DEMONSTRATION REPORT

Live Site Demonstrations: Former Camp Beale

Demonstration of MetalMapper Static Data Acquisition and Data Analysis

ESTCP Project MR-201157

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14. ABSTRACT

This project involved 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 200 seed items for use in measuring the capabilities of the advanced EMI sensors tested, the subsequent collection of the 9 acres of EM6-MK2 data, and the intrusive investigation of the 2,143 targets (including seed items) selected for additional investigation with the advanced sensors. The second team was responsible for the cued survey of 1,491 of the 2,143 targets using the MetalMapper, one of the advanced electromagnetic induction (EMI) sensors tested during this project. 1,232 targets were surveyed with the MetalMapper in the open field area; 259 targets were surveyed with MetalMapper and man-portable sensors in the combined area; and the remaining 652 targets were selected in wooded areas for the testing of man-portable sensors operated by other demonstrators. Comparison of the MetalMapper dig list with the ground truth set resulted in a 78 percent reduction in the number of clutter digs.

15. SUBJECT TERMS

Metal Mapper, EMI, UXO, MEC, Camp Beale, discrimination, classification

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Final Report

Table of Contents

Figures

Tables

Acronyms

$\beta 1$, $\beta 2$, $\beta 3$	polarizabilities along principal axes of target
BUD	Berkeley UXO Discriminator
CD	cultural debris
cm	centimeter
DAQ	data acquisition computer
DGM	digital mapping
DoD	Department of Defense
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
ft.	foot
FUDS	formerly used defense site
GPS	Global Positioning System
Hz	hertz
ID	identification
IDA	Institute for Defense Analyses
in.	inch
ISO	industry standard object
IVS	instrument verification strip
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
P_{class}	probability of correct classification
N_{fa}	number of false alarms
OER	Ordnance & Explosives Remediation
QC	quality control
RA	removal action
RCWM	recovered chemical warfare materiel
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
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 the former Camp Beale 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 ESTCP Unexploded Ordnance (UXO) Classification Study, Camp Beale, California, 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 200 seed items for use in measuring the capabilities of the advanced EMI sensors tested, the subsequent collection of the 9 acres of EM6-MK2 data, and the intrusive investigation of the 2,143 targets (including seed items) selected for additional investigation with the advanced sensors. The second team was responsible for the cued survey of 1,491 of the 2,143 targets using the MetalMapper, one of the advanced electromagnetic induction (EMI) sensors tested during this project. 1,232 targets were surveyed with the MetalMapper in the open field area; 259 targets were surveyed with MetalMapper and man-portable sensors in the combined area; and the remaining 652 targets were selected in wooded areas for the testing of man-portable sensors operated by other demonstrators.

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 two ground truth sets: one that identified a number of native fuzes as clutter, and one that identified these fuzes as TOI. Because all of the native fuzes were officially classified as TOI, the fuzes as clutter ground truth set is considered the more descriptive for MetalMapper results. Comparison of the dig list with this ground truth set resulted in the correct identification of more than 99 percent of the TOI on site (one TOI incorrectly classified as clutter) and a reduction in the amount of clutter that would have been dug by approximately 78 percent.

The largest implementation issue on the project was a series of recurring software crashes that led to an average production rate of 115 points collected per day with the MetalMapper. Although the exact cause of the crashes is still unknown, Geometrics is aware of the problem and working to correct it. Additional demonstration studies using this technology are planned for this year and upcoming years, and it seems reasonable to assume that these problems can be corrected before or during these studies. In addition to potentially refining the equipment, future studies look to focus on more demanding sites, with higher anomaly densities and a wider range of munitions sizes than those at Camp Beale.

1.0 INTRODUCTION

Currently up to 90 percent 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 the former Camp Beale.

1.1 BACKGROUND

The Fiscal Year 2006 defense appropriation contained funding for the "Development of Advanced, Sophisticated Discrimination Technologies for Unexploded Ordnance (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 [in.] mortar) and benign topography and geology. All of the classification approaches demonstrated were 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. Camp San Luis Obispo (SLO), California, was 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 all included smaller TOI than either of the previous sites. Great success was achieved identifying 37-millimeter (mm) projectiles, fuzes, and larger TOI with the advanced sensors.

To build upon the success of these studies, 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. Past studies included open field pastures; the current study area included four acres of medium density wooded areas. The demonstration area at the former Camp Beale included about 6 acres of open field area and 3 acres of wooded area to provide increasing difficulty to test the high standards established in the previous studies. Parsons was responsible for managing the site, performing a surface sweep of the survey area, seeding, EM61-MK2 data collection/processing, MetalMapper data collection/analysis, and excavating the 1,943 anomalies associated with the survey area.

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 (FUDS). The cost savings are expected to be particularly significant at removal action (RA) sites. Parsons is currently involved with U.S. Army Corps of Engineers (USACE) on 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.

This demonstration consisted of the cued interrogation of previously identified EM61-MK2 anomalies using advanced EMI systems. The advanced EMI MetalMapper system was demonstrated over 6 acres of open area. Three developmental EMI systems—the Naval Research Laboratory's 2x2 TEMTADS Array, Lawrence Berkeley National Laboratory's (LBNL) handheld Berkeley UXO Discriminator (BUD), and Sky Research's Man-Portable Vector (MPV)—were tested by other vendors within 3 acres of wooded area and 1 acre of open area (combined area). The developmental EMI systems are discussed in separate reports submitted by the respective demonstrators.

1.3 REGULATORY DRIVERS

As part of the cleanup of former 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 with the potential for Department of Defense (DoD) budget cuts to affect the amount of money that will be available for future remedial actions.

2.0 TECHNOLOGY

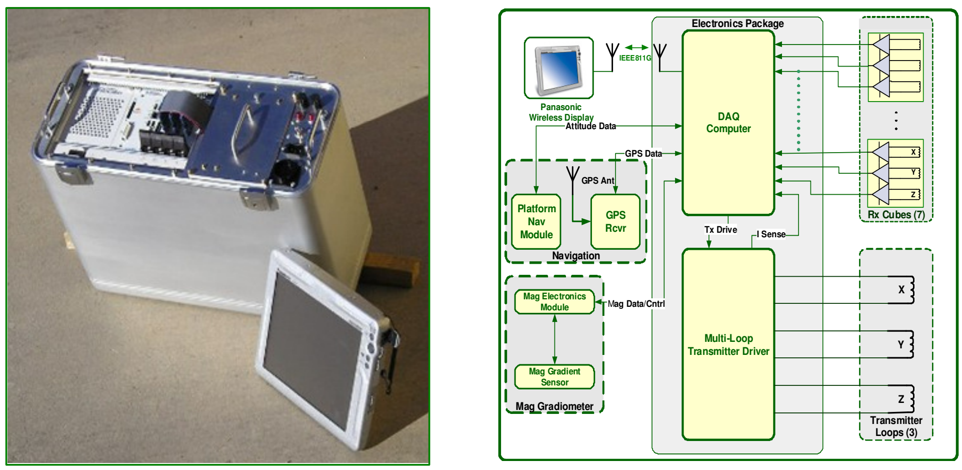
2.1 TECHNOLOGY DESCRIPTION

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 PC 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 (GPS) 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.

Figure 2-1: DAQ and DAQ Functional Block Diagram



A) MM DAQ assembly with Panasonic terminal.

B) Function block diagram of MM system

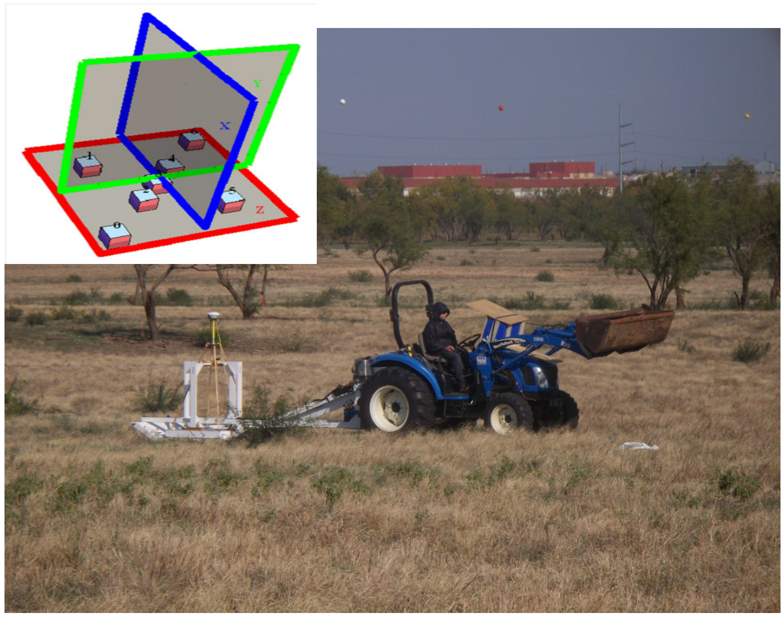
Data are acquired in time blocks that consist of a fixed number of transmitter cycle "Repeats". Both the period (T) and the repeat factor (N) are operator selectable and are varied in multiplicative factors of 3. The MetalMapper also averages an operator-specified number of acquisition blocks (NStacks) 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. A photo of the typical configuration of the instrument used for collecting cued data is shown in **Figure 2-2**.

In its present (third generation) form, the MetalMapper technology has been demonstrated and scored at the Standardized UXO Technology Demonstration sites at YPG (blind grid only), at APG (blind grid plus direct fire and indirect fire areas), and most recently at SLO and Camp Butner in connection with 2009 and 2010 classification studies 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 and Camp Butner.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

There are a few advanced EMI sensors that are similar to the MetalMapper in theory and design, with the most comparable being the TEMTADS 5x5 and the BUD. The TEMTADS 5x5 consists of 25 pairs of transmit/receive coils oriented in a 5x5 grid pattern, approximately 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.

Figure 2-2: Antenna Array and Typical Deployment of the MetalMapper System



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. Additionally, its effectiveness in areas with extremely high anomaly densities is currently unknown, although data were collected in high-anomaly-density areas during a demonstration study at performed Fort Sill in late 2011. Results for the Fort Sill study are currently unavailable.

3.0 PERFORMANCE OBJECTIVES

The primary performance objectives for this demonstration include:

- Evaluating if classification techniques will work at the former Camp Beal site;
- Evaluating where classification techniques will work at former Camp Beale; and
- Evaluating the cost effectiveness of classification techniques in the areas at former Camp Beale where classification is determined to be effective.

The specific performance objectives for this demonstration are summarized in **Table 3-1**.

3.1 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability to completely survey the site and obtain valid data.

3.1.1 Metric

The metrics for this objective were the down-line distance between adjacent data points and the maximum coverage gap in the final, mapped EM61-MK2 data.

Table 3-1: Performance Objectives for This Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Data Collection Objectives			
Complete coverage of the demonstration site	Along line point spacing Survey coverage	• Mapped survey data	98% of data points <= 25cm along line >= 98% coverage at 0.5m line spacing
Repeatability of instrument verification strip measurements	Amplitude of electromagnetic anomaly Measured target locations	• Twice-daily instrument verification strip survey data	Amplitudes ±25% Location ±25cm
Detection of all targets of interest (TOI)	Percent detected of seeded items	• Location of seeded items • Anomaly list	100% of seeded items detected
Analysis and Classification Objectives			
Maximize correct classification of 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

Table 3-1: Performance Objectives for This Demonstration (Continued)

Performance Objective	Metric	Data Required	Success Criteria
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 < 15cm (1σ) Z < 10cm (1σ)

3.1.2 Data Requirements

Quality control (QC) tools in Geosoft's Oasis montaj software were used to check the percentage of points more than 25 centimeters (cm) from each other and the total area of data gaps in each surveyed grid.

3.1.3 Success Criteria

This objective were considered to have been met if at least 98% of the mapped data points were within 25cm down line of each other and if at least 98% of the site was mapped at the proposed line spacing of 50cm.

3.2 OBJECTIVE: REPEATABILITY OF IVS MEASUREMENTS

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

3.2.1 Metric

The metrics for this objective were the amplitude and down-track position of the maxima obtained from each of the twice-daily surveys of the instrument verification strip (IVS).

3.2.2 Data Requirements

Daily IVS survey data were used to judge this objective.

3.2.3 Success Criteria

This objective is considered met if the measured amplitude for each object in the IVS was within 25% of the expected response and if the position of the anomaly was within 25cm of the known location.

3.3 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

Quality data should lead to a high probability of detecting the TOI at the site.

3.3.1 Metric

The metric for this objective was the percentage of seed items detected using the specified anomaly selection threshold.

3.3.2 Data Requirements

The target list developed using the EM61-MK2 data was compared to the known locations of the items seeded during the project to judge this objective.

3.3.3 Success Criteria

The objective is considered met if 100% of the seeded items were detected.

3.4 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 items remaining at the site as TOI.

3.4.1 Metric

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

3.4.2 Data Requirements

MetalMapper data were 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. The Institute for Defense Analysis (IDA) used scoring algorithms to compare the "dig" targets to the list of items identified as TOI during the intrusive survey.

3.4.3 Success Criteria

The objective is considered met if all of the items of interest are correctly labeled as TOI on the prioritized anomaly list.

3.5 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

This is 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 is a function of the degree to which responses that do not correspond to TOI can be eliminated from consideration during the intrusive investigation.

3.5.1 Metric

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

3.5.2 Data Requirements

MetalMapper data were 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" targets. IDA used scoring algorithms to compare the "no dig" targets to the list of items identified as Non-TOI during the intrusive survey.

3.5.3 Success Criteria

The objective is considered met if more than 50% of the non-TOI items can be correctly labeled as Non-TOI.

3.6 OBJECTIVE: SPECIFICATION OF NO-DIG THRESHOLD

In a retrospective analysis as 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, not all targets may be dug, so the success of the approach will depend on the ability of an analyst to accurately specify their dig/no-dig threshold.

3.6.1 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 are the metrics for this objective.

3.6.2 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.

3.6.3 Success Criteria

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

3.7 OBJECTIVE: MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

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

3.7.1 Metric

The number of anomalies for which reliable parameters cannot be estimated is the metric for this objective.

3.7.2 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.

3.7.3 Success Criteria

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

3.8 OBJECTIVE: CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the target parameters that are 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.

3.8.1 Metric

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

3.8.2 Data Requirements

The inverted or fit locations determined for each target during MetalMapper analysis and the locations of recovered items, as recorded by the intrusive teams, were compared to determine the difference between the two.

3.8.3 Success Criteria

The objective is considered to be met if the estimated X, Y locations are within 15cm (1σ) of the actual locations and if the estimated depths are within 10cm (1σ).

3.9 OBJECTIVE: INTRUSIVE

The reliability of the demonstration depends on the correct identification of the anomalies intrusively investigated. This objective concerns the ability of the intrusive personnel to identify and document the anomalies in accordance with the intrusive plan.

3.9.1 Metric

The metrics for this objective is the accuracy and precision of the locations once they are located during the demonstration.

3.9.2 Data Requirements

The GPS survey data collected during the seed emplacement vs. the final demonstration analysis were used to confirm this objective.

3.9.3 Success Criteria

This objective will be considered to be met if all seeds are placed in the ground according to the seeding plan (Appendix C) and a comparison to the location recorded by the intrusive team.

4.0 SITE DESCRIPTION

The former Camp Beale is approximately 10 miles east of Marysville, California, in Yuba County. The demonstration area chosen by ESTCP includes historic ranges used from 1948 to

1959. Currently, the demonstration area lies approximately 2 miles east of the active Beale Air Force Base installation boundary just off Waldo Road. The demonstration area is currently owned by the State of California and is managed as the Spenceville Wildlife and Recreation Area. A large percentage of the land within the former Camp Beale is undeveloped and used for agriculture (primarily livestock).

The demonstration area chosen by ESTCP includes historic ranges used from 1948 to 1959. Based on archives search report findings, ranges on Camp Beale included the use of light, medium, and heavy tanks; self-propelled anti-tank gun; 37mm anti-aircraft guns; 105mm howitzers; 81mm mortars; and 4.2 inch mortars. Ranges and bombing targets surrounding the demonstration area include small arms (Ranges 6, 11, and 12) and ground to air artillery ranges (Range 13) and three overlapping bombing targets that were used by both the Air Force and Navy.

In 1959, the U.S. Government declared the portions of Beale Air Force Base as excess, and a surface clearance was conducted prior to the transfer of the property. The property was transferred to the State of California between 1962 and 1969 and was recommended for surface use only. Currently, the area consists of the Spenceville Wildlife and Recreation Area.

An aerial photo of former Camp Beale and the demonstration area is shown in **Figure 4-1**.

4.1 SITE SELECTION

The former Camp Beale was chosen based on partially wooded terrain, steep slopes, and a wide mixture of munitions, which increased the complexity of the classification process. The first site in the series, former Camp Sibert in Alabama, had only one TOI, and item "size" was an effective discriminant. A hillside range at the former SLO in California was selected for the second of these demonstrations because of the wider mix of munitions, including 60mm, 81mm, and 4.2-in. mortars and 2.36-in. rockets. The third site chosen was the former Camp Butner in North Carolina, which was known to be contaminated with items as small as 37-mm projectiles, adding yet another layer of complexity into the process.

4.2 GEOLOGY

The principal physiographic units in the area are the dissected alluvial uplands west of the Sierra Nevada, the foothills section of the Sierra Nevada, and the Sierra Nevada Mountains. The dissected alluvial uplands consist of low hills and gently rolling country that merge with the foothills of the Sierra Nevada on the east and the low alluvial plains of eastern Sacramento Valley on the west. The foothills lie to the east of the alluvial uplands and are an undulating to very steep region at the base of the Sierra Nevada Mountains. Geologic units outcropping in the area include the basement complex of metamorphosed igneous and sedimentary rocks and igneous batholiths and intrusives, andesitic and rhyolitic volcanic rocks, the Laguna Formation and related continental deposits of Pliocene and Pleistocene age, the Victor Formation and related continental deposits of Pleistocene age, and river deposits of Holocene age (USACE, 1997).

The three primary near-surface soil profiles are related to geomorphic location: alluvial upland, Sierran foothills, and mountain series. The alluvial uplands in the area are underlain by silty sands with gravel, which cover the weathered granite bedrock surface. The surface soil consists of approximately 15 inches of grayish-brown, coarse-grained silty sand with gravel. The subsoil is pale-brown, coarse-grained silty sand with gravel. The highly weathered granodiorite is about 30 inches below the surface. Permeability is moderately rapid. The foothills of the Sierra Nevada are underlain by sandy and gravelly silts, covering vertically tilted metamorphic rock. Typically, the surface layer of the soil is a brown gravelly silt with sand, about 4 inches thick. The subsoil is yellowish red gravelly silt with sand. Metamorphic schist bedrock typically is found at a depth of about 20 inches (USACE, 1997).

4.3 MUNITIONS CONTAMINATION

The suspected munitions in this demonstration area include but are not limited to:

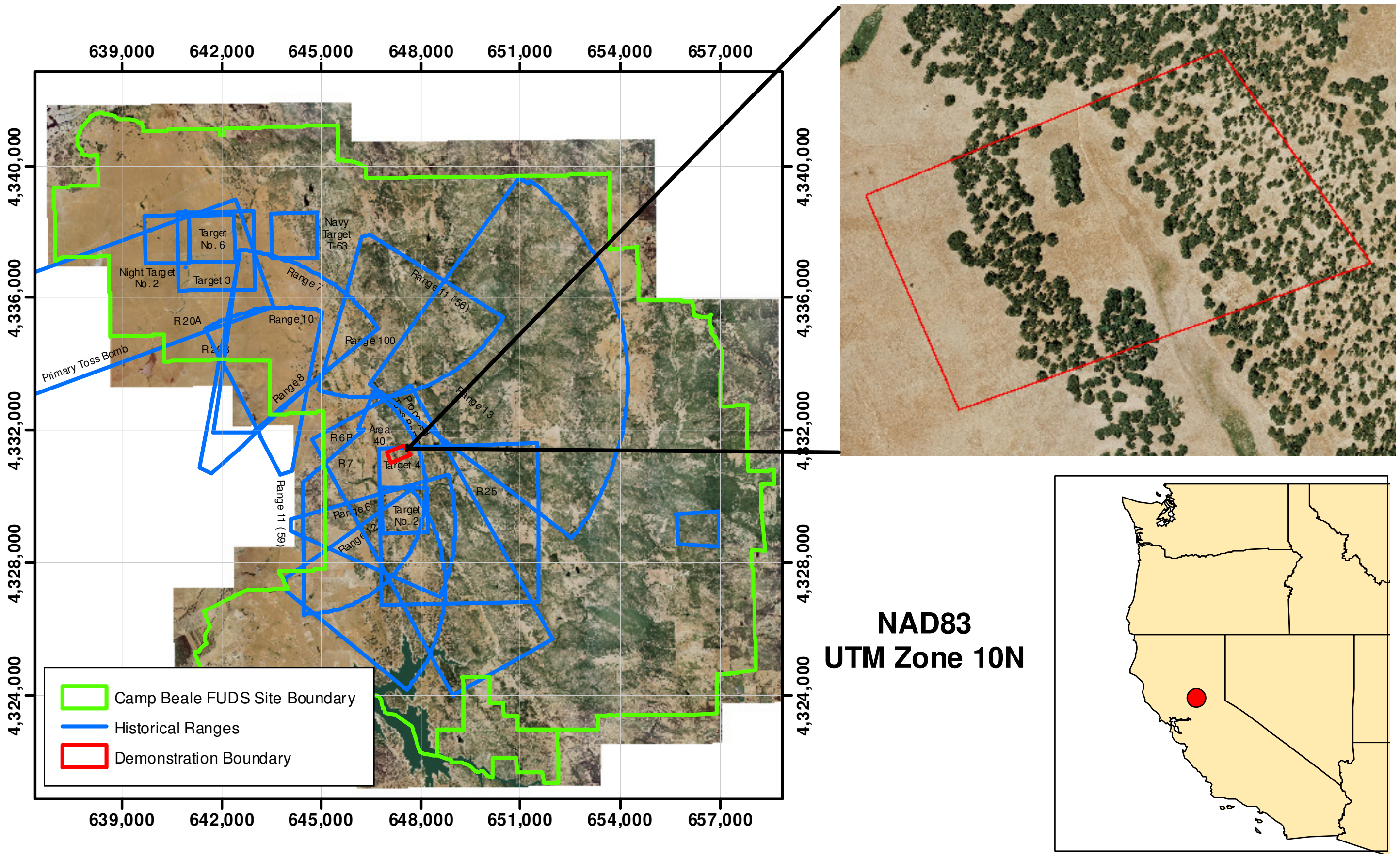
- 37mm projectiles
- 60mm mortars
- 81mm mortars
- 105mm projectiles

At the site of this demonstration, evidence of 81mm mortars and 105mm projectiles was found during the site inspection intrusive investigation in 2005. It is also suspected that 60mm mortars may be present. In addition, 37mm projectiles have been found scattered throughout the former Camp Beale and are included as another suspected munition in this area. Due to the complex historical usage of this site over many years and the overlapping network of historical ranges throughout, it is also likely that other munitions types beyond those listed above may be encountered.

4.4 SITE CONFIGURATION

The demonstration site covers approximately 9 acres. The EM61-MK2 was used to survey the 9-acre site with 100% coverage. The 50-acre demonstration area is shown in **Figure 4-2**.

Figure 4-1: Location of the Demonstration Study Area



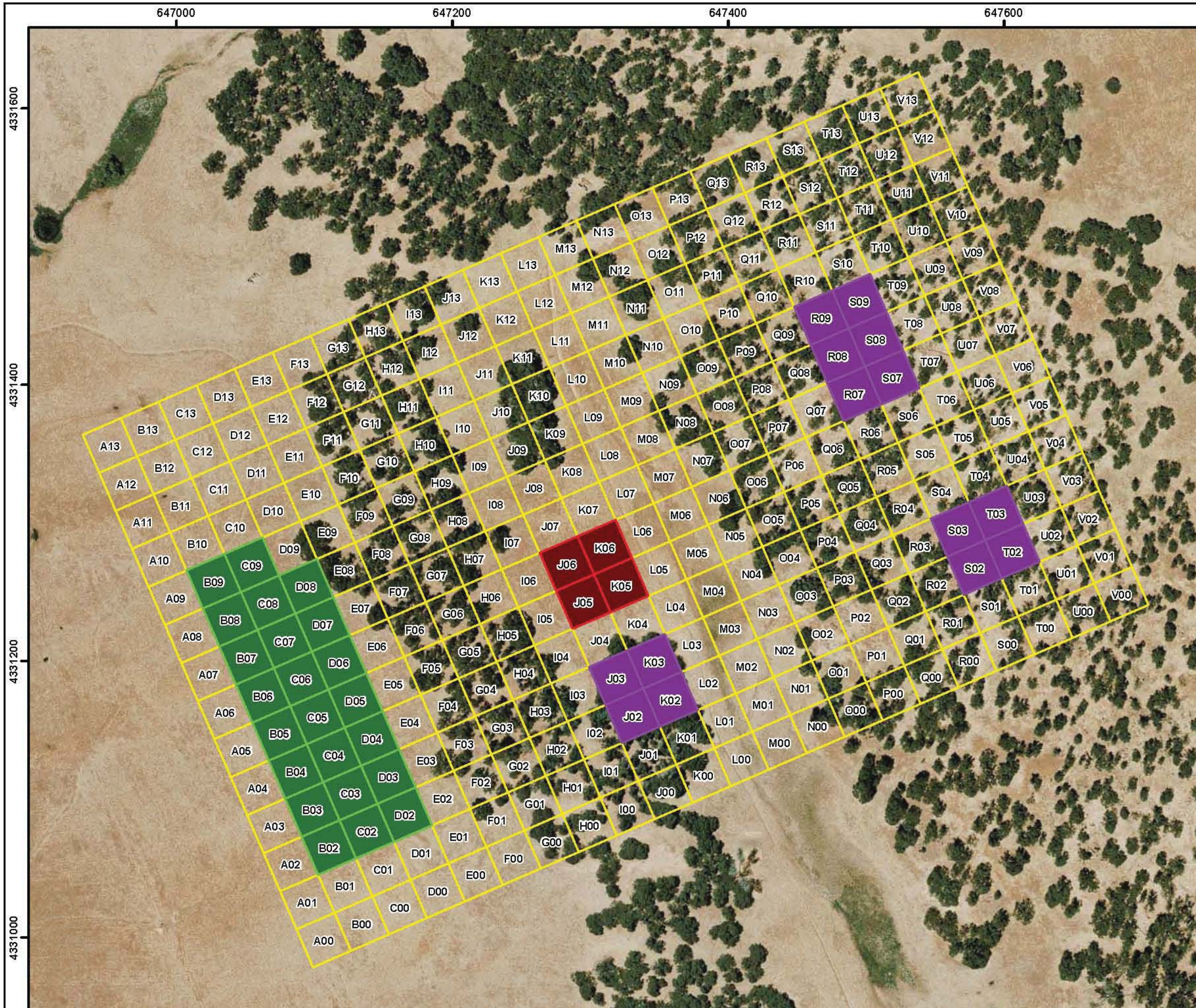


Figure 4.2

Grid Layout
Former Camp Beale

Yuba County, California

Legend

- Combined Grids
- Combined Area
- MM Grids
- Metal Mapper Area
- Portable Grids
- Portable Areas
- NAEVA Grid

Site Location in California

N

Image: 2001 Orthophoto
Projection: UTM Zone 10 NAD83, Map Units in Meters

Meters
100 50 0 100

PARSONS	U.S. ARMY SOUTH PACIFIC DIVISION RANGE SUPPORT CENTER
DESIGNED BY: BL	**Grid Layout**
DRAWN BY: BL	
CHECKED BY: JY	SCALE: As Shown — PROJECT NUMBER: 748036.01110
SUBMITTED BY: NA	DATE: April, 2011 — PAGE NUMBER: 13
	FILE: Figure1_1.mxd

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

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

The ESTCP Program Office coordinated data collection activities. This included all preparatory activities, arranging for data collection by well-validated systems, preprocessing of the data to include positioning of each sensor reading and any overall filtering required, oversight of selection of anomalies for analysis from each geophysical data set, and compilation of a master anomaly list.

Data analysis demonstrators were provided with the survey data and data from as many cued targets as they choose. They processed individual data sets using existing routines to extract target parameters. These parameters were passed to the classification routines which, after training on a limited amount of site-specific ground truth, were used to produce prioritized anomaly lists.

Validation digging was coordinated by the Program Office. Since this was a demonstration, all anomalies on the master anomaly list were investigated. The underlying target was uncovered, photographed, located with a cm-level GPS system, and removed. Each analysis demonstrator was able to request ground truth data for training, either the ground truth from a small number of grids chosen by the Program Office or from a subset of the sensor anomaly list of the demonstrator's choosing. At the conclusion of training, each demonstrator submitted an initial ranked anomaly list for each data set analyzed. These lists were ordered from the item the demonstrator was most confident was a munitions through the item the demonstrator was most confident was not hazardous and indicated the threshold the demonstrator chose for initial digging. Anomalies for which the demonstrator could not extract meaningful parameters were placed at the top of the list. Dig results from the first round of digging were provided to each deomstrator, following which the demonstrators construct 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 how well each demonstrator ordered their ranked anomaly list(s) and specified the threshold separating high confidence clutter from all other items. The secondary objective was to determine the classification performance that could be achieved by each approach through a retrospective analysis.

5.2 SITE PREPARATION

5.2.1 Acquire Site-Specific Information

The demonstration site falls within the historical bombing Target 4 and the Proposed Toss Bomb target area. As stated above, evidence of 81mm mortars and 105mm projectiles was recovered as part of the site inspection intrusive investigation in the demonstration area, and it was also suspected that 60mm mortars might have been present. In addition, 37mm projectiles have been found scattered throughout the former Camp Beale, so they were included as another suspected munition. Due to the complex historical usage of this site over many years and the overlapping network of historical ranges throughout, it was thought possible that other munitions types beyond those listed above may have been encountered.

5.2.2 First-Order Navigation Points

To avoid confusion between and among various demonstrators, it was important that all survey data and validation activities were conducted on a common coordinate system. Two first-order survey monuments were installed at the site. The points are labeled 1 and 2, their coordinates are given in **Table 5.1**.

Table 5-1: Geodetic Control Locations

ID	Northing	Easting	Elevation NAVD88 (m)
Beale 1	4331339	646936.3	100
Beale 2	4331030	647071.7	100

5.2.3 Surface Clearance

As part of the Camp Beale ESTCP study, Parsons UXO personnel conducted instrument-aided surface clearance before the digital mapping (DGM) 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, Parsons also conducted minor brush clearing, cutting low-lying branches and removed fallen trees from the demonstration area. This operation lasted one week starting on April 19, 2011. The majority of items found on the surface sweeps were barbed wire, along with small munitions fragments. Two notable items identified during the surface clearance were an empty 75mm projectile and a large pile of barbed wire that was eventually moved out of the survey area. These are shown in **Figures 5-1a** and **5-1b**.

5.2.4 EM61-MK2 Coverage Survey

DGM data were collected using a hand-towed EM61-MK2 time-domain electromagnetic sensor. Positioning was accomplished using either RTK GPS, Trimble Robotic Total Station (RTS), or fiducial methods, depending on the availability GPS signal and tree density in the wooded area. The EM61-MK2 was set up in the four-channel mode.

Figure 5-1: Items Identified during Surface Clearance

A: Empty 75mm Projectile

B: Barbed Wire

The standard EM61-MK2 consists of two 0.5m by 1m coils, separated vertically by a distance of 30cm, set on a pair of wheels. For this project, wheels were used with the instrument, which held the bottom coil 0.4m above the ground. The EM61-MK2 sensors were set to record four time gates from the bottom coil.

The GPS equipment used to collect positional data included a Trimble R8 antenna and base station. The rover collected positional measurements at a rate of 1 Hz and transmitted them to the EM61-MK2 data logger or field computer.

DGM data were collected using grid-based system in both open fields and wooded areas on individual 30m by 30m grids. Grid-based data were collected in parallel lines spaced 0.5 m apart and were intended to cover 100 percent of the area being investigated. GPS data were used on the majority of the demonstration areas where a GPS signals were not affected by tree density. Fiducial and Trimble RTS was used in the denser wooded areas.

5.2.5 Seed 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 former Camp Beale on April 25, 2011, through May 6, 2011. The seeding locations covered approximately 9 acres in five separate areas at the site in both open pasture and wooded grids. The location of each seed item was established with a Trimble 5800 RTK GPS system and a Trimble RTS for the wooded areas. The Base Station control point used for this operation was established previously in Universal Transverse Mercator (UTM) Zone 10N, WGS84 coordinates. All seed items, with the exception of small industry standard object (ISO), items were received from the Army Research lab in Maryland.

Parsons flagged 200 locations with the Trimble GPS and RTS units and established anomaly avoidance at each location to ensure a clean area for emplacement. All 200 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. Prior to 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 by Parsons. The dip angle specifications were set to a 45-degree tolerance, with the exact angles measured with a level. Exact angles above horizontal, 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 the final QC check was completed. This 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 accomplished, the backfilling was started with a shovel to prevent any excess movement of the seed items.

Seed items for the former Camp Beale Area included 37mm projectiles, 60mm projectiles, 81mm projectiles, 105mm projectiles and small ISO items. **Table 5-2** lists the seed items.

Table 5-2: Seeded Items

Seed item	Total
Small ISO	65
37mm	59
60mm	34
81mm	33
105mm	9
Total	**200**

5.2.6 Establish an Instrument Verification Strip and Training Pit

A clean area based on EM61-MK2 data was located in grid M05 as the IVS area; this area was flat and equidistant to the demonstration grid areas. A 50-foot (ft.) by 150ft. area was used to establish the IVS and test pit used for daily verification of proper sensor operation and calibration to be used to collect sensor data for algorithm training. **Table 5-3** lists the IVS seed items.

Table 5-3: IVS Items

IVS item	Depth (cm)	Orientation
Shot put	30	Horizontal
105mm HEAT (high explosive anti-tank) missile	45	Horizontal
60mm w/o fin	15	Horizontal
37mm	15	Horizontal
1in. x 4in. pipe nipple	15	Horizontal

5.3 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. During the demonstration at Camp Beale, the antenna array was placed in a wooden sled attached to the rear three-point hitch of a Kabota 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 10Hz, 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 IVS Data Collection

A test pit was constructed at the site before the arrival of the MetalMapper data collection team. The pit was an approximately 3ft. by 3ft. by 3ft. hole that allowed the collection of static MetalMapper data over TOI items 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 at two different depths for a total of eight readings per item. **Table 5-4** indicates the various measurements collected in the test pit.

Table 5-4: Data Collected in the Test Pit

Item ID	Depths (cm)	Orientations
Empty pit (static - 5 min)	N/A	N/A
Steel sphere	27	N/A
37mm projectile	10, 20	Horizontal (along track and across track), 45° down, 90° down
60mm mortar	20, 30	Horizontal (along track and across track), 45° down, 90° down
81mm mortar	25, 45	Horizontal (along track and across track), 45° down, 90° down
105mm projectile	30, 45	Horizontal (along track and across track), 45° down, 90° down
Small industry standard object (ISO)	20	Horizontal (along track and across track), 45° down, 90° down
Flare casing (native)	25	Horizontal (along track only), 45° down, 90° down
75mm (native; blown open)	25	Horizontal (along track only), 45° down, 90° down
Unknown fragment (native)	25	Horizontal (no specific orientation), 90° down

In addition to the test pit data, data were collected over one of two IVSs twice daily. One of the IVSs was in the central portion of the site and was constructed before the MetalMapper team's arrival. This strip consisted of five items of various sizes, a steel sphere, small ISO, 37mm projectile, 60mm mortar, and 105mm projectile. It was intended that this strip be used throughout the project, but the drive time between this IVS and most of the MetalMapper targets on the west side of an intervening hill was deemed excessive. To save time driving between the IVS and the targets and to avoid undue stress on the MetalMapper during the drive, Parsons set up another IVS on the west side of the site near the survey area. This second IVS consisted of three items: a 37mm projectile, 60mm mortar, and 81mm mortar. IVS data were collected at one of the two strips before and after daily data collection. All data collected over the IVS strip were inverted in the field as described in Section 6.2 and compared to the Camp Beale 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 15cm X,Y and 10cm depth; and
- The item identified by the target library comparison was compared to the actual buried item, and it was expected that the identified item matched TOI with a confidence high enough that it would be marked as a dig (0.7 confidence expected in the field)

All IVS data met the above requirements.

5.4.2 Background Data

Background data were collected at least twice daily, typically before each survey of the IVS strip. Daily background data were collected at designated locations adjacent to the IVS strip. Additional background points were collected at the operators' discretion during the day if they felt another point was necessary for any reason (changes to the configuration of the DAQ to minimize software crashes, changing field conditions such as rain, and etc.). One of the lessons learned from this project was that background measurements should be collected more often to account for potential changes such as drying dew throughout the morning and across-site differences in soil and/or geology. Parsons introduced more frequent background collection for later projects.

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 Camp Beale. Once the MetalMapper was positioned correctly above the target, the operator collected a data point using the settings indicated in **Table 5-5**.

Table 5-5: Acquisition Parameters Used during the Camp Beale Demonstration

Mode	Tx Mode	Hold-Off Time (us)	Block Period(s)	Rep Fctr	Dec Fctr (%)	Stk Const	Base Freq (Hz)	Decay Time (us)	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 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 1,729 data points during the project for 1,491 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 40cm 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 any targets that did not invert correctly during processing or for targets with modeled locations greater than 40cm 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), and the quality of static data points were reviewed visually using the plotting capabilities of the acquisition software. 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 40cm. Re-shots were collected for all targets with offsets greater than 40cm.

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 former Camp Beale began in July 11, 2011, and ended on August 22, 2011. Operations began with the site-specific training, which included prepping the staging area for intrusive activities and performing equipment checks. The staging area consisted of a 20ft.-long metallic storage unit and a mobile office at the Spenceville Wildlife compound. All Parsons intrusive equipment was stored at the compound and locked at the end of the day. Daily equipment check included confirming GPS accuracy over known monuments, EM61-Mk2 static tests, and handheld analog instruments calibrations.

Intrusive investigation of the 2,143 anomalies started in grid R09 and concluded on grid B02. All 2,143 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. Seven 55-gallon drums were filled with the sandbags, weighing 842 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 included Parsons and Ordnance & Explosives Remediation (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 Camp Beale intrusive activities included the following:

- Schonstedt Magnetic Locator (Model GA-52Cx)
- Whites Metal detector
- EM61-MK2
- Trimble 5800 GPS system
- Digital level
- Miscellaneous hand tools
- Digital cameras

5.6.2 Field Procedures

Reacquisition of all targets was conducted using the Trimble 5800 GPS system. The Trimble 5800 GPS base station was set up on survey monument Beale 1 and checked daily on monument Beale 2. Parsons flagged all target locations with a plastic pin flag that was 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 the magnetic north. Inclination was determined by 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 Trimble Geo XT units. The intrusive operations consisted of two intrusive teams. Each team was responsible for reacquisition, intrusive, and anomaly documentation. Once enough anomalies were processed, the least-busy team conducted the EM61-MK2 QC over the excavated holes.

Munitions debris (MD) and cultural debris (CD) scrap 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 were shipped on October 4, 2011, to the Army Research Lab in Welcome, Maryland. 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.

Figure 5-3: Intrusive Operation Photos

5.7 VALIDATION

As part of the intrusive operation, Parsons investigated 2,143 anomalies, which included 200 seed items. The average completed digs per day were 93, based on 23 intrusive days. The majority of the MD encountered consisted of unidentified munitions fragments. No MEC items were discovered during the intrusive operation. The anomaly breakdown in the study area was as follows:

Table 5-6: Intrusive Results

Type	Anomalies
Overall Results(9 acres)	
Cultural Debris	194
Munitions Debris	1710
No Contact	39
Seed	200
Open Area Grid (5 acres)	
Cultural Debris	173
Munitions Debris	944
No Contact	3
Seed	112
Combined Grids (1 acre)	
Cultural Debris	3
Munitions Debris	236
No Contact	0
Seed	20
Wooded Grids (3 acres)	
Cultural Debris	18
Munitions Debris	530
No Contact	36
Seed	68

5.8 MUNITIONS DEBRIS SCRAP

MD and CD scrap recovered from the demonstration area at the former Camp Beale amounted to approximately 842 pounds. The MD/CD scrap filled six 55-gallon drums, all with locks and numbered custody seals. Shipping information, along with certified and signed DOD 1348 forms, was included with the final transfer of the drums. YRC shipping picked up the drums on October 6, 2011. The shipment included the eight 55-gallon drums and six wooden crates, which included the inert 105mm projectiles. The shipment was delivered to Glen Harbaugh at the Army Research Lab in Welcome, Maryland. The total weight of the shipment was 1,690 pounds.

6.0 DATA ANALYSIS AND PRODUCTS

The MetalMapper was used to collect static data over 1,491 targets (including 30 test targets not intended for inclusion on the ranked dig list) identified at former Camp Beale 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 identification (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 10N 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., Static00001_2621). Preprocessing was typically completed in batches of half days, with the day split to account for differing background data. Background files were usually collected in the mornings and afternoons in a geophysically quiet location adjacent to the IVS before the collection of IVS data. Unless there appeared to be a problem with a background file, data collected before noon were typically corrected using the morning background file; data collected after noon were corrected with the afternoon background file.

6.2 PARAMETER ESTIMATION

All MetalMapper data points were inverted using UX-Analyze to determine a number of 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 reinverted 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

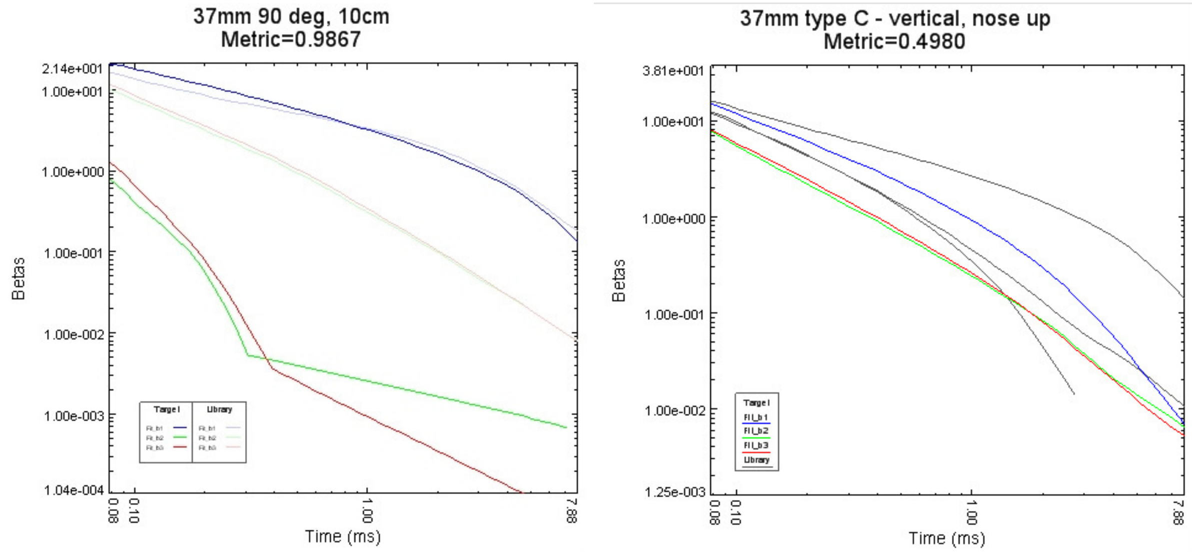
The polarization curves developed for each target, including any single-object-only results and secondary multiple-object results, were compared to a library of known polarization curves compiled using test stand data and test pit data from Camp Beale. The items in the Camp Beale comparison library were limited to the TOI expected at the Camp Beale site: 37mm, 75mm, and 105mm projectiles; 60mm and 81mm mortars; and small ISOs. Examples of various types of these items were used (e.g., four different versions of 37mm projectiles, three types of 105mm projectile), but items not expected at the site, such as hand grenades and rockets, were not included. All initial comparisons between the measured targets and the library data were also performed using an equal weight for all three primary polarizabilities (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. The processor either determined that the results were usable as they were or made a note in the target database in Geosoft that further processing was necessary. Results were deemed usable if the reviewer identified three reasonable-looking polarization curves or if a curve for the primary axis of polarization (β1) could not be identified. In these cases, the target was either left for ranking according to the decision statistic developed for the project (Section 4.0) or, for those targets without an identifiable β1 curve, classified as Can't Analyze. While the data for Can't Analyze targets was not usable for classification purposes because UX-Analyze cannot effectively compare a target without a primary polarizability to the library data, the result for that target was considered "usable" in that no further analysis would be performed on that target.

Targets with results not necessarily deemed usable on the first pass included those for which one or more non-β1 curves appeared to be poor data for any reason or targets that appeared to be "ordnance-like" but did not have a particularly good match to any of the library objects. Ordnance-like was defined as an object with relatively equal (i.e., symmetric) secondary axes of polarizability (β2 and β3) for which the magnitude of β1 was not less than β2 and β3. It was considered possible that targets with these characteristics were examples of ordnance not expected at the site and, therefore, not in the comparison library. **Figure 6-1** shows examples of the types of targets flagged during the first examination of the data: one with poor results for multiple polarization curves, and one that appears symmetric but with a poor match to any library object.

Figure 6-1: Targets Flagged for Additional Processing

A: β2 and β3 curves appear to be poor data **B:** Target is symmetric, but poor metric



Targets with one or more apparently poor β2 or β3 curves, as shown in Figure 1A, were recompared to the library data with the poor curves removed from the comparison. This was accomplished by changing the comparison weight for the poor-quality data to 0 (size: 1; shape 1: 1; shape 2: 0; or size: 1, shape 1: 0, shape 2: 0). In these cases, the revised, β1/ β2- or β1-only based confidence metrics were used when calculating the decision statistic used to rank each target.

6.3.2 Training Data

The training data request for Camp Beale was composed of targets flagged as ordnance-like, as described above. Various examples of these items were added to a separate target library and compared to the other symmetric objects, with the end result that five items added to the library fit all of the others with a confidence of 0.75 or higher. Five examples of each of four of the library items (20 total) were requested as training data. The fifth object was so similar to the rest of the examples from the site that only one example (BE-2528) was requested.

Out of the requested targets, only BE-2528, a native fuze, was identified as TOI. This target was added to the full Beale comparison library, and the full list of targets was compared to the library a second time to determine final confidence metrics for each.

6.3.3 Decision Statistic

Classification for the Camp Beale project was accomplished using the confidence metrics generated for each target during the comparison to the library data. The metric calculated for all three curves was used unless poor curves were identified by the analyst, as described in Section 6.3.1. In that event, the metric calculated for the β1/β2- or β1-only matches was used. The decision statistic used for the project was simply the final confidence metric selected for each target (β1/β2/β3, or β1/β2- or β1-only). No additional weight was given to targets that had three usable curves rather than one- or two-only because there were relatively few targets for which less than three curves were used. Targets were ranked based on decreasing confidence that they were TOI. The final dig list was completed in three stages, as described below

6.4 DATA PRODUCTS

6.4.1 Dig List Stage 1

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

- Training Data: 21 items selected as described in Section 6.3.2
- Can't Analyze: 34 items without usable β1 curves
- Likely TOI (Category 1): Decision statistic greater than 0.700
- Can't Decide (Category 2): Decision statistic between 0.600 and 0.700
- Likely Clutter (Category 3): Decision statistic less than 0.600

The stop-dig threshold was set at a decision statistic of 0.650 (mid Category 2), with the Training Data and Can't Analyze targets also considered digs. The Stage 1 dig list was only compared to the project seed items identified as "QC seeds." This comparison identified two seeds that would have gone un-dug based on the Stage 1 list: BE-2217 and BE-2277. BE-2217 was an ISO buried at 14cm with a decision statistic of 0.638. Because this target was one of the un-dug targets within Category 2, the decision was made to extend the dig threshold to the bottom of Category 2 (0.600) for the next Stage of the dig list.

BE-2277 was a 37mm projectile buried at 15cm in the vicinity of four pieces of barbed wire (**Figure 6-2A**). The decision statistic for this item was 0.270, which put it relatively close to the bottom of the dig list. The data point for this target was collected within the 25cm of the pick location, the modeled location of the target was within 10cm of the collection location, and there were no obvious signs of poor data (e.g., high noise or poor signal strength). For this target, the multiple object solver simply could not separate the 37mm response from the barbed wire responses, resulting in a poor match to any munition (**Figure 6-2B**). The nondetection of this item led to a reanalysis of the can't analyze category, although it was finally decided that there was no reason to believe that the data for this target were poor.

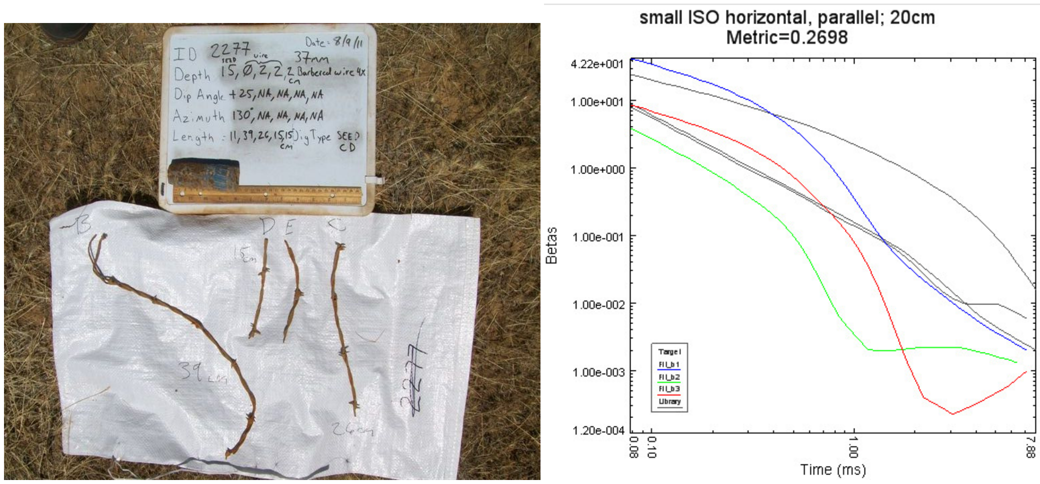
6.4.2 Dig List Stage 2

The Stage 2 dig list was submitted with the following parameters:

- Training Data: 23 items, including QC Seeds BE-2217 and BE-2277
- Can't Analyze: 45 items without usable β1 curves
- Likely TOI (Category 1): Decision statistic greater than 0.650
- Can't Decide (Category 2): Decision statistic between 0.650 and 0.575
- Likely Clutter (Category 3): Decision statistic less than 0.575

Figure 6-2: Target BE-2277

A: Recovered Items **B:** Response Curves



Modifications between the Stage 1 dig list and the Stage 2 dig list included the addition of the two missed QC seeds to the Training Data set, the addition of 11 targets to the Can't Analyze list, and the changing of category break points to lower decision statistics based on the nondetection of BE-2217 with the Stage 1 dig list. The Stage 2 dig list was considered an actual dig list, and the full set of intrusive results for the targets marked as "dig" were returned following the submittal. For this list, the stop-dig point was set at a decision statistic of 0.600.

The dig results indicated that the lowest-ranked TOI was BE-2019, which had a decision statistic of 0.647. The final 97 investigated targets were all non-TOI, so there appeared to be no reason to modify the dig threshold further for the final, Stage 3 dig list.

6.4.3 Dig List Stage 3

The final dig list was submitted with the following parameters:

- Training Data: 23 items, including QC Seeds BE-2217 and BE-2277
- Can't Analyze: 45 items without usable β1 curves
- Likely TOI (Category 1): Decision statistic greater than 0.600 – Dig
- Likely Clutter (Category 3): Decision statistic less than 0.600 – Do not dig

The only change between the Stage 2 and Stage 3 dig lists was the elimination of Category 2. Investigated Can't Decide targets from Stage 2 were changed to Category 1, and targets with decision metrics between 0.600 and 0.575 (i.e., un-dug Category 2) were changed to Category 3. The final list included 422 digs out of the 1,470 total targets. Sixty-eight of these were either targets used as Training Data or Can't Analyze anomalies, with the remainder ranked according to the decision statistic. The stop-dig threshold was set at rank number 354.

7.0 PERFORMANCE ASSESSMENT

7.1 OBJECTIVE: COMPLETE COVERAGE OF THE DEMONSTRATION SITE

The reliability of the survey data depends on the extent of coverage of the site. This objective concerns the ability to completely survey the site and obtain valid data.

7.1.1 Metric

The metrics for this objective were the down-line distance between adjacent data points and the maximum coverage gap in the final, mapped EM61-MK2 data.

7.1.2 Data Requirements

QC tools in Geosoft's Oasis montaj software were used to check the percentage of points more than 25cm from each other and the total area of data gaps in each surveyed grid.

7.1.3 Success Criteria

This objective was considered to have been met if at least 98% of the mapped data points were within 25cm down line of each other and if at least 98% of the site was mapped at the proposed line spacing of 50cm.

7.2 OBJECTIVE: REPEATABILITY OF IVS MEASUREMENTS

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

7.2.1 Metric

The metrics for this objective were the amplitude and down-track position of the maxima obtained from each of the twice-daily surveys of the instrument verification strip.

7.2.2 Data Requirements

Daily IVS survey data were used to judge this objective.

7.2.3 Success Criteria

This objective is considered met if the measured amplitude for each object in the IVS was within 25% of the expected response and if the position of the anomaly was within 25cm of the known location.

7.3 OBJECTIVE: DETECTION OF ALL TARGETS OF INTEREST

Quality data should lead to a high probability of detecting the TOI at the site.

7.3.1 Metric

The metric for this objective was the percentage of seed items detected using the specified anomaly selection threshold.

7.3.2 Data Requirements

The target list developed using the EM61-MK2 data was compared to the known locations of the items seeded during the project to judge this objective.

7.3.3 Success Criteria

The objective is considered met if 100% of the seeded items were detected.

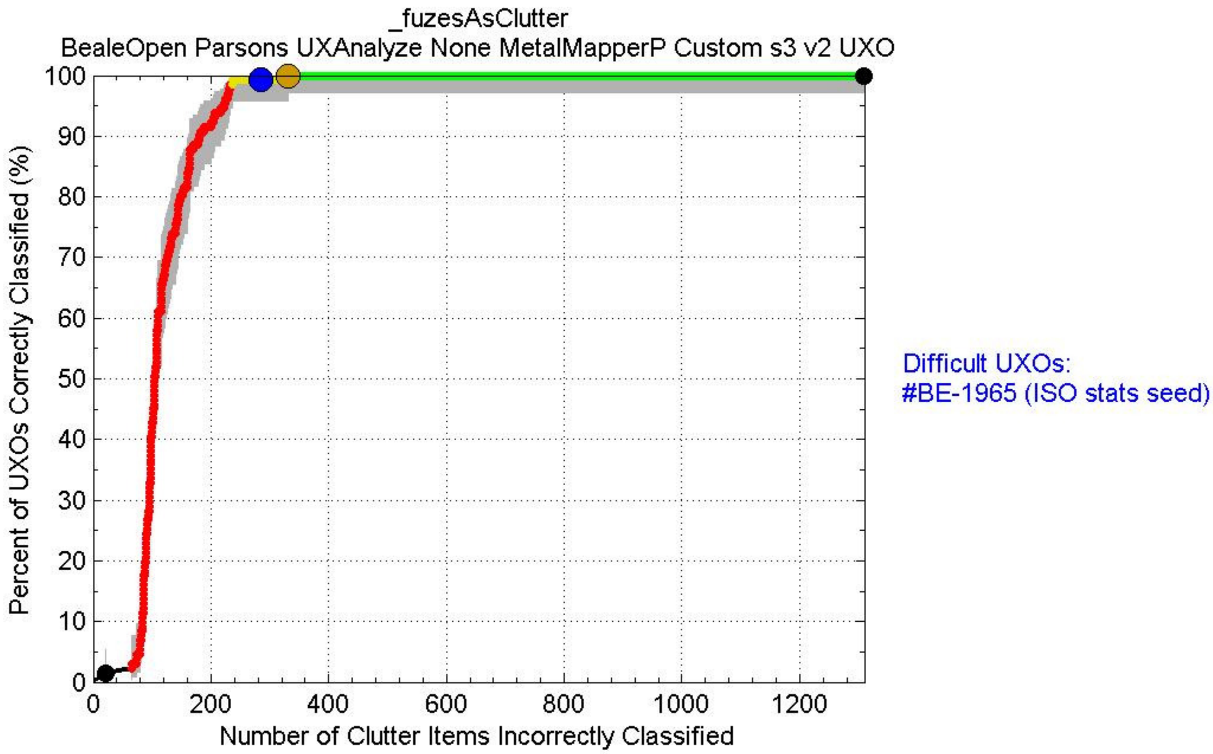
7.4 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF TOI

The submitted dig list was compared to ground truth data from Camp Beale by the IDA. The IDA compared the results against two sets of ground truth results. The only difference between the ground truth sets was the way in which 32 fuzes found at the site were categorized. These fuzes were native to the site (i.e., not seeds) and were deemed nonhazardous MD when they were recovered by the dig teams. However, they were quite distinctive and were UXO-related, and there was a fairly large number of them at the site. Therefore, they were identified alternately as UXO and MD by the IDA in the two sets of ground truth results.

The results of the dig list comparisons to the two ground truth lists were judged according to performance objectives identified for the project in the Camp Beale demonstration (Parsons, 2011). **Table 3-1** contains the performance objectives and identifies the criteria by which they were judged. Results for both sets of ground truth were compared to the first three: the correct classification of TOI, non-TOI, and the specification of the dig threshold. Because there was only one set of can't analyze anomalies and the location of recovered items was identical between ground truth sets, there was only one result for the objectives regarding the number of can't analyze anomalies and the offsets between recovered items and identified locations. The results of the submitted dig list with respect to each project objective and each set of ground truth data, if applicable, are detailed below.

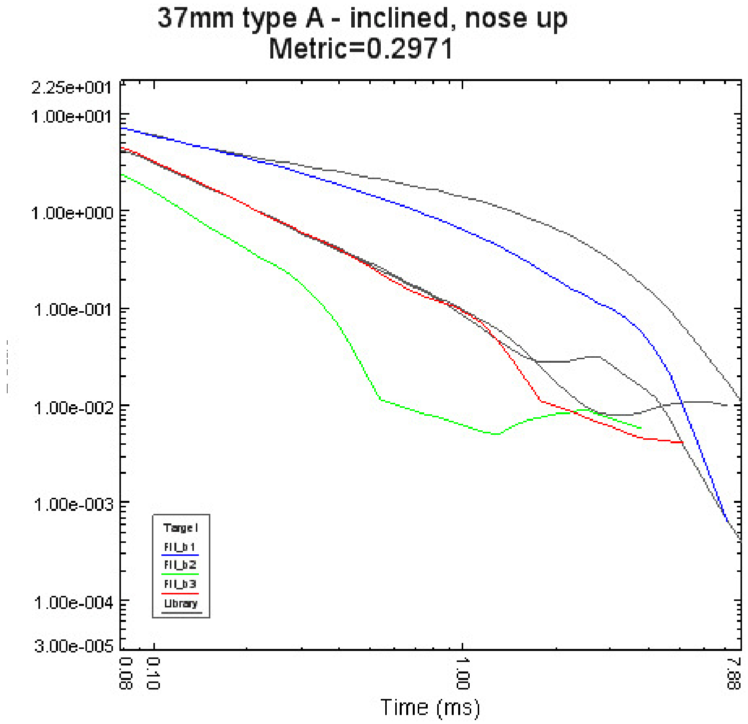
Some of the 1,470 targets for which data were collected at Camp Beale ended up being multiple picks on the same source, so only 1,441 digs were performed during the project. For the fuzes as clutter ground truth set, 131 of the 1,441 digs were classified as TOI, leaving 1,310 true negatives in this data set. It also reduced the number of items in the dig list that needed intrusive investigation from 422 to 415. **Figure 7-1** shows the receiver operating characteristic (ROC) curve for the fuzes as clutter ground truth data. As indicated in the figure, 130 of the 131 TOI (99.2 percent) at the site were correctly identified as targets that should be dug. The one item missed, BE-1965, was a small ISO with a decision metric of 0.567. The performance objective success criterion was the correct classification of all TOI, so the misidentification of BE-1965 is a failure with regard to the objectives.

Figure 7-1: ROC Curve for Fuzes as Clutter



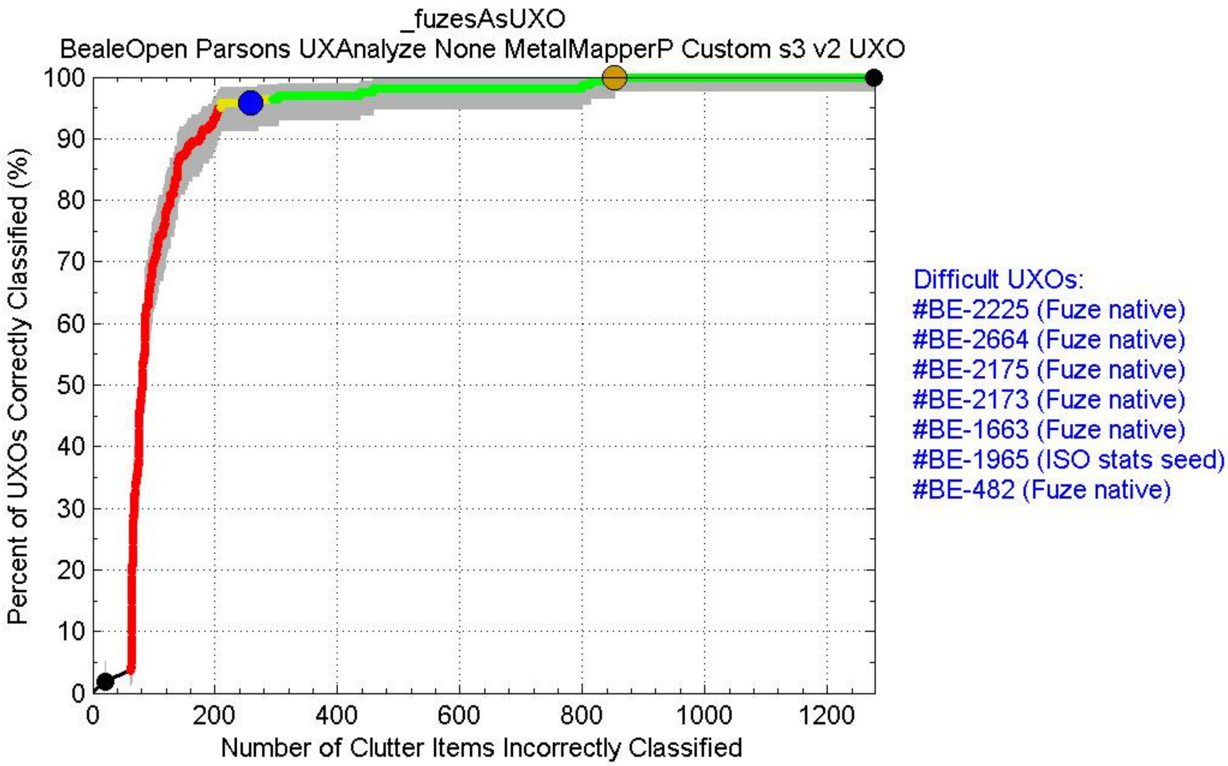
The lack of inclusion of this target in the dig category was based on a 3-curve comparison confidence metric of 0.547, which was below the 0.600 threshold for Category 1. Further investigation of the target indicated that the data had a relatively low signal (signal amplitude of 13.97) and some noise (beta noise value of 0.11). Although neither of these values is extremely low or high, respectively, the analyst did indicate that the β2 curve appeared to be unusable (**Figure 7-2**). Therefore, the confidence metric used for ranking this target was the β1/β2-only of 0.567 rather than the 0.297 indicated in the figure. Upon reinspection, it still does not appear that the β1 curve is poor enough to consider this a Can't Analyze target, although the β3 curve could be considered unusable. Using the β1-only result for this target would have resulted in a confidence metric of 0.892 and classification as a target that should have been dug.

Figure 7-2: Polarization Curves for Target BE-1965



For the fuzes as UXO ground truth set, 164 of the 1,441 digs were classified as TOI, leaving 1,277 true negatives in this data set. **Figure 7-3** shows the ROC curve for the fuzes as clutter ground truth data. One hundred and fifty-seven of the 164 TOI (95.8 percent) in this data set were correctly identified as targets that should be dug. However, in addition to BE-1965 (the ISO missed in the fuzes as clutter ground truth), six native fuzes were incorrectly identified as clutter in this ground truth set.

Figure 7-3: ROC Curve for Fuzes as UXO



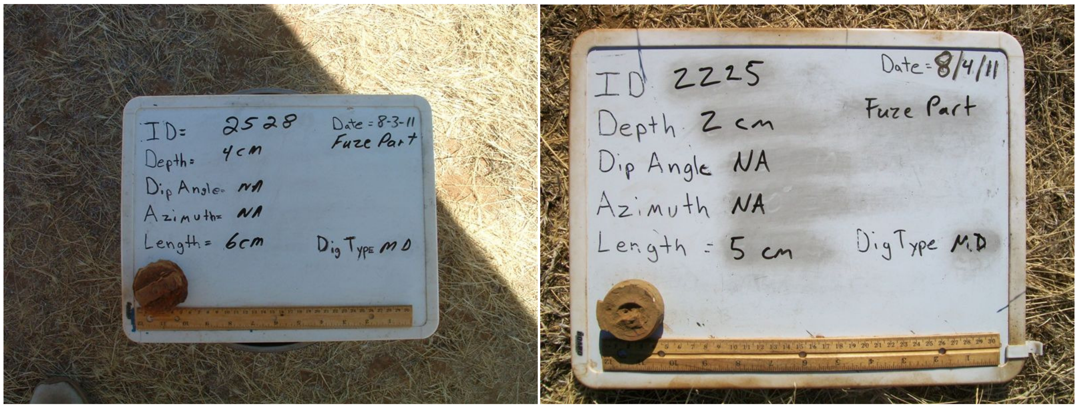
While 27 native fuzes were identified correctly following the addition of training item BE-2528 to the library, the six missed were different types than the ones characterized by BE-2528. The missed versions were generally smaller and appear to be different metallically, as shown in **Figure 7-4.** The missed fuzes generally agreed with each other fairly well geophysically in that the addition of two, BE-2173 and BE-2225, to the comparison library generated a match with the others with a confidence of 0.750 or higher. While the BE-2528-type fuzes were numerous and distinctive enough to stand out to the analyst as a potential unknown type of UXO, the others did not. It is possible that the use of a parameter space plot constructed using decay vs. size may have led to the detection of these items, but is not a certainty. Therefore, it appears that knowing these types of fuzes were present and adding examples to the comparison library would have been the only way to guarantee their detection using library matching classification techniques.

7.5 OBJECTIVE: MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

The submitted dig list correctly identified 78.2 percent (1,024 of 1,310) of the clutter as clutter in the fuzes as clutter ground truth comparison and 79.8 percent (1,020 of 1,277) of the clutter as clutter in the fuzes as UXO ground truth comparison. Both versions are well above the performance objective of reducing the number of false alarms by greater than 50 percent.

Figure 7-4: Native Fuze Types

A: BE-2528 **B:** BE-2225



7.6 OBJECTIVE: CORRECT SPECIFICATION OF NO-DIG THRESHOLD

Because items were missed in the comparison of the dig list to both ground truth sets, the no-dig threshold on the submitted dig list was set incorrectly. In the case of the fuzes as clutter ground truth set, the last TOI was a small ISO that had a decision metric of 0.567. It was 47 targets below the stop-dig threshold at 0.600. If the dig threshold had been correctly set at the last TOI item, 74.7 percent of the clutter digs would have been eliminated.

The lowest-ranked TOI in the fuzes as UXO ground truth set was BE-2225, which was at dig 1,017, significantly below the dig threshold. If the dig threshold had been correctly set at the last TOI item, only 33.2 percent of the clutter digs would have been eliminated.

The no-dig threshold in the only dig list submitted was actually relatively low with regard to the decision statistic (0.600 out of a possible 1.000) and was based on training and QC seed information that suggested a buffer of approximately 0.040 between the lowest reasonably ranked QC seed item (decision metric of 0.638) and the threshold. One of the QC seeds, BE-2277, a 37mm buried in the midst of a number of pieces of barbed wire, had a decision statistic of 0.270 based on a set of polarization curves that looked nothing like ordnance. Because the curves appeared to be based more on the barbed wire results rather than the 37mm, it was not considered practical to either add this item to the library or to lower the dig threshold in order to detect it. Therefore, the dig threshold set for the site is still considered appropriate; and the TOI detection failures for both sets of ground truth are due to the analytical failures described in Section 7.4 rather than an incorrectly located dig/no-dig threshold.

7.7 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

A total of 45 targets were classified as Can't Analyze on the single dig list submitted. This corresponds to slightly more than the 2 percent limit specified in the performance objectives. As discussed in Section 3.3, all targets without a usable β1 curve were classified as Can't Analyze in the Camp Beale data set. It is expected that additional data examination, including an analysis of the signal amplitude and offset between the picked and collected point locations, is likely to reduce the number of Can't Analyze targets required. Using this strategy, potential Can't Analyze targets with low signal amplitude collected where they should have been collected (i.e., likely indicative of poor EM61 data for the original target) would be considered good MetalMapper data despite poor β1 curves.

7.8 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. In the TOI version, the fuzes as UXO ground truth set was used for comparison.

The success criteria for this performance objective were X, Y offsets for which one standard deviation of the dataset was less than 15cm and one standard deviation of the depth offset was less than 10cm. The performance objective was passed for the TOI comparison, with calculated standard deviations of 9.6cm for the horizontal offset and 5.0cm for the vertical offset. The results for all of the targets marked as digs were slightly above the criteria for the horizontal offset, with calculated standard deviation of 19.3cm. The depth calculation was within the criteria with a standard deviation of 9.1cm.

In the comparisons, the modeled location of the target was the fit X, Y, and Z coordinates, while the actual location was defined as the closest measured location to the fit location. This only mattered in the case of targets for which multiple objects were recovered from the vicinity of the picked location. However, much of the discrepancy seen in the X, Y locations for all of the "dig" targets is likely due to multiple-object locations being modeled as single objects during inversion. While the multiple object solver option in UX-Analyze was employed for inversion, it does not appear to have been successful in every case. The notable example is BE-2277, the 37mm QC seed buried in the vicinity of a number of pieces of barbed wire that was not identified as multiple sources and looked nothing like UXO. There does not seem to be a ready solution to the slight discrepancy between the performance objective and the results for the "dig" targets, although the results for the TOI were positive.

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 Former Camp Beale 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 9-1**.

Although the MetalMapper and tractor used for data collection at Camp Beale were funded by ESTCP, standard rental costs and prep fees were used to determine the cost for the Camp Beale project had Parsons rented these items for the duration of the project. Weekly costs for equipment on a typical project were calculated using only items that would be required each week and not items like mobilization, prep, or shipping fees that would be one-time items on most projects. Survey and analysis costs were tracked using a task-specific number in Parsons project controls system.

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. At the former Camp Beale, classification eliminated 78% of digs at a cost of $59 per target.

The overall cost of excavating the 1,491 MetalMapper anomalies was $188,549 ($126/anomaly). With a reduction of 1,020 excavations, this would represent a cost savings of $75,480. However, 471 anomalies would have required MetalMapper data collection and processing at an estimated cost of $24,492 ($59 x 471). Therefore the overall cost savings would have represented $50,988.

Table 9-1: Details of the Costs That Will Be Tracked.

Cost Element	Data Tracked During Demonstration	Estimated Costs
Seeding/EM61 Survey Costs		
Seed Emplacement/initial set up	Costs for surface sweep, seed emplacement, surveying seeds	$114,287
Survey costs	The survey costs will include the time spent in the field collecting and recording data	$75,055
MetalMapper Survey Costs		
Instrument Costs	MetalMapper Rental ($500/day; 21 days)	$10,500
	MetalMapper Prep Fee (project)	$1,000
	MetalMapper Shipping (project)	$2,700
	Tractor Rental (project)	$1,440
	Tractor Mob/Demob (project)	$100
	RTK GPS Cost ($800/week; 3 weeks)	$2,400
	Shipping (RTK GPS, etc; project)	$324
	Total	**$18,464**
	Per Target	$12.38

Table 9-1: Details of the Costs That Will Be Tracked (Continued).

Cost Element	Data Tracked During Demonstration	Estimated Costs
MetalMapper Survey Costs (Continued)		
Survey Costs	Field-related labor (2 geophysicists, UXO Technician II), equipment set-up, test pit data collection, cued data collection, preprocessing, initial target inversion for QC checks, non-equipment direct costs (per diem, hotel, fuel, and etc.)	$56,869
	Per Target	$37.91
Analysis Costs	All processing and analysis performed following the completion of field activities	$13,566
	Per Target	$9.04
Intrusive Costs		
Investigations	All costs related to the intrusive investigation	$271,389
	Cost per anomaly to intrusively investigate	$126

8.2 COST DRIVERS

Based on the factors described above, the total per target cost for the MetalMapper-related work Camp Beale project was $59.33. Although backed by the actual costs for the project, Parsons considers this a fairly significant overestimation of the actual costs that would be necessary for future projects based on the following factors specific to Camp Beale:

- Training required for field team that was completely unfamiliar with the MetalMapper;
- Unfamiliarity also led to a significant number of re-shots during the first week of the project; and
- Numerous software crashes related to some combination of the GPS unit, the IMU, Windows 7, the data acquisition program, and/or the touch screen on the MetalMapper resulted in a significant number of software crashes.

When the MetalMapper worked as planned, the field team generally had no problem collecting data at a rate of greater than 200 points per day. However, the issues discussed above resulted in an average production rate of only 117 points per day. 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 specific cause of the crashes is still unknown, but it should be reasonable to assume that the root cause can be fixed before the MetalMapper is used on a project with a significant number of targets. Once fixed, a production rate of twice the one achieved at Camp Beale is not out of the question.

For the intrusive investigation phase of the Camp Beale, Parsons investigated 2, 143 anomalies in 23 intrusive days. The average anomalies intrusively investigated per day was 93 anomalies which exceeded the estimated 80 anomalies per day planned for the project. The most common item excavated at Camp Beale 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 require 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 two threshold for QC, identifying frag and barbed wire pits early potentially saved intrusive time.
- Moving heavy equipment throughout the site was very time consuming on the very uneven terrain at Camp Beale but proper planning minimized this need.
- Pinpointing small anomalies quickly with the EM61-MK2 minimizes 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 big 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 approximately $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 75 percent reduction in the number of clutter items that could be eliminated from intrusive investigation would yield a potential cost savings of $360,000 based on the following assumptions:

- 10,000 anomalies at $100/anomaly for intrusive investigation equals a cost of $1,000,000.
- Reduction of 7,500 anomalies equals a reduction of $750,000 in excavation costs.
- MetalMapper costs for analyzing 10,000 anomalies at $39/anomaly equals a cost of $390,000.
- Total net savings under this scenario equals $360,000 (36 percent).

9.0 IMPLEMENTATION ISSUES

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

- The EM3D software crashes discussed briefly 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 dig not cause delays ranging from an hour or so of lost production to most of the day. Parsons used the MetalMapper from Camp Beale for data collection during another project at Fort Sill, Oklahoma, and the crashing problems persisted. This is an issue that needs to be resolved before consistent production of 200+ points per day can be achieved.
- The field crew using the MetalMapper at Camp Beale was completely new to the technology. As could be expected, production and data quality was low while the crew familiarized themselves with the MetalMapper. Data quality issues were based on the number of re-shots required for data collected early in the project, when re-shot percentages were up to approximately 20 percent of the collected points. By the end of the project, re-shot rates were down to a few targets per day.
- 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, both in the field to ensure that MetalMapper points are collected within a reasonable distance of the intended point and during analysis to ensure that the results generated for a given point actually represent that point.
- All targets with poor $\beta 1$ 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 cases such as these, an analysis of the signal amplitude and EM target vs. MetalMapper collection vs. MetalMapper fit locations may have resulted in fewer Can't Analyze targets.

REFERENCES

1. "Work Plan for Seeding, Geophysical Data Collection, and Intrusive Investigation, Live Site Demonstration, Former Camp Beale, California," Parsons, April 2011.

APPENDIX A

POINTS OF CONTACT

Appendix A: Points of Contact

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