Developing a Site Assessment Methodology Using ArcPad and GPS Technology

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Abstract

Environmental site assessments offer prospective land purchasers a relatively inexpensive and expeditious means of acquiring valuable information regarding the potential presence of site contamination. GIS and GPS technology provide field scientists with powerful tools to assist site reconnaissance and data collection. This paper presents a methodology that effectively streamlines and automates portions of the assessment process. Developing a customized GIS environment allows for in-house preliminary assessments, which generate results that are easily transferred to handheld data collectors equipped with customized mobile GIS software and GPS receivers. This facilitates further field data collection with high levels of quality and accuracy.

1.0 Introduction

Environmental site assessments have become a valuable instrument, allowing both public and private agencies, as well as any potential land purchaser, the ability to determine the natural and physical characteristics of a site to help guard against unforeseen contaminants that may have significant remediation costs. Phase I Environmental Site Assessments (ESAs) in particular have offered potential purchasers a relatively inexpensive and expeditious way to garner this information before they decide to proceed to more detailed steps of assessment or purchase the site in question. As governments have increasingly required these assessments in compliance with federal environmental legislation as part of the innocent landowner defense (i.e., Comprehensive Environmental Response, Compensation, and Liability Act of 1980), many firms and agencies have begun to employ personnel whose responsibilities include performing these assessments. Phase I ESAs can be performed in part utilizing Geographic Information Systems (GIS) software to increase the utility of a Phase I ESA and further decrease the amount of time involved to complete one.

1.1 Overview of Methodology

The objective of this project is to develop a state-wide methodology that effectively automates a portion of the site assessment process within a GIS framework, allowing inexperienced or novice GIS users the ability to quickly determine the characteristics of a site before going into the field. The second intent of the automation process is to simultaneously provide a detailed map of the site that would allow the field technician to expeditiously and easily locate the site while in the field utilizing Global Positioning Systems (GPS) receivers capable of sub-meter accuracy. The final component of this project will utilize similar mobile GIS software on mobile PC devices to capture additional site information while in the field using customized forms within the GIS environment.

The proposed methodology will be evaluated by analyzing actual labor costs for the one year period following full implementation of the new technology and associated protocol. The current methodology will be similarly evaluated by analyzing labor costs for the full year prior to full implementation. This evaluation will allow for a comparison of both methods to determine the overall effectiveness of the proposed method at reducing labor costs. It should be noted that labor costs will be normalized by the acreage assessed at each individual job site for each year that is analyzed.

2.0 Background

Phase I ESAs provide prospective land purchasers with a relatively inexpensive, expeditious and non-intrusive means of determining the potential presence of contaminants at a particular site. In addition to providing this valuable information, a Phase I ESA satisfies one of the requirements for the innocent landowner defense to CERCLA liability. This act mandates that for a landowner to qualify for liability exemption, they must ensure an "all appropriate inquiry into the previous ownership and uses of the property consistent with good commercial or customary practice" as detailed in 42 USC § 9601(35)(B).

2.1 Standards for the Performance of Phase I Environmental Site Assessments

To ensure the uniform performance of Phase I ESAs, the American Society for Testing and Materials (ASTM) established standard site assessment practices to fulfill the due diligence responsibilities of participants in real estate transactions. This manual, designated as E 1527-00, details the steps necessary to perform an adequate ESA that satisfies portions of CERCLA liability exemption requirements. ASTM describes that the purpose of a Phase I ESA "is to identify, to the extent feasible pursuant to the process prescribed herein, recognized environmental conditions in connection with the property" (ASTM 2000: p. 1). ASTM requires that a Phase I ESA contain four main elements: a records review, site reconnaissance, interviews and a report (ASTM 2000).

2.2 Overview of Geographic Information Systems

Most GIS researchers and professionals have adopted a definition of GIS established by the National Science Foundation as "a computerized data base management system for capture, storage, retrieval, analysis, and display of spatial (locationally defined) data" (Huxhold 1991: p. 29). The developer and manufacturer of the software used in this project, Environmental Systems Research Institute (ESRI), modified this definition and described it as "an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information" (ESRI 1990: p. 1-2).

D.J. Maguire, a leading GIS researcher, suggests that GIS evolved from a relationship resulting from the interconnectedness of four main computer and information systems: computer cartography, remote sensing, database management, and computer-aided design. (Maguire 1991). The significance of this notion lies in the presupposition that GIS is not simply a map-making tool; rather, it is a sophisticated computer information system that provides database information with a locational component, allowing for spatial data analysis the likes of which would be extremely difficult to accomplish manually using paper-based methods.

This project highlights some of the key advantages of a relatively new addition to ESRI's line of software packages: mobile GIS. ESRI's mobile GIS software package, ArcPad, integrates GIS technology with increasingly popular mobile computing and GPS technologies. This software allows mobile device users the benefits of both mobile mapping and traditional GIS tools. ESRI purports that "mobile GIS comprises the integration of four technologies: GIS, lightweight hardware, the GPS and wireless communication" (ESRI 2002: p. 3). For the purposes of this project, wireless communications will not be used and, therefore, not addressed in the context of this study. However, the tremendous improvement in the quality and accuracy of data collection in the field will be addressed and will also factor into the overall success of the study.

2.3 Overview of the Global Positioning System (GPS)

The GPS was developed by the U.S. Department of Defense in the 1970's as a means of assisting the military in strategical and tactical operations (El-Rabbany 2002). It is generally described as a "satellite-based navigation system" that is now a dual-use system for both military and civilian purposes (El-Rabbany 2002: p. 1). It provides users with real-time positioning information "anywhere in the world under any weather conditions" (El-Rabbany 2002: p. 1). It can provide information to an unlimited number of users and for this reason, it is often categorized as a "one-way, passive-use system" (El-Rabbany 2002: p. 1).

The GPS, at a minimum, consists of a constellation of 24 operational satellites (El-Rabbany 2002). While a constellation of 24 satellites is necessary to give worldwide positioning coverage, there is generally more than this minimum number available at any given time. "To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes. With this constellation geometry, four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of 10° is considered" (El-Rabbany 2002: p. 1-2).

In order for the GPS to function properly, three components must be involved: the space segment, the control segment, and the user segment (El-Rabbany 2002). The space segment is comprised of the constellation of satellites described earlier. Each of these satellites transmit a signal navigation message that contains, "along with other information, the coordinates (the location) of the satellites as a function of time" (El-

Rabbany 2002: p. 3). The control segment consists of a network infrastructure of tracking stations across the globe. These tracking stations monitor the constellation of GPS satellites to ensure the integrity of the system, among other things (El-Rabbany 2002). The final element is the user segment, which includes both categories of GPS users- civilian and military. A user equipped with a GPS receiver and antennae is capable of receiving signals from GPS satellites which may then be used to determine position at any location on earth, so long as a minimum of three satellites signals are received (El-Rabbany 2002).

2.4 The Impetus for Using GIS & GPS Technology in the Performance of a Phase I ESA

One of the priorities for this project is to determine whether these technologies can be incorporated into the performance of a Phase I ESA to effect a greater degree of efficiency in the Phase I process. GIS technology has facilitated spatial data analysis in a vast number of applications. Here its application is proposed as a method to reduce the amount of time necessary for firms to perform Phase I ESA, thereby reducing the associated costs as well. This has the potential to not just benefit firms providing these services, but other stakeholders.

The integration of GPS technology into the method also compounds the potential for successful project results. The advent of the combination of mobile GIS and GPS capabilities has allowed for data collection that is high in spatial quality as well as geographically accurate. Oftentimes, firms providing Phase I ESA services are only given a legal description when tasked with a project. The site in question may be in a rural area, leaving environmental professionals in a quandary when determining where the physical location of the site is, as well as property boundaries. GPS technology, coupled with aerial imagery in a GIS format, has offered environmental professionals a high degree of geographic certainty when determining site location and performing site reconnaissance. Not only are site visits enhanced, but the automation of a preliminary site analysis within a GIS environment further reduces the time necessary researching the natural and physical characteristics of a site and notifies the environmental professional of natural or physical aspects that should require further investigation during site reconnaissance.

3.0 Methods

3.1 The Current Method of Performing a Phase I ESA

To facilitate a proper understanding of an internal process for performing a Phase I ESA and provide a qualitative basis for comparison with the proposed new methodology incorporating GIS and GPS technology, attention will be first directed toward the current protocol for conducting a Phase I ESA. Since the fundamental process of performing a Phase I ESA was addressed in the Background section of this paper and does not differ between either method, this section will attempt to highlight only the technological processes of the current method, or apparent lack thereof. Generally, a firm that is hired to perform a Phase I ESA is provided with a modicum of reference information regarding the site that is to be investigated. At a minimum, this usually includes the county the site is located in, as well as the corresponding Section, Township and Range so that the site may be more accurately located using the Public Land Survey System (PLSS) for Florida. Also, the firm is often provided a legal description of the property boundaries of the site to be assessed.

While the county information is useful as a starting reference point, it is the Section, Township and Range location that allows the investigator to determine the site's location within a square mile area (the area of one PLSS section block), given the site's boundaries do not cross section lines or otherwise include more than one section (Figure 1).

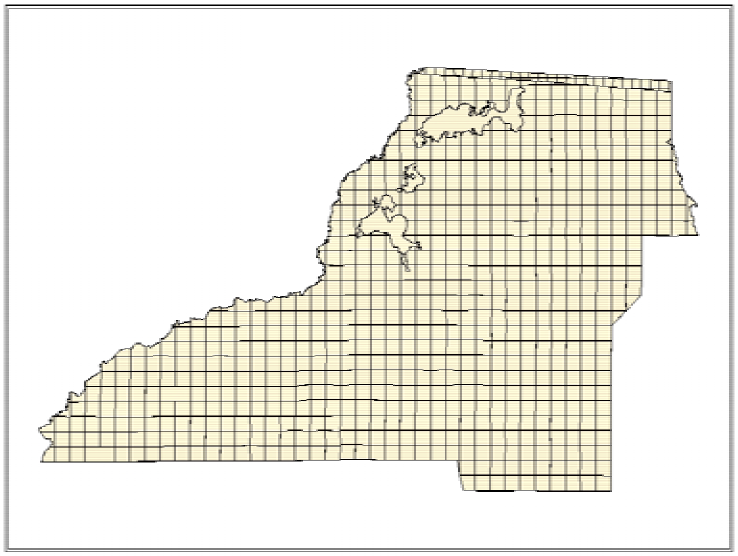

Figure 1. Public Land Survey System for Leon County, Florida

The majority of sites do fall within a single PLSS section, and this is where some of the difficulties with the former method begin. A significant number of Phase I ESAs in Florida are performed on sites that are primarily rural in nature and, most importantly to the investigator, location. For instance, the Florida Department of Environmental Protection (FDEP) will hire a firm to perform a Phase I ESA on a site that is being considered as an acquisition to state conservation holdings. Most of the properties that FDEP desires for conservation purposes are sought because of their natural character or environmental sensitivity. These sites are often located in more rural areas. These rural locales often leave the investigator with no physical address for the site and can make locating the site, with a high degree of certainty, a difficult endeavor. Unfortunately, there is little to aid the investigator in locating the site while in the field. Most sites do not have fence lines demarcating their boundaries and fewer still have signs indicating their whereabouts. This lack of locators can often leave the investigator in a predicament as to whether or not the correct site is being investigated.

It is at this stage where mistakes that occur in the field can lead to costly repercussions later in the site assessment process. A firm has to pay for the investigator to travel to conduct a site visit. There the investigator accumulates further labor-hours performing the site reconnaissance duties. The problem arises when the investigator unknowingly conducts the site visit at the wrong location. This usually results in the investigator not being aware of the mistake until the site visit is over and they have returned back to the home office. Now they are forced to return to the area and locate the correct site location. This costs the firm additional money in the form of increased labor and time to complete an assessment. It also introduces liability issues as the investigator could be potentially trespassing on private property while conducting the assessment at the wrong site.

While there is the above-mentioned difficulty of assessing the wrong site, there are also other duties required using the former method that involve time and money, ultimately requiring the firm to pay more to conduct a site assessment. First, there is the cost of locating historic aerial imagery of the site, assuming the right site has been located. Usually this work is contracted out to other companies that specialize in this type of service. Also, before an investigator can even begin the assessment, they must first go the property appraiser's office of the county the site is located in and retrieve a PLSS map of the county to identify the site so that a specific location can be determined. As mentioned before, this merely locates the square mile section the site is located in and does not aid in specifically determining the site boundaries.

In some counties, just obtaining the PLSS map can be a costly process that adds a significant amount of time to the overall assessment. For instance, in Monroe County the county seat (and the property appraiser's office) is located in Key West. For an investigator to locate a site in Key Largo or Islamorada, they must first travel all the way south to Key West to obtain the needed map, and then travel back north to the site. This whole process of just retrieving a map can add another day to the site visit. It will be revealed in later sections that these are unnecessary expenses when the process is enhanced by incorporating GIS and GPS technology.

3.2 The Proposed Method of Performing a Phase I ESA

The method proposed here initiates with the acquisition of reference information regarding the site that is to be investigated. While a client may provide more information about a site, the firm will generally receive a section location based on the PLSS system. It is useful to reiterate at this juncture that this method is intended for use in the state of Florida. This is due to the fact that the scope of the data used in this project is confined to the geographical extent of Florida, limiting its application on a broader scale. That being said, as well as Section, Township and Range information specifying a site's location, a legal description of the property is often provided. The benefit of a supplied legal description to the proposed method will be discussed shortly.

An overarching objective of this project is to not only offer a method that increases the efficiency of the performance of a Phase I ESA, but offers the technology in a manner that will allow users will little or know GIS experience the capability to easily use the required software. GIS software is used to perform a preliminary remote assessment of the site and its surrounding environment. More specifically, the GIS software used at this stage of the procedure is ArcView GIS 3.2a, developed and manufactured by ESRI. The framework of ArcView GIS 3.2a was used as a foundation for an internal site assessment application. This application was developed using AVENUE, the native programming language for ArcView GIS.

Once the preliminary site assessment has been performed, the user may wish to print this map for the report document or to take into the field for further reference information during site reconnaissance. To aid the user in packaging the map into a more presentable format, the final component of the application generates a layout of the site assessment analysis. The final step in this process before a site visit can occur is the preparation of the mobile PC device for data collection and navigation purposes. To accomplish this component of the project, mobile devices using Windows CE platforms are employed as the field data collection units. In order to use all the GIS data prepared prior to this point, a GIS software package must be used on the mobile device. For this, ArcPad 6.0.1, also developed by ESRI was chosen as the GIS software. This software was specifically designed for use on mobile devices using the Windows CE operating system.

All the vector and raster data is transferred to the mobile device and a new ArcPad project is created containing all these data layers. To aid the investigator in the assessment, aerial imagery is scanned and orthorectified so that it may be used as a base map on the mobile device to allow for visual identification of features from a remote perspective. Now the investigator has quick access to all relevant data while in the field. In order to perform accurate field data collection, sub-meter GPS receivers are used to locate the investigators position on the earth. This allows the investigator to collect geographically accurate data in the field, and ensures, with a high-degree of certainty, that the correct site is being investigated. This feature is obviously helpful in the more rural locations of Florida. The GPS also allows the investigator to navigate to the site more efficiently, reducing the time it takes to initially locate the site when coupled with the GIS software loaded with reference data such as road networks and aerial imagery.

To facilitate data collection in the field and reduce errors in data entry, custom forms were created for field data input. These forms were created using the ArcPad Application Builder and Visual Basic programming. A custom toolbar was created, also using the Application Builder, which contains a button that launches the Visual Basic form script.

The logic behind this program is relatively linear in nature. When the user wants to collect a data point while in the field, the process is initiated when the button is selected and the data frame window is tapped. This launches the script that first determines if communications with the GPS receiver has been established by ArcPad, if it has not then communication with the GPS object is activated and the script continues. Once the receiver has been activated, the script continues by locating a point at the current GPS location. This opens the custom form designed earlier that is linked to a point shapefile in the ArcPad project (Figure 2). There are entries for each field in the shapefiles attribute table in the form design. Data entry error is reduced by providing dropdown boxes that contain lists for likely field attributes.

Figure 2. Custom Form for Mobile GIS Data Collection

In order to ensure that data collection is accurate in the field, other items retrieved from communications with the GPS receiver are also incorporated into the attributes for a particular data point. More specifically, GPS position quality measurements such as Position Dilution of Precision (PDOP) and Estimated Position Error (EPE) levels are retrieved when a data point is located and automatically input into the point attribute table. The user doesn't do anything to record these measurements other than instruct the software to locate a data point at the GPS position by tapping the data frame window. When the investigator returns from the site visit, the data can be transferred back to a desktop PC and the quality of each data point can be further verified by analyzing these position quality measurements.

This whole process culminates at the conclusion of the Phase I ESA process when the investigator assimilates all gathered information into a report, which is then delivered to the client. The manner in which the data is gathered allows the investigator to quickly prepare report tables and figures using GIS software and pre-defined layout templates. The next section will further discuss the quantitative benefits associated with the employment of this method.

4.0 Results

4.1 Fiscal Analysis and Comparison of Evaluated Time Periods

The table below illustrates the comparison of labor costs between the evaluated time periods.

CASE STUDY	LABOR COSTS	TOTAL ACREAGE	LABOR COST PER ACRE
CURRENT METHOD	$60,032.07	12,804.64	$4.69
PROPOSED METHOD	$78,358.20	58,764.17	$1.33

COST REDUCTION			**$3.36**

Table 1. Comparison of Costs for Each Evaluated Time Period

For the comparison of methodologies, a year-long evaluation of each method was performed to determine which method offered the better dollar value. The current method was evaluated using a period of time ranging from May 1, 2001 until April 30, 2002. The total acreage assessed during this period was 12,804.64 acres, with total labor costs required for the performance of Phase I ESAs calculated at $60,032.07. Based on these results, the labor cost per acre during this period was $4.69. The full implementation date for the proposed method was May 1, 2002, so the evaluation period for this method was from this date until April 30, 2003. The number of assessments increased for the year, which resulted in a direct increase in labor costs to $78,358.20, during which a total area of 58,764.17 acres were assessed. For this evaluation period, the labor cost per acre was $1.33. For the total observation period, the difference in labor cost per acre resulted in a savings of $3.36 per acre when the transition was made to the proposed method.

5.0 Discussion and Conclusion

Based on the analysis of the current and proposed methods, the study and proposed method can be considered a definite success. The overarching goal of this project and the proposed method was to effectively reduce the time required to perform a Phase I Environmental Site Assessment from start to finish, while delivering a valuable product to a client that fulfilled its expected function. As expected, the project was successful in effectively demonstrating that GIS and GPS technology could be incorporated into Phase I ESAs to facilitate beneficial results in both the short and long-term.

5.1 Quantitative Success of Proposed Method

When the test firm made the decision to employ the proposed method on a long-term basis, a cost savings of $3.36 per acre was realized over the course of a year. Given the difference in cost per acre between the current and proposed method over the evaluated time period, this firm experienced a decrease in labor costs of nearly 72 per cent when making the transition to the proposed method. While a decrease in labor costs to this degree may not be typical, it is indicative of the benefits one could expect from utilizing the technology in a similar manner.

5.2 Strengths and Weaknesses of Proposed Method

Perhaps the greatest strength of the proposed model is that the longer it is employed the more effective and valuable it becomes. With each new site that is assessed, historic aerial imagery is acquired and georeferenced for present and future use. This method allows for the incremental assembly of an historic aerial imagery database for the entire state. Once an image is processed, it can be used repeatedly for other sites in the same vicinity, should they arise. This is a one-time investment in labor costs that will pay off perpetually.

The same can be said for personnel using the equipment. There is a learning curve that must be addressed as personnel become familiar with the new equipment and technology, which may result in an upfront increase in labor costs. As comfort levels rise, however, the time required to perform these assessments using the proposed method will continue to decrease while other benefits may still be enjoyed.

Other observed strengths of the proposed method using GIS and GPS technology during the evaluation period include:

- Reduction of time spent in field.
- Reduction of time spent performing manual data input.
- Reduction of errors in field data entry.
- Reduction of time required to quality control the data.
- Field data may be uploaded directly to a PC. This reduces the time necessary to transcribe handwritten field notes and also reduces error in transcription.
- Reduction of time spent to create final reports.
- Equipment and technology allow for the rapid assessment of site data.
- GPS and GIS technology assure that correct site is assessed the first time. Uncertainty of location in the field is eliminated.
- Site investigators no longer have to drive to the property appraiser's department of county a site is located within to locate site on plat maps. This further reduces time spent in the field.
- Accuracy and quality of data and reports are increased.
- Custom forms may include validation that may allow or disallow data entry.
- Custom forms can provide chronological history of data collection utilizing automated date and time stamps.
- Handheld software and customizations are designed to perform on a variety of hardware platforms providing flexibility with little to no modification of software code.
- GIS may be further utilized in the field to analyze data and allow users to locate prior sampling events.
- Desktop GIS products provide query functions that allow that user to select a range of coordinates, sampling dates, sampling types, etc...

While there were a number of strengths to the proposed method, there were also weaknesses that became evident throughout the course of the project. The primary weakness is the initial investment of time and resources required to train personnel in how to use the equipment and technology. This is true with most every new procedure or method. In order to reap the benefits that technology may offer, you first have to invest the time necessary to learn how to effectively use it. While efforts were made to make this method easily digestible to those with a modicum of GIS knowledge, there is still a learning curve that must be addressed before the technology may be used to its utmost potential. The other identified weakness centered around a user's presuppositions on what the technology is designed to offer and how it operates. Particularly, GPS technology has limited application potential that depends on the environmental conditions of the site being assessed. The common misconception encountered among new users is that a GPS receiver will work in any environment, under any condition. As familiarity increases and the user becomes more comfortable with the product, the limitations of the hardware become more evident. This allows the user to screen a site for satisfactory conditions before the decision is made to employ the technology on a particular site.

6.0 Acknowledgements

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