DEMONSTRATION REPORT

Perform MetalMapper Classification Treatability Investigations as Part of Remedial Investigation/Feasibility Studies Hawthorne Army Depot - Walker Lake Land Test Range

ESTCP Project MR-201232

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Acronyms

$\beta 1$, $\beta 2$, $\beta 3$	polarizabilities along principal axes of target
mV/A	millivolt per ampere
σ	standard deviation
BUD	Berkeley UXO Discriminator
cm	centimeter
DAQ	data acquisition computer
DGM	digital geophysical mapping
DoD	Department of Defense
EMI	electromagnetic induction
ESTCP	Environmental Security Technology Certification Program
ft.	foot
GPS	global positioning system
HWAD	Hawthorne Army Depot
Hz	hertz
ID	identification
IMU	inertial measurement unit
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
MR	munitions response
MRS	munitions response site
N	repeat factor
NRL	Naval Research Laboratory
OD	other debris
QC	quality control
RTK	real-time kinematic
SERDP	Strategic Environmental Research and Development Program
T	period
TOI	targets of interest
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 an Environmental Security Technology Certification Program (ESTCP)-funded treatability study at the Hawthorne Army Depot (HWAD) Walker Lake Land Test Range Munitions Response Site (MRS) under ESTCP project munitions response (MR)-201232. The 2013 treatability study at HWAD was conducted with three primary objectives:

- Test and validate detection and discrimination capabilities of a currently available advanced electromagnetic induction sensor 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.
- Use the results of the treatability study as the basis for a cost estimate that includes the use of the MetalMapper in a HWAD feasibility study being performed concurrently with the ESTCP project.

Parsons had two separate teams working on the project. One team was responsible for site setup, the placement of 72 seed items for use in measuring the capabilities of the MetalMapper advanced electromagnetic induction (EMI) sensor tested during the project, and the intrusive investigation of targets (including seed items) selected for additional investigation with the advanced sensors. The second team was responsible for the collection of dynamic MetalMapper data over approximately 9 acres and the cued survey of 1,800 targets identified in the dynamic data. The MetalMapper field collection effort took place over 5 weeks with average production rates of 1 acre per day for the dynamic survey and 225 targets/day for the cued survey. Average production rates for the cued survey were lowered by weather and hardware issues but were typically in the range of 300–350 on days without any problems.

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. Dynamic data were collected using only the Z transmit loop and the seven receivers, although only the responses measured by the Z loop on each receiver were used in calculating the dynamic response. Data from the X and Y loops on the receivers may be used in an attempt to classify targets using the dynamic data in the future, although that analysis was not performed as part of this project. Target locations for the cued survey were selected from the dynamic data set.

Cued data were collected using all three transmitters and 21 receiver loops. The collected data were inverted and analyzed using the UX-Analyze add-on to Geosoft's Oasis montaj software. Once analysis was complete, a ranked dig list was submitted for the site. The intrusive investigation was performed following the submittal of the ranked dig list and included two stages: the investigation of all 504 targets identified in the dynamic data set within a defined area regardless of classification decision and the investigation of another 134 targets classified as digs outside of this area.

Twenty-seven of the 504 targets in the "investigate all" area were unclassified in the ranked dig list because they required re-shots that could not be collected following unrepairable damage to the sled used to transport the MetalMapper. Therefore, the effectiveness of the MetalMapper in separating targets of interest (TOI) from clutter in this area was determined using 477 of the 504 targets. A total of 114 items considered to be TOI were removed from 70 of the cued target locations (multiple TOI were recovered from a number of locations).

Two of the recovered TOI items were found near MetalMapper cued data points classified as non-TOI. However, both were recovered below the 60-cm depth of detection required for the project, and neither was within 60 cm of a dynamic target, meaning that they were not detected in the dynamic survey and no cued point was collected within a distance that would suggest they should have been classified correctly. They were only found because the dig team was still able to identify a response with the EM61 following the excavation of the item that was collected/classified and the team chased the signal outside of the 60 cm radius surrounding the predicted source location. The analyst later confirmed that there was no peak over the recovery locations in the dynamic data collected over these items. Therefore, the non-TOI classifications were considered correct for the nearby MetalMapper points. Classifications were correct (i.e. labeled as "digs") in the remaining 68 target locations where TOI were recovered.

Twenty-eight of the TOI were recovered from below 60 cm, indicating that the MetalMapper can classify items below this depth as long as they are shallow enough to be detected with adequate precision in the dynamic survey. Approximately 92% of the 409 non-TOI locations were correctly classified as non-TOI in the ranked dig list. Of the 134 locations classified as digs and excavated outside of the "investigate all" area, 110 (82%) were identified as TOI during the intrusive investigation.

1.0 INTRODUCTION

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

This project was performed as a treatability study funded by the Environmental Security Technology Certification Program (ESTCP) under Munitions Response (MR) Project 201232. This study was designed to evaluate classification methods on a small portion of the 6,803 acres of the land portion of the Walker Lake Land Test Range MRS that is known to contain UXO consisting of rockets ranging in size from 2.25 inches (in.) to 5 in. The intent is to use the results of the treatability study to use advanced geophysical classification as an remedial alternative in a feasibility study currently being conducted at the Walker Lake Land Test Range MRS.

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 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- 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. ESTCP organized a number of demonstrations at MR sites across the country between 2006 and 2013, generally with new variables added to the classification challenges at each subsequent site (e.g., increased target density, increased response from local geology, mixed munition sizes ranging from small to very large, wooded areas). Additionally, the subsequent projects included the use of smaller, man-portable EMI sensors such as the Naval Research Laboratory's (NRL's) TEMTADS 2x2 cart, Lawrence Berkeley National Laboratory's (LBNL's) man-portable Berkeley UXO discriminator (BUD), and Sky Research's man-portable vector machine. All of the EMI sensors tested to date have quite successful in discriminating between TOI and clutter.

The earlier demonstration projects were focused on proving that the technology was effective by comparing theoretical dig lists to real-world sources by excavating all of the targets at a given site and comparing the known source results to the predicted source results. More recent projects have been focused on leaving metal classified as non-TOI in the ground following the completion of the project. An ESTCP- and U.S. Army Corps of Engineers–funded pilot study at the former Camp Beale in California and a non-ESTCP-related removal action performed at two sites at the former Camp Sibert resulted in over 7,000 dynamic target sources remaining undug at

both sites, with regulator concurrence. No TOI were misclassified at either site, and prior to the addition of quality assurance verification digs, the reduction in necessary clutter digs was above 90% for each.

1.2 OBJECTIVES OF THE DEMONSTRATION

This type of approach has the potential to reduce the number of excavations required to effectively remove the explosive safety risk (MEC) at a given site, which would result in significant cost savings related to the closure of formerly used defense sites. The cost savings are expected to be particularly significant at removal action sites. A portion of the Walker Lake Land Munitions Response Site (MRS) has already been subject to a time-critical removal action, during which numerous UXO items were recovered. Parsons is currently performing a feasibility study for HWAD, which includes identifying cleanup options for the remainder of the Walker Lake Land Test Range MRS. The treatability study was intended to determine whether advanced EMI sensors could effectively differentiate between TOI and non-TOI at this site and, if it was determined to be effective, to be the basis for including the use of advanced geophysical classification techniques as an alternative in the feasibility study for the Walker Lake Land Test Range MRS.

1.3 REGULATORY DRIVERS

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

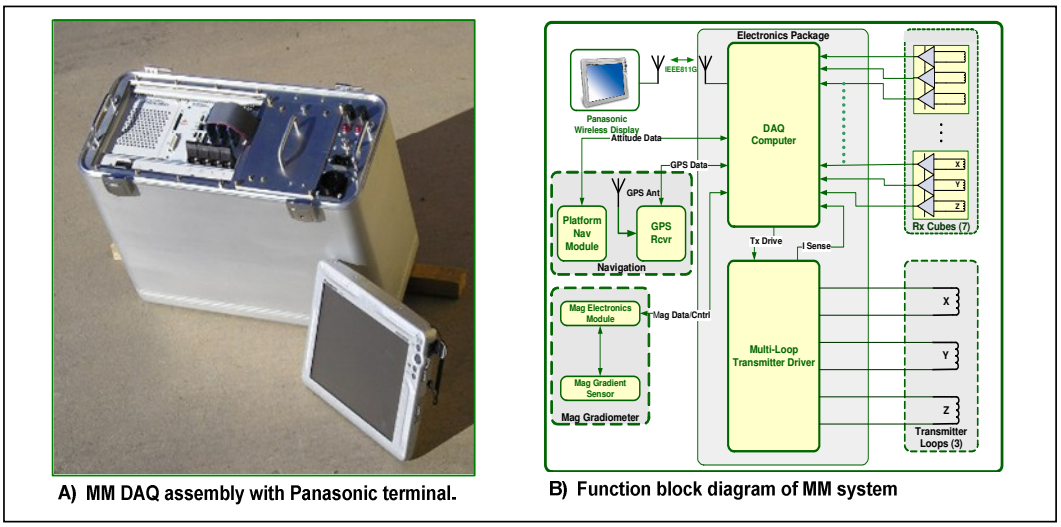
2.0 TECHNOLOGY

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 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.

Figure 2.1
DAQ and DAQ Functional Block Diagram

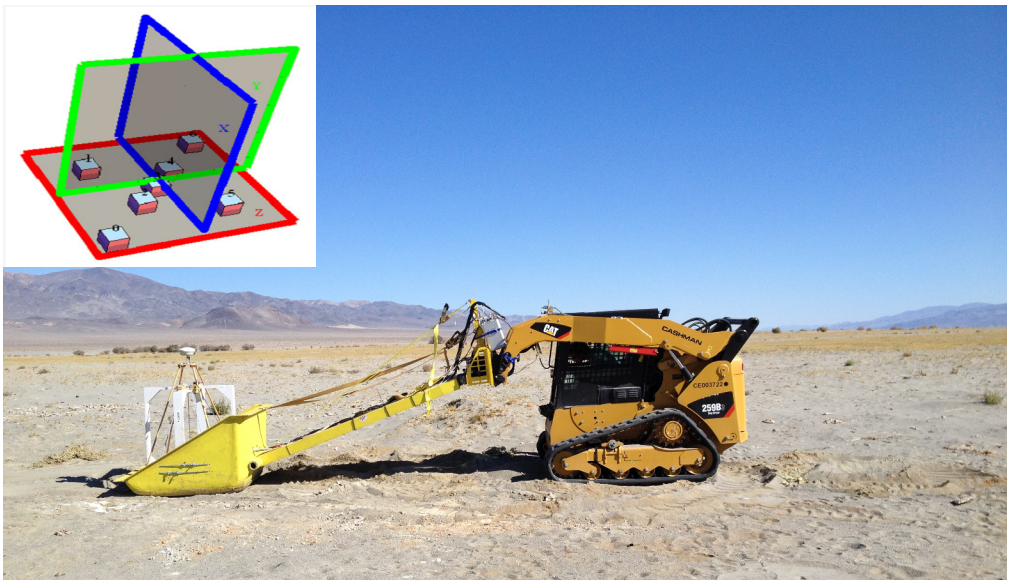


The MetalMapper has two modes of data collection: dynamic and static. Data collected in dynamic mode results in data files containing many data samples. Generally speaking, dynamic mode data are collected while the antenna platform is in motion. Static mode data collection is employed for cued surveys. As its name implies, the antenna platform remains static or

motionless during the period of data acquisition. Depending on the acquisition parameters (e.g., sample period and stacking parameter) it can take tens of seconds to complete a static measurement. The results of the static measurement are written into a binary data file containing only a single data point representing the average (stacked) result, usually over tens or even hundreds of repetitions of the transmitter's base frequency.

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

Figure 2.2
Antenna Array and Deployment of the MetalMapper at HWAD



In its present (third generation) form, the MetalMapper has been demonstrated and scored at numerous live site demonstrations carried out by ESTCP. The performance of the MetalMapper at these sites is documented in formal reports issued by the various contractors working on those projects.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

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

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. Effective ways to transport the system are also still in development. Parsons attempted to use a tractor to transport the system prior to renting the skid steer shown in Figure 2.2. However, the sled proved to be too heavy when mounted to the front of the tractor, and the tractor threatened to tip over every time the operator attempted to turn. The low center of gravity on the skid steer fixed the weight problem, but the sled itself developed numerous problems during the surveys, including a broken hinge, a worn out base through the course of the dynamic survey, and a bent tow-strap anchor point that finally put an end to the cued survey. The sled used for this project was a prototype intended to be used by contractors to identify design flaws prior to the next version, and it remains to be seen how long the next version will last.

3.0 PERFORMANCE OBJECTIVES

The primary performance objectives for this demonstration included:

- Evaluating if classification techniques will work at the HWAD site
- Evaluating the cost effectiveness of classification techniques at HWAD if classification is determined to be effective

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

Table 3.1
Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Dynamic Data Collection Objectives			
Repeatability of instrument verification strip (IVS) measurements	Amplitude of dynamic response	Twice-daily IVS survey data	Amplitude within 25% of standard response
Spatial coverage	Extended footprint coverage	Mapped survey data	90% of tracks with spacing no greater than 70 cm and none greater than 90 cm
Down track point spacing	Point to point spacing	Mapped survey data	90% of points with down-track spacing < 10 cm and 100% < 15 cm
Detection of all targets of interest	Percent of seeded anomalies detected	Locations of seed items Dynamic target list	Dynamic target selected within 60 cm of all seed items
Cued Data Collection Objectives			
Repeatability of IVS measurements	Percentage of IVS items identified correctly	Twice-daily IVS survey data	98% of IVS items identified correctly with a confidence metric of > 0.80
Correctly position MetalMapper relative to source	Distance between collection location and modeled target location	Location of MetalMapper during collection Modeled source location	100% of modeled locations within 40 cm of collection point unless re-shot also outside radius
Correctly position MetalMapper relative to dynamic target	Distance between MetalMapper collection location and dynamic target location	Dynamic target list Location of MetalMapper during collection	100% of collection points within 40 cm of EM61 target location

Table 3.1 (cont)
Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Analysis Objectives			
Maximize correct classification of targets of interest	Percentage of TOI retained.	Prioritized anomaly list Intrusive results	Approach correctly classifies all TOI
Maximize correct classification of non-Target of Interest	Number of false alarms eliminated.	Prioritized anomaly list Intrusive results	Reduction of false alarms by > 75% while retaining all TOI
Specification of no-dig threshold	Probability of correct classification and number of false alarms at demonstrator operating point.	Prioritized anomaly list Intrusive results	Threshold specified by the demonstrator to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as "Unable to Analyze."	Demonstrator target parameters	Reliable target parameters can be estimated for > 95% of anomalies on the detection list
Correct estimation of target parameters	Accuracy of estimated target parameters.	Demonstrator target parameters Intrusive results	X, Y < 15 cm (1σ) Z < 10 cm (1σ)

3.1 REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

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

3.1.1 Metric

The metric for this objective was the measured response for each instrument verification strip (IVS) seed versus a standard value determined for each over the course of the dynamic survey.

3.1.2 Data Requirements

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

3.1.3 Success Criteria

This objective was met if the dynamic response for each of the seed items in the IVS strip was within 25% of a standard, expected response. Because the expected responses versus depth for specific ordnance in dynamic MetalMapper surveys are nearly completely unknown, the standard

response for each was defined as the average of all of the measurements collected over each item during the course of the dynamic IVS surveys.

3.2 SPATIAL COVERAGE

The MetalMapper detection survey should cover a maximum of the area of interest so that all detectable targets are detected. Targets are detectable if the transmitted field is sufficiently strong to reach the target and if the measured target response is sufficiently strong in return to exceed a given threshold. Simulations suggest that there is no loss of detectability when a target is located 10 centimeters (cm) to the side of each receiver.

Only the five middle receivers (1 to 5 using the UX-Analyze 0 to 6 designations for the receivers) were used in calculating response in the dynamic survey. The outermost of these receivers are approximately 25 cm to the outside of the coil. Adding 10 cm to each side as discussed above results in an effective footprint of 70 cm.

3.2.1 Metric

The metrics for this objective were collected coverage area versus between-line gaps larger than the footprint of the instrument (70 cm) and versus between-line gaps large enough that there was a considerable risk that a TOI might be missed completely (90 cm).

3.2.2 Data Requirements

The percentage of the coverage area with between-line gaps larger than 70 cm and 90 cm were calculated for each day's data using the foot print coverage tool in Oasis montaj's UX-Detect tool.

3.2.3 Success Criteria

This objective was met if more than 90% of each day's coverage area had a line spacing of 70 cm or less and if there were no between-line gaps of greater than 90 cm.

3.3 DOWN TRACK POINT SPACING

As with the spatial coverage, the down track point spacing objective ensures that the detection survey covers the area of interest such that no potential TOI are missed due to data gaps. This metric covers the distance between measurements along the path of the survey line.

3.3.1 Metric

The metrics for this objective were the percentage of down line point to point spacings greater than 10 cm from each other and the percentage greater than 15 cm from each other.

3.3.2 Data Requirements

The percentage of the coverage area with down line gaps larger than 10 cm and 15 cm were calculated for each day's data.

3.3.3 Success Criteria

This objective was met if more than 90% of each day's point to point spacings were less than 10 cm from each other and if there were no down-line gaps of greater than 15 cm.

3.4 DETECTION OF ALL TARGETS OF INTEREST

The reliability of cued data depends on acceptable instrument positioning during data collection in relation to the actual anomaly location.

3.4.1 Metric

The metric for this objective is the percentage of anomalies that are within the acceptable distance of the center of the instrument during data collection from the actual target location.

3.4.2 Data Requirements

The centers of all seed items were measured using a RTK global positioning system (GPS) when they were placed in the ground. Dynamic target selections were compared to the known seed item locations as dynamic target lists were submitted, and the horizontal distance was calculated between the seed locations and the nearest dynamic target location.

3.4.3 Success Criteria

The objective was considered met for each seed item if a dynamic target was within 60 cm of the measured seed location.

3.5 CORRECTLY IDENTIFY SEED ITEMS IN THE INSTRUMENT VERIFICATION STRIP

The IVS strip constructed at HWAD contained four seed items and a cleared background location. MetalMapper data were collected over the IVS twice daily.

3.5.1 Metric

The metric for this objective is the percentage of IVS items correctly classified during the project.

3.5.2 Data Requirements

Daily IVS data were collected and processed in the same manner as all other target points acquired during the project. Following analysis, each IVS target was labeled with an identified source object and a confidence metric that quantified the degree of match between three polarizability curves generated from the measured IVS data and three polarizability curves for a similar item in a target library. For the purposes of the IVS, the confidence metric used for classification purposes was generated using $\beta 1 : \beta 2 : \beta 3$ ratios of 1 : 0.5 : 0.5.

3.5.3 Success Criteria

The performance objective for the project was the correct classification of all IVS seed items with a confidence metric of 0.80 or higher. Due to the potential for the occasional collection of a poor data point without the operator's immediate knowledge, the success criteria was slightly lower than 100%, with the project deemed successful if more than 98% of the IVS data points were classified correctly.

3.6 CORRECTLY POSITION SENSOR RELATIVE TO SOURCE

High-fidelity estimates of a target's principal polarizability curves depend on adequate illumination of the target along each of its principal axes. Targets with horizontal offsets of 40 cm or more from the center of the MetalMapper are not adequately illuminated, and thus their symmetry properties are sometimes not apparent. While the goal was to place each sensor directly on top of the source item, adjacent targets and geologic conditions can result in modeled or fit locations for the source object a significant distance from the collection point.

3.6.1 Metric

The metric for this objective was the distance between the location of the sensor for a given point and the modeled location for the source object following inversion.

3.6.2 Data Requirements

The MetalMapper sensor location is determined during the inversion of the collected data and is resolved using the location identified by the GPS sensor directly over the middle of the sensor and pitch and roll data supplied by an inertial measurement unit (IMU). The sensor location is reported as the X_Array and Y_Array channels in the Geosoft target database. The location of the source object is also calculated during target inversion and was defined as the Fit_X[8] and Fit_Y[8] channels in the Geosoft target database. The distance between these two locations was calculated for cued data point.

3.6.3 Success Criteria

The performance objective was for all single object solver targets to have modeled source locations within 40 cm of the center of the collection sensor unless a re-shot had already been performed on that target or the point was collected solely so that a point was collected within 40 cm of a dynamic pick location (Section 3.7).

3.7 CORRECTLY POSITION METALMAPPER RELATIVE TO DYNAMIC TARGET

The use of the dancing arrows display to position the MetalMapper during data collection can sometimes lead to a significant discrepancy between the location of the MetalMapper during collection and the location of the actual target being investigated as selected in the dynamic data. The location of the MetalMapper relative to the picked point was compared to ensure that a MetalMapper point was collected within a reasonable distance of each selected dynamic target.

3.7.1 Metric

The metric for this objective was the distance between the location of the MetalMapper sensor for a given point and the selected dynamic target location.

3.7.2 Data Requirements

The MetalMapper sensor location was determined during the inversion of the collected data and was resolved using the location identified by the GPS sensor directly over the middle of the sensor and pitch and roll data supplied by the IMU. The sensor location was defined as the X_Array and Y_Array channels in the Geosoft target database. These were compared to the target locations selected in the dynamic survey data.

3.7.3 Success Criteria

The performance objective was for all collection points to be within 40 cm of the intended location. However, the standard USACE offset objective for dynamic target locations compared to known seed locations is ½ the survey line spacing plus 35 cm, which would have resulted in an acceptable offset of 60 cm for this project. As the success criterion was considerably less than this value, an exception was made for this criterion if it was clear that data were collected over the intended source and that the collected data were usable. Points collected farther than 40 cm from the dynamic target location were considered acceptable if there were no other dynamic targets within 1.5 m of the target in question and if there were no identifiable problems with the collected data, such as noisy data or a poor collection to fit offset (Section 3.6).

3.8 MAXIMIZE CORRECT CLASSIFICATION OF TOI

One of the two main objectives of this pilot study was to show that classification could correctly identify all seeded items and any native items that resembled ordnance that could be considered MEC as TOI. Native items including practice warheads, motors, and functioned or previously detonated but intact high explosive warheads were identified as TOI during the intrusive investigation if they resembled a potentially hazardous item to the degree that not investigating such items would present a serious hazard.

3.8.1 Metric

The metric for this objective was the percentage of items classified as TOI following the intrusive investigation that were correctly identified as objects that should be dug in the final ranked dig list.

3.8.2 Data Requirements

Following data collection, MetalMapper data were analyzed to create a prioritized dig list, which assigned each target to one of four categories: 1) TOI 2) Non-TOI, 3) Can't Analyze, or 4) Training. The targets classified as either TOI, Can't Analyze, and Training were considered "dig" targets. The list of items identified as TOI following the completion of intrusive operations, including seed items, was compared to those targets marked "dig" in the ranked dig list. If any Training items had been identified as TOI upon recovery, the item(s) would have been added to the classification library to identify other similar sources at the site.

3.8.3 Success Criteria

The performance objective was the correct identification of all TOI (including blind seed items) as targets that should be intrusively investigated, or "dig" targets. The project was considered successful if 100% of the TOI were labeled as "dig" targets in the final ranked dig list. No distinction was made between a target correctly identified as TOI and a target identified as a Can't Analyze point for this objective. Each TOI simply needed to be indicated as a target that should be investigated.

3.9 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.

3.9.1 Metric

The metric for this objective was the percentage of items classified as non-TOI following the intrusive investigation that were correctly identified as objects that did not need to be intrusively investigated in the final ranked dig list.

3.9.2 Data Requirements

Following data collection, MetalMapper data was analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) Non-TOI, or 3) Can't Analyze. The targets classified as non-TOI were considered "no dig" or non-TOI targets. The list of items identified as non-TOI following the completion of intrusive operations was compared to those targets marked "no dig" in the ranked dig list. Two thousand targets were intrusively investigated during this project. Therefore, all targets not investigated during the intrusive effort are considered non-TOI.

3.9.3 Success Criteria

The performance objective was considered met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI (Section 3.8) above the dig threshold.

3.10 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

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

3.10.1 Metric

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

3.10.2 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 cued data.

3.10.3 Success Criteria

The performance objective was considered met if reliable parameters could be estimated for greater than 95% of the targets on the prioritized dig list.

3.11 CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the modeled location for target source objects. The correct estimation of the location, both horizontally and vertically, increases confidence in both the dig team and stakeholders that the correct source object is being investigated if the estimated location is relatively close to the recovered object's location.

3.11.1 Metric

The distance between the inverted target location and the location of the object(s) recovered during the intrusive investigation was the metric for this objective.

3.11.2 Data Requirements

The dig list submitted to the intrusive team contained X, Y locations for each target as determined during inversion of that target. The dig teams will measure the offset between any recovered items and the location listed on the dig sheet. The offsets will be compared following the completion of the project.

3.11.3 Success Criteria

The project objective was considered met if one standard deviation of the distance between the estimated X, Y locations and the recovery locations are within 15 cm and the estimated depths are within 10 cm (1 standard deviation [σ]).

4.0 SITE DESCRIPTION

4.1 SITE DESCRIPTION

The HWAD Walker Lake Land Test Range MRS is in Mineral County, Nevada, approximately 143 kilometers southeast of Reno, Nevada (225 kilometers by road). The Walker Lake Land Test Range MRS encompasses 9,210 acres of land and water on the south end of Walker Lake. The demonstration was conducted in an area in the MRS immediately to the southwest of the completed time-critical removal action areas. The location of the demonstration grids is shown in Figure 4.1.

4.2 SITE SELECTION

This site was chosen as one in a series of sites for demonstration of the classification process. Sites, including this one, provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions. Further information about ESTCP's classification program can be found at http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response. This site was selected for the program because of its terrain and an opportunity to involve a stakeholder community, including state regulators, in the classification pilot program.

4.3 BRIEF SITE HISTORY

Starting in 1930, HWAD was called Naval Ammunition Depot Hawthorne and was used for the storage, servicing, and issuing of ammunition. During World War II, the role of the installation expanded. In 1977, Naval Ammunition Depot Hawthorne was transferred to the U.S. Army and renamed Hawthorne Army Ammunition Plant, and it was designated HWAD in 1994. Currently HWAD is used to issue, receive, store, inspect, renovate, demilitarize, and dispose of conventional ammunition (Parsons, 2013).

According to interviewed personnel and documentation starting in 1970, the Walker Lake Land Test Range MRS was used during World War II, the Korean War, and the post-Korean War period (URS Group, Inc. [URS], 2008). The Walker Lake Land Test Range was used from 1942 to around 1954 to test the Hedgehog depth charges, but only the firing capabilities were tested, and thus they were not fired toward Walker Lake. A portion of the MRS was reported to have been used by personnel from the Naval Weapons Center China Lake in the 1950s for firing of incendiary material into Walker Lake (Parsons, 2013).

In 1974, clearance activities resulted in the removal of more than 6,000 pieces of munitions debris (MD), weighing more than 75 tons. Duds were marked and destroyed, but remaining ordnance was buried in eight pits along the center line of the range between the launch pad and the shore line (URS, 2008). In May 1977, 88 live rounds were found in a burial pit near the shore of Walker Lake (URS, 2008); this pit is believed to be one of the eight pits. According to former HWAD personnel, as part of a compliance agreement, dated June 25, 1991, between the U.S. Army and the Nevada Division of Environmental Protection, the Walker Lake Land Test Range MRS is to be swept quarterly for removal of MEC and MD (TechLaw, 2003).

4.4 MUNITIONS CONTAMINATION

The suspected munitions in the Walker Lake Land Test Range MRS include:

- 2.25-in., 2.75-in., 3.5-in., 4.5-in., 5-in., 7.2-in. rockets (high explosive, sub-caliber aircraft rocket, folding-fin aircraft rocket, high-explosive antitank, high explosive dual-purpose, high-velocity aircraft rocket, semi-armor piercing, surface spin-stabilized rocket, high capacity)

4.5 SITE GEODETIC CONTROL INFORMATION

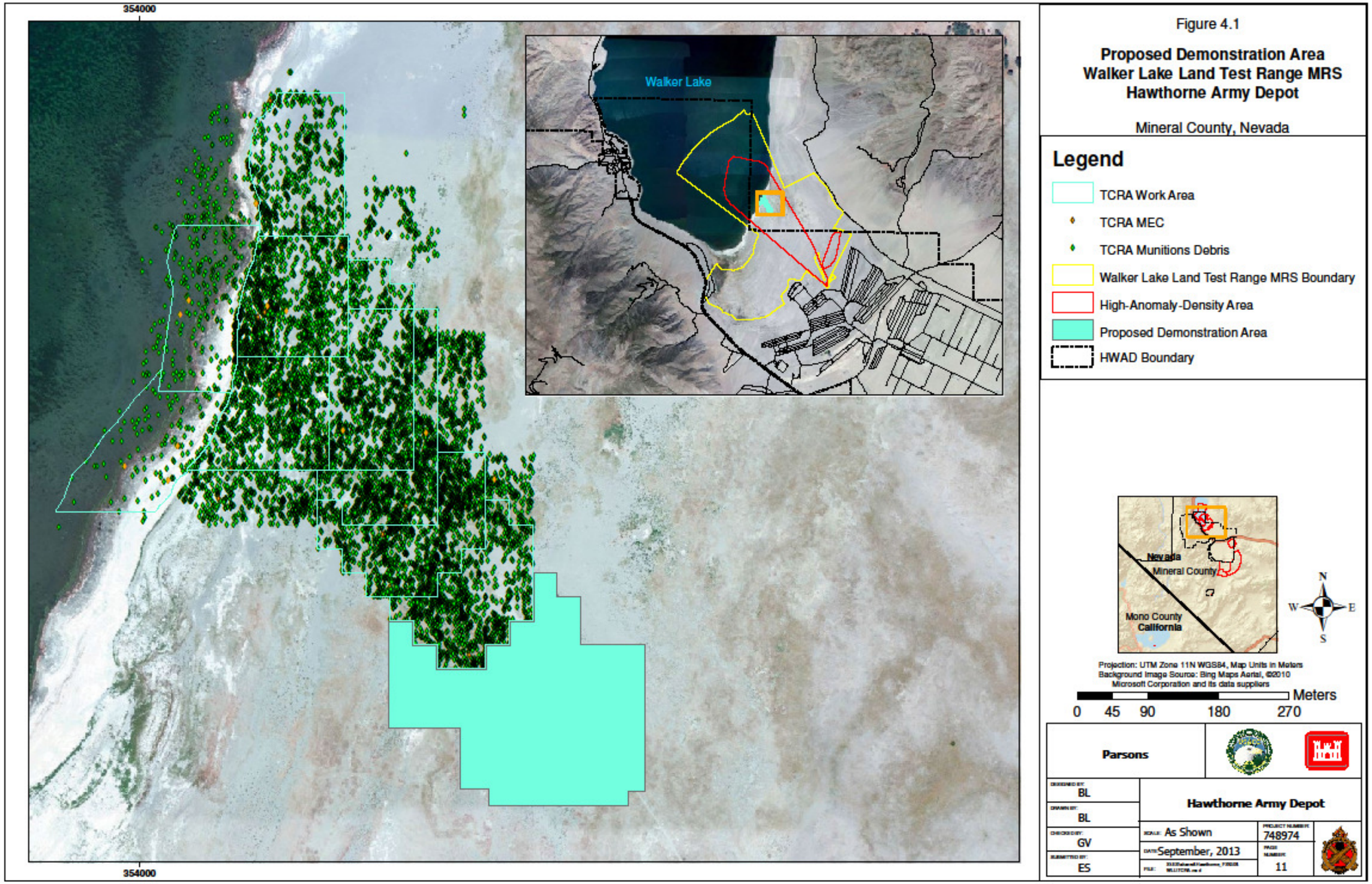
The coordinates for the locations of the existing first-order points used for this demonstration are provided in Table 4.1.

Table 4.1
Geodetic Control Locations

ID	Northing (m)	Easting (m)	Ellipsoid Height (m)
ESTCP1	4278642.954	356628.727	1251.849
ESTCP2	4278741.427	356756.201	1259.919

4.6 SITE CONFIGURATION

The location chosen for the demonstration site is shown on Figure 4.1. A shapefile delineating the demonstration site boundary and a text file of the corner coordinates are available from the ESTCP Program Office.


354000
Walker Lake
354000
Figure 4.1
Proposed Demonstration Area
Walker Lake Land Test Range MRS
Hawthorne Army Depot
Mineral County, Nevada
Legend
TCRA Work Area
TCRA MEC
TCRA Munitions Debris
Walker Lake Land Test Range MRS Boundary
High-Anomaly-Density Area
Proposed Demonstration Area
HWAD Boundary
Nevada
Mineral County
Mono County
California
N
W
E
S
Projection: UTM Zone 11N WGS84, Map Units in Meters
Background Image Source: Bing Maps Aerial, ©2010
Microsoft Corporation and its data suppliers
Meters
0 45 90 180 270
Parsons
BL
BL
GV
ES
Hawthorne Army Depot
As Shown
September, 2013
748974
11

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

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

Many projects to date have used the EM61 metal detector for the digital geophysical mapping (DGM) portion of the project and have collected cued MetalMapper data over target locations identified in the EM61 data. At HWAD, the MetalMapper was also used to collect the dynamic DGM data prior to the cued survey, mostly due to the relatively flat topography at the site that lent itself to dynamic MetalMapper data collection. The dynamic MetalMapper data were used to select targets on anomalies in the dynamic data set potentially representative of subsurface MEC items in much the same as that any other DGM dataset would be processed. The MetalMapper was then used to collect cued data over the targets identified in the dynamic data. Cued data were processed existing routines to extract target parameters. These parameters were passed to a classification routine developed for the project that was used to produce a ranked anomaly list.

The primary objective of the demonstration was to assess how well the ranked anomaly list succeeded in separating high confidence clutter from all other items. A secondary objective was to determine the classification performance that could have been achieved through a retrospective analysis.

5.2 SITE PREPARATION

5.2.1 Survey of Historical Records

Historical information on this site has been referenced in the *Remedial Investigation Report, HWAD Walker Lake Land Test Range Munitions Response Sites, Mineral County, Nevada* (Parsons, 2013).

5.2.2 First-order Navigation Points

All survey data and validation activities ***must*** be conducted on a common coordinate system. Two first order navigation points were set at the site by a professional land surveyor prior to the start of the project. The coordinates for these points are included in Table 4.1.

5.2.3 Brush Cutting/Surface Clearance

All visible metal objects were removed from the surface of the demonstration area prior to data collection.

5.2.4 Seeding Operation

Typically, at a live site such as this, there is a high ratio of clutter to TOI and only a small number of TOI are found in the investigation 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 HWAD from October 6, 2013, through October 12, 2013. Large and medium industry standard objects (ISOs) and inert 2.75-in. warhead projectiles were buried throughout the 10-acre survey area as blind quality control (QC) seed items before beginning detection survey data collection. Two additional inert 2.25-in. sub-caliber aircraft rocket warheads were placed on the surface prior to the surface sweep. The location of each seed item was established with a Trimble R8 RTK GPS system. The base station control point used for this operation was established prior to the start of this investigation using Universal Transverse Mercator (UTM) Zone 11N, WGS84 coordinates. Seeds consisted of 9 large and 48 medium ISOs and 15 inert 2.75-in. rocket warheads. The inert warheads were borrowed from the Hawthorne Ordnance Museum (five), the NRL (nine), and one found during the surface sweep. Additionally, one large and two medium ISOs and one 2.75-in. inert rocket warhead were used for the IVS.

Parsons seeded 72 items and practiced anomaly avoidance at each location for safety and to ensure a clean area for emplacement. All 72 seeds were placed at the planned depths and orientations. Excavation operations involved manual procedures to meet precise specifications and to minimize burial evidence. Prior to emplacement, magnetic north was determined. The seed item was positioned with the nose pointing to the azimuth and orientation planned. A photo was taken of the seed item at the burial location. The seed item was then photographed along with a whiteboard showing emplacement information.

Seed location holes were not backfilled until final QC checks were complete. QC checks consisted of comparing the location with the original designated location; capturing the center location of the emplaced seed item with GPS; and checking the depth, inclination and dip angle of each seed item. After these checks were complete, the hole was backfilled with a shovel to prevent any excess movement of the seed items. A list of the seed items emplaced for the project is included in Table 5.1.

Table 5.1
HWAD Demonstration Seed Items

Seed item	Total
Medium ISO	48
Large ISO	9
2.75-in	15
Total	**72**

5.2.5 Establish an Instrument Verification Strip and Training Pit

A relatively anomaly-free area for use as the IVS was identified in the southeast corner of the site. The strip used for the IVS was roughly 25 m long. A list of the seed items placed in the IVS is included in Table 5.2.

Table 5.2
IVS Seed Items

IVS item	Description	Depth (cm)	Orientation
T-001	Medium ISO	25	Horizontal
T-002	Large ISO	35	Horizontal
T-003	Background location	N/A	
T-004	2.75-in. rocket warhead	35	Horizontal
T-005	Medium ISO	25	Horizontal

5.3 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. During the treatability study, the antenna array was placed transported via a sled mounted to the front of a tracked skid steer (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 5 Hz. The two instruments were connected to the DAQ via USB (universal serial bus) ports. Incoming GPS data were used both to navigate along predefined survey lines for the dynamic survey or from point to point in the dynamic survey and to locate the collected response data. IMU corrections are not performed in real time and integrated with the incoming GPS data on the MetalMapper screen, but they were used to correct the locations of all collected GPS points based on the pitch, roll, and yaw information recorded with the GPS measurements.

5.4 CALIBRATION ACTIVITIES

5.4.1 Test Pit and Instrument Verification Strip Data Collection

A test pit was constructed at the site to determine the dynamic data target selection threshold and to collect cued data over ordnance items not already represented in existing MetalMapper libraries. The pit was an approximately 4-foot (ft.) by 2-ft. by 2-ft. hole in a cleared area of the site near the IVS strip.

Prior to the start of dynamic data collection, 10 lines of dynamic data were collected over a 2.75-in. rocket laid horizontal in the hole at a depth of 60 cm to determine the target selection threshold for the dynamic survey. Five lines were collected at 25-cm offsets (i.e., directly over the item and at 25 and 50 cm to either side) in one direction over the item, and five at the same offsets in a perpendicular direction. These data were considered to represent four separate surveys over the projectile, two for each direction. For each direction, the 0- and 50-cm offset lines were considered one survey (projectile directly underneath a survey line), and the two

25-cm offset lines were considered the other (projectile exactly ½-line spacing offset from a survey line). The response for the projectile for each survey was defined as the maximum response returned by the item for any of the lines included in the survey. The lowest response for the four surveys was approximately 23 microteslas per second (mV/A). A dynamic target selection threshold of 20 mV/A was used for the project to provide some buffer for data collected under less ideal topographic conditions than those present at the test pit.

Cued data were also collected over a 2.25-in. rocket and a 2.75-in. rocket warhead in the test pit. Test pit items were generally oriented in four directions relative to the MetalMapper (vertical, 45 degrees along path, horizontal along path, and horizontal perpendicular to the path) at a two depths, one selected to produce a strong signal-to-noise ratio for each orientation of the test object and one to determine what the polarizability curves for each item could be expected to look like with the item at or near the expected depth of detection. In addition to the rockets measured in the test pit, cued data were collected over an inert 5-in. rocket warhead recovered during the surface sweep and over two examples of entire 5-in. rockets partially exposed within or near the survey area. Because these were much larger items than the 2.25-in. and 2.75-in. rockets, data were collected over them by raising the sensor above the item on the ground surface rather than placing the items in a hole.

In addition to the test pit data, data were collected over the IVS twice daily during both the dynamic and cued surveys. All data collected over the IVS strip were processed as described in Section 6.2 and compared to either expected responses (dynamic) or the Hawthorne target library (cued). The following tests were performed for the collected IVS data:

- Dynamic: the response measured for each seed item was compared to a minimum expected response determined for that item. Unlike the EM61, for which there are expected response versus depth curves for standard seed and ordnance items, the responses versus depth for the MetalMapper are almost completely unknown. Therefore, the minimum expected response for each IVS seed was defined as the average response for that item throughout the course of the project minus 25%.
- Cued: the item identified by the target library comparison was compared to the actual buried item, and it was expected that the identified item matched the seed item with a relatively high confidence (≥ 0.80 for the weighted confidence metric). Identified results were considered a match to the IVS seed as long as the sizes of the two items were relatively similar (i.e., medium ISO seed identified as a 2.75-in. rocket warhead was acceptable, medium ISO identified as a full 5-in. rocket was not).

IVS testing results are detailed in Sections 7.1 and 7.5.

5.4.2 Background Data

Background data were generally collected every 2 hours throughout the project. MetalMapper background collection points were determined by the operator who searched for a clear location using the dancing arrows display on the computer screen. Background data were collected more than once every 2 hours if the operator felt another point was necessary for any reason (e.g., changes to the configuration of the instrument, changing field conditions such as rain).

5.5 DATA COLLECTION PROCEDURES

5.5.1 Dynamic Data

Dynamic data were collected by driving the MetalMapper across the project site along parallel lines spaced 50 cm apart. The MetalMapper had a GPS antenna directly over the center of the sensor, which transmitted real-time positioning data to the data acquisition computer DAQ. The location of the instrument during collection was displayed on the DAQ screen along with the predetermined locations of the data lines to be collected. The operator drove at a speed of less than 1 m/s, keeping the instrument centered on the selected line with the aid of a light bar at the top of the DAQ screen that indicated when the GPS deviated from the predetermined path and in which direction the deviation occurred. IMU data were collected simultaneously with the MetalMapper data, although the data from this instrument are not integrated in real time on the screen. The IMU data were used in post-processing to correct the sensor location for pitch, roll, and yaw variations due to terrain. These corrections were very important at HWAD because the site contained numerous sand dunes that caused significant pitch and roll changes during the survey. The MetalMapper data acquisition parameters for the dynamic survey are contained in Table 5.3.

Table 5.3
Dynamic Data Acquisition Parameters

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)
Dynamic	Z	50	0.1	9	20	1	90	2776	19	0.1	10

5.5.2 Cued Data

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, and setting the MetalMapper down on the point. Reacquisition of the dynamic 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. Once the MetalMapper was positioned correctly above the target, the operator collected a data point using the settings indicated in Table 5.4.

Table 5.4
Cued Data Acquisition Parameters

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	8328	50	9	N/A

Static targets were identified according to the ID determined for each target picked in the dynamic 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).

5.5.3 Scale of Demonstration

Dynamic data were collected over 9 acres of the 10-acre project site. Dynamic data were not collected over the final acre because the bottom of the MetalMapper sled wore down as the survey progressed. The sled, which was a prototype intended to identify design flaws that became apparent after semi-long term use, was one of a kind, and replacement parts were not available. The bucket that holds the MetalMapper (Figure 2.1) consisted of two pieces, the full bucket itself and a protective base bolted to the bottom of the bucket. Figure 5.1a shows the wear sustained by the protective base, which was discarded after approximately 7 acres of the survey. The survey was continued without the discarded base to the point that the field team felt the bucket itself (Figure 5.1b) was becoming damaged to the point that the cued survey would no longer be possible if it got any worse.

Figure 5.1
Wear on the bottom of the MetalMapper Sled

a. Protective Base **b. Bucket Base**

A total of 1,880 targets were identified in the dynamic data for further evaluation via the cued survey. The cued survey covered 1,882 data points for 1,800 targets. The remaining 80 targets could not be collected due to another failure in the sled. Two tow straps are used to lift the bucket holding the sensor during travel from one point to the next. In this case, the arm that the tow straps attach to crumpled, as shown in Figure 5.2. Because this part was unreplaceable in the time available to the field team, the cued survey was considered complete. The 82 extra points were re-shots of already collected points due to a high offset between the location of the center of the MetalMapper and the location of the dynamic target or the modeled source location. An offset of 40 cm was considered the greatest acceptable distance between the two points in both cases. In cases where it was obvious to the field team that the distance between the two was greater than 40 cm when the initial point was collected, they immediately collected a re-shot directly over the dynamic target location.

Figure 5.2
Broken Sled Arm

5.5.4 Sample Density

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

5.5.5 Data Quality Checks

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

A final check on the quality of static data was performed after initial inversion was performed using the UX-Analyze module in Oasis montaj. Inverted target locations were compared to data collection locations to determine if offsets between the two were greater than 40 cm. The collection location was also compared to the location of the EM61 target. It was intended that re-shots be collected for targets for which either of these cases were true. However, given the damage to the sled, no re-shots were collected save those that were performed in the field as described in Section 5.5.3. Targets requiring re-shots that were never able to be collected were considered unclassifiable and were not considered when statistics regarding the effectiveness of the MetalMapper at HWAD were calculated.

5.5.6 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 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 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. Located and background corrected .CSV files were imported into Oasis montaj for further processing and analysis.

5.6 INTRUSIVE PROCEDURES

Parsons' intrusive operations at Walker Lake Land began on Dec 2, 2013, and ended on December 19, 2013. 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 two 20-ft.-long connex boxes approximately 1 mile east of the survey area. All Parsons intrusive equipment was stored in the connex 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 (Schonstedt) calibrations.

The intrusive investigation was performed following the submittal of the ranked dig lists and included two subareas. Dig list 1 included 504 targets identified in the dynamic data set within the "investigate all" area regardless of classification. Dig list 2 included 307 additional targets classified as TOI outside of the original "investigate all area." Each of the 504 anomalies on dig list 1 were intrusively investigated. Of the 307 TOI anomalies on dig list 2, only 134 targets were intrusively investigated. The remaining 173 targets classified as TOI were not investigated due to time constraints that arose when the majority of the first 134 digs ended up being large TOIs, many of which were identified as MEC/MPPEH. Because so many of the recovered native sources were TOIs, there was enough site data that the project could be evaluated successfully without investigating the remaining targets on the sig list. All intrusively investigated anomalies were documented per the demonstration work plan. All MD was identified and moved to a locked connex for storage and later disposal. Potential MEC/MPPEH items that could not be moved were left where found to be blown in place during the demo operation. 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 OTIE, the UXO explosives subcontractor. The field team consisted of a senior UXO supervisor, a site safety and health manager, and five Parsons personnel and two ordnance and explosives remediation 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 HWAD intrusive activities included the following:

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

5.6.2 Field Procedures

Reacquisition of all targets was conducted using the Trimble R8 GPS system. The GPS base station was set up on survey monument ESTCP 2 and checked daily on monument ESTCP 1. Parsons flagged all target locations with a PVC pin flag marked with the target identification and EM61-MK2 pre-value. 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 or that the pre-millivolt reading had been reduced by at least 75%.

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

All seed items recovered from intrusive operations were stored in a secure area and prepared for final shipment. Five inert 2.75-in. warheads were returned to the Ordnance Museum in Hawthorne, NV. The remaining seed items (nine 2.75-in. warheads and two 2.25-in. sub-caliber aircraft rocket warheads found during the surface sweep) were shipped on December 19, 2013, to the Army Research Lab in Waldorf, Maryland.

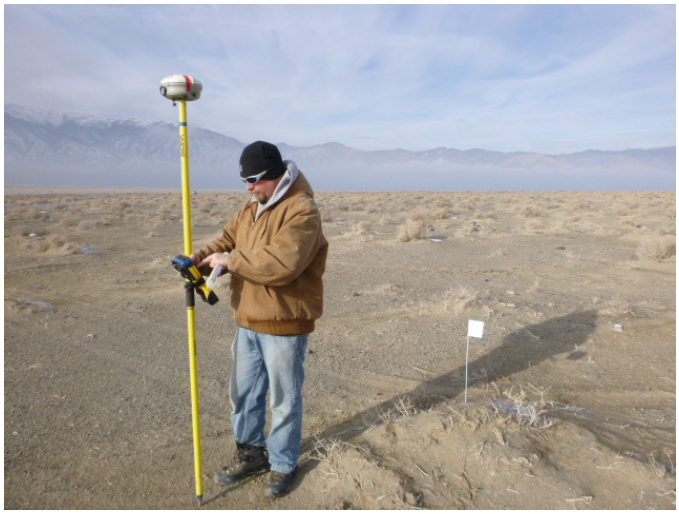
All target locations were backfilled after completion of the excavation. After the final anomalies were excavated and backfilled, Parsons conducted a walkthrough and confirmed that all holes were filled and no trash was left.

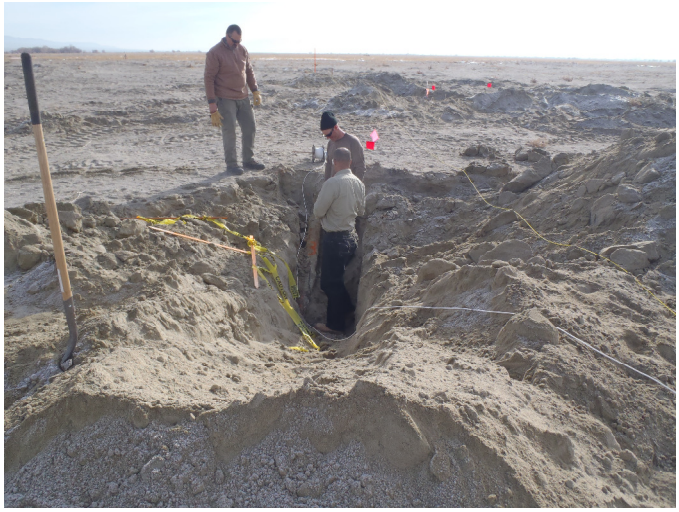
Excavation data collected by the intrusive team was manually entered into a Microsoft Access database and reviewed daily. The daily information required the target identification (ID) to be connected with intrusive documentation, photo, and GPS coordinates. Assessment of each target item required the coordinates to match the original location and the picture to match the documented findings. Results of the intrusive investigation are shown in Table 5.5. Photographs of the intrusive operation are shown in Figure 5.3.

Table 5.5
Intrusive Results

Type	Anomalies	Percent
Other Debris	3	<1
Munitions Debris	578	91
No Contact	14	2
Seed	43	6
TOTAL	638	100

Figure 5.3
Intrusive Operation Photos





5.7 MUNITIONS DEBRIS MANAGEMENT

MD and other debris (OD) scrap recovered from the demonstration area at HWAD amounted to more than 7,000 pounds. The MD/OD scrap was stored in a locked 20-ft. connex. Parsons' senior UXO and site safety officer certified all MD scrap by thoroughly going through each piece individually before final disposition in the sealed container provided by Demil Transport Services in Gila Bend, AZ. On December 19, Demil Transport Services delivered a shipping container to the site. The MD and scrap was transferred by hand from the connex to the shipping container. Demil Transport Services then removed the container and all the scrap and MD offsite. Shipping information, along with certified and signed DoD 1348 forms, was included with the final transfer of the MD.

6.0 DATA ANALYSIS AND PRODUCTS

The MetalMapper was used to collect dynamic data over 9 of the 10 intended acres and static data over 1,800 of the 1,880 targets identified in the dynamic survey. The uncollected area/targets were not collected due to the failure of various pieces of the prototype sled used to transport the MetalMapper sensor at the site. The processing and analysis steps that were used to generate a dig/no dig decision for each target are described below.

6.1 DYNAMIC DATA

6.1.1 Preprocessing and Processing

Raw MetalMapper data, both dynamic and static, 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., "Dyn" or "Stat"). The acquisition software then automatically appends a five-character numerical index to the filename prefix to form a unique root name for the data file (e.g., Dyn00001). The index is automatically incremented after the file has been successfully written. Each dynamic survey line was stored as a separate file. Preprocessing of the .tem files was accomplished using TEM2CSV, a program specifically developed for this purpose. Very little preprocessing was done to the dynamic data using TEM2CSV aside from reformatting the binary data to a file structure that could be imported into Geosoft.

Dynamic data processing and target selection were performed in the field according to recommendations from SAIC, the company that developed the UX-Analyze add-on to Geosoft's Oasis montaj. While the processing strategy was judged to have been successful during the field project based on the detection of all of the seed items surveyed, it was felt that a different processing strategy might be more successful upon further review of the data following demobilization from the site. The processing strategy used in the field is described in the "original" sections below, and the most successful alternate processing strategy is described in the "revised" sections.

Original

Once in Geosoft, the data were processed to convert data from the geographic coordinate system used for collection to the UTM Zone 11N coordinate system used for processing. Data locations were also corrected according to the IMU data collected concurrently. Heading, pitch, and roll information from the IMU were smoothed using an 11 fiducial low-pass filter prior to correction, so data point locations were not incorrectly moved based on outlier IMU data caused by quick sensor movements during data collection. The Z receiver response data from the five middle receivers were averaged to produce a single array channel (19 time gates) of response. A sum channel was calculated from the array by adding the responses measured from time gates 5 through 9, and the sum channel was leveled using a 150-point median filter. The sum channel was then gridded and displayed on the site map. A latency correction was applied, as necessary, to remove any chevron patterns evident in the dataset.

Revised

The sum channel for the revised data set was calculated using time gates 10–13 rather than 5–9 with the assumption that the later gates would prove effective in reducing the amount of small clutter selected as targets in the first data set. The leveling process was also revised to disregard 10% of the lowest response values and 70% of the highest response values to reduce the effect the higher values originally had on the median subtracted from the unleveled response. The result was fewer negative values surrounding the larger peaks in the data set.

6.1.2 Target Selection

Original

Targets were selected using the Blakely test algorithm in the UX-Detect package in Oasis montaj with a threshold of 20 mV/A. The Blakely test selections were then reviewed by the processor, who merged target picks on the same anomaly and/or added picks to unpicked peaks evident on the color-shaded grid map. After the target list for each dataset was finalized, a footprint size was calculated for each using the Calculate Signal Strength, SNR, and Size option in the UX Detect menu in Geosoft with a 2 m window and a background of 5. Most targets with an areal extent of less than 1 m^2 were removed from consideration as potential TOI and were not added to the list of targets to be further investigated in the cued survey. The 1 m^2 threshold was originally selected by the project geophysicist, who identified a threshold that seemed to eliminate smaller anomalies easily identifiable as clutter while retaining anomalies large enough to potentially be TOI; it was confirmed by the QC geophysicist who ensured that all known seeds were retained after the removal of picks on smaller-sized anomalies. All targets removed based on size were reviewed by the processor, who was responsible for the final decision on whether they were added to the cued target list.

Revised

A 6-mV/A threshold was used to pick targets in the 2-acre area in which EM61 and TEMTADS data were also collected based on the dynamic test pit data collected at the beginning of the project (lowest value for 2.75-in. rocket at 2 ft. was 6.2 mV/A). However, this threshold failed to detect all of the targets classified as TOI in that area based on the cued MetalMapper data. A 5 mV/A threshold was used to reselect targets in the full 9-acre survey area based on the seed/classified TOI results in the 2-acre area. Following reselection, the target list was compared to the seed item list, and it was determined that two medium ISOs buried horizontally at 50 cm below ground surface were not selected as targets. The selection threshold was revised again, to 4.75 mV/A, in order to detect these items. After all of the seed items had been initially selected as targets, the size of each anomaly was calculated using a 2-m background and a 2-m window. Most anomalies with sizes less than 0.7 m^2 were considered indicative of small clutter and were removed from consideration as targets. However, all removals were reviewed, and some were kept at the discretion of the analyst.

Various other time gate and receiver combinations were tested, including single gates, different summations of earlier and later gates, splitting the responses for individual receivers, and examining the responses for the x and y orientations in addition to the z orientation. Given the nature of the TOI present (i.e., relatively large and deep), the average of the five middle z receivers was judged to be the most useful response calculation. See Target Counts.xlsx for full list of other channels assessed.

6.1.3 Results

The original target list contained 2,948 anomalies before the size filter was applied; the size filter reduced this number to 1,880 for the cued target list. The revised list contained 1,929 targets before the size filter was applied and 1,357 after, a nearly 28% reduction from the 1,880 on the original cued target list. One TOI, a native 2.75-in. rocket warhead recovered at a depth of 67 cm (below required depth of detection) was not included on the revised target list.

After the lists were finalized, the offsets between the selected targets for each list and the seed locations and the recovered TOI locations were compared. The standard deviation for the offsets between the original target list and the seed items was 8 cm, while the standard deviation for the revised target list was 18 cm. All revised target locations were within 60 cm of their respective seed item location with the exception of one medium ISO that was selected despite being buried just outside of the surveyed area (offset of 115 cm). The standard deviation for the offsets between the original target list and all TOI was 47 cm, while the standard deviation for the revised target list was 26 cm.

6.1.4 Other Sensors

Although not detailed in the demonstration plan, Parsons also collected dynamic EM61 and TEMTADS 2x2 (TEMTADS) data across 2 acres of the 9-acre MetalMapper site for comparison with the MetalMapper dynamic data. The additional data collection was performed following remobilization in March 2014. Collection activities were limited to 2 days with each instrument, and very little QC testing was done given time constraints; although enough testing was done to ensure that each sensor was in working order. The processing and target selection steps used for the EM61 and TEMTADS data are described below. The success of each target selection strategy was judged by ensuring that seed items still present on site (all inert 2.75-in. rocket seeds were removed before demobilization of the intrusive teams in December 2013) and those targets classified as TOI in the cued MetalMapper survey (see Section 6.2) were selected as targets.

EM61

Preprocessing involved similar leveling to the revised MetalMapper leveling process: ignored 10% of lowest values and 70% of highest for a 15-s rolling statistics median filter. Targets were picked using a ch1-ch3 sum channel and a 20-mV threshold, which was based on a 22.7-mV expected response for a 2.75-in. warhead at 60 cm per NRL testing. Channel 3 by itself was also considered for target selection, but the minimum expected threshold of 3.3 mV per the NRL tables proved to be too low to be particularly useful. A total of 262 targets were selected in the 2-acre area in which EM61 and TEMTADS data were collected, slightly lower than the 277 targets picked in this area using the MetalMapper target selection process outlined above. Given the much larger area that can be covered by an EM61 towed array each day, it seems this would be the most reasonable dynamic data collection option.

TEMTADS

Preprocessing and leveling was accomplished in the same manner as the MetalMapper and EM61 data. Various response channels were created for each of the four receivers and receiver orientations, although only two primary calculations were used. The first was the response for each individual receiver orientation when that receiver's respective transmitter fired (e.g., Rx1z response for Tx1 pulse, Rx2z for Tx2 pulse). The second was a response for each receiver

orientation calculated by averaging the response measured by that receiver after each of the four transmitters fired:

$$\sqrt{(Rx1z_Tx1)^2 + (Rx1z_Tx2)^2 + (Rx1z_Tx3)^2 + (Rx1z_Tx4)^2}$$

Although only the Rx1z receiver calculations are shown, similar responses were calculated for all four receivers and for each receiver axis (x, y, and z).

Various channels were gridded and visually compared to the known seed locations and TOI locations per the cued MetalMapper results. It was apparent in the visual comparisons that the x and y receiver responses were not detecting the deeper (~50 cm) medium ISOs particularly well. This was true for the averaged receiver responses as well, so gridding and target selection was performed using only the single transmitter, z-orientation response values. Two sum channels were created using these data, one using the summed responses for time gates 5 through 12 and one using the summed responses for time gates 9 through 13. Table 6.1 shows the target selection criteria and results for the two channels, and it clearly indicates that the later time gates were more effective in reducing the number of targets that would have been necessary on a subsequent cued target list. The target counts cannot be directly correlated to the EM61 target count or the 2-acre MetalMapper target count because the last 15 feet of the 2-acre survey area (~0.07 acres) were not completed with the TEMTADS due to time constraints on the unit, which was required on another site.

Table 6.1
TEMTADS Target Selection Results

Gridded Channel	Selection Threshold	Anomaly Filter	Final Target Count
z5-12	7 mV/A	0.25 m^2 size, calculated using 3 mV/A background and 2-m window	637
z9-13	2 mV/A	1.0 m^2 size, calculated using 0.5 mV/A background and 2-m window	343

6.2 CUED DATA

6.2.1 Preprocessing

Raw cued files were stored as described in Section 6.1.1, with each cued target stored as a separate file. Although the cued target ID was not used as the file name in the .tem file, the target ID was stored in the file according to name of the target highlighted on the MetalMapper screen during collection. TEM2CSV was also used to preprocess the cued data files. In this case, TEM2CSV converted the points from the geographic coordinate system used for collection to the UTM Zone 11N coordinate system used for processing and corrected the collection location based on the IMU data collected with the MetalMapper data in addition to the same type of reformatting performed for the dynamic data.

Background correction of the cued points was performed in Geosoft. The first step was a review of each day's background points when compared to the background dataset as a whole. Geology across the site was not expected to be particularly variable, so it was assumed that any

background points significantly different than the others in the set were due to either a point collected over a small piece of subsurface metal not noticed during collection or faulty equipment. Each day's background points were also compared to each other by reviewing the 63 decays (three transmitters and seven tri-axial receivers) for each point. As with the comparison to the full site background dataset, it was not expected that background values should vary significantly through the day. Any background points showing significant variability from either the site wide background dataset or in-day dataset were not used to correct any of the cued target data points. A list of background points not used was maintained in the project's Microsoft Access database.

6.2.2 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 performed twice using the UX-Analyze batch processing mode, once using the single object solver and once using the multiple object solver. The multiple object solver returns seven results for each target based on different algorithms used to group the point cloud generated during inversion into one or more sources. The version used for each target was the one that had the highest weighted confidence metric match to an item in the classification library (Section 6.2.4). All results for a given target (single object and all multiple object results) were then compared to determine which method returned a result more indicative of TOI.

6.2.3 Confidence Metrics

The polarizability curves developed for each target were compared to a library of known polarizability curves compiled using previous test stand data, known TOI from other sites, and the test data collected at HWAD (Section 5.4.1). The items in the HWAD comparison library were 2.25-in. rockets, 2.75-in. rockets, 3.5-in. rockets, 5-in. rockets and separate components of those rockets (i.e., motors and warheads), as available. Examples of other ordnance listed in Section 4.4 were not available for testing and addition to the library. However, the non-signal flare ordnance in the list, 4.5-in. rockets, 7.2-in. rockets, and 300-pound depth charges, were expected to be large enough that it could be easily identified by the analyst during review of the polarizability curves generated for each target or would be evident as an item much larger than most clutter at the site a parameter space plot generated for the dataset (Section 6.2.4).

An initial comparison between the measured targets and the library data was performed using a weighted confidence metric for the three primary polarizabilities (size: 1, shape 1: 0.5, shape 2: 0.5). During this comparison, the seven results from the multiple object solver were compared to the library, and the one with the highest confidence metric was selected for use with that target. If the result selected was not the one already in the target database, the database result was replaced. All further confidence metrics were generated using the multiple object result selected during the weighted metric comparison. In addition to the weighted confidence metric generated during the initial comparison of the results to the library, three more metrics were generated for each target:

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

As a first step, each target was examined by looking at a figure showing the two closest matches for the weighted, two-curve, and one-curve comparisons to the library. Results were generally grouped into one of five groups:

1) All three polarizability curves (β1, β2, β3) were usable
2) Only two of the curves (β1, β2) were usable
3) Only β1 was usable
4) No usable curves, but it was determined unlikely that there was a source large enough to be TOI in the acquisition location or the target in question was picked on the edge of a dynamic anomaly and there was another point collected on that anomaly that was of sufficient quality for use in classification
5) Can't analyze (no usable curves, and it was considered likely that the curves were unusable despite the existence of a source potentially large-enough to be TOI)

The difference between targets deemed likely to have a source potentially related to and those with unusable curves due to a small or nonexistent source was typically determined based on the modeled location of the source relative to the collection point and the appearance of the anomaly in the dynamic dataset. Targets on the edge of anomalies that had source locations modeled toward another peak on that anomaly were generally considered useable data, given the likelihood that the source was underneath a different target, as were poor MetalMapper data collected over small anomalies that looked like they were potentially due to geophysical noise in the dynamic dataset rather than an actual large source. Additionally, the field team recorded notes in their logbook for all targets that could not be found near the picked location using the MetalMapper's dancing arrows. Targets with such notes were also removed from consideration as Can't Analyze targets.

6.2.4 Classification Decisions

Classification decisions were made for the HWAD project primarily using the four confidence metrics generated for each target during the comparison to the library data. They were categorized with respect to the likelihood that they were TOI based on the decision logic shown in Table 6.1.

The data were then evaluated using a parameter space plot that graphed each target using a decay (time gates 8–32) versus size comparison (Figure 6.1). Colors were used to differentiate between targets classified as digs based on the decision logic in Table 6.1 and the remaining non-digs. The analyst first rechecked the polarizability curves for all non-digs within areas occupied by digs to ensure that they were not just misclassified during the initial classification process. Any targets having polarizability curves generally indicative of a cylindrical object (β1 greater than roughly equal β2 and β3 curves) were added as digs. Remaining non-digs within dig areas were typically plate-like objects that happened to have decay/size characteristics similar to ordnance.

The training data selection for HWAD was also based on the parameter space plot. In this case, two clusters of targets were evident to the analyst (Figure 6.1). Clusters are generally indicative of the same type of item, and should be investigated to ensure that that item is not a type of unexpected ordnance at the site not represented in the classification library. Five targets were

selected from these two clusters for intrusive investigation, three from the upper group and two from the lower group, with the intention that if any were identified as TOI following investigation it would be added to the library. The confidence metric calculations for the site the site would then be rerun, and items matching the newly identified TOI would be reclassified as digs. Only four of the five targets were excavated due to time constraints, but the results were consistent enough for the targets that were dug that the last was unnecessary. Both clusters are due to relatively standard ordnance fragments that are not hazardous by themselves. The lower cluster is comprised of rocket motor venturis (Figure 6.2), and the upper consisted of rocket fins (Figure 6.3).

Table 6.1
Categories for HWAD Cued Targets

Category	Dig	Weighted or three-curve confidence metric	Two-curve confidence metric	One-curve confidence metric	Comment
0	Yes	NA	NA	NA	Can't analyze; data deemed unusable for classification
0.5	Yes	NA	NA	NA	Training data
1	Yes	≥ 0.60	≥ 0.70	≥ 0.80	All three are true
2	Yes	NA	≥ 0.70	≥ 0.80	One non-β1 curve considered poor; other two true
3	Yes	NA	NA	≥ 0.80	Two non-β1 curves judged poor; β1 curve looks like TOI
4	Yes	NA	NA	NA	Added based on size, decay, or size and decay, or confidence metrics close with noise but not enough noise to classify as can't analyze
5	No	< 0.60	< 0.70	< 0.80	Any one of three is true
6	NA	NA	NA	NA	Targets requiring re-shots that were not re-shot

Figure 6.1
Parameter Space Plot (Decay 8-32) Used for Training Data Selection

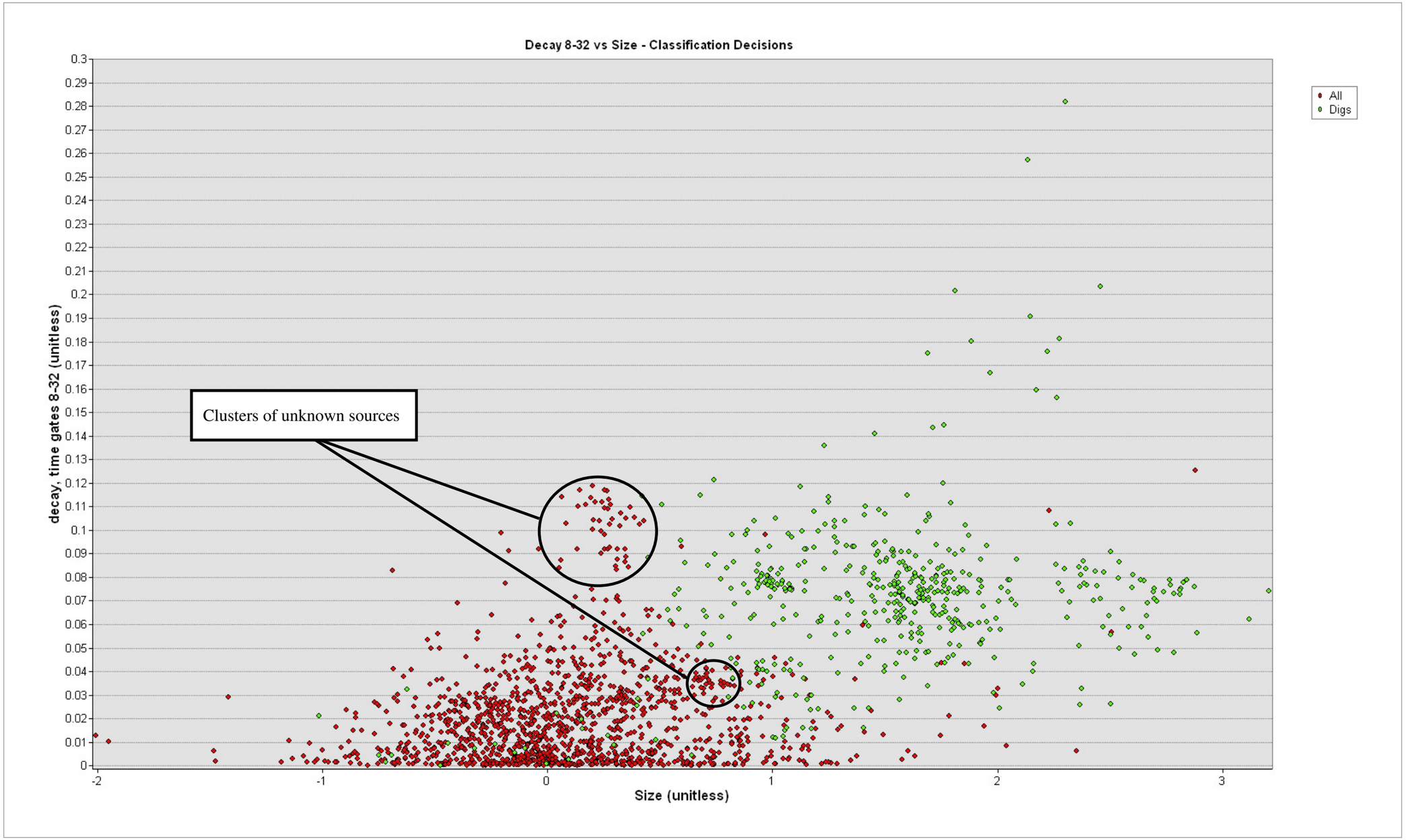


Figure 6.2
Intrusive Results for Lower Cluster Training Targets

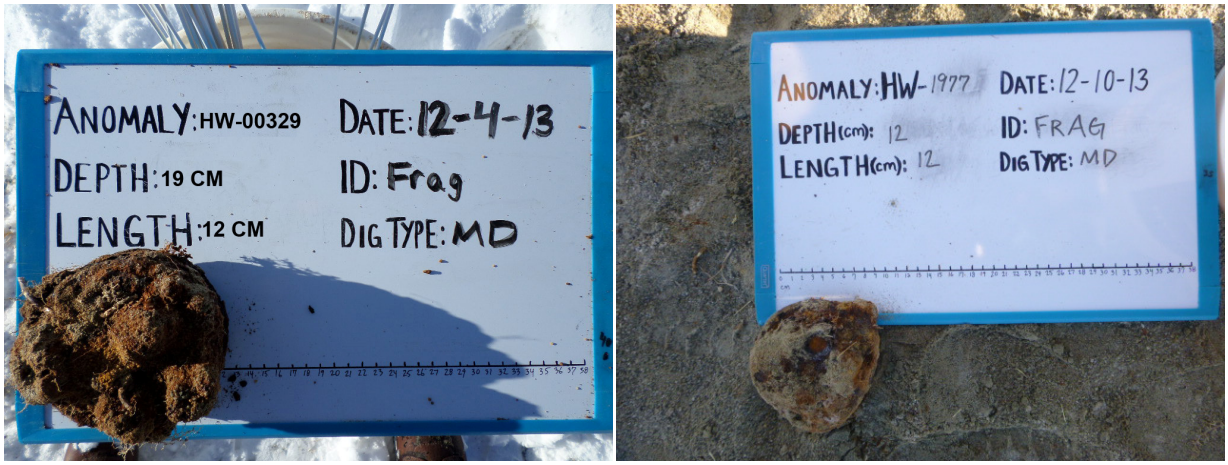
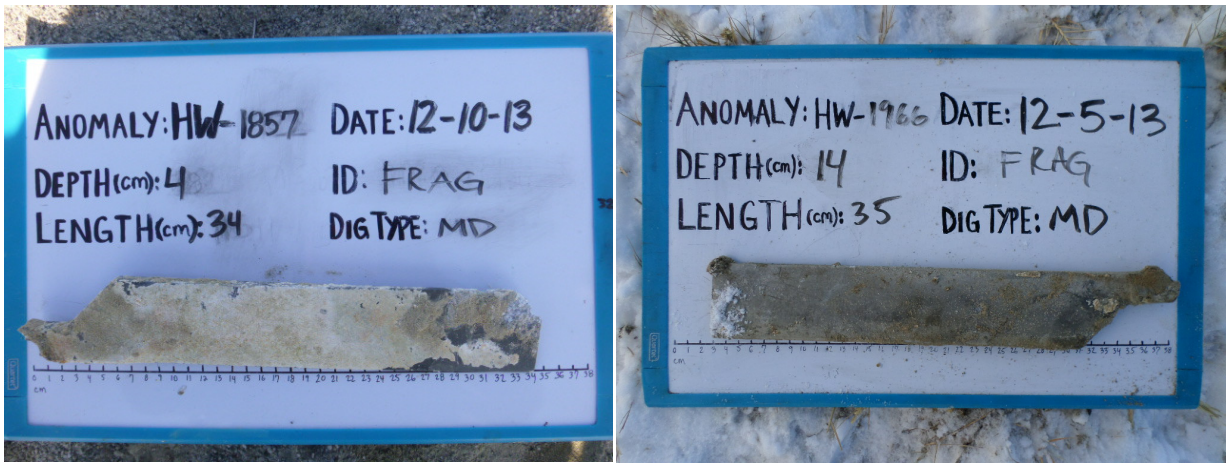


Figure 6.3
Intrusive Results for Upper Cluster Training Targets



6.3 DIG LISTS

All collected targets were ranked according to category and confidence metric. Categories were sorted from high to low, and targets within each category were sorted by descending confidence metric. Targets were sorted using the weighted confidence metric, with the exception of the category 2 targets (two-curve metric used for sorting) and the category 3 targets (one-curve metric used for sorting). The dig list submitted following completion of the project contained all of the targets for which MetalMapper data were collected.

Two separate dig lists were also given to the dig team for the intrusive investigation. The first contained only the 504 targets within the area in which all targets would be investigated regardless of classification. The second contained only targets classified as digs that were not already covered on the initial list of 504. Table 6.2 contains the applicable classification statistics for the project as a whole and for each of the two dig lists submitted to the dig team.

Table 6.2
Dig List Summary Statistics

Statistic	Project (number / %)	First 504 (number / %)	Remaining Targets (number / %)
Targets collected	1,800 / 100	504 / 100	1,296 / 100
Targets classified	1,724 / 96[1]	477 / 95[1]	1,247 / 96[1]
Targets labeled as digs	410 / 23.8[2]	103 / 21.5[2]	307 / 24.6[2]
Can't Analyze	19 / 1.1[2]	8 / 1.7[2]	11 / 0.9[2]
Training	5 / 0.3[2]	4 / 0.8[2]	1 / 0.1[2]
Priority 1	369 / 22.8[2]	87 / 18.2[2]	282 / 22.6[2]
Priority 2	5 / 0.3[2]	1 / 0.2[2]	4 / 0.3[2]
Priority 3	2 / 0.1[2]	0 / 0[2]	2 / 0.1[2]
Priority 4	10 / 0.6[2]	3 / 0.6[2]	7 / 0.6[2]
Targets labeled as clutter	1,314 / 76.2[2]	374 / 78.4[2]	940 / 75.4[2]

[1] 76 targets identified as requiring re-shots were not re-shot due to time constraints. These were placed at the end of the ranked dig list (category 6) and were not included in statistic calculations

[2] Percentage calculated according to number classified, not number collected.

7.0 PERFORMANCE ASSESSMENT

7.1 REPEATABILITY OF IVS MEASUREMENTS

Nineteen dynamic surveys of the IVS strip were performed during the project. The results from all 19 surveys over each IVS item were averaged to produce an expected response for each. The responses for each item in each survey were compared to the expected response minus 25%. Only one failure was noted for any of the tests. This was a response of 125 mV/A versus an expected response of 174 mV/A for IVS item #4, a 2.75-in. practice rocket, in the first IVS test collected during the project (AM test on 10/23). Because this was the first IVS strip run during the project, the failure was attributed to operator error rather than equipment failure.

7.2 SPATIAL COVERAGE

All of the dynamic datasets passed the primary coverage objective, with all covering more than 97% of their respective areas with a 70-cm or less spacing. All gaps above 90 cm were due to either terrain that could not be covered by the equipment (gap on north end of site due to large sand dunes) or cultural features (historic lake level marker in southeast corner of the site).

7.3 DOWN TRACK SPACING

One dataset failed the down track spacing objective of greater than 90% of the points with spacings less than 10 cm from each other. Twelve percent of the points in the November 5 dataset were greater than 10 cm from the previous point. Because this was the last day for which the sled was deemed usable for dynamic collection, the data were deemed usable for target selection, and the field team moved on to static collection. A number of days contained points greater than 15 cm from each other, which technically failed the 100% of points less than 15 cm from each other. However, in most cases, point-to-point distances exceeding 15 cm were in the middle of points well within 10 cm of each other (e.g., 10 spacings between 5 and 7 cm from each other, a 16-cm spacing, and another 10 within 5 and 10 cm of each other). It is suspected that the spacing exceedances were caused when the sensor rotated quickly forward or backward when going up/down sand dunes. Because there was little the operator could do about it and the points were spaced throughout the dataset rather than in groups of high-speed data, randomly spaced spacings greater than 15 cm were not considered an issue with regard to data quality.

7.4 DETECTION OF ALL TARGETS OF INTEREST

Targets were selected over all seed items covered by the dynamic survey within the required radius of 60 cm. The largest offset between a dynamic target selection and a known seed location was 50 cm. Dynamic targets were within 40 cm of 59 of the 61 seeds covered by dynamic survey and within 30 cm of all but seven seeds.

7.5 CORRECTLY IDENTIFY SEED ITEMS IN THE IVS

All of the cued IVS points were identified as the correct seed item or background location (no match to anything in the library). The lowest confidence metric recorded for the IVS points was a 0.952, well above the required metric of 0.90.

7.6 CORRECTLY POSITION METALMAPPER RELATIVE TO SOURCE

Twenty-eight of the targets needing re-shots that were not collected due to sled failure required re-shots based on modeled source locations greater than 40 cm from the collection point. An additional 128 had been collected to modeled locations greater than 40 cm but were judged usable by the analyst based on these possible factors:

- The target was classified as TOI despite having a modeled location greater than 40 cm from the collection location.
- The operator noted during collection that there was no source evident at the dynamic target location (based on the dancing arrows display), so data were collected directly on top of the dynamic location to satisfy the requirements of the collection to dynamic target distance DQO.
- The target was picked on a peak in a larger anomaly for which at least one other target within the anomaly was already classified as a dig.
- The version of the target selected for classification (multiple object solver version of the point selected rather than single object solver version) was more indicative of TOI than a modeled point within 40 cm of the collection location despite being outside of the DQO radius.

7.7 CORRECTLY POSITION METALMAPPER RELATIVE TO DYNAMIC TARGET

Forty-eight of the targets needing re-shots that were not collected due to sled failure required re-shots based on collection locations greater than 40 cm from the dynamic target location. An additional 165 had been collected to dynamic selection locations greater than 40 cm but were judged usable by the analyst based on a number of possible factors:

- The target was classified as TOI despite the offset between the collection location and the dynamic target.
- The target was picked on a peak in a larger anomaly for which at least one other target within the anomaly was already classified as a dig.
- The collected data looked reasonable (i.e., inversion good, no noise) and there were no other dynamic targets within 1.5 m of the dynamic target in question, signifying that the operator collected data over the intended source.
- The collection location was outside of the dynamic survey area, indicative of a source that was not fully covered by the dynamic survey.

7.8 MAXIMIZE CORRECT CLASSIFICATION OF TOI

Results with regard to the correct classification of TOI were determined for the 504 targets intrusively investigated regardless of classification decision and for those targets excavated outside of the 504-target area based on their classification as dig targets.

Out of the 504 targets excavated at the start of the intrusive investigation, 477 had classification decisions. The remaining 27 were identified as category 6 targets that could not be classified due to pending re-shots that were never collected. Classification statistics were compiled using only the 477 targets with valid classification decisions. Of the 477 targets investigated, 70 resulted in one or more TOI (114 individual pieces of TOI were recovered from the 70 target locations), which were either seed items or native items identified as TOI upon excavation. Sixty-eight of

the 70 TOI locations were classified as dig targets on the ranked dig list. The two TOI locations classified as non-digs are discussed below.

Target 1868 was a 5-in. rocket warhead recovered at a depth of 100 cm and 81 cm from the nearest dynamic target selection (Figure 7.1). The dynamic response value at the recovery location was 15.5 mV/A, well below the 20 mV/A threshold used for target selection. Figure 7.2 shows the shows the multiple object solver modeling results for target 2105, which indicate two small pieces of metal underneath the sensor during collection and a larger object at depth off to the side of the collection location. The large source models in the location of the warhead, but the fit location was 15 cm outside of the effective sensor radius and closely resembles a noisy model of background. Background or noisy models outside of the sensor radius are a common result for the multiple object solver, so the result was ignored given the distance from the sensor. The dig team was sent back to this location to confirm that the recovery location for the warhead was correct and to recheck the dynamic target selection location. The warhead recovery location was confirmed, but a backhoe had been used to excavate the warhead and the dynamic target location had already been excavated as part of the hole for the warhead. The team rechecked the spoils pile and found two pieces of munitions fragments that are suspected to be the source of the dynamic peak. The warhead was recovered 40 cm below the depth of detection for the project, and no cued point was collected within a distance that would suggest it should have been classified correctly. Therefore, the no-dig classification for this target is considered correct.

Figure 7.1
Dynamic Pick and Recovery Location for Target 1868

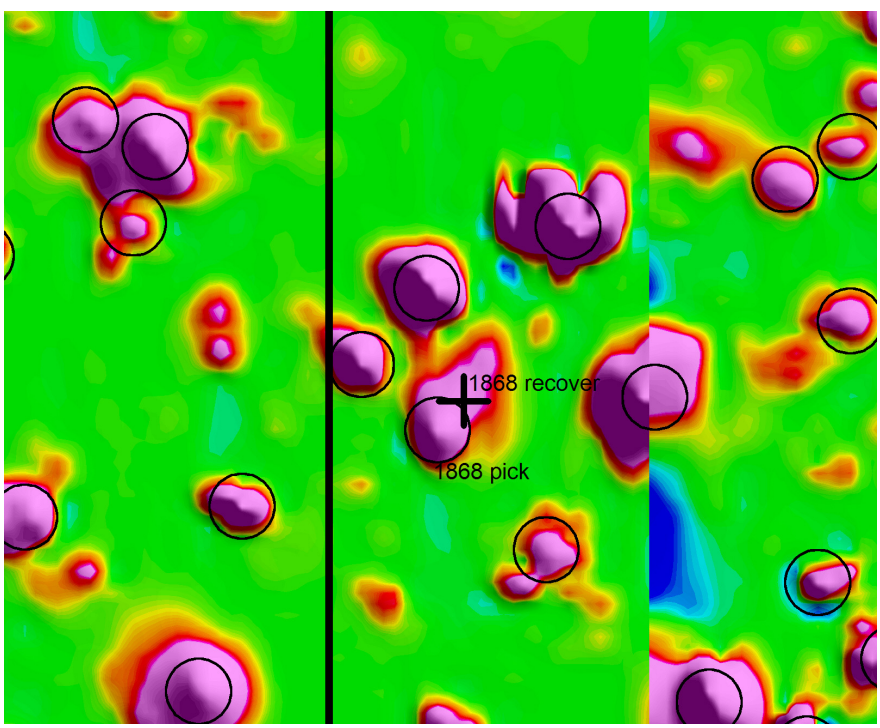
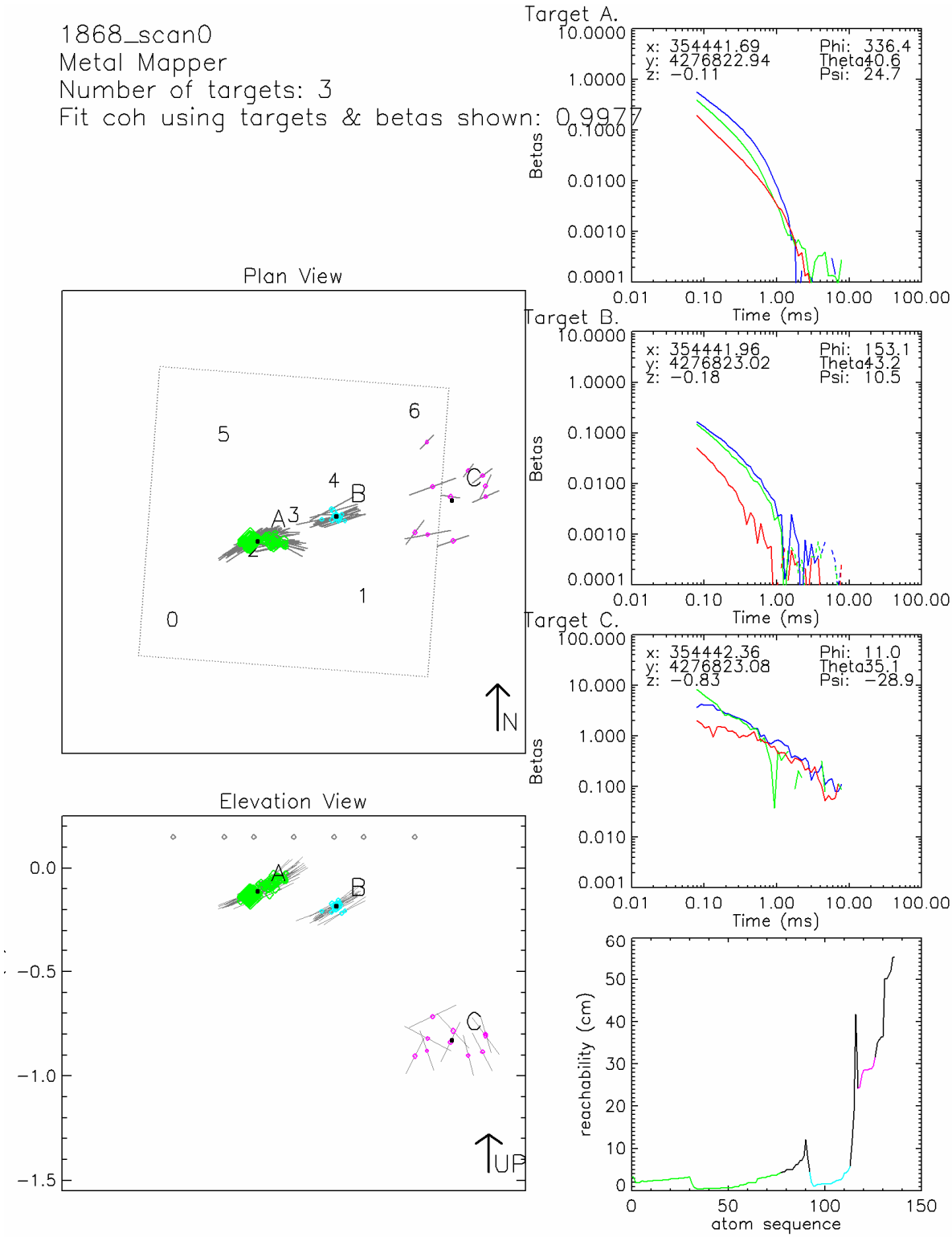
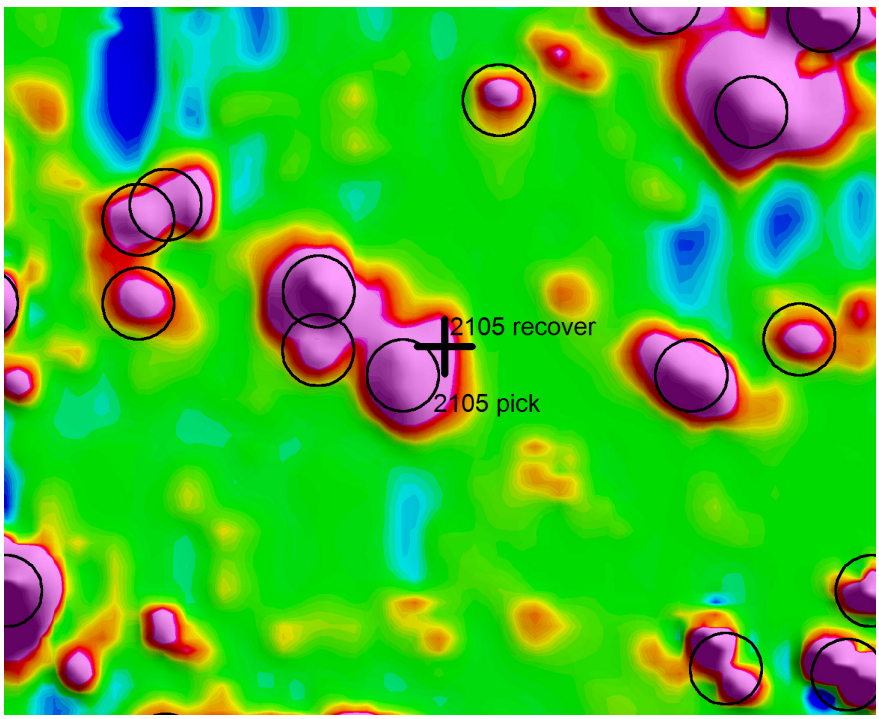


Figure 7.2
Multiple Object Solver Model for Target 1868



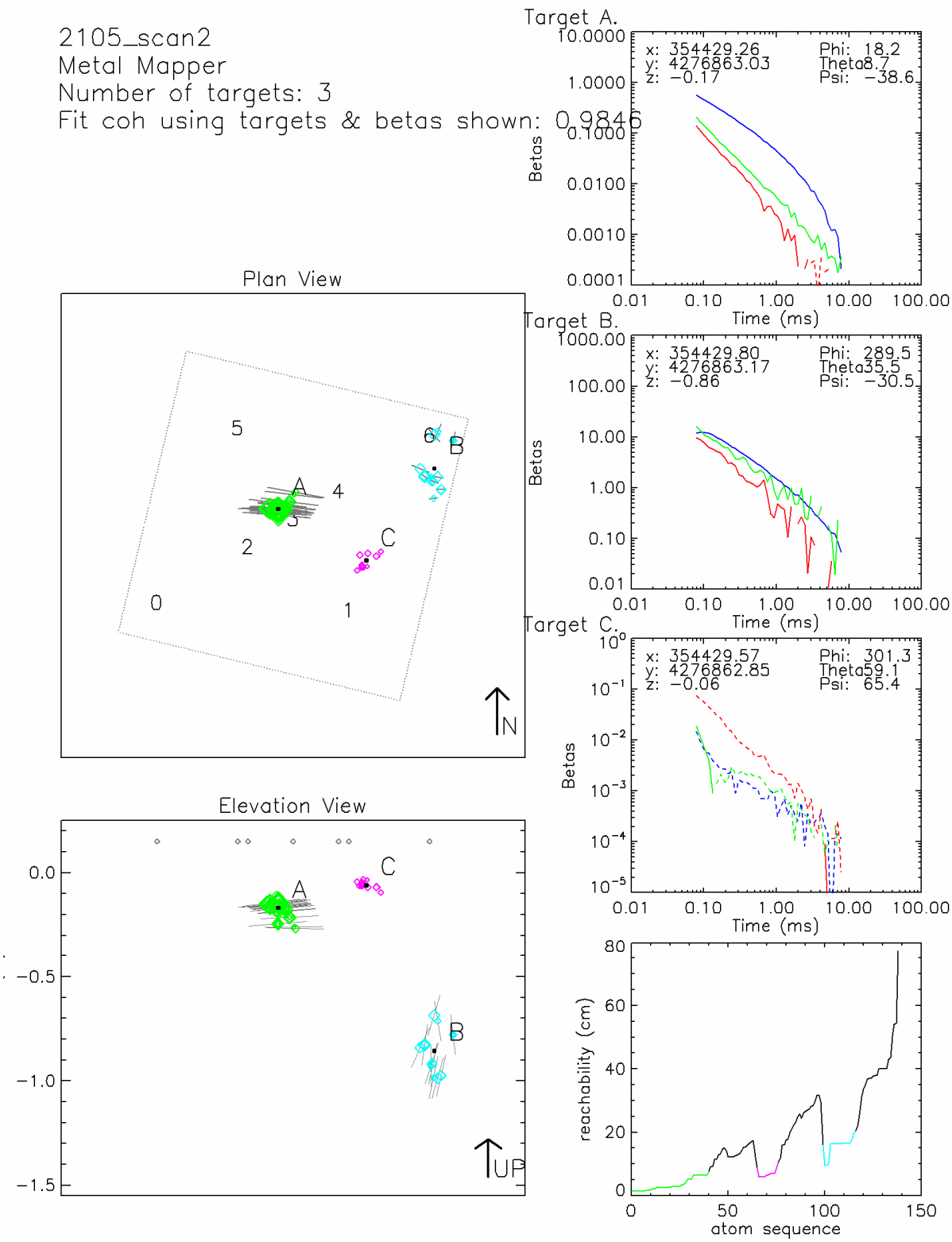
The second location with TOI recovered at a recommended non-dig was target 2105. This was a 2.75-in. rocket recovered at a depth of 88 cm and 1.08 m from the nearest dynamic target selection location (Figure 7.3). The dynamic response value at the recovery location was 12.9 mV/A, also well below the 20 mV/A threshold used for target selection. Figure 7.4 shows the multiple object solver modeling results for target 2105. As with target 1868, the model includes a large object at depth approximately 15 cm outside of the effective sensor radius of the MetalMapper. In this case, a somewhat cylindrical munition fragment was recovered 5 cm from the predicted source location for the single object solver result for 2105, which was the result chosen for this target. This source was considered a reasonable result for the single object solver polarizability curves, which were reasonably similar to the curve shown for Target A in the multiple object solver model. As with 1868, the warhead was recovered below the depth of detection for the project, and no cued point was collected within a distance that would suggest it should have been classified correctly. Therefore, the no-dig classification for this target is considered correct..

Figure 7.3
Dynamic Pick and Recovery Location for Target 2105



In addition to correctly classifying all TOI over which cued data points were collected, the 44 seed items outside of the 504-dig area were also correctly classified as dig targets in the ranked dig sheet. Based on these results, the project is considered to have passed the performance objective of correctly classifying all TOI.

Figure 7.4
Multiple Object Solver Model for Target 2105



In addition to the targets investigated regardless of classification, 134 targets classified as digs were excavated outside of the initial 504-target area. Of these, 110 (82%) contained at least one item identified as TOI upon excavation. Ninety-seven of these were recovered from above the 60-cm depth of detection, and the other 13 were recovered below this depth.

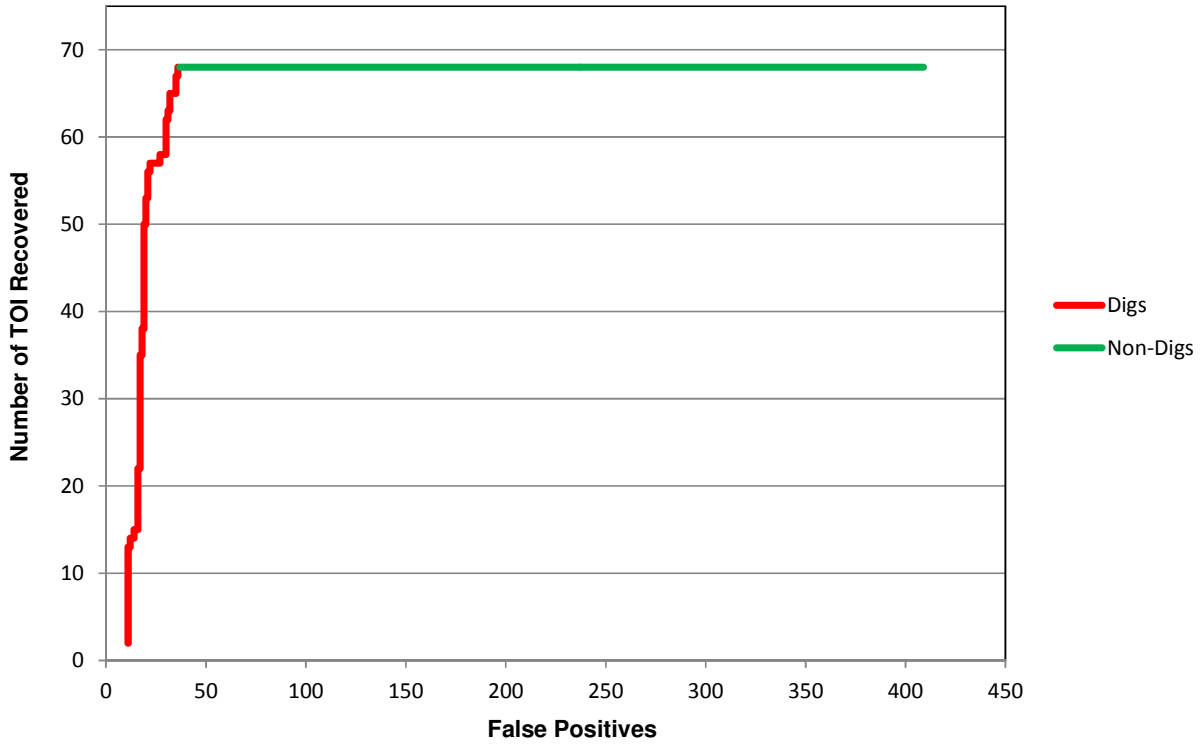
7.9 MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

The removal of the 68 TOI over which cued points were collected from the 477 targets classified for the initial intrusive investigation left a total of 409 non-TOI targets. The submitted dig list correctly identified 374 of the 409 (92%) as targets that did not need to be intrusively investigated. This is well above the objective of a non-TOI reduction of 75%.

7.10 CORRECT SPECIFICATION OF NO-DIG THRESHOLD

The receiver operating characteristics curve for the 477 classified digs intrusively investigated regardless of classification decision is shown in Figure 7.5. As indicated in the chart all of the TOI in this group of targets were correctly identified as dig targets, with only 34 non-TOI targets dug. The remaining 374 non-TOI targets were correctly classified as non-digs. Because there is little distance on the curve between the last TOI and the stop dig point in the dig list (i.e., the start of the green line), it does not appear that there is much room for improvement in the location of the stop dig point. The no-dig threshold specified is considered appropriate for this site.

Figure 7.5
Receiver Operating Characteristics Curve for Targets Excavated Regardless of Classification Decision



7.11 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Nineteen of the 1,724 classified targets (1%) were classified as Can't Analyze due to data considered unusable by the analyst. This is above the performance objective of less than 5% classified as Can't Analyze.

7.12 CORRECT ESTIMATION OF TARGET PARAMETERS

The target parameters estimated in this case were the X, Y, and relative Z (depth) coordinates of the targets. The success criteria for this performance objective were X, Y offsets for which one standard deviation of the dataset was less than 15 cm and one standard deviation of the depth offset was less than 10 cm. Metrics were calculated for the category 1 digs (i.e., completely usable MetalMapper data), for all of the excavated targets with the exception of those classified as category 6 (uncollected re-shots), and for just the excavated targets that had been classified as non-digs. In the case of targets with more than one recovered source, only the closest to the predicted location was used for the calculation.

All three calculated standard deviations for the horizontal offsets were above the performance objective, with 30 cm for the category 1 digs, 25 cm for the dataset as a whole, and 20 cm for the excavated non-digs. For most sites, the offsets distance for the non-digs is greater than the distance for the digs due to the lack of a source at some of the dynamic target locations. At HWAD, there were very few targets for which the complete lack of a source was the reason for the non-dig classification. In this case, the non-digs were classified as such because they were

relatively small, both in physical size and geophysical signature, compared to the TOI at the site. Predicted locations for the non-TOI were more accurate than those for the TOI because the centers of the non-dig sources were relatively close to the tips and tails. The TOI at HWAD were quite large, particularly entire 5-in. rockets, which were on the order of 2 m long. There were also a large number of demolition pits excavated during the intrusive investigation. The assumption for TOI with large offsets between the predicted and measured locations is that the predicted location was based on MetalMapper data that inverted on the end of a large rocket/warhead/demolition pit, while the measured location was collected in the middle of that object. While the measured offset for the dig targets was greater than the performance objective, it is not expected that the increased offset would lead to missed TOI on future projects.

The calculated depth offsets were similar to those for the horizontal offsets, with decreasing standard deviations from the category 1 digs (standard deviation of 17.5 cm) to the dataset as a whole (standard deviation of 14.9 cm) to just the non-digs (standard deviation of 12.6 cm). The decrease is assumed to be due to the size differences between smaller non-TOI and larger TOI described above. Again, it is not expected that failure of the performance objective would lead to missed TOI at the site. For future work at HWAD, it is advised that the tip and tail locations of large ordnance be recorded in addition to the center of the object for comparison with the predicted locations.

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

Table 8.1
Details of Costs Tracked

Cost Element	Data Tracked During Demonstration	Estimated Costs
Seeding/EM61 Survey Costs		
Seed emplacement/initial set up	Costs for surface sweep, seed emplacement, surveying seeds	$26,000
MetalMapper Survey Costs		
Survey costs	Dynamic detection survey (9 acres): Field-related labor (two geophysicists and one UXO Tech III), equipment setup, test pit and IVS data collection, preprocessing, initial target selections, non-equipment direct costs (per diem, hotel, truck rental tractor, GPS, MetalMapper, shipping, fuel, etc.)	$78,500 $8,722/acre
Survey costs	Cued classification survey (1,800 targets): Field-related labor (two geophysicists and one UXO Tech III), equipment setup, cued data collection, preprocessing, initial target inversion for QC checks, non-equipment direct costs (per diem, hotel, truck rental, fuel, etc.).	$39,700 $22/target
	Instrument rental costs: MetalMapper, tractor, GPS, etc.	$18,608 $11/target
	All processing and analysis performed following the completion of field activities	$5,375 $3/target
	Total cued reacquisition costs	**$36/target**
Intrusive Costs		
Investigations	All costs related to the intrusive investigation	$116,111
	Cost per anomaly to intrusively investigate	$182/target

9.0 IMPLEMENTATION ISSUES

There were a few notable implementation issues for the HWAD project, all related to the mechanism used to transport the MetalMapper:

- Parsons originally tried to mount the sled to the front of a tractor, using a John Deere skid steer adapter in place of the typical bucket. The tractor lifted the sled without trouble, but the weight balance was such that the tractor tipped sideways when the operator attempted to turn. Because it was clear that trying to maneuver the tractor across the sand dunes at the site was a safety hazard, the team lost about a day and a half of survey time while an alternate vehicle was identified and the sled was moved from the tractor to the replacement tracked skid steer. The skid steer proved to be ideal for the site.
- The sled itself also led to some lost time. The pillow blocks that formed the hinge between the basket that held the batteries and the sled arm broke, along with two of the bolts holding the mounting plate for the pillow blocks to the sled arm, on one of the first days of dynamic collection. It is suspected that the blocks broke after the bolts and that much of the wear on the bolts came on previous projects, particularly Waikoloa in Hawaii, where terrain conditions were much worse than at HWAD. Much of the sled needed to be disassembled to replace the broken parts. The two bases on the bucket that held the sensor also wore down considerably during the project, to the point that the dynamic survey had to be stopped before completion for fear that the sensor would fall out. Finally, the arm on the basket that is essentially responsible for holding the bucket upright tore the welds holding it up, which put an end to the cued data collection. The sled has since been returned to the manufacturer, which is making modifications to reinforce points that failed over the course of the prototype's life.

10.0 REFERENCES

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TechLaw, 2003. *Final U.S. Army Closed, Transferring and Transferred Range/Site Inventory for Hawthorne AD, NV*. March.

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