DEMONSTRATION REPORT

Perform MetalMapper Classification Treatability Investigations as Part of Remedial Investigation/Feasibility Studies
LIVE SITE DEMONSTRATIONS
Pueblo Chemical Depot

ESTCP Project MR-201232

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14. ABSTRACT
This report describes in detail the procedures, methods, and resources Parsons used to complete an Environmental Security Technology Certification Program (ESTCP)-funded demonstration of classification technologies for munitions response at the Pueblo Chemical Depot (PCD) Solid Waste Management Unit (SWMU) 7 under ESTCP project munitions response (MR)-201232.

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Draft Report

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Acronyms

β1, β2, β3	polarizabilities along principal axes of target
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
HD	high density
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
m^2	square meter
mm	millimeter
MD	munitions debris
MEC	munitions and explosives of concern
MPV	man-portable vector machine
MR	munitions response
mV/A	millivolt per ampere
N	repeat factor
NRL	Naval Research Laboratory
PCD	Pueblo Chemical Depot
QA	quality assurance
QC	quality control
RTK	real-time kinematic
SERDP	Strategic Environmental Research and Development Program
SWMU	Solid Waste Management Unit
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 demonstration of classification technologies for munitions response at the Pueblo Chemical Depot (PCD) Solid Waste Management Unit (SWMU) 7 under ESTCP project munitions response (MR)-201232. The 2015 demonstration at PCD 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 demonstration to identify targets that will be excavated as part of a subsequent investigation at the site.

Parsons had two separate teams working on the project. One team was responsible for site setup, the placement of 40 seed items for use in measuring the capabilities of the MetalMapper advanced EMI sensor tested during the project; the second team was responsible for the collection of dynamic MetalMapper data over approximately 5.4 acres and the cued survey of 1,164 targets identified in the dynamic data. The MetalMapper field collection effort took place over 3 weeks with average production rates of 0.8 acre per day for the dynamic survey and 232 targets/day for the cued survey.

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. Target locations for the cued survey were selected from the dynamic data set. An attempt was made to select targets using a dipole filter analysis method that used data from 21 receiver orientations, but the size of the smallest target of interest, a fuze booster, and extremely high anomaly densities across the site limited the effectiveness of this method. Dynamic targets were selected using only the data from the receiver Z (parallel to ground surface) loops.

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. For QC purposes, the ranked dig list was compared to the seeds over which cued data were collected.

Twenty-eight of the 1,165 targets collected were unclassified in the ranked dig list because they required re-shots that could not be collected due to time and budget constraints. Therefore, the effectiveness of the MetalMapper in separating targets of interest (TOI) from clutter in this area was determined using 1,137 targets. Because an intrusive investigation was not part of this project, seeded test items were the only known TOI at the site. Ten seeds were covered by the cued survey. Removal of the 10 correct classifications from the "dig" targets and the 10 seeds from the total number of targets survey left 55 targets classified as digs (TOI or inconclusive) out of a total of 1,127 targets. This represents a 95.2% reduction in clutter digs even if all 55 remaining digs are false positives. The actual nature of these targets will be determined during the intrusive investigation at the site, which has not yet been scheduled.

1.0 INTRODUCTION

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 Solid Waste Management Unit (SWMU) 7 at the Pueblo Chemical Depot (PCD).

This project was performed as a demonstration of classification technologies for munitions response funded by the Environmental Security Technology Certification Program (ESTCP) under Munitions Response (MR) Project 201232. This demonstration was designed to evaluate classification methodology at a site that is known to contain subsurface MEC from open burn operations performed between 1953 and 1990, primarily for the destruction of mortars, projectiles, and rockets. An earlier “mag and dig” clearance performed in 1997 removed approximately 15,500 pounds of munitions debris (MD) and non-MD scrap from the site, including 18 MEC items. This clearance was performed to a depth of 1 foot (ft.) below ground surface, and full quality assurance/quality control (QA/QC) checks were performed for only 14 of the 72 200-ft. by 200-ft. grids cleared. The site was selected for the ESTCP program for the following reasons:

- The former use of the site as an open burn area rather than a firing range as has been typical on previous demonstration projects
- The unknown extent of MEC contamination at the site with regard to the anomaly density remaining following the 1-ft. clearance and with regard to the success of the earlier clearance because QA and/or QC checks were not performed on many of the grids.

The results of the demonstration will also be available if/when an advanced classification remedial alternative is evaluated in a subsequent Corrective Measures Study Work Plan.

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 2015, 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 Black Tusk Geophysics' man-portable vector machine (MPV). All of the EMI sensors tested to date have been 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 un-dug 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.

Past ESTCP demonstration sites have focused on former firing ranges, while SWMU 7 was a former open burn ground. It was expected that both the pattern of anomaly distribution and the types of deformation found in native MEC and MD items would be different at this site than at past sites. The general objective of the project was to determine if the use of advanced EMI sensors (i.e., MetalMapper) would achieve the same results at an open burn ground as those proven to be achievable at most firing ranges. Specific performance objectives were developed to test the MetalMapper. In addition to the detection and correct classification of TOI, these include maximizing the percentage of non-TOI items correctly classified, identifying the types of TOI prior to intrusive investigation, identifying the general type of non-TOI (e.g., fragment, horseshoe, rebar) prior to intrusive investigation, minimizing the number of targets classified as "inconclusive", and estimating target parameters such as location and depth correctly.

The second objective of the demonstration was to evaluate the use of classification technology for MEC site characterization at sites similar to SWMU 7. The classification results will initially be evaluated to characterize the nature and extent of contamination at the site with limited or no intrusive data. A separate project is expected to include intrusive investigation of some of the classified anomalies.

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 funding that will be available for future remedial actions.

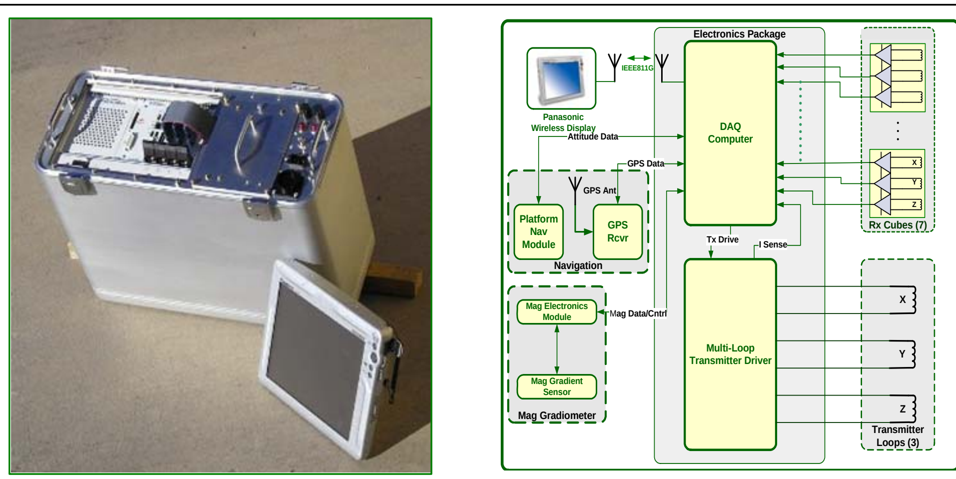
2.0 TECHNOLOGY

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) as can the transmit loops that are driven. The seven receiver antennas allow 21 independent measurements of the transient secondary magnetic field for each transmit loop that is driven.

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 as a tractor. The instrumentation package also includes two external modules that provide real-time kinematic (RTK) global positioning system location (GPS) 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



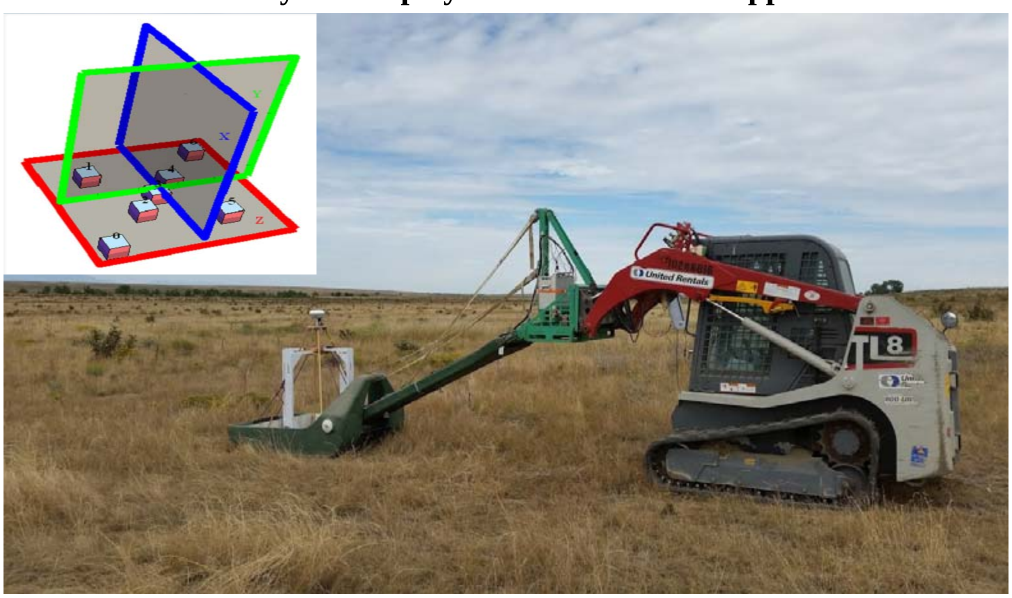
A) MM DAQ assembly with Panasonic terminal.

B) Function block diagram of MM system

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 PCD



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 2x2 and the MPV. The TEMTADS 2x2 consists of four pairs of transmit/tri-axial receive coils oriented in a 2x2 grid pattern, approximately 1 meter (m) to a side. The MPV is composed of a single circular Z-direction transmitter with five tri-axial receivers mounted in a cross pattern within the transmitter housing. This configuration is typically used for dynamic data collection, while two additional square transmitters, oriented orthogonally to the Z-loop, can be added for cued data collection. 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 fairly limited in their availability. Although vehicle transport is not out of the question for either of the other two sensors, a great deal of thought and development has gone into making the MetalMapper the most vehicle friendly of the three sensors. As a result, production rates are typically higher for the MetalMapper, particularly for cued data collection.

While the MetalMapper is the most amenable to vehicle-based operation, 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 vehicle-based transport and, therefore, use in relatively flat, open fields. It is the least effective of the three sensors in wooded areas.

3.0 PERFORMANCE OBJECTIVES

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 Selected location within 25 centimeters (cm) of known location
Spatial coverage	Extended footprint coverage	Mapped survey data	95% 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 98% < 15 cm[1]
Detection of all targets of interest	Percent of seeded anomalies detected	Locations of seed items Dynamic target list	Dynamic target selected within 40 cm of all seed items
Cued Data Collection Objectives			
Correctly identify seed items in IVS	Percentage of IVS items identified correctly	Twice-daily IVS survey data	100% of the IVS items identified correctly with confidence metric of >0.90
Correctly position MetalMapper relative to source	Distance between collection location and inverted target location	Location of MetalMapper during collection Inverted target location	100% of inverted locations within 40 cm of collection point unless re-shot also outside radius[2]
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 dynamic target location[3]

Table 3.1 (cont)
Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Analysis Objectives			
Maximize targets of interest (TOI) retained on dig list	Percentage of TOI retained.	Prioritized anomaly list Blind seed list[4]	100% of the TOI identified as dig targets
Minimize non-TOI retained on dig list	Percentage of false alarms eliminated.	Prioritized anomaly list Blind seed list[4]	75% of non-TOI left in ground
Correctly identify type of TOI	Percentage of TOI correctly identified by group[5]	Prioritized anomaly list Blind seed list[4]	75% of TOI identified correctly
Correctly predict attributes of non-TOI	Percentage of non-TOI for which at least one attribute is correctly predicted[5]	Analyst justification for non-TOI classification for 50 validation target	100% of predicted non-TOI qualitatively matches justification
Correct estimation of target location	Accuracy of estimated target parameters dig list targets marked as "dig".	Demonstrator target parameters Intrusive results	X, Y < 30 cm (1σ) Z < 15 cm (1σ)

1 98% < 15 cm is intended to account for rapid movement of the GPS due to sled movement over varying terrain over a few points. Any length of data with more than 1 m of point-to-point spacings consistently over 15 cm will be re-collected even if the data set as a whole passes this metric.

2 In addition to targets with both initial and re-shot inverted locations greater than 40 cm from the collection point, targets collected specifically to be within 40 cm of a pick location will not negatively affect this objective if inverted locations are greater than 40 cm from the collection point; targets with dynamic anomaly size of < 0.20 m^2 will not be re-collected.

3 Points with no identified problems (e.g., inversion offset, noise) and no other targets within 1.5 m of the target in question will not be re-collected; targets with dynamic anomaly size of < 0.20 m^2 will not be re-collected.

4 Typically the prioritized anomaly list would be compared to the intrusive results for a demonstration site. The schedule for the intrusive investigation is unknown, so the seed items placed during the project will serve as the basis of comparison for this report.

5 Expected TOI groups will include small (fuze boosters, small ISOs), medium (75-mm projectiles, 60- and 81-mm mortars, 2.36-inch and 2.75-inch rockets, and medium ISOs), medium/large (3.5-inch rockets), and large (projectiles larger than 75-mm and large ISOs).

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 and the distance between the selected target and the known location for each seed item.

3.1.2 Data Requirements

The responses measured over each seed item during twice-daily IVS testing were compared to the expected response, and the X, Y location of the response was compared to the known location of each seed.

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 the expected value and if the selected location were within 25 centimeters (cm) of the known location.

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 cm to the side of the MetalMapper.

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 transect 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 95% 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 the sensor moving too quickly over the survey area. 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

To be correctly classified, all TOI must be selected as targets in the dynamic survey. 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 seeded 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 the RTK 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 40 cm of the measured seed location.

3.5 CORRECTLY IDENTIFY SEED ITEMS IN THE INSTRUMENT VERIFICATION STRIP

The IVS strip constructed at PCD contained three 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 $\beta1 : \beta2 : \beta3$ ratios of 1 : 1 : 1, where $\beta1$, $\beta2$, $\beta3$ are the polarizabilities along principle axes of the target.

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 0.90 or higher.

3.6 CORRECTLY POSITION METALMAPPER 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 each cued data point.

3.6.3 Success Criteria

The performance objective was for all targets to have modeled source locations within 40 cm of the center of the 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). Additionally, following the completion of dynamic data collection, it became apparent that the areal extent of the seed items covered by the survey was much larger than the areal extent of many of the anomalies detected at the 5 times background threshold used for target selection. A 0.2-square-meter ($m^{2)}$ anomaly size threshold was applied to the selected dynamic targets after cued data collection had already started on Transect 3 targets. Offset metrics were not applied to already-collected targets with areal extents less than 0.2 m^2 as they were considered too small to be TOI.

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[8] and Y_Array[8] 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. 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). As discussed in Section 3.6.3, offset metrics were not applied to dynamic anomalies with sizes less than 0.2 m^2 because they were considered too small to be TOI.

3.8 MAXIMIZE TARGETS OF INTEREST RETAINED ON THE DIG LIST

One of the two main objectives of this project was to show that classification could correctly identify all seeded items, native UXO, and intact munitions items (with or without explosive hazard) remaining at the site as targets.

3.8.1 Metric

The metric for this objective was the percentage of seed items correctly identified as objects that should be dug in the final ranked dig list. The comparison of the ranked dig list to all TOI recovered at the site will be performed after an intrusive investigation is performed at the site, but the current schedule for that investigation is unknown.

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 three categories: 1) TOI 2) Non-TOI, or 3) Inconclusive. The targets classified as either TOI or Inconclusive were considered “dig” targets. The list of seed items was compared to those targets marked “dig” in the ranked dig list. Typically, training targets are identified for excavation prior to finalizing the ranked dig list; however, none were identified as necessary for this project. As discussed above, the final list of all TOI recovered during the intrusive investigation is necessary for a complete assessment of classification performance. A comparison of the ranked dig list to the final TOI list will be performed following the completion of the intrusive investigation.

3.8.3 Success Criteria

The performance objective was the correct identification of all 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 Inconclusive for this objective. Each TOI simply needed to be indicated as a target that should be investigated. Further analysis will be performed for all TOI recovered during the intrusive investigation depending on when it takes place.

3.9 MINIMIZE NON-TARGETS OF INTEREST ON THE DIG LIST

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 either a dig or no-dig designation to each target. The targets classified as non-TOI were considered "no dig" or non-TOI targets. The list of items identified as non-TOI on the ranked dig list was compared to the blind seed list. As long as no blind seeds were identified as non-TOI, the non-TOI designation was considered correct. As discussed in Section 3.8, the final list of all TOI (including blind seed items) recovered during the intrusive investigation will be compared to the ranked dig list upon completion of the intrusive investigation.

3.9.3 Success Criteria

The performance objective was considered met if none of the seed items were classified as non-TOI, and more than 75% of targets collected were classified as non-TOI.

3.10 CORRECTLY IDENTIFY TYPE OF TARGET OF INTEREST

In addition to correctly identifying each TOI as a target that needs to be intrusively investigated, there is value in correctly specifying what the source is before the intrusive efforts commence. Knowing the type of ordnance potentially being excavated can have an effect on the distances used for required road closures during excavation. Correctly predicting sources also provides confidence that the classification process is working as intended.

3.10.1 Metric

The metric for this objective was the percentage of TOI items that are assigned to the correct group in the dig list. The groups are described below.

3.10.2 Data Requirements

Those targets identified as a dig target on the submitted dig list were labeled as a either small, medium, or large item. The small group covered fuze boosters and small ISOs; the medium group covered 75-millimeter (mm) projectiles, 60-mm and 81-mm mortars, 2.36-inch (in.) and 2.75-in. rockets, and medium ISOs; the large group covered any projectiles larger than 75 mm and large ISOs. 3.5-in. rockets, which are approximately 90 mm in diameter, were placed into a medium/large group given their size relative to the largest item typically considered medium in size (81 mm mortar) and the smallest item typically considered large in size (105 mm projectile). Identifications were assigned based on the degree of match to the munition or simulant examples in the classification library (Section 6.3).

3.10.3 Success Criteria

The performance objective was considered met if more than 75% of the TOI items were placed into the correct group.

3.11 CORRECTLY PREDICT ATTRIBUTES OF NON-TARGETS OF INTEREST

While the classification of non-TOI does not generally affect intrusive investigation operations, meeting the success criteria for the correct prediction of non-TOI attributes can play an important role in convincing stakeholders of the basis and justification for not intrusively investigating non-TOI items, and it addresses the potential concern of false negative results.

3.11.1 Metric

The metric for this objective was the percentage of non-TOI for which at least one attribute was correctly predicted by the data analyst.

3.11.2 Data Requirements

Rather than predicting size and shapes for all of the targets classified as non-TOI, the QC Geophysicist randomly selected 50 targets classified as non-TOI on the final ranked dig list. The data analyst gave brief explanation as to why each of those targets was classified as a non-TOI. Reasonable explanations included descriptions of target characteristics such as response (too small to be TOI), apparent shape (non-symmetric or plate-like rather than apparently cylindrical), decay (rapid decay indicates item walls too thin to be TOI), or a combination of these descriptions. Other reasonable explanations were accepted as long as they predicted an attribute of the source that could be qualitatively judged by the QC Geophysicist based on the photo of the source taken during the intrusive investigation.

3.11.3 Success Criteria

The project objective was considered met if 100% of the non-TOI recovered qualitatively matched the data analyst’s predictions. Because this performance objective is entirely dependent on photos of non-TOI taken during the intrusive investigation, there is currently no way to determine success or failure. The analyst has provided justification for the 50 non-TOI anomalies selected by the QC Geophysicist, but this objective cannot be measured effectively until after the intrusive investigation.

3.12 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.

3.12.1 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.

3.12.2 Data Requirements

The dig list submitted to the intrusive team contained X, Y, and Z locations for each target as determined during inversion of that target. These were compared to the locations of the blind seed items as measured during burial. Offsets were calculated between the predicted and known locations of the seed items. As for all other classification objectives a full analysis of predicted versus actual locations for excavated targets will be performed following the intrusive investigation.

3.12.3 Success Criteria

The project objective was considered met if one standard deviation (σ) of the distance between the estimated X, Y locations and the known seeds locations were within 30 cm and the estimated depths were within 15 cm.

4.0 SITE DESCRIPTION

4.1 SITE DESCRIPTION

The PCD is located in Pueblo County, Colorado, approximately 15 miles east of the city of Pueblo. SWMU 7 encompasses 66 acres of land in the northwest corner of the PCD. The demonstration will be conducted across 8-m wide transects spaced evenly across the SWMU. The location of the demonstration area and the transect locations are shown on 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 https://www.serdp-estcp.org/Program-Areas/Munitions-Response/Land/Live-Site-Demonstrations. This site was selected for the program because of its former use as an open burn area as opposed to a firing range and available funding for the intrusive effort as part of the Corrective Measures Study Work Plan development.

4.3 BRIEF SITE HISTORY

The land for the PCD was acquired in 1941 and 1942, at which time it was referred to as the Pueblo Ordnance Depot. It was administered by the U.S. Army Ordnance Corps and mainly used for ordnance storage. The maintenance and repair of combat materials was added to the depot's mission in the mid-1940s as equipment returned from overseas at the end of World War II, and the secure storage of chemical weapons began in the 1950s when chemical agents and munitions were transferred to the depot from Rocky Mountain Arsenal in Denver. Through various realignments, the depot has been referred to as the Pueblo Army Depot, Pueblo Depot Activity, and the Pueblo Chemical Depot. The current mission continues to the secure storage of chemical weapons as a plant designed to destroy the stored munitions is constructed on site.

Between 1953 and 1990, SWMU 7 was used for the open burning of munitions, generally in burn trays, although materials were also burned in trenches in the area. Ash and residue from burning operations were reportedly piled in the southeast corner of the burn area. The former location of the Pyrotechnic Burning Cage, used for burning small munitions, rocket motor igniters, and fireworks and designated as SWMU 10, is also completely within the SWMU 7 boundary. SWMU 10 will be remediated and closed as part of SWMU 7 through the Resource Conservation and Recovery Act process.

A munitions removal project was performed in SWMU 7 in 1997. Activities consisted of performing a "mag and flag" clearance operation on 72 200-ft. by 200-ft. grids (66 acres) to a depth of 1 foot. Activities covered the entire open burn area, including a buffer kick-out area. Of the 22,385 anomalies intrusively investigated, 18 live MEC items were recovered along with 15,592 pounds of MD and non-MD scrap. Recovered MEC included projectiles, rocket warheads and motors, mortars, boosters, and a small piece of high explosives. QA/QC verification procedures were only performed on 14 of the 72 grids cleared. The remaining 58 grids were not completed but had various amounts of work completed. Field notes from the project suggest that heavy equipment may be needed to complete the work.

4.4 MUNITIONS CONTAMINATION

The suspected munitions in the SWMU 7 include:

- Fuze boosters
- 75-mm and larger projectiles
- 2.36-in., 2.75-in., and 3.5-in. rockets
- 60-mm and 81-mm mortars

4.5 SITE GEODETIC CONTROL INFORMATION

Two first-order location control points were installed by a professional surveyor licensed in the State of Colorado. One was used for placement of the GPS base station, and the other was used for QC checks. The coordinates for the locations of the 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	4242851.171	554552.675	1401.214
ESTCP2	4242858.571	554531.008	1400.956

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.

Figure 4.1 Proposed Demonstration Area

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 PCD, the MetalMapper was used for both dynamic and cued data collection. An attempt was made to use a dipole filter to identify dynamic anomalies and screen out those too small to be TOI. However, the extremely small size of one of the TOI known to have been found at SWMU 7, the fuze booster, and extremely high anomaly densities at the site limited the effectiveness of this method. Therefore, dynamic targets were selected using response amplitude in much the same way 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 using routines in the UX-Analyze software package to extract target parameters. These parameters were passed to a classification routine 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. Because the intrusive investigation of the site is not part of this project, all performance objective assessment in this report was completed using the blind seeds as the only known TOI.

5.2 SITE PREPARATION

5.2.1 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.

5.2.2 Surface Clearance

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

5.2.3 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. Additionally, for this project, the schedule for the intrusive investigation at the site is currently unknown, and no native TOI information will be available until that is complete. Therefore, the site was seeded with enough TOI to ensure reasonable statistics and to determine, to some extent, the effectiveness of the project prior to the intrusive investigation.

Parsons conducted seeding operations at PCD on August 19, 2015 and 20, 2015. Industry standard objects (ISOs) and inert munitions were buried throughout the survey area prior to the dynamic survey. 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 13N, WGS84 coordinates.

Parsons seeded 40 items and practiced anomaly avoidance at each location for safety and to ensure a clean area for emplacement. All 40 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
PCD Demonstration Seed Items

Seed item	Total
Small ISO	24
Medium ISO	4
Large ISO	2
Fuze booster	2
60-mm mortar	2
81-mm mortar	2
2.36-in. rocket	2
105-mm projectile	2
Total	**40**

5.2.4 Establish an Instrument Verification Strip

A relatively anomaly-free area was identified adjacent to the storage connex just to the southeast of SWMU 7 for use as the IVS. The strip used for the IVS was roughly 15 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
IVS-1	Small ISO	15	Horizontal
IVS-2	Medium ISO	25	Horizontal
IVS-2	Large ISO	50	Horizontal
IVS-4	Background location		N/A

5.3 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. During the demonstration, the sensor was 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 10 Hz. The two instruments were connected to the DAQ via USB (universal serial bus) ports. Incoming GPS data were used to navigate along predefined survey lines for the dynamic survey or from point to point in the cued 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 Instrument Verification Strip Data Collection

Data was 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 Pueblo 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 for the first five passes over the IVS. All IVS responses were determined using the average of the responses measured by the five middle receivers of the MetalMapper.

- 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 (≥ 0.90 for the β1:β2:β3 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 Function Tests

Although not specified in the demonstration plan, the use of function tests was evaluated during the project. These involved the collection of a background point followed by the collection of a point with ISOs placed in consistent locations on the Z-transmitter housing. Tests were performed using both small ISOs and medium ISOs as the test objects for different parts of the project. The results of the function tests were evaluated by subtracting the background response from the test item response, then comparing the absolute value of the maximum/minimum measured by each of the 21 receiver wrappings on or after time gate 8 with the average of the previous responses measured by each. Function tests were considered successful if the measured responses for each receiver wrapping were within 20% of the average response.

5.4.3 Background Data

MetalMapper background collection points were pre-selected based on the dynamic data. Background data were collected at one of the pre-selected locations at least once every 2 hours. Additional points were collected at intervals less than 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

As shown in Figure 4.1, nine 8-m wide transects were established at approximately 50-m intervals across SWMU 7 in order to determine relative anomaly densities throughout the site. They were identified as Transects 1 through 9, starting with the very small transect on the south end of the site with identification (ID) number increasing to the north. Dynamic MetalMapper data were collected within these transects by driving east-west along parallel lines. Although the dynamic footprint of the MetalMapper is assumed to be 70 cm (Section 3.2), it is difficult to keep the sensor exactly aligned on the intended transect because it is so far in front of the transport vehicle. Therefore, survey lines were collected at 50-cm spacings to ensure full coverage of the survey areas.

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 meter per second, 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 PCD because the site contained numerous drainage ditches 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 between targets 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. The transect locations of dynamic targets were identified in the target number by the first digit. For example, all Transect 3 targets were between 30,000 and 39,999; all Transect 4 targets were between 40,000 and 49,999, etc.

5.5.3 Scale of Demonstration

A total of 5.4 acres of dynamic data collection was performed in Transects 2, 3, 4, 5, 8, and 9. Given extremely high anomaly densities at the site, tens of thousands of anomalies were selected in the collected data. However, many of these were within areas of the site where the analyst considered anomaly densities to be too high for either the accurate identification and selection of individual targets potentially representative of TOI as small as fuze boosters or the accurate classification of collected cued targets given the small size of the fuze boosters and the abundance of subsurface sources. While targets were auto-picked using the Blakely test algorithm within these high-density areas (HD; Section 6.1), they were generally not given target IDs because target selection was not considered effective within these areas. No targets were picked in Transect 5 because the analyst felt that most of this transect would be considered an HD area. A total of 14,215 individual targets were selected and given target IDs, most of these outside of the analyst-defined HD areas, although some targets within these areas were retained at the discretion of the QC Geophysicist.

Out of the 14,215 transect targets, 1,978 were selected by the QC Geophysicist and placed on the cued target list. Based on available time and budget, a total of 1,164 cued targets were collected out of the 1,978 on the cued list.

5.5.4 Sample Density

One data point was collected per target, as described in Section 5.5. Based on available time and budget, re-shots were not collected for cued targets that exceeded either collected location to modeled location (Section 3.6) or dynamic target location to collection location (Section 3.7) metrics. Targets exceeding these metrics for which re-shots typically would have been performed were given their own category on the final dig sheet to reflect their status as collected but requiring uncollected re-shots (Section 6.2)

5.5.5 Data Quality Checks

IVS data collection and function tests were conducted 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.

Checks on the quality of both dynamic and static data were performed during processing using the UX-Detect and UX-Analyze modules in Oasis montaj. Dynamic data were checked for spatial coverage and down-line point spacing; cued data were checked for offsets between the collection location and modeled source location and the collection location and the dynamic target location. A detailed discussion of these checks is contained in Section 3.

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 DAQ 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.

6.0 DATA ANALYSIS AND PRODUCTS

The MetalMapper was used to collect dynamic data over 5.4 acres and static data over 1,164 targets identified in the dynamic survey. 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 primarily performed using the UX-Analyze module in Geosoft’s Oasis montaj. Upon import into Geosoft, all receiver data are given the same position (i.e., the position of the GPS during collection of each data point), which has not been corrected based on the IMU data. These single positions were used to calculate the survey coverage and down-line point spacing metrics. Once these QC checks were completed, the data recorded by each individual receiver were positioned according to where the receivers actually were relative to the position reported by the GPS. In addition to splitting out the data measured by individual receivers, position corrections were applied based on collected IMU data.

The dipole response filter approach was applied to a subset of the collected data in an attempt to evaluate its effectiveness in selecting targets relative to the traditional amplitude response method. This approach differs from the traditional approach in that it uses all available receive channel data to make the decision on whether a viable target exists and should be selected for cued surveying. The dipole response filter method is a two-step process that begins by identifying all possible source locations, followed by taking data about each of these locations and performing 1-, 2- & 3-dipole source model inversions. If everything is consistent, all non-overlapping identified source locations represent legitimate targets for possible selection. Unfortunately, due to the extremely small size of the fuze boosters (TOIs known to have been found at SWMU 7) and extremely high anomaly densities at the site, the desired consistency was very hard to achieve making the amplitude response method the better choice for target selection.

Because of the relatively small size of the fuze boosters suspected to be present on site, only the first time gate measured by the MetalMapper, time gate 5, was used for target selection. Time gate 5 data were exported from the Z-loop response array channel for each receiver. The exported channel was then leveled using a 100-point rolling median filter that ignored 10% of the lowest responses within the window and 40% of the highest responses within the window. The data measured by the two outer receivers, contained in the L[LineNumber].1 and L[LineNumber].7 lines in the Geosoft databases, were unselected so they would not be used during gridding. The leveled data were then gridded and displayed on the site map. A latency correction was applied, as necessary, to remove any chevron patterns evident in the dataset.

Figure 6.1 shows the site-wide results of the dynamic surveys. As shown, there are some areas, outlined in red, where the analyst felt that high anomaly density prevented the selection of individual target locations from being a viable means of completely removing any existing MEC hazard. These areas were delineated prior to target selection. No effort was made to select every peak in these areas during target selection, and very few of the auto-picked anomalies within these areas were added to the cued target list.

Figure 6.1 Site-Wide Dynamic Data Results

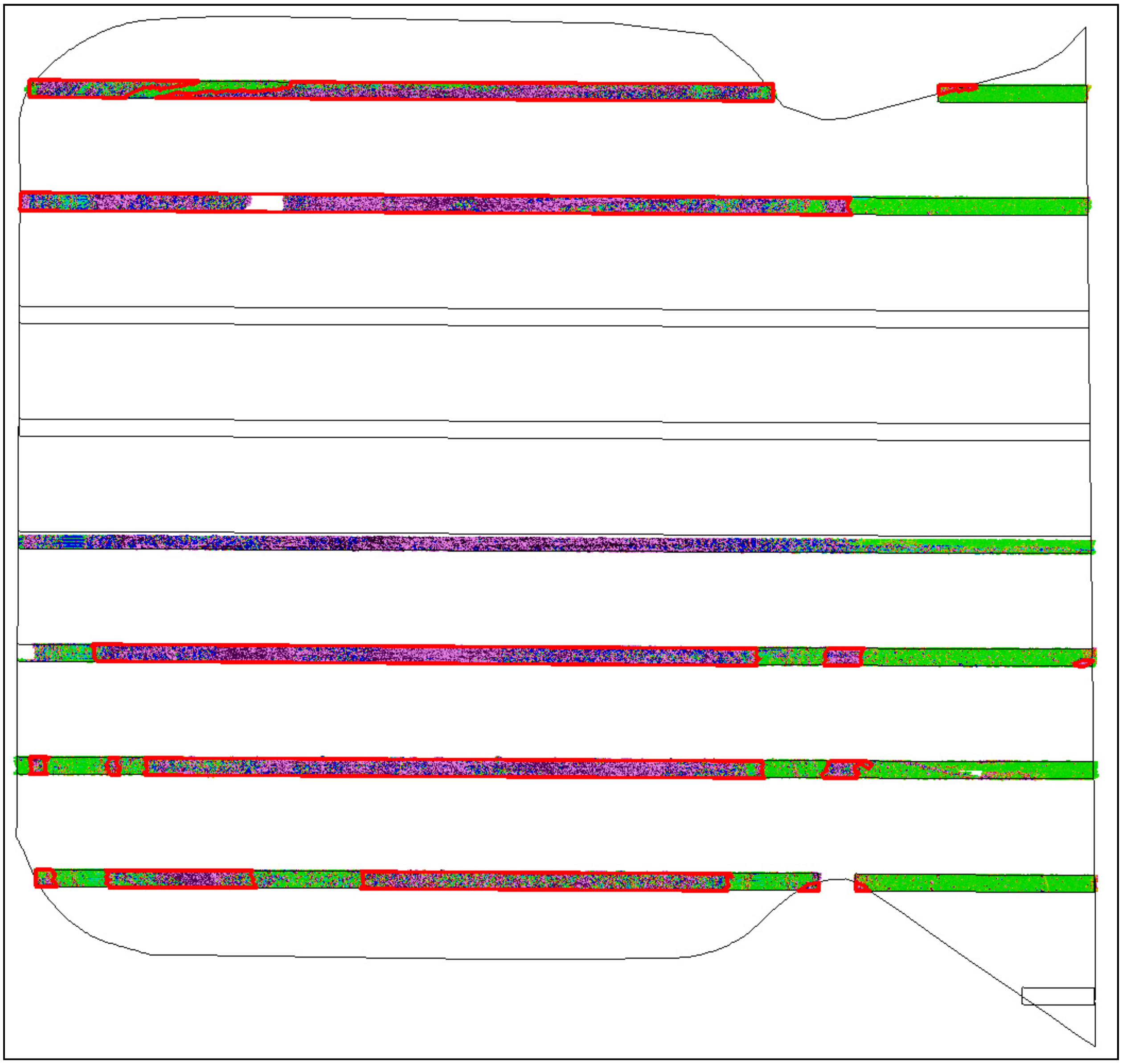


Figure 6.1 shows gridded results for leveled channel 5 data measured by Z-loop of the 5 middle receivers. Data displayed using a linear scale from -2.5 mV/A to 5.0 mV/A. Anomaly densities within the areas outlined in red were considered too high for the effective selection of individual anomalies. Most of Transect 5 was considered high density, and no targets were selected on this transect.

6.1.2 Target Selection

Targets were selected using the Blakely test algorithm in the UX-Detect package in Oasis montaj with a threshold of 1.8 millivolts per ampere (mV/A), which was 5 times the background value calculated over an anomaly-free area in the northeast corner of Transect 3 using the subwindow statistics tool in UX-Detect. Five times background was used as the target selection threshold because there is no expected penetration or detection depth for a fuze booster, which was considered the most difficult to detect TOI at the site. A signal to noise ratio of 5 is typically considered low enough to detect MEC to a reasonable depth compared to the size of the item while also limiting false positives caused by selecting targets on geophysical noise.

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 transect was finalized, a footprint size was calculated for each using the Calculate Signal Strength, SNR, and Size option in UX-Detect. For most of the transects, targets with an areal extent of less than 0.2 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 0.2 m^2 threshold was developed after cued data collection began on Transect 3 due to a large number of Transect 3 cued points for which inversion results returned either no real identifiable source (i.e., fit locations in what appeared to be background areas in the dynamic data) or an extremely small source. Given a limited number of cued points to be collected during the project, the QC Geophysicist determined that a 0.2-m^2 size threshold would limit the number of cued points collected over targets extremely unlikely to be TOI while retaining all of the seeds over which dynamic data had been collected. Because cued data collection started on Transect 3 before the threshold was implemented, there are a number of cued results for targets with areal extents less than 0.2 m^2 on that transect.

6.1.3 Results

Including auto-picked targets within the analyst-defined HD areas, tens of thousands of targets were identified in the dynamic data. For the most part, only targets outside of the HD Area were considered usable for the purposes of building a target list for subsequent cued data collection. A total of 14,215 individual targets were selected and given target IDs, most of these outside of the analyst-defined HD areas. A few of the targets with the HD areas were selected for use by the QC Geophysicist because they either were a seed item or were near a seed item. Targets surrounding seed items in HD areas were selected so the target that was the seed was not readily apparent to either the cued data collection team or the cued data analyst. The final list of targets considered potential targets for cued data collection was compared to the seed items over which dynamic data were collected. All covered seeds outside of the HD areas were successfully detected within 40 cm of the locations measured during emplacement.

Out of the 14,215 transect targets, 1,978 were placed on the cued target list. These were selected by the QC Geophysicist based on the following factors:

- Spatially representative of the entire site
- Included all seed items outside of HD area and a few within these areas
- Ease of cued collection (targets selected based on spatial proximity outside of HD areas)

In addition to the primary objective of identifying targets for the cued survey, the dynamic data were used to determine the average anomaly density for the non-HD areas of the site where targets were picked for possible inclusion in the cued survey. The anomaly density calculation included 1.03 acres of area outside of the HD areas, which contained 1,356 targets with sizes greater than 0.2 m^2. That would equate to an anomaly density of 1,316 anomalies per acre. However, retrospective analysis of the selection threshold was performed by examining the measured responses for the two fuze booster seeds and seven deep (0.25-m depth) small ISO seeds covered by the dynamic survey. The lowest response measured for any of these items was 7.5 mV/A. A new theoretical selection threshold of 6.78 mV/A was calculated by subtracting 2 times the 0.36 mV/A noise value measured at the site from the lowest response measured for the seed items. Using 6.78 mV/A as the selection threshold resulted in 994 targets, for an anomaly density of 965 anomalies per acre. A basic estimate of area not saturated with anomalies in SWMU 7 suggests that the MetalMapper could be used effectively over at least 12.5 acres of the site. Based on the use of the 6.78 mV/A threshold, this area would include approximately 12,000 targets.

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 13N 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 using the UX-Analyze batch processing mode, which included both single object solver and multiple object solver inversions. 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 β1:β2:β3 confidence metric match to an item in the classification library (Section 6.2.3).

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 and known TOIs from other sites. The items in the PCD comparison library were fuze boosters, 75-mm projectiles, 105-mm projectiles, 155-mm projectiles, 60-mm mortars, 81-mm mortars, 2.36-in. rockets. 2.75-in. rockets, 3.5-in. rockets, and separate components of those rockets (i.e., motors and warheads), as available.

An initial comparison between the measured targets and the library data was performed using a 111 confidence metric for the three primary polarizabilities (size: 1, shape 1: 1, shape 2: 1). 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 111 confidence metric generated during the initial comparison of the results to the library, three more metrics were generated for each target:

1) 110 metric - size: 1, shape 1: 1, shape 2: 0
2) 011 metric - size: 0, shape 1:1, shape 2: 1
3) 100 metric - size: 1, shape 0:1, shape 2: 0

Polarizability maps were generated for all results (single object solver and all multiple object solver results) for each target. These maps displayed the inverted polarizability curves for each source and the polarizability curves for the two closest library matches for the 111, 110, and 100 comparisons to the library.

6.2.4 Cluster Analysis

A cluster analysis was performed one the entire cued data set using the "Perform self match / identify clusters" and "Identify similar items" tools in the UX-Analyze module. This analysis was run using a 0.95 cluster threshold and required a minimum of 3 similar objects to define a cluster. A total of seven clusters were identified, one of which was clearly composed of small ISOs based on the confidence metrics for the sources in the cluster. Typically, clusters of self-similar sources would be considered as potential sources of training digs on a project. In this case, the seven non-small ISO clusters were all composed of sources smaller and more thin-walled than a fuze booster based on the sizes and decays calculated for the sources in those groups. It is possible that these are similar sources, such as rocket fins or some other small standard piece of a munition. However, because TOI smaller than a fuze booster is not expected at the site, the identified clusters are not considered indicative of an unexpected TOI and no training digs have been identified.

The comparison of the full polarizability results for each modeled source to the full results for all other modeled sources in the dataset is considered a much more comprehensive comparison than using the decay measured between two specific times within the full polarizability curve, but the dataset was also evaluated using a parameter space plot that graphed each target using a decay (time gates 8–36) versus size comparison (Figure 6.2). As indicated in the plot, there are few obvious clusters of large, relatively slowly decaying objects in the dataset. The locations of three of the non-small ISO clusters identified using UX-Analyze are shown in the bottom left hand corner of the figure; the other three are outside of the displayed range of the plot (i.e., sizes less than -1.2).

Colors were used to differentiate between targets classified as digs based on the analyst's initial review of the polarizability maps (Section 6.2.5) 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 non-symmetric or plate-like objects that happened to have decay/size characteristics similar to ordnance.

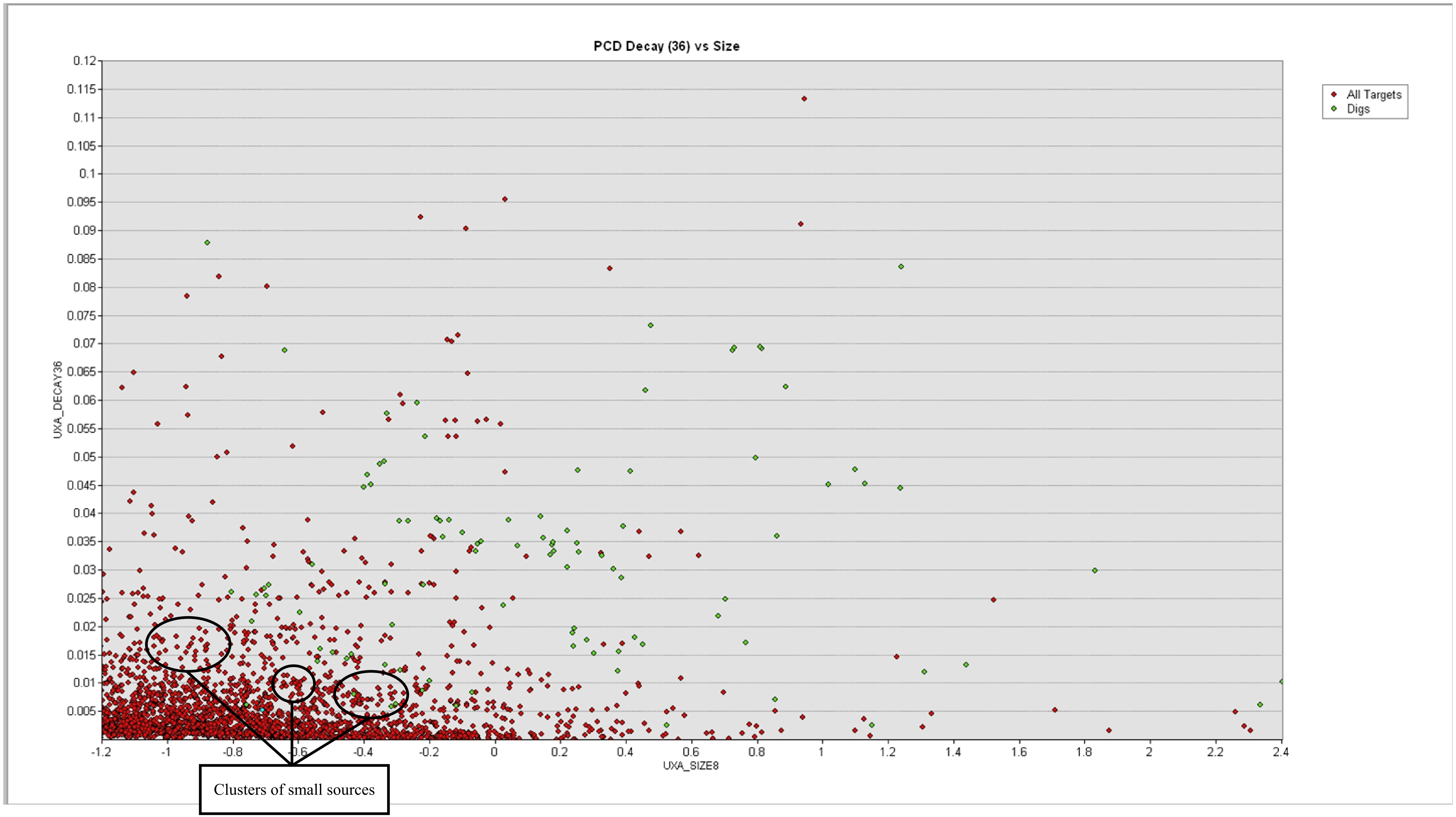
6.2.5 Classification Decisions

The first step in the classification process was a full review of the offsets between the collection point and modeled source locations and the collection point and the dynamic target location. Any targets with no sources within 40 cm of the collection point were identified as requiring a re-shot on the modeled location of the single object solver source ("RS FIT" in the UXA_COMMENTS column of the target database), and any targets without a collection point within 40 cm of the dynamic target were identified as requiring a re-shot directly over the dynamic target ("RS DYN" in the UXA_COMMENTS column of the target database). Time and budget constraints prevented the collection of any re-shots during this project, so all targets requiring re-shots could not be classified effectively. These were placed in their own category on the final ranked dig list.

Once targets requiring re-shots were identified, the analyst performed a full review of the polarizability maps created for each modeled source in the dataset. This review consisted of identifying targets that appeared to be TOI, with a "dig" note generally added to the UXA_COMMENTS column based on the decision logic shown in Table 6.1. The analyst also added notes for targets that were close to passing the metrics in Table 6.1 but were noisy due to the depth of the source or were affected by nearby sources, particularly in HD areas. Finally, the analyst also added notes for sources that should be ignored during further analysis (i.e., space plot analysis, when deciding which source would be chosen as the final representative for a target). Sources the analyst felt could safely be ignored included:

- Multiple object solver results modeling outside of the sensor, particularly if the modeled source appeared to be caused by an adjacent dynamic target
- Sources modeling at significant depth where the dynamic results do not indicate the likely existence of a large, deep source (typically an indication of background being modeled)
- Sources indicative of likely TOI for which the analyst felt another modeled source for that target was a better representation of the expected TOI, based either on TOI size or the modeled location of the source.

Figure 6.2
Parameter Space Plot (Decay 8-36) Versus Size



All "ignore" notes included a justification as to why the analyst felt that source should be excluded from further analysis. The space plot analysis described in Section 6.2.4 was performed after the initial review of the polarizability maps. Once the full initial review of all sources was complete, a single source was chosen to represent each target location. Typically this was the source with the highest 111 confidence metric, although the final decision was also influenced by the analyst's notes.

Table 6.1
Decision Logic Used for Initial Target Review

Possible TOI?	111 confidence metric	110 confidence metric	100 confidence metric	Comment
Yes	≥ 0.70	≥ 0.75	≥ 0.80	All three are true
Yes	NA	≥ 0.75	≥ 0.80	One non-β1 polarizability curve identified as potentially unusable by analyst; other two true for usable curves
Yes	NA	NA	≥ 0.80	Two non-β1 polarizability curves identified as potentially unusable by analyst; β1 curve looks like TOI
No	< 0.60	< 0.70	< 0.80	Any one of three is true for polarizability curves considered usable by analyst

Although the analyst's initial impressions regarding the likelihood that a particular source were recorded during the initial target review, most classification was performed using the "Classify and Rank" module built into UX-Analyze. This module can automate a significant amount of the processing performed for classification data, including inversion; library matching; cluster analysis; classification of all sources as TOI, non-TOI, or Inconclusive; and the selection of a single source to represent each target. All of the cued data collected during the project were run through the entire process using this module separately from the initial review performed by the analyst. There are a number of thresholds that can be set by the analyst within the module, but the most important in the classification process are the decision metric thresholds used to classify and categorize each source. The decision metric, calculated automatically, is an average of the four confidence metrics (111, 110, 011, and 100) determined during the comparison of the source to the library. The analyst used the default thresholds in the "Set thresholds and prioritize" tool within the Classify and Rank module:

- Boundary of buffer and TOI: 0.925 (category 1)
- Boundary of buffer and non-TOI: 0.825 (category 2)
- Boundary of buffer and non-TOI weak targets: 0.750 (category 2), with weak targets defined as those with a signal strength less than 20
- High confidence match to clutter: Not applicable, no comparison to known clutter

As with the earlier initial review, this analysis returned a single classification result for each target. The classify and rank results were compared to the analyst's initial review for each target to identify those targets for which the automated classification performed in UX-Analyze might have missed something noted by the analyst, including:

- Targets classified as TOI based on the analyst's assessment that one or more of the polarizability curves was poor

- Noisy data for a potentially deep target
- Source results potentially affected by other nearby sources
- Targets classified as non-digs (not necessarily non-TOI) because the source modeled for that target was the same source modeled for another target, which was common for larger dynamic anomalies with multiple dynamic targets picked within their boundaries
- Targets classified as Inconclusive based on comparison of the polarizability curves to the dynamic anomaly that were not classified as such automatically.

Classification was considered complete once the classify and rank results were rectified with the analyst's notes.

6.3 RANKED DIG LIST

All collected targets were ranked according to category and decision statistic. The categories used for the project are summarized in Table 6.2, and the decision statistics used were the average of the four confidence metrics calculated during library matching. Categories were sorted from low to high, and targets within each category were sorted by descending decision statistic. Targets classified as TOI were given a predicted size, as described in Section 3.10, based on the library object with the best 111 confidence match to the source in question. If a target was classified as TOI using data with fewer than three usable polarizability curves, the size was determined using the 110 or 100 match as applicable. A brief summary of the decisions made on the final dig list are contained in Table 6.3. Note that there are 1,165 records in the dig list for 1,164 targets. It contains two entries for target 42598. One of these is a non-TOI classification based on a cued point collected 8 cm from the dynamic target and is considered the correct classification decision for 42598; the second is based on a second cued point (location based on the dancing arrows) collected 1.37 m from the dynamic target. It was collected over a completely different dynamic anomaly in an HD area that was not included in the cued targets list compiled by the QC Geophysicist, but the result was a 0.990 decision statistic indicating a 3.5-in. rocket as the predicted source. Because of the strong match to what could be a native TOI, it was left in the dig list. The target ID was not changed because the HD area targets were generally not given target IDs.

Table 6.2
Classification Categories

Category	Dig?	Comment
0	Yes	Inconclusive
1	Yes	High probability TOI; decision statistic ≥ 0.925
2	Yes	Possible TOI based any of: 1) Signal strength ≥ 20 and decision statistic ≥ 0.825 2) Signal strength < 20 and decision statistic ≥ 0.750 3) Added based on analyst notes
3	No	Usable data not matching requirements for category 1 or 2; does not require re-shot
4	No	Requires re-shot

Table 6.3
Dig List Summary Statistics

Statistic	Project (Number / %)
Targets collected	1,165
Targets classified	1,137 / 97.5[1]
Targets labeled as digs	65 / 5.7[2]
Inconclusive	22 / 1.9[2]
Training	0 / 0[2]
Category 1	12 / 1.1[2]
Category 2	31 / 2.7[2]
Targets labeled as clutter	1,072 / 94.3[2]

[1] 28 targets identified as requiring re-shots were not re-shot due to time and budget constraints. These were placed at the end of the ranked dig list (category 4) 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

Seventeen dynamic surveys of the IVS strip were performed during the project. The results from all the first five 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 plus/minus 25%. Eleven response amplitude failures were noted during the project, with responses both higher and lower than the acceptable responses for the IVS items. Only one data location failure was identified, and it was attributed to a driving error rather than GPS failure.

IVS response amplitude failures have been noted on previous projects, particularly with the MetalMapper. Because it is so far in front of the skid steer, slight changes in the direction of the skid steer result in much more significant changes in the location of the sensor. Because there were no other identifiable problems with the sensor during data collection at PCD, the IVS response failures noted during the project have been attributed to the path of the sensor over the items not being repeatable enough to produce a consistent response rather than sensor failure.

The industry has identified this as a continuing problem and is moving towards static functions tests for QC of proper transmitter and receiver operation rather than dynamic repeatability tests. Parsons also performed function tests during the project to see if these tests were a better gauge of instrument functionality than the dynamic tests. Function test methodology is explained in Section 5.4.2. Function test results were generally more favorable than the dynamic results, although seven of these tests also failed. However, all but two of the function test failures were for receiver 4, which is the middle receiver in the MetalMapper. This was consistently the receiver farthest from the test objects. Because of the receiver 4 failures, the locations of the test objects will need to be refined for future projects, but it seems that consistent function test responses should be achievable once the ideal locations are identified.

7.2 SPATIAL COVERAGE

Spatial coverage was determined by transect and by the area covered within each transect (collection was intentionally stopped in Transect 5 due to anomaly density). Offsets were less than 70 cm for more than 99% of the area covered in all transects and less than 90 cm for more than 99.7% of the area covered in all transects.

7.3 DOWN TRACK SPACING

All datasets passed the requirements of more than 90% of the point spacings less than 10 cm from each other and 98% of the spacings less than 15 cm from each other.

7.4 DETECTION OF ALL TARGETS OF INTEREST

All seed items covered by the dynamic survey outside of the analyst designated HD areas were detected within 40 cm of the measured emplacement locations. Two seed items inside HD areas on Transect 9 did not have dynamic targets picked within 40 cm of the measured emplacement locations. These were added to the cued target list by the QC Geophysicist as targets 92807 and 92808 to test the effectiveness of cued data collection in these areas despite the two seeds having been missed in the dynamic survey.

Target 92807, an inert 81-mm mortar at 50-cm depth, was definitely missed by the Blakely test target picking algorithm, which was the only analysis performed inside the HD areas (i.e., the analyst did not review the targets picked within these areas). The anomaly, added target location and modeled source location for target 92807 are shown in Figure 7.1. It appears that nearby extremely high-amplitude anomalies caused the leveling routine to reduce the peak measured over the seed to the point that it was not automatically selected as a target.

Figure 7.1
Target 92807

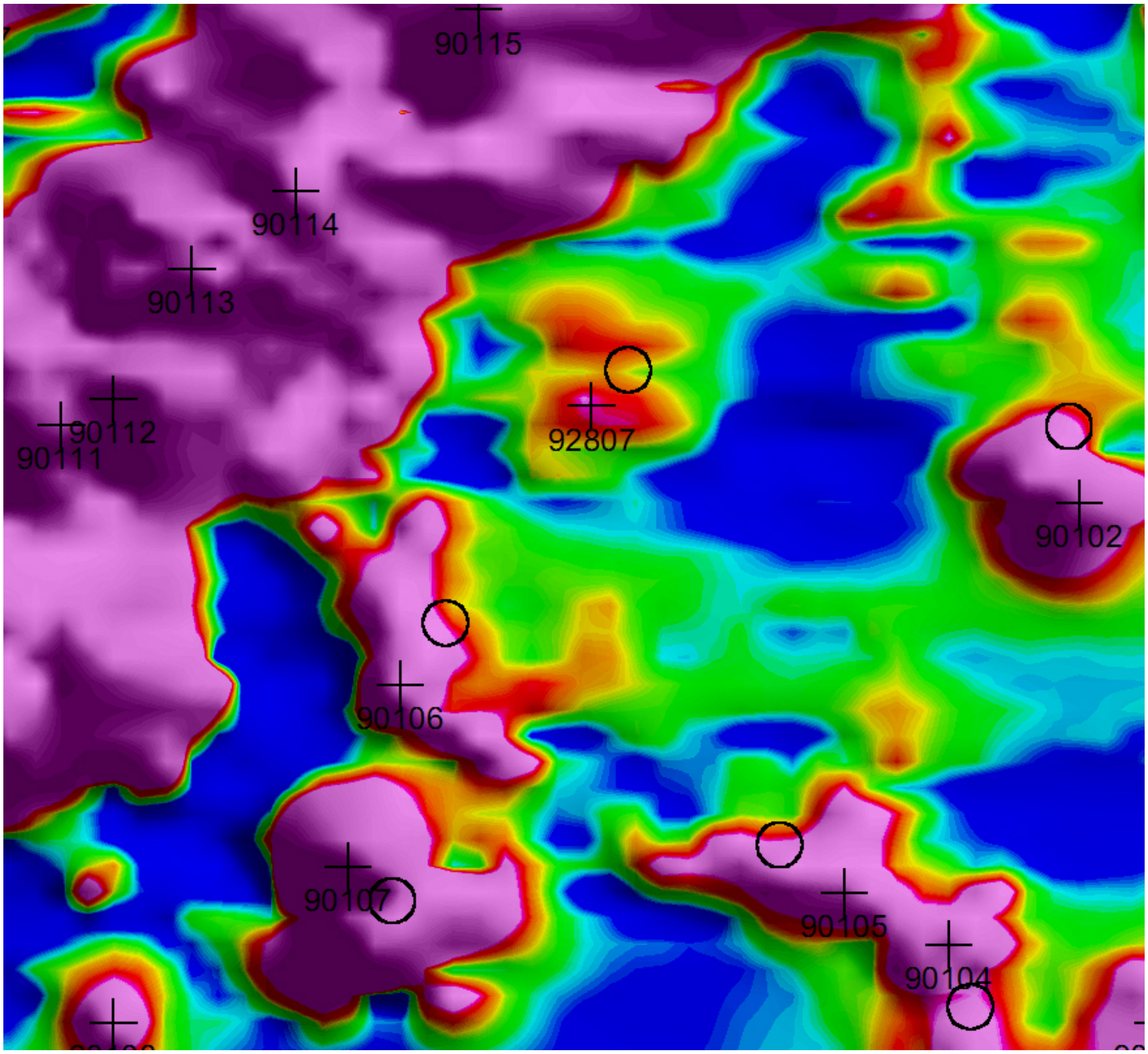


Figure 7.1 shows the location of added target 92807 (cross) and the modeled source location from the cued data (circle).

Figure 7.2
Target 92808

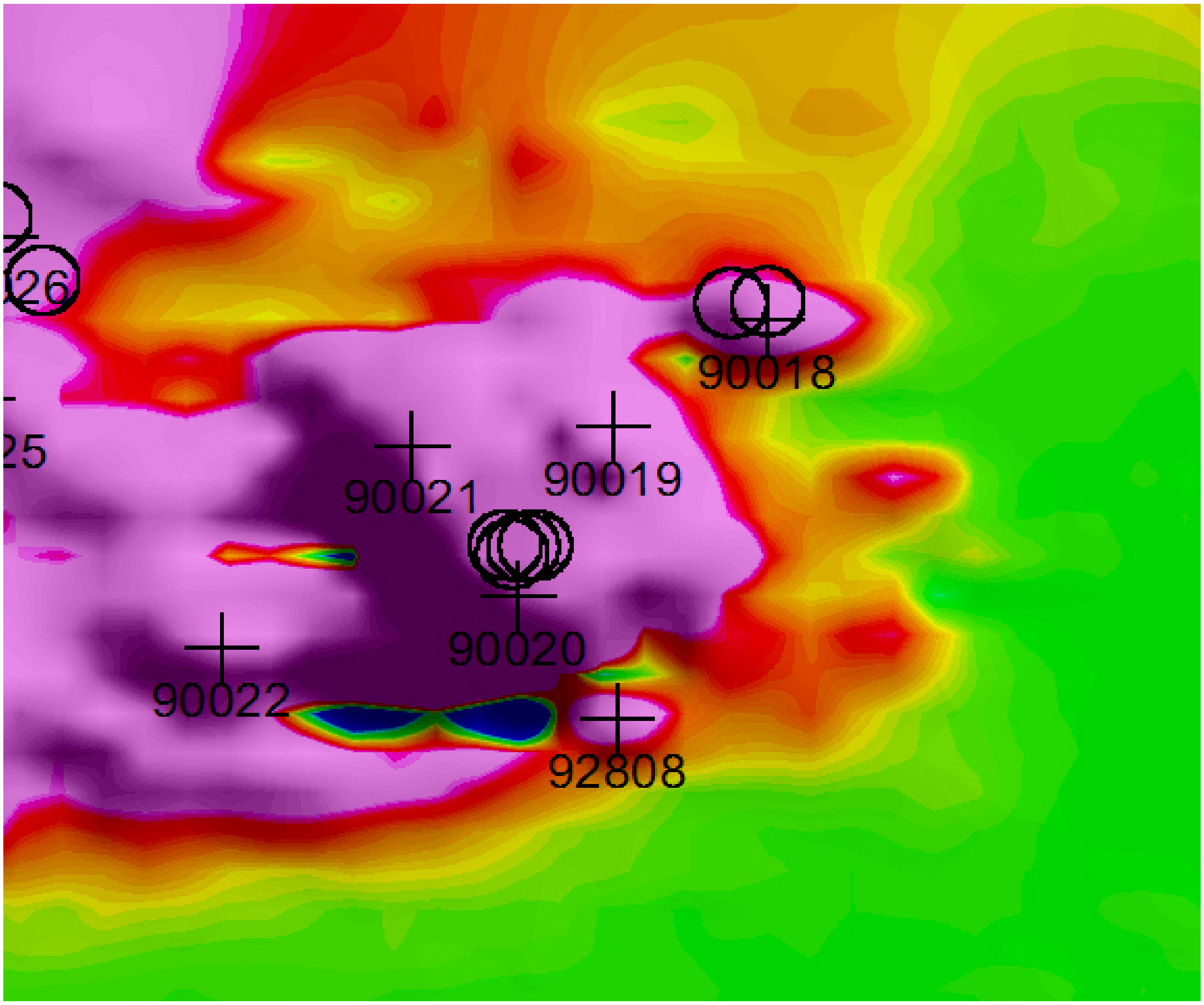


Figure 7.2 shows the location of added target 92808 (cross) and the modeled source locations (circles) of targets 90019, 90020, 90021, 90022, and 92808 from the cued data collected for those targets. Targets 90020, 90021, and 92808 all had classifications suggesting a small ISO source with decision metrics higher than 0.990.

It is less clear if Target 92808, a small ISO at 20-cm depth, was actually missed in the dynamic survey. The nearest dynamic pick prior to the addition of 92808 was 90020 (Figure 7.2), which was 53 cm from the measured emplacement location of the seed. Point 92808, which was added on the anomaly peak nearest the measured burial location, was still 15 cm northeast of the measured location. However, as shown in Figure 7.2, the cued data collected for targets 90019, 90020, 90021, 90022, and 92808 all suggest that the actual location of the seed is much closer to the selected location for target 90020. Targets 90020, 90021, and 92808 all had classifications suggesting a small ISO source with decision metrics higher than 0.990.

Because all seeds outside of HD areas had targets within 40 cm, the project is considered to have passed the objective.

7.5 CORRECTLY IDENTIFY SEED ITEMS IN THE IVS

All of the cued IVS points were identified as the correct seed item in the correct location. The lowest confidence metric recorded for the IVS points was 0.96. The largest horizontal offset was 15 cm, and the largest vertical offset was 7 cm.

7.6 CORRECTLY POSITION METALMAPPER RELATIVE TO SOURCE

Six targets required re-shots due to an offset of greater than 40 cm between the collection point and the nearest modeled source. There was insufficient time to collect re-shots before the end of the project, so these targets could not be classified. All targets with uncollected re-shots were identified as category 4 targets in the ranked dig list.

Forty-seven targets that were classified have collection point to modeled source location offsets 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 data quality objective.
- 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 data quality objective radius.
- The areal extent of the anomaly on which the dynamic target was picked was less than 0.2 m^2.

7.7 CORRECTLY POSITION METALMAPPER RELATIVE TO DYNAMIC TARGET

Twenty-two targets required re-shots due to an offset of greater than 40 cm between the collection point and the intended dynamic target. There was insufficient time to collect re-shots before the end of the project, so these targets could not be classified. All targets with uncollected re-shots were identified as category 4 targets in the ranked dig list.

Twenty-three targets that were classified have collection point to dynamic target location offsets greater than 40 cm but were judged usable by the analyst based on these possible factors:

- The areal extent of the anomaly on which the dynamic target was picked was less than 0.2 m^2.
- A second cued point was collected within 40 cm of the intended dynamic target, but the selected result more closely matched a TOI in the library.
- The operator could not get any closer to the dynamic target due to an obstacle (one occurrence, classified as a dig).

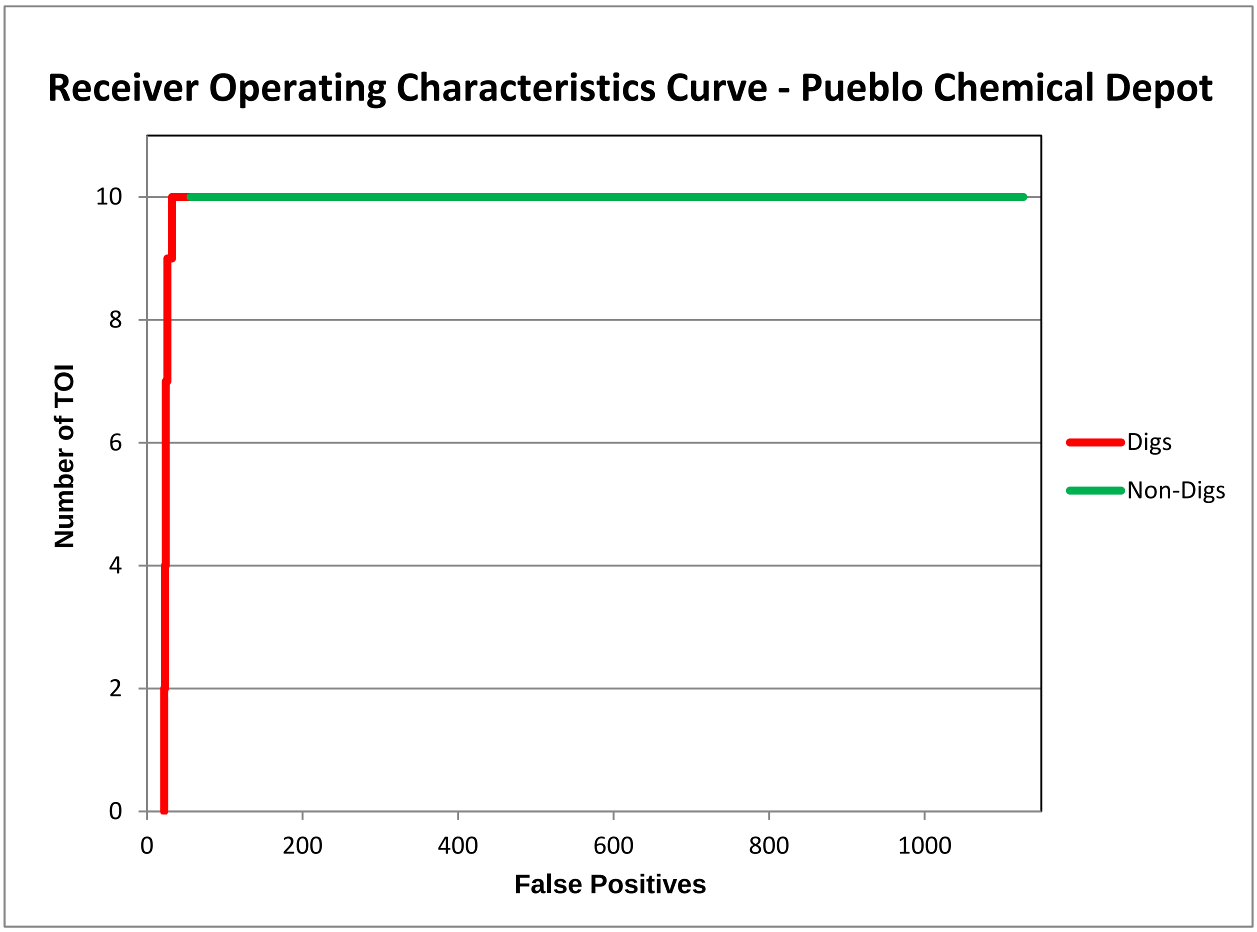
7.8 MAXIMIZE CORRECT CLASSIFICATION OF TOI

Because an intrusive investigation was not part of this project, the correct classification of TOI could only be judged according to the seed items covered by the cued survey. Cued data were collected over 10 seed items, and all were classified as TOI. Eight of the 10 were classified as category 1 digs, the other two were category 2 digs. The lowest decision statistic for any of the seeds was 0.880 for target 92807, the 81-mm mortar that required the addition of a dynamic target when it was missed in the dynamic survey.

7.9 MAXIMIZE CORRECT CLASSIFICATION OF NON-TOI

The removal of the 10 TOI from the 1,137 targets classified leaves a total of 1,127 unknown sources, with 55 of those classified as digs (22 category 0 [inconclusive] and 33 category 1 or 2). Even if all of these end up being false positives after the intrusive investigation, this represents a 95.2% reduction in clutter digs. The receiver operating characteristics curve for the project is shown in Figure 7.3. This is a preliminary curve that considers all of the unknown sources classified as digs to be false positives.

Figure 7.3
Receiver Operating Characteristics Curve



7.10 CORRECTLY IDENTIFY TYPE OF TOI

Of the 10 seeds covered by the cued survey, one was identified incorrectly. Target 40425 was a small ISO at 30 cm depth identified as a medium-sized TOI based on a best library match to an 81-mm mortar. As shown in Figure 7.4, this seed is in the middle of an area containing extremely high anomaly densities. It is expected that nearby sources contributed signal to the measured data, making the seed appear larger than it actually was. None of the various single or multiple object realizations for this target suggested a munition other than an 81-mm mortar.

Figure 7.4
Target 40425

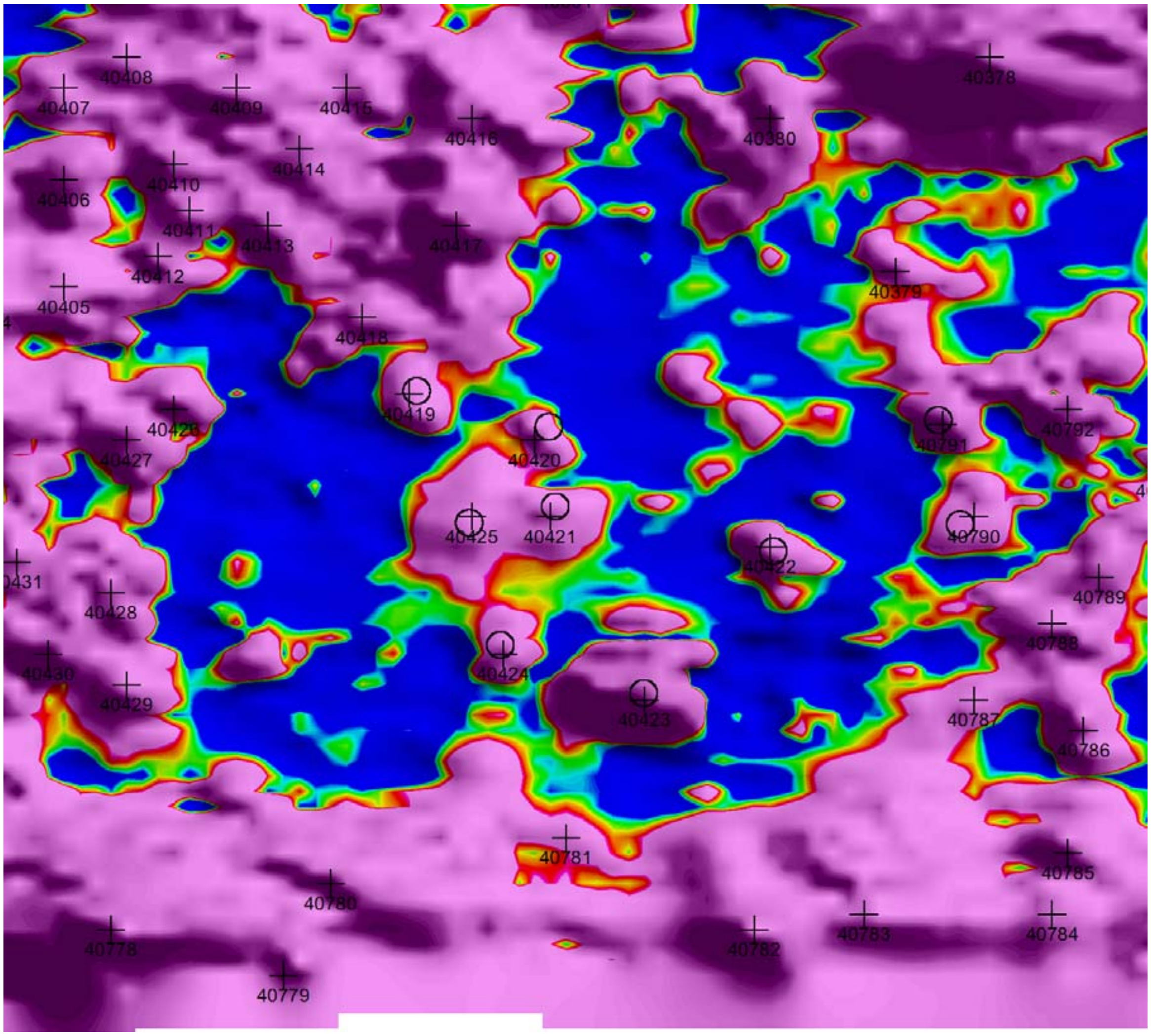


Figure 7.4 shows the location of the dynamic target (cross) and modeled source location (circle) for target 40425.

7.11 CORRECTLY PREDICT ATTRIBUTES OF NON-TOI

Attributes were predicted for 50 non-TOI targets selected by the QC Geophysicist. No determinations can be made regarding the success of these predictions until the intrusive investigation is completed.

7.12 CORRECT ESTIMATION OF TARGET LOCATION

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 1 σ of the dataset was less than 30 cm and 1 σ of the depth offset was less than 15 cm. Metrics were only calculated for the 10 seed items covered by the cued survey given the lack of an intrusive investigation. The σ of the horizontal offsets was 18 cm, and the σ for the vertical offset was 7 cm.

8.0 COST ASSESSMENT

The cost assessment was split into two groups: development of the Demonstration Plan and Explosive Site Plan, Seeding and Surface Sweep, and MetalMapper costs. The MetalMapper costs include instruments, surveying, and analysis costs.

8.1 COST MODEL

The cost model for the PCD demonstration includes the total cost of the project. 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
Demonstration Plan and Explosives Site Plan		
Development and finalizing of the Demonstration Plan and Explosives Site Plan		$58,781
Seeding Survey Costs		
Seed emplacement/initial set up	Costs for mobilization, surface sweep, seed emplacement, surveying seeds	$30,887
MetalMapper Survey Costs		
Survey costs	Dynamic detection survey (5.4 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.)	$44,415 $8,225/acre
Survey costs	Cued classification survey (1,164 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.).	$34,920 $30/target
	Instrument rental costs: MetalMapper, tractor, GPS, etc.	$12,804 $11/target
	All processing and analysis performed following the completion of field activities	$3,495 $3/target
	Total cued reacquisition costs	**$44/target**

9.0 IMPLEMENTATION ISSUES

The two notable implementation issues noted during the PCD demonstration are discussed below.

- Neither the dynamic repeatability tests collected at the IVS nor the function tests performed were as successful as anticipated. Failed response repeatability tests have been attributed to slight deviations in the location of the sensor above the seed items due to the difficulty in repeating the exact same line over these objects given the sensor's location a significant distance ahead of the transport vehicle. The difficulty inherent in this process has been noted on previous projects, with twice-daily static function tests identified as a possible replacement. The use of function tests was attempted at PCD, but multiple failures were also noted with these tests. Function test failures were generally noted for receiver 4, the receiver farthest from the two test objects placed on the sensor during testing. It is expected that function tests will be an adequate replacement for dynamic response tests once an optimal combination of test objects and locations for the objects on the sensor are identified for the MetalMapper
- While the efficient implementation of the dipole filter is a constantly evolving process, it is clear that two factors contributed to its poor performance: the extremely small size of the TOI and the extremely high anomaly densities at the site. The latter complicates matters primarily by introducing more uncertainty in the estimation of the spatially varying background signal that needs to be removed from the data. Even slight mismatches in the adjacent survey line amplitudes in the less dense areas, however, can act as single dipole sources with very low fit quality. Since the TOI is extremely small in this case, the threshold is very low and in the process retains many of these artifacts as possible targets. In addition, there are many instances when using the 3-dipole model inversion doesn't appear to be enough to identify all the sources in the data (even in some of those areas that were identified as not too dense). This is evident by the fact that neither the 3-dipole fit quality increases to an appreciable level, nor do the resulting fit locations from neighboring peaks converge on consistent locations.