TECHNICAL REPORT

Evaluation of Discrimination Technologies and Classification Results – Fort Sill

ESTCP Project MR-201104

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Acronyms

$\beta 1$, $\beta 2$, $\beta 3$	polarizabilities along principal axes of target
σ	standard deviation
BUD	Berkeley UXO Discriminator
CD	cultural debris
cm	centimeter
DAQ	data acquisition computer
DoD	Department of Defense
e^2M	Engineering-Environmental Management, Inc
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
GPS	Global Positioning System
HE	high explosive
HG	hand grenade
Hz	hertz
ID	identification
IDA	Institute for Defense Analyses
ISO	industry standard object
IVS	instrument verification strip
LAW	light anti-tank weapon
LBNL	Lawrence Berkeley National Laboratory
m	meter
MD	munitions debris
MEC	munitions and explosives of concern
mm	millimeter
MPV	man-portable vector
MR	munitions response
N	repeat factor
N_{fa}	number of false alarms
NStack	number of acquisition blocks
OER	Ordnance & Explosives Remediation, Inc.
P_{class}	probability of correct classification
QC	quality control
RCWM	recovered chemical warfare materiel
RI	remedial investigation
RI/FS	remedial investigation and feasibility study
ROC	receiver operating characteristic
RTK	real-time kinematic
RTS	Trimble Robotic Total Station
SERDP	Strategic Environmental Research and Development Program
SLO	Camp San Luis Obispo
T	period
TEMTADS	Time-domain Electro-Magnetic Multi-sensor Towed Array Detection System
TOI	targets of interest
USACE	U.S. Army Corps of Engineers
USB	universal serial bus
UTM	Universal Transverse Mercator
UXO	unexploded ordnance

EXECUTIVE SUMMARY

This report describes in detail the procedures, methods, and resources Parsons used to complete the demonstration project at Fort Sill for Environmental Security Technology Certification Program (ESTCP) Munitions Response (MR)-201104 (Evaluation and Discrimination Technologies and Classification Results) and ESTCP MR-201157 (Demonstration of MetalMapper Static Data Acquisition and Data Analysis). The 2011-2012 ESTCP Unexploded Ordnance (UXO) Classification Study, Fort Sill, Oklahoma, was conducted with two primary objectives:

- Test and validate detection and discrimination capabilities of currently available and emerging advanced electromagnetic induction sensors developed specifically for discrimination on real sites under operational conditions.
- Investigate in cooperation with regulators and program managers how classification technologies can be implemented in munitions and explosives of concern (MEC) cleanup operations.

Parsons had two separate teams working on the project under two different ESTCP project numbers, ESTCP 021104 and ESTCP 201157. One team was responsible for site setup, the placement of 150 seed items for use in measuring the capabilities of the MetalMapper advanced electromagnetic induction (EMI) sensor tested during the project, and the intrusive investigation of the 1,988 targets (including seed items) selected for additional investigation with the advanced sensors. The second team was responsible for the cued survey of those targets with the MetalMapper. These targets were selected from EM61-MK2 data collected during a remedial investigation performed concurrently with, although separately from, the ESTCP demonstration. EM61-MK2 targets were selected in locations designed to test the capabilities of the MetalMapper for an extremely wide range of potential munitions and for much higher anomaly densities than had been present on previous demonstration sites.

The MetalMapper is an advanced EMI system developed by Geometrics, Inc., with support from the ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven triaxial receiver antennas inside the Z (bottom) loop, allowing 21 independent measurements of the transient secondary magnetic field. Data were collected statically, such that one data point was collected for each target selected for investigation. The collected data were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis montaj software. Once analysis was complete, a theoretical ranked dig list (theoretical because all targets were intrusively investigated regardless of demonstrators' stop-dig points) was submitted for scoring by the Institute for Defense Analysis (IDA).

Dig list scoring was based on the number of targets of interest (TOI) correctly identified as items that should be dug and the number of non-TOI or clutter items that were correctly classified as items that did not need to be intrusively investigated. The single dig list submitted by Parsons was scored against the ground truth set compiled following the intrusive investigation. Comparison of the dig list with this ground truth set showed the correct identification of more than 97% of the TOI on site (7 of 290 TOI incorrectly classified as clutter) and a reduction in the amount of clutter that would have been dug by approximately 61%.

The largest implementation issue on the project was a series of recurring software crashes that led to an average production rate of approximately 115 points collected per day with the MetalMapper. The crashes were later attributed to the multi-port serial-to-universal serial bus (USB) adapter used to stream global positioning system (GPS) and inertial movement unit data from the respective instruments into the MetalMapper. Geometrics has since identified a replacement adapter that eliminates the vast majority of the crashes experienced with the unit at Fort Sill. Typical collection rates without crashing problems are on the order of 200 to 300 points per day, depending on target density and terrain. In addition to the software crashes, one of the transmitter boards failed during the project and needed to be replaced. Diagnosis of the problem and shipping/replacement resulted in about 10 hours of project downtime.

1.0 INTRODUCTION

Currently, up to 90% of excavation costs on most unexploded ordnance (UXO) / munitions and explosives of concern (MEC) projects are related to removing scrap metal that does not represent an explosive hazard. Significant cost savings could be achieved through the use of geophysical discrimination methods that could reduce the number of excavations required to remove explosive hazards from sites. The objective of this project is to demonstrate the use of advanced electromagnetic induction (EMI) sensors in static data acquisition mode and associated analysis software. To achieve these objectives, a controlled test was conducted at Fort Sill.

1.1 BACKGROUND

The Fiscal Year 2006 defense appropriation contained funding for the "Development of Advanced, Sophisticated Discrimination Technologies for UXO Cleanup." The Environmental Security Technology Certification Program (ESTCP) responded by conducting a UXO discrimination study at the former Camp Sibert, Alabama. The results of this first demonstration were very encouraging. The conditions for discrimination were favorable at this site and included a single target of interest (TOI; 4.2-inch mortar) and benign topography and geology. All of the classification approaches demonstrated correctly identified a sizable fraction of the anomalies as arising from nonhazardous items that could be safely left in the ground. Both commercial and advanced sensors produced very good results. ESTCP chose Camp San Luis Obispo (SLO), California, as the site for the second study, which provided greater challenges in topography and a wider mix of TOI. Again, the results were very positive, with increased discrimination of TOI versus nonhazardous items. In 2010, the third ESTCP study was conducted at the former Camp Butner, North Carolina, which included smaller TOI than either of the previous sites. Great success was achieved in identifying 37-millimeter (mm) projectiles, fuzes, and larger TOI with the advanced sensors. ESTCP sponsored a fourth study in 2011 at the former Camp Beale, California, a site with a wide range of TOI, moderate to steep terrain, and trees. Previous studies included open field pastures; the study area at Camp Beale included medium-density, wooded areas to provide increasing difficulty to test the high standards established in the previous studies. Additionally, the Camp Beale project included the use of smaller, man-portable EMI sensors such as the Naval Research Laboratory's Time-domain Electro-Magnetic Multi-sensor Towed Array Detection System (TEMTADS) 2x2 cart, Lawrence Berkeley National Laboratory's (LBNL) man-portable Berkeley UXO discriminator (BUD), and Sky Research's man-portable vector (MPV) machine. All of the EMI sensors tested at the former Camp Beale were quite successful in discriminating between TOI and clutter.

The study area at Fort Sill was chosen by ESTCP to test the capabilities of the MetalMapper over a much wider range of potential UXO types than had been present at previous demonstration sites and to test its discrimination capabilities in areas with much higher target densities than were present at previous demonstration sites.

1.2 OBJECTIVES OF THE DEMONSTRATION

This type of approach has the potential to reduce the number of excavations required to effectively remove the explosive safety risk (MEC) at a given site, which would result in significant cost savings related to the closure of formerly used defense sites. The cost savings are expected to be particularly significant at removal action sites. Parsons is currently involved

with U.S. Army Corps of Engineers (USACE) projects at several MEC and recovered chemical warfare materiel (RCWM) sites that could be used for additional testing and refining of the process required for this type of discrimination approach.

1.3 REGULATORY DRIVERS

As part of the cleanup of former Department of Defense (DoD) sites, buy-in is required from regulatory agencies at the federal, state, and local levels. The advancement in classification sensors and their successful deployment at real-world sites needs to be documented for their use to be accepted by the applicable regulatory agencies. Their acceptance of the use of this technology at sites for which they are ultimately responsible will be particularly important because of the potential for DoD budget cuts to reduce the amount of money available for future remedial actions.

2.0 TECHNOLOGY

2.1 TECHNOLOGY DESCRIPTION

The MetalMapper is an advanced EMI system developed by Geometrics, Inc., with support from the ESTCP. The MetalMapper draws elements of its design from advanced systems currently being developed by G&G Sciences, Inc. (supported by Naval Sea Systems Command, the Strategic Environmental Research and Development Program [SERDP], and ESTCP) and by LBNL with support from SERDP and ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven triaxial receiver antennas inside the Z (bottom) loop. Typically, the transmit loops are driven with a classical bipolar pulse-type time domain electromagnetic waveform (i.e., alternating pulse polarity with a 50% duty cycle). Depending on the survey mode (e.g., Static/Dynamic), the fundamental frequency of transmission can be varied over the range $1.11 \leq f \leq 810$ hertz (Hz). The seven receiver antennas allow 21 independent measurements of the transient secondary magnetic field.

The data acquisition computer (DAQ) is built around a commercially available product from National Instruments. The National Instruments DAQ is a full-featured personal computer running Windows 7. The DAQ, electromagnetic transmitter, and batteries for the system are packaged in an aluminum case that can be mounted on a pack frame, on a separate cart such as a hand truck, or on the survey vehicle such a tractor. The instrumentation package also includes two external modules that provide real-time kinematic (RTK) global positioning system location and platform attitude (i.e., magnetic heading, pitch, and roll) data. These modules are connected to the DAQ through serial RS232C ports. A block diagram of the DAQ system is in **Figure 2.1**.

The MetalMapper has two modes of data collection: dynamic and static. Data collected in dynamic mode results in data files containing many data samples. Generally speaking, dynamic mode data are collected while the antenna platform is in motion. Static mode data collection is employed for cued surveys. As its name implies, the antenna platform remains static or motionless during the period of data acquisition. Depending on the acquisition parameters (e.g., sample period and stacking parameter), it can take tens of seconds to complete a static measurement. The results of the static measurement are written into a binary data file containing only a single data point representing the average (stacked) result, usually over tens or even hundreds of repetitions of the transmitter's base frequency.

Data are acquired in time blocks that consist of a fixed number of transmitter cycle "repeats." Both the period (T) and the repeat factor (N) are operator selectable and are varied in multiplicative factors of 3. The MetalMapper also averages an operator-specified number of acquisition blocks (NStacks) together before the acquired data are saved to disk. The decay transients that are received during the off times are stacked (averaged) with appropriate sign changes for positive and negative half cycles. The decays in an individual acquisition block are stacked, and the decays in that block are averaged with other acquisition blocks (assuming the operator has selected NStack greater than one). The resultant data are saved as a data point. The typical configuration of the instrument used for collecting cued data is shown in **Figure 2.2**.

Figure 2.1: DAQ and DAQ Functional Block Diagram

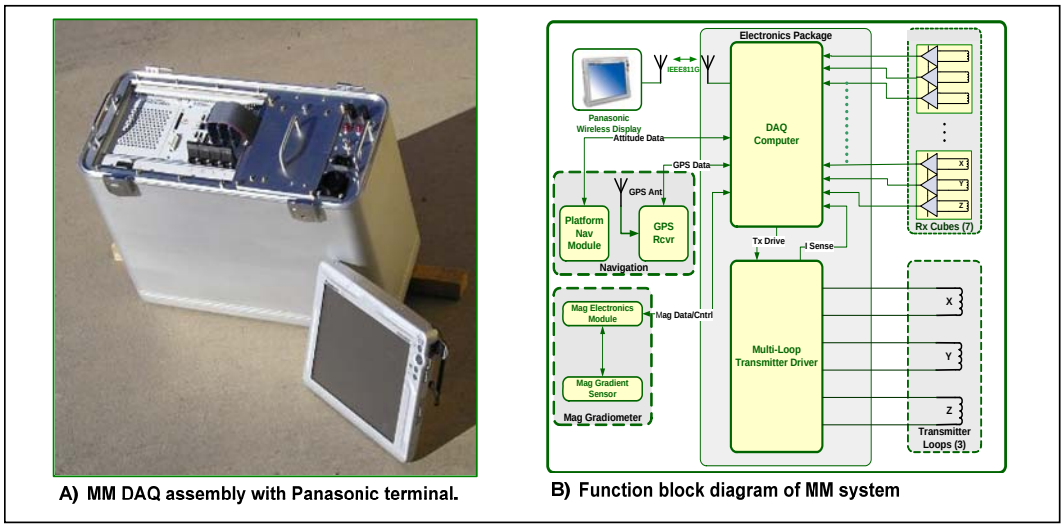
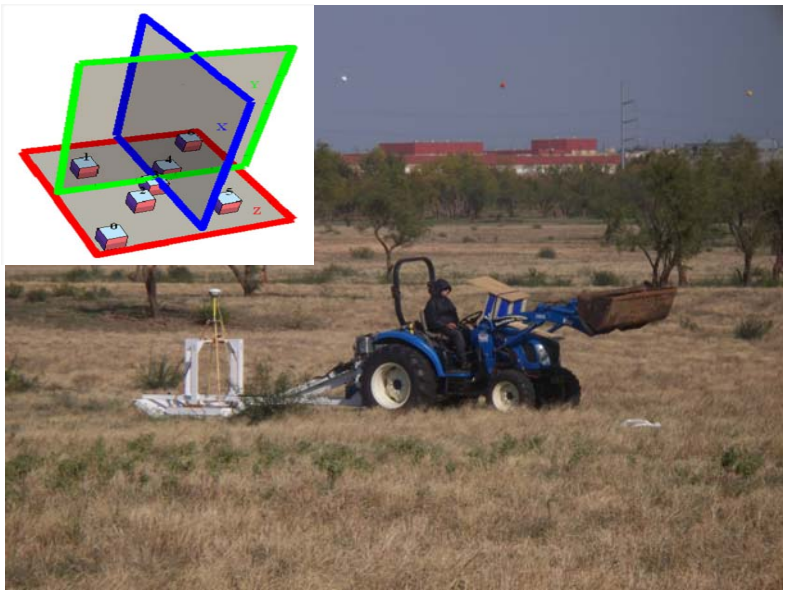


Figure 2.2: Antenna Array and Typical Deployment of the MetalMapper System



In its present (third generation) form, the MetalMapper technology has been demonstrated and scored at the Standardized UXO Technology Demonstration sites at the Yuma Proving Ground (blind grid only), at Aberdeen Proving Ground (blind grid plus direct fire and indirect fire areas), at SLO and Camp Butner in connection with 2009 and 2010 classification studies, and at Camp Beale during 2011 live site demonstrations carried out by ESTCP. The performance of the MetalMapper at these sites is documented in formal reports issued by the Aberdeen Test Center and by the various demonstrators who analyzed the data collected at SLO, Camp Butner, and Camp Beale.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

There are a few advanced EMI sensors that are similar to the MetalMapper in theory, design and size, with the most comparable being the TEMTADS 5x5 and the full-size BUD. The TEMTADS 5x5 consists of 25 pairs of transmit/receive coils oriented in a 5x5 grid pattern, about 2 meters (m) to a side. The BUD is composed of three orthogonal transmitters and eight pairs of differenced receivers. These instruments have been part of the ongoing ESTCP classification demonstrations, and similar results have been documented for all three during previous projects. The main advantage of the MetalMapper is that it is currently commercially available, while the other two advanced EMI sensors are generally only used by the organizations that developed them. As discussed in Section 1.1, other man-portable EMI sensors were tested successfully at Camp Beale. As with the TEMTADS 5x5 and the BUD, these sensors are not yet commercially available.

The greatest limitation of the MetalMapper is its size—both of the sensor itself and of the accompanying computer, screen and cables. The system is designed primarily for use in relatively flat, open fields and cannot currently be used effectively in wooded areas.

3.0 PERFORMANCE OBJECTIVES

The primary performance objectives for this demonstration include:

- Evaluating whether classification techniques will work at the Fort Sill site
- Evaluating where classification techniques will work at Fort Sill
- Evaluating the cost effectiveness of classification techniques in the areas at Fort Sill where classification is determined to be effective

The specific performance objectives for this demonstration are summarized in **Table 3.1**.

3.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

The reliability of the survey data depends on the proper functioning of the survey equipment. This objective concerns the twice-daily confirmation of sensor system performance.

3.1.1 Metric

The metrics for this objective were the distance between the modeled and actual locations of the seed items in the instrument verification strip (IVS) and the classification results for each point collected over an IVS seed.

3.1.2 Data Requirements

Twice daily surveys of the IVS were used to judge this objective.

3.1.3 Success Criteria

This objective was met if the modeled X and Y locations of the IVS seed items are within 15 centimeters (cm) of the actual locations, if the depth (Z direction) is within 10 cm of the actual burial depth, and if the seed items are classified as the correct munition type.

3.2 OBJECTIVE: SUCCESSFUL REAQUISITION OF TARGETS WITH THE METALMAPPER

Data collected directly over target source items should lead to a high probability of detecting the TOI at the site.

3.2.1 Metric

The metric for this objective was the distance between the center of the MetalMapper when cued data is collected and the modeled location of the source item.

3.2.2 Data Requirements

The center of the MetalMapper was determined following pre-processing of the MetalMapper data and was a function of the Global Positioning System (GPS) position measured when the data was collected and the attitude (pitch and roll) of the sensor. The modeled location of the source item was determined following initial inversion of the data.

Table 3.1: Performance Objectives for This Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
Repeatability of instrument verification strip (IVS) measurements	Measured target locations Correct classification of IVS seeds	• Twice-daily instrument verification strip survey data	X, Y < 15 cm (1σ) Z < 10 cm (1σ) IVS seed item identified correctly
Successful reacquisition of targets with MetalMapper	Offset between collection and modeled target locations	• GPS-located collection location • Modeled target location	95% of original or re-shot target locations <40 cm from modeled locations
Analysis and Classification Objectives			
Maximize correct classification of targets of interest (TOI)	Number of TOI retained	• Prioritized anomaly lists • Scoring reports from Institute for Defense Analyses (IDA)	Approach correctly classifies all TOI
Maximize correct classification of non-TOI	Number of false alarms eliminated	• Prioritized anomaly lists • Scoring reports from IDA	Reduction of false alarms by > 50% while retaining all TOI
Specification of no-dig threshold	Probability of correct classification and number of false alarms at demonstrator operating point	• Demonstrator-specified threshold • Scoring reports from IDA	Threshold specified by the demonstrator to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as "Unable to Analyze"	• Demonstrator target parameters	Reliable target parameters can be estimated for > 98% of anomalies on each sensor's detection list
Correct estimation of target parameters	Accuracy of estimated target parameters	• Demonstrator target parameters • Results of intrusive investigation	X, Y < 15 cm (1 standard deviation [σ]) Z < 10 cm (1σ)

3.2.3 Success Criteria

The objective was considered to be met if 95% of the collection locations (either original collection locations or re-shots collected due to excessive offsets) were within 40 cm of the modeled locations.

3.3 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

One of the two main objectives of this demonstration was to correctly classify all seeded items and any MEC remaining at the site as TOI.

3.3.1 Metric

The metric for this objective was the number of items on the MetalMapper anomaly list that were correctly classified as TOI.

3.3.2 Data Requirements

Following data collection, MetalMapper data was analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) Non-TOI, or 3) Can't Analyze. The targets classified as either TOI or Can't Analyze were considered "dig" targets. Institute for Defense Analyses (IDA) personnel used their scoring algorithms to assess the results.

3.3.3 Success Criteria

The objective was considered to be met if all of the items of interest were correctly labeled as TOI on the prioritized anomaly list.

3.4 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This was the second of the two primary measures of the effectiveness of the classification approach. In addition to correctly classifying TOI, the effectiveness of the MetalMapper in discriminating munitions was a function of the degree to which responses that did not correspond to TOI could be eliminated from consideration during the intrusive investigation.

3.4.1 Metric

The metric for this objective was the number of targets on the ranked anomaly list created using the MetalMapper data that were be correctly classified as Non-TOI.

3.4.2 Data Requirements

Following data collection, MetalMapper data was analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) Non-TOI, or 3) Can't Analyze. The targets classified as Non-TOI were considered "no dig" or non-TOI targets. IDA personnel used their scoring algorithms to assess the results.

3.4.3 Success Criteria

The objective was considered to be met if more than 50% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI above the dig threshold.

3.5 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis, as was performed in this demonstration, it is possible to tell the true classification capabilities of a classification procedure based solely on the ranked anomaly list submitted. In a real-world scenario, all targets may not be dug, so the success of the approach depended on the ability of an analyst to accurately specify the dig/no-dig threshold.

3.5.1 Metric

The probability of correct classification, P_{class}, and number of false alarms, N_{fa}, at the dig/no dig threshold in the prioritized dig list were the metrics for this objective.

3.5.2 Data Requirements

Following data collection, MetalMapper data was analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) Non-TOI, or 3) Can't Analyze. The category into which each target was placed was determined using a decision statistic developed during analysis of the MetalMapper data. The dig/no dig threshold for this project was the decision statistic value that separated targets classified as TOI from those classified as Non-TOI. IDA personnel used their scoring algorithms to assess the results.

3.5.3 Success Criteria

The objective was considered to be met if more than 50% of the non-TOI items were correctly labeled as Non-TOI while retaining all of the TOI at the specified threshold.

3.6 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters could not be estimated using the collected MetalMapper data could not be classified. These anomalies were placed in the dig category, which reduces the effectiveness of the classification process.

3.6.1 Metric

The number of anomalies for which reliable parameters could not be estimated was the metric for this objective.

3.6.2 Data Requirements

Those targets for which parameters could not be reliably estimated were identified as such on the prioritized dig list submitted following analysis of the MetalMapper data.

3.6.3 Success Criteria

The objective was considered met if reliable parameters could be estimated for > 98% of the targets on the prioritized dig list.

3.7 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that were estimated in the first phase of the analysis. Successful classification is only possible if the input features are internally consistent. The obvious way to satisfy this condition is to estimate the various target parameters accurately.

3.7.1 Metric

Accuracy of estimation of target parameters is the metric for this objective.

3.7.2 Data Requirements

Target parameters were provided as part of the final results submission. These estimated parameters were compared to those measured during the intrusive investigation.

3.7.3 Success Criteria

The objective was considered to be met if the estimated X, Y locations were within 15 cm (1 standard deviation [σ]) and the estimated depths were within 10 cm (1σ).

4.0 SITE DESCRIPTION

Fort Sill was chosen as the next in a progression of increasingly more complex sites for demonstration of the classification process. The first site in the series, former Camp Sibert, AL, had only one TOI (4.2-inch mortar), and item "size" was an effective discriminant; moreover, this site involved benign topography and geology. Additional demonstrations were conducted at Camp SLO, CA; Camp Butner, NC; the Pole Mountain Target and Maneuver Area, WY; and Camp Beale, CA. Each site added complications such as an increased number of munitions types (including smaller munitions generally more difficult to identify from munitions fragments) and/or more difficult topographic (i.e., hills and trees) or geologic conditions.

The study area at Fort Sill was chosen by ESTCP to test the capabilities of the MetalMapper over a much wider range of potential UXO types and in areas with much higher target densities than had been present at previous demonstration sites. Fort Sill is an approximately 94,000-acre site in Comanche County, OK (Figure 4.1). The seeding and demonstration were conducted in four grid locations within the active Rocket Pond Remedial Investigation/Feasibility Study (RI/FS) Area (554.62 acres). Grids were selected based on EM61-MK2 data collected in June and July 2011 during an ongoing RI/FS.

4.1 SITE SELECTION

Grids were selected as follows:

I03, L04, and K04: These three grids are on the edges of known firing range target areas. Portions of these grids contain very high target densities, including areas where picking individual targets would be considered impossible using the EM61 data. In a typical removal action, a mag and dig or scrape and sift operation would be considered necessary before re-mapping with an EM61 to select any remaining targets. For this project, targets were picked on larger peaks in these areas, although the target lists are by no means comprehensive. A subset of the targets in these areas was investigated using the MetalMapper to determine the effectiveness of the instrument in an extremely high-target-density area. It was expected that the overlapping signatures of numerous subsurface sources would have a detrimental effect on data quality and usability in these areas. All targets outside of the extremely high density areas were investigated, with the goal of finding a target density threshold at which the MetalMapper was no longer able to successfully discriminate targets.

I01: This grid is northwest of a known target area and had a relatively high number of targets. However, the vast majority of these targets were single-point targets that could be investigated without the need for a mag and dig operation. It was also expected that many of these would be MEC related, given their proximity to an area where numerous 40-mm grenades were found during RI/FS surface sweeps.

C09: Area of low target density. It was expected that few, if any, of the targets in this area will be MEC related. Investigation of targets in this grid is expected to show the usefulness of the MetalMapper in identifying sources that would not need to be intrusively investigated during a removal action.

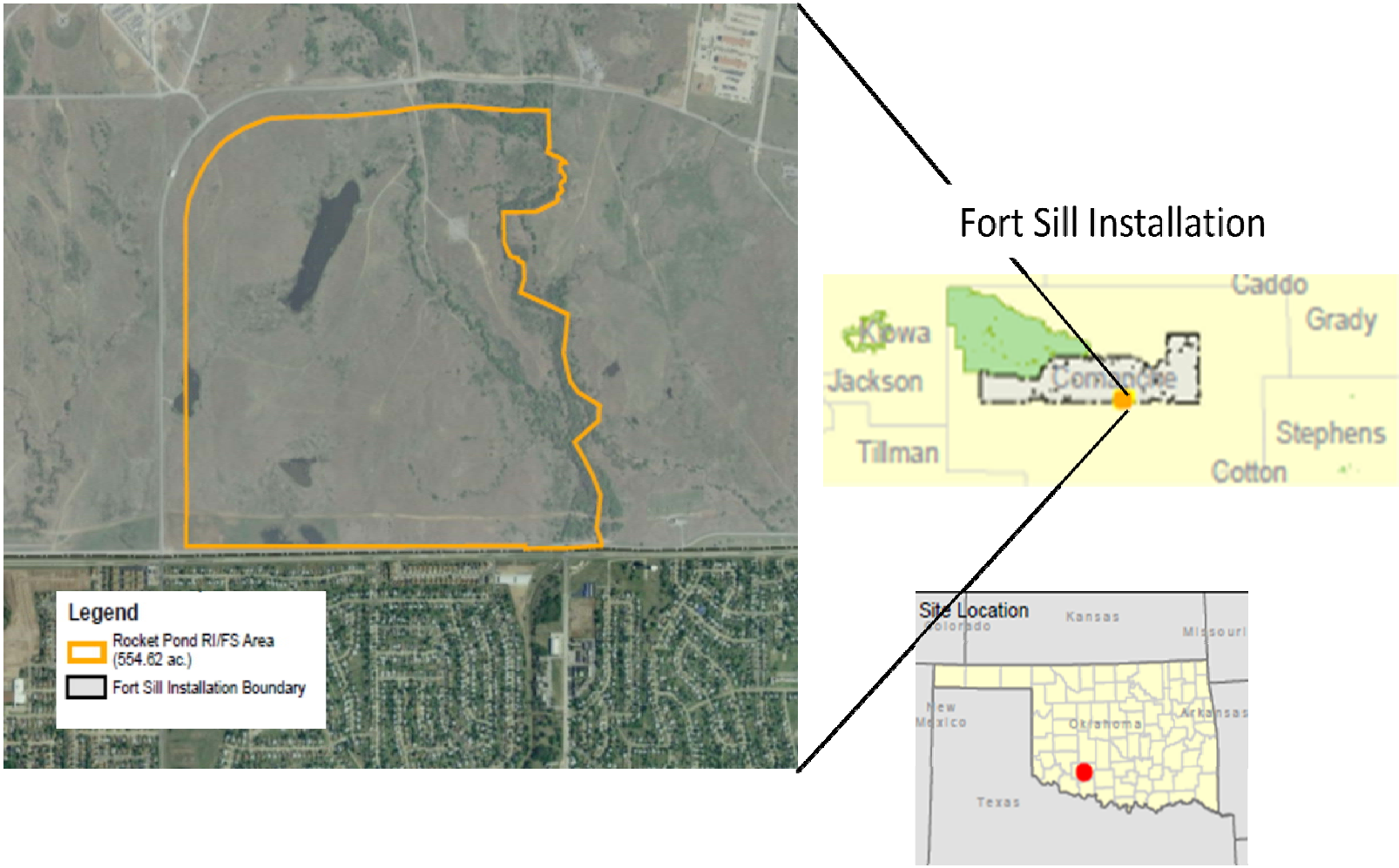


Figure 4.1: Location of Demonstration Study
Four grid locations to be placed within Rocket Pond RI/FS Area.

4.2 BRIEF SITE HISTORY

Fort Sill was originally called Camp Wichita and was created in 1869 by Major General Philip H. Sheridan, who led a campaign into Indian territory to stop hostile tribes from raiding border settlements in Texas and Kansas. Major Sheridan later renamed it in honor of Brigadier General Joshua W. Sill, killed during the Civil War. In 1901, the City of Lawton was established along the southern boundary of Fort Sill. The Fort Sill mission has changed from cavalry to field artillery and air defense artillery. Fort Sill is currently an active military installation. The Wichita Mountains National Wildlife Refuge is along the northwest boundary of the installation. Oklahoma City is about 90 miles northeast of Fort Sill, and Dallas-Fort Worth is approximately 180 miles south. The 52nd Street MEC Clearance Area (156.91 acres) is adjacent to former ranges within the Rocket Pond Area (554.62 acres of active RI/FS area), which was used for weapons systems training involving 40-mm grenades, 66-mm light anti-tank weapon (LAW) rockets, and 2.36-inch and 3.5-inch rockets

4.3 SITE GEOLOGY

Fort Sill lies in the Rolling Red Plains and Rolling Red Prairies Land Resource Areas. The Wichita uplift consists of a central mass of igneous rocks, which is partially surrounded unconformably by a thick section of Cambrian and Ordovician sandstone and limestone. The Post Oak conglomerate underlies the major portion of the installation west of East Cache Creek. It is composed of rhyolite and granite porphyry conglomerates of Permian Age. The granite boulder conglomerate in the west grades into the rhyolite porphyry conglomerate in the east. Both are coarsest in texture near the mountains and become finer to the south. The Permian Hennessey Group is composed mainly of red to gray shale with some fine-grained sandstone. This is the predominate formation east of Cache Creek. It overlies the Garber sandstone. Sand, gravel, and cobbles with numerous rock outcrops occur in the uplands of the Wichita Mountains, which dominates the mid to northwestern area of Fort Sill (Engineering-Environmental Management, Inc. [e^{2}M], 2005).

4.4 SITE SOIL

The mid to southern part of Fort Sill, where the intrusive investigation area is located, is dominated by silty clay soils of low to high plasticity. The soils on the creek floodplains are commonly silty clay or clayey silt with a clay pan and low to medium plasticity. A clay pan is commonly developed in the soil. The Lawton soil series is commonly found on the nearby level to rolling upland plains. The soil in the western part of Fort Sill generally has a clay subsoil. The eastern portion also generally has a clay subsoil, which is developed on sandstone and shale with low to medium plasticity (e^{2}M, 2005).

4.5 MUNITIONS CONTAMINATION

Prior to any intrusive investigation in the area, munitions suspected in the demonstration area included, but are not limited to:

- 20-mm cartridges
- 40-mm cartridges
- Hand grenades

- 37-mm projectiles
- 40-mm projectiles
- 60-mm projectiles
- 75-mm projectiles
- 2.36-in rockets
- 3.5-in rockets
- 66-mm LAW rockets
- Fuzes (grenade, projectile, and rocket)

4.6 SITE CONFIGURATION

The demonstration site is made up of five grid locations within the Rocket Pond RI/FS area: C09, I01, I03, K04, and L04. The study used EM61-MK2 data collected as part of the remedial investigation (RI) for Fort Sill to avoid existing anomalies during burial of the seed items. The demonstration area is shown in Figure 4.2.

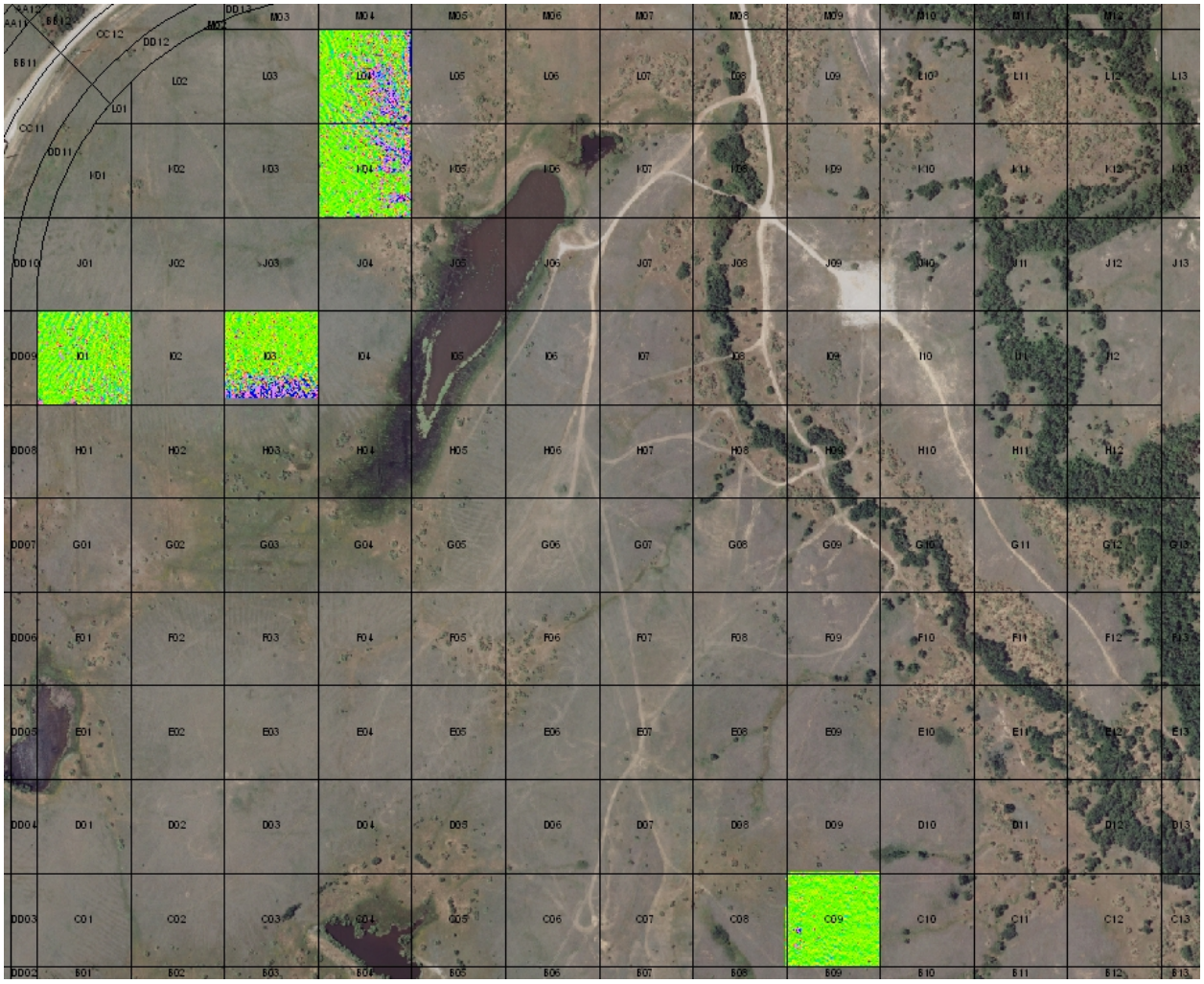


Figure 4.2: Grids and EM61 Data to Be Used for Selecting Targets for Cued MetalMapper Surveys

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this program was to demonstrate a method for using classification in the munitions response process. The three key components of this method are 1) collection of high-quality geophysical data and principled selection of anomalous regions in those data, 2) analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties, and 3) the use of those parameters to construct a ranked anomaly list.

The initial geophysical data collection was performed as part of the ongoing Rocket Pond RI/FS. The ESTCP Program Office coordinated the selection of anomalies for analysis from the geophysical data set collected in the demonstration and compiled a master anomaly list.

Cued MetalMapper data was collected over all targets on the master anomaly list to extract target parameters. These parameters were passed to a classification routine which, after training on a limited amount of site-specific ground truth, was used to produce a prioritized anomaly list.

Validation digging was then performed for all anomalies on the master anomaly list. The underlying target(s) were to be uncovered, photographed, located with a cm-level GPS system, and removed. Ground truth data was then requested for classification training, if necessary.

At the conclusion of training, an initial ranked anomaly list was submitted. This list was ordered from the item deemed most likely to be a munition through the item deemed most likely to be not hazardous. It also included the threshold constituting the dig/no-dig point in the list. Targets for which meaningful parameters could not be extracted were placed at the top of the list. Dig results from the first round of digging were provided before the construction of a final ranked anomaly list, with each anomaly marked dig or no-dig. These final inputs were scored by the IDA with emphasis on the number of items that are correctly labeled nonhazardous while correctly labeling all TOI.

The primary objective of the demonstration was to assess the order of the ranked anomaly list and the ability to specify the threshold separating high-confidence clutter from all other items. The secondary objective was to determine the classification performance that could be achieved through a retrospective analysis.

5.2 SITE PREPARATION

5.2.1 Survey of Historical Records

Much of the historical information on this site has been summarized in the *Final Work Plan for Rocket Pond Remedial Investigation / Feasibility Study*(Parsons, 2011).

5.2.2 Acquire Site-Specific Information

The demonstration site falls within the Rocket Pond RI/FS Area. The range has formerly been described as being used for 40-mm grenade, 66-mm LAW, and 2.36-inch and 3.5-inch rocket weapons system training. These weapons, along with the ones listed in Section 4.5, were recovered during the RI/FS project or are suspected to be present at the site. Due to the historical

usage of this site over many years it is also likely that other munitions types beyond those listed above may be encountered.

5.2.3 First-Order Navigation Points

It is important that all survey data and validation activities be conducted on a common coordinate system. Two first-order survey monuments exist at the site. The points are labeled Grierson 1945 and Lawton North Base, their coordinates are given in Table 5.1.

Table 5.1: Geodetic Control Locations

ID	Latitude	Longitude	Elevation NAVD88 (m)
Grierson 1945	34°39'26.39988"N	098°25'43.74497"W	378
Lawton North Base	34°38'43.87655"N	098°25'20.13066"W	369.47

5.2.4 Surface Clearance

As part of the RI/FS, UXO personnel conducted instrument-aided surface clearance before the digital geophysical mapping surveys. The main objective of the surface clearance was to ensure that no hazardous items would be encountered before the nonintrusive phases in the demonstration area and to remove metallic surface debris from the grids. In addition to the surface clearance, minor brush clearing was also performed, including cutting low-lying branches and removing fallen trees from the demonstration area. A more detailed summary of the surface clearance operations and results can be found in the RI/FS (Parsons, 2013).

5.2.5 Initial EM61 100% Coverage Survey

As part of the site selection process, the ESTCP Program Office used the 100% coverage EM61 survey of the site performed under the RI for Fort Sill. These data were used to define the final demonstration site and guide the seed plan.

5.2.6 Seeding Operation

At a live site such as this, the ratio of clutter to TOI is such that only a small number of TOI may be found in the investigation area—far from enough to determine classification performance with acceptable confidence bounds. To avoid this problem, the site was seeded with enough TOI to ensure reasonable statistics.

Parsons conducted seeding operations at Fort Sill on September 8 and 9, 2011. The seeding operation covered approximately 5 acres in the five RI grids selected for use in the demonstration. The location of each seed item was established with a Trimble R8 RTK GPS system. The base station control point used for this operation was established for the RI/FS project in Universal Transverse Mercator (UTM) Zone 14N, WGS84 coordinates. Seed items were received from Army Research lab in Welcome Maryland, Huntsville Army Corp office and the Hawthorne Ordnance Museum in Hawthorne, Nevada. Small industry standard objects (ISOs) were ordered from McMaster Carr.

Parsons flagged 150 locations with the Trimble GPS and Robotic Total Station (RTS) units and established anomaly avoidance at each location to ensure a clean area for emplacement. All 150 seed locations were dug to proper size and depth. Digging operations involved both mechanical and manual procedures to meet exact specifications and to minimize burial evidence. Before emplacement, magnetic north was determined. Once magnetic north was established, the seed item was positioned with the nose pointing to the exact azimuth and dip angle specified to Parsons. The dip angle specifications were set to a 45-degree tolerance in which the exact angles were measured with a level. Exact angles above horizontal and below horizontal were recorded. After all the emplacement requirements of depth, inclination, dip angle, length, and location were completed, a photo was taken of the seed item in the burial location. All the emplacement information along with the seed item and north direction is visible in the photos.

Seed location holes were not backfilled until final quality control (QC) checks were complete. QC checks consisted of comparing the location with the original designated location; capturing the center location of the emplaced seed item with GPS; and checking the depth, inclination, and dip angle of each seed item. Once these checks were complete, the hole was backfilled with a shovel to prevent any excess movement of the seed items.

Seed items for the Fort Sill demonstration project included 37-mm projectiles, 2.36-inch rockets, 40-mm projectiles, MKII hand grenades (HG), flare canisters, LAW rocket motors, and small ISOs. A list of the seed items emplaced for the project is included in **Table 5.2**.

Table 5.2: Fort Sill Demonstration Seed Items

Seed Item	Total
Small ISO	34
37 mm	62
40 mm	22
MKII-hand grenades	20
2.36-inch rockets	3
Rifle grenade	5
LAW rocket motor	1
Flare canisters	3
Total	**150**

5.2.7 Establish an Instrument Verification Strip and Training Pit

A clean area for use as the IVS was identified in grid M05 using the RI/FS EM61-MK2 data. This location was flat and equidistant to most of the demonstration grid areas. A 50-ft by 150-ft area was identified for use as the IVS and test pit. A list of the seed items placed in the IVS is included in Table 5.3.

Table 5.3: IVS Seed Items

IVS Item	Description	Depth (cm)	Orientation
IVS-01	40 mm	20	Horizontal
IVS-02	37 mm	20	Horizontal
IVS-03	MkII hand grenade	20	Horizontal
IVS-04a[1] IVS-04b	Rifle grenade Anti-tank mine fuze	20 20	Horizontal Horizontal
IVS-05	2.36-inch rocket	20	Horizontal

(1) Rifle grenade was not easily detectable with the MetalMapper, so was replaced with the anti-tank mine fuze in the interest of proving that the MetalMapper was functional.

5.3 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. During the demonstration at Fort Sill, the antenna array was placed in a wooden sled attached to the rear three-point hitch of a tractor (**Figure 2.2**). A Trimble R8 GPS was mounted directly above the sensor array using a wooden tripod, and an inertial measurement unit was attached to the wooden support used to stabilize the X- and Y-direction transmitters, also directly above the center of the array. These instruments streamed positional data constantly, at a rate of approximately 10 Hz, although the stream rate for the GPS was modified throughout the project in an attempt to solve repeated software crashes. The two instruments were connected to the DAQ via USB (universal serial bus) ports, and the incoming data were used both to navigate from point to point and to locate the collected data.

5.4 CALIBRATION ACTIVITIES

5.4.1 Test Pit and Instrument Verification Strip Data Collection

A test pit was constructed at the site before the arrival of the MetalMapper data collection team. The pit was an approximately 3-foot by 3-foot by 3-foot hole that allowed the collection of static MetalMapper data over TOI expected at the site. The test pit data could then be used for comparison with field data collected over unknown targets. Test pit items were generally oriented in four directions relative to the MetalMapper (vertical, 45 degrees along path, horizontal along path, and horizontal perpendicular to the path) at a single depth selected to produce a strong signal-to-noise ratio for each orientation of the test object. TOI placed in the test pit were a mix of intact, inert munitions items received from the USACE and intact or partial, inert munitions items recovered at the Fort Sill site during the RI. MetalMapper data were collected over the following items:

- 2.36-inch rocket (2 versions: oblong warhead (hollow), conical warhead (w/ ballast bar)
- 2.36-inch rocket (warhead only)

- 60-mm mortar illumination round
- Rifle grenade, practice (2 versions; not much noticeable difference)
- 75-mm canister (empty)
- 40-mm grenade, practice (4 versions: with cartridge, without cartridge, with spotting charge, and solid aluminum
- Time fuze, M19-14
- 2.5-inch ballistic windshield
- Mine, M2A1 (2 versions: full base and partial base)
- Horseshoe (2 versions)
- Anti-tank mine fuze
- LAW rocket (2 versions: not much noticeable difference)

In addition to the test pit data, data were collected over the IVS twice daily. The items in the IVS are identified in Table 5.3. All data collected over the IVS strip were inverted in the field as described in Section 6.2 and compared to the Fort Sill target library as described in Section 6.4. Two tests were performed using the IVS data:

- Inverted locations were compared to the known locations for the IVS seed items, with the differences between the modeled and known locations expected to be less than 15 cm for X and Y and 10 cm depth.
- The item identified by the target library comparison was compared to the actual buried item, and it was expected that the identified item matched the TOI with a relatively high confidence (0.7 weighted metric confidence expected in the field). Identified results were considered a match to the IVS seed as long as the sizes of the two items were relatively similar (e.g., 37-mm projectile seed identified as a 40-mm seed was acceptable, 37-mm projectile identified as a 105-mm projectile was not).

IVS testing results are detailed in Section 7.1.

5.4.2 Background Data

Background data were collected at least every 2 hours and each time the MetalMapper moved from one area of the site to another. Background data were collected at designated locations in each grid that were identified before data collection by examining the EM61-MK2 data for clean areas. Additional background points were collected at the operators' discretion during the day if they felt another point was necessary for any reason (e.g., changes to the configuration of the DAQ to minimize software crashes, changing field conditions such as rain).

5.5 DATA COLLECTION PROCEDURES

The operator moved the array by lifting the sled, navigating to the vicinity of each selected point using the graphic display on the computer monitor in front of him, and setting the MetalMapper down on the point. Reacquisition of the EM61 targets selected for cued data collection was accomplished using "dancing arrows" displayed on the monitor. The "dancing arrows" display shows the seven receivers in the array, arranged as they are in the Z-coil, typically with a blue arrow pointing out of each. The arrows point toward the metallic source nearest each of the receivers. Under ideal conditions, there is one source in the vicinity of the selected point, and all of the arrows point inward toward the center of the array. In the case of multiple sources, one or more of the outer arrows may point outward from the array toward another piece of metal.

Generally, the operator attempted to position the array such that, at least, the arrows in the three receivers closest the middle of the coil were pointing at each other.

The MetalMapper's single-point or cued-collection mode was used for all data collection at Fort Sill. Once the MetalMapper was positioned correctly above the target, the operator collected a data point using the settings indicated in **Table 5.4**.

Table 5.4: Acquisition Parameters Used during the Fort Sill Demonstration

Mode	Tx Mode	Hold-Off Time (µs)	Block Period(s)	Rep Fctr	Dec Fctr (%)	Stk Const	Base Freq (Hz)	Decay Time (µs)	No. Gates	Sample Period (s)	Sample Rate (S/s)
Static	ZYX	50	0.9	27	10	10	30	8333	50	9	N/A

Static targets were identified according to the identification (ID) determined for each target picked in the dynamic EM61-MK2 survey. In the case of repeated measurements associated with a single target point, 10,000 was added to the original ID (e.g., the re-shot for 0001 was 10001).

5.5.1 Scale of Demonstration

Parsons' field team collected 2,116 data points during the project for 1,988 targets. Additional points were either re-shots of already collected points due to a high offset between the location of the center of the MetalMapper and the modeled location of a target or for points that may have been incorrectly identified during collection. A distance of 40 cm between the array location and the modeled location was considered the greatest acceptable distance between the two points. Re-shots were collected for any targets with a larger offset.

5.5.2 Sample Density

One data point was collected per target, as described in Section 5.5; re-shots were collected for targets with modeled locations greater than 40 cm from the collection location.

5.5.3 Data Quality Checks

An instrument calibration check was conducted a minimum of twice a day (at the beginning and the end of the field day). These checks ensured that the instrumentation was functional, properly calibrated, and stable.

A final check on the quality of static data was performed after initial inversion was performed using the UX-Analyze module in Oasis montaj. Inverted target locations were compared to data collection locations to determine if offsets between the two are greater than 40 cm. Re-shots were collected for all targets with offsets greater than 40 cm.

5.5.4 Data Handling

Data were recorded in binary format as files on the hard disk of the MetalMapper DAQ. These data were offloaded to other media at least once, and sometimes more frequently, per day. The computer's hard disk had enough capacity to store all the data from the entire site, so these data were not erased until they had been thoroughly reviewed and archived. The data file names acquired each day were cataloged (usually on a spreadsheet) and integrated with any notes or

comments in the operator's field book. All data ended up on the hard drives of one or more laptop computers used to post-process data. Data were also archived to a data server in the Parsons office.

Raw binary files were preprocessed using the TEM2CSV software package, which outputs "preprocessed and located" data files in a text readable format (.CSV). Preprocessing included the location of the point in UTM meters and subtraction of background. Located and background corrected .CSV files were imported into Oasis montaj for further processing and analysis.

5.6 INTRUSIVE PROCEDURES

Parsons' intrusive operations at Fort Sill began in October 20, 2011, and ended on November 14, 2011. Operations began with site-specific training, which included prepping the staging area for intrusive activities and performing equipment checks. The staging area was used with ongoing Parsons RI and removal action projects. All Parsons intrusive equipment was stored at the Parsons Fort Sill compound and locked at the end of the day. Daily equipment checks included confirming GPS accuracy over known monuments, EM61-MK2 static tests, and handheld analog instruments calibrations.

Intrusive investigation of the 1,988 anomalies started in grid L04 and included K04, I03, I01, and C09. All 1,988 anomalies were intrusively investigated and documented per the demonstration work plan. All excavated anomalies, excluding the seed items, were placed in a sandbag and later in a plastic 55-gallon drum for storage. Nine 55-gallon drums were filled with the sandbags, with a total weight of 1,741 pounds. Seed items intrusively investigated were stored in a separate bin and inventoried daily. Once all the seed items were accounted for, they were shipped off site.

Personnel on site to conduct the intrusive operation were from Parsons and from Ordnance & Explosives Remediation, Inc. (OER), the UXO explosives subcontractor. The field team consisted of six Parsons personnel and two OER personnel. Parsons' site safety and health manager and the Parsons' site manager conducted daily site safety briefings, as appropriate.

5.6.1 Equipment

The equipment used during the Fort Sill intrusive activities included the following:

- Schonstedt magnetic locator (Model GA-52Cx)
- Whites metal detector
- EM61-MK2
- Trimble R8 GPS system
- Digital level
- Miscellaneous hand tools
- Digital cameras

5.6.2 Field Procedures

Reacquisition of all targets was conducted using the Trimble R8 GPS system. The GPS base station was set up by Parsons Fort Sill RI and removal action project members and was available to Parsons ESTCP personnel. Parsons flagged all target locations with a plastic pin flag marked

with the target identification and EM61-MK2 pre-value. The depth estimations determined the initial approach to every target. To preserve the azimuth and inclination of the anomalies, the digging of all targets began with skinning the surface manually by hand. Azimuth data reflected magnetic north; inclination was determined using a digital level; and readings reflected positive or negative from horizontal. Location data captured by GPS was used to document the center mass and elevation of each item. A photograph was collected of the item with written dig result data on a whiteboard. Lastly, an EM61-MK2 unit was used to scan the location to confirm the absence of all metallic items from that target location.

The Parsons team leader who orchestrated the movements of the different tasks associated with the information-gathering process recorded all documentation on a Trimble Geo XT unit. The intrusive operations consisted of two intrusive teams. Each team was responsible for reacquisition, intrusive, and anomaly documentation. Once enough anomalies were processed, the less-busy team conducted the EM61-MK2 QC over the excavated holes.

Munitions debris (MD) and cultural debris (CD) collected from target locations was stored in labeled burlap sandbags with the pin flag. Parsons' senior UXO and site safety officer certified all MD scrap by thoroughly going through each piece individually before final disposition in the sealed bins.

All seed items recovered from intrusive operations were stored in a secure area and prepared for final shipment. The seed items from Army Research Lab in Welcome Maryland, which included the 37-mm projectiles, were shipped on November 2, 2011; the remaining seeds were shipped back on November 21, 2011. The shipments included certified and signed DoD 1348 forms and additional letters signed by Parsons' senior UXO personnel.

All target locations were backfilled after completion of the excavation. Once the final anomalies were excavated and backfilled, Parsons conducted a walkthrough and confirmed that all holes were filled and no trash was left.

Excavation data collected by the intrusive team was digitally downloaded to a database and reviewed daily. The daily information required the target ID to be connected with intrusive documentation, photo, and GPS coordinates. Assessment of each target item required the coordinates to match the original location and the picture to match the documented findings. Photographs of the intrusive operation are shown in **Figure 5.1**.

Figure 5.1: Intrusive Operation Photos

5.7 VALIDATION

As part of the intrusive operation, Parsons investigated 1,988 anomalies, which included 150 seed items. An average of 86 digs was completed daily, based on 23 intrusive days. Most of the MD encountered consisted of unidentifiable munitions fragments. No MEC items were discovered during the intrusive operation. The anomaly breakdown for the 1,908 intrusive results (80 intrusive locations were eliminated based on the distance from the dig location to the MetalMapper fit location exceeding 60 cm or the MetalMapper collection point exceeding 2 m of an EM61 pick location) in the study area is summarized in Table 5.5.

Table 5.5: Intrusive Results

Type	Anomalies
Cultural debris	282
Munitions debris	1,172
Range-related debris	95
No contact	69
TOI	140
Seed	150

5.8 MUNITIONS DEBRIS SCRAP

MD and CD scrap recovered from the demonstration area at Fort Sill amounted to approximately 1,741 pounds. The MD/CD scrap filled nine 55-gallon drums, which were all locked and labeled with numbered custody seals. Certified and signed DoD 1348 forms were included with the final transfer of the drums. YRC shipping picked up the drums on December 22, 2011, and the shipment was delivered to Glen Harbaugh at the Army Research Lab in Welcome, Maryland.

6.0 DATA ANALYSIS AND PRODUCTS

The MetalMapper was used to collect static data over 1,988 targets identified at Fort Sill based on EM61-MK2 data. The processing and analysis steps that were used to generate a dig/no dig decision for each target are described below.

6.1 PREPROCESSING

Raw MetalMapper data are collected and stored as .tem files. The MetalMapper acquisition software uses a convention for assigning a unique name to each data file without the need to manually enter the name. The operator supplies a prefix for the root name of the file (e.g., "Static"). The acquisition software then automatically appends a 5-character numerical index to the filename prefix to form a unique root name for the data file (e.g., Static00001). The index is automatically incremented after the file has been successfully written. Although the target ID is not used as the file name in the .tem file, the target ID is stored in the file according to name of the target highlighted on the MetalMapper screen during collection.

Preprocessing of the .tem files was accomplished using TEM2CSV, a program specifically developed for this purpose. TEM2CSV subtracted the site background from the data point using a background file specified by the user, converted the points from the geographic coordinate system used for collection to the UTM Zone 14N coordinate system used for processing, and exported the resulting data to a .csv file that could be imported into The UX-Analyze package in Geosoft's Oasis montaj software. The exported .csv file name contained both the collection ID and the target ID (e.g., 2621_Static00001_2621). Preprocessing was typically completed in batches based on time and location to account for differing background data. Unless there appeared to be a problem with a particular background file, data were tied to the nearest background point in time. If the MetalMapper switched collection grids for any reason during the day, a background point was collected before leaving the first grid and upon arrival at the second grid.

6.2 PARAMETER ESTIMATION

All MetalMapper data points were inverted using UX-Analyze to determine modeled parameters for each target. These parameters included the location, size, and orientation of the source object; the polarizability of each axis of the object; and information regarding the quality of the data and the relative match between the inverted data and the expected model.

All target inversion was initially performed using the UX-Analyze batch processing mode with the multiple object solver enabled. Targets for which multiple objects were identified using the multiple object solver were re-inverted using the batch processor without the multiple object solver enabled. In these cases, the single object and multiple object results were compared to determine which method returned a result more indicative of TOI. Although the multiple object result may have approximated the expected model to a higher degree, the result more indicative of potential TOI was used for target ranking to be conservative.

6.3 CLASSIFIER AND TRAINING

6.3.1 Confidence Metrics

The polarization curves developed for each target, including any single-object-only results and secondary multiple-object results, were compared to a library of known polarization curves compiled using test stand data and test pit data from Fort Sill. The items in the Fort Sill comparison library were limited to the TOI expected at the Fort Sill site, which was a fairly extensive list: 37-mm, 40-mm, 75-mm, and 4.5-inch projectiles; 2.36-inch, 2.75-inch and 3.5-inch rockets; 60-mm mortar illumination rounds; 66-mm LAW rockets; rifle grenades; MkII hand grenades; practice mines; and various fuzes. Examples of various types of these items were used (e.g., four different versions of 37-mm projectiles, four types of 40-mm grenades), but items not expected at the site, such as bombs, were not included. Comparisons between the measured targets and the library data were performed using the Advanced Target Classification feature in UX-Analyze. The Advanced Target Classification algorithm compares quantities derived from the polarization curves (size, shape 1, shape 2) for each target to the same quantities derived for the polarization curves for library items. All initial comparisons were performed using an equal weight for the three derived quantities (size: 1, shape 1: 1, shape 2: 1). The classification results for each target were then examined by the data processor.

The first examination of the classification results was performed to determine the usability of each result. Results were generally grouped into one of five categories:

1) All three polarizability curves ($\beta1$, $\beta2$, $\beta3$) were usable.
2) Only two of the curves ($\beta1$, $\beta2$) were usable.
3) Only $\beta1$ was usable.
4) No usable curves, but it was determined unlikely that there was a target large enough to be TOI in the acquisition location.
5) Can't analyze (no usable curves, and it was considered likely that the curves were unusable despite the existence of a source potentially large-enough to be TOI).

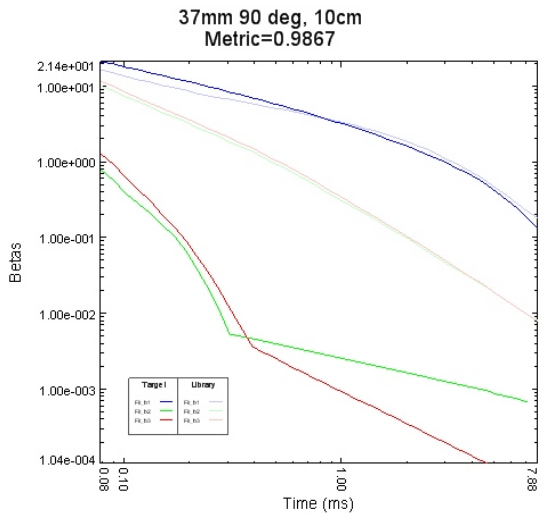
The difference between targets deemed likely to have a source potentially related to TOI (can't analyze) and those with unusable curves due to a small or nonexistent source was typically determined based on the modeled location of the source relative to the collection point and the signal strength calculated for the target in question. If the source was modeled within 40 cm of the collection location and the signal strength was less than 20, the target was considered a small source picked as a target due to the low selection threshold used for EM61-MK2 target selection (9.3 millivolts for a sum channel calculated as ch1 + ch2 + ch3). Targets with signal amplitudes higher than 20 were considered potentially large objects for which the data might be poor. Additionally, the field team recorded notes in their logbook for all targets that could not be found in the vicinity of the picked location using the MetalMapper's dancing arrows. Targets with such notes were removed from consideration as Can't Analyze targets.

In addition to the equal-curve-weighting confidence metric generated for the initial examination of the results for each target, three additional confidence metrics were generated:

1) Weighted metric – size: 1, shape 1: 0.5, shape 2: 0.5
2) 2-curve metric – size: 1, shape 1: 1, shape 2: 0
3) 1-curve metric – size: 1, shape 1: 0, shape 2: 0

Various metrics were used for classification, as described in Section 6.3.3, or if some of the results were unusable. The target shown in **Figure 6.1**, for example, was classified using only the 1-curve metric.

Figure 6.1: Target with Poor β2 and β3 Curves

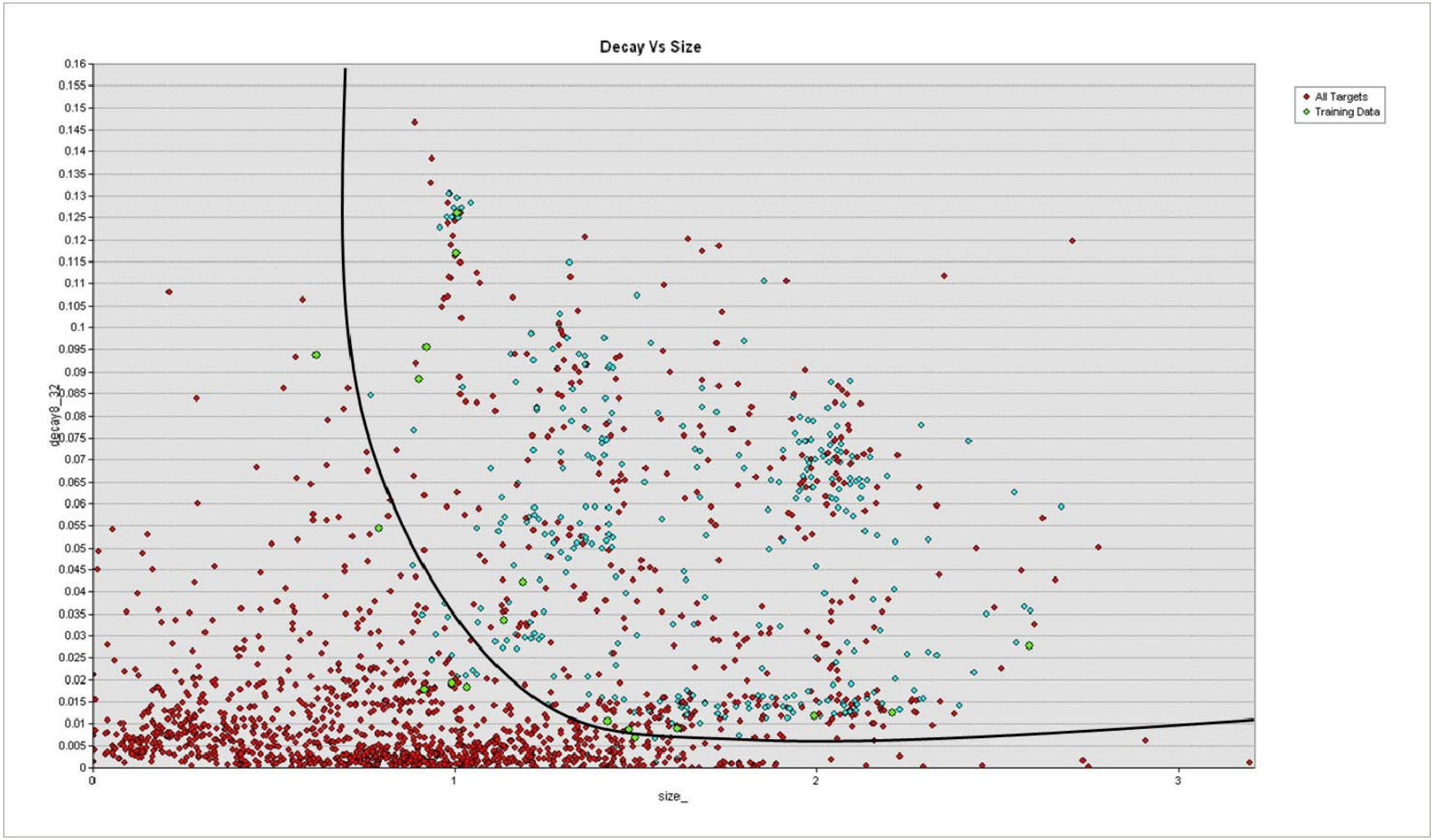


6.3.2 Training Data

The initial training data request for Fort Sill was composed of 18 targets selected based their similarity to ordnance based on the library match and on their location within a decay (time gates 8–32) vs. size space plot (**Figure 6.2**). These targets all had weighted confidence metrics greater than 0.700, 2-curve metrics greater than 0.8, and 1-curve metrics greater than 0.9 (blue highlighted points on space plot). Additionally, all were picked relatively close to a size/decay curve that seemed to reasonably separate the majority of the smaller items at the site with lower confidence metrics (likely clutter; left side of curve) from the larger items at the site, typically with higher confidence metrics (potential TOI; right side of curve). The green points represent the targets selected as training data.

Out of the requested targets, six were TOI. All were to the right/top of the separation curve shown on the space plot, although some were fairly close to the boundary. These results suggested that the curve could not be trusted to completely separate TOI from non-TOI, but that it was very likely that targets to the left of the curve were non-TOI unless extremely high confidence metrics suggested otherwise. Additionally, the training data indicated that the cluster of targets with decays between 0.11 and 0.15 and a size of approximately 1 were practice rocket fuzes that were not considered TOI. As a result, this cluster of targets was considered non-TOI regardless of confidence metric on all dig lists.

Figure 6.2: Space Plot Curve Used for Training Data Selection



6.3.3 Decision Statistic

Classification for the Fort Sill project was accomplished using three of the confidence metrics generated for each target during the comparison to the library data: the weighted metric, the 2-curve metric, and the 1-curve metric, and the space plot. The Stage 1 dig list was compiled using the following classifier:

- Priority -1: training data.
- Priority 0: can't analyze.
- Priority 1 (Category 1): weighted confidence metric > 0.575 **and** 1-curve confidence metric > 0.8 **and** plotted to the right/top (greater size/decay values) of the break curve drawn on the space plot.
- Priority 2 (Category 1): targets classified using only 2-curve or 1-curve matches **and** targets plotted to the right of the space plot curve that the analyst felt should be investigated.
- Priority 3 (Category 2 digs): targets plotting to the left/bottom of the space plot curve (smaller size/decay) with weighted confidence metric > 0.575 **and** 2-curve confidence metric > 0.8 **and** 1-curve confidence metric > 0.9.
- Priority 4 (Category 2 non-digs): targets plotting to the left/bottom of the space plot curve (smaller size/decay) with weighted confidence metric > 0.575 **and** 1-curve confidence metric > 0.8 not already identified as Priority 3.
- Priority 5 (Category 3): targets not meeting the above criteria.

All targets to the right/top of the space plot curve not already classified as priority 1 targets were re-examined by the analyst to determine whether they should be included as priority 2 targets. Given the long term and varied use of the site, there was a potential for various unknown munition types to be present in the demonstration area. Therefore, the analyst generally added any symmetric ($\beta 2$ and $\beta 3$ roughly equal and nonspherical [all 3 βs equal] / non-plate-like [$\beta 2$ and $\beta 3$ larger than $\beta 1$]) targets as priority 2 digs.

The decision statistic used to rank the targets was calculated as 5 - priority + weighted confidence metric. The decision statistic was then sorted from high to low to order the targets on the dig list.

6.4 DATA PRODUCTS

6.4.1 Dig List Stage 1

The dig lists submitted for the Fort Sill project contained 1,908 of the 1,988 targets investigated. The 80 targets not submitted on the dig lists were not considered due to large discrepancies between the MetalMapper collection points and the EM61 target locations (8 removed from consideration due to the lack of a MetalMapper collection point within 2 m of the EM61 target) or between the source location predicted by the MetalMapper and the final dig location (71 removed from consideration due to an inverted location greater than 60 cm from any intrusive location).

The Stage 1 dig list was submitted with the following parameters:

- Training Data: 18 items selected as described in Section 6.3.2.

- Can't Analyze: 19 items without usable β1 curves.
- Likely TOI (Category 1): Decision statistic greater than 3.0.
- Can't Decide (Category 2 Digs): Decision statistic between 2.0 and 3.0.
- Can't Decide (Category 2 Non-Digs): Decision statistic between 1.0 and 2.0.
- Likely Clutter (Category 3): Decision statistic less than 1.

The Stage 1 dig list was compared only to the project seed items identified as QC seeds. This comparison identified three seeds that would have gone un-dug based on the Stage 1 list: FS-727, a signal flare, and FS-909 and -1302, both hand grenades. The signal flare was not in the TOI library used for matching the unknown target curves and was roughly spherical and so was not added as a priority 2 dig. Although hand grenades were represented in the library, they were all MkII grenades and were somewhat dissimilar from the two missed by the Stage 1 list (**Figure 6.3A and B**). Similarly to the signal flare, the polarizability curves for the missed grenades indicated spherical objects rather than cylindrical objects, and these were not added by the analyst as priority 2 digs. It is also worth noting that the metrics for FS-909 were high enough (weighted metric of 0.584 [M27 signal cartridge], 1-curve metric of 0.878 [M19-14 time fuze]) for it to be selected as a dig. However, the low decay value (0.002) for this item suggested it was not worth keeping as a dig.

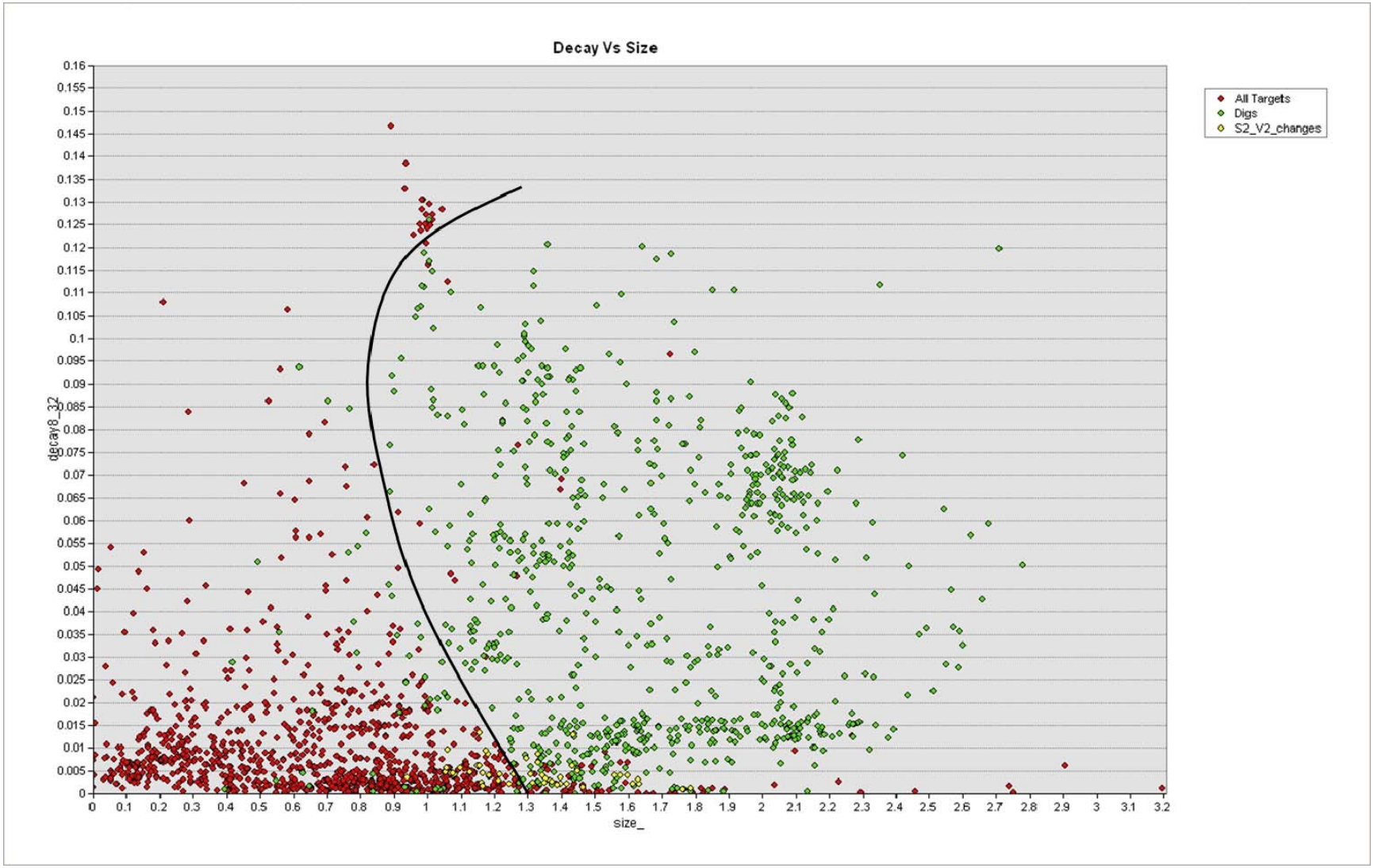
Because none of the missed TOI were particularly well represented in the library, these TOI were added to the library, and the library was re-compared to the data set so that any unknown objects similar to these would match one of them and be added as a dig to the stage 2 list. In addition, the separation curve on the space plot was modified such that the curve no longer filtered out targets to the bottom of the curve (**Figure 6.4**).

Figure 6.3: Hand Grenades at Fort Sill

A: MkII Grenade (in library)

B: Missed seed (not represented)

Figure 6.4: Stage 2 Dig List Space Plot



6.4.2 Dig List Stage 2

Classification for the Stage 2 dig list was performed in the same manner as classification for the Stage 1 dig list (Sections 6.3.3 and 6.4.1), except that the former priority 5 targets were split into two groups. Those to the right of the space plot curve (larger size) were left as priority 5 targets, those to the left were given a priority of 6. This change was made to rank larger targets higher on the dig list. With the addition of a priority 6, the decision statistic was calculated as 6 - priority + weighted confidence metric.

In addition, between the submissions of the two dig lists, it was noted that changes to UX-Analyze between released versions of Oasis montaj had possibly resulted in incorrectly calculated confidence metrics. Therefore, the confidence metrics for all targets were re-calculated for all targets before classification for Stage 2. The type of changes made between UX-Analyze versions ensured that confidence metrics for targets could only increase with the re-calculation. Therefore, no Stage 1 digs were re-classified as non-digs for the Stage 2 list; only additions were made. The yellow points in **Figure 6.4** are the targets added as digs between Stage 1 and Stage 2.

Dig results following the Stage 2 digs with respect to the space plot are shown on **Figure 6.5**. As indicated in the figure, three TOI (blue points on the figure) were recovered to the left of the curve used throughout the project to separate likely TOI from likely clutter. As a result, it was felt that the most conservative approach for this site would be to ignore the space plot curve for the most part and dig everything with confidence metrics suggesting possible TOI. The exception to this rule was a group of venturis and fuze couplers that tended to cluster in the feature space with decays between 0.0175 and 0.02 and sizes between 0.9 and 1.0. As with the practice fuzes discussed in Section 6.3.2, this cluster of targets was considered non-TOI regardless of confidence metric.

6.4.3 Dig List Stage 3

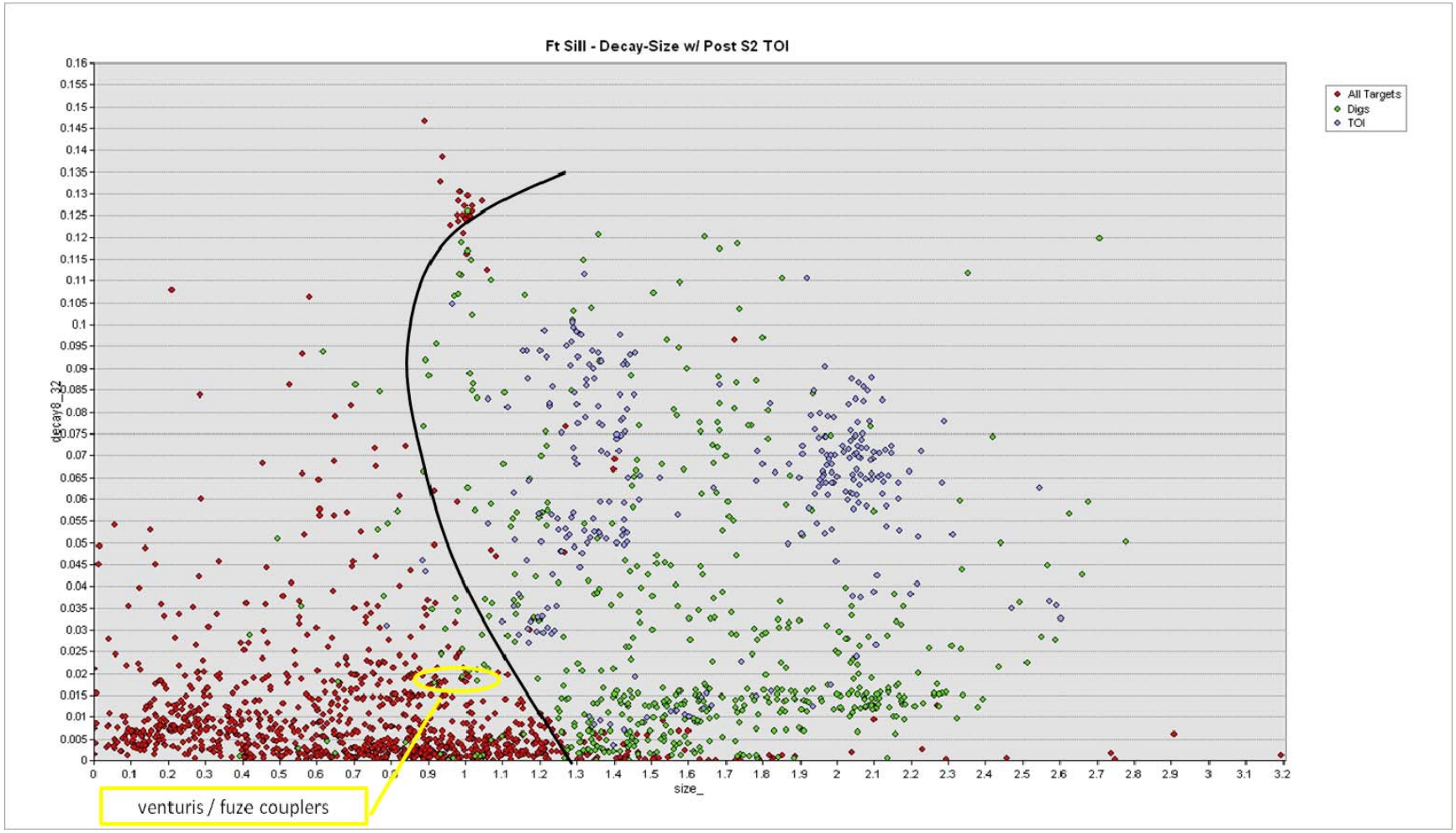
The final dig list was compiled using the following classifier:

- Priority -1: training data.
- Priority 2: can't analyze.
- Priority 1 (Category 1): weighted confidence metric > 0.575 **and** 1-curve confidence metric > 0.8 **and** plotted to the right (larger size) of a break curve drawn on the space plot.
- Priority 2 (Category 1): targets classified using only 2-curve or 1-curve matches **and** targets plotted to the right of the space plot curve that the analyst felt should be investigated. All targets with non-plate-like symmetry and decays above 0.10 to the right of the space plot curve were added as Priority 2 targets regardless of confidence.
- Priority 3 (Category 1 digs): targets plotting to the left of the space plot curve (smaller size) with weighted confidence metric > 0.575 **and** 2-curve confidence metric > 0.8 **and** 1-curve confidence metric > 0.9.
- Priority 4 (Category 1 digs): targets with weighted confidence metric > 0.575 **and** 1-curve confidence metric > 0.75 not already identified as Priority 3.
- Priority 5 (Category 3): targets to the right (larger size) of the space plot curve not meeting the above criteria.

- Priority 6 (Category 3): targets to the left (smaller size) of the space plot curve not meeting the above criteria and targets that otherwise would have been digs but were likely to be non-TOI based on training data and stage 2 dig results (clusters of venturis, motor/fuze couplers, and rocket practice fuzes).

The major change between the classifier above and the previous version is the addition of the former category 2 non-digs as digs (priority 4 targets). The final dig list included 860 digs out of a total of 1,908 targets (45% dig rate).

Figure 6.5: Post Stage 2 Dig List Space Plot Showing TOI



7.0 PERFORMANCE ASSESSMENT

7.1 OBJECTIVE: REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

Three IVS seed items were incorrectly classified (i.e., weighted confidence that the seed item was the seed item or a similarly-sized TOI was less than 0.7) during the project. Because these three failures were out of a data set of 155 IVS items surveyed over the course of the project, the IVS failure rate was slightly less than 2%. Two of the three incorrect classifications occurred on September 21, 2011 (first day of data collection) and occurred over a rifle grenade and a 40 mm grenade. Based on observations made during the test pit data collection and the detection failure on September 21, it was determined that rifle grenades were somewhat difficult to detect with the MetalMapper. Therefore, Parsons felt that they were not ideal items to be used in the IVS, which was intended to verify that the instrument was working correctly on a daily basis rather than to test the limits of its classification abilities. Therefore the rifle grenade was replaced in the IVS strip with a mine fuze for all later testing. The non-detection of the 40 mm grenade on the same day was attributed to new-operator error in that the sensor was incorrectly located over the seed item. Further instruction was given regarding the use of the dancing arrows display to position the sensor. The final failure was the non-detection of the 37 mm projectile in the IVS on the evening of October 2, 2011. This miss appears to have been instrument related, as the third polarization curve appears to be unusable. Using only a 2-curve match, as would be standard for such a case with production data, results in the correct classification of this item without any trouble. Because poor data is collected occasionally with the MetalMapper and can be rectified by looking only at the usable curves for a target, this "miss" was not deemed particularly concerning.

The standard deviations of the horizontal and vertical differences in location between the actual and modeled locations of the seed items were 4.7 cm and 5.4 cm, respectively. Both are well within the stated goals of 15 cm for the horizontal and 10 cm for the vertical.

7.2 OBJECTIVE: SUCCESSFUL REACQUISITION OF TARGETS WITH METALMAPPER

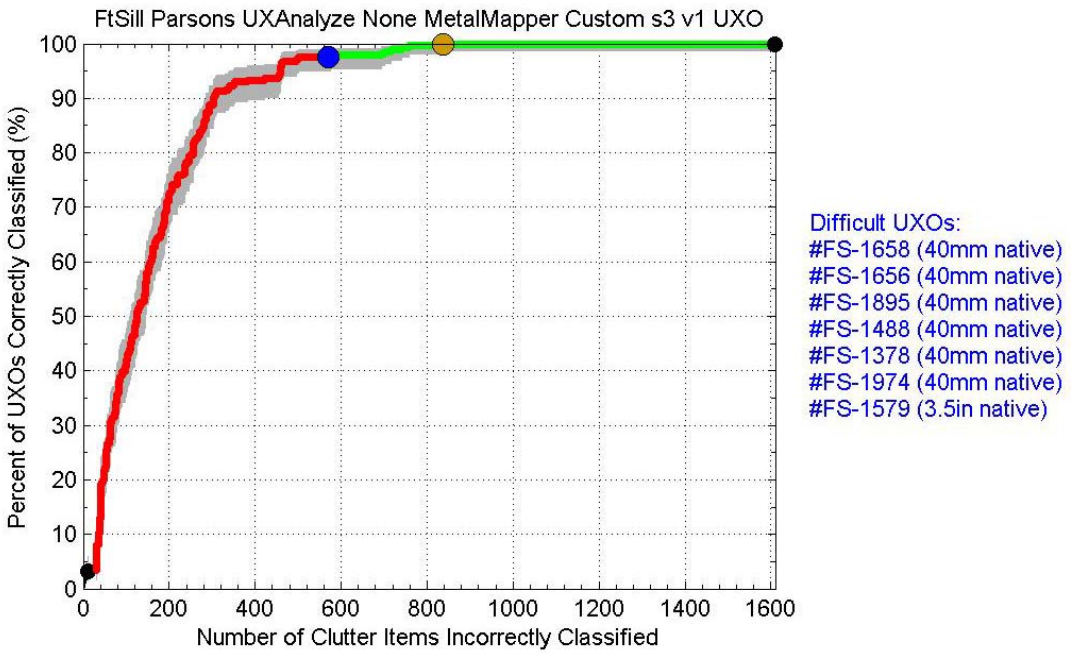
Forty, or approximately 2%, of the 1,908 final targets used for classification had a modeled location greater than 40 cm from the collection location. This is well within the stated limit of less than 5% of the targets with an offset greater than 40 cm. Additionally, 25 of the 40 targets with offsets greater than 40 cm were digs on the final dig list. It is standard practice to not collect a re-shot for any targets that would be considered digs on the first pass, regardless of collection to fit offset. The remaining 15 targets are those for which a re-shot was also offset greater than 40 cm from the modeled source, or for which second objects from the multiple object solver or single objects were better matches to TOI than sources modeled closer to the collection point that were discarded during classification.

7.3 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

The submitted Stage 3 dig list was compared to ground truth data from Fort Sill by the IDA. The Stage 3 dig list was compared to the complete set of validated dig results. This comparison identified seven TOI that would have gone un-dug based on the final dig list: FS-1579, an

expended 3.5-inch rocket motor, and FS-1378, -1488, -1656, -1658, - 1895, and -1974, all 40-mm grenade fragmentation balls. Out of the 1,908 targets classified for this project, 274 were considered TOI following the intrusive investigation. Given the seven misses, 283 of the 290 TOI (97.5%) of the TOI at the site were correctly classified as targets that should be dug. **Figure 7.1** shows the receiver operating characteristic (ROC) curve for the Fort Sill dig list.

Figure 7.1: ROC Curve for Fort Sill



Of the TOI-detection failures, the classification of FS-1579 as likely clutter is considered to be the most concerning. The classification results (**Figure 7.2**) show that its closest match in the library was a 2.36-inch rocket warhead, with a confidence metric of 0.573. Both this metric and the 1-curve metric (0.731) were below their respective thresholds for classification as a TOI of 0.575 and 0.800, respectively. While there was a 3.5-inch rocket in the library, it was a full-up round and not just the motor, which is the likely reason this item did not match anything in the library to a higher degree. However, upon retrospective analysis, the curves do indicate a cylindrical object; and its size of 2.1 is well past the threshold of approximately 1.3 used as the dividing line for adding symmetric objects as priority 2 targets. It should have been added based on the classification rules. The fact that it was not added as a category 1 target was based on a failure by the analyst to correctly identify it as a large symmetric object.

The other TOI missed were all 40-mm grenade fragmentation balls, or pieces of these balls, filled or partially filled with high explosive (HE). Two examples are shown in Figures **7.3A** and **7.3B**. As shown in the figures, these items are extremely small. The analysis team was also unaware that these were present at the site during analysis, resulting in these items not being added to the library. Their small size and thin wall thickness also resulted in a cluster amongst a large portion of the clutter at the site on the space plot (**Figure 7.4**).

Figure 7.2: Classification Results for Target 1579

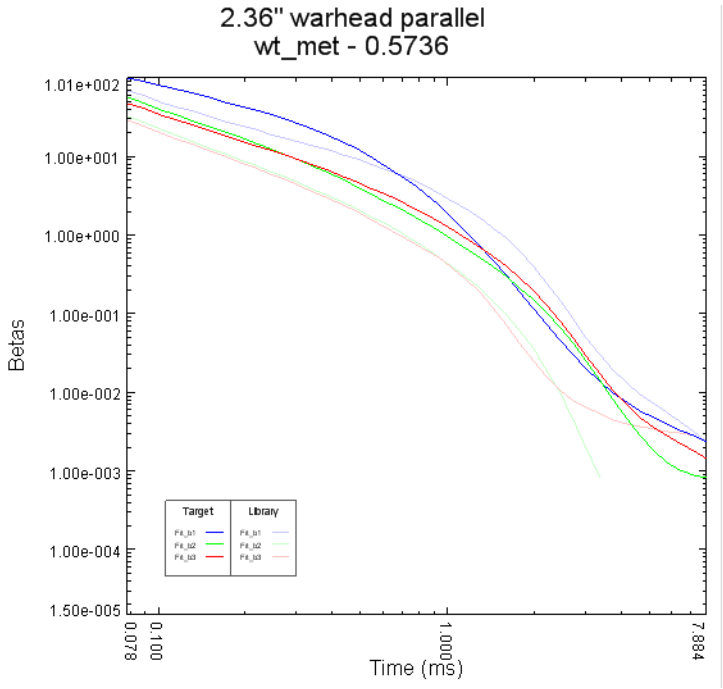
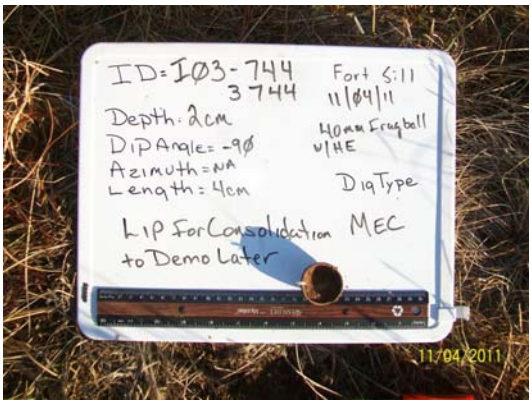


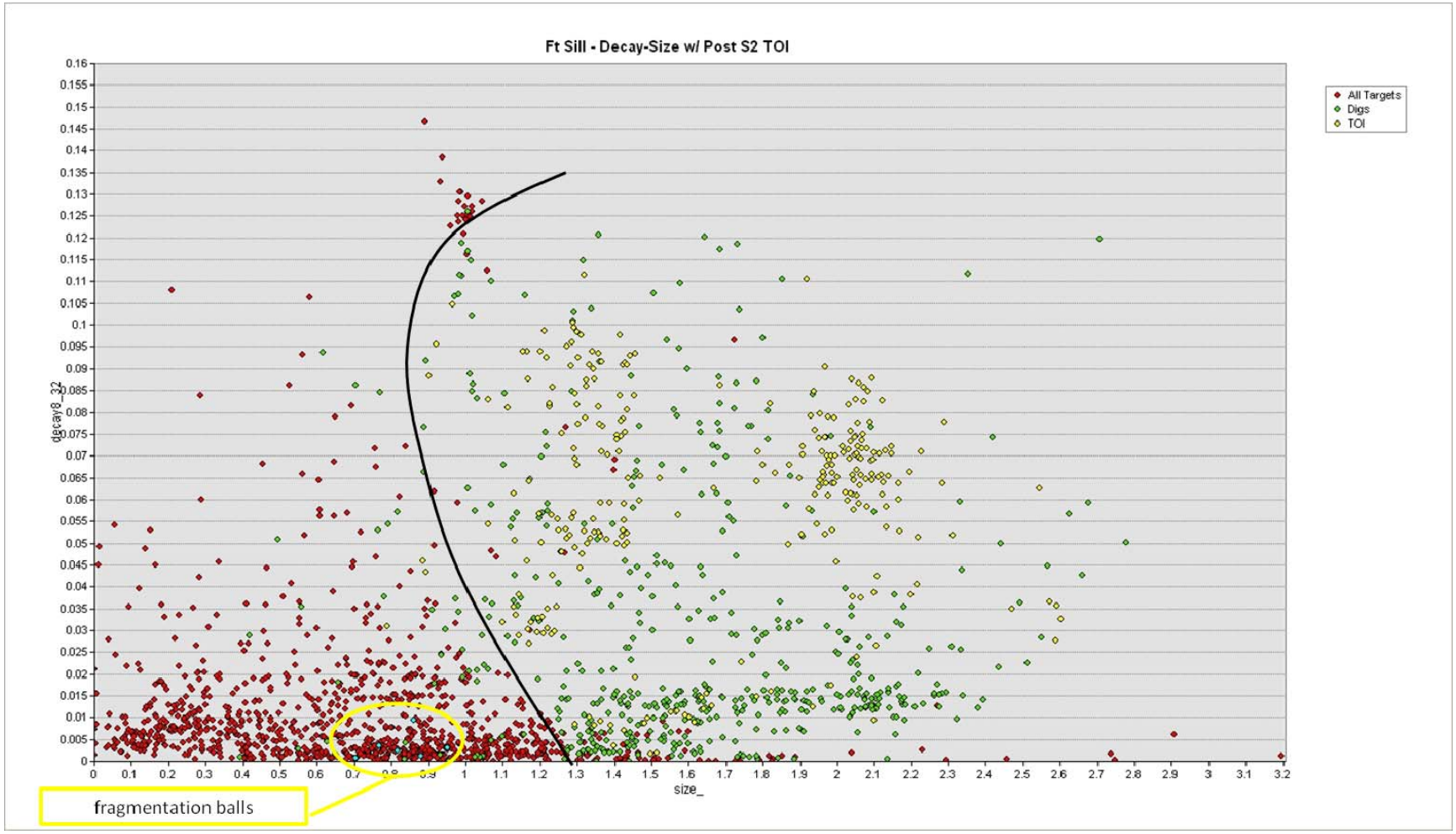
Figure 7.3: Native Fuze Types

A: FS-1656



B: FS-1974

Figure 7.4: Space Plot Showing the Location of Fragmentation Balls



The first step in the failure analysis for these items involved the addition of the two shown above to the project library. FS-1656 was a half ball with some HE residue remaining in the intact half; FS-1974 appears to be a full ball based on the picture and its larger decay (the highest for any of the balls recovered). The four other examples of these items recovered were not nearly as intact as FS-1974 and included half of the ball or less. The addition of these two items to the library and re-classification of the remaining four with the revised library did not elicit positive results. The 1-curve only match, which was used as a primary TOI/non-TOI threshold for the entire project, was less than 0.75 for three of the other four items. Lowering the 1-curve only threshold for the project would have resulted in a huge number of additional digs. Therefore, re-classification of the site with the revised library was not considered a reasonable plan.

Because the six balls recovered tended to be in the same location in the feature space plot, decay and size were used as a starting point to determine how many additional digs would be required for the project if all targets in this portion of the feature space were classified as digs. Additionally, because the fragmentation balls are relatively consistent in shape, axial and plate symmetry characteristics were added to the analysis. The six recovered balls were used as the data set, and one standard deviation was added to each of the four characteristics—decay, size, axial symmetry, and plate symmetry—to determine how many additional targets at the site matched fragmentation balls. Fifty-four targets, including the six fragmentation balls, were identified. The addition of these 54 targets and the selection of FS-1579 as a dig results in a total of 915 digs out of the 1,908 targets at the site (48%). The thresholds used for each of the characteristics are contained in **Table 7.1**.

Table 7.1: Fragmentation Ball Detection Metrics

ID	Axial Symmetry	Plate Symmetry	Decay	Size
1378	1.32	1.16	0.003	0.951
1488	1.3	1.19	0.002	0.764
1656	1.47	1.37	0.001	0.831
1658	1.65	1.48	0.001	0.703
1895	1.56	1.23	0.004	0.766
1974	1.11	1.88	0.009	0.817
Standard Deviation (σ)	**0.197**	**0.271**	**0.003**	**0.084**
High Limit (max + σ)	**0.913**	**0.889**	**0**	**0.62**
Low Limit (min + σ)	**1.847**	**2.151**	**0.012**	**1.04**

7.4 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

The submitted dig list correctly identified 64.3% (1,041 of 1,618) of the clutter as clutter in the data set, although this did include the misidentification of seven TOI as non-TOI. The addition of the 55 targets described above, including seven TOI, adds 48 non-TOI digs to the project. This results in a revised clutter detection rate of 61.3% (993 of 1,618). Even with the addition of the fragmentation ball targets, the dig list is above the performance objective of reducing the number of false alarms by greater than 50%.

7.5 OBJECTIVE: CORRECT SPECIFICATION OF NO-DIG THRESHOLD

Because items were missed in the comparison of the dig list to the ground truth sets, the no-dig threshold on the submitted dig list was set incorrectly. Target FS-1579, the only non-fragmentation ball TOI, was five items below the stop-dig threshold. The last of the fragmentation balls, FS-1658, was 274 items below the threshold. However, as indicated in Section 7.3, simply lowering the threshold was not judged to be the most effective way to identify these items. Based on recommended changes to the classifier, notably the addition of any digs within the fragmentation ball "window" detailed in **Table 7.1**, the current stop-dig threshold is deemed appropriate.

7.6 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

A total of 19 targets were classified as Can't Analyze on the single dig list submitted. This corresponds to less than 1% of the 1,908 targets analyzed. This is below the stated goal of less than 2% Can't Analyze targets.

7.7 CORRECT ESTIMATION OF TARGET PARAMETERS

The target parameters estimated in this case were the X, Y, and relative Z (depth) coordinates of the targets. Because the goal with this objective is to direct the dig teams to the correct locations for TOI, the comparison of estimated coordinates to actual coordinates was only performed for TOI and for those targets marked as digs in the ranked dig list.

The success criteria for this performance objective were X, Y offsets for which one standard deviation of the dataset was less than 15 cm and one standard deviation of the depth offset was less than 10 cm. The horizontal offset for the TOI data set was above the performance objective with a calculated standard deviation of 22 cm. The depth offset was well within the performance objective, with a calculated standard deviation of 5 cm. The results for all of the targets marked as digs were similar, with calculated standard deviations of 23 cm for the horizontal offset and 9 cm for the vertical offset. It is assumed that the relatively high target densities at the site are responsible for the larger-than-expected horizontal offsets and that the multiple object solver in UX-Analyze is not modeling location as effectively as expected. However, the 7 cm difference between the project objective and the result does not seem to be an insurmountable problem.

8.0 COST ASSESSMENT

The cost assessment was split into two groups: MetalMapper costs and conventional intrusive costs. The MetalMapper costs include instruments, surveying, seeding, and analysis costs; the conventional intrusive costs include surface sweep, data collection, and intrusive costs.

8.1 COST MODEL

The cost model for the Fort Sill demonstration includes the total cost of the project and potential savings from the classification process. The total cost includes the seeding operation, MetalMapper operations, processing, and intrusive operation. Estimates for each operation are listed in **Table 8.1**.

Table 8.1: Details of Costs Tracked

Cost Element	Data Tracked During Demonstration	Estimated Costs
Seeding Costs		
Seed emplacement/ initial setup	Costs for seed emplacement, surveying seeds	$39,185
MetalMapper Survey Costs		
Instrument costs	MetalMapper rental ($500/day; 25 days)	$12,500
	MetalMapper prep fee (project)	$1,000
	MetalMapper shipping (project)	$1,800
	Tractor rental (project)	$1,280
	Tractor mob/demob (project)	$50
	RTK GPS cost ($800/week; 3 weeks)	$2,400
	Shipping (RTK GPS, etc.; project)	$324
	Total	**$19,534**
	Per target	**$10.14**

Table 8.1: Details of Costs Tracked (Cont)

Cost Element	Data Tracked During Demonstration	Estimated Costs
Survey Costs	Field-related labor (two geophysicists, UXO Technician II), equipment setup, test pit data collection, cued data collection, preprocessing, initial target inversion for quality control checks, non-equipment direct costs (e.g., per diem, hotel, fuel) Per target	$50,492 **$26.46**
Analysis Costs	All processing and analysis performed following the completion of field activities Per target	$14,100 **$7.39**
Intrusive Costs		
Investigations	All costs related to the intrusive investigation Cost per anomaly to intrusively investigate	$234,100 **$111**

Although the MetalMapper and tractor used for data collection at Fort Sill was funded by ESTCP, standard rental costs and prep fees were used to determine the cost for the Fort Sill project had Parsons rented these items for the duration of the project. Survey and analysis costs were tracked using a task-specific number in Parsons' project controls system. Also, the target list given to Parsons at the beginning of the project did not contain the seed items buried at the site before the survey, so the MetalMapper needed to be remobilized for the collection of these targets approximately 2 weeks after initial data collection. Remobilization costs are not included in the following calculations, although the cost of two days of additional field work for the collection of the seed items has been added to the instrument and survey costs.

The final result of the classification process provides an alternative approach to the final costs of the intrusive operations. The analysis compares costs of using MetalMapper vs. digging all anomalies classified as no-digs. The cost model assumes the use of the classifier that would identify the fragmentation balls as TOI. As discussed in Section 7.4, this classifier is expected to reduce the number of clutter digs necessary at the site by 61%. The cost of MetalMapper classification and analysis at Fort Sill was $43.99 per target.

The overall cost of excavating the 1,988 EM61-Mk2 anomalies was $234,100 ($118/anomaly). The overall cost of the MetalMapper survey ($84,126) plus the cost of excavating the 915 targets marked as digs on the final dig list ($107,970, assuming $118/anomaly) is $192,096, which is more expensive than simply excavating all of the EM61-MK2 targets. However, this is a factor of the relatively small scale of the demonstration project. As shown in Section 8.3, the MetalMapper would likely prove to be a cost-saving tool on a larger scale project.

8.2 COST DRIVERS

Based on the factors described above, the total per target cost for the MetalMapper-related work for the Fort Sill project was $43.99. Although backed by the actual costs for the project, Parsons considers this an overestimation of the actual costs for future projects based on the following factors specific to Fort Sill:

- Training was required for a field team that was partially unfamiliar with the MetalMapper.
- The three-point hitch on the first tractor delivered for the project did not fit the adapter on the sled used to carry the sensor, and approximately a day and a half were spent trying to adapt the unadaptable and waiting for a new tractor to be delivered.
- Numerous software crashes related to what turned out to be a poor serial-to-USB adapter limited the production rate at the site.
- Another day was spent diagnosing a faulty transmitter board and installing a replacement.

The issues discussed above resulted in an average production rate of only 115 points per day while collection was possible. The software crashes were, by far, the largest cause of the relatively low production, with significant portions of some days spent trying to fix the problem. The cause of the crashes (the serial-to-USB adapter used for streaming GPS and inertial movement unit data into the computer) has since been identified and replaced. Production rates at sites with more difficult terrain than that at Fort Sill have been upwards of 200 points per day, in some cases reaching as high as 250 to 300 points per day.

Parsons investigated 1,988 anomalies in 23 intrusive days for an average of 86 anomalies per day, which slightly exceeded the estimated 80 anomalies per day planned for the project. The most common item excavated at Fort Sill was frag. Efficiency among the intrusive teams was the main factor in the production or lack of production throughout the project.

- The predetermined path of processing a group of anomalies which required the least amount of movements for the intrusive teams with all their equipment was the single most important factor in production.
- Other factors related to production included multiple contact anomalies, which were frequent, based on the low EM61-MK2 channel 2 threshold for QC. Identifying frag and barbed wire pits early potentially saved intrusive time.
- Pinpointing small anomalies quickly with the EM61-MK2 minimized the standby time of the actual digging; small pieces of frag were difficult to locate with the wide EM61-MK2 sensor. Having an experienced EM61-MK2 operator helped this process.
- The weather was a large factor during the summer months, areas with no shade required more breaks and water intake for the intrusive teams.

8.3 COST BENEFIT

For a production removal action project with 10,000 anomalies selected for investigation, we would expect the MetalMapper costs to be reduced to a maximum of $39/anomaly (based on a production rate of 200/day) for data collection and processing. We would also expect the intrusive costs to be closer to $100/anomaly. Assuming a 60% reduction in the number of clutter items that could be eliminated from intrusive investigation would yield a potential cost savings of $50,000 based on the following assumptions:

- 10,000 anomalies at $100/anomaly for intrusive investigation equals a cost of $1,000,000.
- Reduction of 6,000 anomalies equals a reduction of $600,000 in excavation costs.
- MetalMapper costs for collecting and analyzing 10,000 anomalies at $39/anomaly equals $390,000.
- Total net savings under this scenario equals $210,000 (21%).

9.0 IMPLEMENTATION ISSUES

There were a few notable implementation issues regarding the MetalMapper survey:

- The software crashes discussed in Section 8.2 were the largest issue faced by the field team. There were very few days during the field project in which these crashes did not cause delays ranging from an hour or so of lost production to most of the day.
- The first tractor delivered to the site for transporting the MetalMapper did not have an adjustable 3-point hitch and could not be modified to accept the adapter on the MetalMapper sled. Time was lost while first attempting to find a way to adapt the sled to the hitch and then finding a new tractor after adaptation proved to be impossible with the tools at hand.
- The MetalMapper and the MetalMapper crew needed to be remobilized to the site after it became apparent that the targets collected during the first mobilization did not include the seed items buried specifically for testing the detection capabilities of the MetalMapper. This proved to be due to a lack of coordination between the field team collecting the data, who should have realized that they were using a target list that could not have the seed items in it, and ESTCP, which did not send a final target list (the field team was purposefully kept unaware of the seed item locations) containing the seeds before the start of collection.
- During the collection and analysis of the data, little consideration was given to the distance between the picked target location from the electromagnetic survey and the collection and fit locations of the MetalMapper points for the targets. Future analysis should consider these offsets—in the field to ensure that MetalMapper points are collected within a reasonable distance of the intended point, during analysis to ensure that the results generated for a given point actually represent that point, and during the intrusive investigation to ensure that dig results are tied to the correct MetalMapper target.
- All targets with poor β1 curves were classified as can't analyze for this project. It is likely that some of the Can't Analyze targets were collected at EM61 target locations that may have been generated as targets due to EM61 noise or duplicate pick on an anomaly better represented by a different EM61 target. In such cases, an analysis of the signal amplitude and electromagnetic target vs. MetalMapper collection vs. MetalMapper fit locations may have resulted in fewer Can't Analyze targets.

10.0 REFERENCES

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