Collecting and Managing VGI Infrastructure Assessments in Support of Stability Operations

by

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In memory of my father, Gary Potter (DUSTOFF 15) August 19, 1947 – October 04, 2017

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List of Abbreviations

AI	Area of Interest
AO	Area of Operations
AGE	Army Geospatial Enterprise
CAT	Civil Affairs Team
COP	Common Operating Picture
DSCA	Defense Support to Civil Authorities
DOD	Department of Defense
FEMA	Federal Emergency Management Administration
GIS	Geographic Information Systems
GISci	Geographic Information Science
MRRD	Ministry of Rural Reconstruction and Development
NCDCDS	National Committee Digital Cartographic Data Standards
NGA	National Geospatial Intelligence Agency
NGO	Non-Governmental Organization
OSM	Open Street Map
PMESII-PT	Operational Variables
SDI	Spatial Data Infrastructure
UNDP	United Nations Development Program
USACE	United States Army Corps of Engineers
UKAID	United Kingdom Department for International Development
USAID	United States Agency for International Development
VGI	Volunteered Geographic Information

Abstract

Humanitarian assistance, disaster response and stability/peacekeeping operations are an important part of current national defense strategy and represent an opportunity for the United States to project goodwill around the world. This thesis explores using Volunteered Geographic Information (VGI) to streamline the process through which aid and assistance is routed to those most in need. The acronym SWEAT-MSO (Security, Water, Electricity, Academics, Trash, Medical, Safety, Other) describes the metrics the United States Military uses for evaluating infrastructure health in support of foreign stability operations. SWEAT-MSO features are coded as green, amber, red or black based on the severity of damage and their ability to function. Assessments are currently completed by deployed service members but by incorporating VGI, this burden can be shifted to those who live and work within an affected area. Under the proposed framework, volunteers use a browser-based infrastructure assessment app to capture metrics and store them within a spatial database for analysis by Civil Affairs (CA) teams. VGI assessments are displayed in real time within a common operating picture that spreads awareness of infrastructure issues throughout the area of interest. This thesis demonstrates the VGI infrastructure assessment concept by creating a custom app to collect assessments and a common operating picture dashboard to display the results of the assessments. Unskilled volunteers collected test assessments in two rural communities and the results were analyzed for spatial and thematic accuracy. The successful collection of targeted infrastructure metrics and the user reviews of the assessment app and the operations dashboard indicate that this method can be expected to produce results in a forward deployed environment.

Chapter 1 Introduction

In the opening decades of the 21st century, many nations, particularly the United States, have been forced to engage in prolonged humanitarian assistance and stability campaigns. Recent campaigns in Iraq and Afghanistan stand out but there are dozens of other examples that get only a small fraction of the attention that the previously mentioned nations receive. While global instability is on the rise, resources dedicated to building global stability are stretched thin.

While there are many factors increasing the difficulty of stability missions, there are also reasons for optimism. The globe is more connected than ever before. Mobile devices are prolific even in otherwise austere locations. The proliferation of technology presents an opportunity to harness spatial data to change the paradigm of stability operations.

Democratization of GIscience is changing the world (Goodchild 2007; Goodchild and Glennon 2010). To an extent this process is happening organically. Collaborative mapping services such as Ushahidi have sprung up in areas affected by violence and political strife. Non-Government Organizations (NGO) also use crowdsourced data to effectively address humanitarian issues. Governments, as usual, are relatively slow to fully embrace the benefits of this emerging technology and have fallen behind the private sector (Hammon and Hippner 2012). This thesis creates a template for a web application that units deployed in support of global stability operations can use to collect spatial data relating to community infrastructure needs. Research combines elements of Geographic Information Science (GIS) in emergency management and governance, VGI quality, Spatial Data Infrastructure and Joint Doctrine in conducting infrastructure assessments.

1.1 Motivation

Motivation for this project takes several forms. The primary interest is to make collecting infrastructure assessments and performing other stability tasks safer and more efficient. As a former army officer with experience in stability operations the author has firsthand knowledge of the challenges inherent to these types of endeavors (Figure 1). The author has also witnessed the positive impact that efficiently run infrastructure projects can have on the lives of the people living in impoverished areas. Poor governance and systemic poverty are major contributors to global instability yet the resources to address such challenges are scarce and must be utilized effectively. Protracted “nation building” type operations that seek to address the foundations of instability such as those seen in the Iraq and Afghanistan wars are no longer feasible given current resources and political constraints. This project harnesses VGI and local talent to capture needed information safely and efficiently to address infrastructure deficiencies.

Figure 1: The author on a village assessment in Kandahar Province Afghanistan in 2011

1.1.1. Advancing the Practical Applications of VGI

This research builds on a wide body of research incorporating VGI. Using VGI in the conduct of humanitarian assistance, disaster relief or populating spatial databases is nothing new but this application puts a new spin on the practice. Once fully implemented, VGI as a method for completing infrastructure assessments will provide a viable alternative to paper assessments and will allow concurrent collection of assessments across an entire area of interest. The challenges and opportunities of VGI infrastructure assessments explored in this research are applicable to other endeavors that seek to assess physical infrastructure in denied areas. While this method may not be suitable for all situations, the broad acceptance of VGI applications for infrastructure assessments can pave the way for other public-sector VGI projects.

1.2 Understanding the Operational Environment

Under the Unified Land Operations concept there are four types of decisive action tasks that can be assigned to Army units (other specialized missions nest within these tasks). These tasks are Offense, Defense, Stability and Defense Support to Civil Authorities (DSCA). In each of these tasks understanding the operational environment is of the utmost importance. The operational environment encompasses aspects of the military, and nonmilitary, environment that differ from one area to another and affect operations (Department of the Army 2012). The operational variables, seen in Table 1 and remembered using the acronym PMESII-PT, are used to capture vital facets of the environment that planners and commanders need to understand their AO (Department of the Army 2017). This thesis focuses primarily on applications within the Stability and DSCA tasks because they have the greatest applicability outside the military context and within the GISci community at large.

Table 1: The Operational Variables. (Department of the Army 2017)

Variable	*Description*
Political	Describes the distribution of responsibility and power at all levels of governance—formally constituted authorities, as well as informal or covert political powers
Military	Explores the military and paramilitary capabilities of all relevant actors (enemy, friendly, and neutral) in a given operational environment
Economic	Encompasses individual and group behaviors related to producing, distributing, and consuming resources
Social	Describes the cultural, religious, and ethnic makeup within an operational environment and the beliefs, values, customs, and behaviors of society members
Information	Describes the nature, scope, characteristics, and effects of individuals, organizations, and systems that collect, process, disseminate, or act on information
Infrastructure	Is composed of the basic facilities, services, and installations needed for the functioning of a community or society
Physical environment	Includes the geography and manmade structures, as well as the climate and weather in the area of operations
Time	Describes the timing and duration of activities, events, or conditions within an operational environment, as well as how the timing and duration are perceived by various actors in the operational environment

Stability operations seek to create conditions where the inhabitants of an area see their situation as "legitimate, acceptable and predictable" (Department of the Army 2012). DSCA encompasses the process through which state and local authorities can request the use of federal military resources in support of civilian activities. Typical requests cover disaster relief, assisting with a special event such as the Super Bowl or addressing law enforcement challenges such as riots or insurrections that overwhelm the resources of local agencies.

Table 2 describes the respective tasks and their associated purpose inherent to DSCA or stability operations. In general, DSCA occurs domestically and faces strict constitutional limits on what activities can and cannot be conducted. Stability Operations pursue similar ends as DSCA but occur on foreign soil under specific conditions arranged with a host government under the umbrella of a Status of Forces Agreement.

Table 2: Stability and DSCA Tasks (Department of the Army 2012)

Stability	**Defense Support of Civil Authorities**
Tasks:	***Tasks:***
• Establish civil security • Establish civil control • Restore essential services • Support to governance • Support to economic and infrastructure development • Conduct security cooperation	• Provide support for domestic disasters • Provide support for domestic chemical, biological, radiological, and nuclear incidents • Provide support for domestic civilian law enforcement agencies • Provide other designated support
Purposes:	***Purposes:***
• Provide a secure environment • Secure land areas • Meet the critical needs of the population • Gain support for host-nation government • Shape the environment for interagency and host-nation success • Promote security, build partner capacity, and provide access • Refine intelligence	• Save lives • Restore essential services • Maintain or restore law and order • Protect infrastructure and property • Support maintenance or restoration of local government • Shape the environment for intergovernmental success

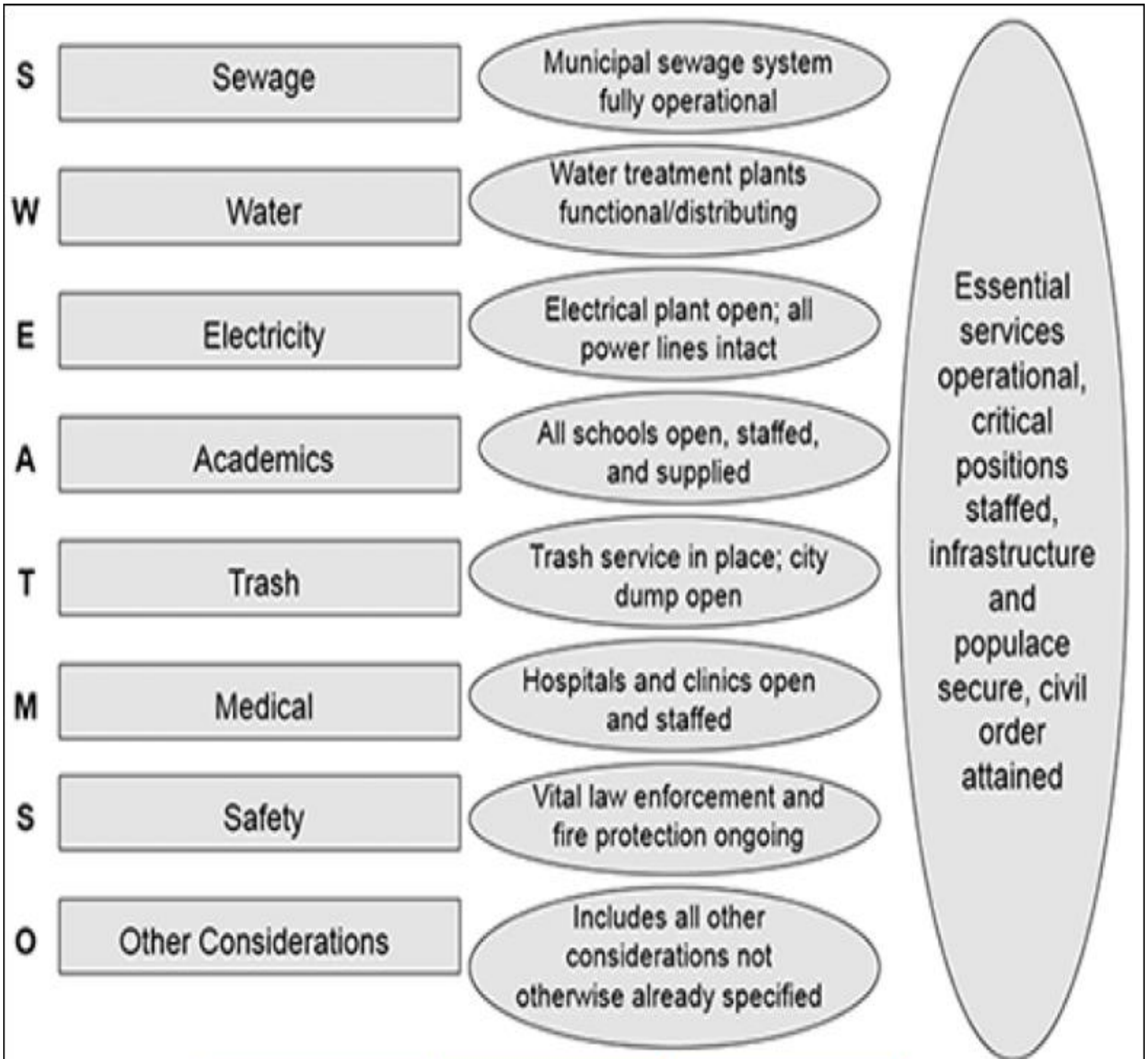
1.3 Infrastructure Assessments in Stability Operations

Infrastructure assessments help planners allocate resources and determine priorities of effort. These assessments help planners understand the operational environment by answering infrastructure information requirements as outlined in the operational variables. During a tour of duty in southern Afghanistan in 2010-2011, the author completed hundreds of such assessments of local communities. The purpose was to determine the baseline needs of local communities. Following the initial assessment, communities deemed to be most in need of essential services would be visited by professional engineer teams for a more robust infrastructure survey. After a potentially lengthy process, contracts for infrastructure development were drafted and work could begin. Building host nation capacity and fostering confidence in local governance meant certifying measures of performance and effectiveness. With that goal in mind infrastructure assessments continued for the life of a project and beyond.

Mounting dedicated patrols to conduct assessments in isolated villages is logistically taxing and potentially dangerous to both the supporting service members and the local inhabitants. These challenges meant that the critical work of rebuilding communities and restoring services was often relegated to a lower priority than other tasks. The limited numbers of units available dictated that even in the best of times progress on the assessments was slow. In practice, many units attempted to delegate assessments to local community leaders. Since these surveys were paper-based and still had to be sorted and verified this technique only marginally reduced the workload on beleaguered project officers.

Metrics of infrastructure health in military operations are contained in the Engineer Reconnaissance Manual ATP 4-34.8. Metrics are evaluated by the basic criteria of green, amber, red, or black (Figure 2). In general, green is determined by 100% functionality of the pertaining feature, amber for 50-99%, red for less than 50% functionality and black for destroyed or non-existent services. Complete scoring criteria are shown in Appendix A. The example given in Figure 2 is specific to the sewage category.

It is important to note that the health of a village's infrastructure depends on more than a value assigned to its structure. Assessments are generally completed during on-site inspections of a village combined with the testimony of local stakeholders. For instance, an assessment team would seek the advice of local teachers to determine whether schools are open, staffed and supplied before assigning a score to the academic category. This face-to-face component helps the assessor make an accurate assessment of the structures that factors in the social components of infrastructure health.



Category	Green	Amber	Red	Black
Sewage	Sewage system works consistently	Sewage system works but treatment status undetermined	No treatment observed but treatment plant exists	No Sewage treatment system, destroyed
	No sewage observed and no odor	No raw sewage observed but odor present and/or system damaged	Raw sewage observed and odor is present	Raw sewage is a public health concern
	Operational in 100% of public facilities	Sewage operational in 50% or more of public facilities	Sewage operational is less than 50% of public facilities	No operational sewage in public facilities

Figure 2: SWEAT-MSO definition and sewage scoring criteria
(Department of the Army 2016)

1.3.1. Post Assessment Infrastructure Surveys

An infrastructure survey is completed following the initial infrastructure assessment. The primary difference between the two is the degree of technical information and the amount of expertise required to complete them (Department of the Army 2016). By nature, the infrastructure assessment is a quick, tactical, analysis conducted by frontline troops in what may be an unsecured environment (Figure 3). The survey is usually completed by dedicated engineer teams with associated support from medical, veterinary, civil affairs, communications, and other specialties as appropriate. The survey also requires an area to be secure while the infrastructure assessment does not. The first page of the infrastructure survey for the sewage element is shown in Appendix B. Infrastructure surveys encompass elements of the assessment but the survey itself is not a component of this research. Infrastructure surveys are discussed here to give the reader a holistic view of the process.

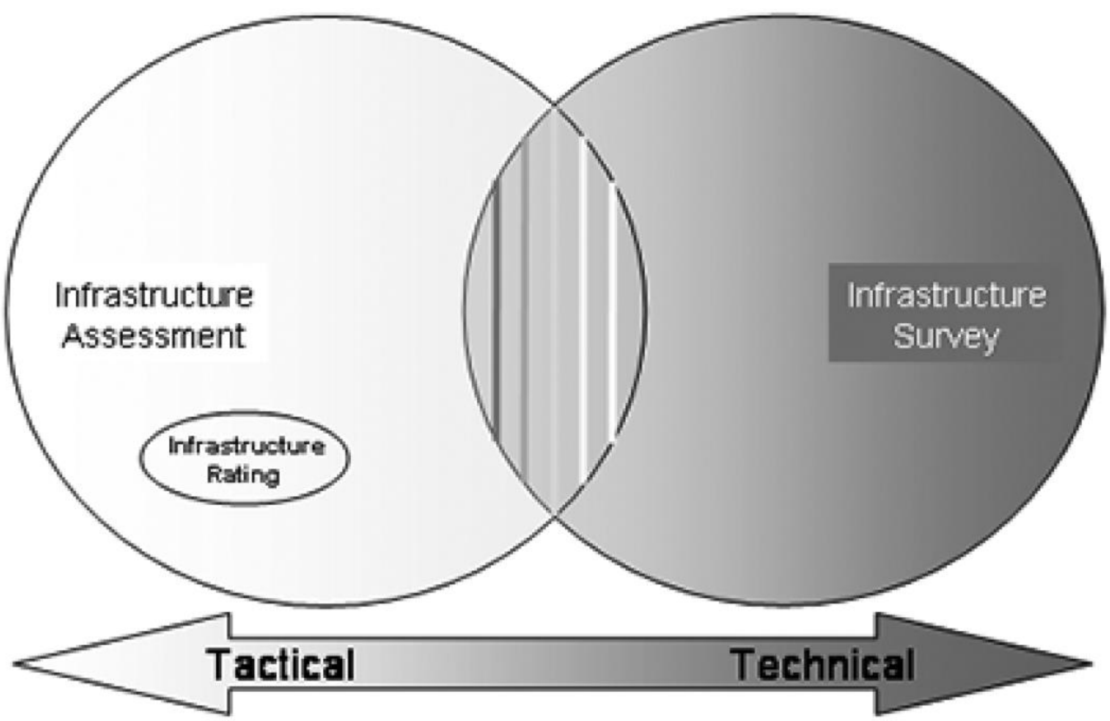


Figure 3: Overlap of infrastructure assessments and surveys (Department of the Army 2017)

1.4 Research Objectives

The primary objective of this project was to build an application to facilitate volunteer collection of infrastructure assessments in accordance with published doctrine. Sewage, Water, Electricity, Academic, Trash, Medical, Safety and Other infrastructure are the target features for capture. This project includes a detailed workflow to demonstrate the feasibility of using VGI submitted via commonly available mobile devices and their embedded GNSS receivers to capture pertinent features and effectively store them within the Army-Enterprise-Database. Once VGI assessments are submitted they will populate a customizable dashboard that enhances situational understanding of the AO and facilitates timely and accurate infrastructure decisions.

The application can be tailored to the unique needs of geographically and culturally disparate audiences. Different areas have different requirements and the assessment application was designed to maximize flexibility. The workflow was designed to accommodate individuals who are digital natives but who otherwise may have extremely limited formal education. Methods of ensuring data quality and completeness within the database were explored.

1.5 Thesis Structure

The remainder of this thesis is organized into four chapters. Chapter 2 reviews related work in the fields of VGI, spatial data quality, data management, stability operations and the ways these fields intersect. Chapter 3 explores the design and use of the application and operations dashboard. Results are found in Chapter 4. Conclusions and recommendations for future study are found in Chapter 5.

Chapter 2 Related Work

Crowdsourced data is ubiquitous in the modern world. Average users may only be vaguely aware of its prevalence but the news feeds on social media, mobile mapping services and even popular mobile games all rely on user-generated information. OpenStreetMap (OSM) is a common platform that allows users to submit spatial information that, in aggregate, can expose very meaningful trends. Crisis maps on platforms like OSM have sprung up to tell the story of many thousands of individuals caught in the midst of tragedies both large and small (Ahn, Hervé, and Zinsz 2017). One such mapping platform, Ushahidi, has seen tremendous grassroots success in telling the stories of people mired in disaster that would otherwise go unheard. An example from the Ushahidi Syria Tracker capturing instances of chemical weapons use is seen in Figure 4 (Okolloh 2009; Ushahidi 2018). Such maps are powerful because they harness an impulse to do something and enable any user equipped with a mobile device to generate content that tells an individual story in the context of a larger event (Bittner, Michel, and Turk 2016) .

This chapter reviews research relevant to the field of VGI in general while focusing on research most applicable to applying VGI in support of stability operations. While a great deal of research was uncovered on crowdsourced spatial data in disaster areas and in emergency management, much of it dealt with data mining of social media feeds or verifying accuracy and other highly specific topics. However, there were some authoritative works on using VGI to maintain accountability of disaster aid which closely resembles the goal of this project.

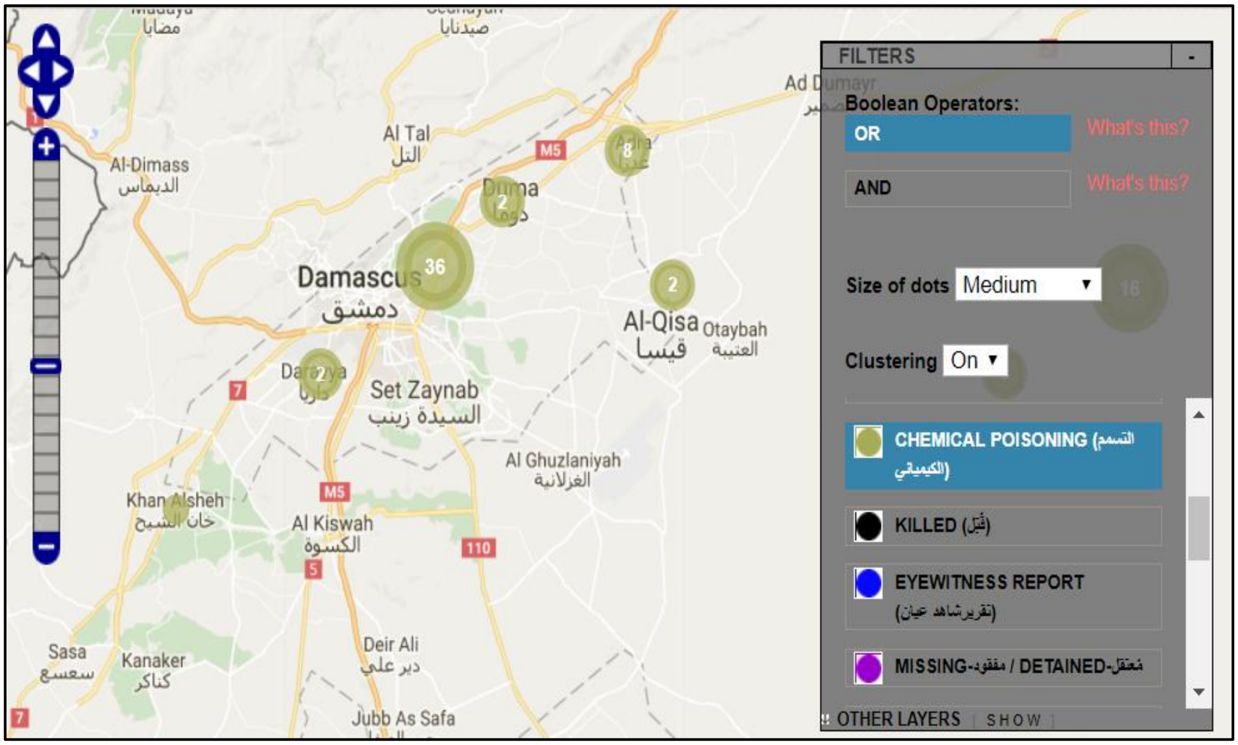


Figure 4: Ushahidi VGI submissions for Syria chemical attacks (Ushahidi 2018)

2.1 Volunteered Geographic Information (VGI)

VGI is considered a subset of the broader internet phenomenon of user generated content. Michael Goodchild coined the term to describe the actions of geographic amateurs who “create, assemble and disseminate” spatial information online (Goodchild 2007). VGI is an extension of Web 2.0. Web 2.0 describes the democratization of the web and the shift of power to the ordinary user such that they can generate content. There are valid concerns with VGI. There is a noted inconsistency in quality regarding spatial and attribute accuracy in crowdsourced data. Some researchers have suggested ethical boundaries regarding collecting and using VGI. Ethical concerns are especially stark when the data collected has the potential to violate privacy or basic human rights. (Fleming, Sedano, and Carlin 2018).

Despite the issues VGI has opened new ways for the public to access and produce spatial data. Various works describe VGI as powerful because it is cheap, easy, flexible and "accurate enough" to be useful in a wide range of activities (Johnson and Sieber 2013).

2.1.1. Spatial Data Quality Standards for VGI

Spatial data quality is an ongoing concern in GIScience that will likely never be fully resolved. Like other sciences, introducing an error into a process causes cascading errors that can drastically affect the output. Since VGI is collected by volunteers (volunteers are not necessarily unskilled) there are concerns about user error and the variations in the positional accuracy of different devices. The National Committee for Digital Cartographic Data Standards (NCDCDS) introduced six requirements for digital cartographic data in 1988 (Morrison 2013) . There are multiple formulations regarding spatial data quality, but most researchers have retained the original six NCDCDS elements and added additional elements to reflect current technology.

Van Oort (2006) looked at a variety of methods for determining spatial data quality. Methods used by the NCDCDS, International Standardization Organization (ISO), International Cartographic Association (ICA) and others were found to have overlapping criteria. The combined elements of spatial data quality from these sources are seen in Table 3.
Oort also formulated a three-part fitness-for-use methodology for spatial data that considers: (1) the information needed for the intended application; (2) the constraints of using spatial data such as legal or financial liabilities or costs; and (3) if spatial data quality contains risks, whether the risks are acceptable.

Table 3: Elements of spatial data quality (Van Oort 2006; Morrison 2013)

NCDCDS Elements of Data Quality	
Lineage of Spatial Data	Lineage for spatial data is; where the data came from, how it came to be, and what processes were used in its production.
Positional Acuracy	Excluding temporal and positional attributes, these accuracies look at all of the other attributes of the data set.
Attribute Accuracy	Positional accuracy is the accuracy of the values of the pertinent coordinates.
Logical Consistancy	This element focuses on the relationships in the data set, and the consistency of their structure
Completeness	Completeness is an assessment of the absence of pertinent data or the presence of superfluous data. A key component of completeness is an understanding the producer's intent as to the scope of the data set.
Temporal Quality	Spatial data quality can be assessed temporally as expired, current, or not yet valid. Additionally, the time lapse between change in ground truth data and its representation in the data set is a critical component of this element.
Van Oort Additions To Elements of Data Quality	
Semantic Accuracy	A broadly defined element, encompassing the interconnectedness of the other elements and includes uncertainties other than error.
Usage Constraints	Usage is how the user employs or exploits the data set. Purpose is the means of employment or exploitation the producer planned for the data set. Constraints are broadly defined to include direct costs, legal restraints for use and application of the data, and contractual limitations for data employment.
Variation in Quality	This element assesses variations in quality within the data set and the extent of uniformity within those variations.
Meta-Quality	This element is an assessment of the quality of the data quality assessment itself.
Resolution	Resolution is often the starting point is collecting data for analysis, and this element can be a subset of the other identified elements.

2.1.2. Benefits and Shortcomings of Crowdsourced Data

VGI has the benefit of being able to produce content where there is none or where it is so scarce and incomplete that content is of little or no value the consumer. A volunteer with local knowledge but lacking formal training can sometimes create products superior to that which a "mapping expert in a distant government agency" might produce (Goodchild 2012). The downside is that VGI carries no guarantee of quality. Goodchild goes on to suggest three mutually supporting methods of approaching VGI quality. These methods help determine whether VGI features are: (1) valid contributions; (2) something useful but containing errors; or (3) something that should be rejected. The three methods were the crowdsourcing approach, the social approach, and the geographic approach.

2.1.2.1. Crowdsourcing Approach

Goodchild (2012) identified three distinct meanings to the term crowdsourcing. The first seeks a solution to a problem by referring it to a population, without regard to qualifications, and expecting that the "crowd" will come up with an adequate solution. This technique is widely used in the age of the web but is not strictly dependent on technology.

The second and third meanings have less focus on solving problems and more emphasis on harnessing the wisdom of a crowd to correct errors or corroborate the statements of an individual. The second interpretation of crowdsourcing was explained by using a metaphor of citizens reporting wildfires. While one report from a trustworthy source can be compelling, multiple corroborating reports from different vantage points paint a much more complete picture of an event. By this interpretation each new report lends additional credence to spatial clusters of similar reports.

The third interpretation of crowdsourcing Goodchild (2012) highlights is the tendency of a crowd to converge on the truth. The premise that large numbers of volunteers will generate a self-policing ecosystem of information is what allows platforms like Wikipedia to thrive. If an individual commits an error then, in most cases, other users can be expected to notice and correct the error. An exception occurs with more obscure data. In a geographic context a prominent feature will receive more attention than an isolated one. People are also more likely to assist in the resolution of an issue they are interested in. Given that the intended audience for this project resides in more isolated areas with fewer services, a key driver for success will be creating enough interest to motivate the participation of residents.

2.1.2.2. Hierarchy Approach

The next approach to VGI quality is the social or hierarchy approach. This approach depends on the participation of trusted individuals. Research has shown that there is a distribution in the frequency of participation among users of a crowdsourcing platform. A few individuals make many contributions while many individuals make only single or a small number of contributions. This approach introduces a metric for reliability and trust for users who make frequent contributions that are factual and correct. Members higher on the "social ladder" may obtain certain edit or discretionary permissions that are not afforded to less trusted users.

This approach will be less applicable in the context of infrastructure assessments since the gate keepers who manage the data and maintain the data infrastructure will be within a government hierarchy and not one that exists only in the context of the VGI platform. The proposed infrastructure application will also be primarily marketed to stakeholders within the components of the infrastructure assessment. The trust placed in the status of these individuals will negate the need for a network of privileged contributors.

2.1.2.3. Geographic Approach

The third approach is the geographic approach. This method largely tracks Waldo Tobler's (1970) First Law of Geography which states that "all things are related but nearby things are more related than distant things". This method requires an element of human verification to contrast what facts are known about a location and what are reported via VGI. Science or other conventions define what may or may not occur at a given location. An overly simplistic but effective example would be that a submission for a coffee shop located in a lake is likely to have been placed there by error. Goodchild (2012) wrote that the research for this approach was promising but the lack of automation in the process limited it's potential.

Within the context of stability operations, the geographic approach will likely be very useful. Units engaged in stability operations are intimately familiar with the human and environmental geography of their operating areas. Villages in a given region tend to follow a template dictated by the human and environmental geography of the area. Using a combination of remote sensing and human intelligence, the data corroborators in the Civil Affairs Teams will be able to determine the general usefulness of a crowdsourced data point.

2.1.3. Positional Accuracy with VGI

Positional accuracy in VGI is a concern since the GPS devices contained in the average smart phone are not of survey or professional grade accuracy (Heipke 2010). The spatial relationship between features is often of critical importance in scientific research. The 6-15 m horizontal accuracy of a typical smartphone is often good enough for navigation or recreational purposes but leaves something to be desired when collecting field data (Schaefer and Woodyer 2015). While seeking to quantify the accuracy of volunteered data, Haklay (2010) compared OSM data to the Ordnance Survey of Great Britain. The study showed an average commonality of 80% between the OSM and Ordinance Survey overlays with percentages of overlap varying from 60% to 89%. Haklay found that the accuracy of a dataset cannot be greater than the margin of error of the GNSS receiver or the imagery points they are extracted from. If aerial imagery has a 5 m resolution, error cannot be less than 5 m. If a GNSS receiver has a self-location error between 5-10 m, then the error cannot be less than 10 m.

Another interesting study on positional accuracy in VGI compared relative positional accuracy of popular mobile devices, recreation grade GNSS receivers and survey grade equipment. The purpose was to study the effects of device choice on location reporting. In one experiment, a Trimble 5600TS with 5 cm accuracy was compared with a Garmin eTrex receiver in measuring a distinct historical site in the UK. The mean difference between points taken by the two devices was 1.15 m (Figure 5). The author noted that factors such as weather, time, vegetation, slope and the number of satellites being tracked can all adversely impact receiver accuracy (Schaefer and Woodyer 2015).

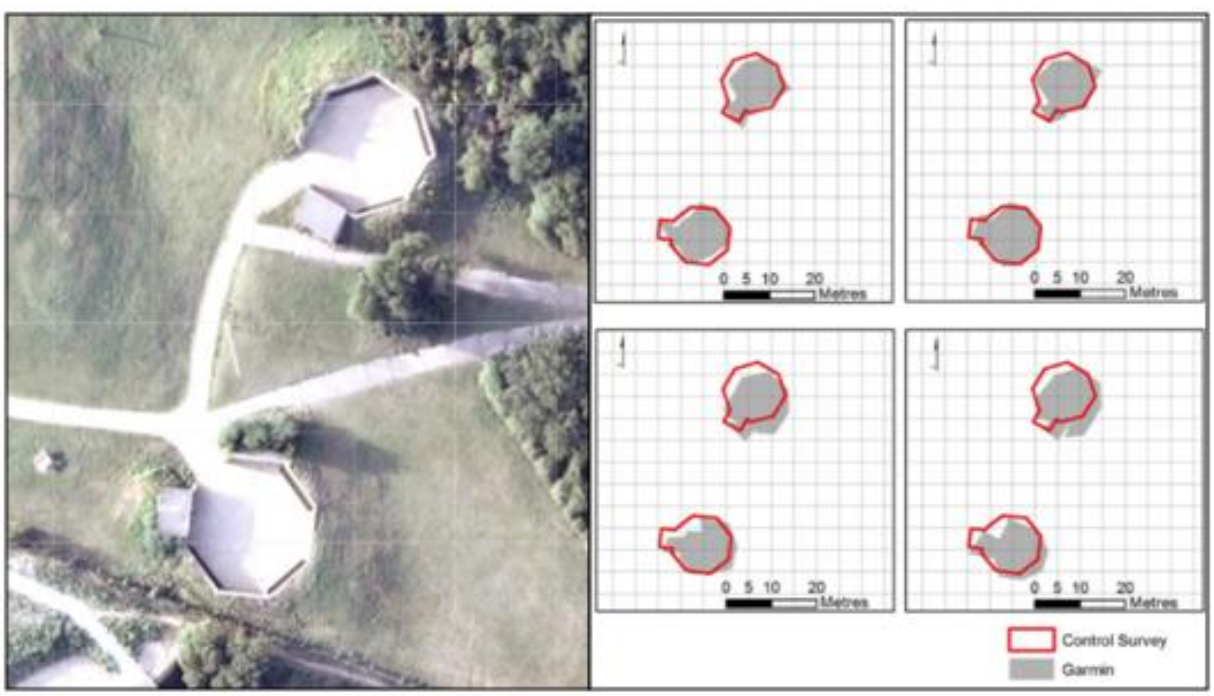


Figure 5: Accuracy comparison of survey grade and recreational GNSS devices (Haklay 2010)

2.1.4. Public Sector Use of VGI

Geographic information production is traditionally the domain of elite and professional organizations within government, academia and certain corporate entities who specialize in such products. In the contemporary environment that paradigm is shifting. There are many recent examples of VGI supplementing or even replacing professionally made products and GIS professionals are taking notice (Goodchild 2012). The National Geospatial Intelligence Agency (NGA) is the premier agency for collecting spatial intelligence and producing the products that guide policy decisions. In late 2015, the NGA established a working group titled the VGI TRIAD which explores three supporting legs of crowdsourced spatial data. Those legs being: Active VGI, Passive VGI and Community Sourcing. The active component queries the public about specific geographic features, the passive component feeds data to the public for further VGI "enrichment" and the community sourcing component establishes a forum for analysts to collaborate on datasets in real time (Mortenson 2016).

On a local level, the appeal of vast pools of data harvested by engaged citizens at little cost to cash strapped governments is contributing to a gradual acceptance of VGI in the public sphere. Challenges remain and there are limits to the extent public entities will expose themselves to liability by using VGI. One study found municipal governments in the UK, Australia, Western Europe, and the USA were often initially eager to embrace VGI, but enthusiasm waned as projects neared implementation. VGI as an abstract concept is appealing but in practice bureaucratic hurdles can bog down projects and sap enthusiasm (Johnson and Sieber 2013). Projects of high fiscal or public safety consequence are unlikely to rely solely on the use of crowdsourced data. Those will continue to be largely handled by professionals. Creative uses of VGI on behalf of fledgling governments in crisis may face less bureaucratic resistance than if similar methodologies were employed by more developed countries.

2.1.5. Use of VGI in Stability Operations and Improving Local Governance

A service member assigned to stability tasks in a conflict zone can expect a host nation government to suffer from a lack of legitimacy in the eyes of its citizens. As a junior officer engaged in these operations, the author frequently encountered residents who had complete faith in coalition forces to accomplish tasks but who would refuse to engage with agents of their own government. Those citizens believed, not without cause, that their government was corrupt and impotent and that engaging with it brought mortal peril and no possibility of positive results.

Unfortunately, the volunteer nature of VGI lends itself to abuse in the context of stability operations. Bad actors will inevitably co-opt the process to siphon resources towards their own causes, subvert the lawful government, lead friendly forces into ambushes and engage in countless other nefarious schemes. Abhorrent behavior can and will occur on any platform that encourages public participation. Geographic platforms may be particularly vulnerable to bad online behavior because online contributions will lead to responses in the real world (Elwood, Goodchild, and Sui 2013). Careful vetting of claims submitted via the infrastructure survey is essential. Follow up infrastructure surveys of the initial assessments must be corroborated with up-to-date threat assessments and risk analysis and executed with caution.

VGI has the potential to engage citizens and presents local governments with a way of proving competency and thus initiating a cycle of participation. Once initiated, this cycle is mutually beneficial. The government saves money and citizens have an outlet to leverage their talents and knowledge to support decision making within their government. According to Johnson and Sieber (2013), two-way participation of this type changes the dynamic of citizens as sensors into a more effective relationship of citizens as partners. A web-based VGI application enables citizens to participate anonymously while contributing to their government and community without the overt appearance of picking sides.

2.1.6. Military Geospatial Data Management

Brigade Combat Teams and all Civil Affairs Battalions have dedicated Geospatial Engineer Teams (Department of the Army 2017). Geospatial engineers are responsible for managing the enterprise geospatial database within their organization. They are also responsible for generating and analyzing the geospatial data captured within their organization. The Army Geospatial Enterprise (AGE) shown in Figure 6 is a distributed geodatabase that supports an Army-Wide Common Operating Picture. A joint database supporting the entire DOD and partner agencies is administered by the NGA and draws from all service component databases.

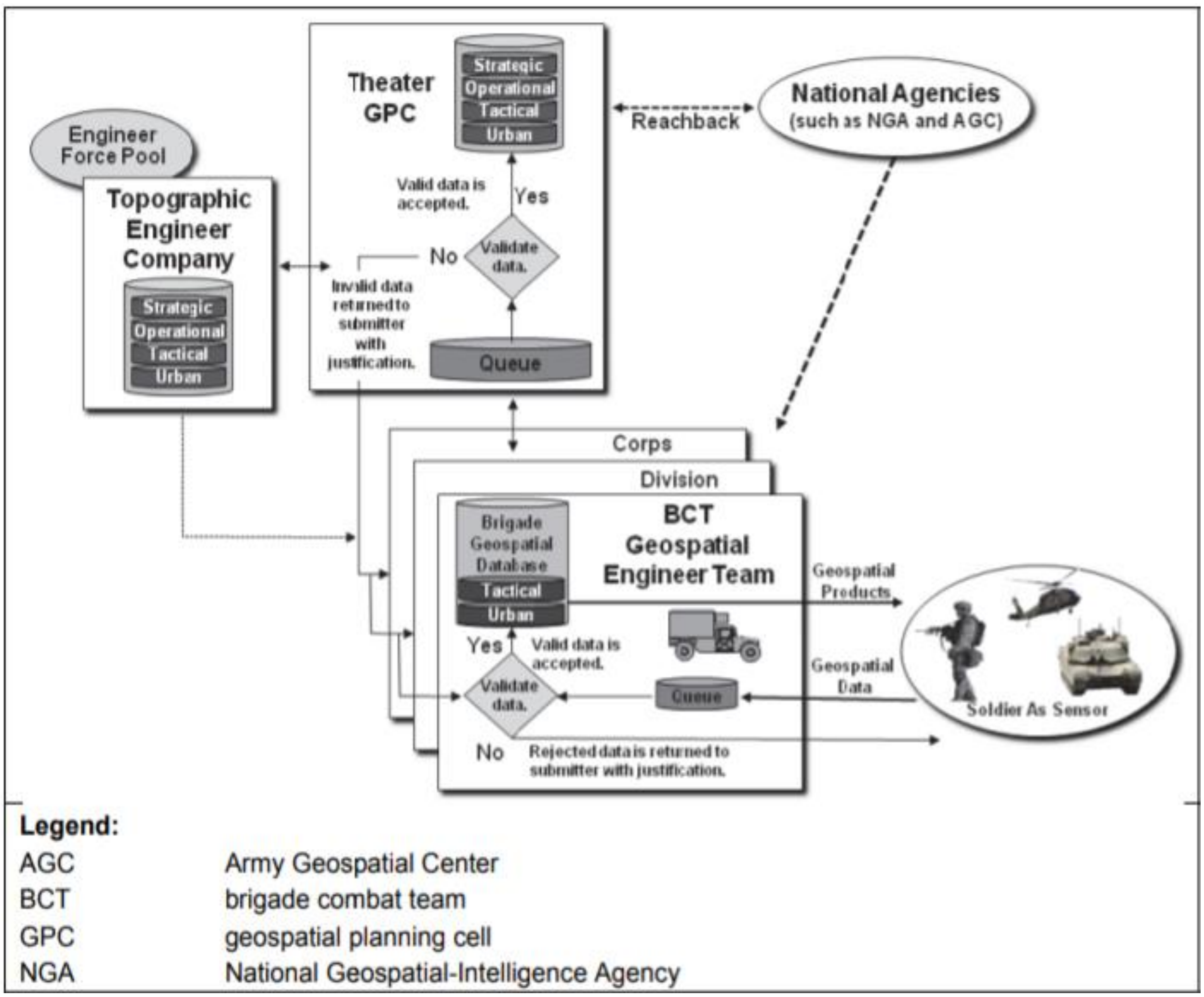


Figure 6: Army Geospatial Enterprise data flow (Department of the Army 2017)

2.2 Existing Infrastructure Assessment Applications

The Instrument Set, Reconnaissance and Surveying (ENFIRE) Kit is currently issued to engineer teams to perform engineer tasks which includes infrastructure assessments. The kit includes a Toughbook computer, a laser range finder, a survey grade GNSS receiver and several other components. The software suite includes Esri ArcGIS Desktop as part of the Distributed Common Ground System - Army. The ENFIRE Kit allows geospatial information to be captured and transmitted to an enterprise geodatabase in real time (Northrop Grumman 2018). Unlike host-nation application users, the administrators will be required to maintain a secure communications network. The ENFIRE kit allows spatial information to be cached within the standalone Toughbook computer and uploaded to the AGE when attached to a secure network.

The Federal Emergency Management Administration (FEMA) in cooperation with the American Red Cross developed a damage assessment methodology to conduct assessments in the wake of disasters. This methodology defines structures as affected, minor, major or destroyed based on the severity of the damage. Like infrastructure assessments these damage assessments are usually carried out by dedicated teams of collectors. The assessments are aggregated and affected communities are assigned a score that helps determine their eligibility and need for aid (Federal Emergency Management Administration 2016). VGI is increasingly being utilized to assist collection teams in this effort. One novel approach proposed using spatial video to rapidly survey large swaths of terrain. Spatial video can be collected from a variety of means including airborne sensors or drones but they can also be rapidly collected by an individual driving through an affected area. After collection, geotagged still frame photos are analyzed to assign damage criteria to affected structures (Lue, Wilson, and Curtis 2014).

2.3 Using Technology in Unsecured Areas

Secure Access in Volatile Environments (SAVE) is a research foundation funded by UK AID. The group studies humanitarian efforts in conflict zones and attempts to quantify results. SAVE recommends using a variety of methods to verify that development and humanitarian aid is reaching the intended recipients. Verification methods include phone and in-person interviews, radio broadcasts, internet surveys and remote sensing. The study noted Afghanistan and South Sudan as locations where some residents are afraid to carry mobile devices out of intimidation of armed criminal groups. Syria, Turkey, Somalia, and Iraq reported much more freedom to openly use technology in aid reporting (Schepard 2016). With these examples in mind, the appropriateness of any single method of assessment collection should be considered against the reality on the ground in a particular area of operations. Benefits and challenges of using digital devices to aid data collection in volatile areas are shown in Table 4.

Table 4: Benefits and challenges of digital aid surveys (Schepard 2016)

Benefits	Challenges
Rapid transmission of data	Requires physical access (N/A for VGI)
Reduced work steps (no data entry from paper forms)	Can attract the attention of armed/criminal groups
Surveys can be easily adjusted	Encourages closed question formats
Easier detection of abuse in data collection	Potential unequal distribution of results
Lower visibility for enumerators using small handheld devices	Technology viewed with suspicion
Can prevent unauthorized viewing	Requires some technical literacy
Allows collection of multimedia data	Access to electrical power and connectivity

Chapter 3 Requirements and Design Methodology

This chapter presents the requirements and design methodology for producing the infrastructure assessment application, web map and operations dashboard.

3.1 Survey Workflow

This research produced a simple and intuitive workflow that supports the collection of of infrastructure metrics within a given area of operations (Figure 7).

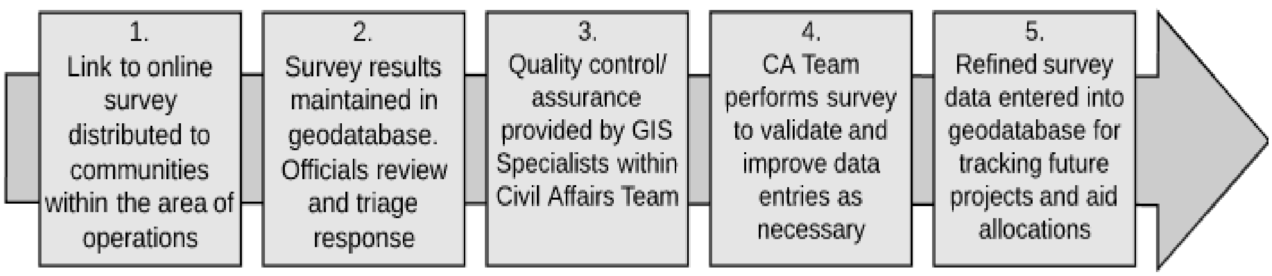


Figure 7: Crowdsourced village assessment workflow

Infrastructure metrics support recovery in affected areas by enabling the District Stability Framework Process shown in Figure 8. Building confidence in the population while reducing accelerants of conflict and providing for basic needs and services help produce lasting stability (USACE 2016). Situational awareness is enhanced by knowing the location and severity of damaged infrastructure. Analysis is conducted on the spatial data harvested to identify trends. Design is based on feedback from local stakeholders identified in the assessments. During the implementation phase, project benchmarks are independently monitored to ensure all measures of performance and measures of effectiveness are being met.

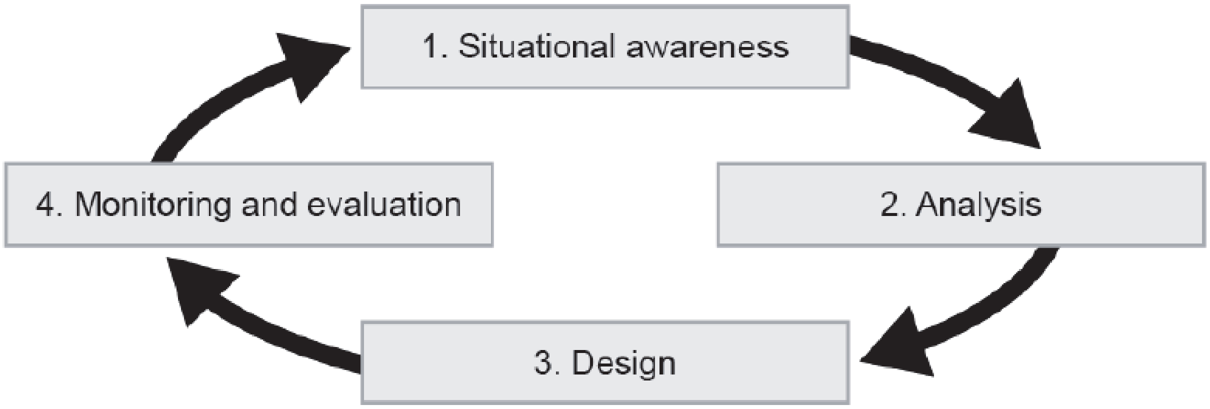


Figure 8 District stability framework process (Department of the Army 2012)

Infrastructure assessments will be reviewed by units engaged in stability operations but the assessments themselves will be spearheaded by host governments with the assistance of NGO's and development organizations such as USAID and the UNDP. Military units in partnership with local government officials, police and community leaders will advertise the surveys in centers of gravity such as markets and places of worship. The surveys will also be prominently placed within aid and development websites. The Afghanistan Ministry of Rehabilitation and Rural Development (MRRD) and the USAID sponsored Afghanistan Infrastructure Rehabilitation Program (AIRP) are examples of such web pages. The Farsi and English versions of their websites and the MRRD Facebook page are shown in Figure 9.

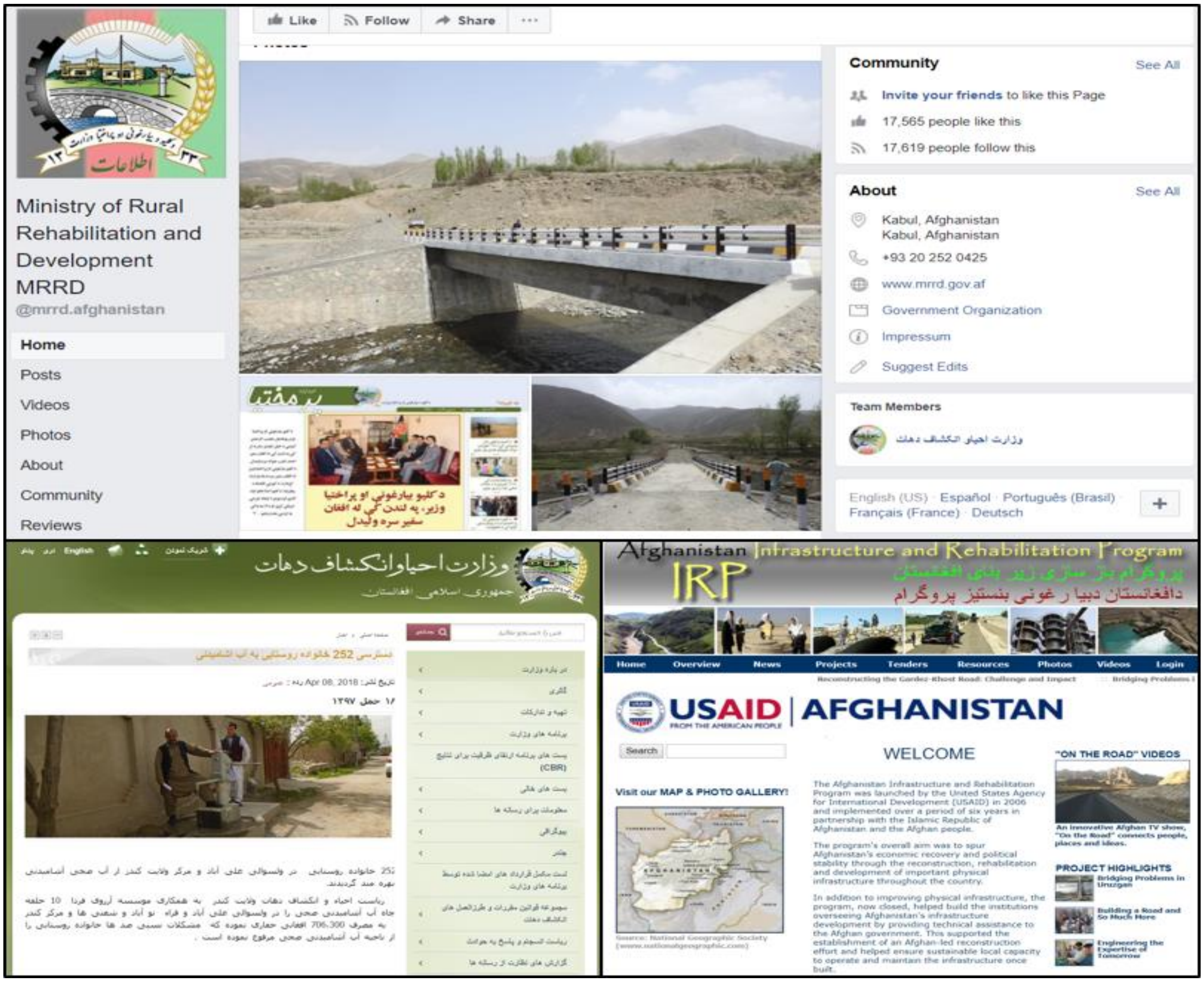


Figure 9: Afghanistan aid and infrastructure websites hosted by USAID and MRRD (2018)

Submitted infrastructure data will be reviewed and vetted by development staff. Depending on the stage of the operation, this task may fall to uniformed service members within the AO encompassing the feature or it may fall to another entity within an aid agency or the host government. The review corroborates the data with available intelligence and deconflicts responses with other ongoing projects or operations. Full infrastructure scoring criteria is found in Appendix A. If all infrastructure reports across all categories are green, then the priority for that village will be low. If multiple categories in another village are ranked as amber, red, or black then that village will be a higher priority for engineer teams to visit for a formal infrastructure survey. The VGI infrastructure database is iterative. Entries will continue to be accepted, reviewed, and updated for the lifecycle of a project. All records and procedures are to be maintained and documented for ultimate transition to host nation government control.

3.2 Overview of Study Area used for Proof of Concept

While this research focuses on the applicability of applying VGI in conflict or disaster areas. Testing occurred within a pair of communities in the Sierra Nevada Foothills of Tulare County. This area was chosen because the author was raised there and is intimately familiar with the terrain and culture of the region. In certain respects, the region mirrors areas where stability operations are needed. Many of the residents are first generation immigrants and residents of the area suffer from poverty and crumbling infrastructure. Conditions of severe drought and serious flooding are common and damage from wildfires or floods are annual worries. The communities are isolated and do not have contiguous borders with other communities which simplifies the task of sorting assessments.

Tulare County is located south of Fresno and runs from the San Joaquin Valley into the foothills of the Sierra Nevada Mountains. The county is home to approximately 400,000 people as of the 2010 Census. Agribusiness is the largest economic driver in Tulare County (US Census Bureau 2010) with that sector dominated by dairy, other cattle products, and varieties of citrus fruit. The World Agriculture Exposition, colloquially known as “The Farm Show” is the world’s largest agriculture exposition of its kind and occurs every February in the city of Tulare. The climate in the region ranges from ~20° F in the winter to well over 100° F in the summer. The foothills depend heavily on various rivers flowing from the Sierra Nevada Mountains for agriculture, power generation and tourism. For the remainder of this thesis the region encompassing the general area of the test communities is described as AO Tulare (Figure10).

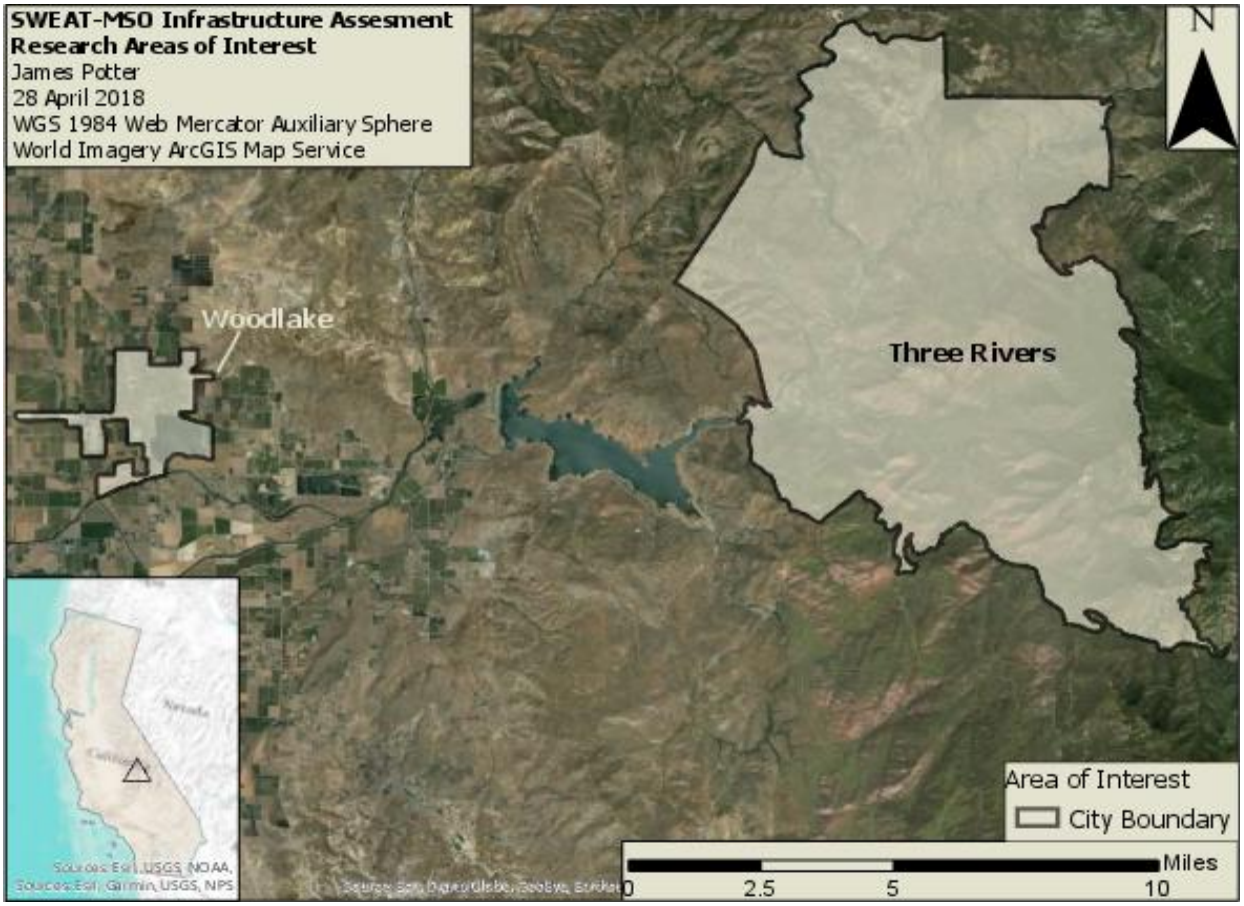


Figure 10: Overview of study area in Tulare County CA

3.2.1. Three Rivers

Three Rivers is the easternmost and more rural of the two study communities. The name is derived from the town's location at a junction of the North, Middle and South Forks of the Kaweah River. The Kaweah is a tributary of the man-made Lake Kaweah which serves as the westernmost border to the town. The eastern edge terminates where the Sequoia National Park and Sequoia National Forrest begin. The 2010 census places the population of Three Rivers at 2,182. The town's history includes ranching and mining as well as more recent arrivals drawn to a thriving "new-age" movement. Public infrastructure is limited in Three Rivers. There is a K-8 public school but the town lacks educational facilities beyond 8th grade. Power generation comes from two hydro-electric plants and a solar farm. Most homes and neighborhoods utilize groundwater wells for drinking water. Medical and emergency services are provided by a small general practice doctor's office and a county fire station which also houses an ambulance. There is a single Sheriff Deputy in the town but no permanent police station. The town's population has shrunk during recent decades as the population ages and the tourism economy consolidates.

3.2.2. Woodlake

Woodlake is a small community in the San Joaquin Valley. The town has a semi-arid climate and is primarily a ranching and agriculture-based community. The population hovers near 7,600 residents living within a 2.5 square mile area surrounded by citrus groves that abut the Sierra Nevada Foothills to the east (City of Woodlake 2018). The town has a permanent police force, a high school, and some larger stores so many residents of Three Rivers travel here to shop or to send their teenage children to high school. According to the 2010 census residents identifying as Hispanic or Latino represented 87.7% of the town. The relative poverty of the population contributes to a general lack of services and infrastructure. About 36% of families residing within Woodlake have an income placing them below the federal poverty threshold.

3.3 Survey components

The components of an infrastructure assessment as defined in this research are contained in the acronym SWEAT-MSO (Sewage, Water, Electricity, Academics, Trash, Medical, Safety, Other). The feature descriptions are seen in Table 5. These metrics fulfill the infrastructure requirement of the operational variables. Because they are the most tangible aspect of infrastructure these metrics focus primarily on structures. According to published engineer doctrine regarding infrastructure assessments, location must be established for each pertinent structure. Efforts must also be made to determine the value to the community from the perspective of the population (USACE 2016).

Table 5: Infrastructure category feature descriptions

Attribute Name	Type	Data Source	Notes
Sewage	Point	VGI	Center Point of Waste Water Treatment Facility
Water	Point	VGI	Center Point of primary water source
Electricity	Point	VGI	Center point of primary power source
Academic	Point	VGI	Center point of academic facilities
Trash	Point	VGI	Entrance point of collection area
Medical	Point	VGI	Entrance point of medical facilities
Safety/Security	Point	VGI	Center point of police/military facilities
Other Concerns	Point	VGI	Center point of noteworthy feature

Doctrine does not specify what specific geographic features should be recorded. The specific deficiencies that should be recorded are also not explicitly specified. The assessment relies on the best judgement of those providing the data to determine where deficiencies lie.

For qualitative decisions a simple binary assessment of 'works' or 'does not work' is sufficient to record in the assessment so that deficiencies can be noted. For quantitative decisions the Black – Green scoring criteria outlined in Appendix A will be applied. While completing an assessment the following questions should be asked for each category:

Sewage: What is the status of the local sewage system? Where is sewage treated? Do health and environmental risks exist?

Water: Where are the potable water sources? Are they adequate? Has testing occurred?

Electricity: What is the status of power generation facilities? Status of transmission infrastructure? What critical facilities are without power? Where are fuel supplies?

Academic: Where are the schools in need of rebuilding or repair? What is the school age population k-8? Do post primary education facilities exist?

Trash: Is there a system for removing waste? Does waste accumulation create health or environmental risks? Where is the trash disposed of?

Medical: Where are the available medical facilities? Are there emergency services? Are there veterinary facilities? What medical specialties are in the area? Are there facilities for vulnerable populations (women, children, elderly)?

Public Safety: Are there police and fire services available? Where are the facilities?

Other: Annotate the locations of any special hazards or concerns held by community leaders.

- Transportation Networks: Airport Location? Downed bridges/roadway obstructions?
- Fuel Distribution: Location of fuel supply? Sufficient for all residents and businesses?
- Housing: Structurally sound with utilities access? Log location of destroyed homes.
- Explosive/Hazmat: Annotate all locations.
- Connectivity: Television/Radio/Newspaper access? Is there internet connectivity? Is cellular telephone service available?
- Worship: Where are religious facilities? Are the needs of all faiths adequately met?

The information listed above is only intended as a rough guide for determining the humanitarian and civic assistance needed in a given location. If any site or facility has circumstances not directly addressed, it should be logged as a data point in the assessment and then described as accurately as possible.

3.4 System requirements

Users of this system fall into two distinct categories. The training and equipment needed will be slightly different depending on whether the user is a collector or an administrator.

3.4.1. User Requirements

The residents of the host nation living in areas needing assessment will be the primary collectors. The application is accessible on any web browser using commonly available computers, tablets, or mobile devices. People residing in impoverished areas of the world may not have IT Infrastructure enabling regular internet access, but cellular service is widespread. Afghanistan had the worst internet connection speed in the world as of mid-2016 but even users in that country have 3G or better coverage 79.6% of the time (Open Signal 2017).

The application does not require any specialized training or knowledge to operate. The application is designed for use by people with minimal formal education but who have the knowledge and skills to manipulate basic information technology. The user interface is simple and intuitive and includes only basic functionality. Language and minor variations to format will be made based on the area of operations. Functions that do not facilitate completing the infrastructure assessment are not included in the app. Due to security concerns basic users will not be able to see the results of their submission or other user's submissions. While this stipulation may seem extreme, many communities in conflict areas do not want their homes on the map. By not advertising the location of infrastructure projects bad actors will not be able to use this data to target the projects or the people that they benefit.

3.4.2. Administrator requirements

The administrators of the geodatabase and web map are those service members and government officials who have responsibility for compiling and acting upon infrastructure assessments. The lowest echelon responsible for viewing and editing submissions would be a Company Intelligence Support Team (COIST) and progressing through the ranks of planning cells up to a Theater Plans (G3) or Engagement (G9) Officer. Administrators within these organizations will require access to the ArcGIS Online and ArcGIS Pro software suites. They will also require access to the Surevey123 App and the Esri Operations Dashboard and Web AppBuilder applications. The apps mentioned are included within the ArcGIS Online subscription. The unit Geospatial Engineering Team is the point of contact for all software and technical needs to support the infrastructure application.

3.5 GIS Software Required

This section outlines the choice of platform and software for the users to collect data and for the administrators to archive and analyze the collected data.

3.5.1. Software Choice

Administrators will view collected data within the Esri Desktop and ArcGIS Online suites of programs. This decision was made due to the use of Esri products within military geospatial teams and on common soldier equipment such as the ENFIRE Kit. The web map layer displays a map of the area of interest with individual features delineating infrastructure contained in a geodatabase. ArcGIS Online is viewable on mobile devices and has a robust suite of widgets designed for use by military personnel so it's selection brings many benefits to the user beyond viewing infrastructure assessments.

Users gather VGI on Esri Survey123. Survey123 allows users to submit data directly into the geodatabase hosted on ArcGIS Online. The permissions are set so that users of the app cannot modify, update, or delete any data hosted on the server. This software was chosen because of ease-of-use and that it has no requirement for a user account to submit data. Future versions of this project may use a custom app for collecting infrastructure surveys. The initial map extent will display an area of interest set by the administrator.

A common operating picture displaying all infrastructure assessments within the AO is displayed and managed through the Esri Operations Dashboard app. Operations Dashboard for ArcGIS is a web app that provides visualization and analytics for a real-time operational view. The dashboard shows user selected views and queries of layers published to ArcGIS Online.

3.5.2. Platform Choice

This application allows submissions by anyone with access to the website. The use of a web-based application means the only limitation is access to an internet connection. While the browser-based survey does not require any software, the use of ArcGIS Online is available on mobile applications. This feature allows data administrators to analyze submissions in the field.

3.6 Web Map Application Creation

This section outlines the creation of the infrastructure assessment on Survey123 and the steps required to prepare the data for storage in the geodatabase.

3.6.1. Structuring Geodatabase for submissions

To display the collected data an enterprise geodatabase was created in ArcGIS Pro with the database set as an SQL_Server. The feature classes within the geodatabase are the elements of SWEAT-MSO contained in the infrastructure assessment. The geodatabase was then registered, packaged, and uploaded to ArcGIS Online. As Survey123 infrastructure assessments are submitted, the data is automatically populated in ArcGIS Pro and ArcGIS Online.

3.6.2. Coordinate System for collected data

All data is collected in the Shapefile format (.shp). All shapefiles are points and represent components of the assessment. The web map and shapefiles are in the WGS 1984 Web Mercator Auxiliary Sphere projected coordinate system.

3.6.3. Symbology of Infrastructure Features in ArcGIS Pro

Symbology describes the use of symbols to represent spatial features on a map. A feature submitted on Survey123 defaults to a single symbol for all feature classes. This arrangement is not ideal for conveying an understanding of infrastructure problems. The symbology of the layer will not generally be seen by the application user. To be consistent with other features in the Army Enterprise Geodatabase, symbology was selected to make all graphics consistent with approved joint military symbology (Defense Information Systems Agency 2014). The selected symbology for SWEAT-MSO is seen in Figure 11.

Figure 11: Symbology selected for SWEAT-MSO in ArcGIS Pro

3.6.4. Infrastructure Feature Attributes

Each infrastructure point includes attributes to help describe the feature. Attributes include the village name, assessor name, assessor email, date/time survey collected, infrastructure category, infrastructure type, color rating of assessed feature, importance of assessed feature to the community, additional Information and 2x by attachment (photo) fields. The fields not selected by the user include an OBJECTID field to capture a unique identifier. The OBJECTID field is important because it keeps data from being corrupted and allows different tables to join for more complex spatial analysis.

Within the infrastructure type field there is a drop-down selection with 32 options that give more specificity to the type of feature being targeted. These options include infrastructure features such as libraries and TV stations. While SWEAT-MSO categories are the primary collection goal, users are encouraged to include additional pictures, notes and information on infrastructure type to ensure entries are verifiable and correct. Including these fields helps paint a more detailed picture about community needs and deficiencies.

The attribute fields shown in Figure 12 were configured so that the field alias had a uniquely identifiable name. When the desktop map was published to ArcGIS online all attribute fields were transferred to the published data. This ensured continuity between both platforms.

Village Name	Assessor Name	Assessor Email	Date Survey Collected	Infrastructure Cate	Color Rating	Additional Information	Infrastructure Type	Other	Importance
Three Rivers	Potter, James	email@email.com	4/23/2018 7:00:00 AM	SEWAGE	Green	Most homes have sept...	Sewer	<Null>	Low
Three Rivers	Potter, James	email@email.com	4/23/2018 7:00:00 AM	SAFETY/SECURITY	Green	Additional Information...	Fire Station	<Null>	Low
Three Rivers	Potter, James	email@email.com	4/26/2018 7:00:00 AM	ACADEMIC	Green	Three Rivers County Li...	Sewer	<Null>	Low
Three Rivers	Potter, James	email@email.com	4/26/2018 7:00:00 AM	OTHER	Green	Three Rivers Chevron S...	Fuel Station	<Null>	Low
Three Rivers	Potter, James	email@email.com	4/26/2018 7:00:00 AM	OTHER	Green	Kaweah Commonwealth	Newspaper Office		Low
Woodlake	Potter, James	email@email.com	4/26/2018 7:00:00 AM	SEWAGE	Amber	Public Restroom Bravo...	Public Toilet	<Null>	Low
Woodlake	Potter, James	email@email.com	4/26/2018	WATER	Green	Bravo Lake Stormwater...	Irrigation Water Source		Low

Figure 12: Attribute table of infrastructure features

3.6.5. Other features included in the geodatabase

The layer USA_Census_Populated_Places was added from the Esri Living Atlas for populated areas throughout the USA as defined by the 2010 Census. This layer was clipped to only include boundaries and attributes for the communities of Woodlake and Three Rivers. The clipped feature contains the attributes of FID, ObjectID, State, State FIPS, Place Type, Place FIPS, HousingUnits, Total_Pop, Pop_SqMi, Area_SqMi and shape. These are similar statistics to what would be needed for an infrastructure assessment. Layers for major roads and rivers within town boundaries were explored but not included in the final product due to the cluttering they caused on the map.

3.7 Infrastructure Assessment Application Development

This section describes the construction of the assessment survey on Survey123 and publishing the survey to ArcGIS Online.

3.7.1. Survey 123 Workflow

Survey123 for ArcGIS is a simple and intuitive data gathering application that allows surveys to be quickly created and disseminated. While there are other options for collecting field data such as Collector for ArcGIS or with a custom app builder, Survey 123 was selected because it takes no proprietary software or specialized knowledge to operate. The workflow for creating and publishing a Survey123 assessment is contained in Figure 13.

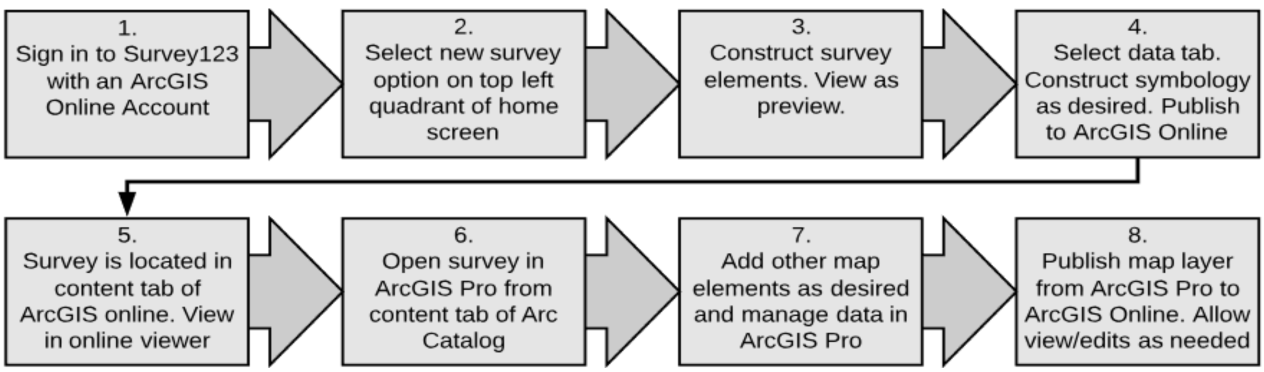
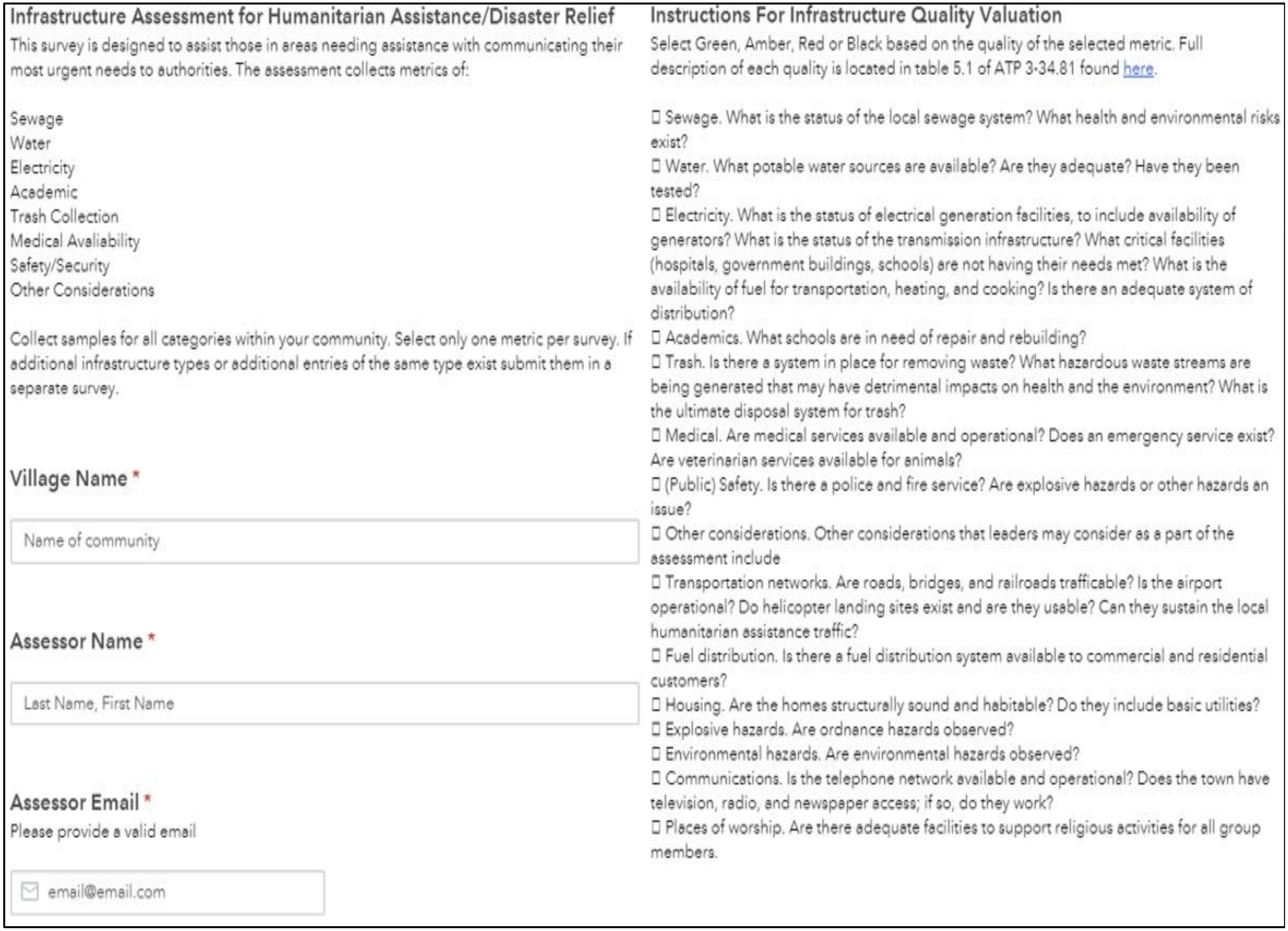


Figure 13: Workflow of building and publishing Infrastructure Survey

3.7.2. Building the survey

To build a survey or view results in Survey123 requires access to ArcGIS Online user credentials and a user account. After logging in and selecting create new survey the blank survey form appears. Survey123 allows the framing of questions using a variety of templates. The question template options include multiple choice, dropdown menus, image and geopoint. The creator of the survey determines the number of questions. The completed survey becomes a feature shapefile. Each question corresponds to an attribute in the feature. Figure 14 shows a screenshot of the final assessment format as seen in a web browser.



Infrastructure Assessment for Humanitarian Assistance/Disaster Relief

This survey is designed to assist those in areas needing assistance with communicating their most urgent needs to authorities. The assessment collects metrics of:

Sewage
Water
Electricity
Academic
Trash Collection
Medical Avaliability
Safety/Security
Other Considerations

Collect samples for all categories within your community. Select only one metric per survey. If additional infrastructure types or additional entries of the same type exist submit them in a separate survey.

Village Name *

Name of community

Assessor Name *

Last Name, First Name

Assessor Email *

Please provide a valid email

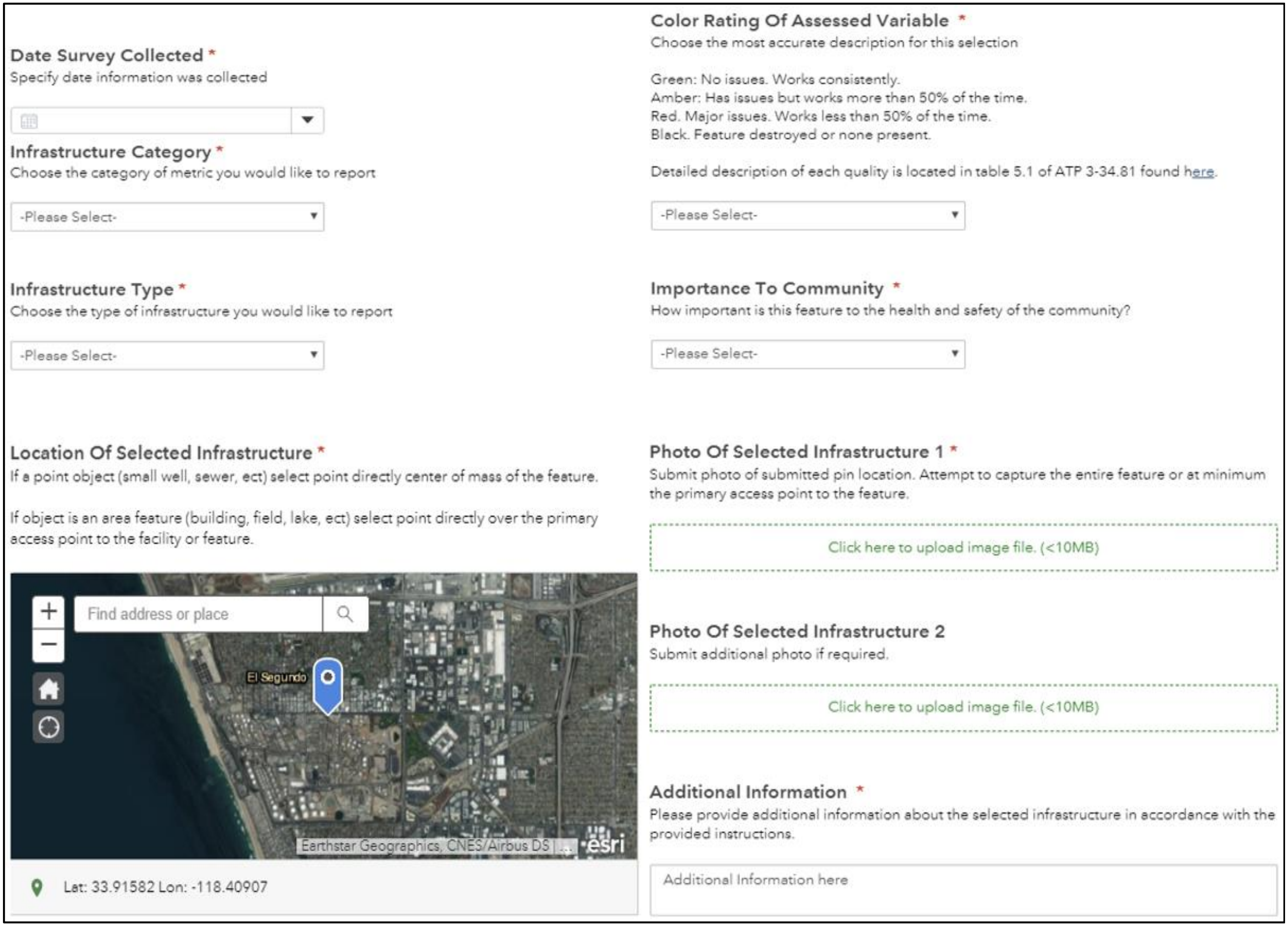
email@email.com

Instructions For Infrastructure Quality Valuation

Select Green, Amber, Red or Black based on the quality of the selected metric. Full description of each quality is located in table 5.1 of ATP 3-34.81 found here.

- Sewage. What is the status of the local sewage system? What health and environmental risks exist?
- Water. What potable water sources are available? Are they adequate? Have they been tested?
- Electricity. What is the status of electrical generation facilities, to include availability of generators? What is the status of the transmission infrastructure? What critical facilities (hospitals, government buildings, schools) are not having their needs met? What is the availability of fuel for transportation, heating, and cooking? Is there an adequate system of distribution?
- Academics. What schools are in need of repair and rebuilding?
- Trash. Is there a system in place for removing waste? What hazardous waste streams are being generated that may have detrimental impacts on health and the environment? What is the ultimate disposal system for trash?
- Medical. Are medical services available and operational? Does an emergency service exist? Are veterinarian services available for animals?
- (Public) Safety. Is there a police and fire service? Are explosive hazards or other hazards an issue?
- Other considerations. Other considerations that leaders may consider as a part of the assessment include
- Transportation networks. Are roads, bridges, and railroads trafficable? Is the airport operational? Do helicopter landing sites exist and are they usable? Can they sustain the local humanitarian assistance traffic?
- Fuel distribution. Is there a fuel distribution system available to commercial and residential customers?
- Housing. Are the homes structurally sound and habitable? Do they include basic utilities?
- Explosive hazards. Are ordnance hazards observed?
- Environmental hazards. Are environmental hazards observed?
- Communications. Is the telephone network available and operational? Does the town have television, radio, and newspaper access; if so, do they work?
- Places of worship. Are there adequate facilities to support religious activities for all group members.

Figure 14: Screenshots of SWEAT-MSO infrastructure assessment application



Date Survey Collected *
Specify date information was collected

Infrastructure Category *
Choose the category of metric you would like to report

-Please Select-

Infrastructure Type *
Choose the type of infrastructure you would like to report

-Please Select-

Location Of Selected Infrastructure *
If a point object (small well, sewer, ect) select point directly center of mass of the feature.

If object is an area feature (building, field, lake, ect) select point directly over the primary access point to the facility or feature.

Find address or place

El Segundo

Earthstar Geographics, CNES/Airbus DS | ...

esri

Lat: 33.91582 Lon: -118.40907

Color Rating Of Assessed Variable *
Choose the most accurate description for this selection

Green: No issues. Works consistently.
Amber: Has issues but works more than 50% of the time.
Red. Major issues. Works less than 50% of the time.
Black. Feature destroyed or none present.

Detailed description of each quality is located in table 5.1 of ATP 3-34.81 found here.

-Please Select-

Importance To Community *
How important is this feature to the health and safety of the community?

-Please Select-

Photo Of Selected Infrastructure 1 *
Submit photo of submitted pin location. Attempt to capture the entire feature or at minimum the primary access point to the feature.

Click here to upload image file. (<10MB)

Photo Of Selected Infrastructure 2
Submit additional photo if required.

Click here to upload image file. (<10MB)

Additional Information *
Please provide additional information about the selected infrastructure in accordance with the provided instructions.

Additional Information here

Figure 14 (cont.)

3.7.3. Creating a Web Map for the Assessment Feature Layer

Once the survey was published to ArcGIS Online as a hosted feature layer it was ready to receive submissions. The next step was to publish a web map from Survey123 to capture the symbology and layer order of the submitted assessments. As discussed in the symbology section the infrastructure assessment feature layer defaults to a single point for every feature. If symbology from ArcGIS Pro is published and the assessment layer is added it overrides the symbology and defaults to the single point. This problem is resolved by publishing a web map for the layer from Survey123 and then adding layers published by ArcGIS Pro.

3.7.4. Publishing a Hosted Feature Layer from ArcGIS Pro

A feature service is used to publish the hosted feature layer which contains multiple feature classes, tables and relationships that are stored on ArcGIS Online and are viewable as a web map. ArcGIS Pro was used to create the desired map layer (.mxd) and geodatabase and then published to ArcGIS Online as a hosted feature layer. ArcGIS Pro and ArcGIS Online have their individual strengths and weaknesses and both were carefully leveraged in this project. ArcGIS Pro is better for data analysis and management while ArcGIS Online allows broader dissemination and collaboration. Because the purpose of publishing the map is to create shared understanding of the infrastructure assessment progress within a given AO the editing functionality of the feature layer was disabled. If needed for future work the permissions can be changed on the item details page of ArcGIS Online. The published AO Tulare webmap is shown in Figure 15.

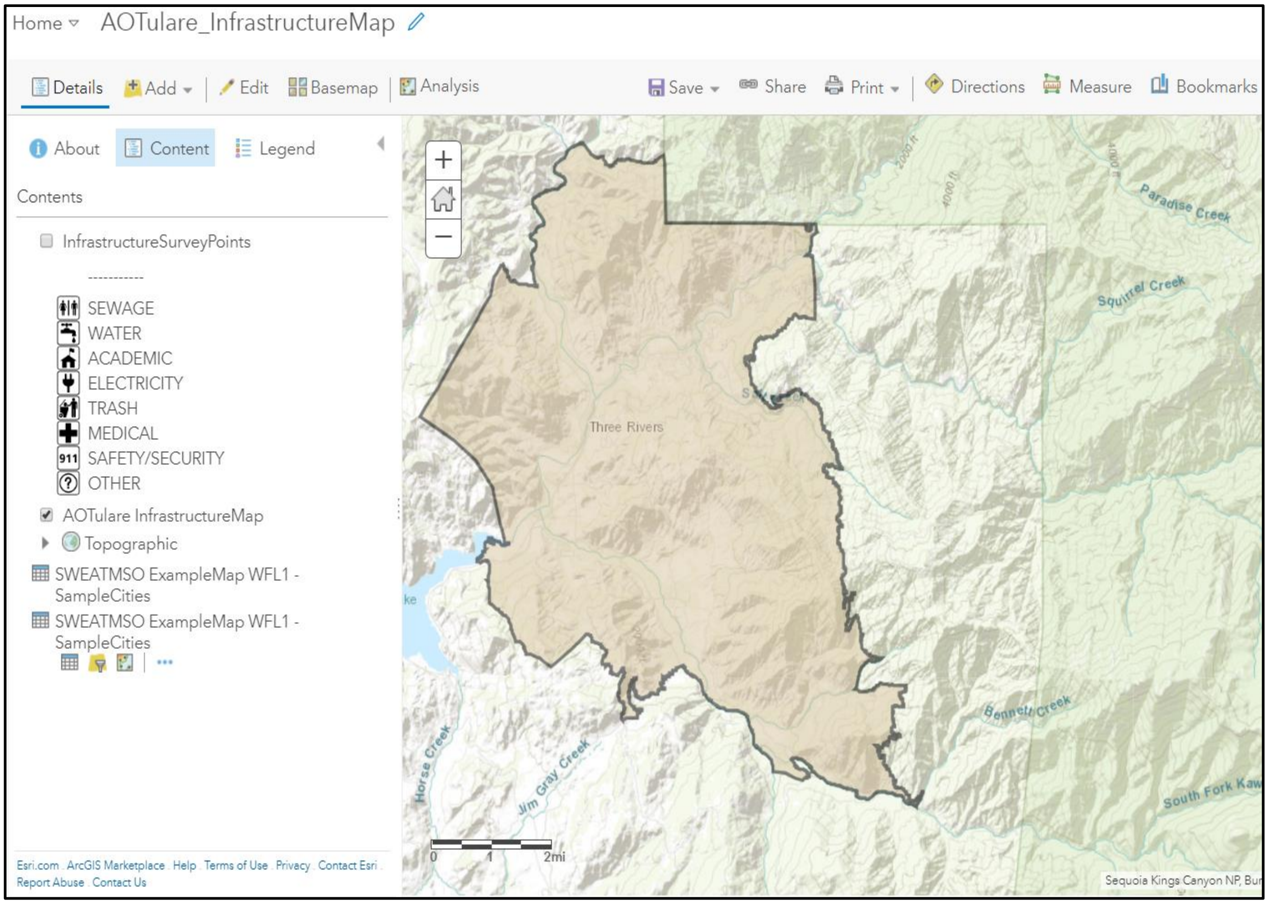


Figure 15: Published AO Tulare map in ArcGIS Online

Several edits had to be made to enhance the functionality of the webmap and ensure its compatibility with the operations dashboard. The desired map extents for Tulare AO, Woodlake and Three Rivers were saved as bookmarks. Pop up views were enabled. The pop-up view was configured to label popups with the community, infrastructure type and status. Scroll over data was also enabled to show that same label information when the mouse hovers over a feature.

3.7.5. Creating a COP for infrastructure needs on operations dashboard

The common operating picture view was created on the Windows application for Operations Dashboard. The customizable dashboards can be viewed either on the Windows app or through a web browser. If viewed on the application there is some increased functionality and an option to view multiple maps simultaneously. The Windows application also allows the use of multiple screens. An operations view with multiple screens can be published to ArcGIS Online but cannot be viewed via a browser. A user attempting to access the operations view in the content tab of ArcGIS Online (Figure 16) will have the option to view the dashboard in either configuration but to open the tab in the Windows app it will first have to be downloaded. The browser option has a simpler interface, but it has the advantage of being viewable from mobile devices or any computer that does not have the Windows app installed.

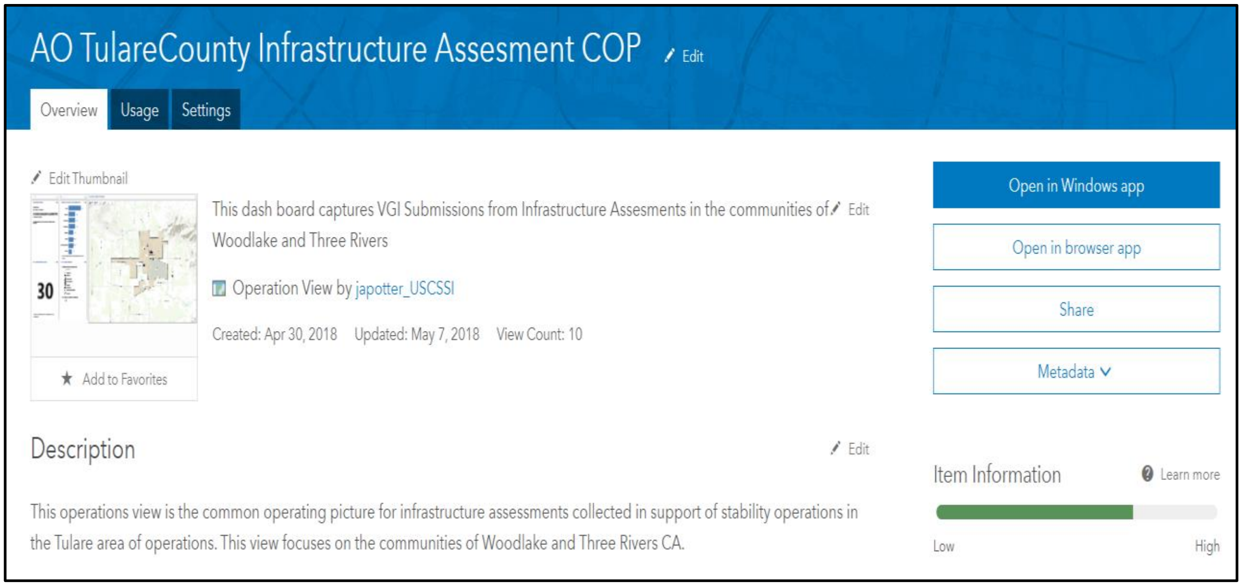


Figure 16: Operations view menu in ArcGIS Online

The common operating picture has a series of widgets designed to display the most pertinent components of the progress of infrastructure assessments in a manner that conveys rapid understanding to the viewer. Within the map window there are options for base map selection, bookmarks, map contents, filters and selecting features.

Several queries were established to filter information based on likely user requirements. The default filter is all features. This setting displays VGI submissions of all types and locations. To display infrastructure in a specific village there is a query where the “Village Name” field contains the value of "Three Rivers" or "Woodlake". Queries filtering submissions based on the extent of damage to the feature are included in the filters for damaged infrastructure. Damage filters look for a color code equal to "not green" AND contain a village name placing them within one of the previously named communities. There is also a query for "submissions last 24 hours". This filter displays options when date submitted equals "less than" 24 hours from the current time. If this filter is used in conjunction with the damaged infrastructure filters, a very narrowly tailored view of current damaged infrastructure can be achieved in a given area.

The widgets shown in Figure 17 are linked to the map window and will display information based on the filter selected. The dashboard notes window contains administrative information essential for understanding the map. Included in the notes are the specific area of concern, the last edit for the map and the responsible unit. The feature count gives the total number of features active on the map extent. The bar graph breaks down the active features by infrastructure category type. The legend displays all symbology for the active layer.

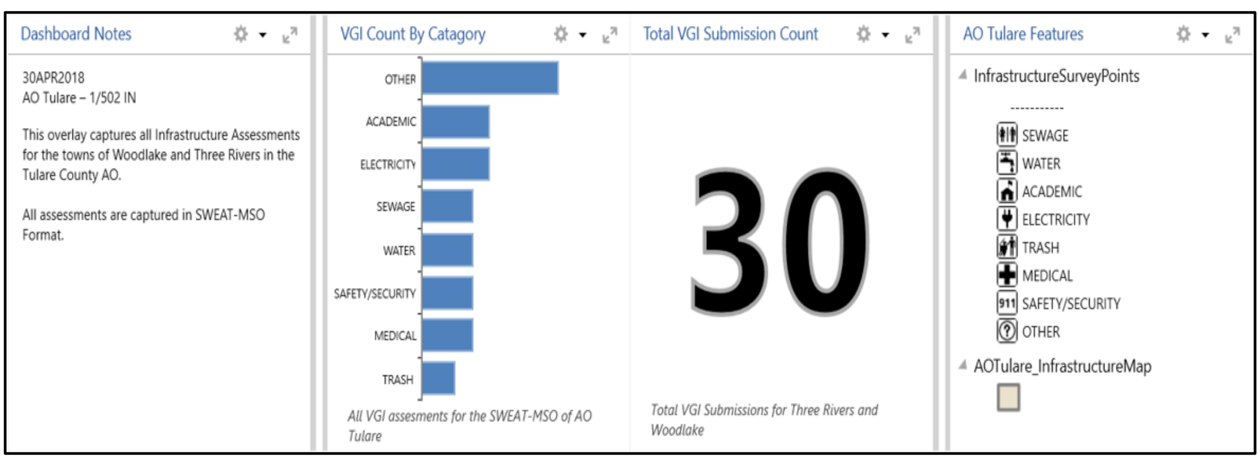


Figure 17: AO Tulare COP and dashboard widgets

Chapter 4 Results

This chapter outlines the results achieved and shows the final maps and dashboard views of the Three Rivers and Woodlake areas. Section 4.1 describes how volunteers were selected, which areas they were assigned and what information and training they received in advance of collecting surveys. User feedback for the application and the web map are included in this section. Section 4.2 presents the results of the volunteer surveys and an analysis of these results is provided in Section 4.3. Section 4.4 reviews of the infrastructure assessment dashboard.

4.1 Assessment Collection

Testing was initiated as soon as a workable framework for the application, web map and dashboard was completed. To collect the infrastructure assessments for Woodlake and Three Rivers the author distributed the survey link to four volunteers residing in the local area. Therese and Katy were assigned to Three Rivers while Marie and Joe collected data in Woodlake. The author described the scenario to the volunteers and informed them that the survey is designed for use in remote environments and that they should only utilize the cellular network rather than wireless internet. The volunteers were made to understand that the data they were collecting was being used to construct an infrastructure assessment of their community.

Volunteers were given no specific directions on how to complete assessments other than the instructions contained in the survey. Each participant was sent a link to their mobile phones via text message and email. Volunteer test data was collected on the 28th and 29th of April 2018. Other test data can be found in the attribute tables from tests conducted by the author.

4.1.1. Survey feedback

Users generally agreed that the survey was intuitive and functional. One consideration mentioned is the impact of small screens on menu selection. While users reported no issues reading the survey instructions or menu items, the drop-down menus within the survey contain many options and the user must scroll through the menu to select the appropriate attribute. There were several cases of users selecting the wrong menu item in the survey due to the lack of fine motor control with the touch screens on smaller mobile devices.

Of interest was how well the infrastructure survey app would perform in areas with poor cellular service. The majority of Woodlake has 3-5 bars of LTE service. Three Rivers has relatively poor coverage with most of the town only receiving 3G coverage and many parts of the town have no coverage at all. Testing demonstrated that surveys would submit with only 2 bars of 3G service, but problems arose when coverage was below that threshold. Since the survey can be used on any web browser, one volunteer described taking a picture and a note of the location and returning to their desktop to complete the survey.

The geotag function defaults to an awkward extent when viewed on a mobile device. The app also defaults to a topo map base map. While the pin is centered directly on the user's device, sometimes the desired location for a feature is not exactly where the user is standing. It takes some manipulation of the device to manually place the pin over the desired location. In one case a user did not know how to change the base map when attempting to place a feature and the location was not easily associated with the default topo map.

In the cases mentioned above the author was able to determine the intended location and feature type from the cross referencing of the different attribute fields. If the user was close and included a picture the author was generally able to infer the intended location.

4.2 Assessment Results

Volunteers collected 30 features in AO Tulare. A total of 16 were reported in Woodlake while 14 were reported within Three Rivers. There were 26 infrastructure features attributed to the green damage category, 2 were amber and 1 each were classified as black or red. The breakdown for all SWEAT-MSO categories by number of entries and damage category is seen in Figure 18.

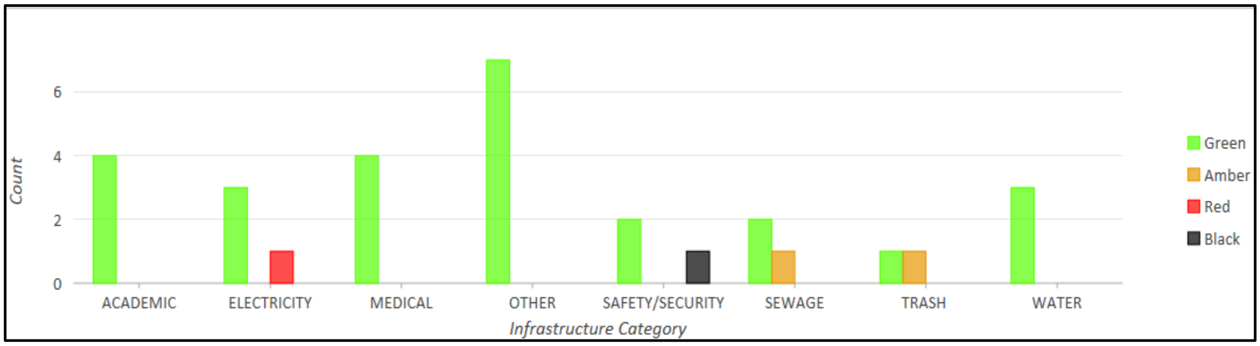


Figure 18: Infrastructure category and damage rating submission counts by type

Of the 30 infrastructure features submitted 2 were reported as within the city limits of a community but were actually located on unincorporated county land. This occurrence is an outlier because in real-world stability operations there will likely be poorly defined community boundaries. For practical purposes if a user submits an infrastructure feature it implies that the feature impacts the health and welfare of that community and should therefore be counted.

4.3 Analysis of VGI Infrastructure Submissions

Submitted assessments were reviewed to ensure validity and quality. Data was assessed by positional and thematic analysis and by comparison to control data. Upon review of the data there were 3 cases of user attribution error. One “OTHER” category was misattributed as an “ACADEMIC” feature. There were also two mislabeled infrastructure types. In these cases, a church was labeled as a cell tower and a school was labeled as a reservoir.

4.3.1. Positional Analysis

To gain an understanding of the positional accuracy of assessments two test features were selected. Volunteers were instructed to submit an assessment for those points. The results of these comparisons are summarized in Table 6.

Table 6: Comparison of VGI submissions for test features

Test Feature 1	Feature 1 (Water Cut Off) Feature Location: 33°55'17.10"N 118°19'38.17"W			
Collector Name	Jon	Jacob	Aimee	Ervin
Submitted Location	Lat: 33°55'17.11"N Long: 118°19'38.07"W	Lat: 33°55'17.18"N Long: 118°19'37.99"W	Lat: 33°55'17.0"N Long: 118°19'38.3"W	Lat: 33°55'17.16"N Long: 118°19'38.13"W
Submision distance from feature	3.8m	3.9m	4.3m	5.2m
Picture Submitted				
Test Feature 2	Feature 2 (Water Pump) Feature Location: 33°55'16.94"N 118°19'36.22"W			
Collector Name	Jon	Jacob	Aimee	Ervin
Submitted Location	Lat: 33°55'17.04"N Long: 118°19'36.12"W	Lat: 33°55'17.00"N Long: 118°19'36.10"W	Lat: 33°55'16.70"N Long: 118°19'35.40"W	Lat: 33°55'16.96"N Long: 118°19'36.03"W
Submision distance from feature	4.1m	3.9m	22.6m	5.3m
Picture Submitted				

The two test features were selected for their prominence and distinguishability. The control point coordinates were taken using a Garmin GPSmap 60CSX. Volunteers were given no prompting on which attributes they should select or any other information other than the standard instructions encountered when submitting the survey. VGI submissions returned a modest degree of accuracy when compared to the control data. Manipulating the “pin drop” geotag in Survey123 requires a degree of fine motor skills but an astute collector can place the point with some precision. If the user is careless in the geotag placement then a high degree of error can be expected. The assessment app instructions specify that the point should be placed directly over the center point of the feature being collected.

4.3.2. Thematic Analysis

There was some variation on the themes of the non-spatial data contained in the VGI assessments. Variations stemmed from different interpretations of what a feature was and to an incomplete menu of options. When producing the content in the Survey123 app the author deliberately used drop down menus or radio buttons to describe as many options as possible. The purpose of standardizing options was to reduce thematic variance between different users. Even with the benefit of defined options some submissions did not fit into a suggested category. In these cases, users selected the “other” type and described the feature in the notes text box. The assessment questions were designed such that the questions mutually reinforce each other. The village name question can be corroborated with the placement of the geotag. The infrastructure category and infrastructure type questions help narrow down the precise nature of the feature, but the essential functions of both questions are to place a feature within the framework of SWEAT-MSO. The photo requirement in each submission offers another tool to cross check the accuracy of the infrastructure type and category questions. Even if one or both type and category questions misattribute the feature, the picture and the context provided by the remaining questions should allow the administrator to correctly identify the feature. As a final resort the volunteer name and email can be leveraged to seek additional clarity on the feature submission.

4.3.3. Control Data Analysis

Test feature attributes are summarized in Table 7. The attribute table for infrastructure submissions was exported to excel and submissions for the test cases were compiled as a table. Volunteers received no coaching for these submissions other than being instructed via text to collect these specific infrastructure points. All submissions included the full names and emails of the participants. Village name submissions included two counts of the town name and two that contained the names of nearby businesses. The village name is relatively subjective and misattributed submissions would not be detrimental in isolated locales. All submissions correctly attributed features to the water category. Most submissions correctly placed the feature type as "other" and put information in the notes that it was some type of water regulation device. One individual left the note information blank, but the author was able to determine intent by viewing the picture and by knowing the category. The importance of the assessed variables ranged between medium and low. Damage criteria was uniformly assessed as green.

Table 7: Comparison of VGI submission attributes for thematic accuracy

Test Feature 1: Flow Control Valve								
Volunteer	Village Name	Category	Type	Notes Information	Importance	Rating	Email	Picture
Jon	Hawthorne	Water	Water Pump	Water Pump	Medium	Green	Yes	Yes
Jacob	Business 1	Water	Other	Water Pump	Low	Green	Yes	Yes
Aimee	Business 2	Water	Other	Water control valve	Low	Green	Yes	Yes
Ervin	Hawthorne	Water	Other	Water main	Medium	Green	Yes	Yes
True Value	NA	Water	Other	Flow control Valve	NA	NA	NA	NA
Test Feature 2: Emergency Water Main								
Volunteer	Village Name	Category	Type	Notes Information	Importance	Rating	Email	Picture
Jon	Hawthorne	Water	Other	Water Pump	Medium	Green	Yes	Yes
Jacob	Business 1	Water	Other	Fire Indicator Post	Medium	Green	Yes	Yes
Aimee	Business 2	Water	Other	Fire main	Medium	Green	Yes	Yes
Ervin	Hawthorne	Water	Other	None Provided	Medium	Green	Yes	Yes
True Value	NA	Water	Other	Water Main	NA	NA	NA	NA

4.3.4. Analyzing Survey Results in Survey 123

Survey 123 offers analytical tools to evaluate survey submissions. Within the analyze tab of the SWEAT-MSO Survey there are options to view the breakdown of each assessment into categories based on the answers given to the assessment questions. The numbers of assessments for each individual participant and for the assessed communities are included in the summary. A time filter can be used to view assessments submitted within a certain window of time. Infrastructure types and categories can be viewed by column, bar, or pie chart or via graduated symbols on a map. Submissions within the additional information tab can be viewed in a table format that gives a count for each time a word is used. The table can also be viewed as a word cloud. The variety of analysis tools available for instant use facilitates a degree of understanding of the infrastructure needs within assessed communities that far exceeds what one can glean from viewing the data. These tools will be put to good use by CA Teams. Figure 19 shows a pie chart of infrastructure submission. The “other” category was the most used selection.

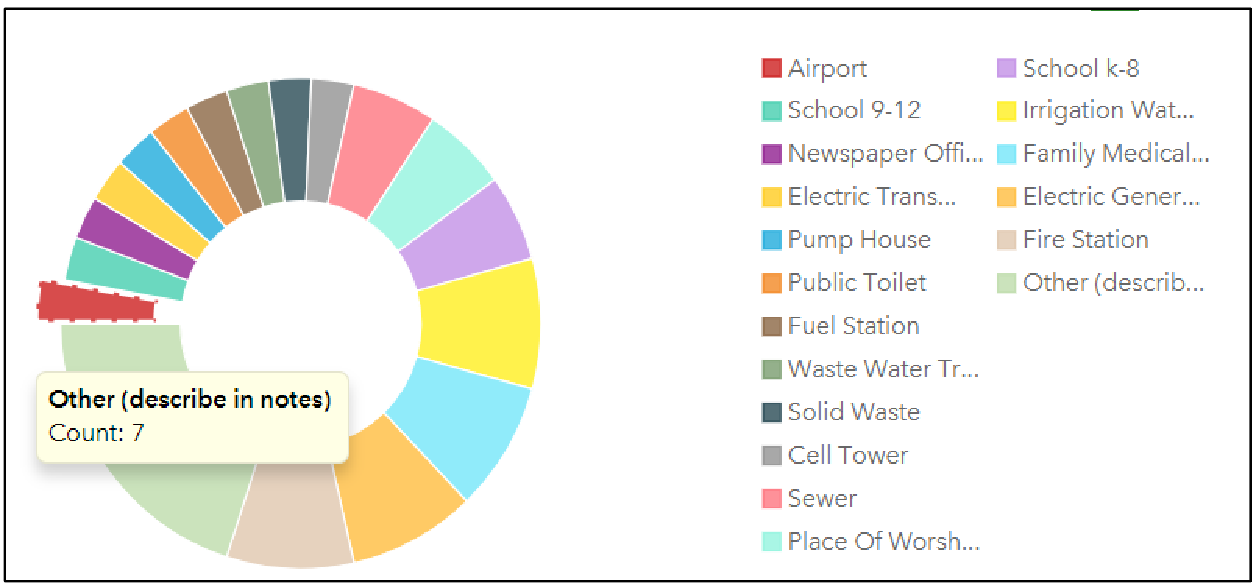


Figure 19: Pie chart displaying infrastructure type submissions in Three Rivers and Woodlake

4.4 Infrastructure Assessment Maps

The maps reproduced in Figure 20 show completed infrastructure assessments for the communities of Three Rivers and Woodlake within the Tulare area of operations. These maps include all marginal map information and can be used to graphically communicate the state of infrastructure needs within the assessed communities.

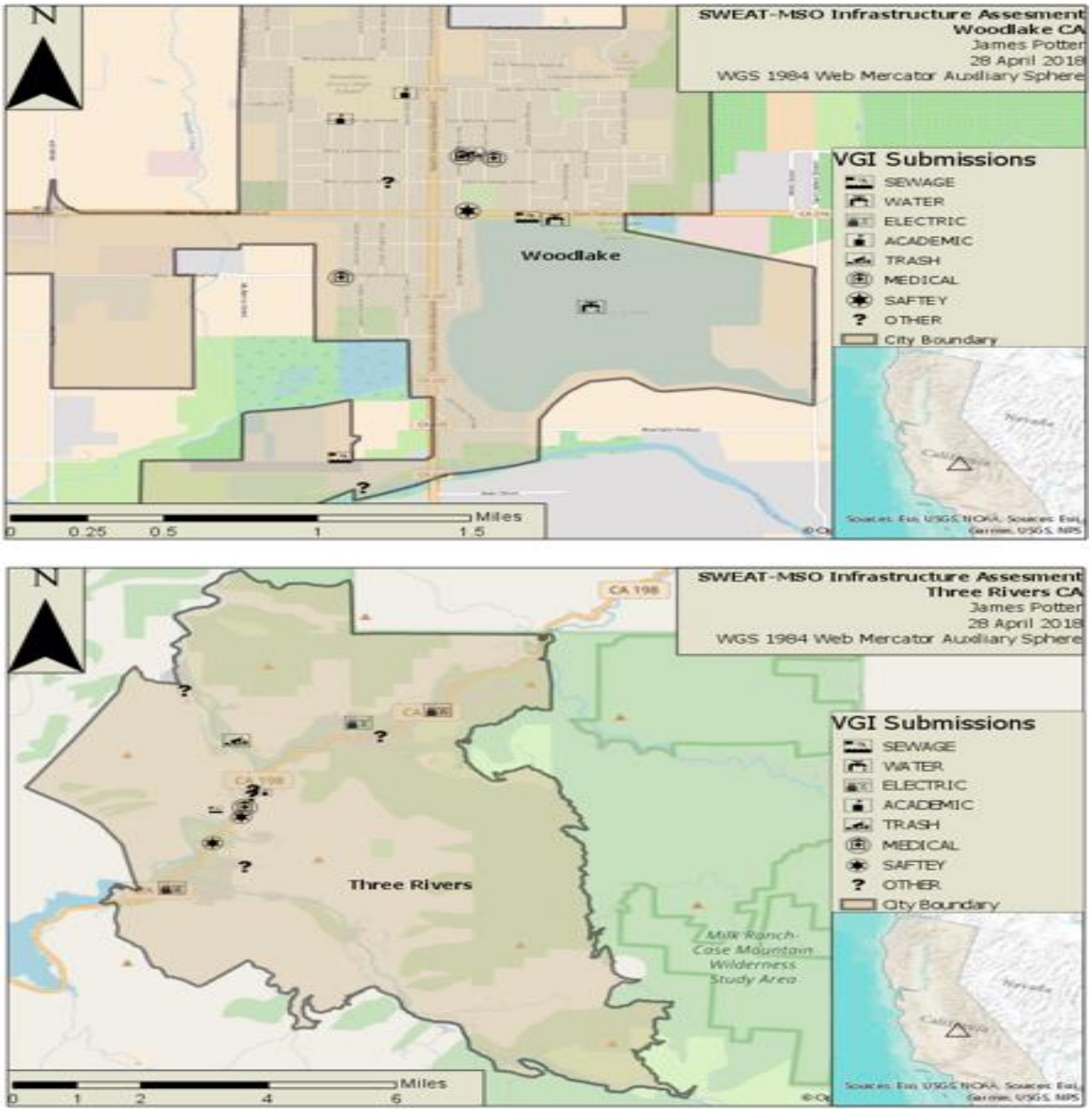


Figure 20: Infrastructure Maps of Woodlake and Three Rivers, CA

4.5 Infrastructure Assessment Dashboard

The completed dashboard shown in Figure 21 displays all infrastructure submissions for the communities of Woodlake and Three Rivers. The dashboard map allows the user to change base maps, turn features on or off, activate filters or select bookmarked map extents. Data cannot be edited from the dashboard view. The active widgets show all pertinent info needed to rapidly convey understanding of the areas infrastructure needs.

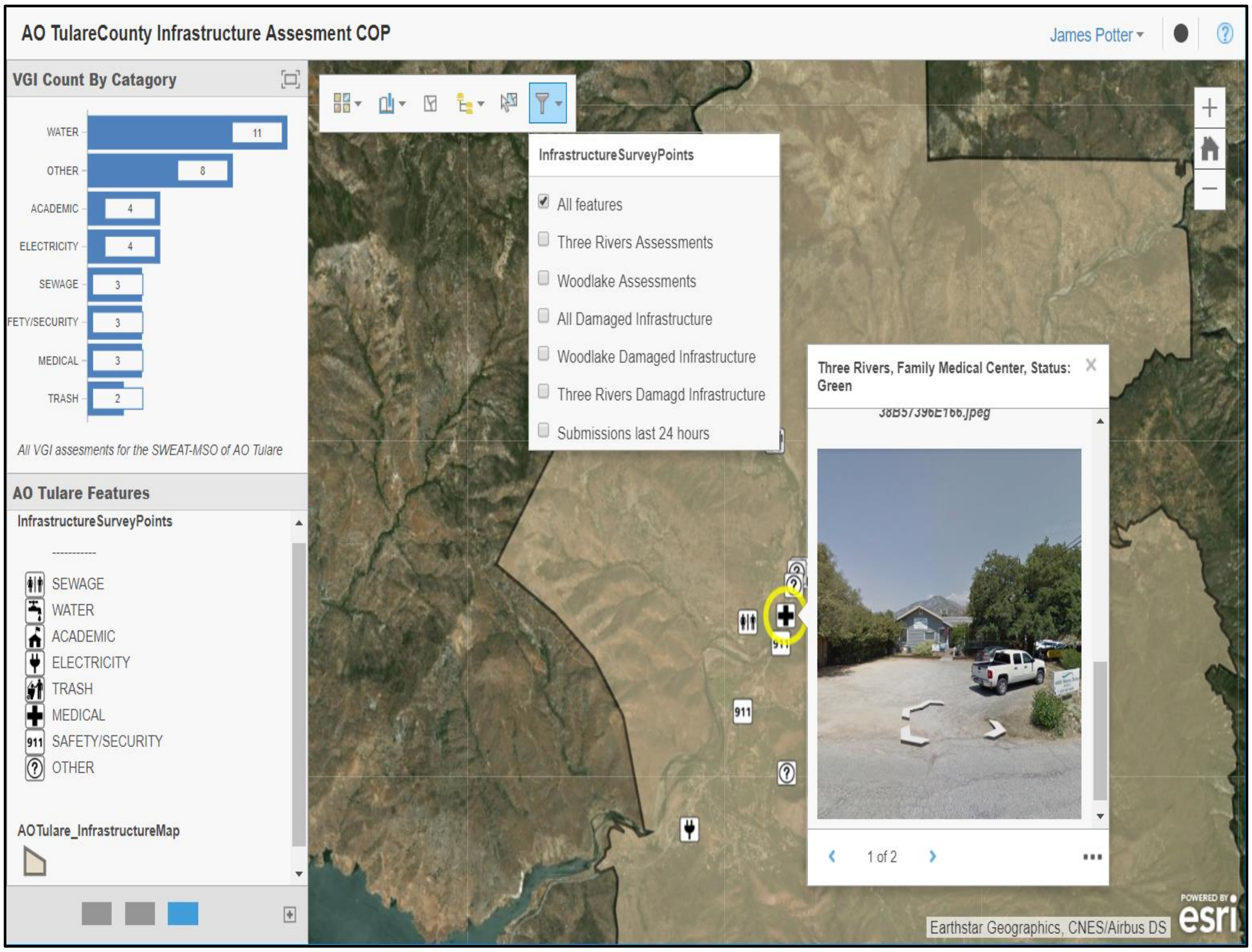


Figure 21: Online COP dashboard for AO Tulare

Chapter 5 Conclusions and Future Work

This chapter discusses the conclusions drawn from developing a web application and an operations dashboard to collect and display infrastructure assessments in support of stability operations. The chapter also discusses challenges encountered while building this application and dashboard and details recommendations for improvement. The chapter concludes with a discussion of the long-term management of the infrastructure assessment application/dashboard and how this project could be scaled up or down to fit a diverse range of operating environments.

5.1 Summary of Application

This project produced a custom SWEAT-MSO survey within the Survey123 app for collecting VGI infrastructure assessments and then built a webmap template to display those assessments. The map was uploaded as a hosted feature layer to ArcGIS Online and imbedded within the Operations Dashboard application. Widgets within the dashboard allow critical information pertaining to infrastructure health to be rapidly processed and disseminated across an organization. All research goals for this project were met. Submissions received on the VGI assessment app and displayed on the dashboard supplements or replaces the traditional method of service members or aid workers traveling to unsecured sites collecting this data in person.

5.2 Project Hurdles

The use of commercially available off-the-shelf software to facilitate this project resulted in challenges as well as opportunities. The benefits include ease-of-use, interoperability with multiple platforms, ability to integrate into the existing Army and DOD enterprise geodatabase and needing little additional training for staff and administrators to integrate into full operational use. While the result was a usable product that portends well for the future of VGI use within stability operations, there are challenges to overcome in future versions of this project, as documented below.

5.2.1. Security of participants and the enterprise system

The nature of stability operations, particularly the fact that they typically take place in contested areas with unstable governments means that security will always be a concern. VGI depends on open and free exchanges of data. Such a dynamic is at odds with the traditional military emphasis on operational and information security. Encouraging mass participation in an endeavor that supports U.S. policy goals introduces the risk that those who have a personal stake in the failure of those policies may attempt to harm or subvert the system.

To protect the integrity of the data and the safety of the volunteers, participants had only limited access to collected data. They would know only about the submissions they personally collected. Participants can also elect to submit assessments anonymously. In many areas of the globe, cultural, religious, or political influences cast suspicion on the use of technology. As discussed in Section 2.3, some insurgent and criminal groups will violently attack individuals found to be using or in possession of a mobile device. The application optimized for use in areas where such security concerns exist should tie their use to local reconstruction and aid organizations and forgo any mention of central government or foreign military entities.

5.2.2. Use in areas of degraded network coverage

While infrastructure assessments can be submitted remotely or from a desktop computer, if used in that manner the assessment will not benefit from the GPS receivers found in most mobile devices. Placing the geotag manually can be done accurately but leaves more room for user error than if a submission is automatically tagged to the location of that device. This subset of user reviews of the assessment application covered the use of the application in areas with poor network coverage. While browser enabled assesments performed surprisingly well in a mountainous area with weak coverage the work was tediously slow, and the application was prone to crashing with intermittent 3G coverage. If the Survey123 application is used, multiple surveys can be collected and archived for submission when coverage is ideal. The reason this option was not used is that downloading the application requires access to an ArcGIS Online account. The browser app in comparison faces the drawback of poor functionality in some areas but anyone with a browser can use it.

5.2.3. Bundling of submissions and limitations of collection using Survey123

The inability of Survey123 to simultaneously submit multiple geotagged points within a single submission or feature layer is a major drawback. This limitation was recognized at the onset of this project but the ability of Survey123 to facilitate collection from anyone with no permissions or authorization needed outweighed this drawback. Many infrastructure features contain distinct components that work in tandem with other components to provide a service but they cannot be reduced to a single spatial feature. The current infrastructure assessment somewhat clumsily overcomes this problem by counting on participants to submit multiple assessments to capture multiple features. Analysis on the back end can then collate these features into systems by using submitted feature descriptions and spatial analysis.

In practice many users may not submit multiple assessments for various features in a single category. Users are likely to pick a prominent feature for submissions and neglect less obvious but nonetheless important infrastructure. There is a high likelihood of clustering near prominent features and administrators will have to use various means including remote sensing and ground truth surveys to determine which feature submissions are most useful. This tendency towards clustering is displayed in the test of spatial accuracy shown in Table 6. Duplicate submissions of the same infrastructure feature were displayed in multiple locations. By comparing attribute information and attached pictures, a CA team can determine the true state of a feature with an acceptable degree of accuracy. Discussion of VGI quality in Section 2.1 discussed the tendency of crowdsourced data to converge on the truth. The crowdsourcing and hierarchical approach suggested by Goodchild (2012) will both be utilized here to ensure submission quality.

5.3 Scalability

The methodology of this assessment can be scaled to cover large geographic areas and support large numbers of users and submissions. The local enterprise geodatabase supporting the collection of the surveys will define the geographic boundaries of an AO and create further subdivisions as appropriate. Local data managers within the Civil Affairs Team or the unit GEOINT Cell will manage the collected data and arrange the dashboard to suite their organizations infrastructure requirements.

Although some techniques, such as spatial video, have been attempted to rapidly assess large, densely packed areas (Lue, Wilson, and Curtis 2014). Collecting infrastructure assessments via the workflow established in this thesis becomes potentially less reliable when adopting the technique to dense urban cores or possible future use within megacities. Operating in relatively poor and isolated communities with underdeveloped infrastructure allows a relative novice to isolate a problem and submit an assessment. The assessment is then triaged and processed by a human operator who provides a measure of quality control. As technological sophistication increases so will the support systems needed to keep it going. This project operated under the assumption that stability operations in more advanced urban locations would operate with some organic host nation public works support and that supporting units will not have to build their assessments from scratch.

5.4 Future Work

Future use of this project depends on transitioning from an abstract academic construct to something that works in the sometimes-messy world of real life stability operations. The design methodology of this project placed a premium on flexibility and user customization. The infrastructure project managers working on public utilities in Columbia will have different requirements than a Civil Affairs Team working on village sanitation services restoration in Iraq. The application and dashboard are designed so that each could tailor the specific questions to their needs within the constraints of SWEAT-MSO and local language and cultural preferences. Some broad changes would improve the framework for collecting VGI in remote areas while still maximizing flexibility.

The next iteration of this project should include a custom app. The Survey123 application worked well but the limitations of the survey in the browser mode make a custom application desirable. Assessment applications would be distributed free-of-charge via aid and reconstruction websites focusing on the area. A browser mode would still be useful, but the application could be downloaded onto a mobile device and used where mobile service was degraded. Infrastructure assessments hosted on the application would be cached during times of degraded connectivity and synced with the spatial database when the device is connected.

The improved infrastructure app would include some increased functionality to bundle multiple features into one submission. In addition to point features the assessment would allow users to submit lines and polygons. An option to link multiple points and features would also be included. For instance, if a participant is submitting for a school there would be an option to tie multiple buildings and points into one submission. The health of a category is more than the damage criteria of a single part of that system. A school may still be able to function optimally if a single building is even moderately damaged.

SWEAT-MSO App version 2.0 will feature an attribute field for users to comment on the completeness of their submitted data. Individual infrastructure features are important but they are not standalone objects. A point may be spatially and thematically accurate but still not convey its importance within the larger system of features. To capture the metric of completeness within a technologically enabled trust network the future app will include a "verified by" tab. Local stakeholders will be known in the area of operations and they can be leveraged as a tool to verify the completeness and accuracy of a submission. This trust network will enhance security and accuracy since submissions can be checked against a list of known actors.

A publicly viewable web map was intentionally not promoted in this project. The security risks of advertising where reconstruction aid is being directed outweigh the benefits of informing the public. That said, a map featuring completed projects that advertises that the projects featured the input of volunteer generated assessments could be featured on government and aid websites. This feature could help drive participation and build confidence in the local authorities while minimizing security risks.

References

Ahn, Eunsu, Camille Hervé, and Laury Zinsz. 2017. "Crowdsourcing for Quality of Life: The Case for Collaborative Crisis Mapping." *Encyclopedia of Emerging Industries*: 122-129. https://hal.archives-ouvertes.fr/hal-01593574.

Bittner, Christian, Boris Michel, and Cate Turk. 2016. "Turning the Spotlight on the Crowd: Examining the Participatory Ethics and Practices of Crisis Mapping." *ACME: An International Journal for Critical Geographies* 15 (1): 207-229. http://www.acme-journal.org/index.php/acme/article/view/1238.

City of Woodlake. "City of Woodlake.", accessed May 23, 2018, http://www.cityofwoodlake.com/.

Department of Defense. 2014. *Joint Military Symbology*. Washington DC: Defense Information Systems Agency.

Department of the Army. 2012. *ADP 3-07 Stability Operations*. Washington DC: Army Publishing Directorate.

———. 2017. *ATP 3-34.80 Geospatial Engineering*. Washington DC: Army Publishing Directorate.

———. 2016. *ATP 3-34.81 Engineer Reconnaissance*. Washington DC: Army Publishing Directorate.

Elwood, Sarah, Michael Goodchild, and Daniel Sui. 2013. "Prospects for VGI Research and the Emerging Fourth Paradigm." In *Crowdsourcing Geographic Knowledge*, 361-375: Springer, Dordrecht.

Federal Emergency Management Administration. 2016. *FEMA Damage Assessment Operations Manual*. Washington DC: Department of Homeland Security.

Fleming, Steven, Elisabeth Sedano, and Margaret Carlin. 2018. "The Ethics of Volunteered Geographic Information for GEOINT Use." *Trajectory Magazine*. http://trajectorymagazine.com/ethics-volunteered-geographic-information-geoint-use/.

Goodchild, Michael. 2007. "Citizens as Sensors: The World of Volunteered Geography." *GeoJournal* 69 (4): 211-221. doi:10.1007/s10708-007-9111-y. http://www.jstor.org/stable/41148191.

——. 2012. "Assuring the Quality of Volunteered Geographic Information." *Spatial Statistics* 1: 110-120. doi:10.1016/j.spasta.2012.03.002. https://www-sciencedirect-com.libproxy1.usc.edu/science/article/pii/S2211675312000097.

Goodchild, Michael and Alan Glennon. 2010. "Crowdsourcing Geographic Information for Disaster Response: A Research Frontier." *International Journal of Digital Earth* 3 (3): 231-241.doi:10.1080/17538941003759255. http://www.tandfonline.com/doi/abs/10.1080/17538941003759255.

Haklay, Mordechai. 2010. "How Good is Volunteered Geographical Information? A Comparative Study of OpenStreetMap and Ordnance Survey Datasets." *Environment and Planning B: Planning and Design* 37 (4): 682-703. doi:10.1068/b35097. http://journals.sagepub.com/doi/full/10.1068/b35097.

Hammon, Larissa and Hajo Hippner. 2012. "The Role of Crowdsourcing for Better Governance in International Development." *Business & Information Systems Engineering* 4 (3): 163-166. doi:10.1007/s12599-012-0215-7. https://search.proquest.com/docview/1024715874.

Heipke, Christian. 2010. "Crowdsourcing Geospatial Data." *ISPRS Journal of Photogrammetry and Remote Sensing* 65 (6): 550-557. doi:10.1016/j.isprsjprs.2010.06.005. https://www-sciencedirect-com.libproxy1.usc.edu/science/article/pii/S0924271610000602.

Johnson, Peter and Renee Sieber. 2013. "Situating the Adoption of VGI by Government." In *Crowdsourcing Geographic Knowledge*, edited by Daniel Sui, Sarah Elwood and Michael Goodyear. 2012th ed., 65-81. Dordrecht: Springer Netherlands. doi:10.1007/978-94-007-4587-2_5. https://link-springer-com.libproxy1.usc.edu/chapter/10.1007/978-94-007-4587-2_5.

Lue, Evan, John P. Wilson, and Andrew Curtis. 2014. "Conducting Disaster Damage Assessments with Spatial Video, Experts, and Citizens." *Applied Geography* Complete (52): 46-54. doi:10.1016/j.apgeog.2014.04.014. https://www.infona.pl//resource/bwmeta1.element.elsevier-98b1223c-b05b-3235-828e-f2ddaf71af34.

Morrison, Joel. 2013. "Elements of Spatial Data Quality." In *Elements of Spatial Data Quality*, edited by Stephen Guptill and Joel Morrison: International Cartographic Association.

Mortenson, Will. 2016. "The "in Crowd": NGA Adopts the Crowdsourcing Model." *Pathfinder Magazine* 14 (2). https://www.nga.mil/MediaRoom/Pathfinder/Pages/Archive.aspx.

MRRD. "Ministry of Rural Rehabilitation and Development.", last modified June 25, http://mrrd.gov.af/fa.

Northrop Grumman. "Instrument Set, Reconnaissance and Surveying (ENFIRE)." Northrop Grumman., accessed May 7, 2018, http://www.northropgrumman.com/Capabilities/ENFIRE/Pages/default.aspx.

Okolloh, Ory. 2009. "Ushahidi, Or 'Testimony': Web 2.0 Tools for Crowdsourcing Crisis Information." In *Change at Hand: Web 2.0 for Development*, edited by Holly Ashley, 65-68: IIED.

Open Signal. "The State of LTE." opensignal.com., last modified November, accessed 26 April, 2018, https://opensignal.com/reports/2017/11/state-of-lte.

Pease, Patricia. 2017. "The Influence of Training on Position and Attribute Accuracy in Volunteered Geographic Information.".

Schaefer, Martin and Tara Woodyer. 2015. "Assessing Absolute and Relative Accuracy of Recreation-grade and Mobile Phone GNSS Devices: A Method for Informing Device Choice." *Area* 47 (2): 185-196. doi:10.1111/area.12172. https://onlinelibrary.wiley.com/doi/abs/10.1111/area.12172.

Schepard, Andrew. 2016. "Eyes and Ears on the Ground: Monitoring Aid in Insecure Enviroments." *Global Public Policy Institute* 54 (4): 543-546. doi:10.1111/fcre.12240. http://onlinelibrary.wiley.com/doi/10.1111/fcre.12240/abstract.

Tobler, Waldo. 1970. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geography* 46: 234-240. doi:10.2307/143141. https://ci.nii.ac.jp/naid/30020890215/.

US Census Bureau. "2010 US Census.", accessed May 6, 2018, https://www.census.gov/2010census/popmap/ipmtext.php?fl=06:0678638.

USACE. 2016. *TR-16-3: Human Infrastructure System Assessment for Military Operations*. Champaign, IL: U.S. Army Corps of Engineers.

USAID. "U.S. Agency for International Development.", accessed June 25, 2018, https://www.usaid.gov/afghanistan/agriculture.

Ushahidi. "Syria Tracker.", accessed May 6, 2018, https://www.ushahidi.com/case-studies/syria-tracker.

Van Oort, Pepijn. 2006. *Spatial Data Quality: From Description to Application*. 1st ed. Rotterdam: Optima.

Appendix A: Coding of Infrastructure Metrics

Area	Green	Amber	Red	Black
Sewage	Sewage system works consistently	Sewage system works but treatment status undetermined	No treatment observed but treatment plant exists	No sewage treatment system, destroyed
	No sewage observed and no odor	No sewage observed but odor present and/or system damaged	Sewage observed and odor present	Presence of raw sewage is a public health issue
	Operational in 100% of public facilities	Operational in 50% or more of public facilities	Operational in less than 50% of public facilities	No operational sewage in public facilities
Water	Water distribution works at 100% capacity	Water distribution works at 50% or more of capacity/some leaks	Water distribution does not work	No water distribution system, destroyed
	Tested as clean and/or local populace is consuming	Appears clean, no smell and local populace states that it is clean	Does not appear clean and local populace states that it is not clean	Tested nonpotable and/or appears contaminated and has bad odor
	Running water in 100% of public facilities	Running water in 50% or more of public facilities	Running water in less than 50% of public facilities	No running water in public facilities
Electricity	Power distribution system works; blackouts are planned	Power distribution system works; blackouts unplanned	Power distribution system is unreliable; frequent blackouts	No power distribution system, destroyed
	Electric lines are 100%; no damage/no power loss	Electric lines are 50%; some minor damage/ undetermined power loss	Electric lines are less than 50%; major damage/ noticeable power loss	Electric lines are all down; hot wires exposed; significant power loss
	Power grid station intact; secure	Power grid station operational; unsecure	Power grid station nonoperational; unable to secure	Power grid station stripped; destroyed
Academics	Building is serviceable; all utilities operational; secure	Building is adequate; utilities operate over 50%; not secure	Building is useable; utilities operate less than 50%; not secure	Building is not useable; utilities are nonfunctional
	Academic resources available to all students	Academic resources available to 50% or more	Academic resources available to less than 50%	Extremely limited academic resources
Trash	Formal trash collection system is operational	Formal trash collection system exists but is limited	No formal trash collection system	No trash collection
	Trash collection is in a central area that does not present a health hazard	Unknown central trash collection area	Central trash collection area presents a possible health hazard	Trash is consolidated in an area that presents a health hazard
	No trash buildup in public facilities	Limited trash in public facilities; relatively clean	Public facilities have no means to remove trash	Public facilities have excess trash
Medical	Medical facilities are functional; backup power; minimal equipment issues; secure	Medical facilities are useable; no backup power; some equipment shortages; not secure	Medical facilities are unsanitary; significant equipment/supply shortages	Medical facilities are not useable due to damage and unsanitary conditions; looted
	Emergency services including multiple ambulatory services available	Emergency services exist; ground transport only	No emergency services; ground transport without medically trained personnel	No emergency services
	Veterinary services	Limited veterinary	On-call veterinary	No veterinary

Infrastructure quality metrics (Department of the Army 2016)

Appendix A: Coding of Infrastructure Metrics (cont.)

Area	Green	Amber	Red	Black
	available; animal holding area	services available; inadequate holding area	services; no holding area	services
Safety	Police department functional; secure building; equipment available and operational	Police department functional a minimum of 50%; building securable; equipment available and operational >50%	Police department functional less than 50%; unable to secure building; limited equipment available	Police department is nonfunctional; building is not useable; no equipment
	Fire department functional; secure building; equipment available and operational	Fire department functional a minimum of 50%; building securable; equipment available and operational more than 50%	Fire department functional less than 50%; unable to secure building; limited equipment available	Fire department is nonfunctional; building is not useable; no equipment
Other Considerations: Roads and Railroads	Minimum of a Class C road; can be upgraded; no visible damage	Minimum of a Class D road; damage/upgrade requirements will impact traffic flow	Minimum of a Class E road; upgrade requirements are significant; materials not readily available	Road is not trafficable
	Operational railroad system	Railroad is damaged but resources to repair are available; jacks available	Railroad damage is extensive; resources to repair are not readily available	Railroad system did exist but now has extensive damage to both track and trains
Other Considerations: Bridges and Waterways	Bridges are trafficable; no visible damage	Bridges are trafficable; damage to spans; supports intact	Bridges are not trafficable for military; risky for civilians; damage to spans and supports	Bridges are not trafficable and are impassable
	MLC verified through ERDC or other structural engineer	MLC calculated but not verified due to damage	MLC is ineffective due to damage	Construction repair required before MLC can be determined
	Inspection/evaluation shows original strength assessment valid	Inspection/evaluation determines strength support issues	Inspection/evaluation determines minimal supportable strength	Inspection/evaluation determines bridge cannot support weight
Other Considerations: Airports	Airport capable of supporting military and civilian traffic concurrently; no visible damage	Airport can support limited military traffic; no visible damage	Airport damaged; utilities and structures are not reliable or safe	No working airport
	Runway/taxiway/parking aprons are serviceable; working and parking maximum aircraft on the ground (MOG) greater than or equal to 2 (military)	Runway serviceable but taxiway and parking limited; C130/C17 only	Runway is not serviceable; can repair with available resources	Runway is not serviceable; dimensions will not support military aircraft; major repair and upgrades required
Other Considerations: Housing	Residences are structurally sound and offer protection from the environment	Residences are damaged and need structural evaluation; offer limited protection from the environment	Residences are damaged and structurally unsafe; no protection from the environment	Residences are destroyed
	Utilities are working and reliable	Utilities are working over 50%; not reliable	Utilities work less than 50%; require significant repairs	Utilities are nonoperational

Infrastructure quality metrics (Department of the Army 2016)

Appendix A: Coding of Infrastructure Metrics (cont.)

Area	Green	Amber	Red	Black
Other Considerations: Communications	Telephone system operational and reliable in public facilities	Telephone hookups available; some equipment available; somewhat reliable	Limited telephone hookups and equipment available; not reliable	No telephone hookups or equipment
	Postal system is operational and reliable	Postal system is slow; over 50% of mail delivered	Postal system exists; extremely slow; less than 50% of mail delivered	No postal system
	Media – television (TV), Internet, Radio, Newspaper operational, available, and reliable	One form of media exists, is operational, available, and reliable	One form of media exists but has limited availability and reliability	No form of media
Other Considerations: Hazardous Materials	Hazardous materials/hazardous waste properly segregated, stored, and labeled.	Some hazardous materials/hazardous waste not properly segregated, stored, or labeled	Hazardous materials/hazardous waste not properly segregated, stored, or labeled	Hazardous materials/hazardous waste not segregated, stored, or labeled.
	Containers adequate for the material	Containers not generally adequate, but limited corrosion or damage	Containers inadequate, corroded, and leaking	Containers inadequate, corroded, and leaking
	Safety measures/ secondary containment in place	Inadequate safety measures and secondary containment	No safety measures or secondary containment	No safety measures or secondary containment
	Hazards communications system in place	Limited hazards communications system	No hazards communications system	No hazards communications system
	No leaks or spills	Potential for leaks and spills	Some leaks and spills already present. Contaminants may enter air, soil, groundwater, or water courses	Gross contamination present; contaminants have entered air, soil, ground water, and water courses
	Spill prevention and cleanup measures in place/ available	Limited spill prevention and cleanup measures available	No ability to prevent or cleanup spills	No ability to prevent or cleanup spills
Other Considerations: Attitude	Community leaders not hostile; religious centers are intact; supportive of general engineering effort	Community leaders are neutral; religious centers are damaged but securable	Community leaders are negative; religious centers are damaged and not securable; skeptic of general engineering support	Community leaders hostile; religious centers destroyed; do not want general engineering assistance
	No ethnic tension	Distinct ethnic groups within AO; supportive of general engineering effort if equal among groups	Distinct ethnic groups within AO; one group dominant; general engineering tasks cannot be accomplished for all groups	Ethnic violence occurs; one group extremely dominant; general engineering effort would increase ethnic tension
	Unemployment is less than 50%	Unemployment is greater than 50%; willing and able to work to support general engineering effort	Unemployment is greater than 50%; unable to support general engineering work effort	Unemployment is a serious issue; unwilling to support general engineering work effort
	No formal paramilitary threat	Paramilitary threat briefed at the BCT/RCT level	Paramilitary threat a concern at BCT/RCT level	Paramilitary threat a concern at echelons above BCT/RCT level

Note. Food Supply and Cultural/Historical/Religious are still under development.

Infrastructure quality metrics (Department of the Army 2016)

Appendix B: Infrastructure Survey Form (Sewage)

Form: Sewer – Collection Systems (Target ID ________________)

Inspector ID____________________________

Inspection date/time________________________

Lift Station #______ of ________(GPS)____________

Does the lift station operate? ☐ Yes ☐ No ☐ Unknown Does it have power? ☐ Yes ☐ No

Check breaker and switches for pumps and other equipment. Note any damage and available information on the capacity of the breaker box feeds and breakers____

Does effluent enter or discharge from the station? ☐ Enter ☐ Discharge ☐ Unknown

Note any leakage or flooding including source and quantity ____________________________________

Direction of flow to/from the lift station: ☐ To (Direction: __________) ☐ From (Direction: __________)

Pipe Information (for pipes entering or exiting the station):

Enter: Size in diameter: _______ : IN / MM Material Type (if able to determine): ___________

Exit: Size in diameter: _______ : IN / MM Material Type (if able to determine): ___________

Are pipes damaged: ☐ Yes ☐ No If so, explain: ______________________________

Are pipes leaking steadily: ☐ Yes ☐ No If so, explain: ______________________________

Do pipes have heavy corrosion: ☐ Yes ☐ No If so, explain: ______________________________

Lift Station Pump Information:

Type of Pump: ☐ centrifugal ☐ screw ☐ pneumatic ejector ☐ grinder ☐ other (specify): __________

Does pump operate? ☐ Yes ☐ No ☐ Unknown Is it a backup pump? ☐ Yes ☐ No

Power source for pump: ☐ electrical service ☐ combustion motor Is fuel available? ☐ Yes ☐ No

Size: __________ IN / MM Amperage:_________ AMPS Wattage: ________ WATTS

Capacity: _________ GAL/SEC or LITER/SEC Flow Rate: _________ GAL/SEC or LITER/SEC

Other Relevant Information: ____

Does pump show signs of steady leakage? ☐ Yes ☐ No If yes, give details: ________________

Does pump generate excessive noise? ☐ Yes ☐ No If yes, give details: ________________

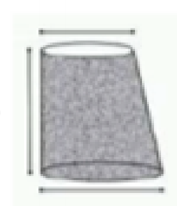
Does pump show signs of heavy corrosion? ☐ Yes ☐ No If yes, give details: ________________

Describe condition of fuel tank and/or fuel lines ____________________________________

Describe security measures at the lift station._ ____________________________________

Manhole #______ of ________ Identify this manhole: ____________________(GPS)

Label the dimensions of the manhole on diagram at the right. FT / M



Does the area around the manhole exhibit signs of distress? ☐ Yes ☐ No

If yes, give details: ____

Is manhole missing or severely damaged? ☐ Yes ☐ No

Are walls out of plumb (1 inch horizontal to 24 inches vertical?) ☐ Yes ☐ No

Do walls show signs of shifting or movement? ☐ Yes ☐ No

If yes, give details: ____

Pipe Information (for pipes entering or exiting the manhole):

Enter: Size in diameter: _______ IN / MM Material Type (if able to determine): ___________

Exit Size in diameter: _______ IN / MM Material Type (if able to determine): ___________

Are pipes damaged: ☐ Yes ☐ No If so, explain: ______________________________

Are pipes leaking steadily: ☐ Yes ☐ No If so, explain: ______________________________

Do pipes have heavy corrosion: ☐ Yes ☐ No If so, explain: ______________________________

Direction of flow to/from the manhole? ☐ To (Direction: __________) ☐ From (Direction: __________)

Photograph Estimate Map Detail Measure Sketch

Partial infrastructure survey form (USACE 2016)