DEMONSTRATION REPORT

MetalMapper Demonstration at the Pole Mountain Target and Maneuver Area, WY

March 2012

Herb Nelson
Anne Andrews
SERDP & ESTCP

ESTCP

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MetalMapper Demonstration at the Pole Mountain Target and Maneuver Area, WY

March 2012

1. Introduction

Classification using the MetalMapper advanced electromagnetic sensor was demonstrated at the former Pole Mountain Target and Maneuver Area (PMTMA), WY in 2011. This report summarizes the results of that demonstration. The document *Implementing Classification on Munitions Response Sites* (Ref. 1) provides practical information for deciding whether classification is appropriate to a particular site and how it is best implemented.

Pole Mountain Target and Maneuver Area, WY –limited variety of munitions used, flat and open, minimal geologic interference, low anomaly density

Munitions – 37-mm projectiles, 57-mm projectile, 75-mm projectiles, 3-in stokes mortars

Results – MetalMapper was used to successfully classify all of the targets of interest and eliminate up to 90% of the clutter. A production contractor field crew collected high quality cued MetalMapper data. Both production contractor geophysicists and the developers of classification methods were successful in using these data to achieve substantial classification. Among the production geophysicists, there was some variation in performance but even the poorest performer was able to correctly classify 2/3 of the clutter while identifying 100% of the TOI.

Classification is motivated by the need to perform munitions response more cost-effectively so that limited clean up dollars can be used to reduce real risk on munitions-contaminated sites sooner. The estimated liability in the FY10 Defense Environmental Programs Report to Congress for Munitions Response is $15.2B. (Ref. 2) The bulk of this liability is $10.0B for the 1703 sites identified in the Formerly Used Defense Sites (FUDS) program and $4.4B for the 2433 sites identified on Active Installations. The remaining $0.8B is in Base Realignment and Closure (BRAC). The estimated completion dates for many sites, particularly in the FUDS program, are decades out if they are to be cleaned up at planned funding levels using current practice.

When a munitions response site is cleaned up, in most cases, it is mapped with a geophysical sensor and the locations of all detectable signals are excavated. Geophysical sensors detect metal and, therefore, many of the detections do not correspond to munitions, but rather to harmless metallic objects. Field experience indicates that 95-99% or more of objects are found to be nonhazardous. Current technology does not provide a means to discriminate between munitions and other items, termed "clutter." As a result, most of the costs to remediate a munitions-contaminated site using current methods are spent on excavating targets that pose no threat.

Classification is a process used to make a decision about the likely origin of a signal. In the case of munitions response, high-quality geophysical data can be interpreted with physics-based models to estimate parameters that are related to the physical attributes of the object that resulted in the signal, such as its physical size and aspect ratio. The values of these parameters may then be used to determine whether the signal arose from a munition or harmless clutter. With reliable classification, only the munitions need to be removed from the site.

The Strategic Environmental Research and Development Program (SERDP) and the Environmental Security Technology Certification Program (ESTCP) have supported the development of purpose-built advanced electromagnetic sensors and associated analysis methods for classification. Following the successful demonstration of classification methods in controlled test environments, ESTCP initiated a Classification Pilot Program to validate the application in real-world conditions. The goal of the program is to demonstrate that classification decisions can be made using an explicit approach, based on principled analysis that is transparent and reproducible. The demonstrations are planned and conducted in cooperation with regulators and program managers in the Services.

The physics governing the electromagnetic response of a metal object is well understood and predictable. Data collected with these sensors contain the same information content on any site and demonstrations to date have confirmed that classification works predictably. Nevertheless, demonstrations will be required at a number of sites to represent the wide variability in munitions types, target densities, terrain, vegetation, geology, land use history, future land use, and other site characteristics that will affect the applicability of classification and to establish cost effectiveness and implementability. The demonstrations also present an opportunity to work out standard operating procedures and establish quality control (QC) measures. Prior demonstrations have been done at the former Camp Sibert, AL, the former Camp San Luis Obispo, CA, the former Camp Butner, NC, and the former Camp Beale, CA. Details about past and ongoing demonstrations can be found on the SERDP-ESTCP web site at http://serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response.

The demonstration at Pole Mountain continues the practice of production geophysics contractors collecting and analyzing advanced sensor data using the MetalMapper. As such, one purpose of the demonstration was to train production contractors using the MetalMapper for the first time. This is an important consideration in evaluating and applying the results. We discourage potential customers from using the demonstration results to rank performers and make contracting selections; analysts will gain experience and improve. Data were also analyzed by experienced teams from the developers of the classification methods. Table 1 shows the participants and their roles in the MetalMapper demonstration.

Table 1. Participants in the MetalMapper Demonstration at Pole Mountain

Task	Performer(s)	Task	Performer(s)
Site Preparation	URS	MetalMapper Data Analysis	Parsons SAIC Sky Research Shaw URS US Army Corps of Engineers
EM61-Mk2 Data Collection and Target Selection	URS (with input from ESTCP)		
MetalMapper Data Collection	Sky Production		
Intrusive Investigation	URS	Scoring	Institute for Defense Analyses

2. Pole Mountain Demonstration Flow

The sequence of the demonstration is outlined in the flow chart in Figure 2-1.

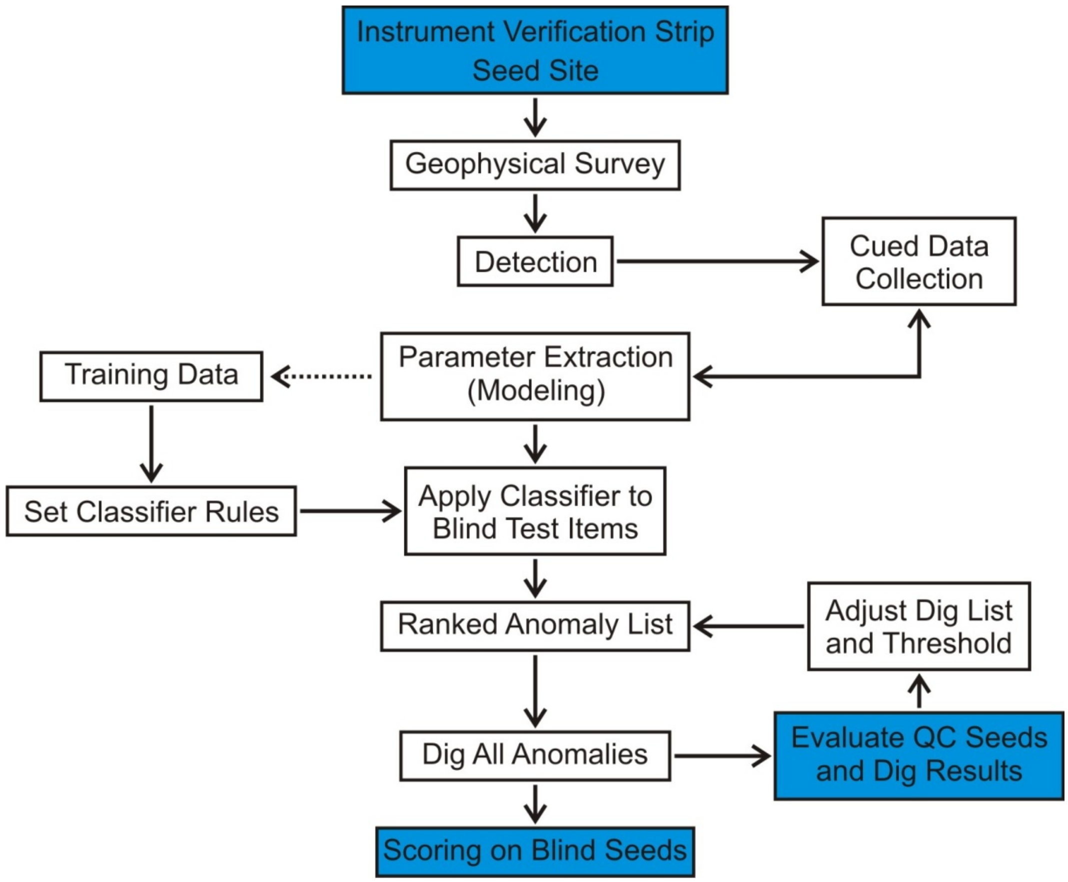

Figure 2-1. Flow chart outlining steps in the demonstration at Pole Mountain. Blue boxes are tasks performed by ESTCP. Others are tasks performed by contractors.

Prior to the beginning of data collection, an instrument verification strip (IVS) was installed and the site was seeded with inert munitions and small industry standard objects (ISOs), 1-in nominal X 4-in pipe nipples. (Ref. 3) Data collectors visited the IVS twice daily to verify equipment function at the start and end of each day. Since there are few native unexploded ordnance (UXO) on any munitions response site, the seeds provided sufficient targets of interest (TOI) to allow a statistically defensible determination of the correct classification of TOI.

Targets of Interest (TOI) are all objects that must be removed from the site. Typically the TOI will include all known or suspected munitions types, any other unexpected munitions, munitions parts such as fuzes that present an explosive hazard, and all seeded items. When classification is applied to a site, the local project team will decide what items constitute TOI.

The site was surveyed with an EM61 to provide an initial list of detected anomalies. The MetalMapper was used to collect cued data over each anomaly. All detected targets were dug up to provide complete ground truth for the purposes of determining performance. The UXO technicians photographed each item that was dug and recorded its location, depth, and description.

The geophysical data were passed to the data analysis teams. A complete overview of the analysis procedures can be found in Ref 1. Briefly, the analysts used methods based on the dipole model to estimate target parameters. Analysts were offered training data from test pit measurements and the opportunity to request additional training data from the recovered targets, as though they were doing a limited number of sample digs. These data were used to set classifier rules – the decisions that separate the anomalies into TOI and non-TOI. The classifiers were then applied to all of the targets that remained blind for each demonstrator. Since training data was by request, the blind target set was different for each demonstration.

The product required from each analyst was a ranked anomaly list as shown in Figure 2-2. One and only one judgment was required for each entry on the anomaly list. The first items on each anomaly list are those targets for which reliable parameters cannot be extracted and therefore must be dug. Next are those items which the analyst is the most confident are TOI. The items are ranked according to decreasing likelihood that the item is a TOI. Any items which the analyst was able to analyze but was not able to make a classification decision on at this time were placed next on the anomaly list. Last are all those items that the analyst was confident are not TOI ranked by their likelihood. This initial list is shown in the left panel of Figure 2-2.

Initial Ranked Anomaly List

Rank	Anomaly ID	Decision Statisitic	Dig	Comment
1	2498	-9999	Y	Can't extract reliable parameters
2	247	.97	Y	
3	1114	.96	Y	High likelihood TOI
4	69	···	Y	
5	811	···	Y	
···	313	···	N	Unable to classify
···	883	···	N	
···	···	···	N	
···	···	···	N	
···	···	···	N	High likelihood not TOI
···	···	···	N	
···	···	···	N	
···	···	···	N	
···	···	.02	N	
···	···	.02	N	
N	···	.01	N	

First Pass Threshold

Final Ranked Anomaly List

Rank	Anomaly ID	Decision Statisitic	Dig
1	2498	-9999	Y
2	247	.97	Y
3	1114	.96	Y
4	69	···	Y
5	811	···	Y
···	313	···	Y
···	883	···	N
···	···	···	N
···	···	···	N
···	···	···	N
···	···	···	N
···	···	···	N
···	···	···	N
···	···	.02	N
···	···	.02	N
N	···	.01	N

Final Threshold

Figure 2-2. Initial and Final Ranked Anomaly Lists. A detailed description is in the text.

The seeds were divided into QC seeds and blind seeds. When analysts submitted their initial prioritized lists, the QC seeds were used to provide feedback if seed targets were missed. Analysts were also provided with the ground truth information on all anomalies in the red part of their lists and any requested anomalies in the yellow part. This is signified by the threshold on the left side of

Figure 2-2. Based on this information, the analysts were then allowed to revisit their rankings and assignments for all items that were still blind until they were satisfied that the best possible classification had been achieved.

In the final list, shown in the right panel of Figure 2-2, the analyst was required to provide a threshold that corresponds to the division between those items recommend for digging and those that can safely remain in the ground. That is, the list is all red and green with a threshold separating the two categories. The final prioritized anomaly lists were scored against the emplaced blind seeds and recovered targets by IDA.

3. Site Description and Preparation

The Pole Mountain Target and Maneuver Area is a 62,448-acre site located east of Laramie, WY. The PMTMA was established in 1879 as the Fort D.A. Russell Wood and Water Reserve. The land status alternated between national forest and military reservation from 1897 to 1925. The Pole Mountain area has also been known as the Crow Creek Forest Reserve, Fort D.A. Russell Target and Maneuver Range, Fort Francis E. Warren Target and Maneuver Range, Pole Mountain Reservation, Pole Mountain Training Annex, and Warren Training Annex. It was extensively used before 1959 as a target and maneuver area by the Army, the Reserve Officers' Training Corps, the Citizens' Military Training Corps, various National Guard units, and the Department of the Air Force. The site is now part of Medicine Bow National Forest.

There are several Munitions Response Sites at the Pole Mountain FUDS; the ESTCP demonstration was conducted in the portion of the site referred to as the Bisbee Hill Maneuver Area. An aerial photo of the demonstration area is shown in Figure 3-1 with the 50-acre demonstration area marked in red.

All visible metal objects were removed from the surface at the site. First order reference points were installed by a registered surveyor for geolocation reference. A quiet area was located near the demonstration area to establish an instrument verification strip (IVS) used for daily verification of proper sensor operation and a training pit to collect sensor data for algorithm training.

A variety of munitions have been reported as used at PMTMA. Physical evidence for the following items was discovered during the recent Remedial Investigation (Ref. 4):

- projectiles containing high explosive (HE) filler (37-mm to 155-mm, and 2.95-inch),
- shrapnel projectiles (75-mm and 3-inch),
- 3-inch Stokes mortars (practice, fuzed), and
- 60-mm mortars containing HE filler.

The objective of the demonstration was to detect and correctly classify all TOI on the site. The analysts were provided information about the historical use and known munitions types. But, the direction specified that, in addition to these munitions, any unexpected munitions would also be considered TOI.

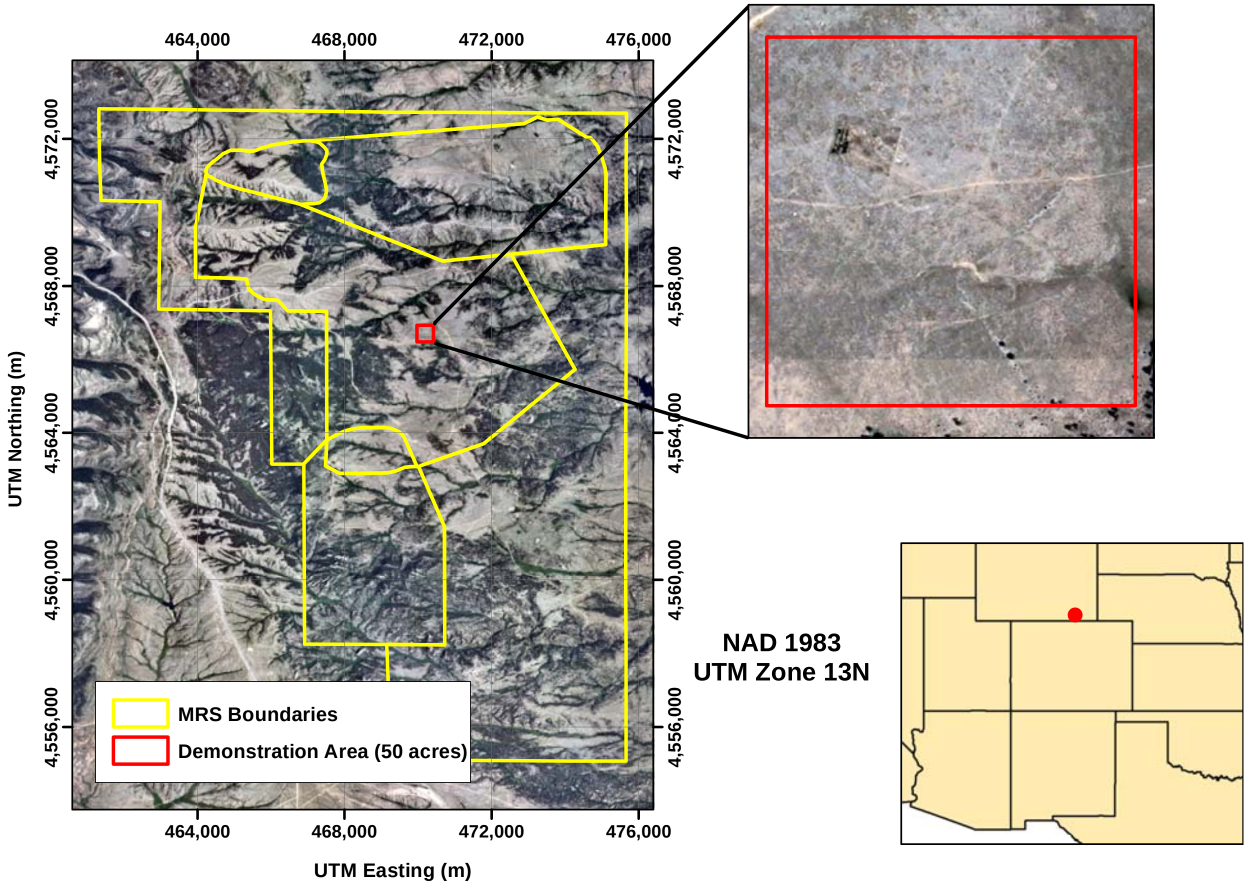

Figure 3-1. Aerial photo of part of the Pole Mountain Target and Maneuver Area showing the demonstration site

At a live site, the number of targets of interest is small, far from enough to determine any demonstrator's classification performance with acceptable statistical confidence bounds. In fact, on the portion of the Pole Mountain site used for this demonstration, no UXO were recovered in the intrusive investigation. Therefore, the site was seeded with enough TOI to ensure statistical validity on measures of classification of targets of interest. The TOI seeds are listed in Table 3-1. The seeds included not only inert munitions, but also industry standard objects. (Ref. 3) The ISOs are also considered TOI and expected to be both detected and correctly classified.

Table 3-1. Seeds Emplaced for the Pole Mountain demonstration

Item	Number	Depth Range (cm)*
Industry Standard Object - Small	40	15-25
37-mm projectile	43	15-30
57-mm projectile	10	20-35
60-mm mortar	41	30
75-mm projectile	25	20-40
3-in stokes mortar	1	30

*Depths are to the center of the object.

No attempt was made to separate the seeds from the surrounding clutter. For safety, seeds were emplaced using standard anomaly avoidance procedures. For realism, the emplacement teams were instructed to replace any metal dug up during emplacement back in the hole with the seeded object.

4. EM61 Detection Survey

An initial survey was performed with an EM61-MK2 in its standard cart configuration with cm-level global-positioning-system (GPS) navigation. These data were used both to provide a common anomaly list for the MetalMapper data collection that followed and to attempt classification using only the EM61 data as a point of comparison.

The data quality objectives for the detection survey were based on the 37-mm projectile, which was expected to be the most difficult to detect TOI at the site. The EM61 survey was performed on half-meter line spacing. The anomaly selection criteria were set to detect a 37-mm projectile at a depth of one foot (30 cm). This depth was chosen as the deepest depth to which a 37-mm could be reliably detected.

The EM61 signal strength in channel 2 versus depth for a 37-mm projectile is shown in Figure 4-1. (Ref. 5) The signal at 30-cm depth for the least favorable orientation is 5.2 mV, which was used as the amplitude threshold for identifying anomalies. This threshold corresponds to detection of all 60-mm mortars to 60 cm, all 75-mm projectiles to 80 cm, and all 3-in stokes mortars to 85 cm.

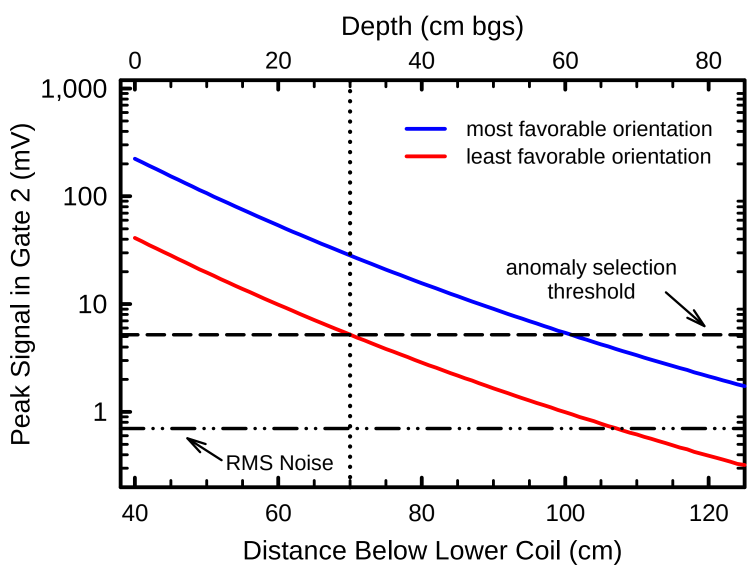

Figure 4-1. EM61 response in Gate 2 versus depth for a 37-mm projectile

The EM61 survey resulted in a total of 2370 anomalies in the 50-acre demonstration area, including the seeds. This translates to approximately 50 anomalies per acre. Little geologic response was seen in the EM61 data and in the subsequently collected MetalMapper data. Details can be found in the vendor's reports. (Ref. 6, 7) All seeds were detected in the EM61 survey using the threshold described above.

5. MetalMapper Data Collection

The MetalMapper developed by Geometrics is designed to be a stand-alone survey and cued detection system. The system, shown in Figure 5-1, is composed of three orthogonal 1-m x 1-m transmitters for target illumination and 7 three-axis receivers for recording the response. Its sampling is electronically programmable and therefore flexible. It measured the decay curve up to 8 ms after the transmitters were turned off. It was deployed in a sled configuration mounted to an all-terrain vehicle. Centimeter-level GPS is used for navigation and geolocation and an inertial measurement unit (IMU) is used to measure platform orientation. In cued mode, MetalMapper is positioned over each anomaly on its target list and collects the full suite of data while stationary. The digital data set produced by MetalMapper is fully described in Ref. 8.

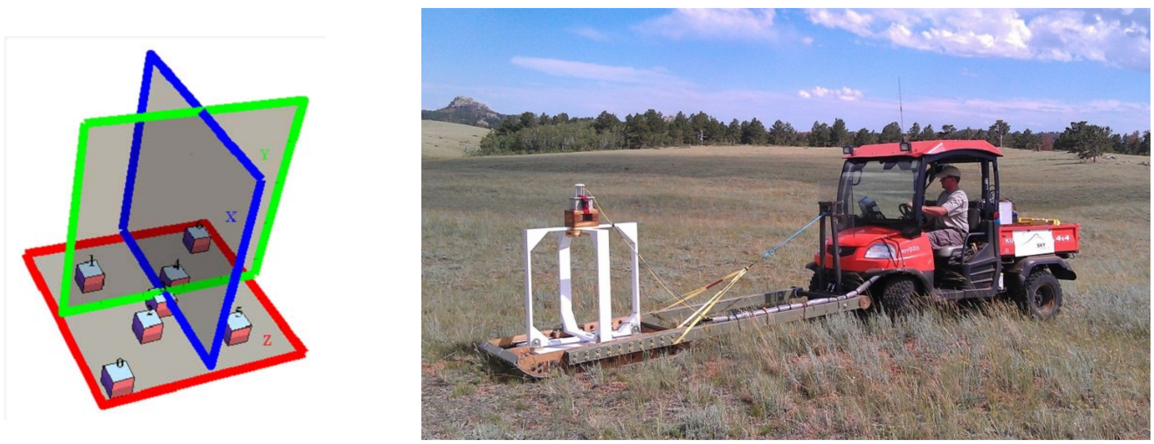

Figure 5-1. Schematic and photo of the MetalMapper as used at Pole Mountain

In this demonstration MetalMapper was used only in cued mode. Because of site limitations, only one data collection was possible; the production arm of Sky Research collected MetalMapper data at Pole Mountain. Details on the data collection and QC procedures for this team can be found in their report. (Ref. 7) The most common QC failure was that the MetalMapper was positioned too far from the anomaly to obtain reliable parameter estimates. If the separation between the center of the MetalMapper and the anomaly location was more than 40 cm, the anomaly was revisited the next day and additional data collected within the 40-cm specification.

Excluding the first and last day's field work, this data collection team averaged 215 cued anomalies per day (32 per hour). They required 125 QC recollects, corresponding to a little over 5% of the anomalies measured.

6. Analysis of MetalMapper Data

The MetalMapper data were analyzed by multiple analysts, including both the developers of the analysis methods and production geophysics vendors. Figure 6-1 shows an overview of the results achieved by all analysts working with the MetalMapper data. The panel on the left shows the percent of TOI correctly classified versus the number of clutter at each analyst's operating

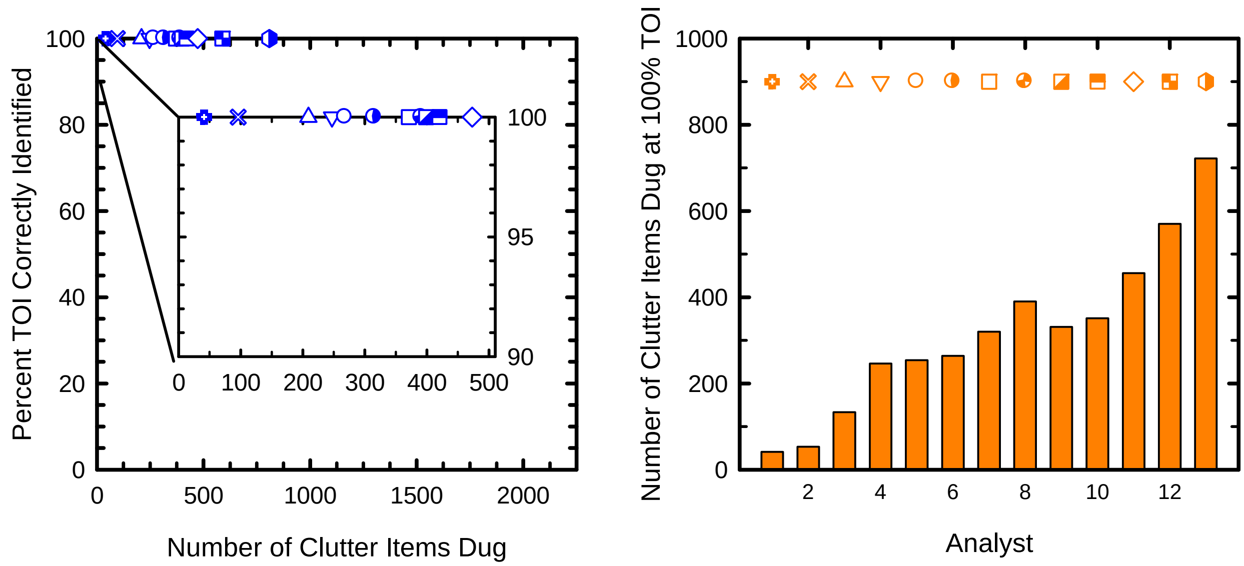

Figure 6-1. Results of all analysts in the Pole Mountain demonstration. The left panel shows the percent TOI correctly identified versus number of clutter at the analysts chosen threshold. The right panel shows the number of clutter that would have to be dug to classify 100% of the TOI, regardless of where the analyst put the threshold.

threshold. The inset expands the upper left of the graph for clarity. Desired performance is to correctly classify 100% of the TOI and eliminate all of the clutter. The panel on the right shows the number of clutter that the analyst needed to dig to get to 100% correct classification of the TOI, regardless of where the analyst put the threshold. This can be thought of as the best the analyst could have done by putting the threshold in exactly the optimum place where the last TOI is found in the ranked list. The symbols above the bars correspond to the symbols in the left panel.

At their specified thresholds, most analysts achieved very good results, correctly classifying 100% of the TOI and eliminating more than 80% of the clutter. This includes both the classification algorithm developers and the production contractors and is quite remarkable, especially considering that this was the first attempt at analyzing MetalMapper data by some of these analysts

The range in performance is shown in the right panel. The best performer could have eliminated all but 50 of the clutter (a 97% reduction) with 100% correct classification of TOI, where as the poorest performer at best could have eliminated about only 66% of the clutter.

6.1 Analysis by Production Geophysicists

The focus in this demonstration was on the performance of production geophysics teams so we present representative examples of the results from these analysts. A complete compendium of all results can be found in the report by IDA. (Ref. 9)

Geophysicists from the production arm of Sky Research analyzed the MetalMapper data collected by their field colleagues using methods developed by the research geophysicists at Sky. (Ref. 7) The results of this analysis are shown in Figure 6-2. The colors on the plot correspond to the red and green colors in the final ranked anomaly list as shown in Figure 2-2. The red are the items the

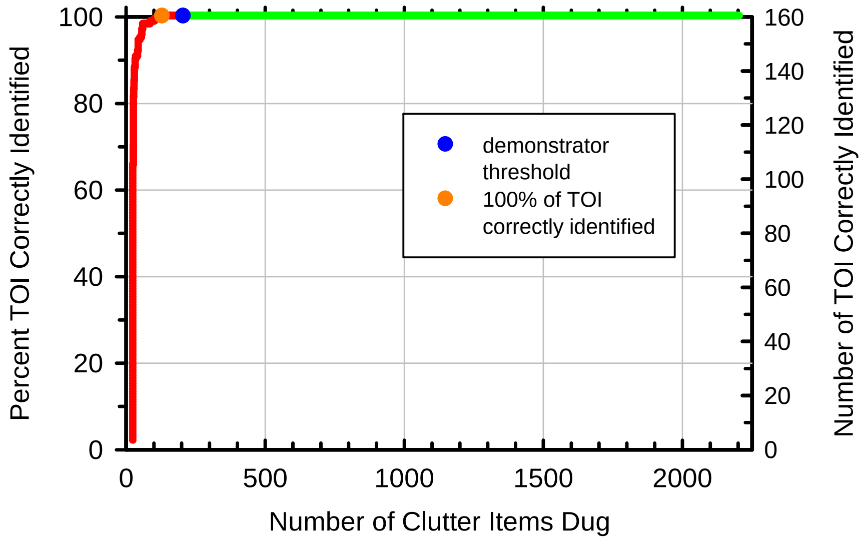

Figure 6-2. Results of the Sky production team analysis of their MetalMapper data

analyst classified as "high likelihood TOI" and the green are those the analyst called "high likelihood not TOI." No anomalies were classified as "unable to classify." The graph plots the percent of the targets of interest correctly classified on the vertical axis and the number of clutter items on the horizontal axis. The offset from zero in the starting point reflects any training data that the analyst requested. Any anomalies classified as "can't extract reliable parameters" would be represented by an initial black line; no anomalies were in this category for this analysis. The blue dot represents the threshold selected by the analyst and the orange dot shows the point on the ranked anomaly list where 100% of the target of interest are captured. Ideally, a classifier would correctly identify all targets of interest in the red with zero clutter and all of the clutter would be in the green. In this case, the red part of the curve would go straight up to 100% and the green part of the curve would run straight across the top axis. Success in these demonstrations was defined by eliminating the maximum amount of clutter while correctly identifying all of the TOI.

In this demonstration, there were 2208 total clutter items as determined from the ground truth. This analyst was able to correctly identify almost 2000 of these items at their threshold, for a possible savings of more than 90% of the digs

Several groups analyzed the Pole Mountain MetalMapper data using the UX-Analyze module of Oasis montaj. Figure 6-3 shows the results of the Parsons analysis. (Ref 10) This analyst labeled a significant number of the anomalies as "can't extract reliable parameters" as shown by the black points in Figure 6-3. Only one of these anomalies corresponded to a target of interest. Of the anomalies for which parameter extraction was successful, these results show the right general trend, in that the red part of the curve rises steeply initially and more than 75% of the clutter anomalies are correctly classified as not TOI.

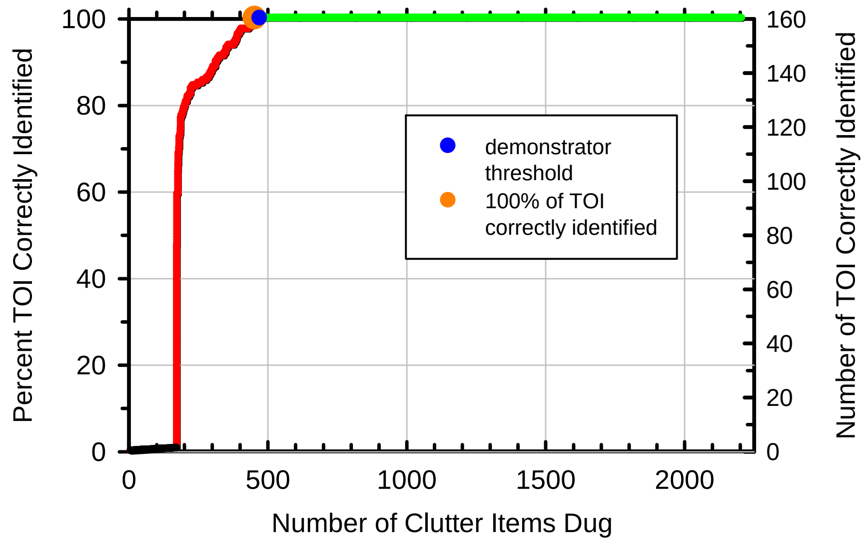

Figure 6-3. Results of the Parsons analysis of the Pole Mountain MetalMapper data

A US Army Corps of Engineers analyst also used UX-Analyze and achieved the results shown in Figure 6-4. (Ref. 11) This analysis is very efficient at the beginning of the ranked anomaly list; the ROC curve is almost vertical. Identifying the last 25 TOI required a significant number of clutter digs. Although the last two TOI identified were a 37-mm projectile and an ISO, the 25 more difficult TOI comprised all possible types. This analyst was able to correctly classify more than 80% of the clutter as not TOI.

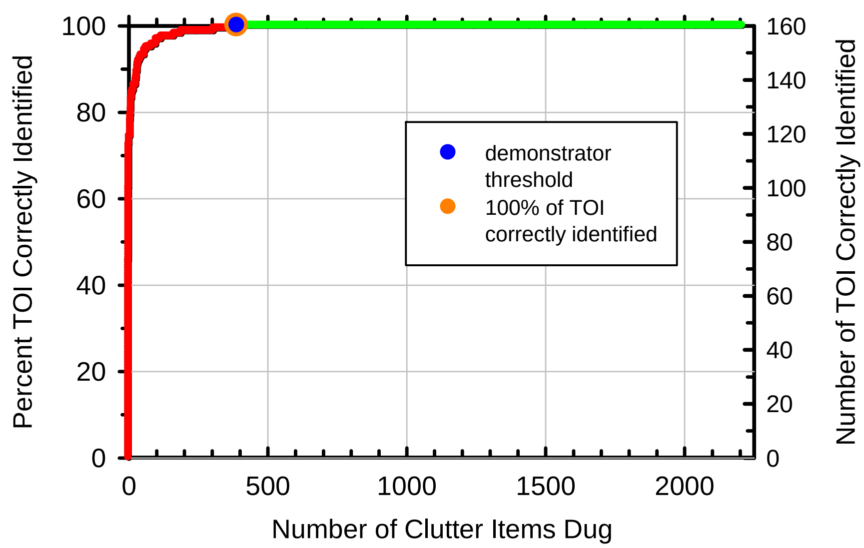

Figure 6-4. Results of a USACE geophysicist's analysis of the Pole Mountain MetalMapper data

A hybrid approach was used by analysts from URS. (Ref. 12) These geophysicists used UX-Analyze to estimate target parameters from the MetalMapper data then used an Artificial Neural Net to order the anomaly list. The ROC curve that results from this analysis is shown in Figure 6-5. After requesting 46 training digs and declaring 51 anomalies as "can't extract reliable parameters," this analyst was able to correctly classify almost 90% of the clutter as non-hazardous.

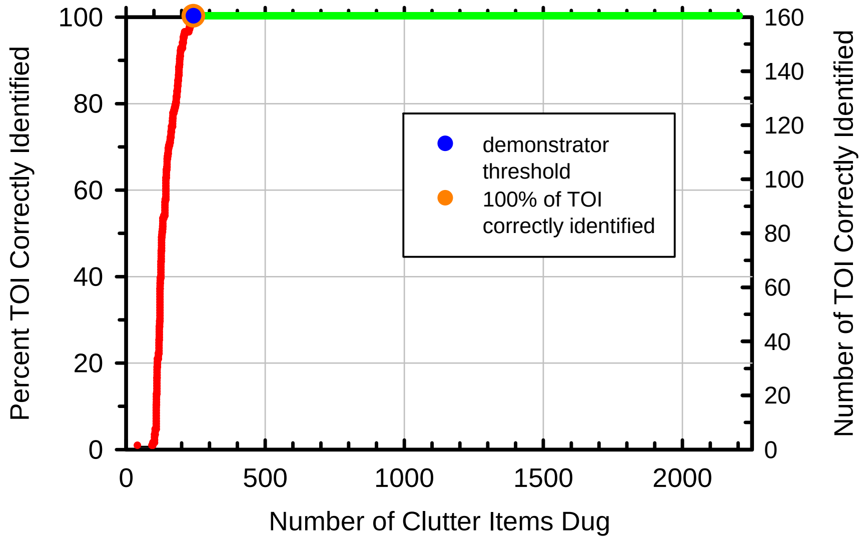

Figure 6-5. Results of the URS hybrid analysis of the Pole Mountain MetalMapper data

Finally, geophysicists from Shaw worked with algorithm developers from Sky Research on an analysis of the MetalMapper data. (Ref. 13) The ROC curve that results from this analysis is shown in Figure 6-6. These analysts only required 96 clutter digs to identify 100% of the targets of interest, meaning they were able to correctly classify more than 95% of the clutter as nonhazardous.

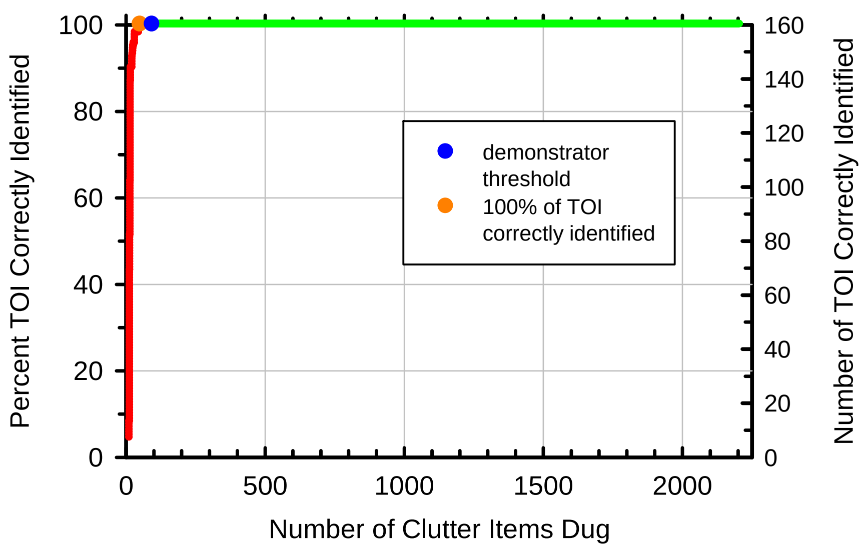

Figure 6-6. Results of the analysis by Shaw geophysicists working with one of the algorithm developers

7. Cost Comparison

The demonstration took place on a small part of the Pole Mountain site and incurred costs for many items specific to a demonstration that would not be needed in an application of classification to a real site. Nevertheless, we can extract meaningful projected performance for the technology and apply reasonable industry unit costs for various elements to arrive at a total cost comparison for clearing an example 500-acre site with and without the use of classification.

We made the following assumptions:

- The example takes place in an area with similar munitions types and the same density of anomalies as seen in the demonstration. Excluding the seeds, there were 2208 anomalies in the 50-acre demonstration area. All of these were clutter. Extrapolating, we would expect about 22,100 anomalies in a similar 500-acre area.
- Although no TOI were found in the small demonstration area at Pole Mountain, we assume a small number, 50, will be found in a larger production operation, and 22,050 clutter items.
- The baseline is an EM61 survey with 0.5-m line spacing. This would be used to select anomalies for digging without classification and the same anomalies would be interrogated with MetalMapper and classified.
- The site is seeded at a rate so on average one seed will be encountered each day of MetalMapper data collection. With an estimate of 22,100 total anomalies and a production rate of 200 anomalies per day, we seed a conservative 125 inert items. These QC seeds would be used whether classification was used on the site or not.
- The classification performance is as achieved by the Sky production team or URS, as shown in Figures 6-2 and 6-5, with ~90% of the clutter correctly identified and remaining undug.
- The unit costs are as shown in Table 8-1.

Table 8-1. Unit cost assumptions

Item	Units	Cost
Digs	Per hole	$125
MetalMapper Classification	Per anomaly	$25 and $35
EM61 Survey Data Collection and Analysis	500 acres	$381,000
Seed Emplacement	125 seeds	$22,650

With these assumptions the costs were calculated using the elements shown in Table 8-2. If classification can be done for $35 per anomaly including both data collection and analysis, which is consistent with the projections of the production companies based on this demonstration, a 54% overall savings is possible. If this cost can be lowered to $25 to classify each anomaly, the potential project savings increases to 61%.

Table 8-2. Cost Comparison for 500 acres of comparable Pole Mountain site

Item	No Classification		Classification		
	Quantity	Cost/$	Quantity	Cost/$ ($35 per MM)	Cost/$ ($25 per MM)
Seeds	125 items	22,650	125 items	22,650	22,650
EM61 Survey	500 acres	381,000	500 acres	381,000	381,000
MetalMapper Classification	n/a	0	22,225 anomalies	777,875	555,625
Seeds Dug	125	15,625	125	15,625	15,625
Native UXO Dug	50	6,250	50	6,250	6,250
Clutter Dug	22,050	2,756,250	2205	275,625	275,625
TOTAL		3,181,775		1,479,025	1,256,775
Percent Savings				**54%**	**61%**

8. Conclusions

Classification was used on the Pole Mountain Target and Maneuver Area to successfully identify all of the TOI and eliminate about 90% of the clutter. A production contractor field crew from Sky collected high quality cued MetalMapper data. Both production contractor geophysicists and the developers of classification methods were successful in using these data to achieve substantial classification. Among the production geophysicists, there was some variation in performance. Additional training is needed so that all analysts are able to identify problems that can be encountered in the multiple analysis steps required in classification.

The Pole Mountain site is not very challenging for classification using an advanced EMI sensor.. Even though the targets of interest included small 37-mm projectiles as well as seeded small ISO's, the site geologic background was very low resulting in high signal-to-noise data in most cases. The anomaly density was low, at about 50 per acre, and did not present any particular difficulty.

9. Acronyms

BRAC	Base Realignment and Closure
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GPS	Global Positioning System
IMU	Inertial Measurement Unit
ISO	Industry Standard Object
IVS	Instrument Verification Strip
QC	Quality Control
RMS	Root Mean Square
SERDP	Strategic Environmental Research and Development Program
TOI	Target of Interest
UXO	Unexploded Ordnance

10. References

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