Data stored in the SDE will be published to a web server as feature services in order to accomplish this.

3.2.2 Volunteer Geographic Information (VGI)

Utilizing data from multiple sources following a disaster can make information collection less difficult. VGI can originate from many sources and is freely contributed by the public. Accessing posts on social media sites such as Twitter, Instagram, and YouTube will increase the potential number of observations to the system. There are several ways this information can be accessed. For this study, Twitter, YouTube, and Instagram will be the main sources of VGI.

Using predeveloped tools, or widgets, Tweets can be overlain on a web map.

This information can be filtered using keywords or through hashtags, which are a keyword prefaced by the ‘#’ sign that is useful for searching. Analysts in the Emergency Operations Center (EOC) can search the filtered data for VGI relevant to the recovery process and view them in a map or enter them into the system for further analysis. The EOC can then call for a field-agent to further inspect and verify the observation that may otherwise go unreported. This will potentially save the field-agent time, as the EOC can directly lead the field-agent to an observation, rather than waiting for him or her to discover it.

Another method of acquiring Tweets is through the use of the Python programming language to download, or “scrape,” the information directly from the Twitter website. Tweets can be searched and downloaded by location or keyword. Once in the program, further filtering can be applied to remove information that is irrelevant to the disaster. If the data contain a location, they can be geocoded and added to a feature class within the SDE. This will allow more complex spatial analysis to be performed on the data.

3.2.3 Mobile Application

The use of Mobile GIS can improve response capability and ensure greater efficiency by supplying data and the means to make better decisions (Erharuyi, 2003). Applications can be developed for modern smartphones and tablets that allow the entry of information, as well as GPS location and media, such as video or photographs, into the database. These applications can store data on the device until a network connection is detected.

3.2.4 Web Interface

The clearinghouse concept is a system for dealing with data accumulation, organization, and dissemination in disaster events (Warren Mills, 2008). Creating an interface that includes methods to visualize and access data, as well as contribute to the system will provide the access network and data handling facility for the SDI. Functionality to include in the Clearinghouse includes

- Provide timely observations for state and federal emergency managers, scientific communities, and the general public
- Coordinate the field investigations of response crews, scientists, and other researchers
- Serve as a data-collection point for emergency response related observations
- Provide information necessary to emergency response activities

This website allows the contribution of observations of a specific event through a standardized form. This form has fields for what was observed, where the observation took place, time, and date. These observations, after review, will then be committed to the system to be overlain with other data that are included in the SDE, as well as VGI.

3.3 System Testing and Analysis

To test the system, information will be gathered from the disaster response community and implemented in the design. Test data will be entered into the system through the multiple designed interfaces. The SDI will be analyzed to determine the usefulness of the system. Some examples of questions that will be asked are 1) how does this SDI improve the disaster management process? And 2) what information was available in this SDI, that wasn't available before? These questions will be answered by 1) the ability of the interfaces, including VGI, to contribute data to the SDI providing more information than traditionally possible or that may have been missed, 2) the connectedness of each of the systems with each other (i.e., when data are entered into the mobile application, does it reflect throughout the SDI?), 3) reduced cost of collecting and managing data by including predeveloped applications when possible, and 4) the ability for data to be relayed in near real-time.

Table 1 SDI users and their background and skills.

User	Profile: Background and Skills
SDI Administrators	Person with strong database management and GIS skills. Able to maintain database and troubleshoot problems that arise.
GIS Analysts	Person who works with GIS from the agencies involved in the SDI. These users have a basic knowledge of GIS and its principals. Can update, edit, and query data and information in database.
Field responders	Person who may not be GIS expert, but has specialty in certain area of response or information reconnaissance.
EOC Operators	Person who has little or no GIS skills. Can use web browser and basic computer knowledge. Understands emergency response activities and goals. Knows what information is needed.
Scientific Community	Person who uses the data entered into the SDI for scientific analysis. Varies from basic computer skills to GIS analysts.
Public	Person with little or no GIS skills. Can use web browser. Contributing data through VGI or accessing the clearinghouse for information through user interface.

Table 2 Interfaces of the SDI and how they will be used within the system.

Interface	Description
Clearinghouse Website	The website will be set up with a web map that displays VGI as well as data added to the mobile app and infrastructure information. Functionality will also include standard observation forms and data submission.
Mobile Application	This mobile application will allow the entry of observational data with a spatial location. In instance of network failure, it will store the information until a network connection is made.
Social Media Websites	Information from social media websites, i.e., Twitter, Flickr, YouTube, Google+, that have certain keywords or hashtags related to the specific event.
Web Map	Map on website that displays spatial data associated with event
Esri	Software used to administer Geodatabase. Add/delete information. Manage versions, services, and users.
SQL Server	Database management software used to create and manage database as well as query data.

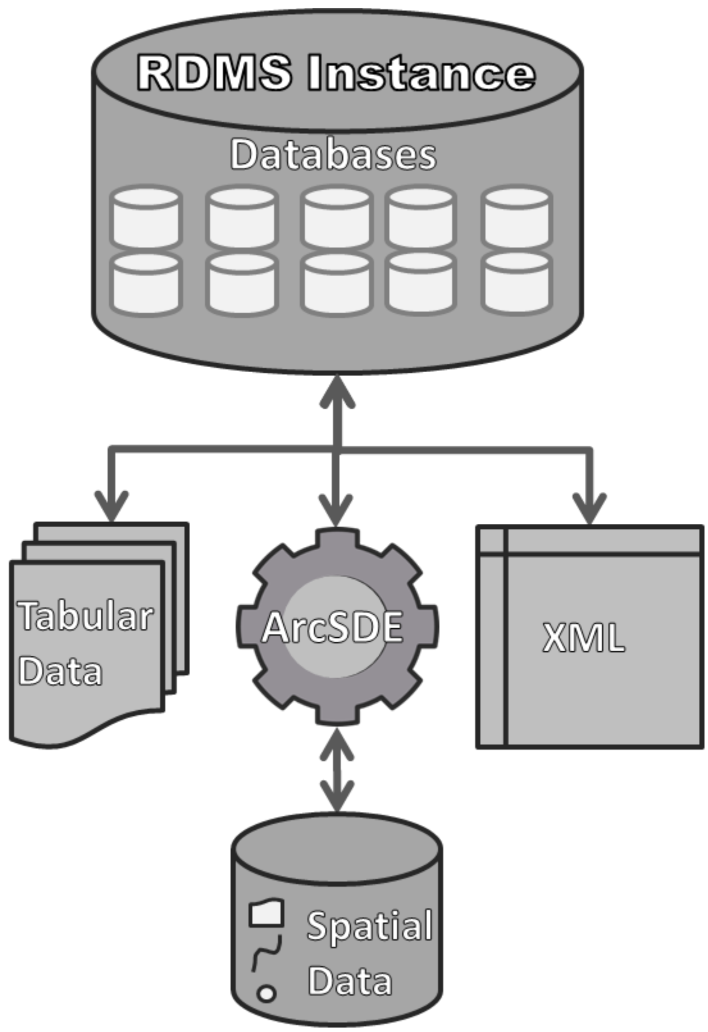


Figure 2 Diagram explaining how ArcSDE fits within the relational database architecture to allow for the incorporation of spatial data.

CHAPTER 4

RESULTS

4.1 SDE

Data for the SDI were gathered from a list of key emergency response layers made available by the Utah Division of Emergency Management (UDEM). These data were divided into three categories: infrastructure, response facilities, and special care. Table 3 shows the layers acquired in their respective categories. The data were obtained through local sources, including Utah's Automated Geographic Reference Center (AGRC), which compiles and manages state of Utah GIS data. These data are regularly updated by the creators of the data and maintained in a central database made available to the public. The layers were added to a Microsoft SQL Server ArcSDE (SDE) spatially enabled enterprise database.

A point layer was created to handle field observations. Attributes for this layer include damage type, severity, priority, observer, date, and general comments. Domains, or predefined values, were established for damage type and severity to limit the input data to valid entries. By setting up domained attributes, drop-down lists of acceptable values are automatically created when editing the data. Users can select the value from this list as opposed to entering values manually, thus making it more user friendly to field responders and GIS analysts recording observations to this layer. Domains also help maintain consistency, integrity, and accuracy within the database. Figure 3 shows the domains established for the Observations layer.

4.2 GIS Maps

Three maps were made using the defined categories (Figure 4–6). Within each map document (MXD file), layers were symbolized and labels were generated. Symbology and label styles were selected from a standard template using the original information provided from the UDEM.

A fourth map was made to handle the observations layer that will be used by emergency responders in the field (Figure 7). This map contains a single point layer where each point represents an observation submitted to the SDI. These data are symbolized using the type and severity of the observation. These four maps feed the feature services that would be added to the online maps. Figure 8 shows how spatial data are added to maps, then through ArcServer become feature services that can be displayed in web maps.

4.3 Feature Services

Feature services allow spatial data stored within the SDE to be accessed through web maps. Esri's ArcServer software was leveraged to create feature services from the MXD files. Feature services were chosen to allow the added functionality of query, create, delete, and update within the web map. *Query* allows questions to be asked of the feature and its attributes. The *create* feature service allows users to add data. *Delete* allows features to be deleted through the service. *Update* allows a feature's geometry or attributes to be changed. This gives users of the system greater ability to interact with the layers. ArcServer was then used to analyze each MXD file for critical errors in order to optimize it for web viewing. Once errors were resolved, the MXDs were published to a web server hosted at the University of Utah. Figure 9 shows the web interface to ArcGIS Server Manager and the three published services.

The Observation layer was published to Esri's ArcGIS Online (AGOL). ArcGIS Online is a cloud based platform that allows organizations to create and share maps, apps, and data ("What Is ArcGIS Online?," 2014). Leveraging this utility allowed for extra functionality to be integrated into data collection. This layer was configured to be editable in both web maps and in mobile applications (Figure 10). Attachments were enabled in order for pictures and video to be captured and tied to an observation with the mobile application. This feature service was also set up to be editable offline, allowing field users to collect observations and make edits to features within the layer, even if the network is down. These edits can then be reconciled back to the database when the user returns to an area with a network. For example, a field user could record the location of a downed power line in an area where the power is out and the mobile network is down. They could take a picture of the power line and attach it to the location. These data would be stored on the device until the field user returns to the EOC where a back-up generator provides power to allow the device to connect to the internet. The recorded observation would then be uploaded to the feature service where it can then be observed by other web maps.

4.4 Web Map

The four web services were added to a basic web map. This allowed for a standard initial web map with basic functionality to be built and quickly deployed. Figure 11 shows the interface of the initial web map. This initial web map can be utilized by multiple organizations in its initial form using prebuilt templates with extended functionality or by creating custom developed web maps with specifically designed tools within the map, or widgets, to enhance functionality. This basic web map also allows for a user to search thousands of available web services, including weather and demographic data, and add them to the map. For example, the EOC could bring in demographic data created by the U.S. Census Bureau in order to better understand affected populations or weather data to track incoming storms that may impact response efforts.

The Infrastructure, Special Populations, Response Facilities, and Observations feature services were added to the web map. Symbology and labeling are embedded into each service. This creates a consistent look, or common operating picture (COP), for each user (Figure 12). Interface A is the map displayed in the mobile data collection application. Interface B shows the Initial web map. Interface C is the web map embedded within the SDI website. Interface D is the VGI mapping application. Notice that, though each interface is different, each map contains the same features, symbology, and labels, creating a consistent look across all platforms and interfaces.

Users can click on an object within each layer to bring up a pop-up window displaying the attributes of that object. Pop-up windows can be customized to include graphs, links to reports, web pages, or online media. This provides users with much more information than traditionally available in paper maps. Figure 13 shows an example of a pop-up window for an elderly care center. By viewing the pop-up window, emergency responders can quickly find the name, address, contact information, and number of beds for that center.

The web map was configured to allow users to choose varying basemaps in order to help users best visualize the data (Figure 14). Basemaps also provide additional information such as terrain, road names, political boundaries, structure location, and elevation. The basemaps are created and maintained by Utah's AGRC. The data in the basemaps are regularly updated to display the most current information. The basemaps that can be selected include

- Aerial imagery
- Terrain
- Roads
- Features with labels
- DEM Hillshade

The map also displays a legend to explain the symbology of the layers. Each layer within the services can be turned off or on to increase the readability of the map for the EOC and field users. This legend is updated dynamically based off what is currently being displayed in the web map. This reduces clutter within the legend and allows a user to quickly determine what they are seeing in the map. Figure 15 shows various legend displays in the web map. Legend A shows the symbology for the response facilities. In legend B, both the Observation and Special Populations layers are visible in the map and represented in the legend. Legend C shows the symbols representing the infrastructure layer.

4.5 VGI

The map can quickly be shared out by using a variety of predesigned map interface templates. These templates allow a user to add a map to the template to take advantage of different functionality for varying purposes. For this study, a map template was chosen that included a VGI widget. This widget displays Twitter data (Tweets) on the map using standard search (Figure 16). A pop-up window is displayed by clicking on the Tweet that displays the context of the Tweet including: the author, the text content, the time and date it was posted, a link to the original Tweet, and a link to any attachments including pictures and videos. Figure 17 shows the web map displaying the pop-up window associated with a Tweet. The search term can be changed to display custom hashtags that are assigned to a specific event.

The VGI web map was created using JavaScript. The template for this map can be downloaded allowing an organization to customize the look-and-feel of the application. It also allows for the expansion of functionality of the map, including the addition of custom widgets and tools. Using JavaScript also allows the application to be compatible across multiple computing platforms. A user can open the map in Apple OS (iOS) and Windows or open it in a mobile device such as an Android tablet or iPad. The application has the same look, feel, and functionality across each of these platforms.

A second VGI map was created using a separate template. The map includes earthquake fault lines obtained from the United States Geologic Service (USGS) quaternary fault database. Recent earthquake epicenters were also displayed on this map. This map utilized Esri’s Social Media widget that maps current posts from Twitter, YouTube, and Flickr. These posts were filtered by basic search terms and displayed on the map as points, clusters, or a density heat map. Heat maps are used to as a method of visualizing data to determine patterns or density of the data ("Extending Your Map with Spatial Analysis," 2014). Figure 18 shows a screen shot of this heat map. The VGI is filtered in this image by the search word "shakeout OR earthquake" and displayed as a density map. Tweets are clustered to show the density of Tweets in an area. Red areas indicate more Tweets associated with the search term.

4.6 Mobile Application

A mobile application ("app") was set up to allow the collection of observations using smart phones or tablets. This app was configured using the freely available, predeveloped Collector for ArcGIS application. The app also offers the ability to work offline increasing its robustness. A user can define their work area and store basemaps on the device. Collections can also be cached on the device. When the device is reconnected to the network, changes will be reconciled back to the database. Basemaps can be made in the office and/or preloaded onto a device, allowing for faster deployment and improving offline capabilities.

This application utilizes the same initial web map that was created in AGOL, leading to a consistent look across all platforms. Figure 19 shows the web map as viewed through the mobile application. The dot in the middle of the image shows the location of the user. The ring around the dot shows the spatial uncertainty in that location as determined by the GPS. Buttons along the bottom of the image, from left to right, allow the user to center the map on their location, add an observation, search the map for a location, navigate to predefined bookmarked locations, or access a menu with more options.

Using the mobile application, points can be collected to the Observation hosted feature service. Defined values, or domains, that were set up when the data were initiated create preprogrammed dropdown menus when populating that attribute. This makes data collection easier for field responders and creates more accurate and consistent data to support analysis. Figure 20 shows the interface for collecting an observation. Attribute fields can be marked as required assuring that the necessary data are collected. The application will also automatically track the user that last edited a feature. This allows observations to be traced back to the source, ensuring better quality data.

The feature service was also configured to allow attachments to be made to each observation. This allows for photos and videos to be tied to an observation, providing EOC users a way to visually inspect each observation and store images for future study. These attachments can also be viewed by other field responders using the mobile application. Figure 21 shows how attachments can be viewed within the mobile application. This gives other field responders the ability to visually inspect the observation and compare it to the attributes, providing more information than would be possible through paper maps.

Observations taken using the mobile application are then added to the hosted feature service and displayed in every map that is utilizing that service. Figure 22 shows the collected observation displayed in the web map. This gives users in the EOC near-real-time access to information in the field. For example, an EOC operator could hear a report of a damaged bridge. They could then deploy a field crew to visually inspect that bridge. The field crew can then add an observation to the map and include a picture of video of the damage, allowing EOC operators to view the damage and decide a course of action.

4.7 Website

A website was created to provide access to the SDI. The website is hosted on an off-site server to provide robustness to the system in case of a catastrophic event. The website was designed to act as a one-stop location for all information regarding an event for multiple users. Users can view the embedded basic web map or navigate to the VGI web map application, as well as any web map that is created with different functionality to support the event. To supplement the VGI web map, a social media dashboard was created, which includes live feeds of the social media sites Twitter, YouTube, and Instagram. These feeds are filtered using a custom search to display information relative to the event. Figure 23 shows the results of the social media dashboard. By accessing this dashboard, an EOC operator can quickly scan social media sites for any information that might contribute to the response efforts that may not be georeferenced. For example, a person may post a video of a rock fall on YouTube. The EOC can view the video, determine the location, and decide whether the event elicits a need to deploy field crews or emergency responders.

The website also contains the ability for a user to make requests to the EOC. Forms are made available to submit observations, request a map, or request a copy of the data. This functionality can be further automated using custom scripting. In order to ensure consistency in data, the online form for observation submittal is based off a PDF form that can be found on the resource page. Figure 24 shows the form for submitting observations. This engages the public to report even more information that could be included in the SDI in the form of PPGIS. For example, a person may observe an earth fissure in their yard. They can fill out the form detailing their observation. Someone from the scientific community could then contact that individual for further investigation.

EOC operators, the scientific community, or the public can access information through the resources page. This page contains general information on disaster response and other useful information on the current event including general information on emergency response or the science behind the type of event. This page also can be set up to link to information regarding the specific event, such as breaking news provided by local media. Templates and other standardized information are accessed through the Templates page. This includes map templates, style files for symbology, and PDF forms. Making these standards available for responders, analysts, and scientists allows for a consistent look-and-feel for data and products between EOCs throughout the event and future events.

Table 3 Spatial data for the SDI was grouped into three categories to allow for better organization.

Infrastructure	Response Facilities	Special Populations	Observations
Bridges	Armories	Child Care	Field Observations
Dams	Emergency Operations Centers	Elder Care	
Rail Stations	Fire Stations	Schools	
Electric Generation	Hospitals		
Natural Gas Plans	Police Stations		
Natural Gas Storage	Red Cross Shelters		
Refineries	Staging Areas		
Amateur Radio Repeaters			
Long Link Repeaters			
Power Facilities			
Other Power Facilities			
State Fuel Sites			
Light Rail Stations			
Commuter Rail Lines			
Power Lines			
Railroads			

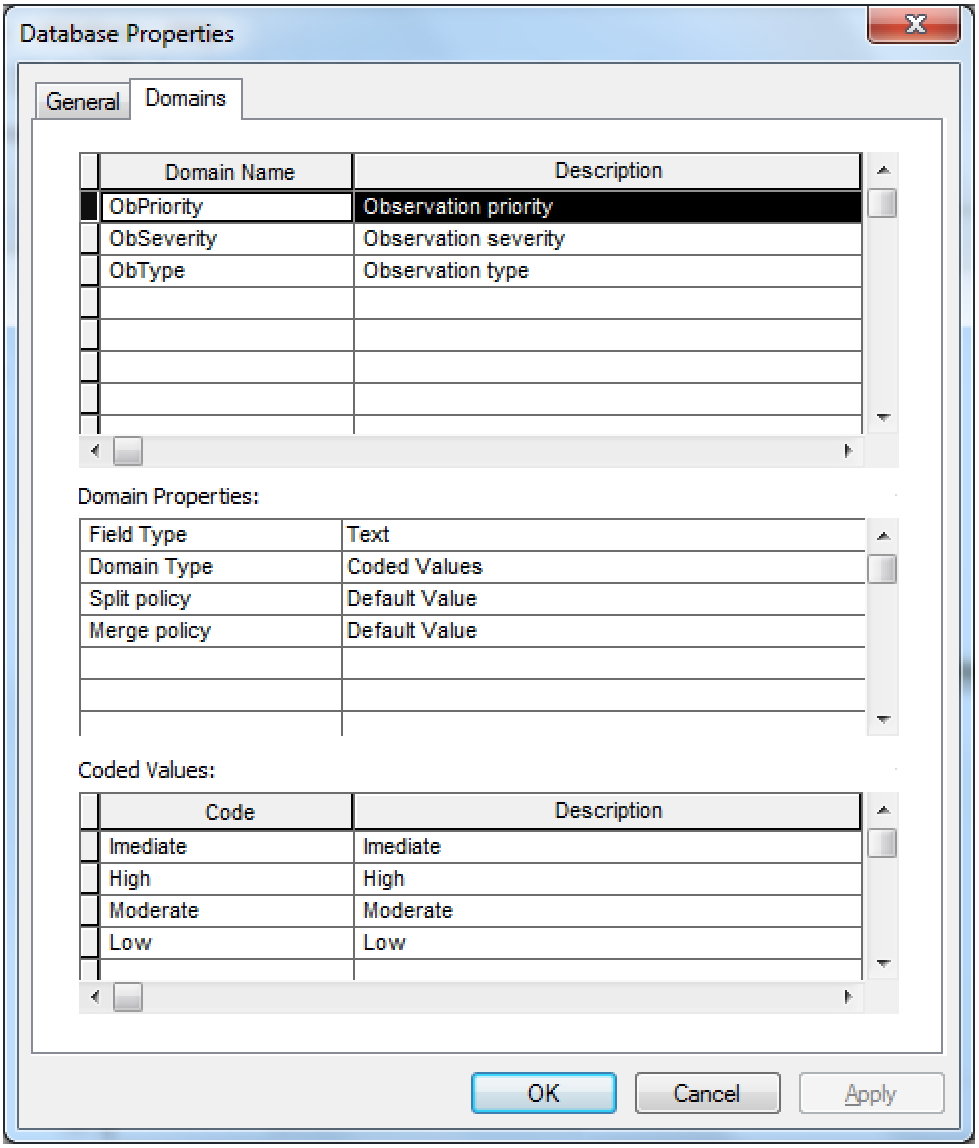


Figure 3 Domains for the Observation layer were created within the database. This allows for quick data entry in the mobile application through drop-down menus.

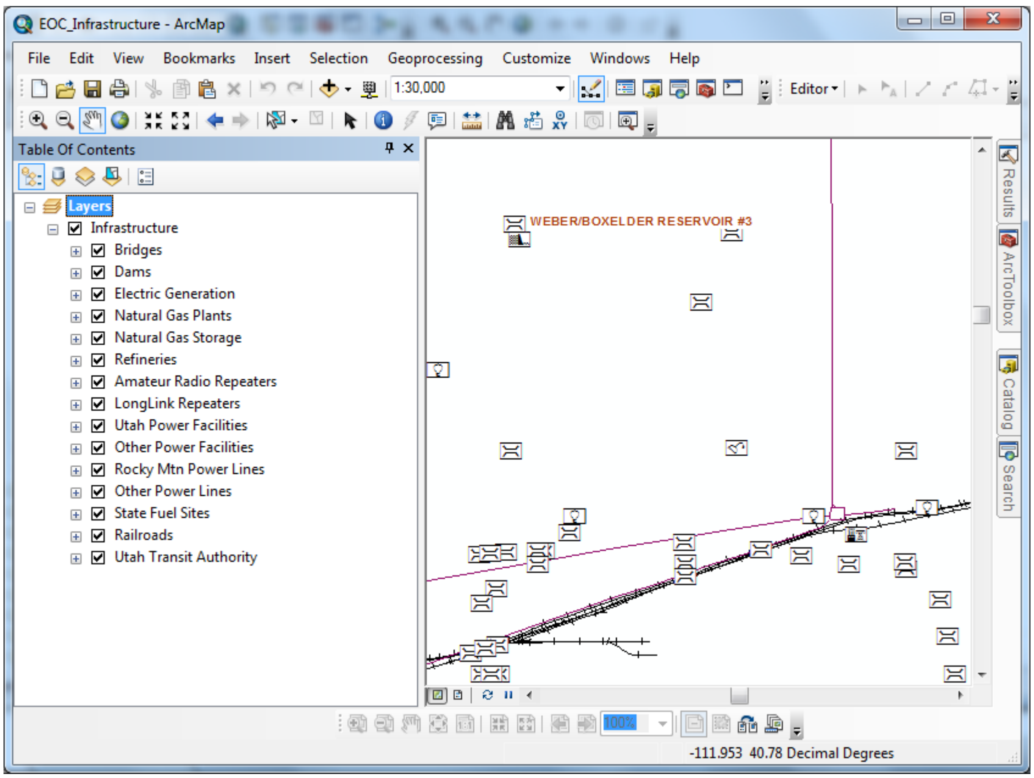


Figure 4 A map containing layers associated with infrastructural data.

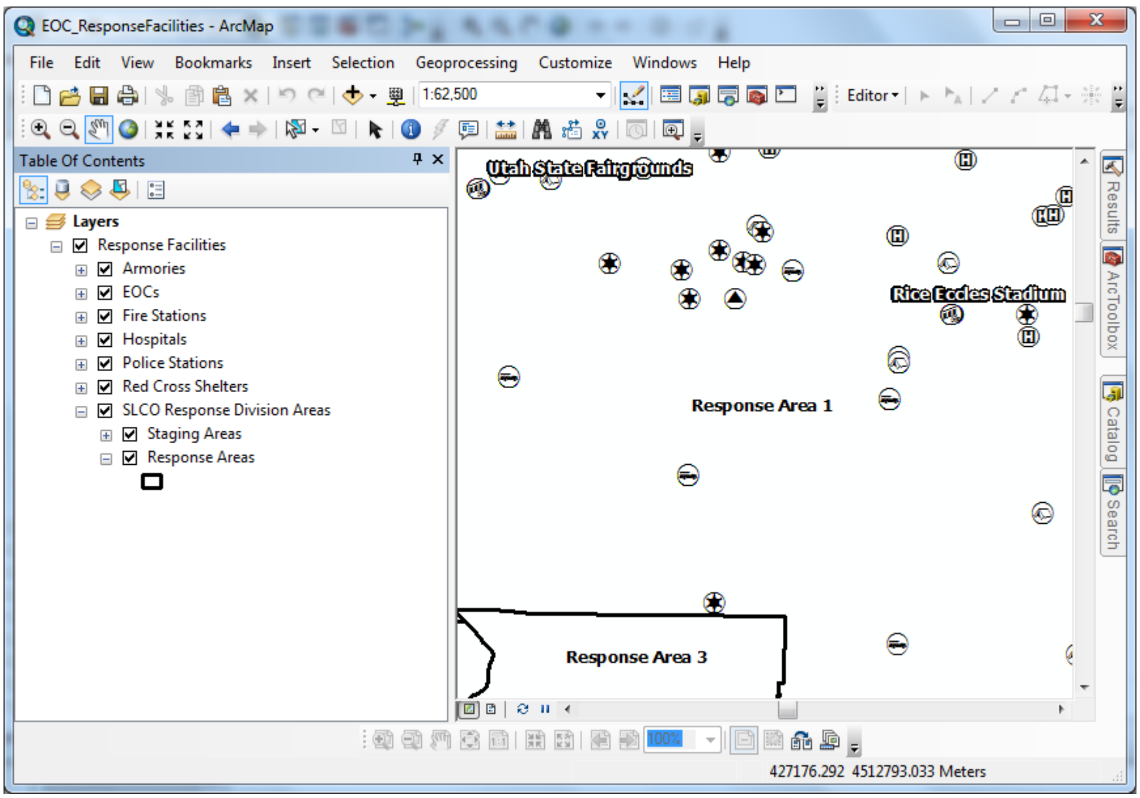


Figure 5 A map containing layers associated with response facilities.

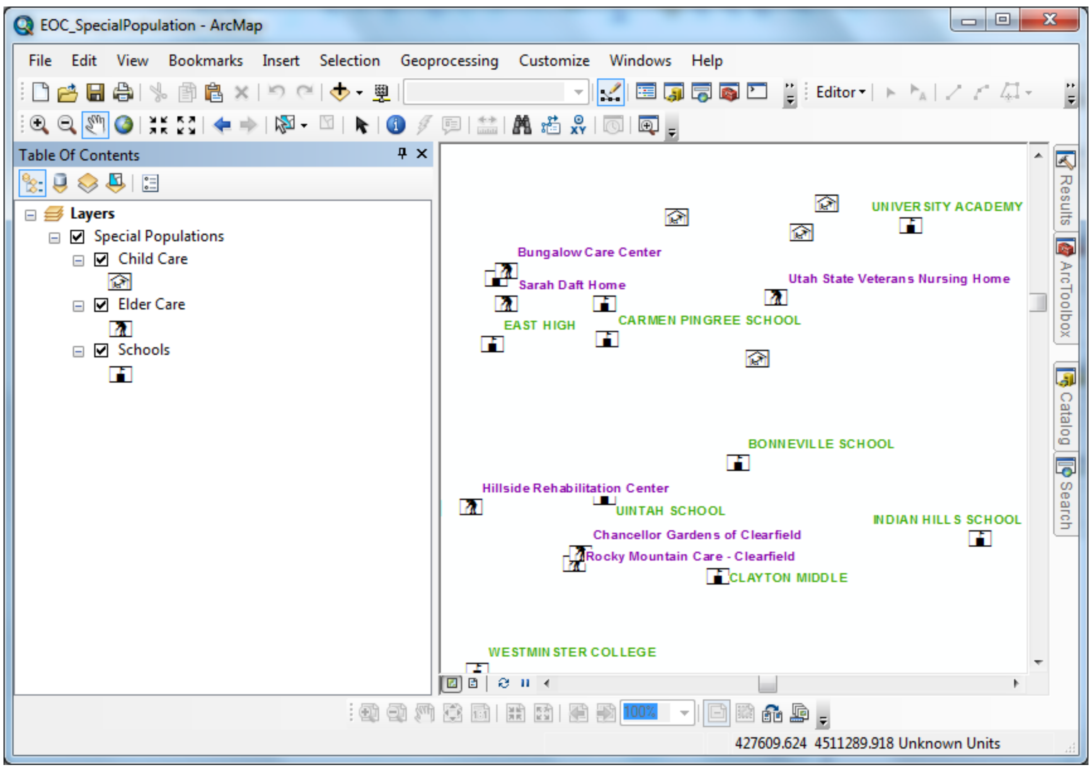


Figure 6 A map containing layers associated with special populations.

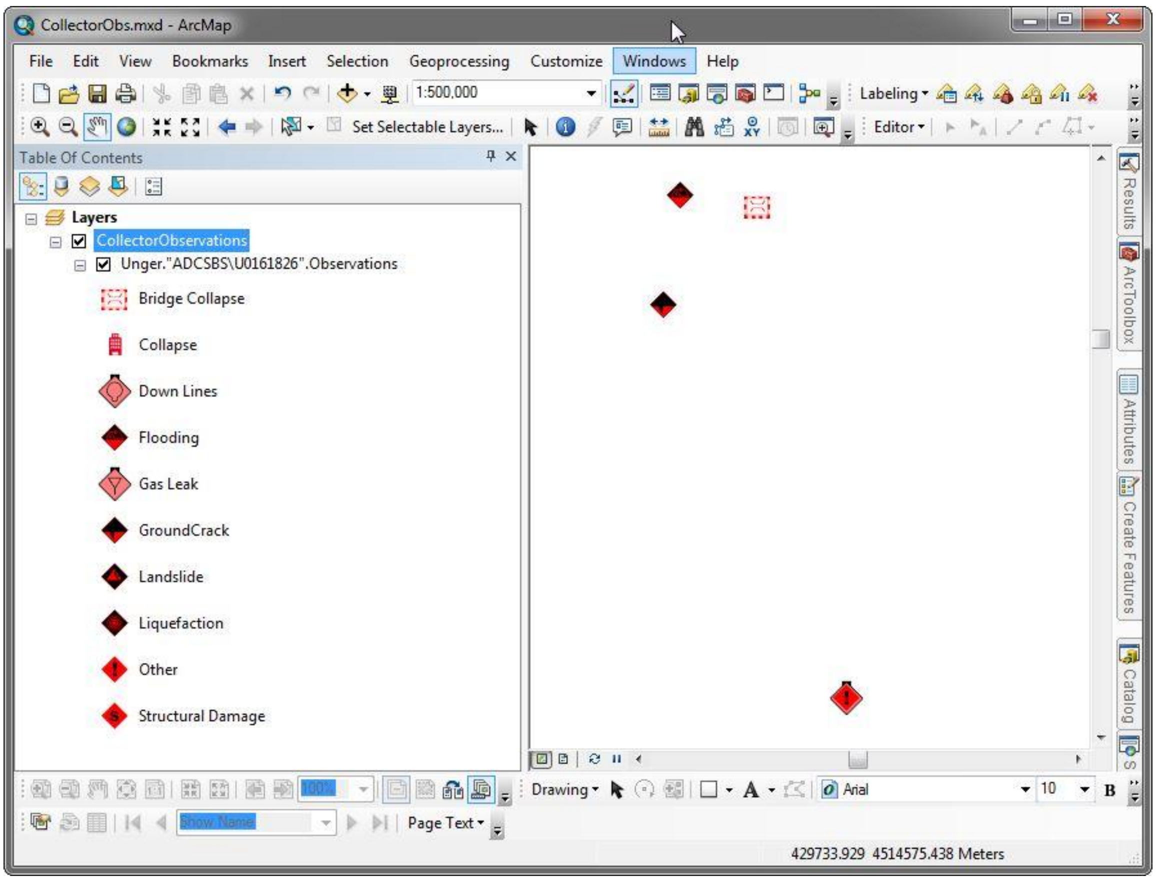


Figure 7 A map containing the layer created to handle the collection of damage observations by field responders.

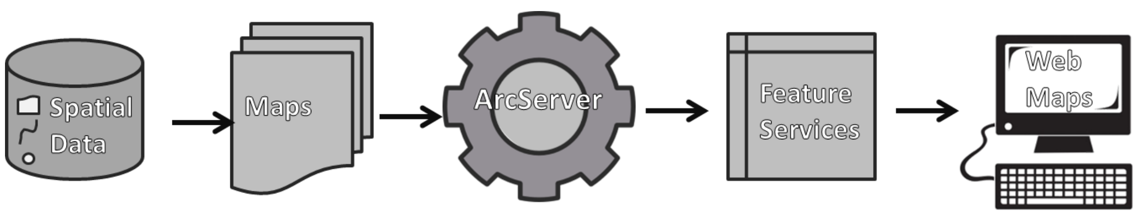


Figure 8 Diagram showing the process of how spatial data can be consumed by web maps by creating Feature Services.

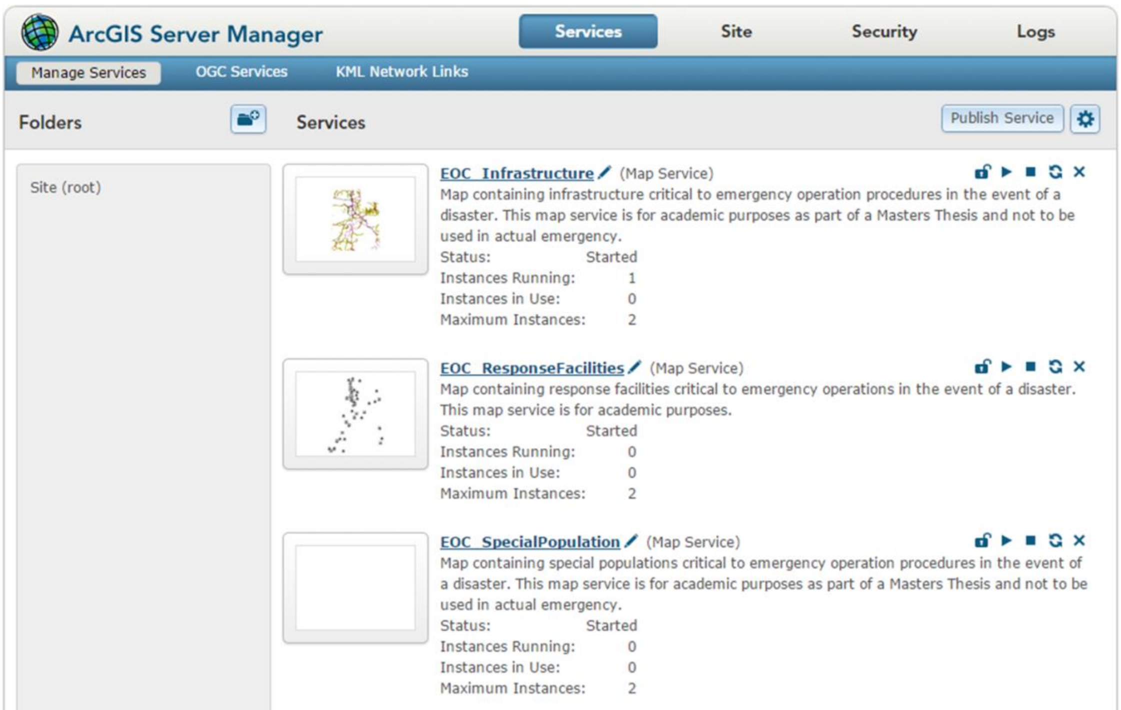


Figure 9 Three feature services were created and added to ArcGIS Server.

Layers

Unger."ADCSBS\U0161826".Observations

Properties

Shared with	UGS Hazards Program
Tags	disaster, managmement, observations, test, collector
Credits	Corey Unger
Size	60 KB
Delete Protection	Enabled
Extent	Left: -180 Right: 180 Top: 90 Bottom: -90
Editing	Editors can add, update, and delete features.
Export Data	Allow others to export to different formats.
Sync	Enabled
Track Edits	Tracking who created and last updated features. Editors can only update and delete the features they add.

Figure 10 The Observation layer was published as a hosted feature service using ArcGIS Online. Settings allow the data to be used offline in the event of network failure.

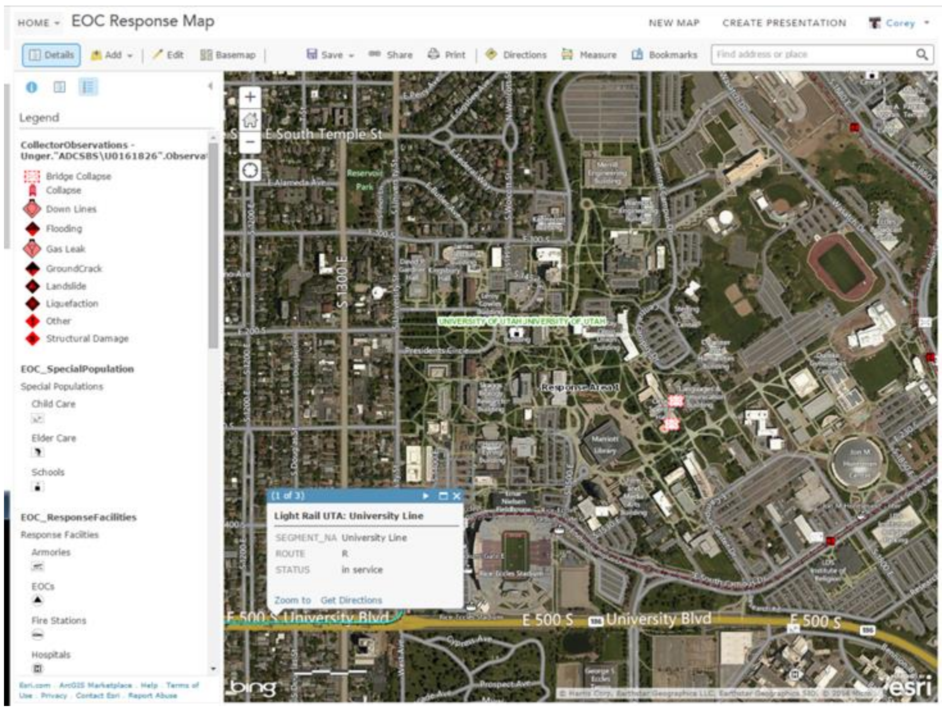


Figure 11 Interface of the initial web map created within ArcGIS Online.

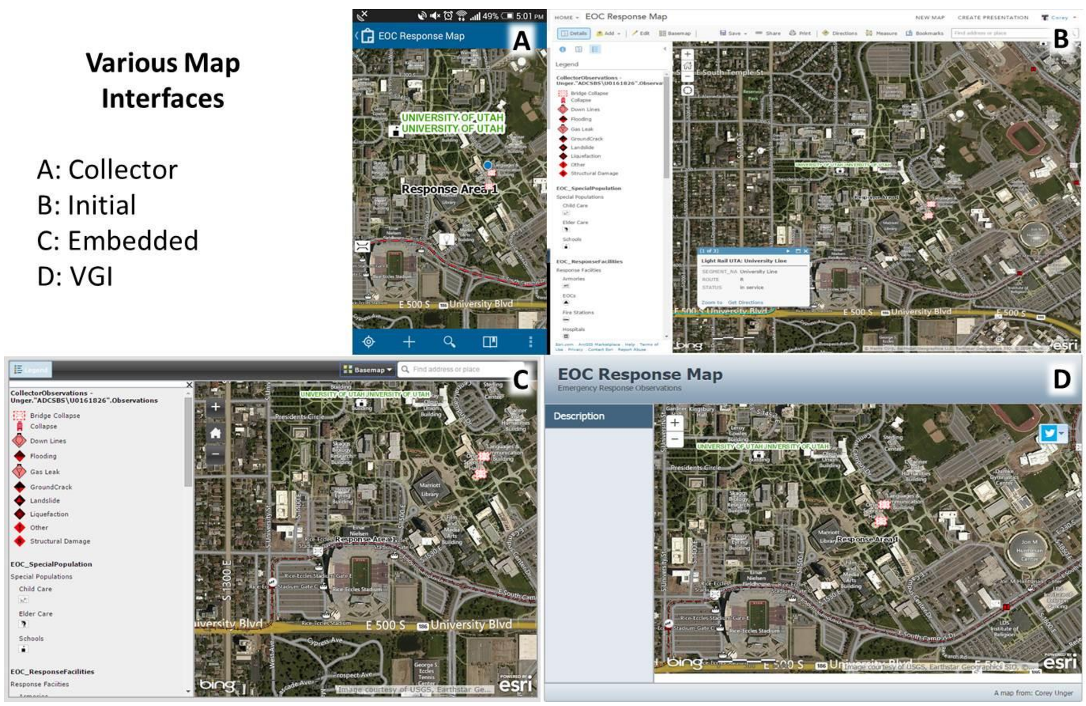


Figure 12 A comparison of the various interfaces of the web map. A consistent look across multiple interfaces reduces the chance for communication error.

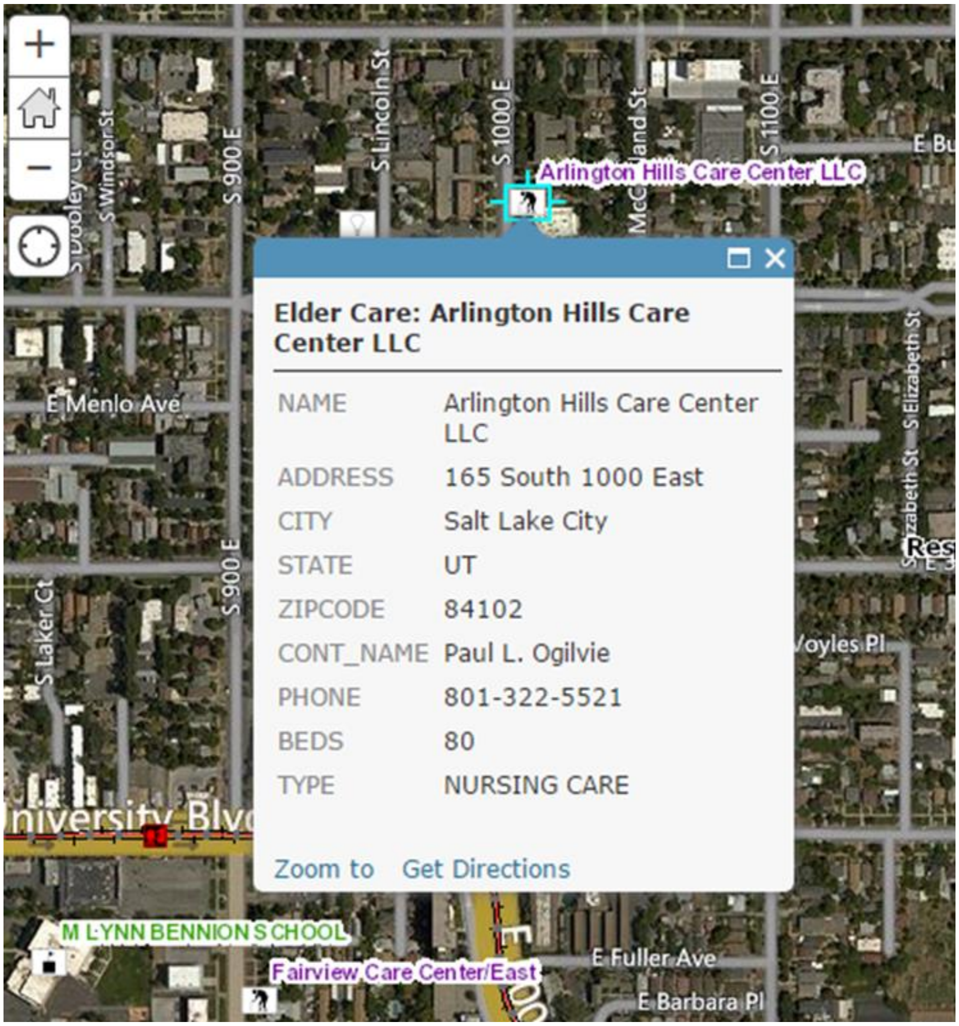


Figure 13 A pop-up window displaying information for an Elder Care center. Users can click on an object within the map to access attributes associated with that object.

Figure 14 Differing base maps can be used to display additional information and increase map readability.

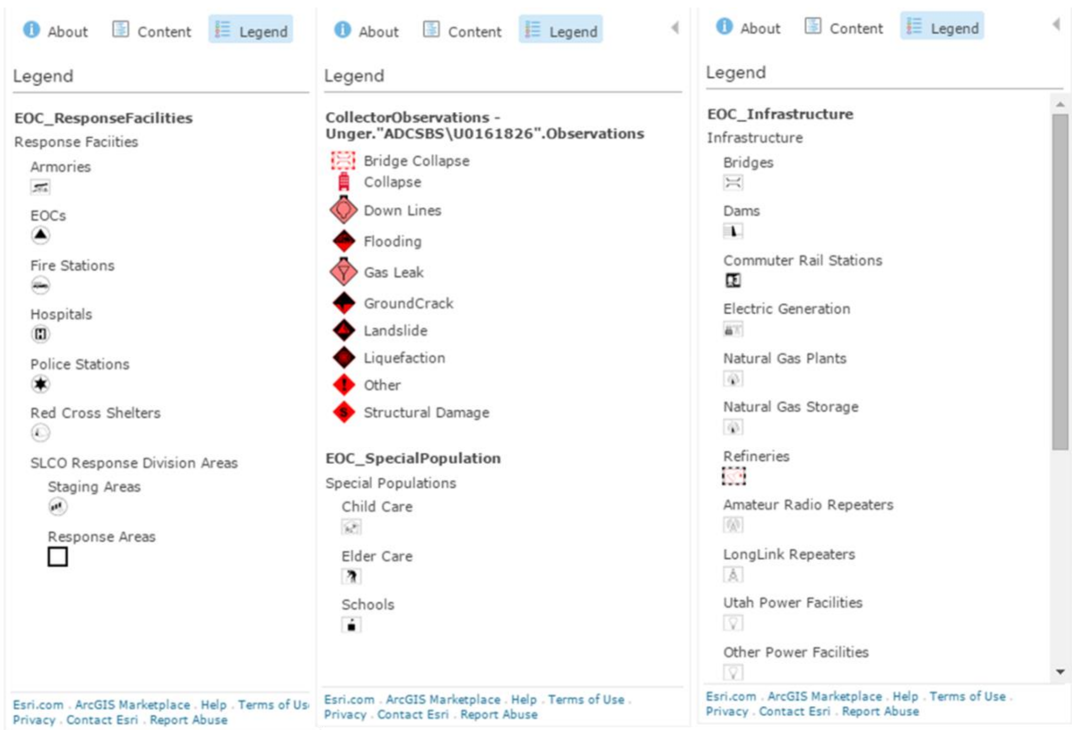


Figure 15 Legends within the web map are dynamically updated to reflect the data that are visible within the map allowing users to identify objects in the map more easily.

Figure 16 A widget within the web map that can be used to customize the search terms for VGI data from Twitter, allowing custom hashtags or search terms to be made for each event.

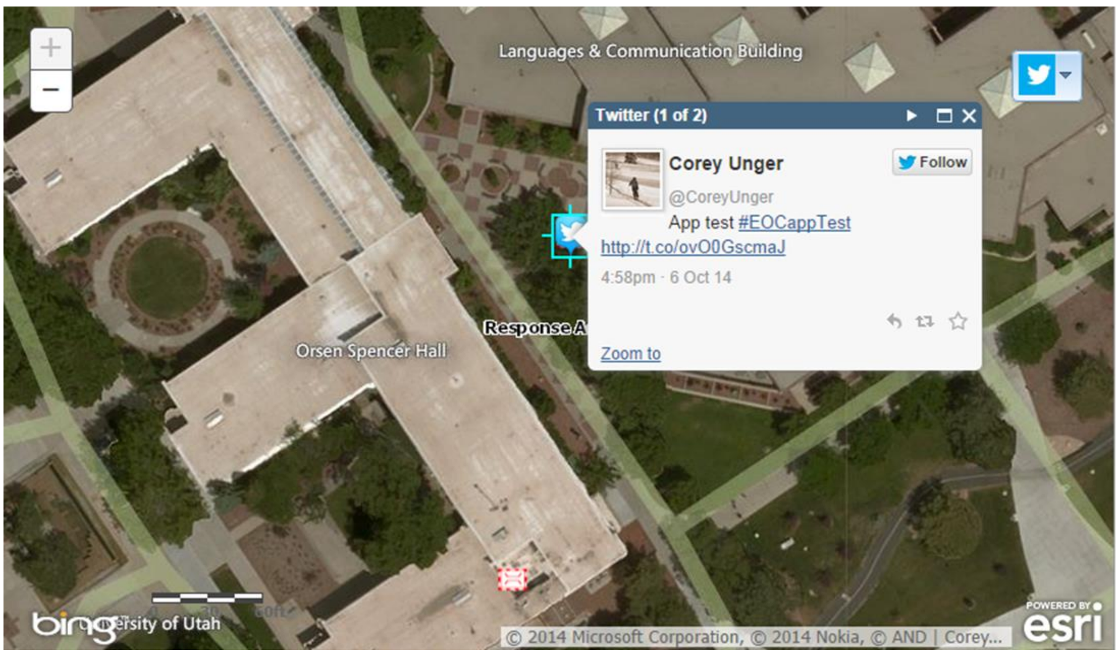


Figure 17 A pop-up window showing information associated with a Tweet that is the result of a search for #EOCappTest in the Twitter widget. EOC operators can view this information in near-real time.

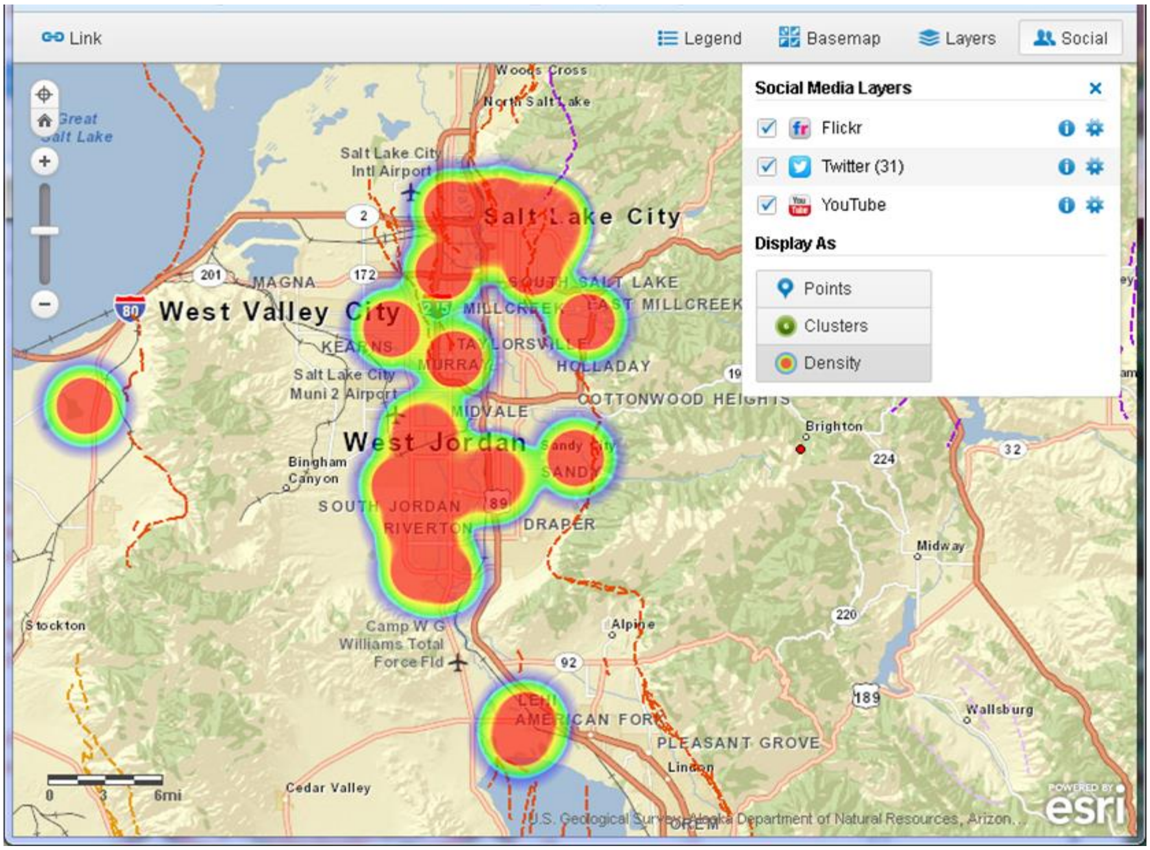


Figure 18 A Density heat map showing clusters of Tweets returned from a search for the term #Earthquake following an earthquake drill in Utah. EOC Operators can quickly determine where people are talking about the event.

Figure 19 Interface of the mobile application. The user's location is shown by the dot near the center of the map.

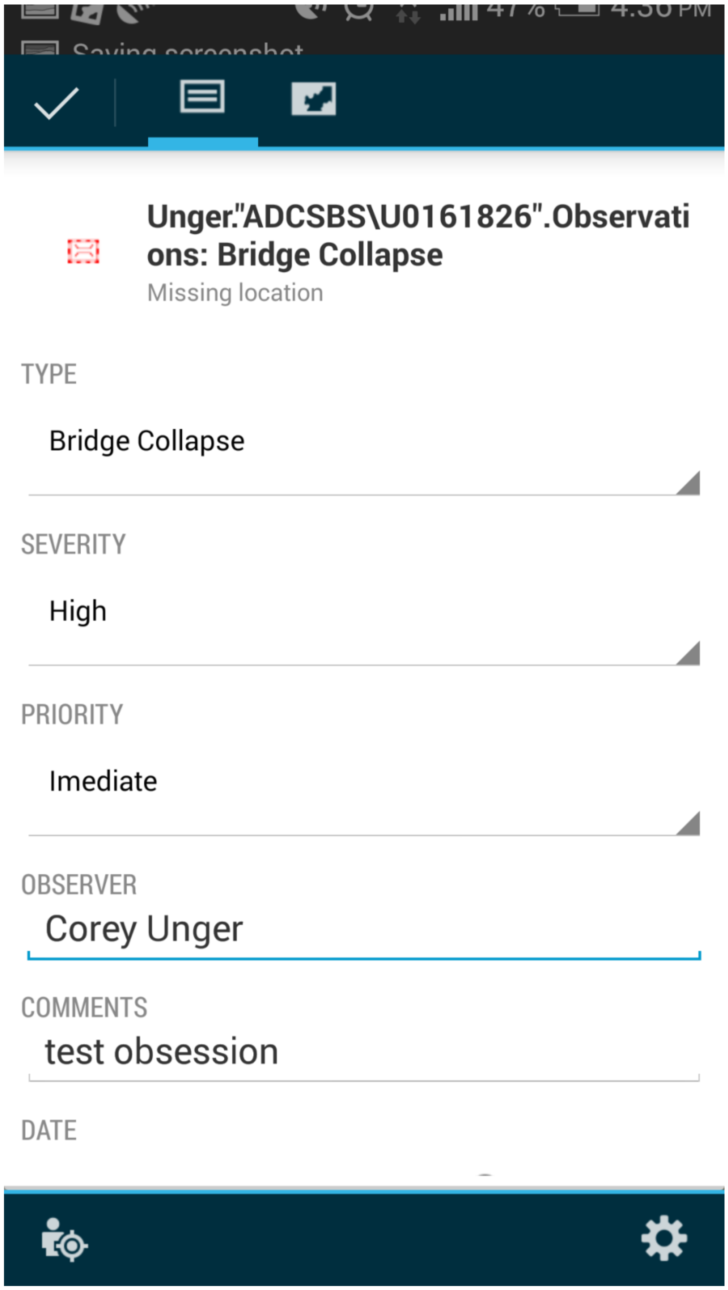


Figure 20 The form used to collect an observation within the mobile application. Drop-down menus create a quick and consistent entry method for field responders.

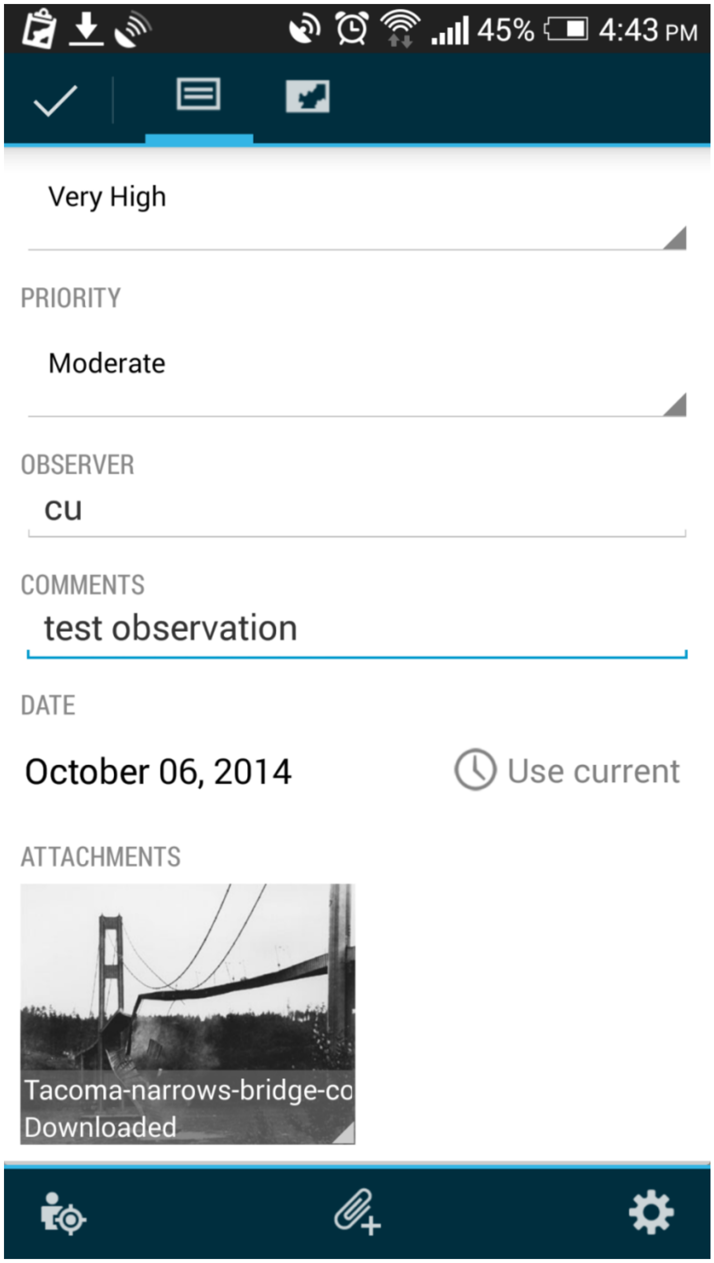


Figure 21 Attachments, such as photos and videos, can be tied to observations within the mobile application, allowing more information about the observation to be communicated with the EOC.

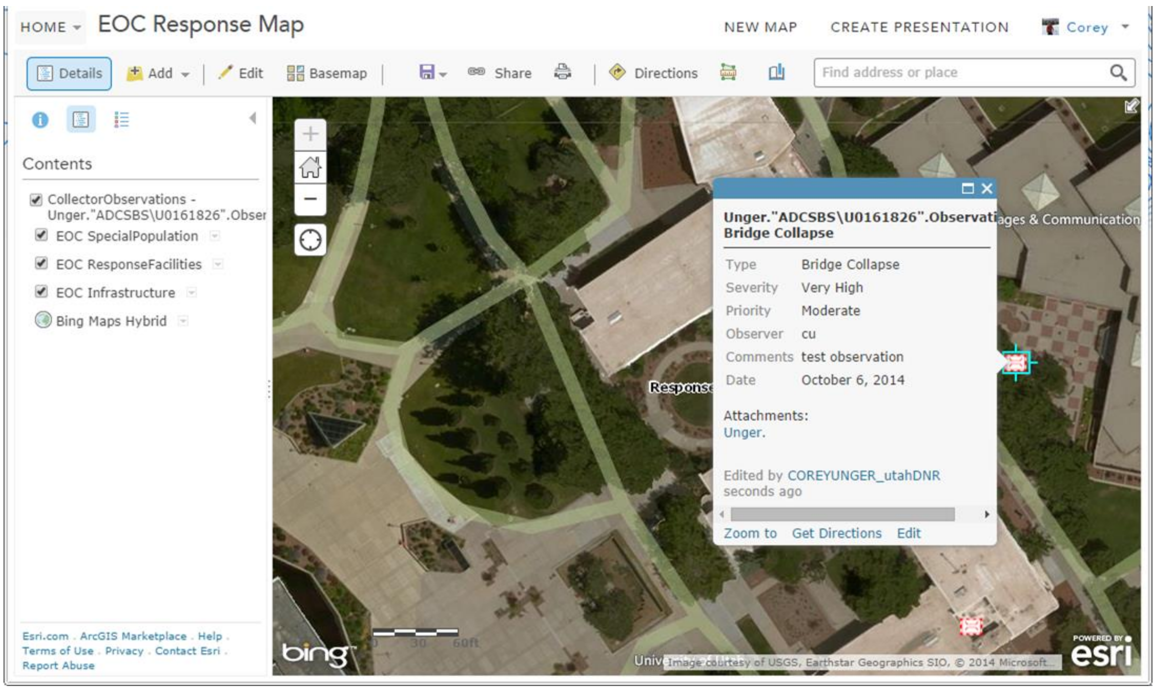


Figure 22 Collections made within the mobile application are immediately added to the SDI and are quickly accessed in the web maps, providing data in near-real time.

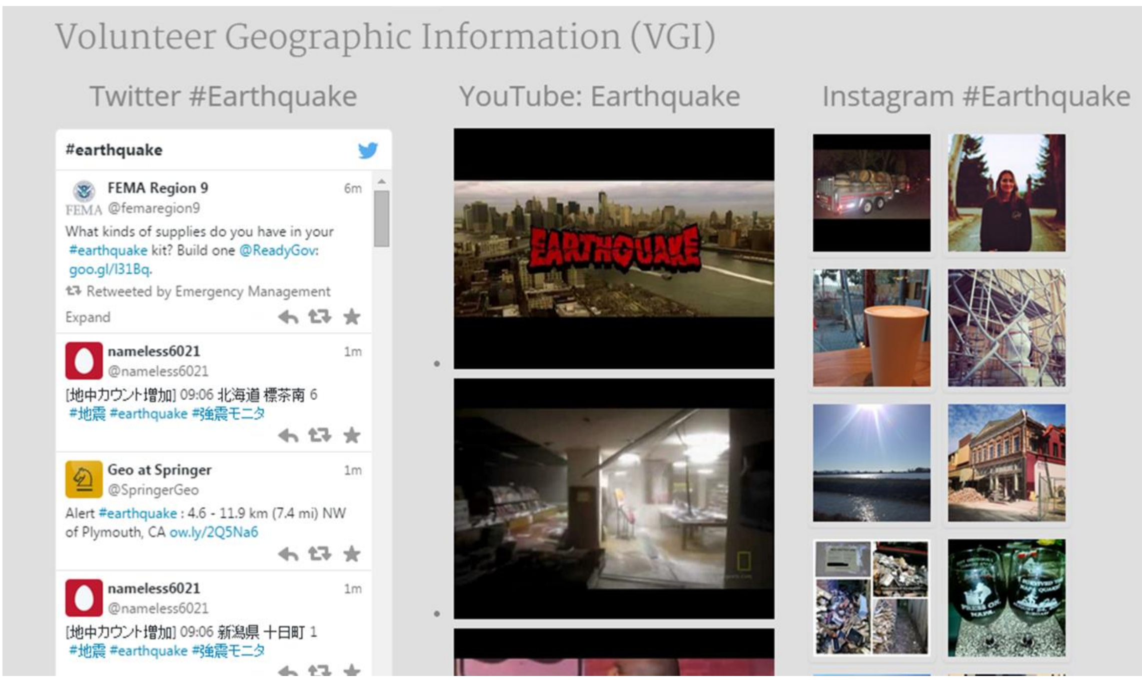
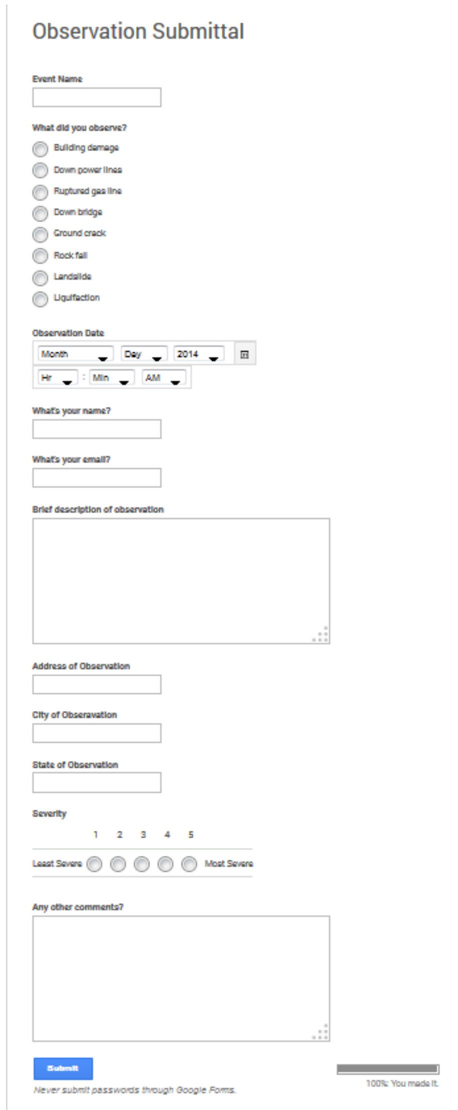


Figure 23 A social media dashboard offers up-to-date information that may otherwise go unnoticed.


Observation Submittal

Event Name

What did you observe?

- Building damage
- Down power lines
- Ruptured gas line
- Down bridge
- Ground crack
- Rock fall
- Landslide
- Liquifaction

Observation Date

Month Day 2014

Hr : Min AM

What's your name?

What's your email?

Brief description of observation

Address of Observation

City of Obseravation

State of Observation

Severity

	1	2	3	4	5	
Least Severe						Most Severe

Any other comments?

Submit

Never submit passwords through Google Forms.

100%: You made it.

Figure 24 A form to submit observations allows the public to contribute information that can be used to aid the response process.

CHAPTER 5

DISCUSSION

The end result of combining the three systems described in this paper (e.g., SDE, a mobile application, and VGI), along with the network of relevant users, is an SDI that improves the volume, quality, currency, accuracy, and access to vital spatial and scientific information following a hazard event. A similar structure instituted in Iran reduced response times by one third (Mansourian, 2006). The SDI acts as a repository for all spatial and scientific data pertaining to a particular event. This allows for future reference and study of the event (Warren Mills, 2008).

5.1 Website

The SDI website provides users of the system access to multiple sources of information to aid in emergency response. Web maps provide a visual representation of spatial data. The Social Media feed provides a source for up-to-date information through different media types: photo, video, and text. The resource page serves as a source for all other information, including templates that could aid field workers and EOC operations. The ability to request data and maps through online forms provides analysts the ability to track these requests and prioritize their handling of the requests. The “Submit an Observation” form provides an extra means for users to contribute information to the system.

As data are added through the mobile application and Twitter, they are displayed on the web map. Likewise, since the data are stored in an SDE, if changes are made to the infrastructure, response facilities, or special population data, this is reflected immediately in the web map. This creates a dynamic, near real-time source of information that EOC operators can access during recovery and response efforts. Functionality included in the web map application increases its usefulness. Pop-up windows provide additional information about features in the web map to be quickly accessed. The ability to switch basemaps and turn layers on and off increases data visibility.

5.2 SDE

Using an enterprise database provided many benefits to the SDI. By using a central location for data, users know where to find the current information, thus eliminating numerous copies of data that may or may not be up-to-date. The SDE works as a repository for all spatial and nonspatial information. These data can be accessed through a web interface or remote connection for display to a wide variety of users. Limiting data editing to select users help secure the data and improve its quality.

Data stored in the SDE is routinely backed up to an off-site location. This allows for the database to be rolled-back to a working state in event of data corruption, such as accidental edits, deletion of data, or server failure. Database backups can be scheduled to automatically occur as part of routine maintenance. Also, since the SDE does not rely on a network connection, data contained within it can still be accessed by internal users in event of network failure. These data can be distributed to other EOCs by alternate means, adding to the utility and robustness of the SDI.

Another type of functionality provided by the SDE but not tested for this project is database distribution. Distributed databases allow for a replica of the database to be distributed, viewed, and edited at an offsite location. These data can be reconciled with the parent database when changes are made. This allows for agencies and EOCs to maintain a local copy of the data that does not rely on a network connection, which they can use for analysis and response and recovery efforts.

5.3 Mobile Application

Response crews need the ability to view and contribute information directly to the SDI, which is provided by the mobile application. Traditional methods involve filling out forms in the field and manually entering them into the system in the office. The mobile application increases accuracy in several ways. First, the mobile app reduces the number of times the data need to be translated, decreasing the chance of errors being made with each translation. Second, with the mobile app, it is possible to implement input constraints to validate data that are entered into each field in the form. This prevents incorrect data from being entered into the database by limiting the valid entries for each field. Third, the form contains required entries, assuring that all necessary data get entered into the database. Finally, this application decreased the amount of time to input the information into the database, allowing operation centers to have more up-to-date information on which to base their decisions.

Using a predeveloped, free mobile-application that is compatible across multiple platforms increases the number of users that contribute observations to the system. The app can be quickly deployed on an iOS or Android device and set up to collect observations. The offline capabilities of this application let users collect data, even when the network is down, adding to the robustness of the application. The security that comes built into the maps displayed in the app allowed for access to mobile data collection to be limited to certain field responders to help assure data accuracy. By allowing attachments to be made to each point, EOC operators can verify the information and gain a better understanding of conditions on the ground.

5.4 VGI

Emergency situations following a disaster necessitate faster data collection than provided by traditional data collection methods. Although the use of VGI in a disaster setting is still in its infancy, there are several benefits of its integration into this application arena. Traditional data collection methods require much more time than VGI (e.g., air photo interpretation). Integration of VGI has the potential to add thousands of sensors (citizens) collecting near-real-time information and contributing it to the SDI at zero additional cost (Goodchild, 2010). These observations will assist EOCs to prioritize emergency response activities and decrease response times.

Including VGI into the SDI could add thousands of observations that would otherwise go missed. The biggest challenges with using these data for this project were filtering data for relevant information and finding a location associated with the data. These two problems could be solved by asking the public to turn on location sharing with their Tweets and creating a custom hashtags or keyword for each specific event.

The Twitter feed in the web map adds more field responders to the system. Users are able to quickly click through the information and through the pop-up window to see the content of the Tweets. Since the VGI is only displayed as a layer on the map and not automatically added to the database, it can be reviewed and verified before it is committed to the system. The ability to view the information in heat maps and clusters lets EOC operators quickly visualize where resources need to be deployed.

CHAPTER 6

CONCLUSION

This thesis poses the question of whether disaster response can be improved by 1) capturing information on an event that scientific or emergency response teams may miss, 2) providing information in near real-time, 3) providing more spatially located information than traditionally possible, and 4) reducing the cost for collecting and managing data. It also sought to answer how VGI may be used for observations and assessment of damage following an event.

The SDI website provides many benefits to the system. It grants users access to multiple sources of information to aid in emergency response. Web maps provide visual representation of spatial data. The Social Media feed provides a source of near real-time information at zero additional cost through different media types: photo, video, and text. The resource page works as a source for all other information, including templates that could aid field workers and EOC operations. The ability to request data and maps through online forms provides analysts the ability to track these requests and prioritize their handling of the requests. Each of these functions improves data sharing and adds observers to the system.

Using a predeveloped, free, mobile application to collect observations increases the speed and accuracy in which EOC operators can obtain information, all while reducing cost. The ability to work offline adds robustness to the SDI by not limiting mobile collection to areas where there is an active-data network. This contributes to the amount of timely spatial information available to decision makers in response efforts.

VGI provides a source of low-cost near real-time information. VGI also effectively increases the number of observers capturing information on the event, thus providing more spatial information than traditionally possible. These data combined with traditional GIS aid emergency operators in disaster management situations. As stated by Zook et al. (2010) VGI allows individuals to report on local and specific conditions, providing additional data that could not be matched by traditional means of data collection. Twitter, emails, status updates, and other sources of VGI allowed information about opportunities to contribute to spread quickly.

Every system has limitations. A contingency plan would need to be in place to facilitate the SDI in event of network failure. Methods that could be further explored could be by using satellites or by transferring data manually through portable storage devices as a contingency plan until the network is restored.

Some challenges faced with VGI include volume of data and lack of locational information. While this information comes with challenges, it can be very useful. When a location is shared, these data can be viewed in a map alongside traditional GIS data. When no location is shared, context from the Tweet can often be used to determine a location. Filters for these data could include using a custom hashtags for each specific event or obtaining the data in spreadsheet format and filtering them manually.

Standardization of VGI would greatly benefit the disaster management process. The use of a standard hashtag for a specific instance could lead to better results by allowing users of the SDI to filter data specifically on that value. Also, requesting that users attach a location to their post could potentially maximize the amount of useful data that is obtained.

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