SUMMARY REPORT

Classification Demonstration at former Camp George West Artillery Range, CO

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1. Introduction

Camp George West Artillery Range, CO –only one munition expected, open access with challenging slopes, minimal geologic interference, medium anomaly density

Munitions – 75-mm projectiles

Results – Both dynamic and cued data were collected with the Man-portable Vector Sensor (MPV). Anomalies were identified from the dynamic survey data and revisited for cued interrogation. The cued data were used to successfully classify all of the targets of interest and eliminate more than 90% of the clutter. One analyst used the dynamic data to classify the targets. Results were, in general, good but one TOI was left just past the analyst's threshold.

Classification using the Man-portable Vector (MPV) advanced electromagnetic sensor was demonstrated at the former Camp George West Artillery Range, CO in 2012. 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.

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 purposebuilt 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 conducted at a number of sites across the country; 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 Camp George West continues the tests of smaller man-portable advanced EM sensors intended for use where terrain or vegetation demand a more maneuverable option. These sensors are less mature and field procedures are not as well established compared to the MetalMapper. For this reason, it is premature to attempt a cost analysis of the use of this sensor. Data were analyzed by experienced teams from the developers of the classification methods. Table 1 shows the participants and their roles in the Camp George West demonstration.

Table 1. Participants in the MPV Demonstration at Camp George West

Task	Performer(s)	Task	Performer(s)
Site Preparation	Parsons	MPV Data Analysis	Dartmouth College SAIC Sky Research, Vancouver*
MPV Data Collection	Sky Research, Vancouver*		
Intrusive Investigation	Parsons	Scoring	Institute for Defense Analyses

*Sky Research, Vancouver personnel are now affiliated with Black Tusk Geophysics

2. Camp George West Demonstration Flow

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

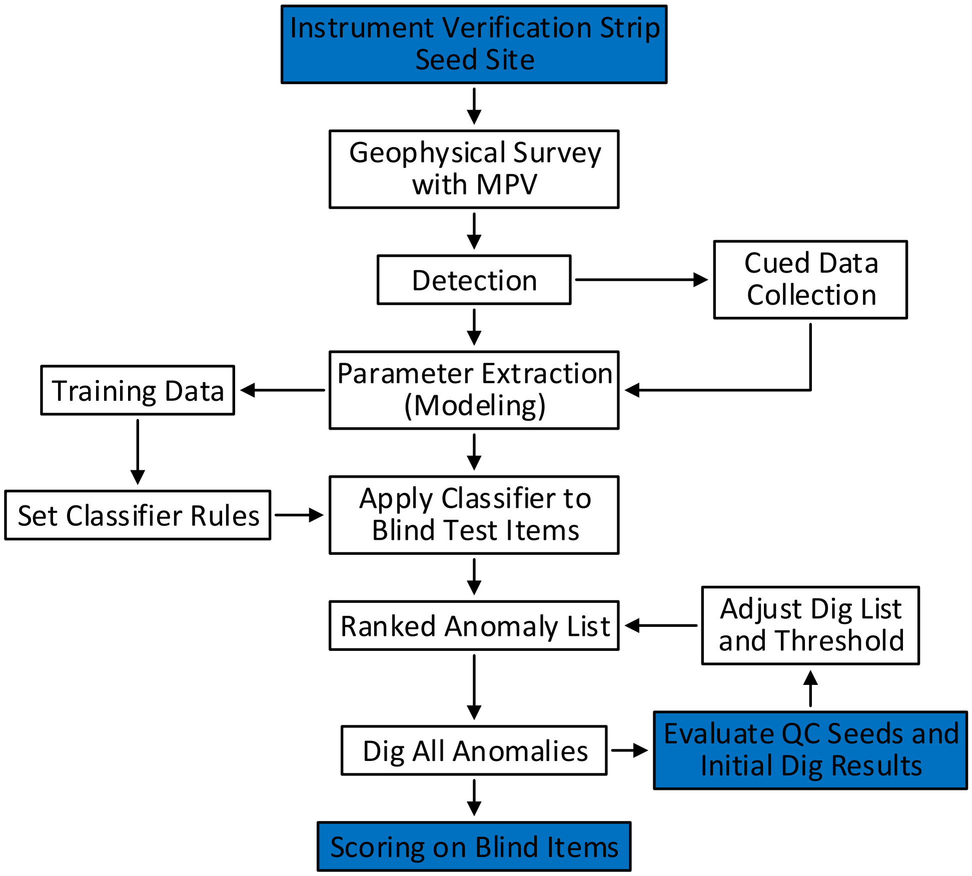

Figure 2-1. Flow chart outlining steps in the demonstration at Camp George West. Blue boxes are tasks performed by ESTCP. Others are tasks performed by contractors.

Prior to the beginning of data collection, an instrument verification strip (IVS) was installed and the site was seeded with inert munitions and medium industry standard objects (ISOs), 2-in nominal x 8-in pipe nipples. (Ref. 3) The data collection team 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 MPV sensor (Ref. 4) was used in both dynamic and cued mode for this demonstration. A dynamic survey was conducted to detect anomalies. Each anomaly was then revisited in cued mode. 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 dynamic and cued 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; an example is shown in Figure 2-2. One and only one judgment is required for each entry on the anomaly list. The first items below the training data 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. These 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. The analysts were required to specify a size estimate for any item marked to be dug. This initial list is shown in the left panel of Figure 2-2.

Initial Ranked Anomaly List

Anomaly ID	Dig on First Pass	Type	Comment
718	Y		Classifier training data
207	Y		
2498	Y		Unable to extract reliable parameters
247	Y	105 mm	
1114	Y	4.2 in	High likelihood TOI
69	Y	155 mm	
811	Y	81 mm	
First Pass Threshold			
313	N		Unable to classify
883	N		
...	N		
...	N		
...	N		High likelihood not TOI
...	N		
...	N		
...	N		
...	N		
...	N		
...	N		

Final Ranked Anomaly List

Anomaly ID	Dig	Type
718	Y	
207	Y	
2498	Y	
247	Y	105 mm
1114	Y	4.2 in
69	Y	155 mm
811	Y	81 mm
313	Y	105 mm
Final Threshold		
883	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	
...	N	

Figure 2-2. Example 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 list in 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 is 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, every item on the list is marked to be dug or not with a threshold separating the two categories. The final prioritized anomaly lists submitted in this demonstration were scored against the emplaced blind seeds and recovered targets by IDA.

3. Site Description and Preparation

The 135-acre Camp George West Artillery Range Munitions Response Site (MRS) was used by the Colorado Army National Guard for artillery training from 1930 to 1945 as an impact area for 75-mm high explosive (HE) projectiles. (Ref. 5) Other portions of the artillery range, including firing points, forward observer position(s), and surface danger zones are not precisely known. The MRS (impact area) is currently owned by the city of Lakewood.

In order to minimize damage to the recreation area, personnel from the City of Lakewood and the ESTCP Program Office settled on a 2-acre demonstration area for this site. The specific 2 acres were chosen based on anomaly densities interpolated from an initial transect survey. An aerial photo of the site is shown in Figure 3-1 with the 2-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. An area free of contamination was located near the demonstration area to establish an IVS used for daily verification of proper sensor operation and a training pit to collect sensor data for algorithm training.

The only known munition at this site is 75-mm HE projectiles. The analysts were provided information about the historical use and known munition. In addition to this munition, demonstrators were directed that any unexpected munitions would also be considered TOI.

The final demonstration 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 75-mm projectiles, but also medium industry standard objects (ISOs). (Ref. 3) The ISOs are also considered TOI and expected to be both detected and correctly classified.

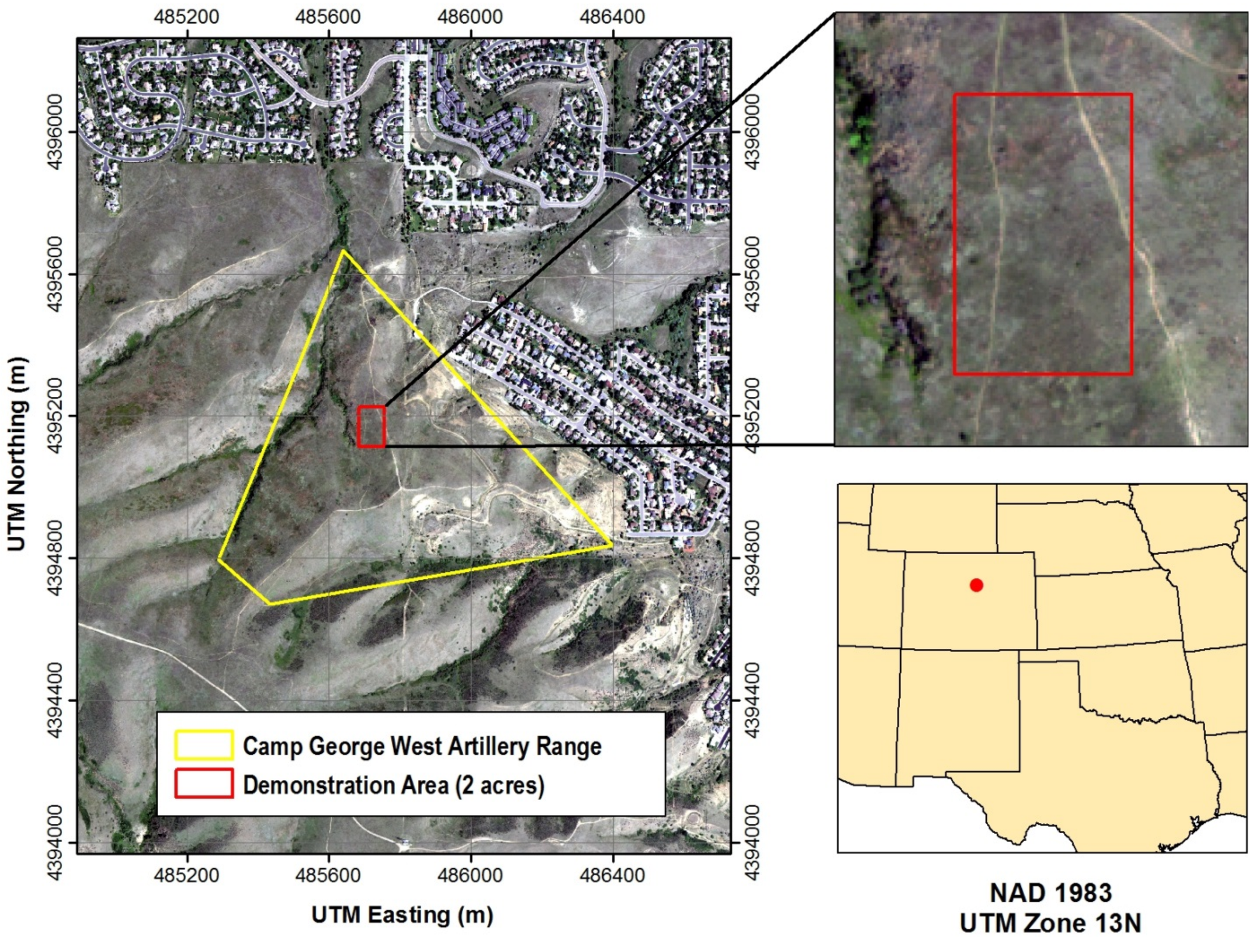

Figure 3-1. Aerial photo of the Camp George West Artillery Range showing the demonstration area

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

Table 3-1. Seeds Emplaced for the Camp George West demonstration

Item	Number	Depth Range (cm)*
Industry Standard Object - Medium	10	15-45
75-mm projectile	30	15-46

*Depths are to the center of the object.

4. MPV Data Collection

The MPV is a time-domain, electromagnetic induction (EMI) sensor composed of a single transmitter coil and an array of five receiver units that measure all three components of the EM field as shown in Figure 4-1. The MPV sensor head for this demonstration comprised a 50-centimenter (cm) diameter circular loop transmitter coiled around a disk that intermittently illuminates the subsurface, and five 8-cm multicomponent receiver units (cubes) that measure the three orthogonal components of the transient secondary EM field decay.

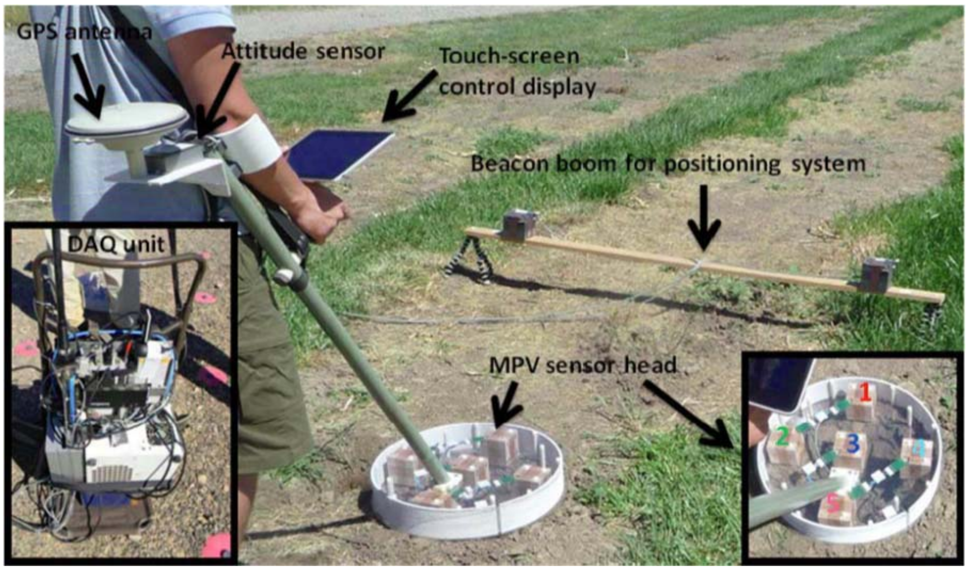

Figure 4-1. Components of the MPV. Left inset shows data acquisition (DAQ) and power unit mounted on a backpack frame. Right inset shows the sensor head from above with cubes numbered.

MPV data were collected in two modes. Survey, or dynamic, data are collected to identify geophysical anomalies. These full coverage data are collected using the attached GPS antenna. After anomalies have been identified, they are revisited in static, or cued, mode to collect more detailed information about the source of the anomaly. The beacon system is used for local positioning in this mode.

4.1 Dynamic Survey

The dynamic MPV survey was carried out along lanes laid out across the site by sweeping the sensor from side to side across the lane. (Ref. 6) The two-person survey crew is seen in Figure 4-2. RTK GPS is used for geolocation during the dynamic survey. Production rates averaged 0.7 acres per day.

The anomaly selection criterion for the detection survey was based on the 75-mm projectiles expected at the site at a depth of two feet. This depth was chosen as the deepest depth to which a 75-mm could be reliably detected.

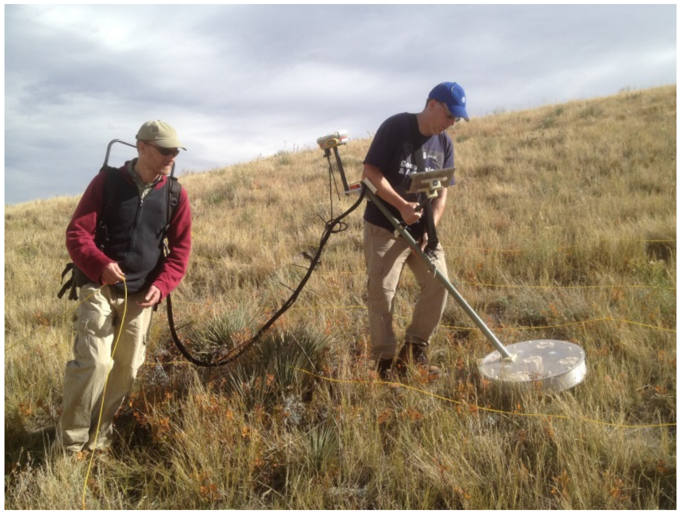

Figure 4-2. Dynamic MPV survey at Camp George West

Since the MPV is a hand-held sensor, the height of the sensor head above the ground is not fixed as would be the case for a sensor mounted on wheels or skids. This complicates the calculation of a sensor response curve that would normally be used to set the anomaly selection amplitude. For this demonstration, the anomaly selection threshold was based on a Monte Carlo simulation of the signal amplitude expected for a 75-mm projectile at 60 cm below the ground surface. For each of the 2000 realizations in the simulation, the projectile was oriented randomly, the sensor head varied between 5 and 10 cm above the surface, and the pitch and roll of the sensor varied from 0 to 20 degrees. The results of the simulation are shown in Figure 4-3.

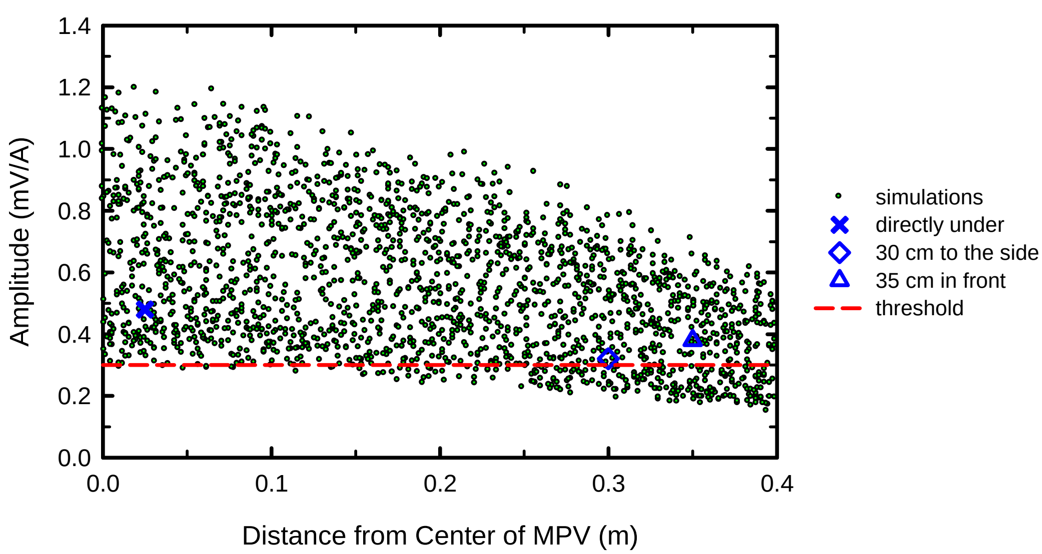

Figure 4-3. Monte Carlo simulation of the response of a 75-mm projectile at 60 cm below the ground to the MPV. The dots correspond to the 2000 conditions simulated, the symbols correspond to test stand measurements made to validate the simulation, and the dashed line corresponds to the threshold chosen for this demonstration.

The anomaly selection threshold was set so that 99% of the 75-mm projectiles at 60-cm depth would be detected. Of course, shallower projectiles would be detected at higher P_D. Using this threshold, there were 567 exceedances in the 2-acre demonstration area. Eighty four of the threshold exceedances were noise spikes that were rejected as anomalies leaving 483 anomalies for cued re-investigation. All 40 seed items were included on this list.

4.2 Cued Survey

The MPV returned to each of the 483 anomalies identified from the dynamic survey for cued data collection. In this mode, MPV initially collects data in a five-point pattern – one measurement directly over the anomaly and four measurements around the anomaly location. If significant signal is observed from the outer receivers, additional points are collected. Local positioning in cued mode is provided by a location beacon, Figure 4-4.

Figure 4-4. MPV cued data collection at Camp George West. The location beacon used for local positioning during cued operation can be seen on the right side of the photograph.

Analysis of the cued data showed that 47 more of the anomalies were due to noise spikes in the survey data and 30 additional buried items were identified from anomalies caused by multiple objects. After accounting for this, a total of 466 items were submitted for analysis and subsequently intrusively investigated. The data collection team averaged 135 cued anomalies per day. (Ref. 6)

5. Intrusive Investigation

A summary of the results of the intrusive investigation is shown in Figure 5-1. The left panel in the figure shows the distribution of the number of items that were recovered from a single hole. As expected given the moderate anomaly density at this site (~250/acre), approximately 75% of the anomalies were caused by a single buried item. The pie chart on the right hand side of Figure 5-1 shows the identities of the recovered objects. The majority of the recoveries were identified as munitions debris; not unexpected for an impact area. Only seventeen items were identified as "other debris" which is surprising given the recreational use of the site.

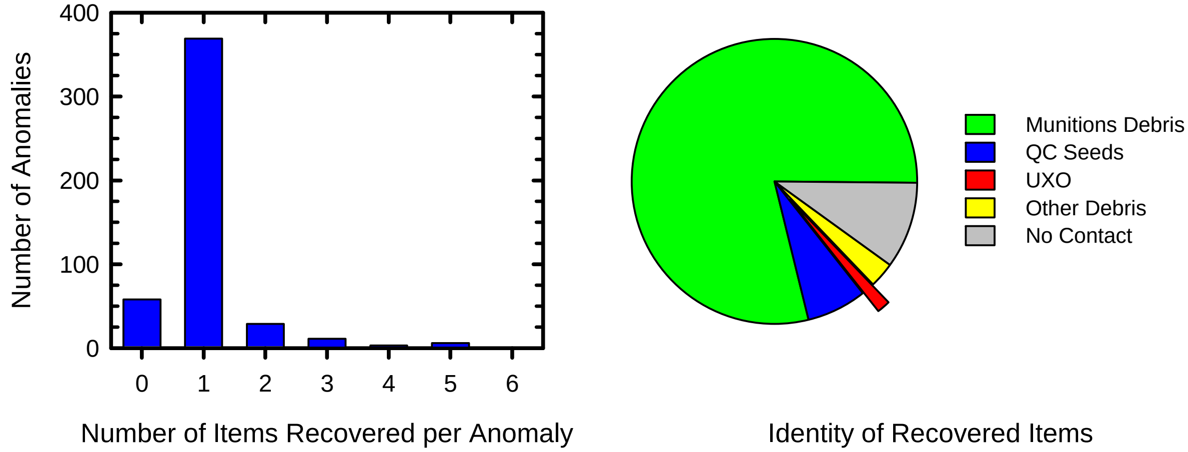

Figure 5-1. Distribution of items recovered per anomaly (left panel) and identity of recovered items (right panel)

Nine UXO were recovered as part of this demonstration. All nine of these items were disposed of by detonation in place by the UXO technicians.

The depth distribution of the recovered items is given by the blue line in Figure 5-2. As at most munitions sites, the vast majority of items were recovered in the top 10 to 20 cm. The depths of the recovered UXO are indicated by the stars on the left side of the plot and the depth range of the seeds by the grey bars. The anomaly selection criterion was based on projectiles at 60 cm, far deeper than any item recovered in this demonstration.

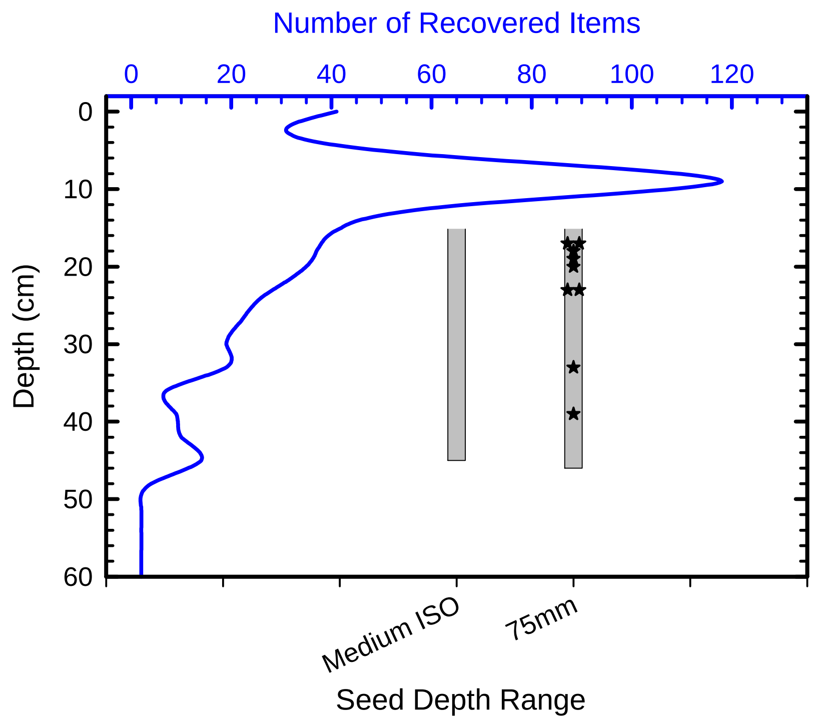

Figure 5-2. Depth distribution of recovered items from Camp George West (blue line). The depths of the nine UXO are marked by stars and the depth range of the QC seeds are shown as grey bars.

The nine recovered UXO are shown in Figure 5-3. They ranged in size and condition from nearly complete 75-mm projectile to sections on the order of one-half to one-third of a complete projectile.

Figure 5-3. Recovered UXO from this demonstration

6. Analysis of MPV Data

The MPV data from this demonstration were analyzed by the firms that are developing analysis methods for the advanced EMI sensors. All of the analysts achieved very good results; a sample of the analyses will be presented here. A complete description of the analysis methods used and results can be found in the demonstration reports prepared by the individual analysts (Refs. 6-9)

6.1 Analysis of Cued Data

An analyst from Dartmouth College processed the cued MPV data using methods developed in house. (Ref. 7) The results of this analysis are shown in Figure 6-1. 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 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."

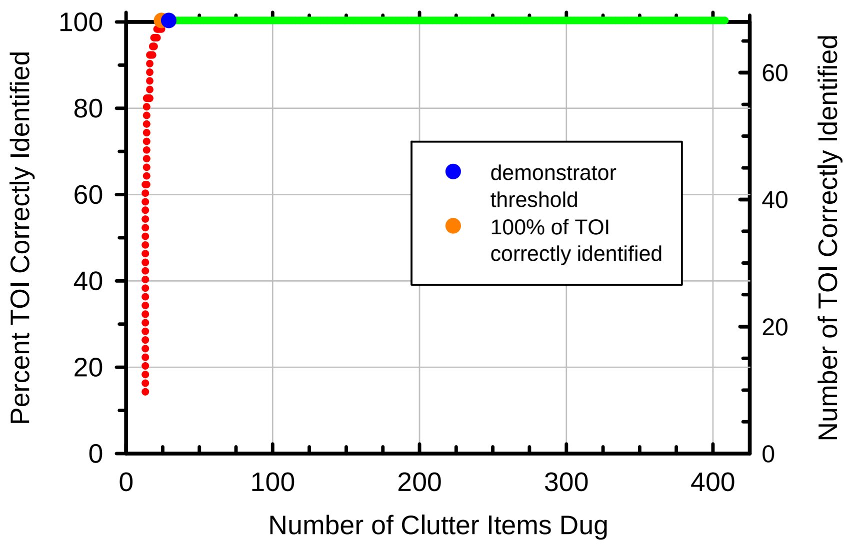

Figure 6-1. Results of a Dartmouth analysis of the cued MPV data

The graph plots the percent of the TOI 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 the 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 TOI 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 409 total clutter items as determined from the ground truth. The Dartmouth analyst was able to correctly identify all but 30 of these items at his threshold, for a possible savings of more than 90% of the digs.

An analyst from Sky Research (now affiliated with Black Tusk Geophysics) achieved similar results, Figure 6-2. This analyst used the 27 training digs requested (8 of which were TOI and 19 clutter) to verify that there were no unexpected small ordnance present on the site and then used a restricted library to identify all the remaining TOI while only digging three more clutter items. This illustrates the performance possible at a site where the number of potential munitions types is limited.

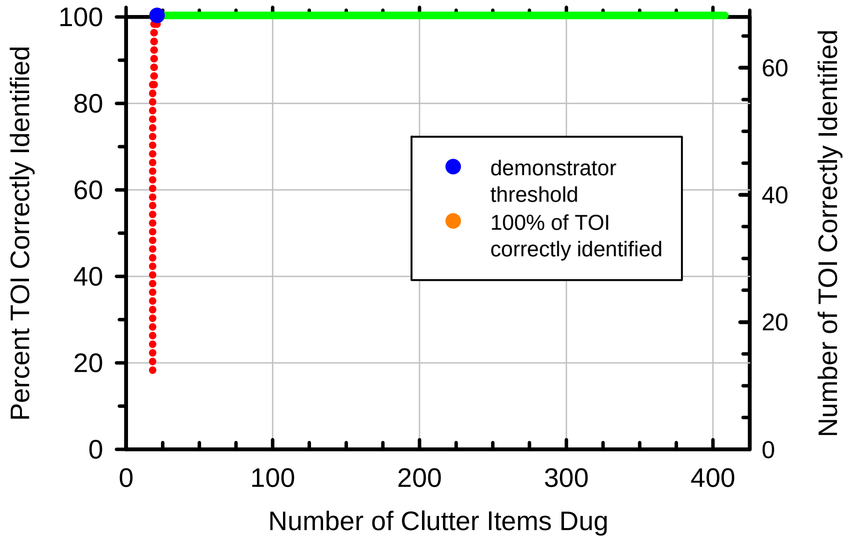

Figure 6-2. Results of the Sky Research analysis of the cued MPV data

6.2 Analysis of Dynamic Data

Another analyst from Sky Research (also currently affiliated with Black Tusk Geophysics) used only dynamic MPV data to extract target parameters and prepare a ranked anomaly list, Figure 6-3. This analyst also achieved good results although the threshold chosen left one UXO not dug (five items on the list after the threshold).

As expected, use of the dynamic data results in a ROC curve that is not as sharp as that achieved using the cued data. The extra clutter digs required, however, are more than paid for by not having to collect cued data. As data collection teams and analysts become more familiar with dynamic data, it will be possible to draw wider conclusions about the usefulness of dynamic data alone.

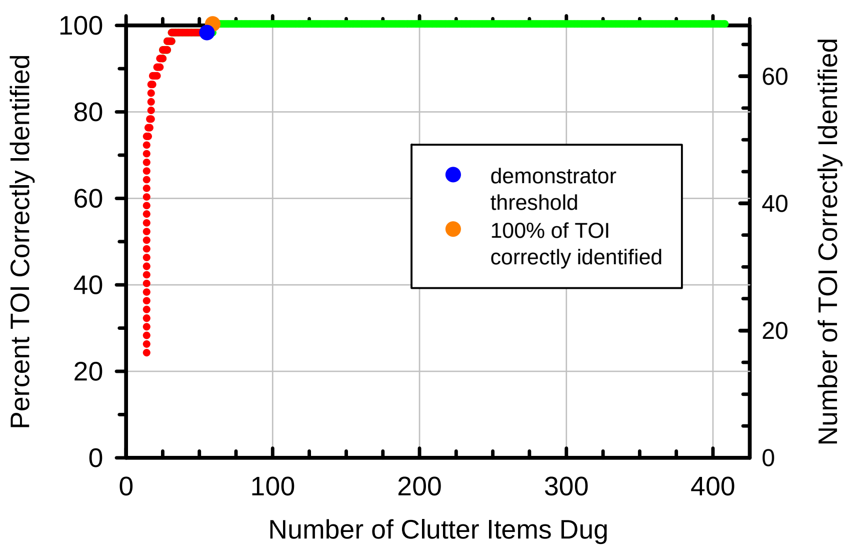

Figure 6-3. Results of the Sky analysis of the dynamic MPV data

7. Conclusions

The Man-portable Vector Sensor was used on the former Camp George West Artillery Range in both dynamic and cued mode. Anomalies were identified from the dynamic survey data using a threshold based on the signal expected from a 75-mm projectile at 60-cm depth. All QC seeds were detected using this threshold. Cued data was collected in a five-point pattern over 466 anomalies in the 2-acre demonstration area. Analysis of these cued data yielded excellent results. All TOI were correctly identified and the best analyst was able to leave nearly 95% of the clutter in the ground. One analyst used the dynamic data only to classify the anomalies; the results were good but the last TOI on the list was five items after the analyst's stop-dig threshold.

The Camp George West site is an excellent site for classification using advanced EMI sensors. The single, relatively large munition expected allows the analysts to efficiently screen out fragments and other debris. The best performing analyst used the training digs to confirm that no smaller munitions were present in the demonstration area and then used a restricted library to very precisely identify the TOI.

The MPV sensor was successful in both dynamic and survey mode on the slopes encountered at this site. As more demonstrations using the portable sensors and dynamic data collection are performed, we will be able to better assess the range of sites for which these methods are applicable.

8. Acronyms

BRAC	Base Realignment and Closure
CO	Colorado
EM	Electromagnetic
EMI	Electromagnetic Induction
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
MPV	Man-portable Vector [Sensor]
QC	Quality Control
SERDP	Strategic Environmental Research and Development Program
TOI	Target of Interest
UXO	Unexploded Ordnance

9. References

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7. Dartmouth Cued Analysis Report, in preparation
8. Black Tusk Cued Analysis Report, in preparation
9. SAIC Analysis Report, in preparation