METHODOLOGY FOR A GIS-BASED DAMAGE ASSESSMENT FOR RESEARCHERS FOLLOWING LARGE SCALE DISASTERS

by

PATRICK SHANE CRAWFORD

ANDREW J. GRAETTINGER, COMMITTEE CHAIR

JIM RICHARDSON
RANDY K. SMITH

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil, Construction, and Environmental Engineering
in the Graduate School of
The University of Alabama

TUSCALOOSA, ALABAMA

2014

ABSTRACT

The 1990s were designated the International Decade for Natural Disaster Reduction by the United Nations General Assembly. This push for decrease of loss of life, property destruction, and social and economic disruption brought advancements in disaster management, including damage assessment. Damage assessment in the wake of natural and manmade disasters is a useful tool for government agencies, insurance companies, and researchers. As technologies evolve damage assessment processes constantly evolve as well. Alongside the advances in Geographic Information Systems (GIS), remote sensing, and Global Positioning System (GPS) technology, as well as the growing awareness of the needs of a standard operating procedure for GIS-based damage assessment and a need to make the damage assessment process as quick and accurate as possible, damage assessment procedures are becoming easier to execute and the results are becoming more accurate and robust. With these technological breakthroughs, multi-disciplinary damage assessment reconnaissance teams have become more efficient in their assessment methods through better organization and more robust through addition of new datasets. Damage assessment personnel are aided by software tools that offer high-level analysis and increasingly rapid damage assessment methods.

GIS software has advanced the damage assessment methods of these teams by combining remotely sensed aerial imagery, GPS, and other technologies to expand the uses of the data. GIS allows researchers to use aerial imagery to show field collected data in the geographic location

that it was collected so that information can be revisited, measurements can be taken, and data can be disseminated to other researchers and the public. The GIS-based data available to the reconnaissance team includes photographs of damage, worksheets, calculations, voice messages collected while studying the affected area, and many other datasets which are based on the type of disaster and the research field. Along with visually mapping the data, geometric calculations can be conducted on the data to give the viewer more information about the damage. In Chapter 4, a tornado damage contour for Moore, Oklahoma following the May 20, 2013 tornado is shown. This damage contour was created in GIS based on the Enhanced Fujita (EF) damage scale, and gives the viewer an easily understood picture of the extent and distribution of the tornado.

This thesis aims to describe a foundational groundwork for activities that are performed in the GIS-based damage assessment procedure and provide uses for the damage assessment as well as research being conducted on how to use the data collected from these assessments. This will allow researchers to conduct a highly adaptable, rapid GIS-based damage assessment of their own.

DEDICATION

This thesis is dedicated to everyone who has helped me fulfill my accomplishments, including family, friends, coworkers, and professors who assisted in my research and the following thesis.

ACKNOWLEDGMENTS

This undertaking could not have been accomplished without the many people who helped me with this work, as well as the people who helped me reach this point in my career. I would like to thank all of my family, friends, colleagues, and coworkers for the help and encouragement I have received as I have been working to finish this thesis.

I am grateful to Dr. Andrew Graettinger for guiding my graduate research which includes the work I have done for this document. I would also like to thank Dr. Thang Dao, Dr. Jim Richardson, and Dr. Randy Smith for agreeing to review this thesis and provide feedback. I could not have completed this research without the help of my friends and coworkers Sufal Biswas, Ali Geranmayeh, David Burkhalter, Wil Stone, Stephanie Farrell, Michael Sherer, Tyler Daniel, Emma Whitaker, Kristi Bardosi, Joe Hollingsworth, Ashley Purkey, Jenna Simandl, Jake Levins, and Ashton Greer for helping in so many ways and providing entertainment while working in the GIS lab.

Finally I would like to thank the University of Alabama and the State of Alabama for providing me with the opportunity to complete this work. I hope this work will shed light on a topic of interest to researchers, create future research opportunities, and illustrate the need for postgraduate research as well as public education.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the wake of large scale disasters, communities and researchers must document damage in order to respond and recover from the event, learn from the disaster, and plan for future disasters. The way that communities respond to these natural and manmade disasters is by conducting damage assessments. These damage assessments are conducted by governmental and insurance agencies in order to understand the loss of life, loss of infrastructure, and economic loss registered by the disaster. Researchers study the effects of the disaster on the natural and built environment. Governmental and insurance agencies have standardized methods for damage assessment, but for researchers the methods are variable. As GIS technology use has expanded in recent decades, damage assessments have changed to incorporate the technology which has greatly improved the accuracy and speed of damage assessment procedures. This thesis will provide a standardized methodology for GIS-based damage assessment for researchers.

The GIS-based damage assessment is a powerful tool for understanding damage because it provides long-term data storage. GIS allows the user to view remotely sensed aerial imagery as well as data collected in the field. Fusing the collected data with GPS track information allows researchers to create a layer of geolocated data points which can be placed onto the basemaps. This provides a way for the user to view damage from aerial and ground-based views simultaneously. Furthermore, GIS tools allow attribute data to be linked to the collected data points. This allows for large amounts of research data to be read while visually inspecting the area in the reports. Many datasets can be added to the map to allow the viewer to further understand the damage. Some of these datasets include damage boundary lines created in GIS to show the extents of the damage, low angle oblique photography captured by low-flying aircraft, crowd-sourced photographs taken immediately following damage and uploaded to social media websites, parcel data for the damaged area, and much more. GIS tools allow for a damage contour to be created which interpolates between inspection photographs to show a raster layer of interpolated damage information at every point in the affected area.

On top of spatially mapping collected information on top of aerial imagery, GIS allows researchers to store information layers in a web portal. This web portal allows researchers as well as the general public to view the results of a damage assessment in an environment where the user does not need access to GIS software. This method of storing and viewing data could allow damage assessment inventories to be created, and areas where multiple disasters occur could view the changes from each disaster. This would be a powerful way to understand the reactions of the communities to the disasters and offer a way to view the changes in the built environment for each disaster occurrence.

This thesis will provide a four-phase methodology for this GIS-based damage assessment which researchers can use as a standard model for future damage assessment. The phases are: preparation, predeployment, in-field data collection, and postprocessing. The phases are chronological and begin before the disaster strikes. The methodology contains procedures to be done in each phase of the damage assessment and provides data collection methodologies which fuse remote sensing inspection photography and GPS track information to geolocate the photographs onto aerial imagery basemaps of the damaged area. The methodology also includes the creation of the web portal where researchers can store the results of the damage assessment. The overall goal of this thesis is to provide a standardized practice for researchers to conduct and store damage assessment information.

1.2 Thesis Organization

This thesis is organized into 6 chapters. Chapter 2, Literature Review and Background, presents a brief history of the evolution of damage assessment methods as well as future implications of GIS-based damage assessment. Chapter 3, Methodology, describes in detail the four-phase damage assessment methodology. Chapter 4, Case Study, documents a team of researchers who used this methodology to conduct a damage assessment following the May 20th, 2013 EF5 tornado in Moore, Oklahoma and presents the results of the damage assessment. Chapter 5, Results, assesses the application of the damage assessment to the case study in Moore. Chapter 6, Conclusions and Future Work, provides closing remarks about the research, states the strengths and weaknesses of the damage assessment methodology, and provides suggestions for future work to improve the methodology in the future. Appendix A provides a step by step methodology for data collection procedures and Appendix B provides a step by step methodology for the creation of a data contour.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND

Damage assessment is a mechanism used to determine the impact and magnitude of damage and resulting needs of individuals, businesses, the public sector, and the community as a whole in the wake of large scale disasters. These assessments are performed in the wake of natural and manmade disasters including tornadoes (van de Lindt et al, 2012), hurricanes (Womble et al, 2008; van de Lindt et al, 2007), earthquakes (Eguchi et al, 2010), floods (Su et al, 2005), oil spills and other hazardous releases (Kara & Verter, 2001), fires (Moodie, 1992), volcanoes (Pareschi et al, 2000), terrorist attacks and more. They are performed to understand damage patterns and to plan for future recovery, aid researchers who study these disasters, and in some cases determine who is at fault for the disaster. Typical damage assessment procedures consist of dispatching reconnaissance teams to an affected area to visually assess and collect field reports and photographs of damage as well as interview victims to understand public response to hazard warnings, property damage information, and recovery behavior. Organizations that perform these tasks include local, state, and federal government agencies such as the Federal Emergency Management Agency (FEMA), insurance companies, and researchers from private companies or public institutions.

2.1 Types of Damage Assessment

Damage assessments are usually gathered by one of two groups. The first includes government agencies or insurance companies who use the damage assessment to understand the extent and distribution of the damage and how the population was affected. The Preliminary

Damage Assessment (PDA) conducted by FEMA after natural disasters is used to gather supporting information for a governor's request for a presidential disaster declaration and is used to estimate damage levels to homes, businesses and infrastructure, and the dollar values of losses. The disaster declaration grants resources such as disaster unemployment assistance, disaster legal services, grants from FEMA, crisis counseling, and loans from the small business administration. Insurance companies use damage assessments to complete adjustments as well as to verify insurance claims submitted by those enrolled in national insurance programs (Dymon, 1999). The second group is composed of researchers who study the effects of the damage on the natural or built environment. This research is widely variable depending on the field of the research. Researchers have performed damage assessments in order to study the effects of oil spills on coastline natural resources after hurricanes (Sauer & Boehm, 1991), measure carbon emissions from forest fires (Isaev et al, 2002), as well as assess performance of construction materials to enhance building codes, and improve response protocols in areas damaged by tornadoes (Prevatt et al, 2011).

2.2 Damage Assessment Methods

Traditionally reconnaissance teams walk the damaged areas collecting information including damage photography and written reports and synthesize data sets to get a picture of the overall damage done by the disaster. These teams frequently cannot collect all available data, so "windshield estimate" sampling surveys are commonly performed on a limited number of buildings and extrapolated these observations to account for large areas (Downton and Pielke, 2005). These sampling surveys negatively affect the accuracy of the damage assessment. GIS enhances the capabilities of the damage assessment by incorporating remotely sensed aerial imagery basemaps captured before and after the event in GIS software overlaid with the field reports and photography collected from the reconnaissance teams, existing datasets of the area such as parcel databases, above and below ground utility locations, modeling datasets such as Light Detection and Ranging (LiDAR) laserscanned point clounds, DEM models offering drainage information, and any other available data. By offering a centralized database to store collected information as well as using aerial imagery to plan and locate blockages in transportation routes, GIS capabilities have been proven to shorten the damage assessment process, sometimes by a factor of two or three (Eguchi et al, 2010).

To perform a robust GIS-based damage assessment certain datasets are extremely beneficial. Pre-disaster basemaps containing aerial imagery, street maps, and geospatial labels are widely available and free via GIS inventories. Post-disaster aerial images are produced and distributed freely to aid in disaster recovery by FEMA as well as Environmental Systems Research Institute (ESRI), a main producer and distributor of GIS products and services. These basemaps offer views of macro-scale damage patterns and allow users to compare the pre- and post-event images in order to quickly gain a general knowledge of the damaged area. Remote sensing photographs are used to temporally document street-level damage in the field. Using GPS technology, these photographs can be geolocated onto the basemap in GIS. This augments the understanding of damage by offering an aerial view of damage through the basemap as well as a temporal, street-level view of the damage through geolocated photographs. Figure 2.1a shows a pre-event aerial image basemap of Tuscaloosa, Alabama before the April 27, 2011 EF4 tornado, and Figure 2.1b shows the aerial image basemap after the tornado with a damage boundary line added to show the extent of damage. Layers can be added to these basemaps that

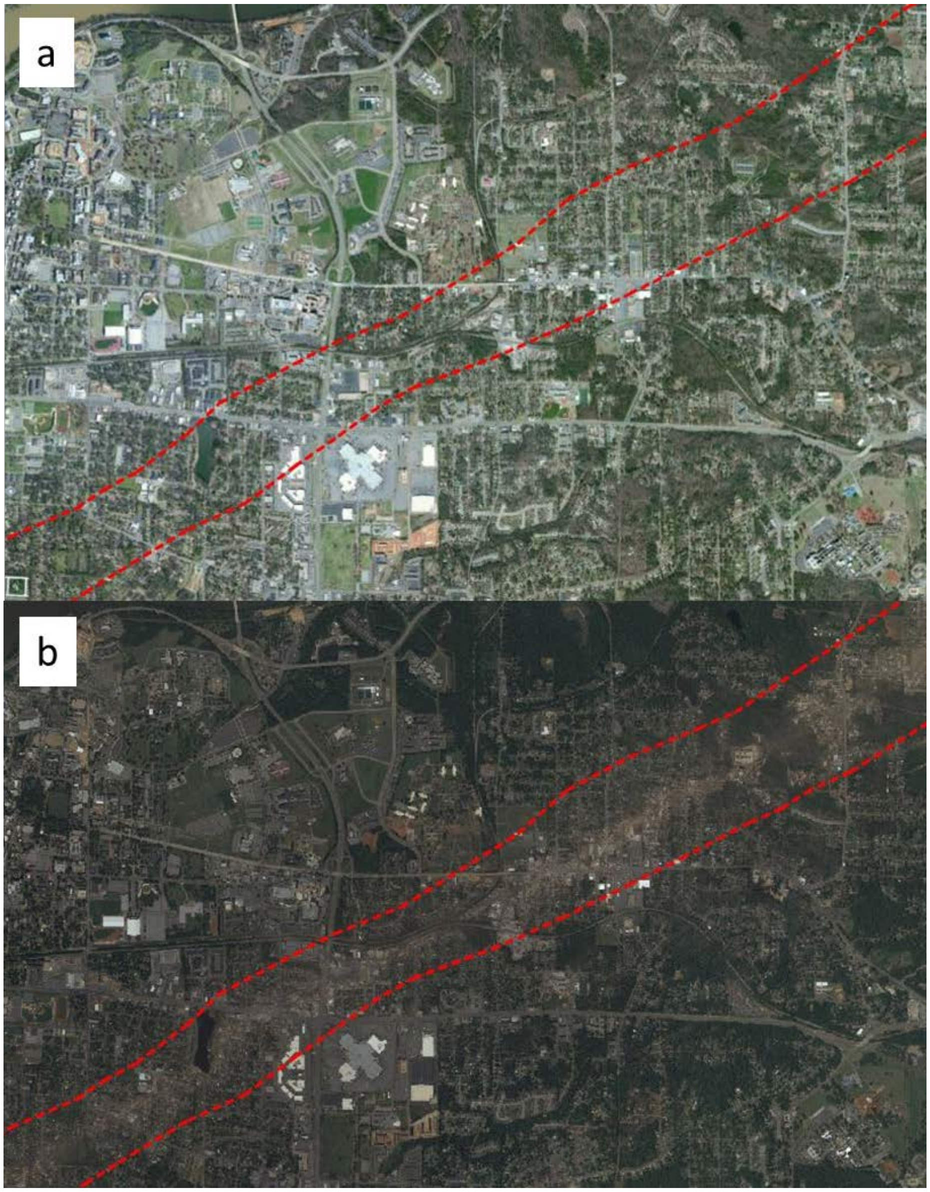


Figure 2.1. Aerial images of Tuscaloosa, Alabama (a) before the May 20, 2013 tornado and (b) after the tornado with the damage boundary denoted by dashed red lines.

provide more detail about the area such as markers for critical infrastructure or utilities in the damaged area, photographs and damage reports that give a street-level temporal knowledge of the damage, locations of relief sources, and models of the damaged areas. Figure 2.2 shows the post-event aerial image of Tuscaloosa along with nodes representing field collected photographs which are color-coded based on severity of damage corresponding to the Enhanced Fujita (EF) damage scale. Multiple layers of collected information can be created and viewed in the GIS map, and attribute tables can be created to store large amounts of information which users can query. As municipalities begin to integrate GIS into their daily workflow, more datasets will become available to give pre-event information of the damaged areas. GIS layers containing critical infrastructure such as schools, hospitals, above and below ground utilities, treatment facilities, etc. can be added to the map to quickly assess and react to the damage in order to keep these facilities online and working for the public.

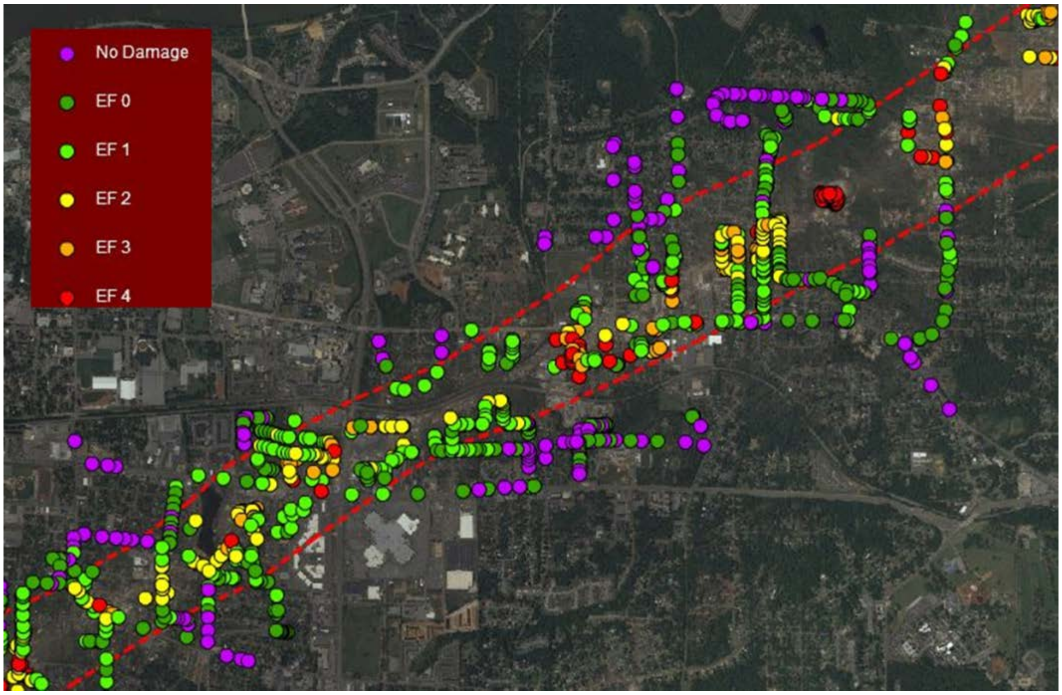


Figure 2.2. Tuscaloosa, Alabama damage assessment with geographically located inspection points color-coded by EF-scale damage (Graettinger, 2012).

2.3 Future Implications of GIS-based Damage Assessment

As existing technology improves and new technology emerges, GIS-based damage assessment techniques will continue to improve. The technological advances made by remote sensing technology and its applications have sped the work of reconnaissance teams in affected areas by allowing personnel to work in multiple locations and upload the data to a centralized database as well as allow the teams to target areas of damage and quickly deliver generalized initial windshield damage assessments while also working to complete more accurate "house-to-house" assessments of building damage (Eguchi et al, 2010). LiDAR technology has been used to create high-resolution three-dimensional models of earthquake damage and structural deformation of buildings after earthquakes (Kayen et al, 2006) as well as calculate building surface area lost in tornadoes (Geranmayeh Kashani et al, 2014). Crowdsourcing is an information technology tool which mines social media network data to gain temporal information and photographs from the damaged areas by people who experienced the disaster (Yamazaki et al, 2001).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter provides a methodology that can be employed to conduct a GIS-based disaster damage assessment through fusing remote sensing and GPS technology. The method presented here explains the use and synthesis of collected data in GIS as well as the creation of a user-friendly web portal used to view the data. The methodology contains four chronological phases: preparation, predeployment, in-field data collection, and post-processing. The preparation phase starts well before a disaster strikes. This phase consists of obtaining necessary equipment and periodically checking the equipment to be sure it is ready to be utilized. The preparation phase also covers training of the proposed methodology. The predeployment phase begins as soon as a disaster occurs and includes defining the research topic, coordinating the reconnaissance team, acquiring funding for travel, arranging lodging, and defining the area that will be inspected by the team. The predeployment phase also includes collecting GIS basemaps of the damaged area before and after the disaster, and creating a framework for a web portal which can be copied and manipulated for multiple damage assessments. The in-field data collection phase starts the day that the team enters the damaged area. Reconnaissance team duties include walking the affected area, photographing items of interest, and collecting information on these items. The post-processing phase begins when the team returns home. The duties of this phase include entering data into GIS, using the GIS to analyze data, and creating a web portal so that the reconnaissance team as well as the public can easily view the results of the damage assessment. The success of the damage assessment depends on the coordination of the team and activities leading up to field inspection, the technology and methods used in the data collection, and the way that the information is synthesized and displayed. Mistakes in any area can be mitigated, but all of these activities are important for a robust damage assessment.

3.2 Preparation Phase

Duties of the preparation phase include obtaining and periodically checking equipment necessary to completing the damage assessment and creating a placeholder web portal that can be copied in predeployment phase when disasters occur. Table 3.1 includes an equipment checklist of items needed for the damage assessment methodology. Much of the equipment which is non-essential to data collection activities can be obtained in the predeployment phase, but data collection equipment including GIS software, cameras, and GPS devices should be obtained in this phase. Data collection equipment should be checked periodically to ensure that equipment is ready for field use when a disaster occurs. To check the equipment, tests following the data collection methods should be conducted to ensure that equipment is in proper condition. Inspection items essential to the data collection methodology include digital cameras, GPS devices, GIS software, and laptop computers. GPS devices used in data collection activities should capture GPS tracks. This GPS track is used to geolocate the inspection photographs. Figure 3.1 shows an example of these GPS devices which capture GPS track information. Digital cameras are useful because they have the ability to capture high resolution

Table 3.1. Equipment list for the damage assessment methodology presented in this chapter.

Laptop Computers	Safety Vests
GPS devices	Batteries
Cameras	Vehicle Magnets Identifying the Inspection Team
Connector Cables for Devices to Transfer Data to Computers	Printed Maps of Damaged Area
Boots	Printer with Paper
Hard Hats	Car Chargers for all Equipment

Figure 3.1. Example of GPS devices which capture GPS tracks.

images and store large amounts of data. Digital cameras that record GPS data for each photograph can also be used for data collection. Recent advances in smartphone camera technology have led to these cameras being used to capture inspection photographs as well as GPS locations. A GPS-enabled camera which automatically collects photographs at a set time interval is also useful for data collection activities. This camera will be helpful for creating a data contour and is explained later in this section. Figure 3.2 shows an example of this type of camera. In the accompanying case study, DSLR digital cameras, GPS-enabled digital cameras, and smartphone cameras were used for data collection activities.

GIS software is used to display aerial basemaps of the damaged area as well as create a layer of geolocated damage photographs collected in the field. The software allows the user to filter data, take measurements, and analyze data. A web portal specific to each damage assessment will be created in the predeployment phase to easily view the data that will be populated by this GIS data. This allows the members of the team who do not have access to GIS software to view the data. The website also allows the public to view the damage assessment. Laptop computers capable of operating GIS software without an internet connection should be

Figure 3.2. GPS-enabled camera that can be set to take pictures at a time interval.

included in the equipment preparation. Operating without an internet connection is important because many damaged areas will not have access to the internet. The laptop should also have a spreadsheet or database software such as Microsoft Excel installed. This software is needed to create a database that will be read into GIS and used to plot the geolocated photographs. The accompanying case study documents an inspection team that used ESRI ArcMap 10.0 to store and analyze data in the damage assessment.

A GIS-based web portal is useful for allowing researchers who do not have GIS software as well as the general public to view the damage assessment. Each damage assessment performed will require a web portal to be created. Constructing the skeleton of the web portal in the preparation phase allows researchers to use the skeleton as a base for web portals needed in future damage assessments. This cuts down on time needed to build these web portals, allowing the team to conduct other activities in the following phases.

3.3 Predeployment Phase

The predeployment phase includes team building, budgeting, and logistics, procuring basemaps, defining an inspection area, and creating a web portal specific to the damage assessement where collected data will be stored. The time between the disaster and the data collection phase is very short, which makes the planning done in the predeployment phase very important. The principal inspector should contact researchers whose past work coincides with the research topic of the damage assessment. Budgeting should be done by assigning unit values to budget items based on the amount of members that the team will have. The budget should account for how each potential team member is traveling to the damaged area. When the team is set, the budget will be calculated based on these values. Housing can be difficult to find near the affected area because many different rescue and relief organizations will be in the area. Researchers should look for hotels in nearby cities that offer an easy commute.

Street and pre-event aerial basemaps can be obtained from GIS inventories located in ArcMap software as well as the ESRI website. Post-event aerial images and basemaps of areas affected by disasters are created by various entities, including the Federal Emergency Management Agency and the Environmental Services Research Institute. These are made available to the public at no cost following large disasters. These basemaps are used by the reconnaissance team to define an inspection area. This area should be small enough to successfully inspect within the data collection phase, and should include the most information rich areas of interest to the reconnaissance team.

Typically the inspection team will assemble at the hotel the night before data collection is scheduled to begin. This meeting will be held with the full team in order to provide an overview of the disaster, discuss the scope of the damage assessment, and determine topics of interest for the team. The team should be divided into groups to perform data collection activities and all members should understand the data collection methodology. If possible, each group should have at least one member who has practiced the methodology to ensure that the procedures are conducted correctly. Special interest topics can be added to the scope of the project during the meeting. These special interests may be potential case studies or items to photograph and add to the damage assessment GIS. In this meeting the team should discuss ways to stay connected while in the field, keeping in mind that cell phone connectivity may not be operational. It is best to plan to meet for lunch on day one of data collection at a predefined location and time.

3.4 Data Collection Phase

The data collection phase begins once the team reaches the inspection area. This phase employs the data collection methodology presented in Appendix A. Based on the objectives of the inspection team, a systematic approach to divide the team and collect information from as many areas as possible should be established. As data is collected a methodology that combines photographs with GPS tracks, in order to obtain a geolocated damage photograph layer, should be used.

3.4.1 The Transect Approach

One approach to collect data in a damaged area is the transect approach where data is collected along transects that run across the affected area, from no damage, through the site, to no damage on the other side. The transect approach is employed to collect cross-sections of damage which give a two-dimensional understanding of the damage along that transect. In this approach, the inspection groups walk paths running approximately perpendicular to the damage area, from an area with no damage on one side of the affected region to a no damage area on the other side of the affected region. As more transects are inspected, the team will develop a two-dimensional understanding of the distribution of damage. Adding additional information to inspected locations and interpolating between sampled points creates a three-dimensional contour of the inspection area. Figure 3.4 shows the transects walked in the damage assessment for the April 2011 Tuscaloosa, Alabama tornado. Transects are typically shown in approximately north-south orientation, but paths were changed where streets do not allow this orientation. Figure 3.5 shows the data collection locations along these transects. For this damage assessment the inspection topic included building damage, but The methodology allows for any inspection topic to be documented. Figure 3.6 shows the three-dimensional damage contour which was created from the data collected in Tuscaloosa. The damage contour for the Tuscaloosa tornado damage assessment is based on damage rated on the enhanced Fujita (EF) scale. The damage contour can be created by interpolating any designation that the team gives to collected photographs.

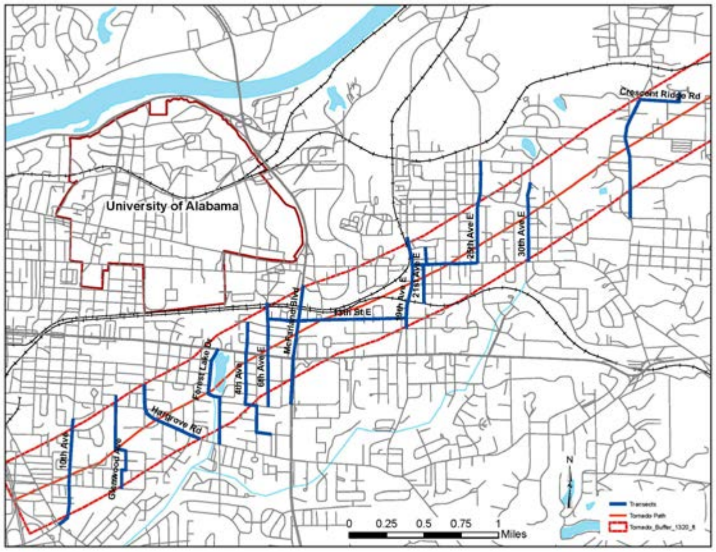


Figure 3.3. April 2011 Tuscaloosa, Alabama tornado damage assessment transect map.

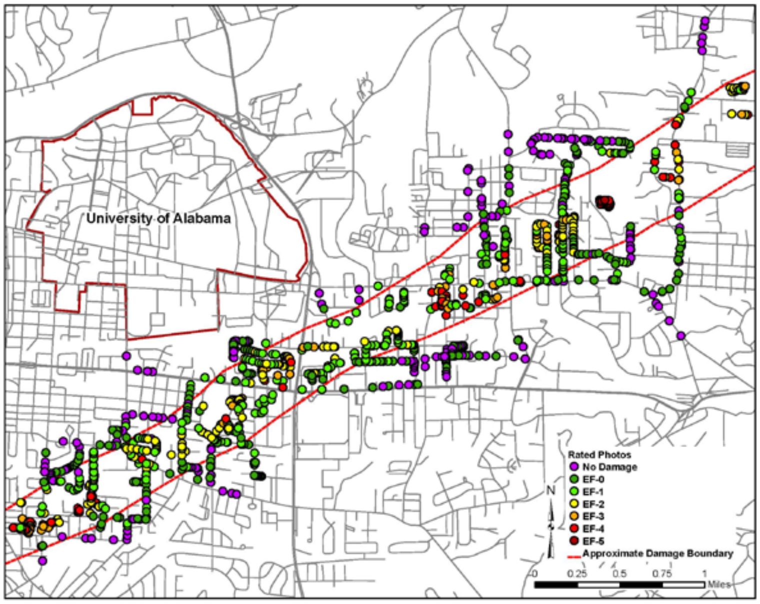


Figure 3.4. Photograph locations for the Tuscaloosa tornado damage assessment.

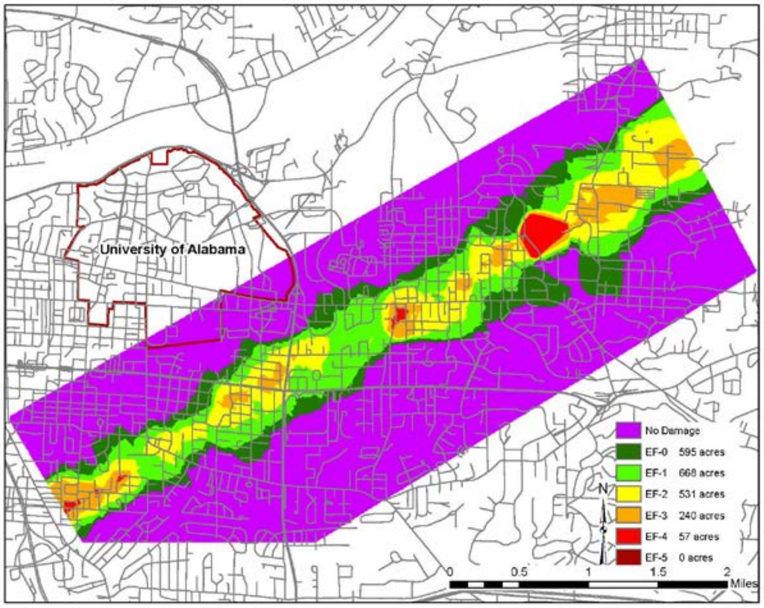
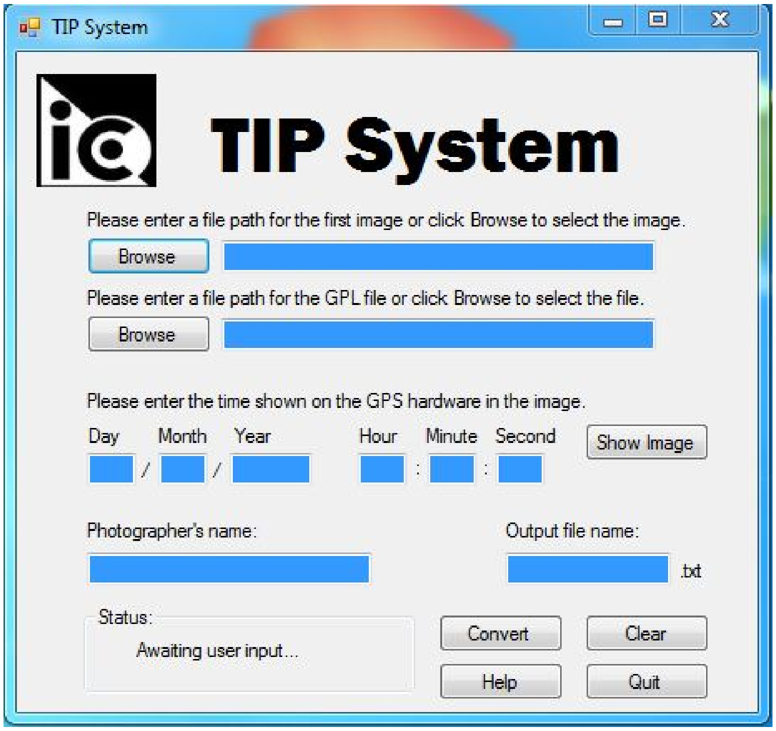


Figure 3.5. The damage contour map color coded based on EF scale and containing areas of each EF rating (Graettinger et al, 2012).

While it is not necessary to document every location along a transect, the distance between documented locations should be short and consistent. If contours of the collected information are desired, it is necessary to document unaffected locations along transects as well. This will ensure that the boundaries of damage are defined. The number of transects collected per day is a function of the amount of time spent in the field, the length of the transects, the number of locations inspected, and the number of inspection groups in the field. When the team finishes data collection procedures, the photographs and information will need to be evaluated and attributed to provide valuable data that was collected at specific locations.

3.4.2 The Time Image Positioning Data Collection Tool

The Time Image Positioning (TIP) system is a data fusion method used to combine inspection photographs and GPS technology in order to obtain geolocated inspection photographs. This method employs software developed at The University of Alabama and works by reconciling the timestamp of each photograph with the time on a GPS track. The software requires a GPS track to be input as a .GPL file, the first photograph in a series of damage photographs, the date and time of the GPS unit in the first picture, a photographer’s name, and the name of the output text file. Figure 3.7 shows the startup screen of the TIP system. Delorme



Please enter a file path for the first image or click Browse to select the image.

Please enter a file path for the GPL file or click Browse to select the file.

Please enter the time shown on the GPS hardware in the image.

Status:

Awaiting user input...

Figure 3.6. TIP System startup screen containing fields for all inputs, browse buttons allowing the user to locate a folder of inspection photographs, and a button allowing the user to view the first image in the folder.

GPS equipment produces a .GPL file format but if other GPS devices are used, an internet converter can be used to convert .GPX files into .GPL files. The most efficient method to process photographs and GPS tracks involves each team member taking a photograph of their GPS unit showing the time displayed on the GPS unit before they take any other photographs. Figure 3.8 shows a picture of a Delorme GPS device with the time on the screen. This picture will be used to reconcile the time difference of the GPS unit and the photographs. The TIP software will read the timestamp of the photograph and compare it to the time of the GPS unit entered by the user. This time difference will be carried through the remaining photographs to find the latitude and longitude of each photograph. The output of the software is a .txt file that contains the image names, corresponding latitudes, corresponding longitudes, and photographer name. Figure 3.9 shows the flow diagram for the TIP system.

Figure 3.7. Photograph of a GPS screen with the time visible.

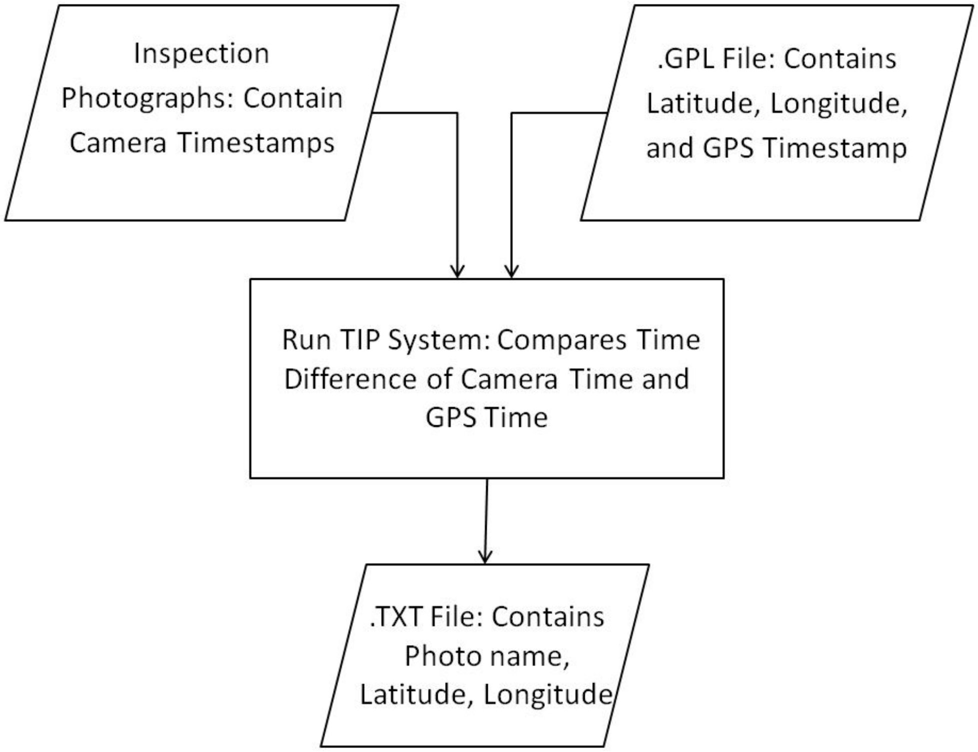


Figure 3.8. Flow diagram of the TIP data collection method.

3.5 GPSExtractor Tool

Digital cameras and smartphone cameras with in built-in GPS capability can be used for data collection, and do not need to be used in parallel with a GPS device and run through the TIP system. A GPS batch extractor tool created at the University of Alabama can be used to create a .txt file with photo names and locations. The tool reads each photograph individually and strips the latitude and longitude information from the photograph. Once every photograph has been read and the location information has been extracted, a .txt file is created. This file contains each photograph name and the associated latitude and longitude information. Converting the .txt file into an Excel spreadsheet and reading the information into GIS is described in the methodology for the TIP system but can also be used for this tool. The reliability of the GPS information in GPS digital cameras and smartphone cameras can be questionable, so the cameras should be tested before they are used in the data collection phase. If the GPS information is inaccurate, the cameras may still be used but will need to be paired with a GPS device and run through the TIP system.

3.6 Postprocessing Phase

The postprocessing phase begins after the team leaves the inspection area and continues until the work is completed each evening. This phase consists of transferring the inspection data to a GIS format and populating the web portal with the GIS data. This phase also includes collecting auxiliary datasets if possible, including geolocated photographs collected from other teams, GIS data available from government sources, etc.

3.6.1 Entering Data into GIS

Converting the text file created by the TIP system or GPSExtractor tool into a spreadsheet format that can be loaded into GIS to create a layer of data is a necessary task in this phase. This layer will be displayed on top of the basemaps. The basemaps will provide macro-scale information about the distribution of damage while the data layer will give a street-level understanding of damage. The map created each night will be used to plan the data collection activities for the next day.

3.6.2 Data Contour

Using the data collection points, a contour map can be created which will provide a tool for easily understanding the severity of distribution of the data at all locations of the inspected area. The contour shows data unique to each dataset and disaster. It also allows the user to calculate the area of each division. In Figure 3.3, the contour created for the Tuscaloosa tornado allowed the team to calculate the total area for each EF rating and what percentage of damage each EF rating created. A methodology for creating a contour is located in Appendix B. When the data contour has been created, it can be added to the web portal as a layer.

3.6.3 Auxiliary datasets

Along with the inspection photos collected by the reconnaissance team, auxiliary datasets supporting the data collected by the reconnaissance team can be added to the GIS. Chapter 4 explains a case study performed in Moore, Oklahoma. Here researchers worked with the social media website Twitter to collect damage photographs taken immediately after the storm and ending a week after the storm. This allowed the reconnaissance team to add photographs taken before the team visited the area. Along with Twitter photographs, the Moore reconnaissance team used FEMA photographs taken on the ground and from helicopter. These photographs made the damage assessment GIS more robust by adding damage information which was not collected by the reconnaissance team in the field. Working with the city of Moore, the team obtained a shapefile of registered storm shelters in the inspection area. These were geolocated and added as layers to the GIS. Auxiliary datasets can be very powerful tools for understanding the disaster and for research.

3.6.4 Web Portal

A web portal should be created to disseminate the data collected for the damage assessment. The web portal can be created using web based mapping technology. Built-in web based mapping functionality allows users to display layers on top of the collected basemaps and toggle each layer on and off. The layers produced in the damage assessment methodology can be displayed as points, lines, polygons, or rasters and plotted geographically in the position where the data was captured. The web mapping functionality allows the user to view collected photographs by selecting associated points. The web portal is important because it creates an environment where temporal data collected after a disaster can be stored, allowing the reconnaissance team to revisit data for research and for the public to view the damage assessment in a format that is helpful, user-friendly and easy to understand.

3.7 Conclusions

The four-phase damage assessment methodology proposed in this chapter allows researchers to systematically perform data collection exercises in the wake of a disaster and store the data in a GIS-based web portal which allows team members and the public to view the results of the damage assessment. The exercises needed to conduct the damage assessment in each phase are included, and supporting appendices provide step-by-step guides that can be used to conduct data collection procedures and create a data contour based on the information collected in the field. The methodology offers a standardized process for damage assessment that can be used by researchers for any inspection topic desired.

CHAPTER 4

MOORE, OKLAHOMA CASE STUDY

4.1 Introduction

On May 20th, 2013, an Enhanced Fujita (EF) 5 tornado struck the city of Moore, Oklahoma. In addition to over $2 billion in economic loss, 24 people were killed and over 350 others were injured (NBC News 2013). The weather system that produced this tornado formed 95 tornadoes from May 18th to May 20th, 2013. In the afternoon hours of May 20th, a supercell formed that produced the tornado that struck Moore. The tornado traveled 17 miles across rural farmlands and dense urban areas and created a swath of destruction up to 1.3 miles wide. Wind speeds were estimated at a maximum of 210 miles per hour, the highest in that area since the 1999 Bridge Creek-Moore Tornado which registered winds of 301 miles per hour (Weather Underground).

Building performance was a research topic for this damage assessment. Moore is composed largely of single-family residential construction. The design of these residential structures and the building connections were also studied. The inspection area was defined around this parameter. An overview map of Oklahoma, Cleveland County, and the approximate 2013 tornado path is shown in Figure 4.1. The area of study was chosen because it contains the most single-family houses in the tornado path. Figure 4.2 illustrates a street map of the inspection area overlaid with the damage boundary of the storm.

Moore has been hit by several large tornadoes in the past two decades, including an F5 tornado on May 3, 1999, an F4 tornado on May 8, 2003, and the 2013 EF5 tornado. Figure 4.3

shows the approximate paths of these three tornadoes. The 1999 tornado caused 36 deaths and 295 injuries, and its path was 38 miles long and up to 1 mile wide according to the National Weather Service (National Weather Service, 2013). This was one of the strongest tornadoes to hit a densely populated area and resulted in over $1 billion in property damage and significant attention from researchers in America. The 2003 tornado caused no deaths, but 45 injuries were reported. The amount of recent devastating tornadoes in Moore prompted the research team to study storm shelters. The topic included research on how many residents had built storm shelters, the different designs of these shelters, and the performance of the shelters after this tornado.

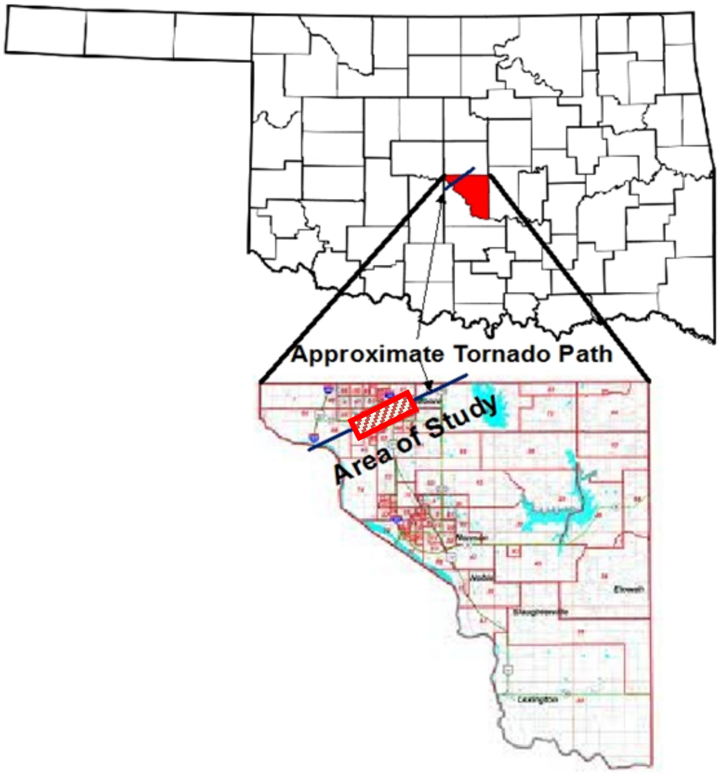


Figure 4.1. Map of Cleveland County, extracted from county map of Oklahoma along with the approximate path of the May 20th tornado shown by the line and the area studied by the research team in the hatched region.

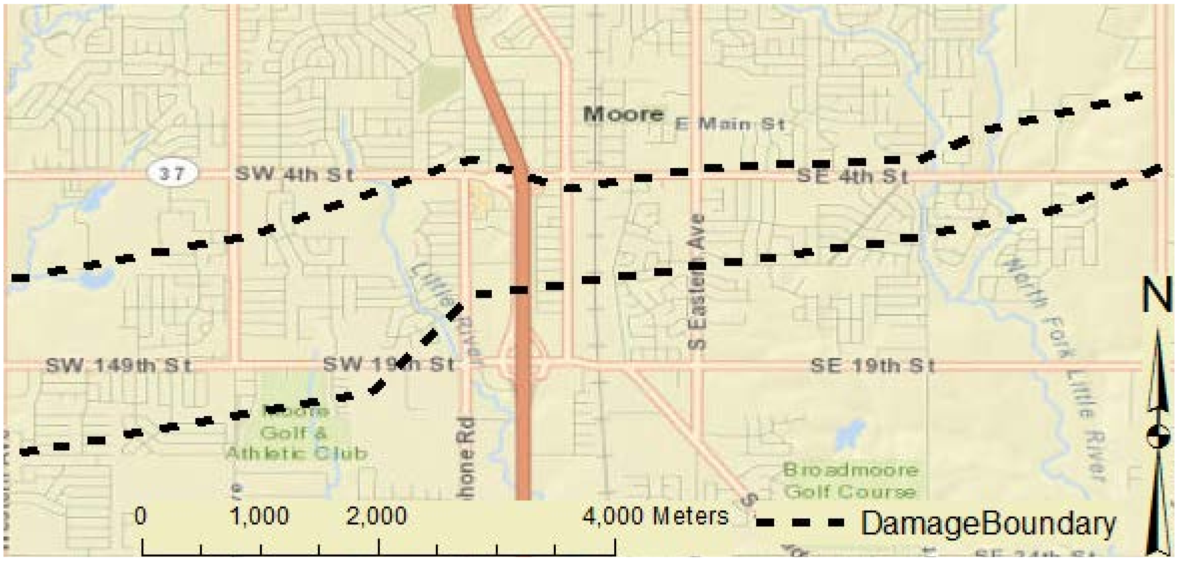


Figure 4.2. View of the Moore, Oklahoma inspection area street map with the damage boundary of the May 20th tornado.

Figure 4.3. Map of the paths of the three major tornadoes to hit Moore in the past 15 years with the May 20th, 2013 tornado shown in red(kfor.com).

4.2 Inspection Methodology

The primary objectives of this data collection exercise were to document damage in the area affected by the tornado, placing a special emphasis on photographing storm shelters and building connections. Data collection was conducted both actively by visually inspecting, photographing, and conducting ground-based Light Detection and Ranging (LiDAR) scans of the damaged area, as well as passively by collecting basemaps of Moore before the trip was taken, data mining social media sites for photographs, and collecting FEMA damage photography in the postprocessing phase. The reconnaissance team was in the field from May 27th to May 29th. Predeployment procedures took place to ensure that the team had all necessary information to complete a rapid, comprehensive damage assessment. Postprocessing procedures took place in order to synthesize the data into useful methods for research.

4.2.1 Preparation Phase

The preparation phase began with team members who had worked on past damage assessments. The data collection methodology grew out of these past damage assessments, including assessments for Hurricane Katrina in 2005, and tornadoes in Tuscaloosa, AL and Joplin, MO in 2011. Tasks performed in the preparation phase for the Moore damage assessment included acquiring the equipment needed to perform the data collection methodology and training the damage assessment methodology to a small number of team members.

The assessment team is equipped with ESRI ArcGIS software including ArcMap and ArcDesktop. For the Moore damage assessment, ArcMap 10.0 was used. A copy of the software was obtained which allowed in field use on a laptop without an internet connection. This was important because internet connectivity is often scarce in damage areas following disasters. Multiple DeLorme GPS devices were employed. The devices are small and easy to store on person while in the field and the devices collect GPS information passively. The uncorrected accuracy of these units is approximately 10 m. The inspection team obtained one Earthmate PN-20 device, one Earthmate PN-40 device, and two Earthmate PN-40 devices to use in data collection activities. Figure 3.1 in the Methodology section of this thesis shows DeLorme Earthmate PN-20, PN-40, and PN-60 GPS devices used in Moore. In addition to the DeLorme GPS units, a ContourGPS camera, shown in Figure 3.2 in the Methodology section of this thesis, was obtained which can be mounted to the window of a vehicle and captures photographs at a time interval set by the user. For the Moore data collection activities the camera was set to take a photograph every three seconds. The ContourGPS records GPS information in the metadata of each collected photograph. A metadata batch extraction program called GPSExtract was created at the University of Alabama which strips the GPS data from photographs and creates a .txt file with the photography name and associated latitudes and longitudes. The file can be converted to a spreadsheet format and used to create a damage photography layer in GIS software. The ContourGPS was intended to be used to collect photographs from the fringes of the tornado path in order to precisely locate the boundaries of the storm. A vehicle was to be driven in areas near the edges of the tornado boundary to collect this information while the reconnaissance team inspected more information-rich areas. While digital cameras are vital to inspection activities, instead of purchasing cameras for the data collection activities, members were relied on to bring personal digital cameras. Recent increases in smartphone camera resolution have allowed these personal devices to be used in data collection activities. Many team members in Moore used smartphones to collect damage photographs. Smartphones embed GPS information in photographs in the same way as the ContourGPS. While this allows the GPSExtractor tool to be used to create a GIS-ready document from smartphone photographs, smartphone GPS technology is not as accurate as the DeLorme units. For this reason the TIP system is the preferred tool for geolocating smartphone photographs, but the metadata extractor can be used in the case of faulty GPS equipment or if members get separated from GPS units in the field.

Equipment testing took place before the team travelled to Moore. These tests were performed by walking local areas and geolocating points using the data collection methodology described in Appendix A. The DeLorme GPS devices were tested individually in order to ensure that each unit was working properly. The ContourGPS was tested by attaching it to the window of a vehicle and set to take a photograph every three seconds.

Testing began with a team member walking a specified loop, taking photographs of landmarks that were easily identifiable in aerial photography. When this process was complete, the photographs and .GPL files were loaded into folders on a computer. The TIP system was used to fuse the DeLorme GPS data with the photographs, and the GPSExtractor tool was used to compare the accuracy of the two tools. The text files obtained from the tools was converted to an Excel spreadsheet and read into ArcMap. Each GPS unit was given a corresponding layer in the map and the points were compared to the actual locations of the photographs in order to check the accuracy of each device. The ContourGPS photographs were compared visually to ensure that they landed on the correct roadways where they were captured. Figure 4.4 shows the GIS map of the equipment tests.

4.2.2 Predeployment

In the days following the Moore tornado, team members created a list of items needed to perform the damage assessment, collected and tested the equipment, obtained GIS basemaps of the damaged area before and after the tornado and created a web portal to store the collected data. The equipment list included data collection equipment, safety equipment, and auxiliary items. The equipment list is contained in Table 3.1 of this thesis.

The team once again tested the equipment and data collection methodology. These tests were conducted to further ensure that the equipment was functioning properly and to familiarize members with the data collection methodology once again. GIS basemaps of Moore containing pre-disaster aerial imagery as well as a pre-disaster street map were collected from an ESRI database which comes standard with ArcMap software. A basemap created from post-disaster aerial images taken by FEMA was also collected from an online ESRI database.

Following the procedure described in the methodology section, a web portal was created at the University of Alabama to store the results of the damage assessment. The portal accesses GIS layers created by the team on a ArcServer to render a webpage that is viewed in an ArcViewer format. Built-in ArcViewer functionality allows user-generated layers to be added to the map on top of the pre- and post-event basemaps. These layers can be toggled on and off at the users ease. Collected damage photographs were stored in this portal and accessed by clicking on the node corresponding to each photograph.

The Moore, OK reconnaissance team using the methodology described in this thesis consisted of 19 members representing The University of Alabama, the University of Florida, Mississippi State University, Oklahoma State University, the University of Oklahoma, Rose-Hulman Institute of Technology, and Simpson Strong Tie. The team was made up of professors, engineering graduate students, and a social scientist. Funding was provided by the National Science Foundation and covered travel, lodging, and materials.

The reconnaissance team arrived in Norman, OK on May 26th, six days after the tornado damaged the city of Moore. A team meeting was held to introduce the members, define an inspection area, explain the data collection methodology, define special interests to document in the field, and locate a rendezvous point for lunch where any problems encountered could be addressed. An inspection area was defined that covered five miles of the storm path through the most densely populated regions of Moore. The area was arbitrarily bound on the west and east by two main streets in order to limit the inspection area to the most information-rich span of the tornado path. Approximate transects for the first day of data collection were established crossing the most easily accessible streets in the city. Figure 4.4 shows the transects established for the first day of data collection activities as well as the bounding streets. The data collection methodology described in Chapter 3 was trained to the team. The instruction included only the procedures applicable to most team members, including how to collect GPS track data with the GPS units and to take a picture of the GPS unit was needed to correct the time signatures of the camera and GPS units in the TIP system. The team identified special topics that were of interest to researchers both on and off the reconnaissance team. These topics became part of the infield

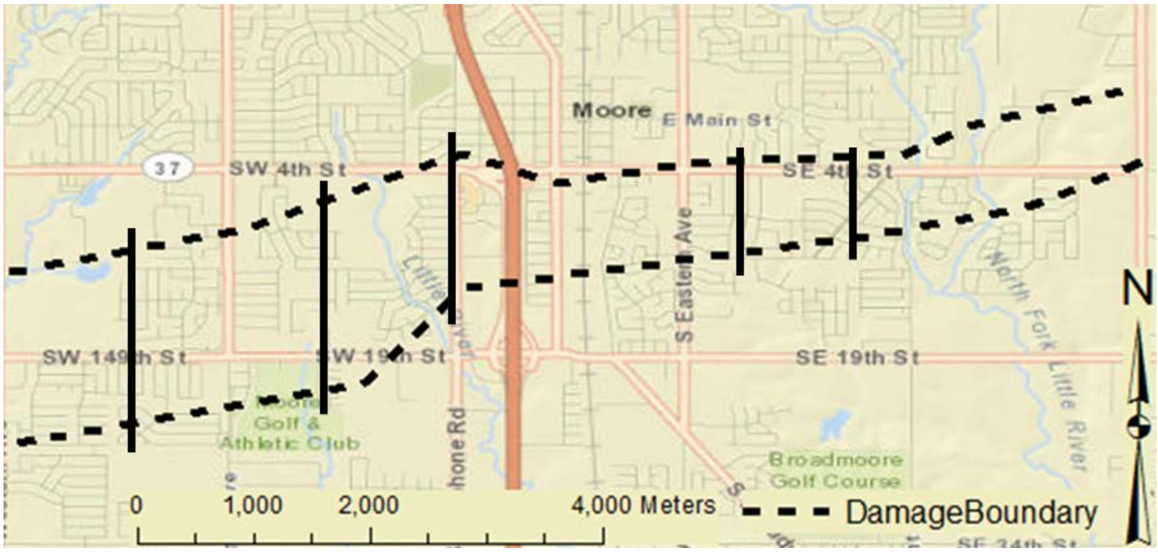


Figure 4.4. Transect locations inspected on May 25.

data collection mission. For the Moore study, these special topics included: above and below ground storm shelters, storm water debris blockages, roof-to-wall and wall-to-foundation connections, and shear wall failures. Groups of three to four members were created for data collection. Each group was assigned a GPS device and a transect to inspect. In order to stay aware of team member locations, a smartphone application called Find My Friends was installed on team members' phones. The application showed the location of each team member on a street map of the city. The map screen of the Find My Friends application is shown in Figure 4.5. This application allowed members of each group to easily locate each other.

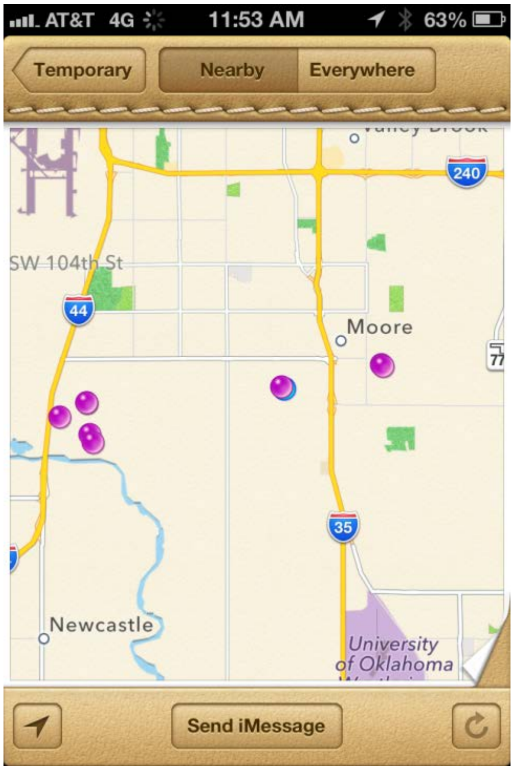


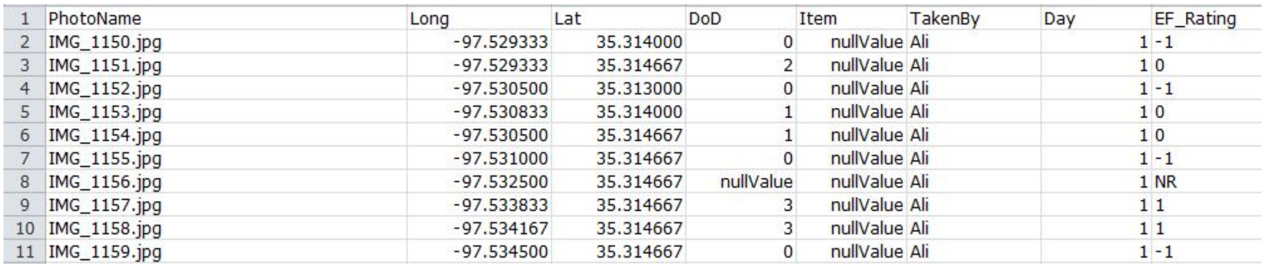
Figure 4.5. Find My Friends application showing locations of team members in Moore.

4.2.3 Field Inspection

The team entered the inspection area on the morning of May 27th. The first task for each member of each was to take a picture of their GPS unit. When this was completed each group followed the approximate path of their assigned transect and documented damaged buildings with photographs. When a group finished a transect, they either started another transect or found an area of special interest to study, such as storm shelter or storm water infrastructure.

When the team returned from the inspection area in the evening, the photographs were rated on the DoD (Degree of Damage) scale where applicable. To accomplish this task, the photographs from each camera were downloaded to a computer and an Excel spreadsheet was created with columns for photograph name, DoD, and Item. Groups of two to four members were created, and each group was given a set of photographs and a document detailing the DoD index for one and two family residences. Each rating group would inspect each photograph and give the building in the photograph a DoD rating. In the Item column of the spreadsheet, the rating group assigned numbers to photographs corresponding to one of the special topics if applicable to the Moore study. DoD was based on building damage, therefore if a building was not documented in the photograph, a DoD was not assigned. Similarly, Item numbers were only assigned when applicable. As this task was being completed, a member of the reconnaissance team processed the photographs and corresponding .GPL file through the TIP program. This created an Excel spreadsheet of Lat, Long, and Photoname columns that was joined to the DoD rating and Item data. This process was repeated for each camera used in the field. When all Excel spreadsheets from all from all team members were created, all spreadsheets were merged into one file incorporating every photograph captured for May 27th. After merging spreadsheets created for every day, the DoD ratings were correlated to EF ratings based on wind speed values.

Figure 4.6 shows an example Excel spreadsheet completed for the first day of data collection. The data collection procedure was repeated on May 28th and May 29th. Although the ContourGPS camera is part of the damage assessment methodology and was tested before arriving in Moore, no photographs were gathered with the device because of technical issues encountered when using the device in the field. This hampered the ability to locate the damage boundary, but FEMA photographs collected in the postprocessing phase helped to fill in data gaps at the boundaries of damage. Figure 4.7 shows the street map of Moore with nodes indicating inspection photographs geolocated in their correct location. Table 4.1 contains



1	PhotoName	Long	Lat	DoD	Item	TakenBy	Day	EF_Rating
2	IMG_1150.jpg	-97.529333	35.314000	0	nullValue	Ali	1	-1
3	IMG_1151.jpg	-97.529333	35.314667	2	nullValue	Ali	1	0
4	IMG_1152.jpg	-97.530500	35.313000	0	nullValue	Ali	1	-1
5	IMG_1153.jpg	-97.530833	35.314000	1	nullValue	Ali	1	0
6	IMG_1154.jpg	-97.530500	35.314667	1	nullValue	Ali	1	0
7	IMG_1155.jpg	-97.531000	35.314667	0	nullValue	Ali	1	-1
8	IMG_1156.jpg	-97.532500	35.314667	nullValue	nullValue	Ali	1	NR
9	IMG_1157.jpg	-97.533833	35.314667	3	nullValue	Ali	1	1
10	IMG_1158.jpg	-97.534167	35.314667	3	nullValue	Ali	1	1
11	IMG_1159.jpg	-97.534500	35.314667	0	nullValue	Ali	1	-1

Figure 4.6. Excel sheet created to map the photographs in ArcMap.

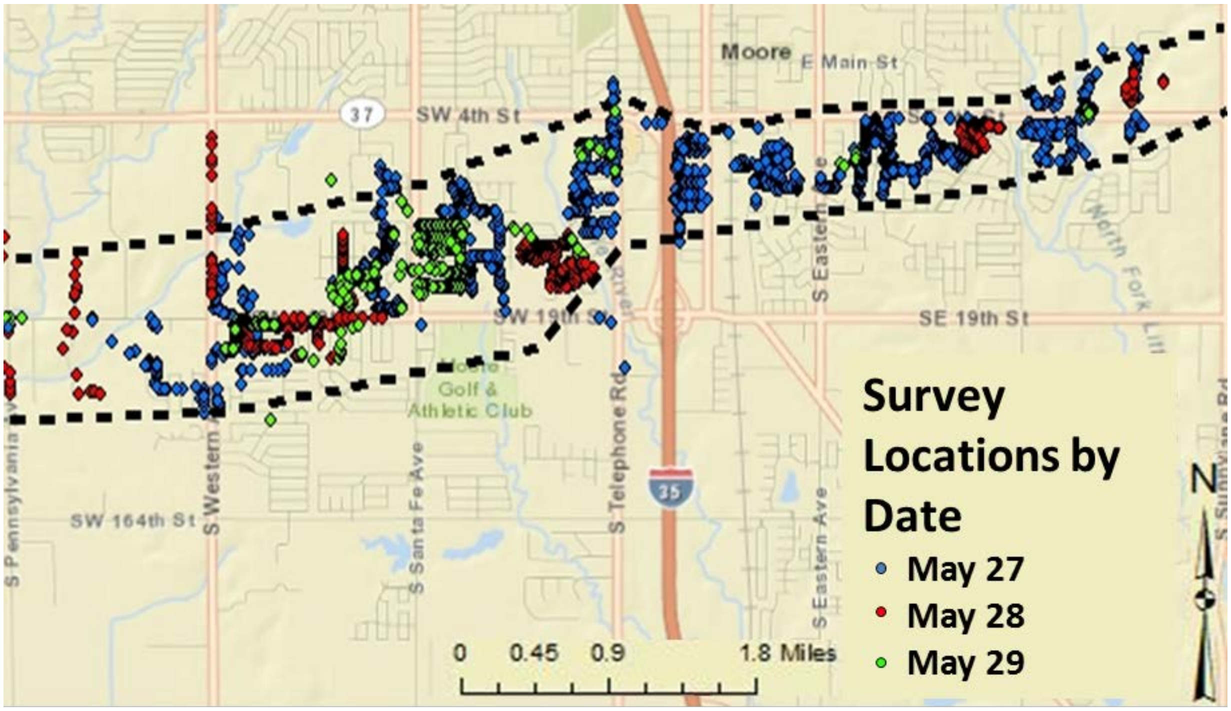


Figure 4.7. Geolocated photographs color coded by the day collected.

summary statistics associated with the data from the Moore inspection. The number of photographs collected each day is presented, along with the number of photographs that were rated on the EF scale, and the percentage of EF rated photographs. The amount of pictures taken was highest on the first day of data collection because groups focused on collecting transect data. The next days were dedicated to collecting photographs of the special topics.

Table 4.1. Photograph data for the data collection of the Moore tornado.

Date	Total Photographs	Rated Photographs	Percent Rated of Day
May 27	2,122	1,126	53.1%
May 28	507	246	48.5%
May 29	631	151	23.9%
Total	3,260	1,523	

Terrestrial LiDAR laserscans were captured for two sites in Moore. The point clouds created by the scans were used to virtually model damage to these areas. Figure 4.8 shows a map of the two areas. The first area includes a neighborhood that was in the direct path of the storm with damage ranging from completely destroyed buildings to buildings with very mild damage. The second scan area covers a street with a wide range of damage. From the centerline of the storm, damage decreases incrementally. Figure 4.9 shows a point cloud rendering of a damaged house in scan area #1, and Figure 4.10 shows the damage pattern in scan area #2. These virtual representations were used to study methods of automated damage assessment by combining terrestrial LiDAR data with GIS basemaps (Geranmayeh Kashani et al, 2014).

Figure 4.8. Areas where laserscans were captured in Moore.

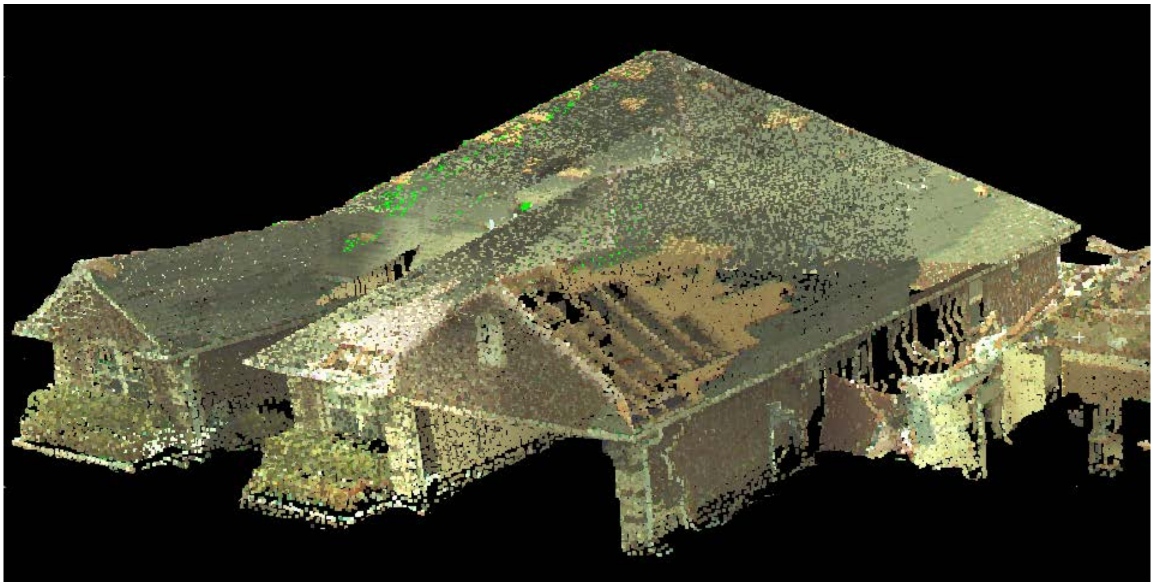


Figure 4.9. LiDAR point cloud of a damaged building from scan area #1.

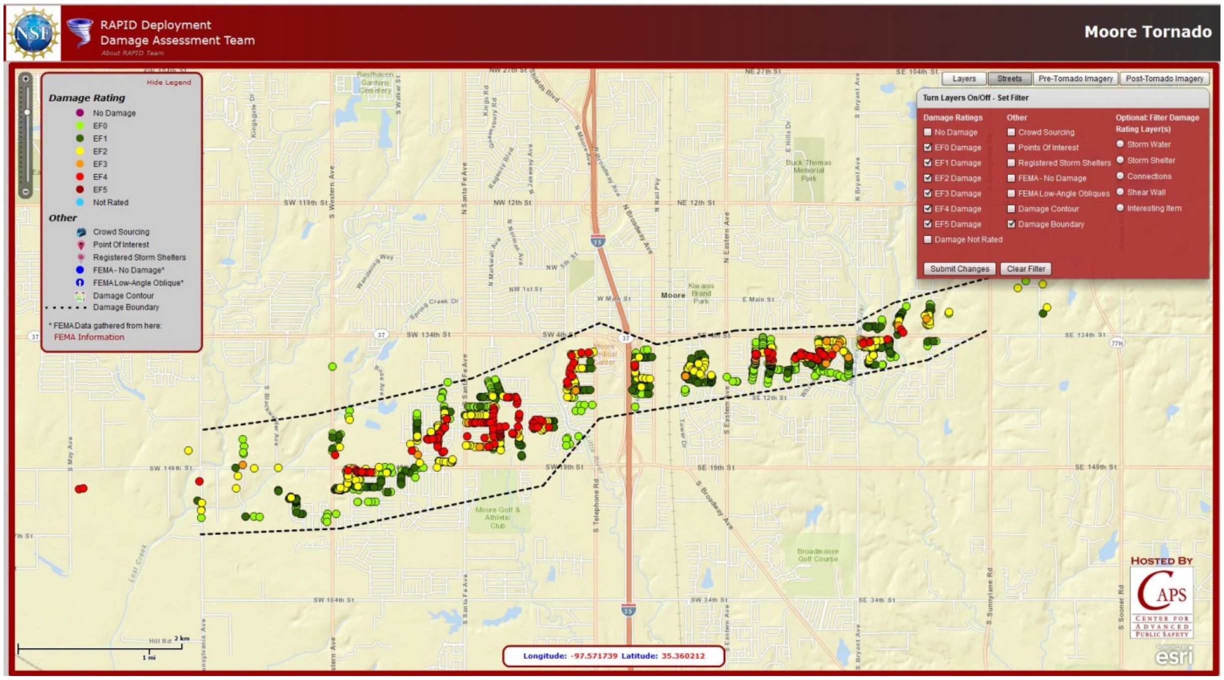
Figure 4.10. 3D representation of scan area #2 showing the gradual decrease in damage moving away from the path of the storm.

4.2.4 Post-Processing

After field inspection in Moore completed, members filtered and analyzed the data that was captured in the field. The tasks involved in this process including displaying the Excel spreadsheet of inspected photographs in GIS to create shapefiles, uploading data to a web portal, searching for additional data from other sources, and creating a damage contour map.

4.2.5 GIS-based Web Portal

To create the GIS shapefiles, the Excel spreadsheet was loaded into ArcMap and the latitude and longitude coordinates of the photographs were used to display the points. The basemaps and aerial imagery collected in the predeployment phase were also loaded into ArcMap. The shapefile of photo locations was loaded into the web portal as well as all collected photographs. Figure 4.11 shows the startup screen of the web portal that includes a legend in the upper left showing the colors corresponding to each EF rating, and a window in the upper right allowing the user to toggle layers and filters on and off. Functionality was programmed into the portal that color-coded inspection points based on the EF rating given to each photograph. Layers were created in the web portal allowing the user to filter desired data on or off. The items



Turn Layers On/Off - Set Filter

Damage Ratings
☐ No Damage
☑ EF0 Damage
☑ EF1 Damage
☑ EF2 Damage
☑ EF3 Damage
☑ EF4 Damage
☑ EF5 Damage
☐ Damage Not Rated

Other
☐ Crowd Sourcing
☐ Points Of Interest
☐ Registered Storm Shelters
☐ FEMA - No Damage
☐ FEMA Low-Angle Obliques
☐ Damage Contour
☑ Damage Boundary

Optional: Filter Damage Rating Layer(s)
○ Storm Water
○ Storm Shelter
○ Connections
○ Shear Wall
○ Interesting Item

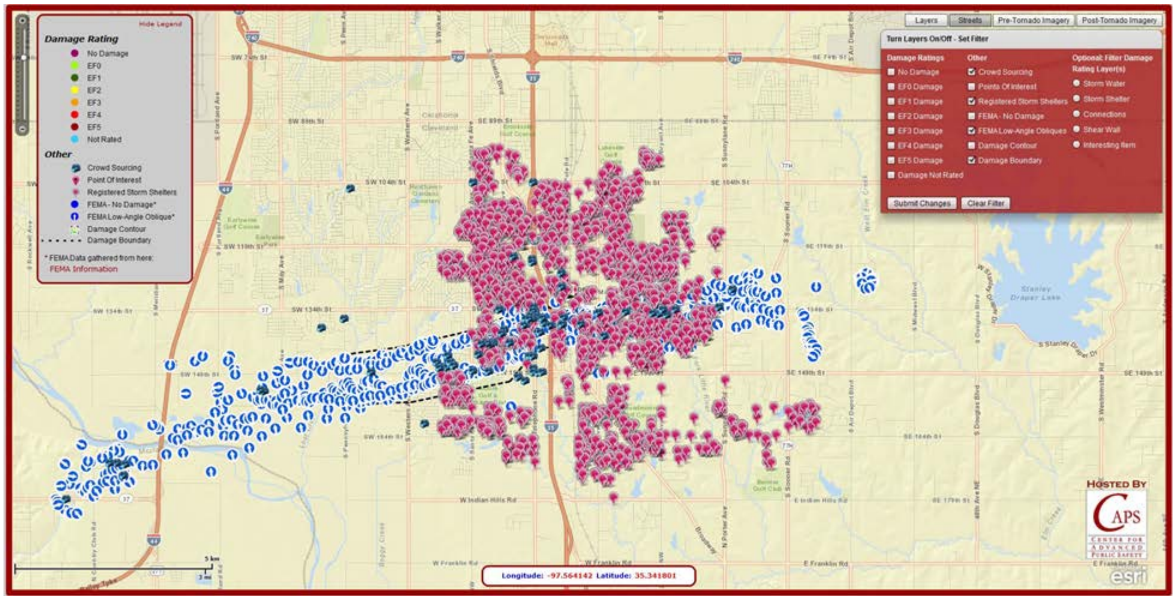
Longitude: -97.571739 Latitude: 35.360212

Figure 4.11. GIS-based web portal used for viewing the Moore damage assessment.

of interest were also added as filters. The filters reduce the number of photographs displayed on the layers that are turned on. For example, if a storm shelter filter is selected, only the storm shelter photographs found in the selected layers are visible. To locate all storm shelters, the user would turn all layers on and then filter the data.

As information was collected from outside sources, more layers were created in the web portal. The information obtained in the post-processing phase included a storm boundary layer, a layer of registered storm shelters provided by the city of Moore, FEMA low aerial oblique photographs, FEMA ground photographs, and crowd sourced photographs collected from Twitter. Where damage photographs end and no damage photographs begin, damage boundary lines were added. These lines were adjusted by visual inspection in areas where no residential buildings existed and therefore no data was collected. These lines were added as a storm boundary layer. The registered storm shelters layer includes shelters in the city of Moore registered between the 1999 tornado and the 2013 tornado. The FEMA low aerial oblique photographs contain photographs taken from helicopter. These photographs were not geolocated correctly, so team members manually corrected the locations by and moving each photograph to the correct location. Location markers were assigned to each of these points on the map to show which direction the FEMA low angle oblique photograph was taken.

Crowd sourced photographs were obtained from the social media website Twitter. A fifty five square mile box was created around Moore and every photograph with latitude and longitude data within the box posted to the website from May 21 to May 29 was collected by the Social Media Tracking and Analysis System (SMTAS) at Mississippi State University. Figure 4.12 includes the storm boundary indicated by dashed black lines, registered storm shelter locations indicated by red markers, crowd sourced photographs indicated by camera markers, and FEMA low aerial oblique photographs indicated by blue markers with white arrows. In the table of contents of the map, layers are drawn from the bottom up. For this reason, the damage boundary is almost unrecognizable because the other three layers are overlaid on top of it on the map. Similarly, the FEMA low angle obliques are displayed under the registered storm shelters,



☐ No Damage
☐ EF0 Damage
☐ EF1 Damage
☐ EF2 Damage
☐ EF3 Damage
☐ EF4 Damage
☐ EF5 Damage
☐ Damage Not Rated

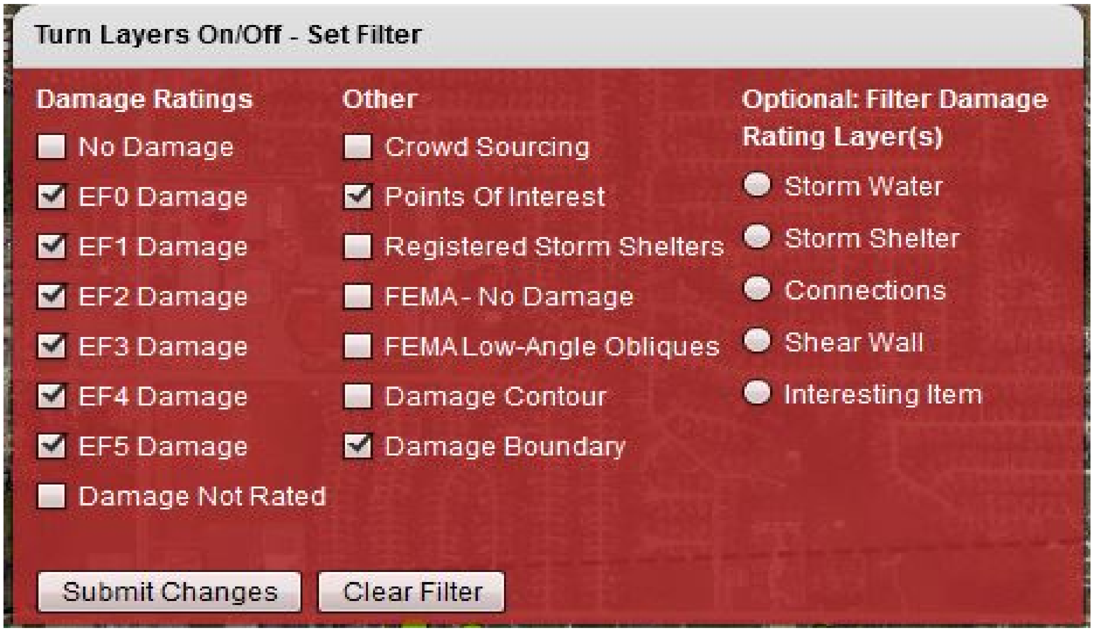
☑ Crowd Sourcing
☐ Points Of Interest
☑ Registered Storm Shelters
☐ FEMA - No Damage
☑ FEMA Low-Angle Obliques
☐ Damage Contour
☑ Damage Boundary

○ Storm Water
○ Storm Shelter
○ Connections
○ Shear Wall
○ Interesting Item

Longitude: -97.564142 Latitude: 35.341801

Figure 4.12. The layer data obtained in the post processing phase of the damage assessment.

which are under the crowd sourced photographs. Figure 4.13 shows the layer and filter menu available on the website. The web portal for the Moore damage assessment is available to the public at esridev.caps.ua.edu/MooreTornado/MooreTornado.html.



Damage Ratings
☐ No Damage
☑ EF0 Damage
☑ EF1 Damage
☑ EF2 Damage
☑ EF3 Damage
☑ EF4 Damage
☑ EF5 Damage
☐ Damage Not Rated

Other
☐ Crowd Sourcing
☑ Points Of Interest
☐ Registered Storm Shelters
☐ FEMA - No Damage
☐ FEMA Low-Angle Obliques
☐ Damage Contour
☑ Damage Boundary

Optional: Filter Damage Rating Layer(s)
○ Storm Water
○ Storm Shelter
○ Connections
○ Shear Wall
○ Interesting Item

Figure 4.13. Menu of the layers and filters available in the web portal.

Team members were unable to add the LiDAR data to the web portal because the dataset was too large. Data compression techniques were conducted in order to get the data into a useful format, but no amount of compression was able to accomplish the task. Team members were still able to view and analyze the data in Leica viewer software in order to complete research activities.

4.2.6 Damage Contour

A damage contour of the inspection area was created in the post-processing phase. The damage contour is a raster interpolation created in GIS based on the collected survey location data. A geostatistic technique was employed that interpolates between survey locations to approximate the EF value at all locations in the inspection area. Using the contour map created from the statistical approach, the area values of each EF rating and the percentage of each rating was computed. Using the geostatistical wizard in ArcMap 10.0, a prediction modeling method called kriging was used to create this damage contour. Appendix B provides a methodology for creating a data contour using GIS tools. Figure 4.14 shows the damage contour for Moore, color coded based on EF rating area. Table 4.2 includes the area of each EF rating and the percentage of the storm each EF rating represents.

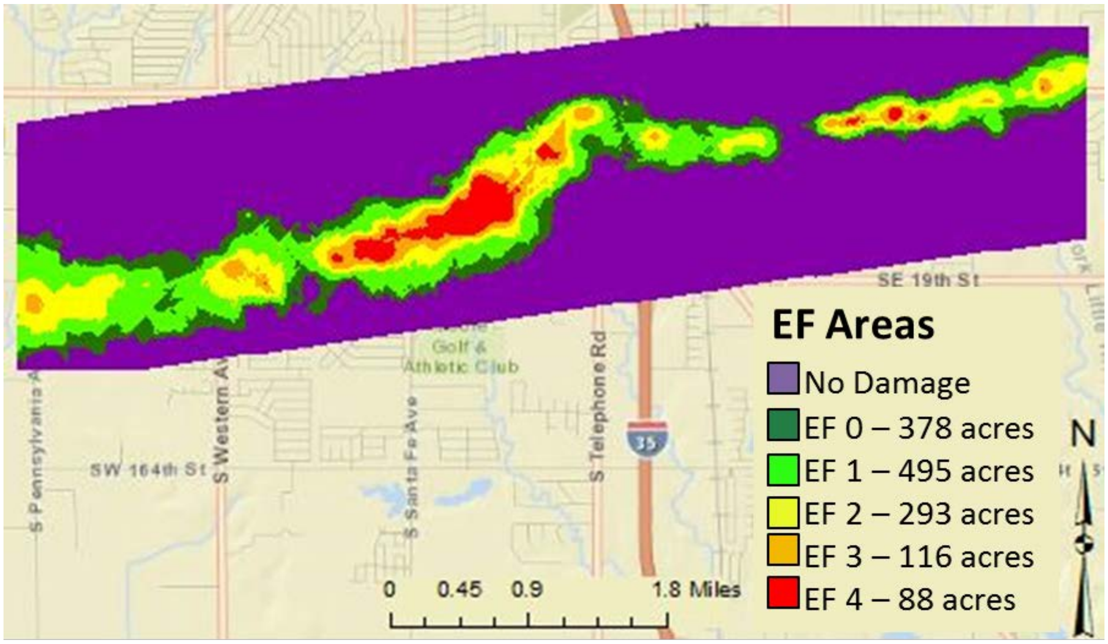


Figure 4.14. Damage contour created for the Moore Tornado.

Table 4.2. Acreage and area percentage of each EF rating in the inspected area.

EF Rating	Area	Percentage of Damaged Area
EF 0	378 acres	27.5 %
EF 1	495 acres	36.1 %
EF 2	293 acres	21.3 %
EF 3	116 acres	8.4 %
EF 4	88 acres	6.4 %

4.3 Conclusion

The case study of the Moore, Oklahoma damage assessment proves that using the damage assessment methodology in Chapter 3 provides a method of data collection, storage, and analysis that is robust and suitable for large scale disasters. The TIP system and GPSExtractor data fusion tools were proved to properly geolocate collected photographs in a GIS map. The web portal was proved to adequately handle GIS maps and layers in a user-friendly environment.

Although the methodology was proven for these datasets, the web portal was not adequate for handling LiDAR data. The point cloud datasets provided by these scans are too large to store in the web portal format, so data compression tools must be researched further that will allow these datasets to be stored and viewed in future damage assessments. The ContourGPS camera was unable to capture photographs near the damage boundaries in the Moore study. This method of data collection is still valid in theory, and tests run in the predeployment phase prove that this is a useful tool for infield data collection. The tests run in the predeployment phase did not familiarize team members with the equipment enough to overcome the problems encountered in the field. This should be a lesson that team members must understand how to use all field equipment before entering the field in order to overcome any problems that may be encountered in the field.

CHAPTER 5

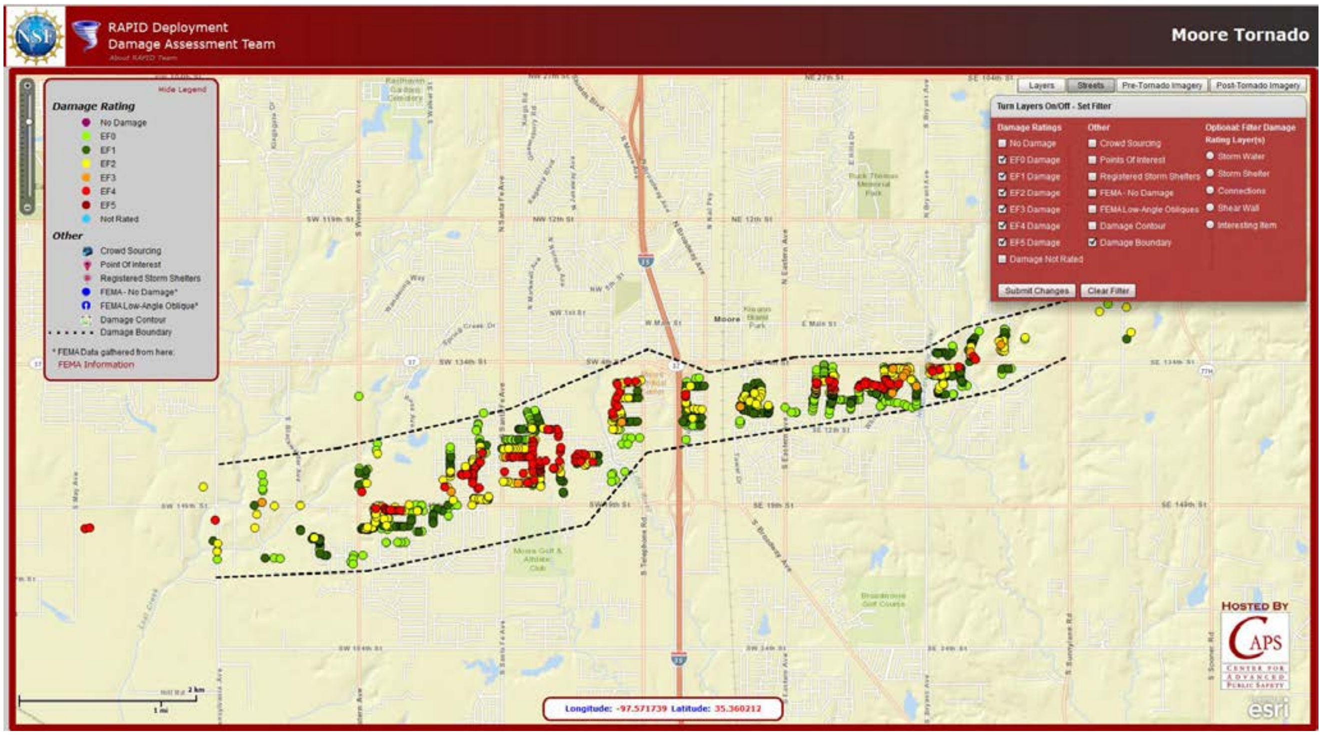
RESULTS

5.1 Introduction

The Moore, Oklahoma damage assessment case study followed all phases of the damage assessment methodology presented herein. The preparation phase included obtaining data collection equipment and periodically performing checks to ensure that the equipment was working properly. The predeployment phase started on May 20th, the day that the tornado damaged the city of Moore. The predeployment phase included assembling a reconnaissance team, procuring funding to cover transportation, locating appropriate housing, collecting basemaps of the affected area including a street map, a pre-event aerial image basemap, and a post-event aerial image basemap, running tests on equipment mimicking the methodology to familiarize users with the equipment and methodology, defining an inspection area, and creating a web portal. The data collection phase lasted from May 27th, 2013 to May 29th, 2013 and included the reconnaissance team dividing into groups, collecting data along transects in the inspection area, using the TIP system and GPSExtractor tool developed at the University of Alabama to geolocate all photographs taken in the field, and uploading these geolocated photographs into the GIS software. The postprocessing phase began on May 30th and continued for several months following the data collection activities. This phase included populating the web portal with the GIS data collected in the field, creating filters to select specific data, procuring datasets of registered storm shelters from the City of Moore, adding pertinent photographs from FEMA, adding crowdsourced photographs from Twitter, creating datasets for the damage boundary, and creating the damage contour.

5.2 Web Portal Overview

The results from the damage assessment are contained in the web portal created for Moore, which allows users to toggle basemaps, datasets, and data filters. Figure 5.1 contains the web portal startup screen for the Moore, OK damage assessment. The map legend is located in the top left corner and explains the labels of each point on the map. Figure 5.2 shows the legend of the map. This legend contains the symbology for each data layer in the webmap and a link to the website where the FEMA datasets were collected. The layers and filters dialog box is located in the top right corner and lists all layers and data filters located on the map. This dialog box is shown in Figure 5.3. Boxes next to each layer label allow the user to toggle the layer on or off. Data filters can be toggled on to show the filter data contained only in the layers which are turned on. To show all points associated with a filter, the user can turn all of the layers on and select the filter. Above the layers and filters dialog box are the basemap layer buttons. This contains the streets basemap, pre-tornado aerial imagery basemap, and post-tornado aerial imagery basemap. Only one basemap can be turned on at a time. The zoom bar is located next to the map legend, and allows the user to zoom in or out of the map.



Turn Layers On/Off - Set Filter

Damage Ratings
- ☐ No Damage
- ☑ EF0 Damage
- ☑ EF1 Damage
- ☑ EF2 Damage
- ☑ EF3 Damage
- ☑ EF4 Damage
- ☑ EF5 Damage
- ☐ Damage Not Rated

Other
- ☐ Crowd Sourcing
- ☐ Points Of Interest
- ☐ Registered Storm Shelters
- ☐ FEMA - No Damage
- ☐ FEMA Low-Angle Obliques
- ☐ Damage Contour
- ☑ Damage Boundary

Optional: Filter Damage Rating Layer(s)
- ○ Storm Water
- ○ Storm Shelter
- ○ Connections
- ○ Shear Wall
- ○ Interesting Item

Figure 5.1. Web portal for the Moore, Oklahoma damage assessment.

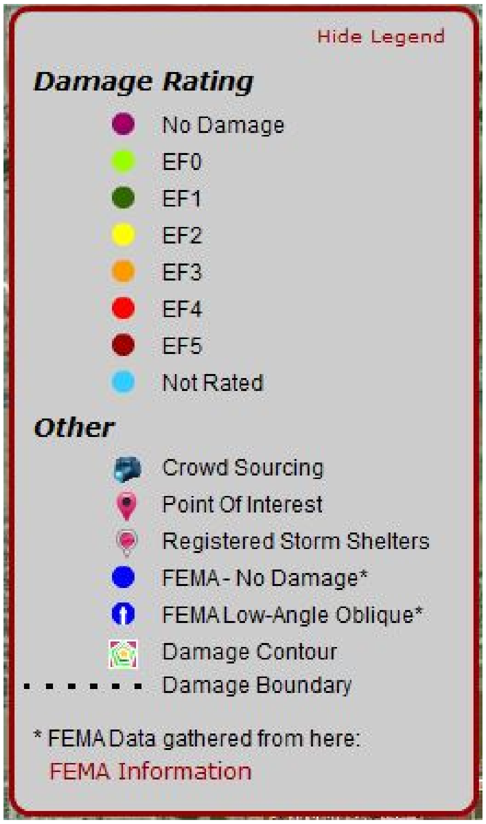


Figure 5.2. Damage assessment map legend containing labels for each layer contained in the map.

Damage Ratings

☐ No Damage
☑ EF0 Damage
☑ EF1 Damage
☑ EF2 Damage
☑ EF3 Damage
☑ EF4 Damage
☑ EF5 Damage
☐ Damage Not Rated

Other

☐ Crowd Sourcing
☐ Points Of Interest
☐ Registered Storm Shelters
☐ FEMA - No Damage
☐ FEMA Low-Angle Obliques
☐ Damage Contour
☑ Damage Boundary

Optional: Filter Damage Rating Layer(s)

○ Storm Water
○ Storm Shelter
○ Connections
○ Shear Wall
○ Interesting Item

Figure 5.3. Layers and filters available in the damage assessment web portal.

The pre- and post-tornado basemaps are useful for comparing damage from an aerial view. The pre- and post-event basemaps of the damaged area with the startup layers displayed on top of the basemaps are shown in Figure 5.4 (a) and (b) respectively. Aerial imagery datasets are limited in showing vertical surfaces of damaged buildings and street-level photography datasets are limited in showing many roofs. The combination of basemaps and collected photography offers simultaneous views of aerial and street-level damage caused by the storm which is important for researchers studying the damage.

Figure 5.4 basemaps of the city of Moore (a) before the tornado and (b) after the tornado. View shown is zoomed in for resolution.

5.3 Moore Storm Shelters

Storm shelters were a research topic because of the history of powerful tornadoes in the city. The storm shelter photographs captured in the Moore damage assessment and the layer of registered storm shelters allowed researchers to perform a thorough analysis of storm shelter statistics, use, and performance in the tornado. Using the inspection photographs of storm shelters and the layer of registered storm shelters, the research team compared locations and revisited collected photography in order to understand the existence of storm shelters in the area. Figure 5.5 shows this view of the web map. The research team found that storm shelters saved lives in many areas of Moore. Many shelters were found in the EF-5 level areas where the damage was most severe. Houses were completely leveled in this area, but the shelters were left intact. One shelter was found in Moore that failed. The shelter was built above ground and was perforated by flying debris. Figure 5.6 shows the photograph of the inside of this storm shelter and the debris that caused the perforation. Research determined that the shelter was not built to FEMA standards and was also located on the outer wall of the house, which is not an ideal location for an above-ground shelter. The result of this research topic suggests that storm shelters have been shown to save lives in these powerful tornadoes.

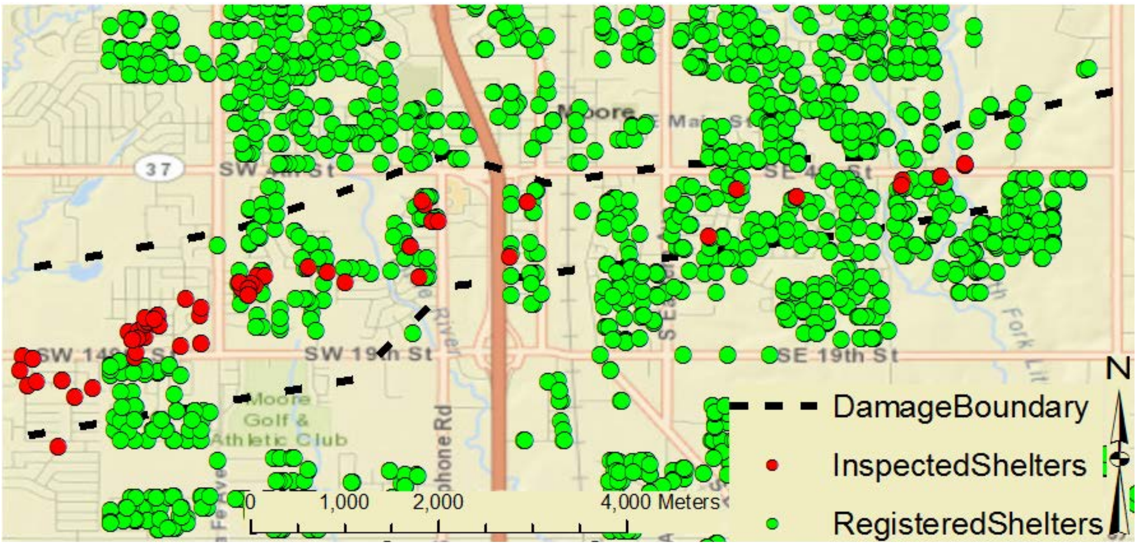


Figure 5.5. GIS map of storm shelters in Moore containing both the layer of inspection photographs taken of storm shelters as well as the layer of registered storm shelters.

Figure 5.6. Above ground storm shelter in Moore that was perforated by flying debris.

5.4 Crowdsourcing photography

Crowdsourcing photography was a research topic for the Moore damage assessment and research on this topic included how inspectors can leverage these sensors in the damage area which provide temporal damage photography to automatically collect data before researchers can access the affected area. The research suggests that contacting social media websites, such as Twitter in the case of the Moore damage assessment, can allow researchers to collect photographs from a specified area surrounding the disaster. Processing the data to filter out photographs which are not useful for research, it was found that this data can be acquired and added as a layer to the web portal. This offers preliminary views of damage which can guide planning and offer research topics before the team enters the damaged area. Figure 5.7 shows the photographs collected from Twitter in the web portal.

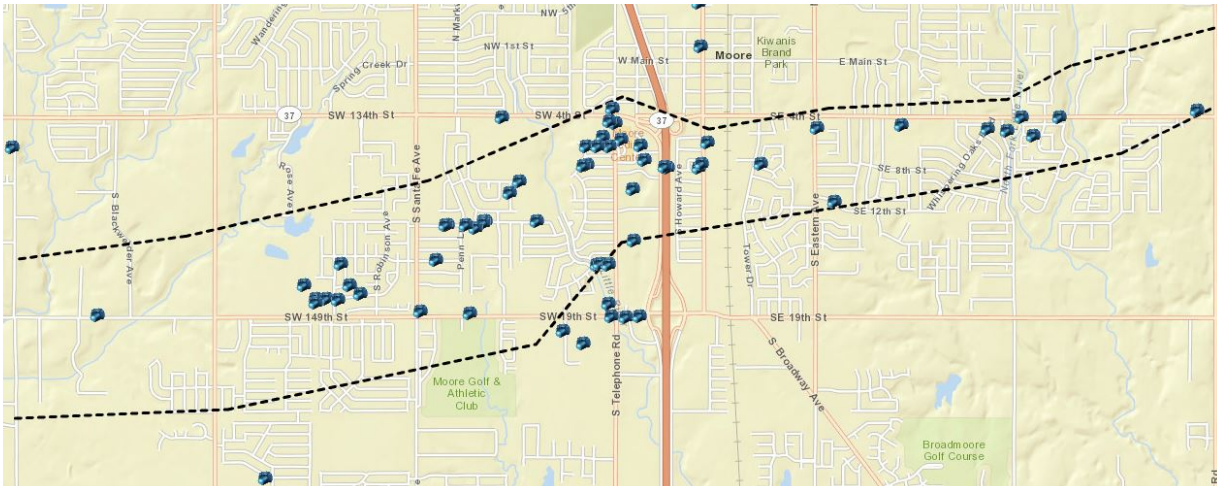


Figure 5.7. Crowdsourcing locations for photographs obtained from Twitter following the Moore damage assessment.

5.5 Damage Contour

The damage contour for Moore was created so that viewers could understand the three-dimensional distribution of damage in the inspection area. The dataset allows the web portal user to locate the level of EF damage at any point in the inspection area. The area of each EF rating was calculated as well as the percent of total damage caused by each rating. Comparing the Moore damage contour to previous contours proved that over 80% of the total damaged area, even in an EF-5 level tornado, is at EF-2 level winds or below. This information allows researchers to offer changes to building codes for tornado-prone areas which stress construction practices suitable to withstand these EF-2 level winds. If policy makers adopt these standards to building codes, cities could save money when these disasters strike because homes will be able to retain structural integrity and stay standing. This will cut down on insurance payouts which will lessen the economic impact of these large scale storms.

5.6 Conclusion

The results contained in this section confirm that the methodology for damage assessment is valid for large scale disasters. This standardized methodology for damage assessment will allow long-term data storage in a web-based format and can be used to revisit data. This data storage format also allows datasets from multiple storms in a similar location to be compared to understand the patterns of disaster for a location. Data collection activities fusing photography and GPS track information were sufficient to geolocate data collected in the field. Postprocessed datasets including analyzed data and auxiliary datasets augment the damage assessment. This thesis can be used by researchers to create a damage assessment for large scale disasters.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

The results of the research illustrate the need for a standardized, research oriented GIS-based damage assessment methodology. This work offers a methodology and proves the methodology through a case study. The methodology contains four phases that begin before the disaster strikes and continues until well after the data has been collected. A web portal created for the damage assessment provides a data storage environment where the damage assessment results can be viewed by researchers as well as the public. This web portal contains temporal damage data and can be revisited in the future. This methodology allows for multiple disaster datasets collected in a similar location to be compared.

The goal of this thesis was to offer a damage assessment methodology and test the accuracy and validity in order to obtain a standardized approach to damage assessment for researchers. Chapter 3 provides an overview of the damage assessment methodology, while Appendix A and Appendix B support the damage assessment methodology by offering users guides for data collection and data contour creation. Chapter 4 describes a case study where the damage assessment methodology was conducted in the wake of the May 20th, 2013 Moore, Oklahoma tornado. This case study includes all phases of the proposed methodology. Chapter 5 states the results of the damage assessment methodology. This chapter also includes all of the layers associated with the damage assessment web portal.

The results of the case study prove that the proposed damage assessment methodology was sufficient to conduct a damage assessment through combining remote sensing photography, track-based GPS units, and GIS software. The results were stored in a web portal which was populated with the GIS data and was able to store multiple datasets collected in the field, created in postprocessing, and obtained from outside sources. While the methodology was sufficient to meet the needs of researchers, future work can be conducted to expand and enhance the results of the methodology.

6.2 Future Work

The damage assessment methodology was applied to a case study where a research team comprised primarily of engineers researched the damage caused by a tornado in Moore. The methodology was created to be applied across different disasters and different fields of study. Damage assessments following different types of disasters and including researchers from different fields of study would further prove that the proposed methodology is a standardized method for researchers to conduct damage assessments. Alternative data collection methods could expand the proposed methodology as well. The case study included various photography datasets, laser scans, and synthesized datasets created in GIS. As new technology emerges, new datasets can be added to the proposed methodology and tested. In the Moore case study, single-family residences were studied as the damage indicators for the storm. To expand the damage assessment for tornadoes, multiple damage indicators, such as light commercial or industrial indicators should be surveyed. This will provide more information about the severity of the storm.

The damage assessment methodology has been proven to be a valid way of documenting damage in an area affected by a large-scale disaster, but not all information collected in the field was loaded into the web portal. Laser scans captured in damaged neighborhoods of Moore were performed, but the amount of data in each scan is very large, and very difficult to convert to a web-based format. Data compression techniques were applied to the laserscans, but no amount of compression allowed the data to be loaded into the web portal. Future damage assessments which find alternate methods of data storage for these large datasets would further enhance the results of the damage assessment.

The direction symbol used for the low aerial oblique photographs was added manually to increase the value of the data. Adding direction to every photograph on the map would be a useful tool for the web portal users. A digital compass could be used to store directional information at certain times. Software similar to the TIP system could be created to match direction information and time to register the direction in which each photograph was captured. In the web portal, many pictures which were taken from the centerline of a road must be analyzed to verify which building in the aerial images matches the building in the photograph. This method would decrease the amount of analysis needed by the user, making the web portal more useful.

The research recommended in this section would increase the accuracy and benefit of the already robust damage assessment methodology. This thesis is offered to future researchers for damage assessment following large scale disasters with the hope that it will benefit and guide the user through the process and produce a useful end result.

REFERENCES

Downton, M. W. & Pielke, R. A. (2005). "How Accurate are Disaster Loss Data? The Case of U.S. Flood Damage." *Natural Hazards*.

Dymon, U.J. (1999). *Effectiveness of geographic information systems (GIS) applications in flood management during and after Hurricane Fran*. Boulder, CO: Natural Hazards Research and Applications Information Center

Eguchi, R. T., Gill, S. P., Ghosh, S., Svekla, W., Adams, B. J., Evans, G., & Spence, R. (2010). The January 12, 2010 Haiti earthquake: A comprehensive damage assessment using very high resolution areal imagery. In 8th International Workshop on Remote Sensing for Disaster Management.

Graettinger, A. J., Grau, D., Van De Lindt, J., & Prevatt, D. O. (2012). "GIS for the Geo-Referenced Analysis and Rapid Dissemination of Forensic Evidence Collected in the Aftermath of the Tuscaloosa Tornado." *Construction Research Congress 2012: Construction Challenges in a Flat World*,ASCE. West Lafayette, In. 2170-2179.

Geranmayeh Kashani, A., Biswas, S., Crawford, P., Graettinger, A., Grau, D. (2014). "Automated Tornado Wind Speed Estimation Based on Damage Data Collected with Terrestrial Laser Scanning." *Journal of Computing in Civil Engineering*.

Isaev, A. S., Korovin, G. N., Bartalev, S. A., Ershov, D. V., Janetos, A., Kasischke, E. S., & Murphy, T. L. (2002). Using remote sensing to assess Russian forest fire carbon emissions. *Climatic Change*, 55(1-2), 235-249.

Kara, B.Y., & Verter, V. (2001). A GIS-based framework for hazardous materials transport risk assessment. *Risk Analysis*.

Kayen, R., Pack, R. T., Bay, J., Sugimoto, S., & Tanaka, H. (2006). Terrestrial-LIDAR visualization of surface and structural deformations of the 2004 Niigata Ken Chuetsu, Japan, earthquake. *Earthquake Spectra*, 22(S1), 147-162.

Moodie, K. (1992). The King's Cross fire: damage assessment and overview of the technical investigation. *Fire Safety Journal*, 18(1), 13-33.

National Weather Service, Tornado Outbreak of May 20, 2013. Retrieved July 2, 2013, from http://www.srh.noaa.gov/oun/?n=events-20130520.

NewsChannel4 Oklahoma City. Interactive Map: 1999, 2003, 2013 Moore Tornadoes. Retrieved December 30, 2013, from http://kfor.com/2013/05/20/interactive-map-1999-2003-2013-moore-tornadoes/.

Pareschi, M. T., Cavarra, L., Favalli, M., Giannini, F., & Meriggi, A. (2000). GIS and volcanic risk management. In *Natural Hazards* (pp. 361-379). Springer Netherlands.

Prevatt, D. O., van de Lindt, J. W., Back, E. W., Graettinger, A. J., Pei, S., Coulbourne, W., ... & Agdas, D. (2012a). Making the Case for Improved Structural Design: Tornado Outbreaks of 2011. Leadership and Management in Engineering, 12(4), 254-270.

Sauer, T., & Boehm, P. (1991, March). The use of defensible analytical chemical measurements for oil spill natural resource damage assessment. In *International Oil Spill Conference* (Vol. 1991, No. 1, pp. 363-369). American Petroleum Institute.

Su, Ming-Daw, et al. "A grid-based GIS approach to regional flood damage assessment." *Journal of Marine Science and Technology* 13.3 (2005): 184-192.

van de Lindt, J. W., Graettinger, A., Gupta, R., Skaggs, T., Pryor, S., & Fridley, K. J. (2007). Performance of wood-frame structures during Hurricane Katrina. *Journal of Performance of Constructed Facilities*, 21(2), 108-116.

Weather Underground, 10 Worst U.S. Tornado Outbreaks. Retrieved July 5, 2013 from http://www.wunderground.com/news/worst-tornado-outbreaks-20130228?pageno=5.

Yamazaki, F. (2001). Applications of remote sensing and GIS for damage assessment. *Structural Safety and Reliability*.

APPENDIX A

STEP-BY-STEP GUIDE TO DATA COLLECTION METHODOLOGY

1. In the predeployment phase, designate one computer to store all of the inspection photographs and download the Time Image Positioning (TIP) software to the computer. Create a folder to store the data collection photographs in. Inside the folder, make subfolders for each data collection date. Inside each date subfolder, create subfolders for each photographer. At the end of each inspection day, photographs collected by each member of the team will be stored in their respective folder. Figure A.1 shows the folder hierarchy.

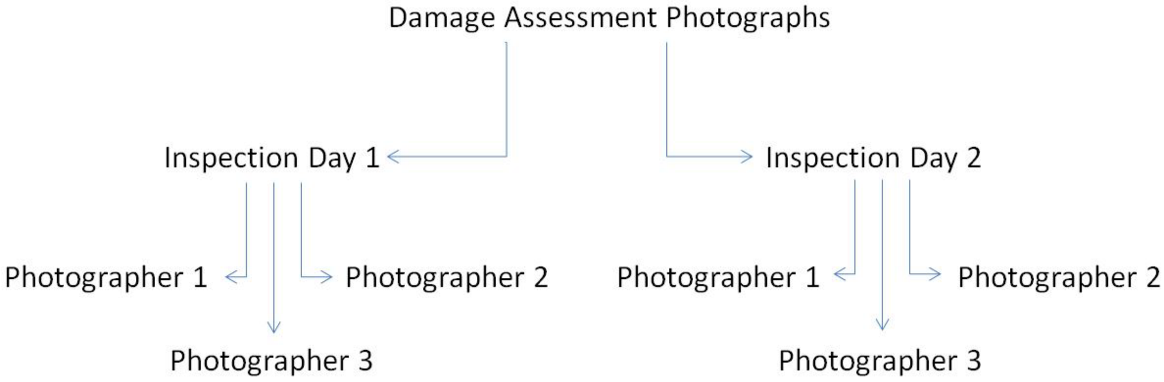
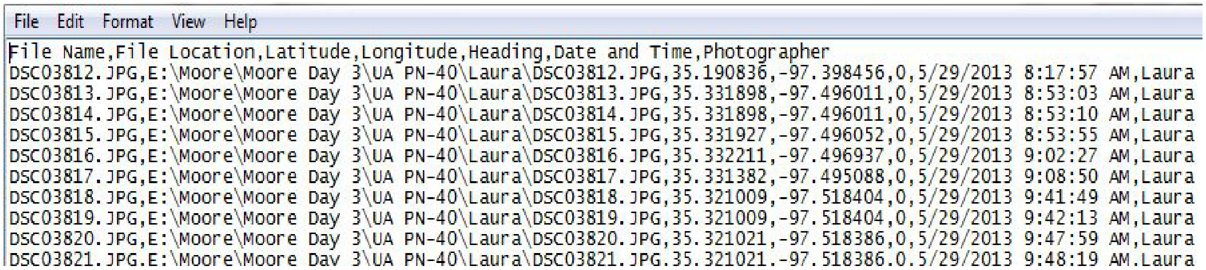


Figure A.1. The hierarchy of data collection photography folders.

2. Each day before arriving to the inspection area, each photographer should take a picture of their GPS device which clearly shows the time on the GPS device. This time will be registered with the time of the photograph in order to correctly geolocate the inspection photographs. This should be the first photograph taken each day.

3. When arriving from the inspection area each day, upload the inspection photographs from each photographer into their corresponding folder. Make sure that the photograph showing the time of the GPS is the first photograph in the folder.
4. Locate the .GPL file stored on each GPS unit. Copy each .GPL file from the GPS units into the folder corresponding to the photographer using that GPS device and the date of inspection. This should be the last file in the folder. Note: if GPS device is not a DeLorme brand GPS, track may be in .GPX format. If so, use an online converter to create a .GPL file.
5. Open the TIP system. Browse and find the first photograph in the folder and add it in the line provided. Browse and find the .GPL file and open it in the line provided. Enter the date and time found on the GPS in the photograph in the lines provided. Enter the photographers name in the line provided. Name the text file that will be created by the system in the line provided. A suggested naming convention is to use the photographers name and the date. Press the convert button to run the software.

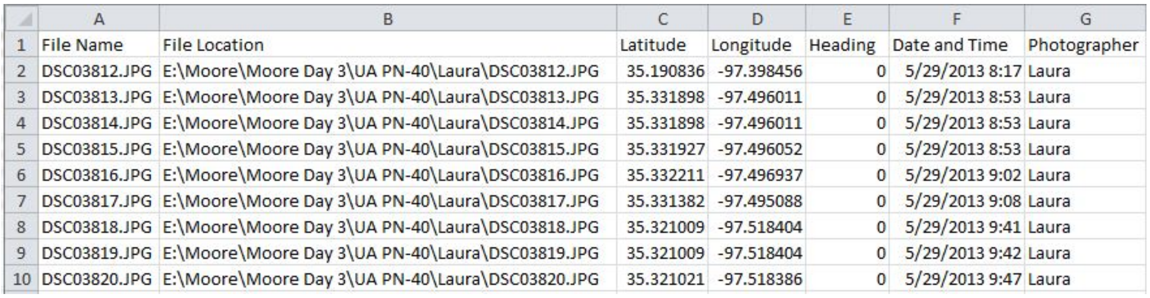
   The TIP system will correct the time from the GPS unit to the time of each photograph and will carry that correction through all of the photographs in the folder, recording the latitude and longitude of each photograph. The system will create a text file in the folder which stores the data. The text file will include headings delimited by commas. The headings are File Name, File Location, Latitude, Longitude, Heading, Date and Time, and Photographer. Figure A.2 illustrates the text file.



```
File Name,File Location,Latitude,Longitude,Heading,Date and Time,Photographer
DSC03812.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03812.JPG,35.190836,-97.398456,0,5/29/2013 8:17:57 AM,Laura
DSC03813.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03813.JPG,35.331898,-97.496011,0,5/29/2013 8:53:03 AM,Laura
DSC03814.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03814.JPG,35.331898,-97.496011,0,5/29/2013 8:53:10 AM,Laura
DSC03815.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03815.JPG,35.331927,-97.496052,0,5/29/2013 8:53:55 AM,Laura
DSC03816.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03816.JPG,35.332211,-97.496937,0,5/29/2013 9:02:27 AM,Laura
DSC03817.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03817.JPG,35.331382,-97.495088,0,5/29/2013 9:08:50 AM,Laura
DSC03818.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03818.JPG,35.321009,-97.518404,0,5/29/2013 9:41:49 AM,Laura
DSC03819.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03819.JPG,35.321009,-97.518404,0,5/29/2013 9:42:13 AM,Laura
DSC03820.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03820.JPG,35.321021,-97.518386,0,5/29/2013 9:47:59 AM,Laura
DSC03821.JPG,E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03821.JPG,35.321021,-97.518386,0,5/29/2013 9:48:19 AM,Laura
```

Figure A.2. Text file output from the TIP system for pictures taken following the Moore, OK tornado.

6. The next step is to convert the text file into an Excel spreadsheet. Open Excel and load the text file created by the TIP system. The Text Import Wizard will open. In Step 1, choose the Delimited button. In step 2, select the Comma in the Delimiters box. Select Next until the Text Import Wizard finishes and the spreadsheet opens. Save the Excel spreadsheet into the folder corresponding to the inspection date and photographer. Repeat this process for each photographer at the end of each day in the field. Figure A.3 illustrates the Excel spreadsheet.



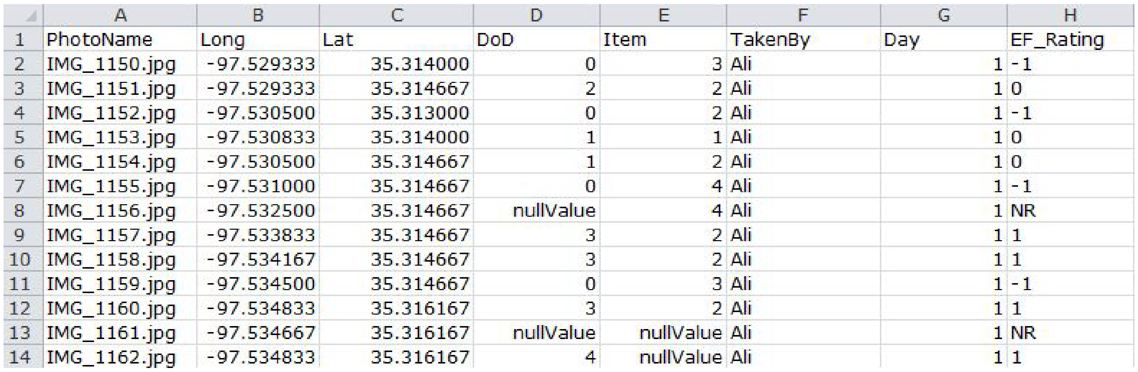
	A	B	C	D	E	F	G
1	File Name	File Location	Latitude	Longitude	Heading	Date and Time	Photographer
2	DSC03812.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03812.JPG	35.190836	-97.398456	0	5/29/2013 8:17	Laura
3	DSC03813.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03813.JPG	35.331898	-97.496011	0	5/29/2013 8:53	Laura
4	DSC03814.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03814.JPG	35.331898	-97.496011	0	5/29/2013 8:53	Laura
5	DSC03815.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03815.JPG	35.331927	-97.496052	0	5/29/2013 8:53	Laura
6	DSC03816.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03816.JPG	35.332211	-97.496937	0	5/29/2013 9:02	Laura
7	DSC03817.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03817.JPG	35.331382	-97.495088	0	5/29/2013 9:08	Laura
8	DSC03818.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03818.JPG	35.321009	-97.518404	0	5/29/2013 9:41	Laura
9	DSC03819.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03819.JPG	35.321009	-97.518404	0	5/29/2013 9:42	Laura
10	DSC03820.JPG	E:\Moore\Moore Day 3\UA PN-40\Laura\DSC03820.JPG	35.321021	-97.518386	0	5/29/2013 9:47	Laura

Figure A.3. Excel database created from the TIP system output text file.

7. When this process has been completed, all of the spreadsheets created for that day can be combined using the copy and paste tool to create a master copy for the day. When the inspection is over, the spreadsheets created for each day can be combined to create a master copy for the inspection trip.

8. At any point in the process, fields can be created or deleted in the spreadsheets. Figure A.4 illustrates the master copy from the Moore, OK damage assessment. Some fields have been deleted. The data in other fields was changed to make it easier to read into

GIS, such as the latitude and longitude fields (labeled long and lat in the master copy). Some fields were created in order to add information to the GIS such as the DoD and EF_Rating columns. The item column relates a photograph to a specific layer in the web portal, such as storm shelter or low aerial oblique.



	A	B	C	D	E	F	G	H
1	PhotoName	Long	Lat	DoD	Item	TakenBy	Day	EF_Rating
2	IMG_1150.jpg	-97.529333	35.314000	0	3	Ali	1	-1
3	IMG_1151.jpg	-97.529333	35.314667	2	2	Ali	1	0
4	IMG_1152.jpg	-97.530500	35.313000	0	2	Ali	1	-1
5	IMG_1153.jpg	-97.530833	35.314000	1	1	Ali	1	0
6	IMG_1154.jpg	-97.530500	35.314667	1	2	Ali	1	0
7	IMG_1155.jpg	-97.531000	35.314667	0	4	Ali	1	-1
8	IMG_1156.jpg	-97.532500	35.314667	nullValue	4	Ali	1	NR
9	IMG_1157.jpg	-97.533833	35.314667	3	2	Ali	1	1
10	IMG_1158.jpg	-97.534167	35.314667	3	2	Ali	1	1
11	IMG_1159.jpg	-97.534500	35.314667	0	3	Ali	1	-1
12	IMG_1160.jpg	-97.534833	35.316167	3	2	Ali	1	1
13	IMG_1161.jpg	-97.534667	35.316167	nullValue	nullValue	Ali	1	NR
14	IMG_1162.jpg	-97.534833	35.316167	4	nullValue	Ali	1	1

Figure A.4. Final Excel database for the Moore damage inspection.

9. When the Excel spreadsheet has been finalized, the information is ready to be input into GIS. For the Moore, OK damage assessment ESRI ArcMap 10.0 was used, so the steps will correspond to this program. Open ArcGIS. Select the Add Data button. Find the Excel spreadsheet and press the Add button. Select the tab of the spreadsheet that the data is located in and add it to the map.
10. In the table of contents, right-click on the layer corresponding to the spreadsheet data and select Display XY Data…. In the window, specify the X field as the longitude column in the spreadsheet and the Y field as the latitude column. Specify <None> for the Z field. Click OK. The geolocated photographs will appear as nodes in the map. Add a basemap to check whether the nodes are in the correct position.

This step-by-step guide started from the predeployment phase of the damage assessment and, using the Time Image Positioning System created at the University of Alabama, allowed inspection photographs to be plotted an a GIS map in the location where the picture was taken.

Once is in the GIS system, the data can be analyzed and manipulated to fit the needs of the investigation. To obtain the TIP system and GPSExtractor tool, contact Dr. Andrew Graettinger at Andrewg@eng.ua.edu.

APPENDIX B

STEP-BY-STEP GUIDE FOR DATA CONTOUR CREATION

1. Load the layer of inspection data into GIS and display the location. Remove any points in this layer that were not rated based on the scale desired for the contour. Add points where the extents of the contour are desired. These points should be labeled as "No Data". When this step is completed, the map should look like Figure B.1.

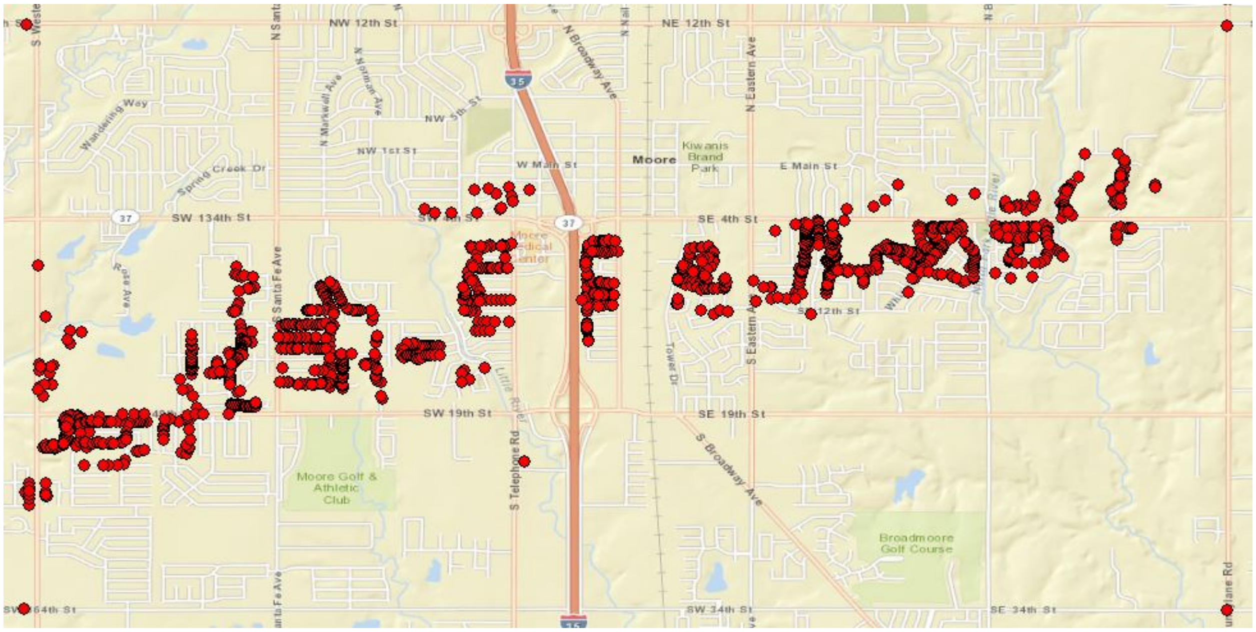


Figure B.1 Collected photographs from the Moore, OK damage assessment. Points labeled "No Damage" have been added at the desired extents of the damage contour.

2. Find the Kriging tool from the Spatial Analyst Toolbar and select it. This will open the Kriging window. In the drop-down menu under the Input point features heading, select the layer of collected points. Under the Z value field, select the damage indicator field. This field must be an integer field in the attribute table. For the Moore damage assessment, the EF rating field was selected. In the Output surface raster field, name the raster output.

3. In the output cell size field, select the size that each cell in the raster should be. This sets the resolution of the raster, and allows the user to easily calculate the area of each damage rating. For the Moore damage assessment, a cell size of 15 ft was specified. The cell value is measured in the units specified on the map. If the map units do not match the desired units, the map data frame can be set in the correct units.
4. There are options to hone the semivariogram as well as the search radius. For this methodology, the preset values are acceptable. Click OK.
5. A raster will appear on the map, but will look very inaccurate. Figure B.2 illustrates what the raster looks like after the kriging tool has been used.

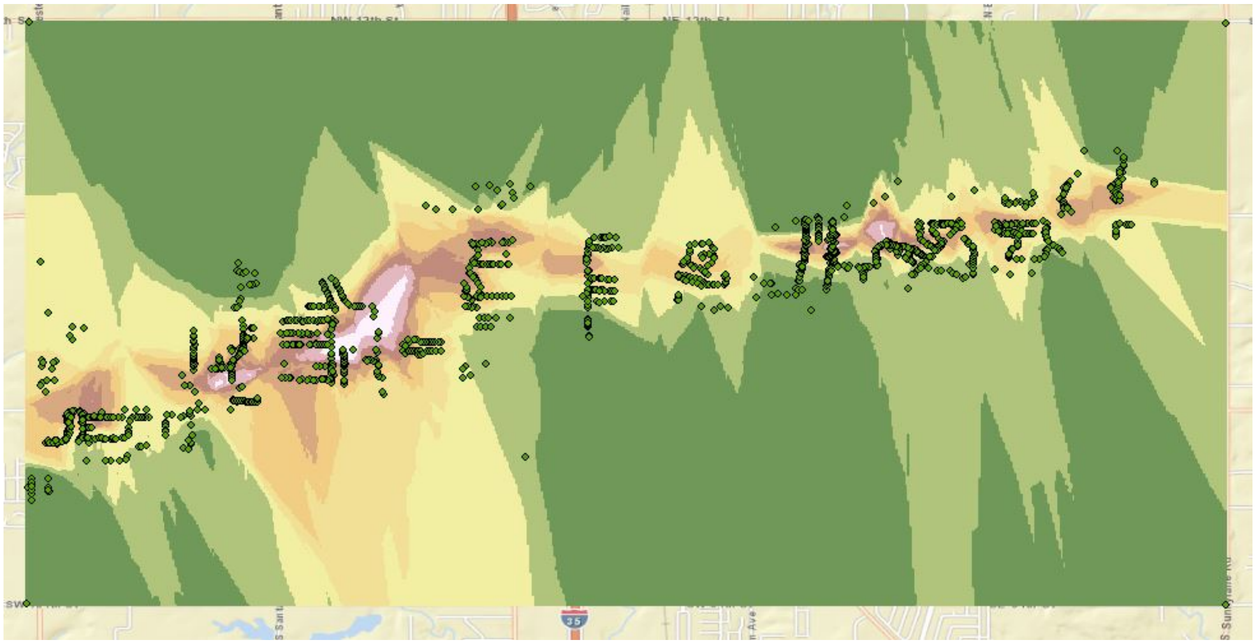
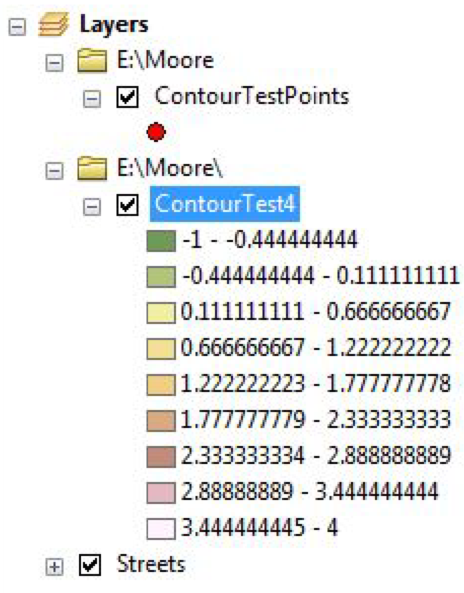


Figure B.2. The raster interpolation created by the Kriging tool. The raster data will need to be processed in order to get an accurate contour.

6. In the Table of Contents, the raster is shown along with the classifications and ranges within each classification. By manipulating these classes and ranges, the contour can be corrected. Figure B.3 shows the output classes and ranges from the Kriging tool.



⊟ Layers
⊟ E:\Moore
⊟ ☑ ContourTestPoints
●
⊟ E:\Moore\
⊟ ☑ ContourTest4
-1 - -0.444444444
-0.444444444 - 0.111111111
0.111111111 - 0.666666667
0.666666667 - 1.222222222
1.222222223 - 1.777777778
1.777777779 - 2.333333333
2.333333334 - 2.888888889
2.88888889 - 3.444444444
3.444444445 - 4
⊞ ☑ Streets

Figure B.3. Table of Contents containing the streets basemap, the collected points, and the raster output from the Kriging tool.

7. Open the Layer Properties window of the raster and select the symbology tab. Under the show heading, make sure the Classified option is selected. In the Classes drop-down menu, select the amount of classes that exist in the damage rating scale being used. For the Moore damage contour 6 classes were selected. These represent EF 0 – EF 4 on the damage rating scale, as well as the no damage rating. Select Apply to change the number of classes.
8. Next, the ranges need to be set. These ranges control the amount of cells that are contained in each class. Select the Classify button. This brings up the classification dialog box. In the break values section, the user can specify the break values desired that will correct the look of the contour. Table B.1 shows the break values used in the Moore damage contour.

Table B.1. Break Values and Cell Counts from the Moore damage contour.

Break Values for the Moore Damage Contour	Cell Count
.3	73214
.8	95968
1.5	56800
2.25	22473
2.9	17085

9. While in the Classification dialog box, the Classification Statistics window can be used to calculate the area of each class. In the Classification Statistics window, Count records the number of cells in each class. By setting the cell size in Step 3, the area of each cell can be multiplied by the number of cells to get the total area of each class.
10. In the methodology tab, the labels and colors for each class can be manipulated by double clicking on the label. Change the class labels to reflect the rating of the damage index.
11. To cut the extraneous areas from the contour, create a polygon shapefile around the desired area of the contour. Locate the Clip tool in the Data Management toolbox.
12. The clip tool requires an Input Raster to be selected. Select the damage contour raster. In the Output Extent box, select the polygon shapefile created in Step 11. Select the Use Input Features for Clipping Geometry button. This button creates a new raster bounded inside the polygon. Name the new raster in the Output Raster Dataset field. Select OK. The new raster is created. Steps 7-10 will need to be repeated in order to correct the new raster. Figure B.4 shows the final Moore, OK damage contour with area values corresponding to each EF value and clipped to a desirable size.

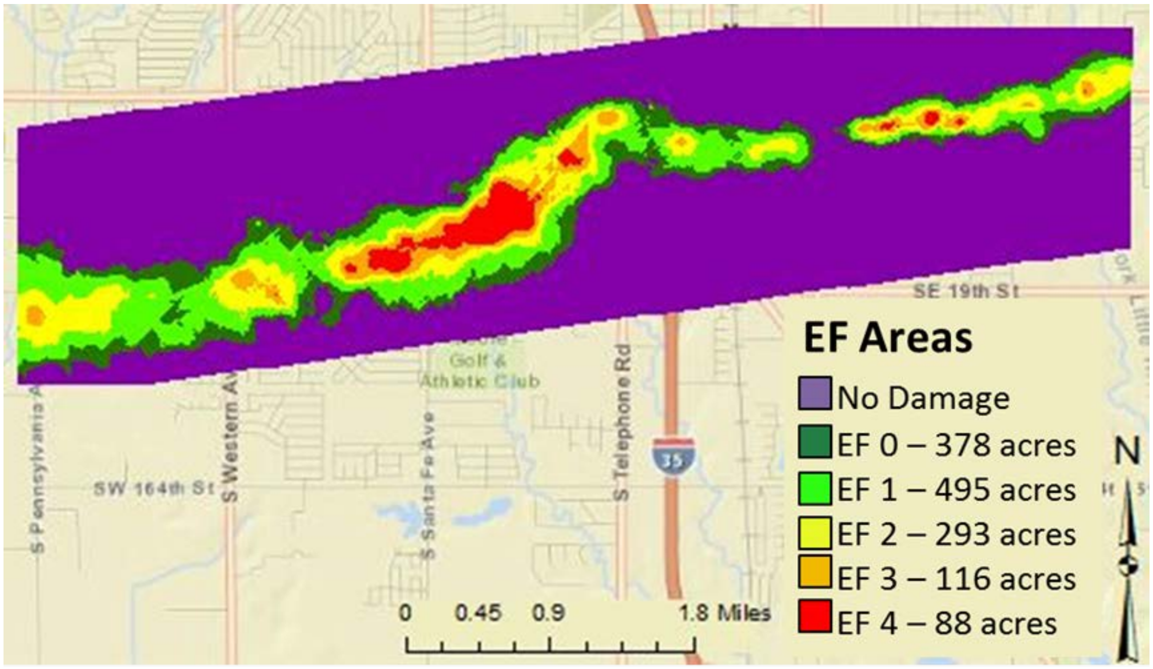


Figure B.4. Final damage contour for the Moore, Ok damage assessment.