# Environmental Security Technology Certification Program

# (ESTCP)

# WAA Man-Portable EM Demonstration
# Data Report

## Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys

## Victorville Precision Bombing Ranges Y and 15

## ESTCP Project # MM-0533

## Victorville, CA

## October, 2006

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# Abbreviations Used

| Abbreviation | Definition |
|---|---|
| AS | Analytic Signal (nT/m) |
| BP | Blossom Point |
| COG | course-over-ground |
| DAQ | Data Acquisition (System) |
| DAS | Data Analysis System |
| DoD | Department of Defense |
| EM(I) | Electro-Magnetic (Induction) |
| ESTCP | Environmental Security Technology Certification Program |
| GPS | Global Positioning System |
| HASP | Health and Safety Plan |
| Hz | Hertz |
| MP | Man-Portable |
| MRA | Munitions Response Area |
| MTADS | Multi-sensor Towed Array Detection System |
| NRL | Naval Research Laboratory |
| nT | nanoTesla |
| PBR | Precision Bombing Range |
| PNNL | Pacific Northwest National Laboratory |
| POC | Point of Contact |
| RTK | Real Time Kinematic |
| SHERP | Safety, Health, and Emergency Response Plan |
| SNL | Sandia National Laboratories |
| SNR | Signal to Noise Ratio |
| TC | Total Coverage |
| UTC | Universal Coordinated Time |
| UXO | Unexploded Ordnance |
| WAA | Wide Area Assessment |

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# ABSTRACT

As part of the Environmental Security Technology Certification Program (ESTCP) Wide Area Assessment (WAA) Pilot Project, Nova Research, Inc. conducted a series of man-portable EMI surveys at the Victorville Precision Bombing Ranges Y and 15, approximately 42 miles southeast of Victorville, CA using a man-portable adjunct of the Naval Research Laboratory (NRL) Multi-sensor Towed Array System (MTADS). 475 anomalies were detected within 14 acres of transect surveys corresponding to coverage of 0.25% of the approximately 5,500 acre site. The survey design plan was designed to expand the site coverage of our earlier magnetometer survey to approximately 2.0% by covering areas not accessible to the tow vehicle during the vehicular survey using the original transect design. The original transect design was prepared by Pacific Northwest National Laboratory and Sandia National Laboratories to allow the tow vehicle to efficiently sample the entire demonstration site while maintaining a statistically defensible probability of traversing areas of interest within the demonstration site that matched the criteria developed from the available archive data and collected in the Conceptual Site Model (CSM). Additionally, 3.3 acres of total coverage surveys were conducted in three small areas (0.75 – 1 acre per area). The vehicular total coverage areas in the northern portion of the site were found to have much higher magnetic anomaly density, ~250 anomalies/acre, than was seen in the southern portion of the site and had been seen previously at other WAA demonstration sites, 80 anomalies/acre or less. Based on site reconnaissance and considering the geology of the area, the high anomaly density was attributed to magnetically active or 'hot' rocks. One man-portable total coverage area was placed in the vicinity of Target PBR #15 as a control. One hundred and nine (109) anomalies were detected as expected from the validated presence of metallic munitions-related material in the area. Two additional man-portable total coverage areas were located within the vehicular total coverage areas Hot #1 and Hot #2. The EM survey results located 1 anomaly within Hot #2 and none within Hot #1, validating the attribution of the high magnetometer anomaly density to magnetically active or 'hot' rocks and not metallic anomalies. A recommendation is made for how to best compare the magnetometer and EM transect results for this site. This data report serves to document the data collected during the demonstration in preparation for the validation phase of the program and further analysis.

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**October, 2006**

## 1. Introduction

### 1.1 Background

The location and cleanup of buried unexploded ordnance (UXO) has been identified as a high priority mission-related environmental requirement of the Department of Defense (DoD). The DoD UXO Response Technology Investment Strategy [1] has identified wide area assessment as one of six technology objectives, with a goal of developing capabilities to perform rapid initial assessment of large areas. The Defense Science Board (DSB) Task Force on UXO (DSB) [2] recently estimated that there are 1400 sites suspected of containing UXO contamination covering approximately 10 million acres in the continental US. By some estimates, as much as 80% of this acreage is quite likely not contaminated with UXO at all. A suite of technologies that can accurately and rapidly delineate the areas on each site that are contaminated from those that are not contaminated would lead to an immediate payback in terms of reducing the acreage that must be carefully examined and potentially cleaned.

The Environmental Security Technology Certification Program (ESTCP) Wide Area Assessment (WAA) Pilot Program consists of a layered suite of technologies deployed as a proof-of-concept demonstration of the DSB's WAA call-to-action. The prototypical WAA site is a large area (10,000's of acres) that may contain isolated areas of concentrated UXO such as aiming points. The top layer consists of (relatively) high-flying sensors (and aircraft) (e.g. orthorectified photography), designed to detect "munitions-related features" such as target rings and craters. The next layer is a helicopter-borne magnetometer array designed to detect subsurface ferrous metal directly. The magnetometer data can be used to locate and define boundaries for targets, aim points, and OB/OD sites. The final layer is a ground survey of portions of the site using a vehicular-towed array of magnetometers. In conjunction with statistical transect planning, the ground survey will aid in defining target locations and boundaries. We have previously demonstrated a final-layer system using a ground-based, towed magnetometer array system. Due to surface geology and terrain limitations, the transect plan cannot always be surveyed in it's

entirety with the vehicular towed-array system. A ground-based man-portable, Electromagnetic Induction (EMI) system was demonstrated as a potential avenue to recoup a portion of the area not accessible to the vehicular system.

### 1.2 Objective of the Demonstration

We have previously conducted a vehicular, towed-array demonstration at the Victorville PBRs Y & 15 WAA Pilot Project demonstration site as part of the WAA Pilot Project [3]. Full-field magnetometer data was collected over the demonstration site along planned transects provided by Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories (SNL) in cooperation with the ESTCP Program Office. These transects were designed based on available archive information and sound statistical sampling methodologies. The survey results were provided to PNNL, SNL, and the ESTCP Program Office for analysis to rapidly delineate UXO contamination sites such as impact areas and bombing targets. 1910 anomalies were detected within 93 acres of transect surveys corresponding to coverage of 1.7% of the approximately 5,500 acre site. 126 acres of total coverage surveys were conducted in small areas (6-30 acres per area) to better characterize the overall site. Due to surface geology and terrain limitations, the entire transect plan could not be surveyed with the vehicular towed-array system. To increase the fractional transect survey coverage, additional acreage was surveyed using a man-portable, litter-carried EM61 MkII system. The vehicular total coverage areas in the northern portion of the site had been found to have much higher magnetic anomaly density, ~250 anomalies/acre, than was seen in the southern portion of the site and had been seen previously at other WAA demonstration sites, 80 anomalies/acre or less. Based on site reconnaissance and considering the geology of the area, the high anomaly density was attributed to magnetically active or 'hot' rocks. To validate the 'hot' rocks assignment of the northern magnetic anomalies, man-portable EMI total coverage surveys were conducted on small subsets (0.75 to 1 acre each) of three vehicular total coverage areas including one area known to contain munitions-related material as a control and two areas in the northern portion of the site.

## 2. Technology Description

### 2.1 Technology Development and Application

#### 2.1.1 Man-Portable, Litter-Carried EM61 MkII System

The demonstration was conducted using a man-portable, litter-carried system developed as an adjunct of the Naval Research Laboratory (NRL) Multi-sensor Towed Array Detection System (MTADS). The MTADS was developed with support from ESTCP. The system hardware consists of low-metallic-content components that are used to carry a single EM61 MkII metal detector (0.5m x 1m, Geonics, Ltd.) over modest areas (10 lane km, 2 acres/day) to detect buried UXO. The sensors are sampled at 10 - 15 Hz and surveys are conducted at typical walking speed, ~2 mph (1 m/s). This results in a sampling density of approximately 10 cm down track. For total coverage surveys, a horizontal sensor spacing of 75 cm is used for the 0.5m x 1.0m sensor coil.

The EM61 MkII is a pulsed-induction sensor which transmits a short electromagnetic pulse (a unipolar rectangular current pulse with a 25% duty cycle) into the Earth. Metallic objects

interact with this transmitted field which induce secondary fields in the objects. These secondary fields are detected by the detection coils that are collocated with and above the transmit coil. An example is shown in Figure 2-1. The instrument consists of two air-core 1m x 0.5m coils housed in fiberglass, a backpack containing a battery and processing electronics, and an optional data logging device. The lower coil serves as the transmitter, and main receiver. The upper (receiver only) coil lies 30cm above the bottom coil. The EM61 MkII can be operated in one of two modes: 1) With 4 time "gates" (216, 366, 660, and 1266 µsec) or 2) in Differential mode, in which 3 time "gates" are measured from the bottom coil (216, 366, 660µsec), and one is measured from the top coil (at 660µsec). Data are recorded using a handheld logger, or alternatively in a PC, using Geonics or custom PC software.

Figure 2-1 – Geonics EM61 MkII coils on a test platform

The sensor position is measured in real-time (up to 20 Hz) with position accuracies of ~5 cm using high performance Real Time Kinematic (RTK) Global Positioning System (GPS) receivers. All position and sensor data are time-stamped with or referenced to Universal Coordinated Time (UTC) derived from the satellite clocks and recorded by the data acquisition computer (DAQ). The complete system is shown in the field in Figure 2-2. The positioning technology requires the availability of one or more known first-order survey control points. The sensor, position, and timing files are downloaded periodically throughout a survey onto removable media and transferred to the data analyst for analysis.

A WAAS-enabled handheld GPS receiver (meter-level, Garmin GPSMAP 76CS) was used for navigating during the transect portion of the demonstration using the built-in point-to-point navigation software. The manufacturer provides software for loading points and routes from a PC into the unit for this purpose.

Figure 2-2 – Man-portable, litter-carried EM61 MkII sensor system as demonstrated

### 2.1.2 Data Analysis Methodology

Each data set is collected using a custom software package developed at NRL in Visual Basic (v6, Microsoft, Inc.). The collected raw data is preprocessed on site for quality assurance purposes using standard MTADS procedures and checks. The data set is comprised of several files, each containing the data from a single system device with unique data rates. The data is merged and imported into a single Oasis montaj (v6.3, Geosoft, Inc.) database using custom scripts developed from the original MTADS DAS routines which have been extensively validated. An example of a working screen from Oasis montaj is shown in Figure 2-3. As part of the import process any data corresponding to a sensor outage, a GPS outage, or a COG stop / reverse, is defaulted or marked to not be further processed. Defaulted data is not deleted and can be recovered at a later time if so desired. Any long wavelength features such as sensor drift are filtered from the data (demedianed).

For the transect surveys, there is no cross-track data from which to generate a two-dimensional representation, so anomaly selection is done looking for anomaly peaks along a downtrack profile. The EM61 MkII provides data for four time gates, the choice of which time gate to use for anomaly detection can be site-specific. Past experience has shown that for simple detection of anomalies under geologically benign conditions, the earliest time gate is typical the best time gate to use for signal–to-noise reasons. If there are sensor drift problems with gate 1 that cannot be removed simply by leveling, a later time gate can be used instead. The second gate has proven to be useful if geology in the area is apparent in the first gate. The first few data sets collected on site were examined and the first time gate was found to be acceptable for anomaly selection. The appropriateness of the choice was monitored during the demonstration. A built-in feature of Oasis montaj was then used to extract peaks above a given threshold from the data. The detected anomaly locations along with the signal magnitude at the peak of the anomaly were provided to the ESTCP Program Office. The down-sampled transect COG (~10 m spacing) was also provided.

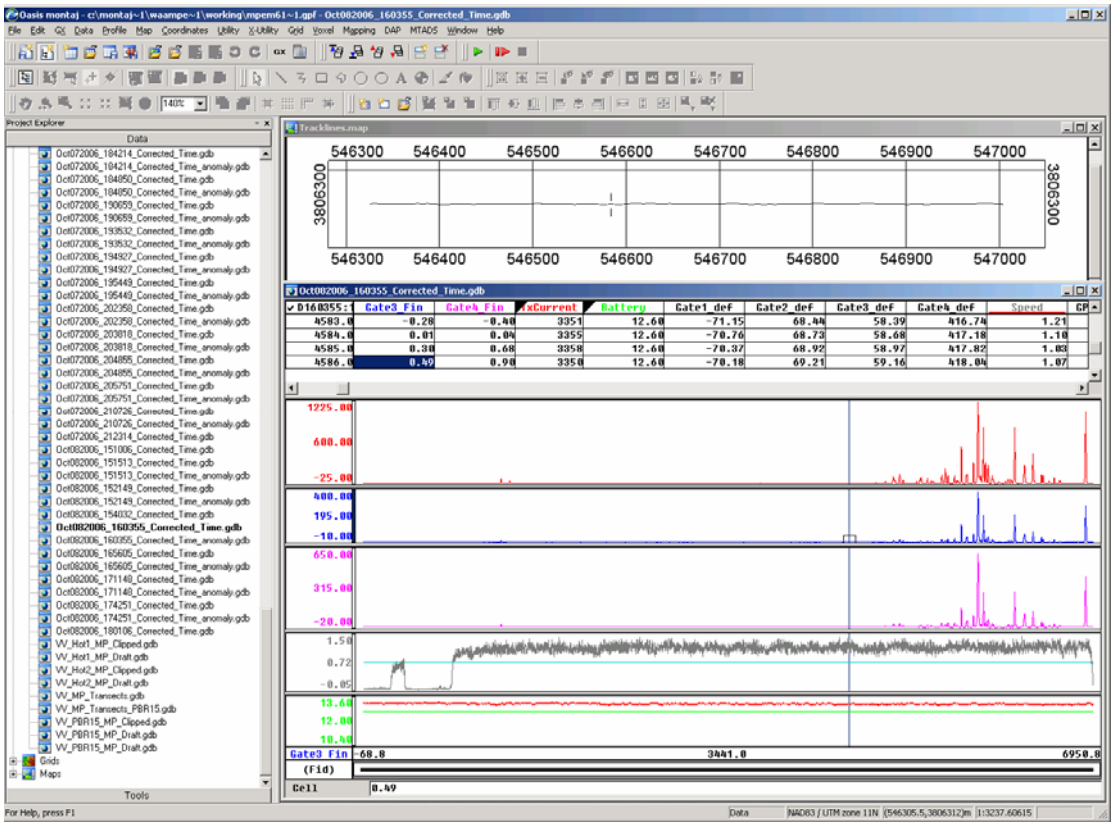

Figure 2-3 – Working screen in Oasis montaj™ of data preprocessing work flow

For the total coverage (100%) surveys, the located demedianed sensor data was imported into the UX-Analyze subsystem of Oasis montaj for individual anomaly selection and analysis. UX-Analyze has been developed, in part from the MTADS Data Analysis System (DAS) software, by AETC and Geosoft under ESTCP funding. Based on experience, the combination of lower coil time gate 3 and the upper coil time gate (both centered at a delay of 660 μs) data was used for the analysis. All anomalies with a peak intensity of greater than 4 mV in time gate 1 were analyzed. An example of a working screen from UX-Analyze is shown in Figure 2-4. A spreadsheet (Excel 2003, Microsoft, Inc.) containing details of the anomaly location and fit parameters is provided. The located demedianed sensor data is also provided for archival purposes.

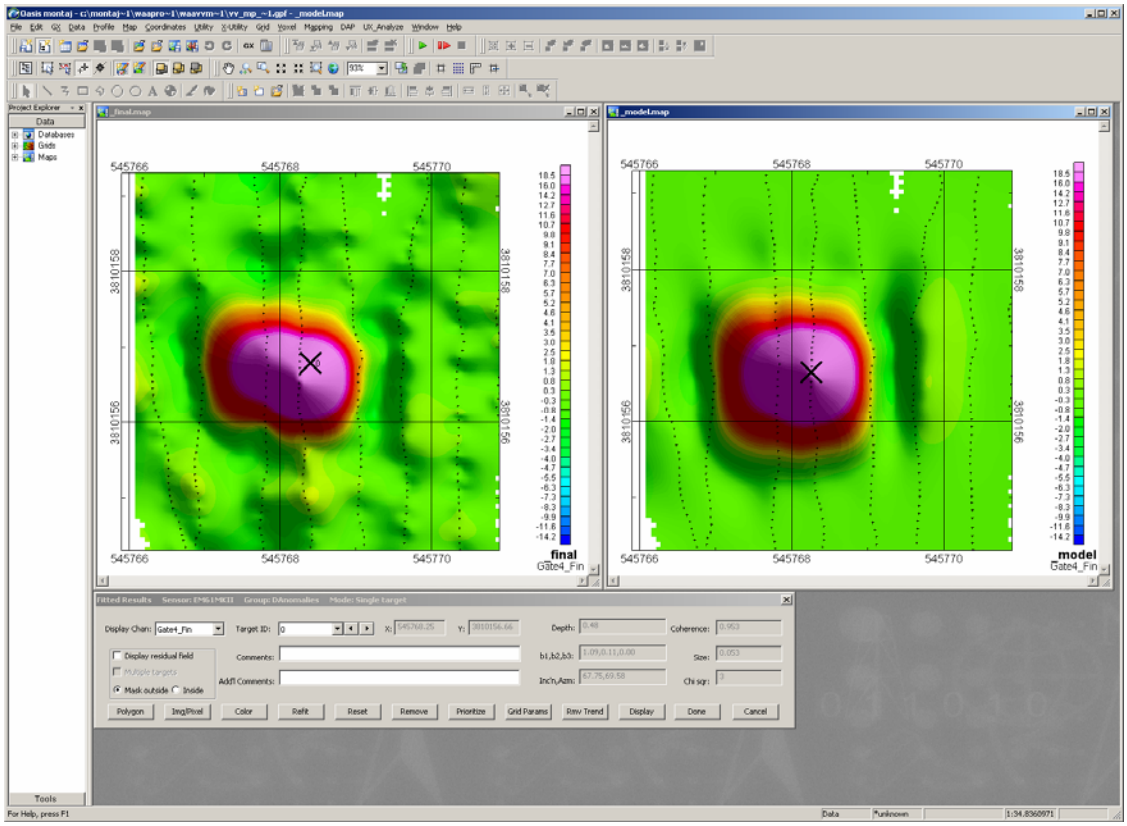


Figure 2-4 – Screenshot of the UX-Analyze working screen

## 2.2 Previous Testing of the Technology

The performance of the vehicular MTADS has been demonstrated at several seeded and live ranges sites over the last decade [4-9]. The MTADS has demonstrated probabilities of detection of 95 to 97% and location accuracies of better than 15 cm with the magnetometer system [7]. The vehicular MTADS has been selected to serve as the ground truth for several ESTCP-supported demonstrations of potential wide area survey systems [10,11,12].

As an example of the performance of the MTADS, the results from the survey of the Target S1 at Isleta Pueblo, NM [12] are discussed here briefly. For the Isleta demonstration, a portion of the site was blind seeded by the ESTCP Program Office with a variety of inert munitions. A total coverage survey was conducted over the site. The anomaly list generated by the MTADS team was then submitted to a neutral third party for independent evaluation. The results were representative of the past performance of the MTADS system. Analyzed anomalies were classified into 6 priority categories where 1 is likely UXO, 3 is unlikely UXO, 4 is unlikely a clutter item, and 6 is likely a clutter item. The probability of detection, $P_d$, and the cumulative alarm rate were determined for including each successive category (from 1 to 6). $P_d$ is the fraction of emplaced items detected and the false alarm rate is given as picks per hectare not corresponding to an emplaced item. For the emplaced items at this demonstration, 89% of the emplaced items ($P_d = 0.89$) were detected and placed in the first three categories with a False Alarm Rate (FAR) of 7 / hectare. The location performance metrics were mean errors of -1 and 4 cm for easting and northing, respectively, with a standard deviation of 12 and 13 cm for the

same. As demonstrated previously, there was no improvement in detection by widening the detection radius from 1.0 to 1.5 m. The detection radius defines how large an error in reported position can still be considered a detection of the emplaced item.

Several hundred detected anomalies were selected for remediation to determine the performance of the systems involved in the overall demonstration. The evaluation metric used was the location difference between the reported location of the anomaly by the MTADS and the actual location reported by the remediation contractor. As was seen for the emplaced items, a large majority of the anomaly picks fall well within the more restrictive 1.0-m halo. The detailed location performance was a mean miss distance of 35 cm. 90% of the anomaly picks were within 59 cm and 95% were within 77 cm of actual remediated location of the anomaly. As was seen for the emplaced items, a large fraction of the remediated anomalies corresponding to munitions or munitions-related fragments were categorized in the first three priority groups with 95% being captured in the first two priority groups.

# 3. Demonstration Design

## 3.1 Testing and Evaluation Plan

### 3.1.1 Demonstration Set-Up and Start-Up

The Victorville WAA Pilot Project Demonstration site encompasses approximately 5,500 acres of the Victorville FUDS. Victorville Precision Bombing Range Y consists of 4,862 acres and the adjoining PBR 15 comprises 640 acres. The two targets are located approximately 42 miles southeast of the town of Victorville, CA. The approximate coordinates for the survey area are given in Table 3-1.

The MTADS Man-Portable (MP) Electromagnetic Induction (EM(I)) system was mobilized to the Victorville site by a traditional shipping company. The necessary GPS equipment, batteries and chargers, and a modest collection of office equipment, radios and chargers, tools, equipment spares, and maintenance items were shipped to a local (Palm Springs) FedEx shipping office and held for pickup by the advance team member.

Due to the remoteness of the survey site, no essential support services are available on-site. Due to the short duration and scope of this demonstration, little was required in the way of support on-site. Nova Research made provisions to provide or purchase the requisite supplies, materials, and facilities from local firms. Power was provided on-site by a gas-powered field generator (2 kW range) to recharge equipment batteries during the day. Batteries were also charged overnight in the field team's hotel rooms. Communications among on-site personnel was provided by hand-held VHF radios. Radios were provided to each group of field personnel. The availability of cellular phone communications on site is non-continuous but was available in a majority of the area that was the subject of this demonstration. A portable toilet was provided onsite to support the field team.

The team personnel arrived in two waves. The advance team member traveled one day early and pick up the shipped items from FedEx and transported them to the work site prior to the arrival

of the remaining team on the second day. The advance team began assembly and testing of the EM system and began preparations for the total coverage surveys. Merrill-Johnson Engineering, Inc. of Victorville, CA has previously established eight geodetic survey points within the demonstration area. The coordinates of all eight points are given in Table 3-2 (horizontal datum: North American Datum of 1983 (NAD83/CORS96); vertical datum: North American Vertical Datum of 1988 (NAVD88); geoid model: National Geodetic Survey Geoid03). The RTK GPS base station receiver and radio link were established on one of the available established control points (NOVA1, which was used exclusively for the vehicular survey as well). Each day the establishment of normal system SNR performance was verified along with the operational state of the RTK GPS system.

Table 3-1 – Coordinates for the Approximate Corners of the WAA Pilot Project Victorville Demonstration Site

| **Point** | **Latitude** | **Longitude** | **Northing (m)** | **Easting (m)** |
|---|---|---|---|---|
| | **NAD83/CORS96** | | **UTM Zone 11N, NAD 83** | |
| SW | 34° 23' 24.23165" N | 116° 32' 03.73678" W | 3,805,505.15 | 542,802.43 |
| NW | 34° 26' 02.02266" N | 116° 32' 02.62074" W | 3,810,365.54 | 542,808.59 |
| NE | 34° 25' 59.25292" N | 116° 28' 51.46962" W | 3,810,303.94 | 547,687.46 |
| SE | 34° 23' 22.26526" N | 116° 28' 53.16285" W | 3,805,468.19 | 547,668.98 |
| MS1 | 34° 23' 22.39906" N | 116° 29' 25.00656" W | 3,805,468.19 | 546,855.84 |
| MS2 | 34° 23' 23.06145" N | 116° 30' 29.58979" W | 3,805,480.45 | 545,206.62 |
| MS3 | 34° 23' 50.70619" N | 116° 30' 29.16476" W | 3,806,332.01 | 545,213.34 |
| MS4 | 34° 23' 51.70337" N | 116° 31' 32.23687" W | 3,806,355.06 | 543,602.81 |
| SW | 34° 23' 24.11198" N | 116° 31' 32.58011" W | 3,805,505,15 | 543,598.02 |

The Site Safety Officer conducted ‘tail-gate’ safety meetings each morning that personnel were on site. The topic(s) for each day’s meeting were at the discretion of the Site Safety Officer. Refer to Appendix D MTADS Safety, Health, and Emergency Response Plan of the vehicular Demonstration Plan for all other site safety related information.

Preventative maintenance inspections were conducted at least once a day by all team members, and any deficiencies were addressed according to the severity of the deficiency. Parts, tools, and materials for select maintenance scenarios were available on site.

### 3.1.2 Period of Operation

The final schedule for the Demonstration is given in tabular form in Table 3-3. The fieldwork was conducted October 2 – 8, 2006.

Table 3-2 – Survey Control Points Installed for the WAA Pilot Project at Victorville PBRs Y & 15

| Point Name | Latitude | Longitude | Ellipsoid Height (m) | Northing (m) | Easting (m) | Elevation (m) |
|---|---|---|---|---|---|---|
| | NAD83/CORS96 | | | UTM Zone 11N, NAD 83 | | NAVD88 |
| NOVA1 | 34° 23’ 33.52094” N | 116° 31’ 37.98792" W | 796.508 | 3,805,794.320 | 543,458.584 | 827.468 |
| NOVA2 | 34° 24’ 43.87014” N | 116° 31’ 57.55568" W | 806.430 | 3,807,958.890 | 542,948.957 | 837.407 |
| NOVA3 | 34° 25’ 40.60227” N | 116° 31’ 25.90349" W | 802.874 | 3,809,710.110 | 543,748.763 | 833.857 |
| NOVA4 | 34° 25’ 45.29604” N | 116° 30’ 25.98072" W | 766.682 | 3,809,861.999 | 545,277.478 | 797.660 |
| NOVA5 | 34° 25’ 54.04117” N | 116° 29’ 31.19413" W | 815.236 | 3,810,138.272 | 546,674.434 | 846.207 |
| NOVA6 | 34° 25’ 05.62289” N | 116° 29’ 12.10592" W | 833.047 | 3,808,649.345 | 547,169.158 | 864.016 |
| NOVA7 | 34° 24’ 38.08707” N | 116° 30’ 10.61886" W | 753.645 | 3,807,793.744 | 545,679.707 | 784.621 |
| NOVA8 | 34° 23’ 33.07497” N | 116° 29’ 40.35276" W | 775.151 | 3,805,795.067 | 546,462.335 | 806.123 |

### 3.1.3 Scope of Demonstration

Data collection was conducted at the Victorville WAA Pilot Project Demonstration Site, 42 miles southeast of the town of Victorville, CA at the request of the ESTCP program office. The demonstration consisted of two parts. First, approximately 50 lane km of 1m-wide transects were surveyed to enhance the coverage of the original transect design which guided the vehicular magnetometer survey conducted in March 2006. A litter-carried, EM61 MkII-based system was used to allow access to areas which were not accessible to the towed array system.

The original vehicular transect design for this WAA Pilot Project demonstration site is shown in Figure 3-1 as light black lines, labeled with the original transect ID number. There were 74 transects in the original design, oriented east / west. The actual course-over-ground (COG) of the vehicular system survey is shown in heavy, colored lines to distinguish each day’s progress. Some areas of the site were not accessible to the vehicular system, leading to portions of the transect plan not being surveyed. This demonstration improved the fractional completion of the transect plan by adding 56 lane km, or 14 acres, of coverage using a man-portable EM system. The maroon, hatched areas in Figure 3-1 were the planning boundaries for the man-portable demonstration.

Secondly, 100% (total) coverage (TC) surveys of three (3) 0.75 – 1 acre areas selected in conjunction with the Program Office were conducted to provide additional data / validation of the results of the vehicular magnetometer survey in the northern ‘Hot’ areas. The total coverage areas were each selected to cover approximately 100 anomalies from one of the vehicular magnetometer total coverage areas. A 0.75-m lane spacing was used for the total coverage areas. The man-portable total coverage areas surveyed were located within the boundaries of the PBR #15 Radial, Hot #1, and Hot #2 vehicular total coverage areas. These areas are shown (in green) in Figure 3-2 along with the results from the vehicular transect surveys. The vehicular transect results include the actual transect paths (course-over-ground) and the locations of detected anomalies from the transect data.

Table 3-3 – Victorville PBRs Y & 15 MP EM Survey Demonstration Field Schedule

| **Date** | **Planned Action** |
|---|---|
| Week of September 18th | Equipment packed at Blossom Point. |
| Monday, September 25th | Equipment transferred to NRL for shipment. |
| Tue, September 26th | Equipment left NRL for hold in Palm Springs, CA. |
| Fri, September 29th | Equipment arrived Palm Springs, CA. |
| Sun, October 1st | Advance personnel arrived in Palm Springs, CA. |
| Mon, October 2nd | Advanced personnel received, deployed to site, and unpacked equipment. Remaining team members arrived in Yucca Valley and continued with site preparation. |
| Tue, October 3rd | Total coverage surveys began |
| Wed, October 4th | Completed total coverage surveys and began transect surveys. |
| Sun, October 8th | Completed transect surveys and packed equipment. |
| Mon, October 9th | Equipment shipped to Blossom Point. Advance personnel departed Palm Springs, CA. |
| Tue, October 10th | Remaining team members depart Palm Springs, CA |
| Thu, October 19th | Equipment arrived at Blossom Point. |
| Week of October 30th | Submitted Draft Data Report to ESTCP. |

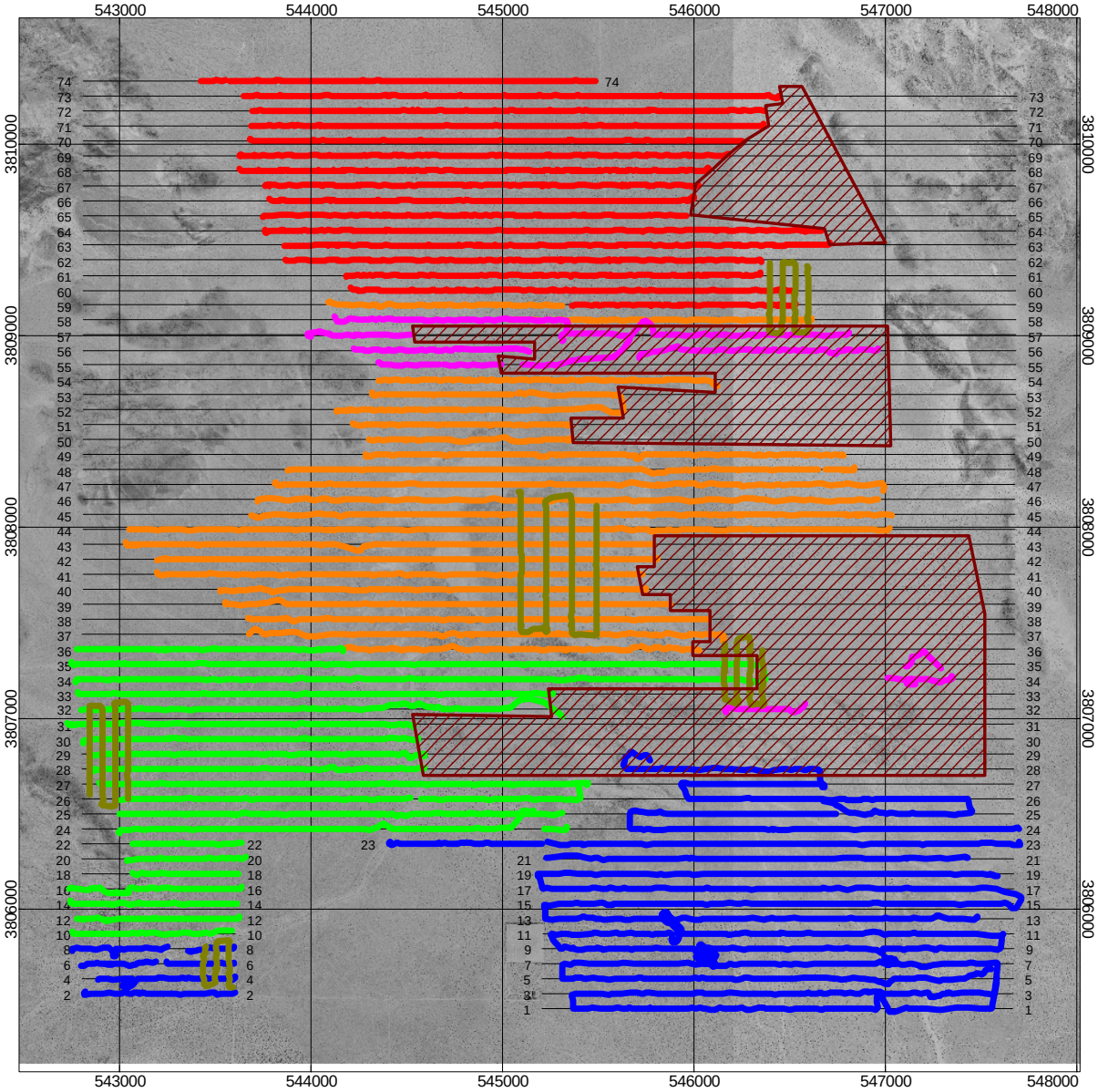


Figure 3-1 – Man-portable EM survey transect concept

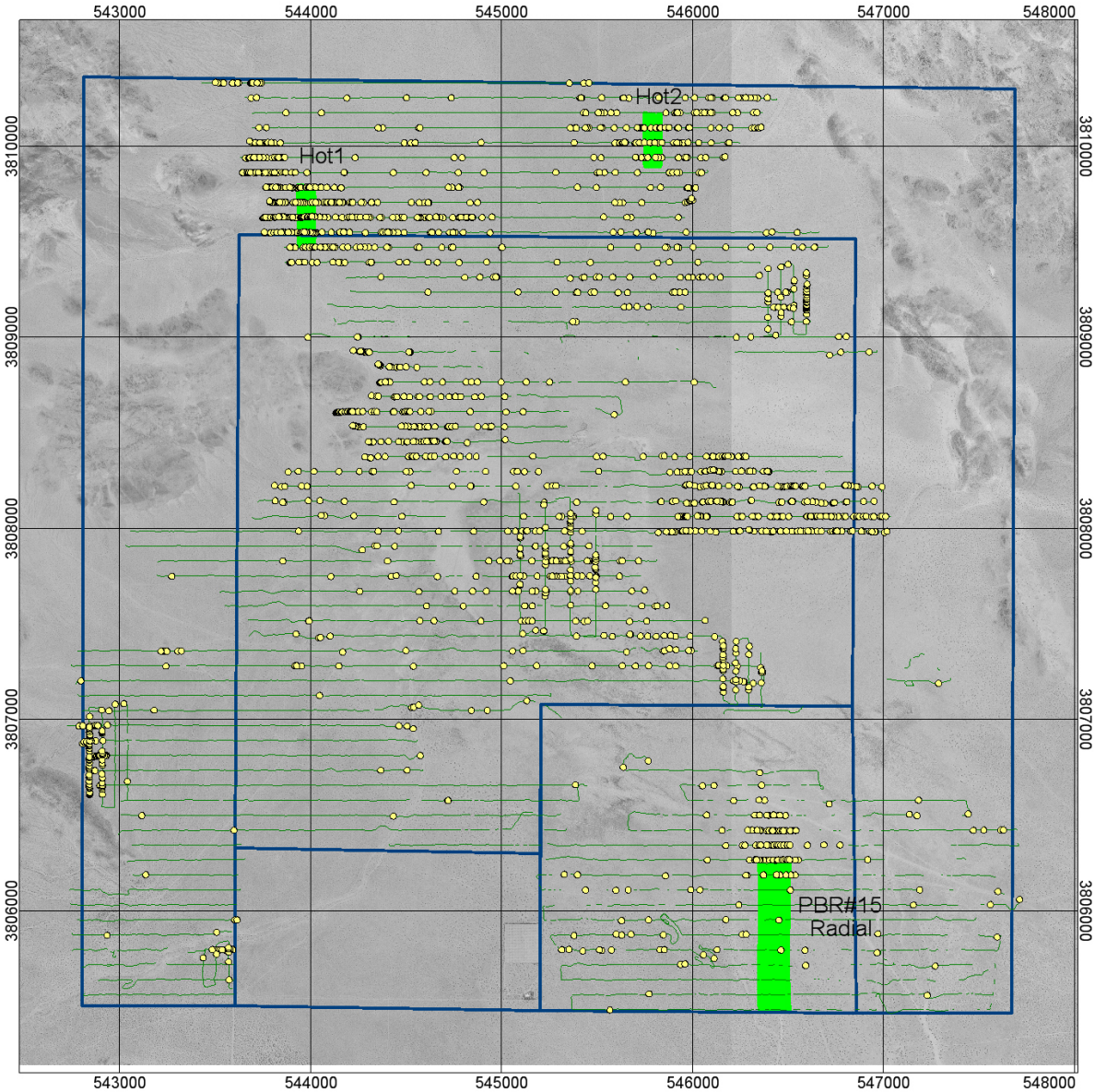


Figure 3-2 – Total coverage areas for further investigation and transect results (course-over-ground and detected anomalies)

### 3.1.4 Operational Parameters for the Technology

The precision collection of high SNR magnetometer data using the MTADS platforms is a mature technology. The rapid and accurate extraction of anomaly location and a measure of anomaly amplitude (in this case, peak anomaly signal) from high-volume transect data collection is the novel component of this series of demonstrations. To accomplish this task an automated method of extracting the anomaly locations from the survey data was required. One such method has been discussed previously [13,14] for magnetometer array systems. Briefly, the located magnetic field data (nT) are collected as normal for an MTADS survey. The demedianed total

field data are converted to analytic signal (AS, nT/m) where the analytic signal is calculated from the squares of the derivatives in the *x*, *y*, and *z* directions:

$$AS = \sqrt{\left(\frac{d}{dx}\right)^2 + \left(\frac{d}{dy}\right)^2 + \left(\frac{d}{dz}\right)^2}$$

The utility of the analytic signal is that anomaly features which are dipolar (have both positive and negative components) in the total field are monopolar in the analytic signal. This facilitates the detection of anomalies. One can then define the parameters and peak cut-off threshold required to eliminate multiple picks per anomaly. Using the selected set of parameters, anomalies can be selected in an automated and consistent fashion and rapidly forwarded for analysis.

In the case of the man-portable, EM61 MkII system used for this demonstration, modifications to this methodology were required. The man-portable system is composed of a single sensor with a 0.5m x 1.0 m footprint. With the single-pass, single sensor transect data collection model used, it is neither possible nor necessary to generate a sensor value grid, or mesh, and to calculate the analytic signal values. The lack of cross track sensor data prevents the generation of any signal grid. Additionally, EM61 MkII data is essentially monopolar within a given time gate once the data is properly leveled so the benefit of converting to the analytic signal is not realized like it s for magnetometer data. For this demonstration, transect sensor data was evaluated as a position-referenced profile of a single time gate using a built-in profile peak picking feature of Oasis montaj (anompick.gx). The profile peak picking feature has only two input parameters, the zero level and the minimum threshold for selected a peak. Time gate 1 data was found to be acceptable for anomaly selection as shown in Figure 3-3. Given that the data is well leveled / demedianed, the zero level parameter is effectively moot and set to 0 mV.

The survey data from several early transect surveys were used to evaluate the minimum peak threshold parameter the Victorville site and the MP EM system. The RMS variation in the sensor data from quiet portions of the data was evaluated and found to be 0.3 – 0.8 mV, or roughly 5 times the static sensor noise levels (See Section 3.1.8 for a discussion of the static sensor values). See Table 3-4 for the time gate values used from transect data.

Table 3-4 – EM61 MkII sensor per time gate dynamic noise levels

| | Std Deviation (1 σ) | | | | | |
|---|---|---|---|---|---|---|
| Date Code | Gate 1 | Gate 2 | Gate 3 | Gate T | Avg Bottom | Overall Avg. |
| Oct042006_195006 | 0.498 | 0.416 | 0.354 | 0.690 | 0.423 | 0.490 |
| Oct042006_221926 | 0.332 | 0.310 | 0.257 | 0.549 | 0.300 | 0.362 |
| Oct042006_215820 | 0.478 | 0.440 | 0.373 | 0.783 | 0.430 | 0.519 |
| | | | | | | |
| | | | | Average | 0.384 | 0.457 |
| | | | | Std. Dev | 0.073 | 0.083 |

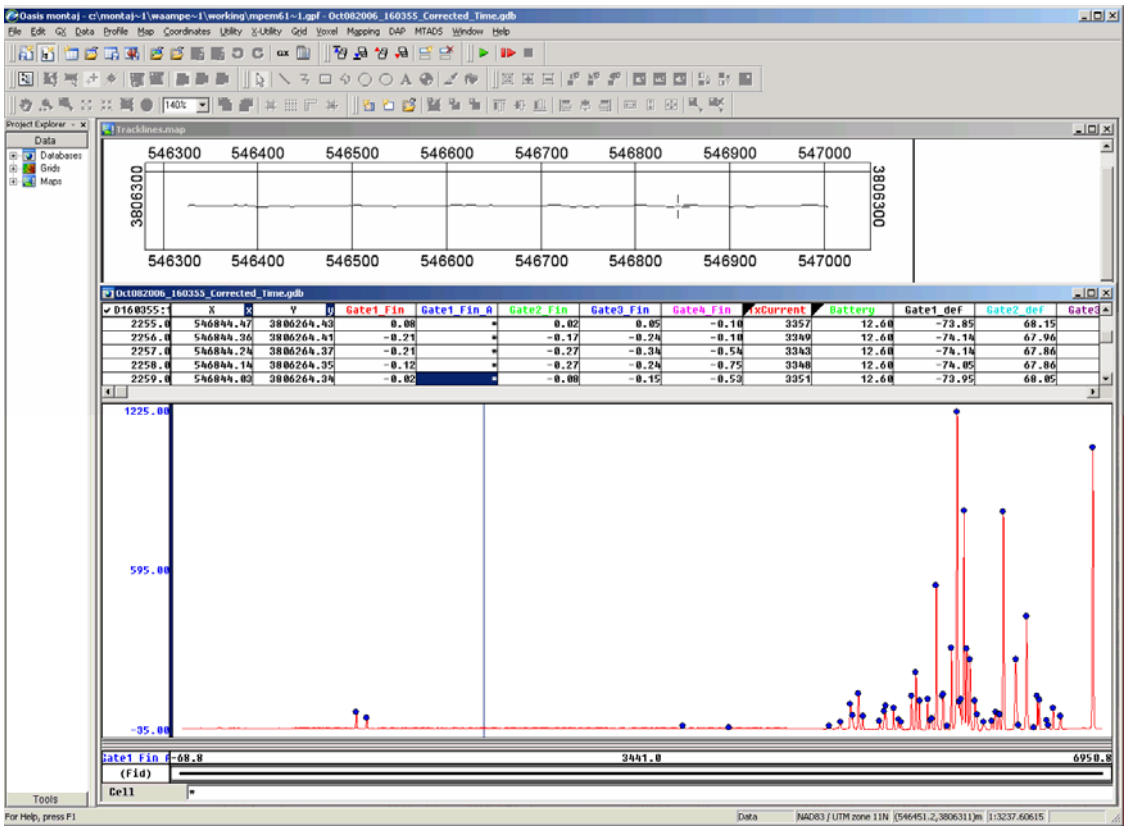


Figure 3-3 – Screenshot from Oasis montaj displaying a profile for time gate 1 and the selected anomalies from the transect using the final minimum peak threshold value

Starting with a minimum peak height threshold of 1 mV and increasing the threshold, a viable minimum peak height threshold was determined for this site / system pair. A minimum peak height threshold value of 4 mV for time gate 1 was found to be the best compromise between sensitivity and spurious anomaly detection and was used for this demonstration. The results for several early data sets are shown in Figure 3-4. The chosen threshold is shown as a vertical red line. Continued review throughout the survey found no need to further refine the minimum peak height threshold value.

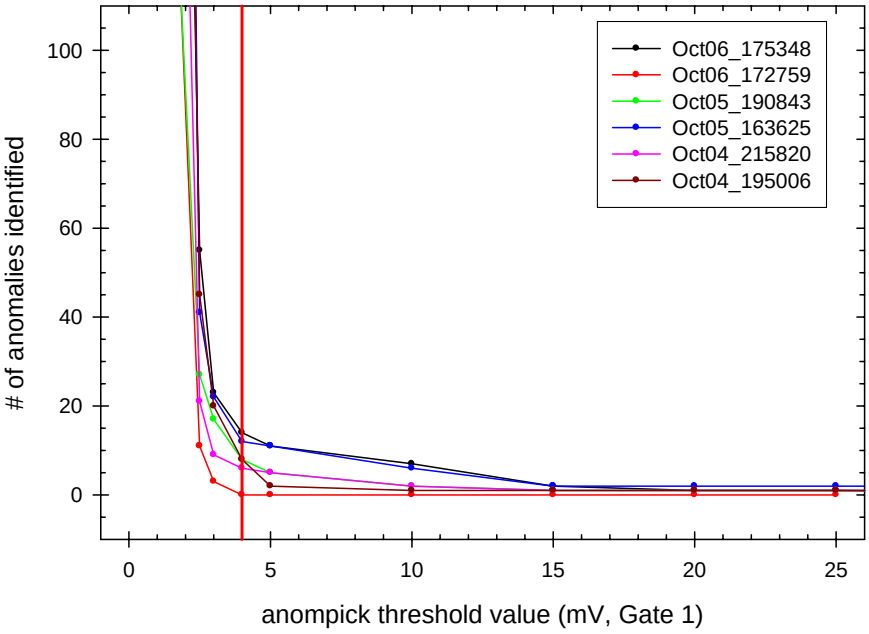


Figure 3-4 – Effect of increasing minimum peak height threshold value for early MP EM data set results. The red line indicates the result for the final parameter value.

### 3.1.5 Comparison of EM and Magnetometer Anomaly Selection Methodologies

The previous vehicular magnetometer survey [14] surveyed approximately 1.7% of the total Victorville WAA demonstration site with magnetometer array transects. A stated goal of this demonstration was to augment the transect coverage using a man-portable EM system that would allow access to areas inaccessible to the tow vehicle using an instrument less sensitive to the local geology identified in the northern portion of the site during the vehicular demonstration. To maximize the utility of this additional data, it is necessary to understand the relationship between results from the two systems and to be able to combine the two data sets into a coherent whole. How to compare results from the two different sensor systems which operate on different principles is not immediately obvious.

Two transect lines were identified from the southern portion of the vehicular survey for inter-system comparison. One kilometer long segments of Lines 19 and 21 were selected for being free of geological interference and for spanning a range of densities of known compact metallic targets. These two lines traversing the area south of Target PBR #15 with Line 21 crossing one of the Target's outer pavement circles and Line 19 further to the south. The vehicular data indicated a large number of anomalies along the selected portion of Line 21 (29 anomalies) and a smaller but non-zero number along the selected portion of Line 19 (8 anomalies). Man-portable EM transect surveys were conducted for the same 1-km long sections of Lines 19 and 21.

To compare the anomaly selection methods for the magnetometer and EM systems, a similar method to that used to establish the site-specific anomaly selection thresholds for each system was used. Anomalies were selected from each transect segment for each sensor at various threshold values. As expected, the number of anomalies selected decreases rapidly as the

threshold is increased above the sensor noise floor until reaching a 'knee' or curvature change beyond which the rate of anomalies selected slows dramatically. This region presumably corresponds to well-defined anomalies well above the noise floor. The final site-specific threshold value used during the demonstrations is chosen to fall in this 'knee' region. For the magnetometer survey, the threshold was chosen conservatively or placed in the higher threshold portion of the 'knee' region at 62.5 nT/m for Victorville. Based on repeated feedback asking for lower threshold results to evaluate their potential utility, the threshold of the EM survey was chosen less conservatively at 4 mV (see Figure 3-4) while maintaining an acceptable rejection level for spurious anomalies. Linear scaling factors were evaluated for the co-registration of EM anomaly selection results with the existing magnetometer results. A scaling factor of 10 for the EM cut-off threshold was found to give good agreement with the magnetometer data. For example, an EM cut-off threshold of 4 mV corresponds to a magnetometer cut-off threshold of 40 nT/m. For anomaly densities, a scaling factor of 0.67 was found to give good agreement between the EM and magnetometer results. The number of anomalies selected per kilometer, a measure of anomaly density, is 50% larger for the EM system than for the magnetometer system for the two transect segments used in this evaluation. These results are shown in Figure 3-5 for Line 19 and Figure 3-6 for Line 21. A small linear offset was required to achieve good co-registration of the anomaly counts (vertical axis in Figure 3-6, -5) for the Line 21 results at high cut-off threshold values. A review of the COGs for the two systems showed less overlap ($\overline{\Delta Northing} = -2.7 \pm 1.2\,\mathrm{m}$) than was achieved for Line 19 ($\overline{\Delta Northing} = 1.3 \pm 1.1\,\mathrm{m}$). Considering the anomaly rich nature of this portion of the PBR #15 target circle, the required offset is attributed to the differences in actual items surveyed by each system and is not thought to be part of the general trend.

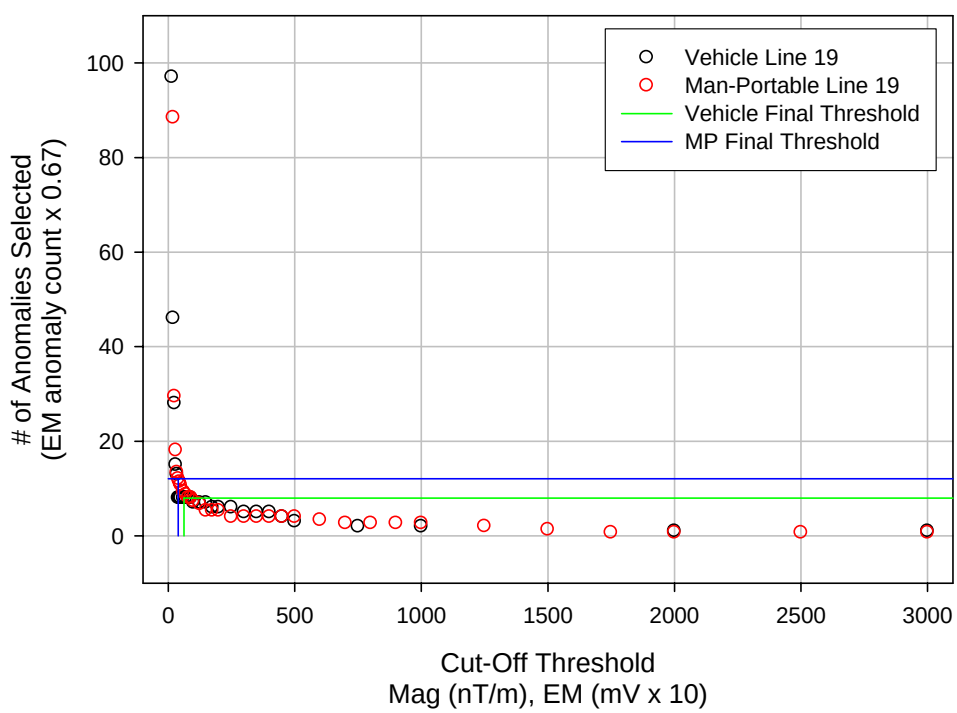


Figure 3-5 – Transect Line 19 cut-off threshold evaluation results

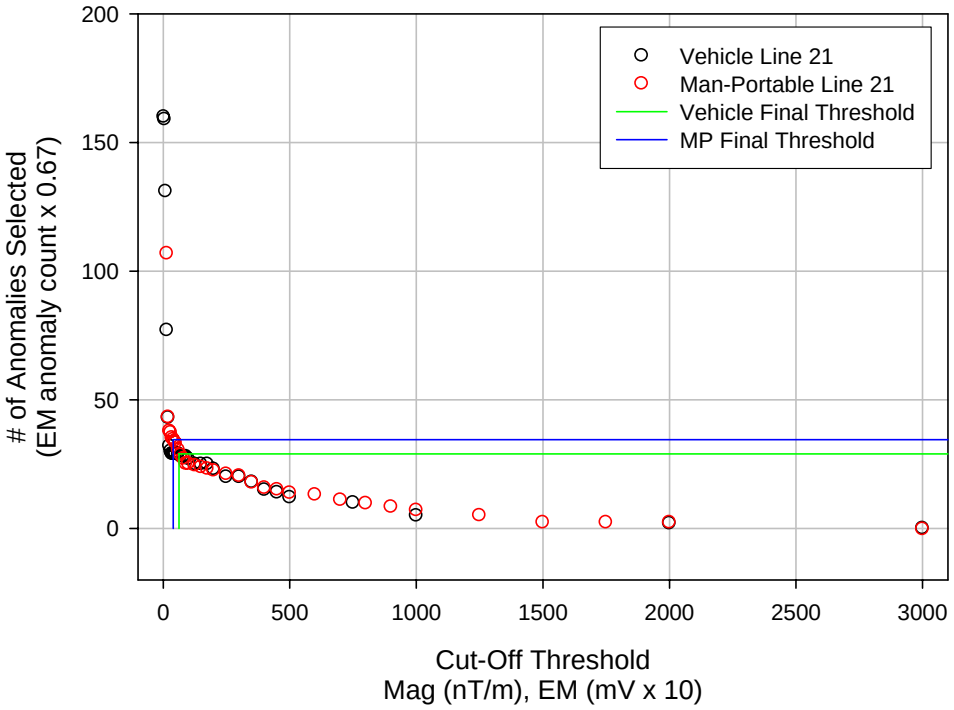


Figure 3-6 – Transect Line 21 cut-off threshold evaluation results

Based on these results, the final recommendation for comparing EM transect anomalies to anomalies from the vehicular system is to scale the EM selection threshold to be one-tenth (0.1x) the magnetometer selection threshold and to scale EM anomaly densities by a factor of approximately two-thirds (0.67).

### 3.1.6 Man-portable EM Transect Survey Results

Transect MP EM data was collected following the design discussed earlier in Section 3.1.3. The MP EM transect plan consisted of segments of 35 of the original East / West transects from the PNNL/SNL transect plan that could not be completed by the vehicular survey due to surface geology and terrain limitations and is shown in Figure 3-7. A track file suitable for use by the MTADS Pilot Guidance software (in Oasis montaj .XYZ format) for this transect plan is included on the attached CD. However, as discussed above, a handheld WAAS-level GPS receiver was used for navigation for this survey instead.

The original East / West-oriented transect plan was designed by PNNL / SNL to cover the entire WAA demonstration area. The design was based on traversing precision bombing targets designed for 100-lbs practice bombs dropped from high-altitude aircraft and 100-lbs HE-laden demolition bombs dropped from low flying aircraft. The design probability of traversing such a 500 ft circular target or feature of interest was set at 100%. The transects were oriented E/W with a 154 m spacing.

The position (easting, northing) and peak signal strength were extracted for each anomaly above an empirically determined threshold for all transect data. Data collection began with the southern-most transects and these data were used to establish the value of the minimum peak

threshold value based on the determined noise floor. Figure 3-8 shows the results of all transect data collected in course of this demonstration. The COGs are shown as green lines and each detected anomaly is shown as an open circle.

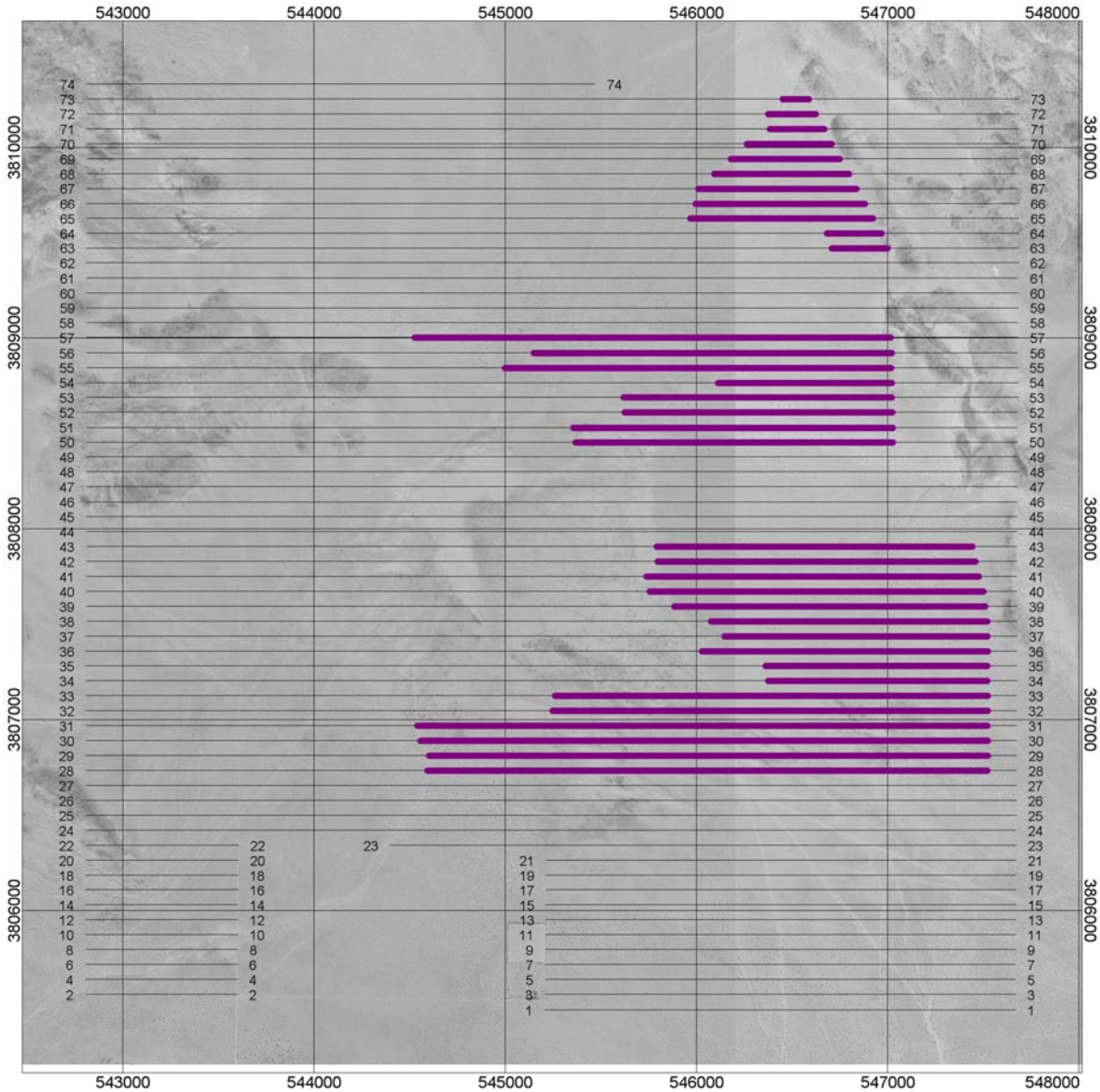


Figure 3-7 – Man-portable transect plan shown in purple. Black lines represent original PNNL/SNL transect plan

The total acreage covered by transect surveys was 14 acres, or approximately 0.25% of the total 5,500 acre site. When combined with the 1.7% site coverage of the vehicular survey, the total site coverage by transects approaches 2%. Transects were broken into one or more segments in the field to minimize off-transect walking time based on road and trail availability. A transect was surveyed in more than one file when the situation warranted, e.g. if the survey is halted for a

GPS outage window. The exact details of the area covered by each survey file are given in an Excel spreadsheet on the attached CD (Victorville MP EM Transect Summary.xls). An excerpt of the annotated listing is given in Table 3-5. The corresponding demedianed EM data, the anomaly list, and the COG files for each transect survey are also supplied on the attached CD in the "Transect Surveys" subdirectory. To allow calibration between the vehicular magnetometer and MP EM surveys, 1-km long portions of Transects 19 and 21 were surveyed by the EM system. Transect 21 crosses over a portion of PBR #15 and Transect 19 is located 154 m to the south.

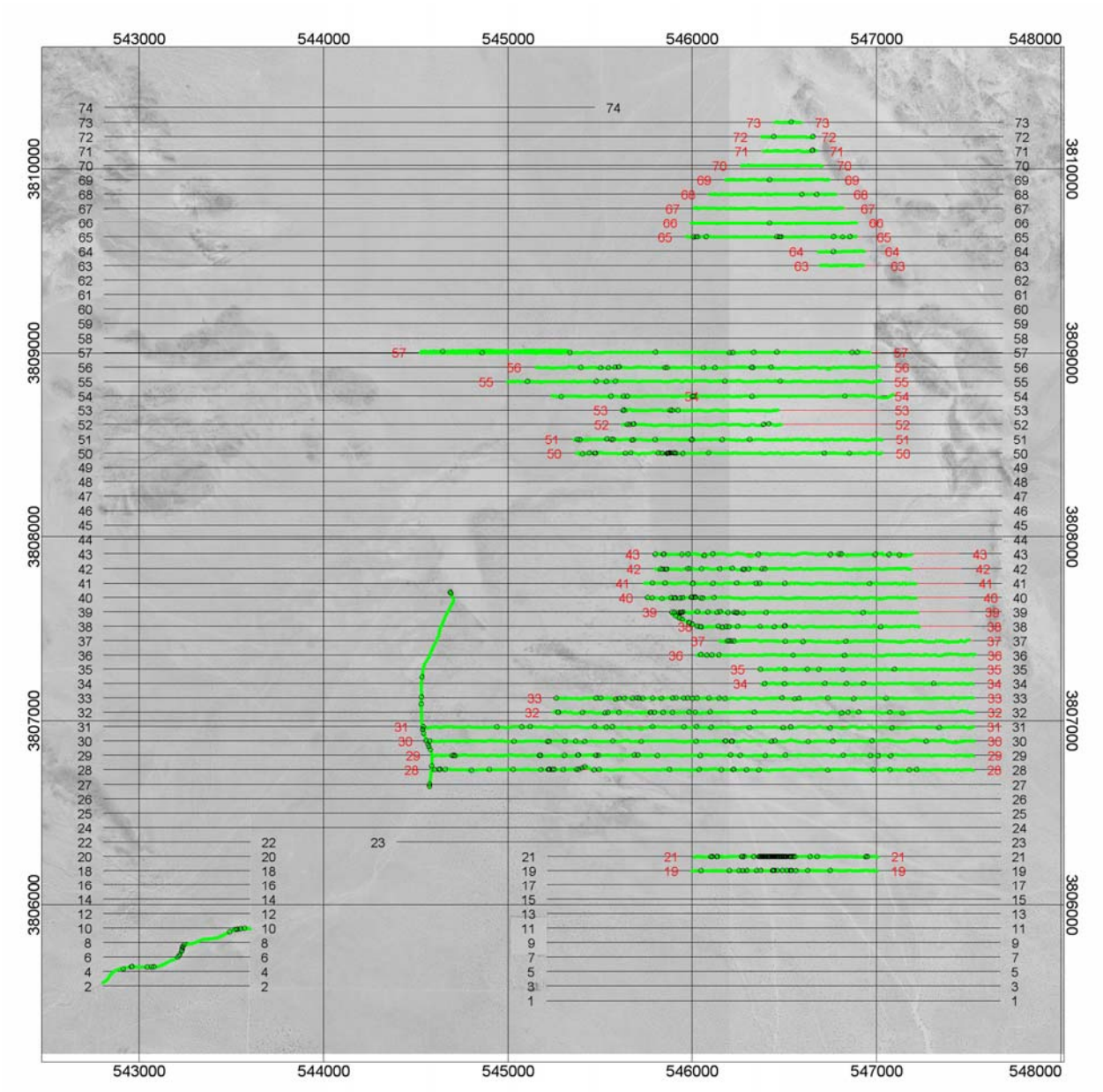


Figure 3-8 – Map showing the transect survey results for the Victorville PBRs Y and 15 demonstration. Transect COGs are shown as green lines and individual detected anomalies are shown as open circles. The black lines represent the original transect plan and the red lines represent the MP transect plan.

Table 3-5 – Excerpt of Annotated Listing of Transect Surveys Conducted During the Victorville PBRs Y and 15 MP EM Demonstration.

| Date / Survey Code | Survey Description | Transect Length (km) | Number of Anomalies Picked |
|---|---|---|---|
| **Day 1 Deliverables** | **10/04/2006** | | |
| Oct042006_195006 | Line 28 E | 1.3 | 8 |
| Oct042006_201739 | Line 29 E | 1.4 | 7 |
| Oct042006_205641 | Line 29 W(1) | 1.4 | 14 |
| Oct042006_212557 | Line 29 W(2) | 0.3 | 3 |
| Oct042006_213433 | Line 28 W(1) | 0.9 | 18 |
| Oct042006_215820 | Line 28 W(2) | 0.8 | 6 |
| | **Totals** | **6.1** | **56** |
| **Day 2 Deliverables** | **10/05/2006** | | |
| Oct052006_144951 | Line 30 E | 1.4 | 8 |
| Oct052006_151220 | Line 31 E | 1.4 | 7 |
| Oct052006_153515 | Line 31 W(1) | 1.0 | 7 |
| Oct052006_162451 | Line 31 W(2) | 0.7 | 4 |
| Oct052006_163625 | Line 30 W | 1.7 | 12 |
| Oct052006_172434 | Line 32 E | 1.4 | 6 |
| Oct052006_175335 | Line 33 E | 1.5 | 8 |
| Oct052006_182603 | Line 33 W | 0.9 | 20 |
| Oct052006_184703 | Line 32 W(1) | 0.5 | 6 |
| Oct052006_190843 | Line 32 W(2) | 0.5 | 8 |
| Oct052006_194805 | Line 34 | 1.2 | 6 |
| Oct052006_201401 | Line 35 | 1.2 | 6 |
| Oct052006_205232 | Line 36 | 1.6 | 6 |
| Oct052006_212131 | Line 37 E | 0.7 | 1 |
| Oct052006_213422 | Line 37 W | 0.7 | 7 |
| | **Totals** | **16.4** | **112** |

### 3.1.7 Man-portable EM Total Coverage Survey Results

The total coverage areas in the northern portion of the site from the vehicular survey were found to have a much higher magnetic anomaly density, ~250 anomalies/acre, than was seen in the southern portion of the site and had been seen previously at other WAA demonstration sites, 80 anomalies/acre or less. Based on site reconnaissance and considering the geology of the area, the high anomaly density was attributed to magnetically active or 'hot' rocks. To validate the 'hot' rocks assignment of the northern magnetic anomalies, man-portable EMI total coverage surveys were conducted on small subsets (0.75 to 1 acre each) of three vehicular total coverage areas. One area was located in the southern portion of the site within the PBR #15 Radial TC area, an area known to contain munitions-related material as a control. Two others areas were located in the northern portion of the site within the confines of vehicular TC areas Hot #1 and Hot #2.

The first area, the PBR #15 Radial MP TC area, is located in the south-east corner of the demonstration site and contains surface-visible fragments of 100-lbs practice bomb and other munitions-related items. This area was chosen as a control for the validation of the vehicular results in the north. Many magnetic anomalies in this area correspond to munitions-related items and should have a corresponding EM signature from the litter-carried system. The magnetic

anomaly map of TC Area PBR #15 Radial is shown in Figure 3-9. The approximate planning location of the MP EM total coverage area is shown in pink. All vehicular anomalies are shown in light gray and the anomalies within the proposed area are shown in black. Figure 3-10 gives a close-up view of the magnetic anomaly map and proposed survey area for clarity. Geosoft polygon (.ply) and ESRI shape files (.shp) of the three 'as-surveyed' MP total coverage areas are included on the attached CD. The Gate 1 EM anomaly map for the PBR #15 Radial MP TC Area is shown in Figure 3-11. The large amplitude, linear anomaly on the western edge of the survey is a metal chain laid out on the surface as a timing reference for the survey. One hundred and nine (109) anomalies were analyzed and fit parameters determined using both 660 μs time gates (top and bottom) and the UX-Analyze tool.

The second vehicular TC area, the Hot #1 TC area, is located in the northwest corner of the WAA demonstration site and contained little or no surface-visible material, cultural or munitions-related. However, the results from the vehicular magnetometer survey identified 1695 anomalies, of which 705 could be fit using the resident dipole model in the MTADS DAS, or 257 anomalies/acre. Given the likelihood of finding volcanic, magnetically active 'hot' rocks in this area, the pattern of anomaly location with respect to the severely weathered hillsides, and surface reconnaissance; the abnormally high anomaly count from the vehicular data in this area has been attributed to 'hot' rocks. If this attribution is correct, the anomaly count should be significantly lower with the EM system and few anomalies should be common between the vehicular and man-portable surveys. The magnetic anomaly map of TC Area Hot #1 is shown in Figure 3-12. A proposed area 30m wide x 150m tall was selected which contains 245 anomalies, of which 104 can be fit, from the vehicular data and is shown on Figure 3-12 in pink. All vehicular anomalies are shown in light gray and the anomalies within the proposed area are shown in black. Geosoft polygon (.ply) and ESRI shape files (.shp) of the three 'as-surveyed' MP total coverage areas are included on the attached CD. The Gate 1 EM anomaly map for the Hot #1 MP EM TC Area is shown in Figure 3-13. The large amplitude, linear anomaly on the northern edge of the survey is a metal chain laid out on the surface as a timing reference for the survey. No EM anomalies of significant signal strength were found.

The third vehicular TC area, the Hot #2 TC area, is located in the northeast corner of the WAA demonstration site and contained little or no surface-visible material, cultural or munitions-related. However, the results from the vehicular magnetometer survey identified 1461 anomalies, of which 704 could be fit using the resident dipole model in the MTADS DAS, or 252 anomalies/acre. In addition to the 'hot' rocks issue seen for TC Area Hot #1, TC Area Hot #2 also contained several large, deep magnetic anomalies. The proposed MP EM area for Hot #2 was chosen to include several of these large deep anomalies as well. The magnetic anomaly map of TC Area Hot #2 is showing in Figure 3-14. A proposed area 25m wide x 150m tall was selected which contains 199 anomalies, of which 101 can be fit, from the vehicular data and is shown on Figure 3-14 in pink. All vehicular anomalies are shown in light gray and the anomalies within the proposed area are shown in black. Geosoft polygon (.ply) and ESRI shape files (.shp) of the three 'as-surveyed' MP total coverage areas are included on the attached CD. The Gate 1 EM anomaly map for the Hot #2 MP EM TC Area is shown in Figure 3-15. The large amplitude, linear anomaly on the northern edge of the survey is a metal chain laid out on the surface as a timing reference for the survey. One anomaly was analyzed and fit parameters determined using both 660 μs time gates (top and bottom) using the UX-Analyze tool. The fit

results for the anomaly are available on the attached CD, but the anomaly depth and size were approximately 0.5m and 5cm respectively.

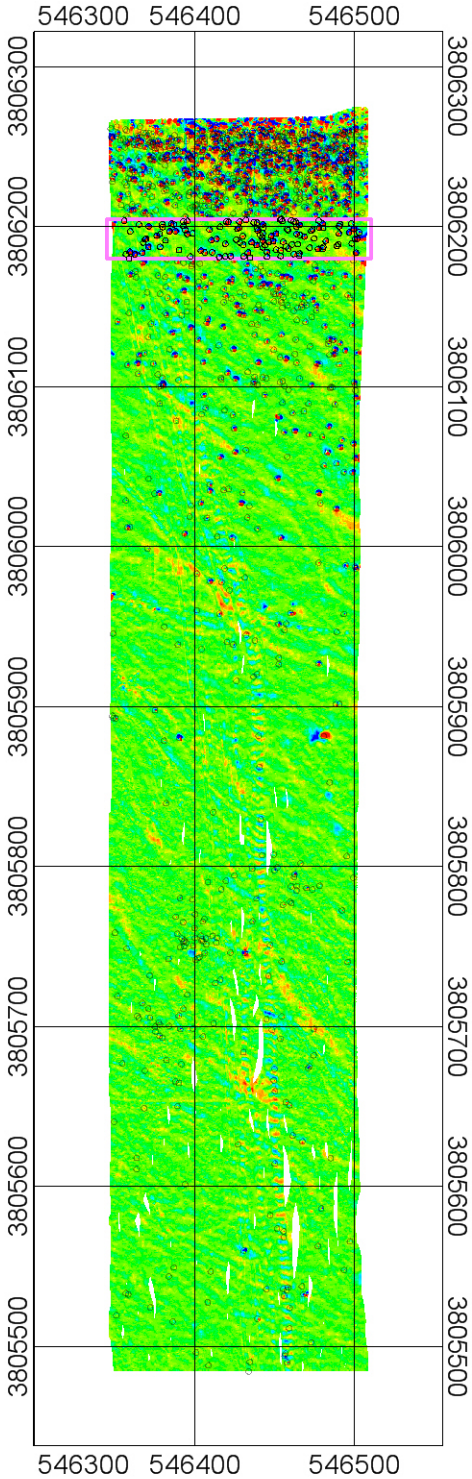


Figure 3-9 – PBR #15 radial magnetic anomaly map with vehicular anomalies and proposed MP EM survey area

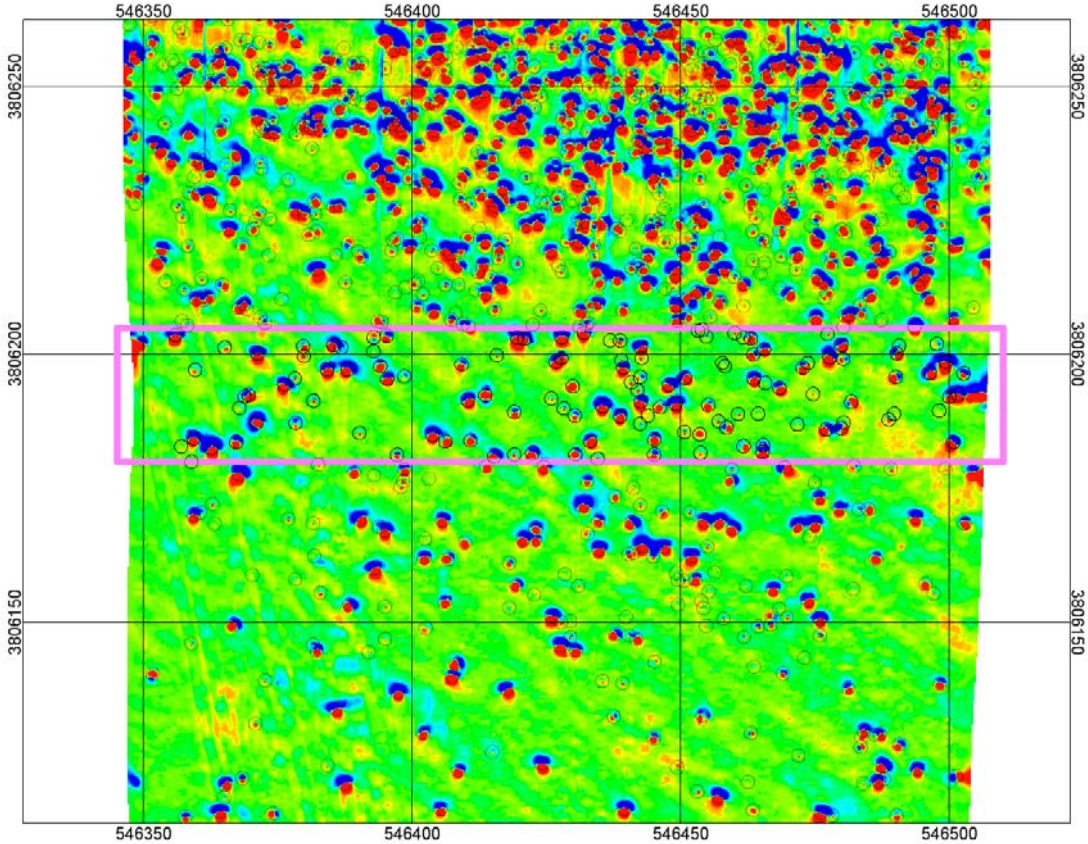


Figure 3-10 – Close up of PBR #15 proposed survey area

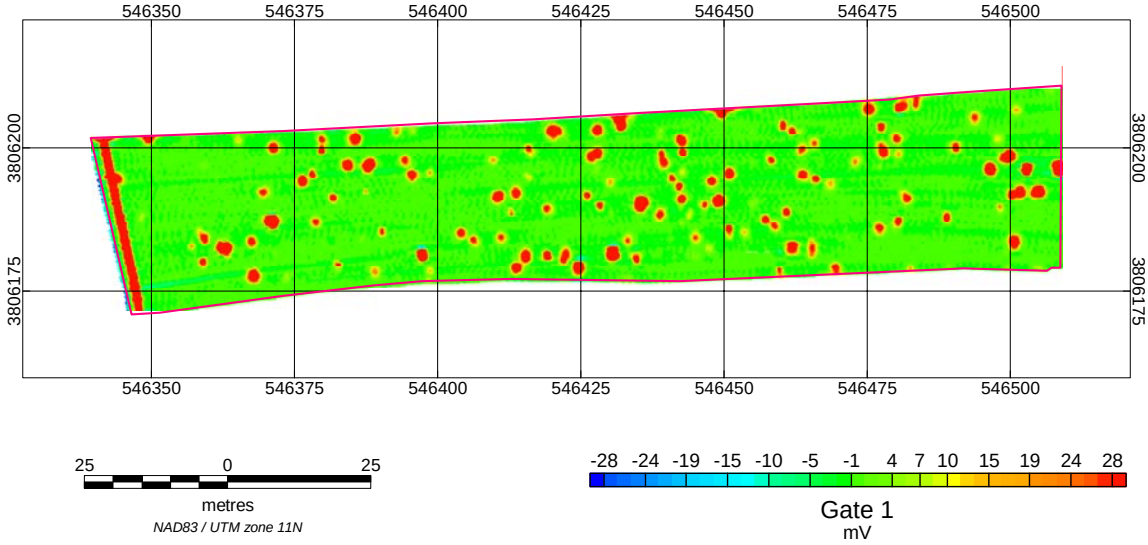


Figure 3-11 – PBR #15 radial EM anomaly map (time gate 1)

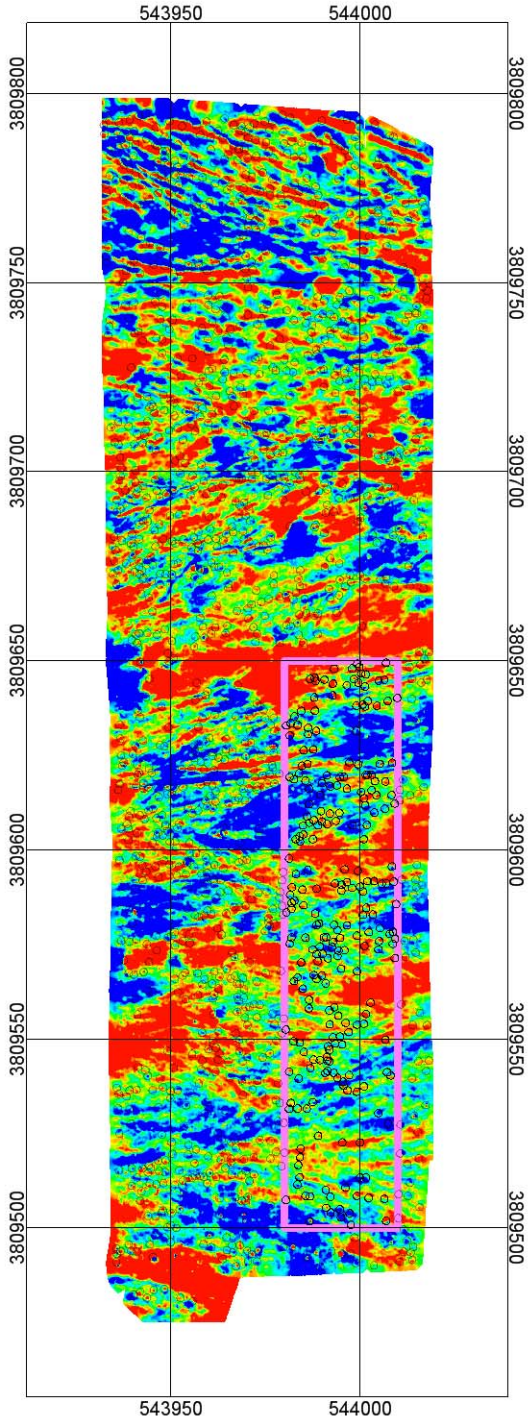


Figure 3-12 – Hot #1 magnetic anomaly map with vehicular anomalies and proposed survey area

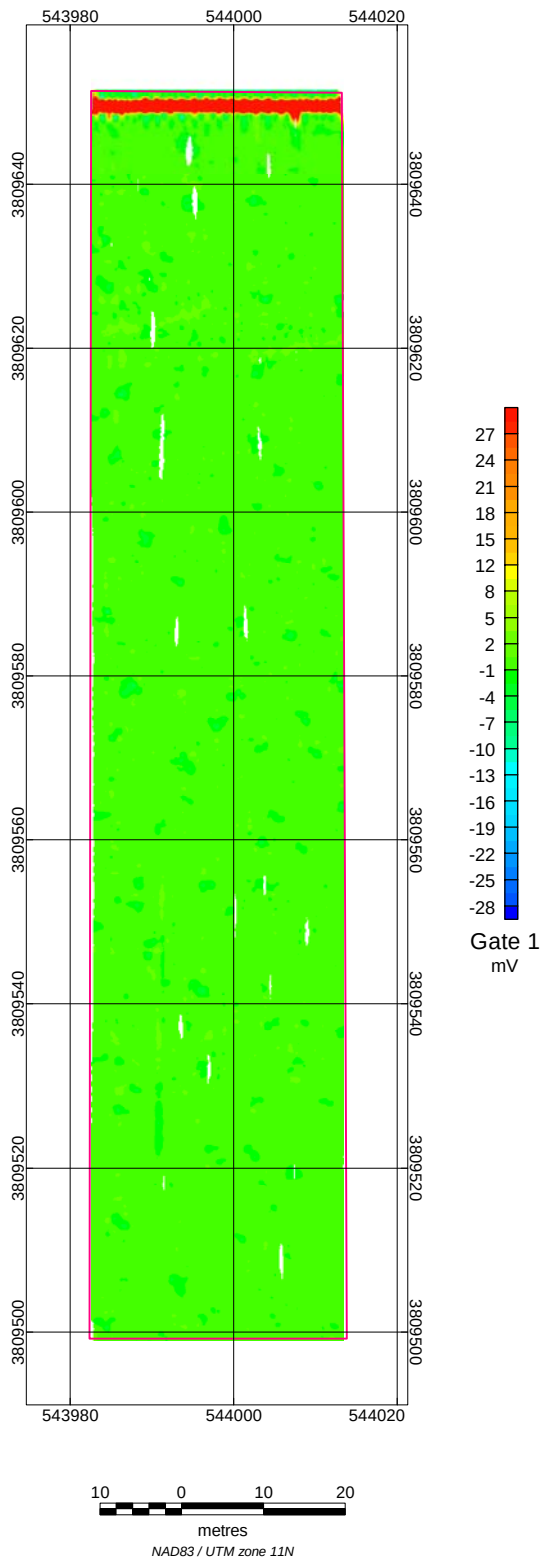


Figure 3-13 – Hot #1 MP EM anomaly map (time gate 1)

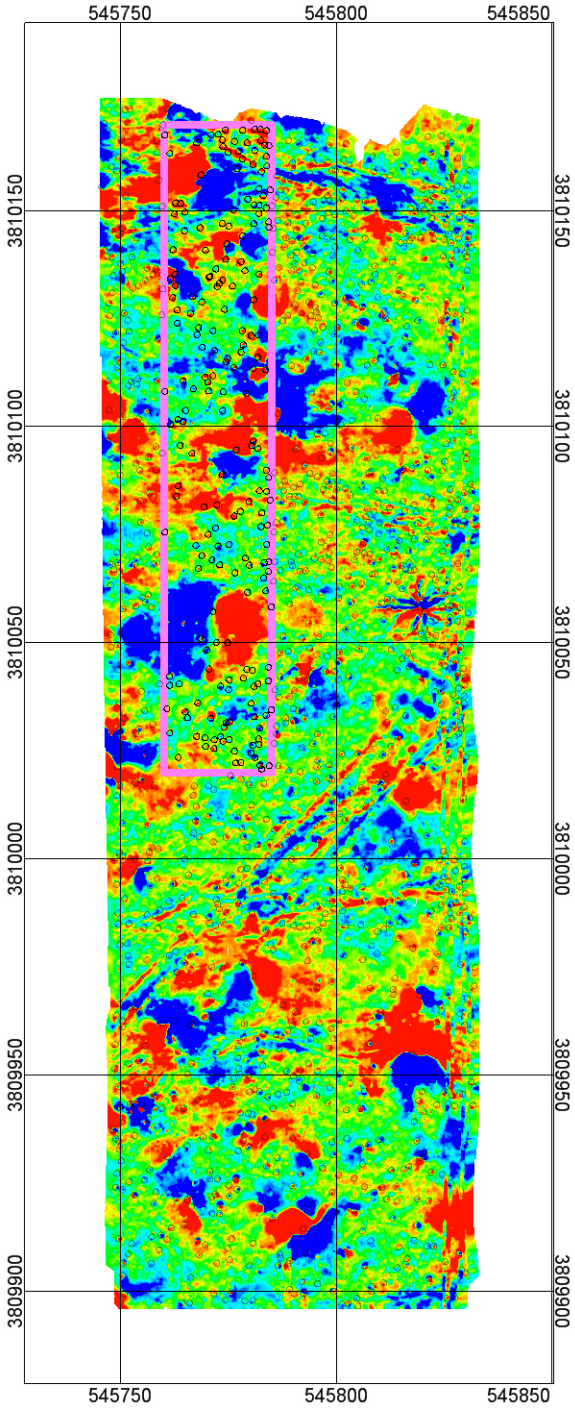


Figure 3-14 – Hot #2 magnetic anomaly map with vehicular anomalies and proposed survey area

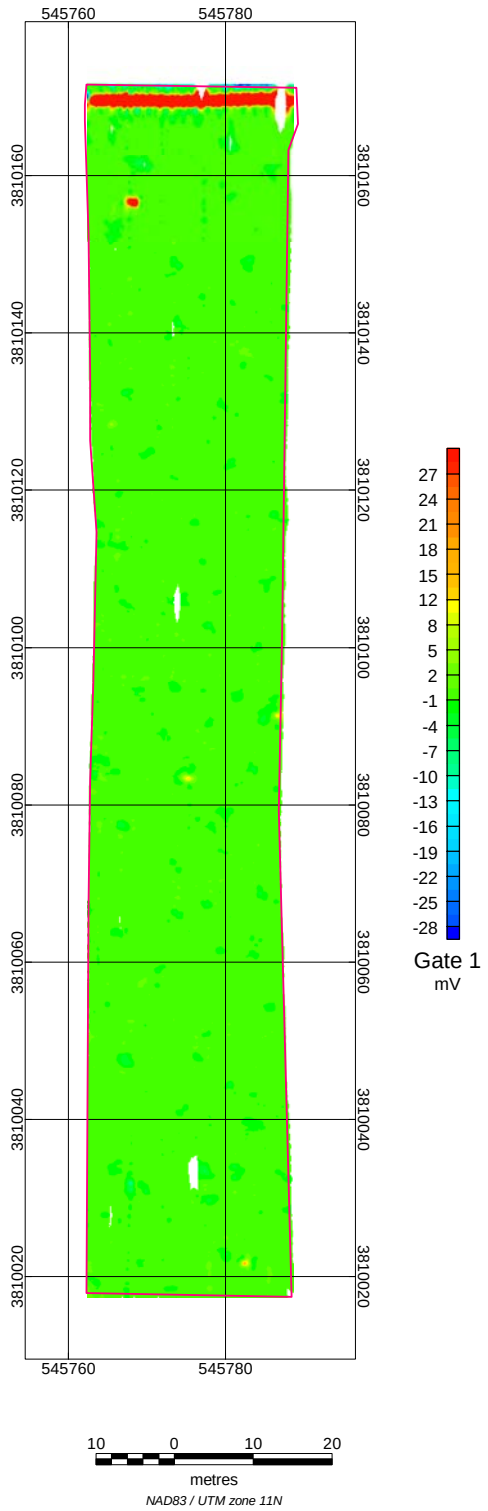


Figure 3-15 – Hot #2 MP EM anomaly map (time gate 1)

### 3.1.8 Calibration Items

As mentioned in Section 3.1.1, a calibration strip of munitions and munitions stimulants was not available for this demonstration. In lieu of such, one of our standard calibration objects, a 4" Aluminum (Al) sphere was placed on a visually-identified clear area and used as an ad hoc calibration object to test system response at the beginning and end of each day. The exact location of the sphere at each measurement was not independently recorded by GPS waypointing but the approximate locations can be extracted from the calibration survey data.

Each field day involving transect surveys commenced with the sensor being warmed up for a minimum of 30 minutes while the RTK GPS network was being established and the team was deploying to the day's survey area. A calibration survey of three round trips over the Al sphere along a path roughly North – South or East – West as dictated by the local environment would then be collected. At the end of the field day, the Al sphere was surveyed again prior to system shutdown at the current location. To evaluate the data from the calibration items, the peak demedianed sensor value for each time gate was determined for each pass (6 measurements total per survey). The peak positive value was extracting using the same anomaly extraction technique as for the transect surveys. The standard deviation (1σ) was then calculated for each survey. The results for each survey of the calibration sphere (average and standard deviation (1σ)) are tabulated in Table 3-6.

Table 3-6 – Position Deviation and Peak Demedianed EM Values for Calibration Sphere

| | Position | | Gate1 | | Gate2 | | Gate3 | | Gate4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date Code | Distance from Average (m) | Std. Dev (m, 1σ) | Average Peak Signal (mV) | Std. Dev (mV, 1σ) | Average Peak Signal (mV) | Std. Dev (mV, 1σ) | Average Peak Signal (mV) | Std. Dev (mV, 1σ) | Average Peak Signal (mV) | Std. Dev (mV, 1σ) |
| Oct042006_145030 | 0.07 | 0.04 | 109.30 | 4.40 | 81.59 | 3.31 | 51.82 | 1.42 | 61.10 | 1.71 |
| Oct042006_221928 | 0.05 | 0.02 | 93.60 | 7.71 | 70.04 | 5.74 | 44.86 | 3.54 | 53.35 | 3.80 |
| Oct052006_144638 | 0.06 | 0.03 | 226.88 | 18.80 | 169.73 | 14.12 | 108.01 | 8.30 | 119.00 | 8.51 |
| Oct052006_223226 | 0.09 | 0.03 | 126.93 | 7.17 | 95.58 | 5.50 | 60.84 | 3.41 | 70.45 | 3.81 |
| Oct062006_145601 | 0.08 | 0.03 | 158.44 | 10.86 | 118.30 | 7.92 | 74.81 | 4.62 | 85.67 | 4.92 |
| Oct062006_223315 | 0.07 | 0.04 | 100.48 | 12.05 | 75.55 | 9.23 | 47.93 | 5.68 | 56.68 | 6.68 |
| Oct072006_151412 | 0.06 | 0.01 | 82.53 | 5.43 | 61.52 | 4.06 | 38.88 | 2.55 | 47.42 | 3.01 |
| Oct072006_212314 | 0.06 | 0.04 | 76.54 | 3.13 | 57.36 | 2.24 | 36.58 | 1.17 | 44.76 | 1.08 |
| Oct082006_151006 | 0.06 | 0.04 | 166.02 | 9.36 | 123.85 | 6.86 | 77.94 | 4.38 | 89.73 | 4.48 |
| Oct082006_180106 | 0.09 | 0.06 | 105.28 | 11.22 | 78.79 | 8.51 | 49.66 | 5.02 | 58.92 | 5.68 |

Figure 3-16 plots the peak EM61 MkII time gate 1 sensor values for all of the calibration data sets in a pseudo-time series. The solid line indicates the aggregate average and the dashed lines indicate a 1σ envelope. Figure 3-17 plots the position deviations for the calibration data sets in a pseudo-time series. As indicated previously, the exact location of the Al sphere was different for each survey and was not independently recorded, so the values reported are for variation from the average of all six measurements comprising each survey.

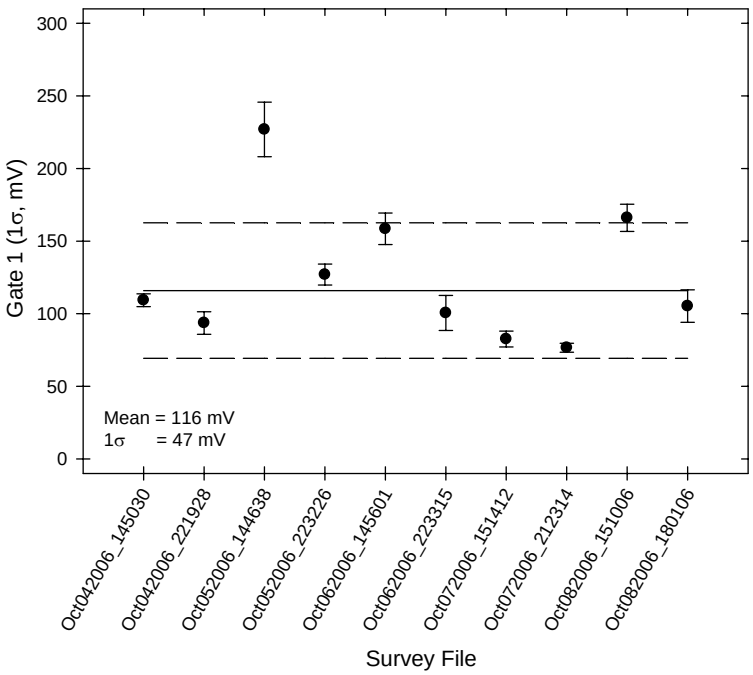


Figure 3-16 – EM61 MkII gate 1 peak values from each Al sphere calibration survey. The result for each data set is shown in order of acquisition. The horizontal axis is survey date code. The solid line represents the aggregate average peak positive value and the dashed lines represent a 1σ envelope.

Static tests of the sensor platform were conducted each survey day involving transect data collection. Generally, during a period of high GPS PDOP (Positional Dilution of Precision) at approximately 9:00 am each day, a static survey was collected to monitor the static sensor levels for the EM61 MkII. GPS data was collected during this survey but suffers from the reduced accuracy of the high PDOP event. Since the primary goal of the static data collection was to evaluate the EM61 MkII sensor and not the positioning which has been evaluated previously [13,14], this compromise was authorized by the Quality Assurance Officer to enhance productivity. A data set was collected for 5-10 minutes while the sensor platform was kept stationary and all team members standing away from the platform. Every effort was made to minimize the movement of personnel and equipment during the survey. The 2-D positioning variation was evaluated by computing the standard deviation of both the northing and easting components of the position data for the entire period and combining them as the square root of the sum of the squares. The standard deviation for the demedianed EM61 MkII data from each time gate was computed and the arithmetic mean was computed for each data set. Results are ported for a) all time gates and b) only bottom coil time gates. In occasional cases, an obvious artifact was present in the data (e.g. a team member moved along side the sensor platform accidentally) and distorting a portion of the static run. In these cases, only the unperturbed data was used. The aggregate average and standard deviation (1σ) of both the positioning and sensor data for all data sets was computed. The results are shown in the follow pseudo-time series figures. Figure 3-18 and Figure 3-19 show the positioning and EM61 MkII variations for the static tests. Table 3-7 summarizes the static test data results.

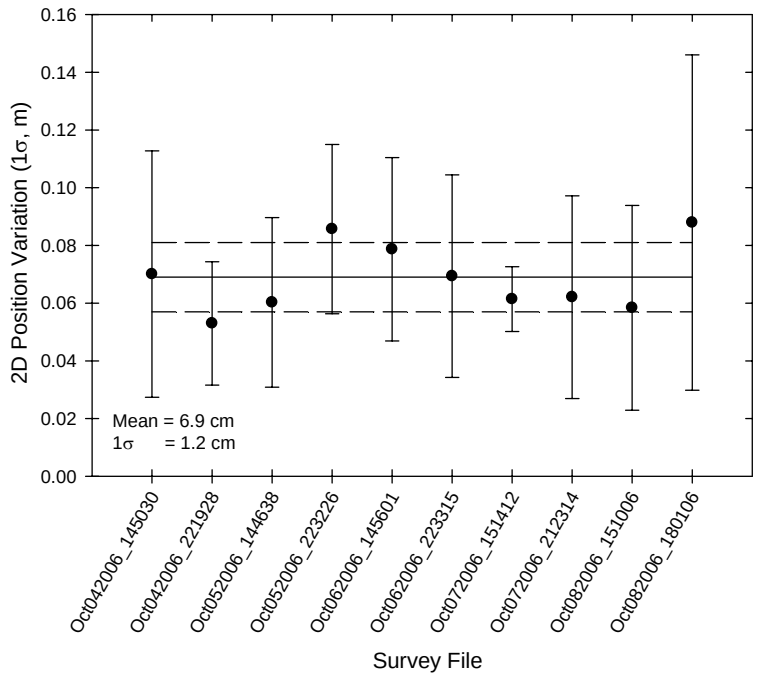


Figure 3-17 – 2D peak locations for the Al sphere for each Al sphere calibration survey. The result for each data set is shown in order of acquisition. The horizontal axis is survey date code. The solid line represents the aggregate average peak positive value and the dashed lines represent a 1σ envelope.

Table 3-7 – Static Test Data Results

| Result Type | Value |
|---|---|
| 2-D Position | 0.50 ± 0.21 cm |
| Demedianed EM61 MkII (bottom gates) | 0.082 ± 0.002 mV |
| Demedianed EM61 MkII (all gates) | 0.096 ± 0.002 mV |

### 3.1.9 Demobilization

At the end of field operations, all equipment, materials, and supplies was repacked. Two team members delivered the equipment to the FedEx shipping office in Palm Springs on October 9th prior to departing Palm Springs, CA.

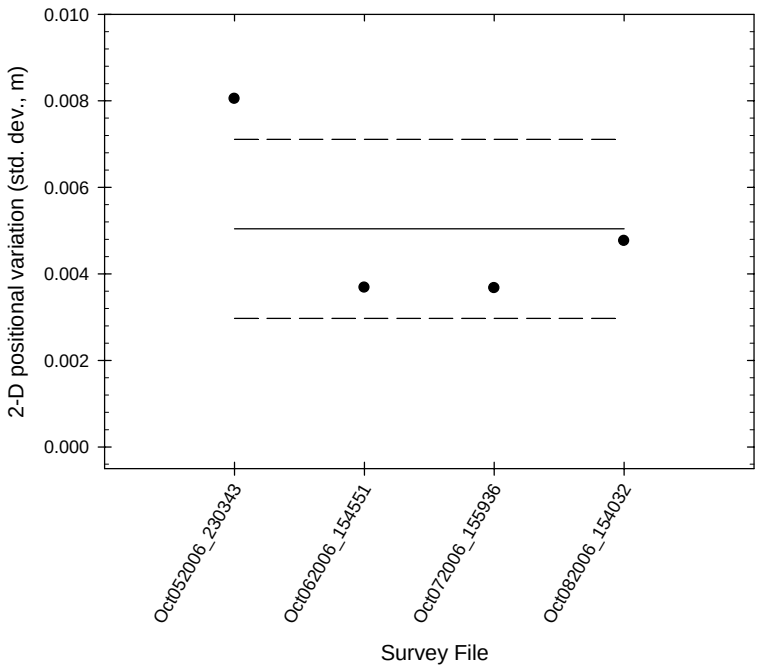


Figure 3-18 – Positional variation data runs for static data collected. The horizontal axis is survey date code. The solid line represents the aggregate average positional variation and the dashed lines represent a 1σ envelope.

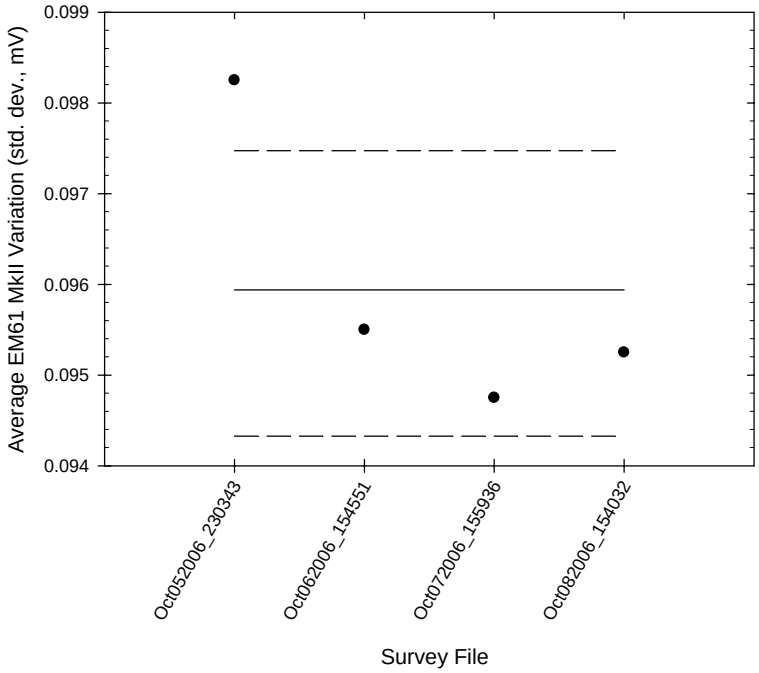


Figure 3-19 – Overall EM61 MkII (all time gates) variation for static data collected. The horizontal axis is survey date code. The solid line represents the aggregate average sensor variation and the dashed lines represent a 1σ envelope.

# 4. References


1. "Department of Defense Unexploded Ordnance Response: Estimated Costs and Technology Investments," Report to the Congressional Defense Committees, March 2001.
2. Report of the Defense Science Board Task Group on Unexploded Ordnance, Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, Washington, D. C., Nov. 2003.
3. "Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Victorville Precision Bombing Ranges Y and 15, 20 – 31 March, 2006, Demonstration Data Report," D.A. Steinhurst, ESTCP WAA Pilot Project Interim Report, May 03, 2006.
4. "MTADS TECHEVAL Demonstration, October 1996," H. H. Nelson, J. R. McDonald, and Richard Robertson, NRL/PU/6110--97-348.
5. "Results of the MTADS Technology Demonstration #2, Magnetic Test Range, Marine Corps Air Ground Combat Center, Twentynine Palms, CA, December, 1996," J.R. McDonald, H.H. Nelson, R.A. Jeffries, and Richard Robertson, NRL/PU/6110—97-349.
6. "Results of the MTADS Technology Demonstration #3," Jefferson Proving Ground, Madison, IN, January 13-24, 1997," H.H. Nelson, J.R. McDonald, R.A. Jeffries, and Richard Robertson, NRL/PU/6110—99-375.
7. "MTADS Unexploded Ordnance Operations at the Badlands Bombing Range, Pine Ridge Reservation, Cuny Table, SD, July 1997," J.R. McDonald, H.H. Nelson, J. Neece, R. Robertson, R.A. Jeffries, NRL/PU/6110—98-353.
8. "MTADS Live Site Survey, Bombing Target #2 at the Former Buckley Field, Arapahoe County, CO," J. R. McDonald, H. H. Nelson, and R. Robertson, NRL/PU/6110--99-379.
9. "MTADS Unexploded Ordnance Operations at the Badlands Bombing Range Air Force Retained Area, Pine Ridge Reservation, SD, September, 1999," J. R. McDonald, H. H. Nelson, R. Robertson, and R. A. Jeffries, NRL/PU/6110--00-424.
10. "Airborne MTADS Demonstration at the Badlands Bombing Range, September, 2001," J.R. McDonald, D.J. Wright, N. Khadr, H.H. Nelson, NRL/PU/6110—02-453.
11. "MTADS Magnetometer Survey of the Badlands Bombing Range, SD Impact Area, Combined Airborne, Vehicular, and Man-portable Survey, September 2002," H.H. Nelson, D.A. Steinhurst, D. Wright, T. Furuya, J.R. McDonald, B. Barrow, N. Khadr, and J. Haliscak, NRL/MR-MM/6110—03-8666.
12. "MTADS Airborne and Vehicular Survey of Target S1 at Isleta Pueblo, Albuquerque, NM, 17 February – 2 March 2003," H.H. Nelson, D. Wright, T. Furuya, J.R. McDonald, N. Khadr, D.A. Steinhurst, NRL/MR/6110—04-8764.
13. "Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Pueblo Precision Bombing and Pattern Gunnery Range #2, Demonstration Data Report," G.R. Harbaugh, D.A. Steinhurst, N. Khadr, Nova Technical Report NOVA-2031-TR-0001, October 3, 2006.
14. "Wide Area UXO Contamination Evaluation by Transect Magnetometer Surveys, Victorville Precision Bombing Ranges Y and 15, Demonstration Data Report," G.R. Harbaugh, D.A. Steinhurst, N. Khadr, Nova Technical Report NOVA-2031-TR-0002, October 3, 2006.

# 5. Points of Contact

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**Hotel Accommodations**

| | |
|---|---|
| Americas Best Value Inn and Suites | 56377 29 Palms Highway<br>Yucca Valley, CA 92284<br>(760) 365-6321<br>Fax: (760) 365-9592 |

# Appendix A. Data Storage and Archiving Procedures

## A.1 Data Formats

Each survey file set contains 4 files which constitute the 'raw data'. The file name structure is MMMDDYYYY_HHMMSS.DeviceType; where MMM is the 3-letter abbreviation of the month, DD is the date, YYYY is the 4-digit year, HH is the file start time hour in 24-hour format, and MM and SS are the start time minutes and seconds. In the following example, the data was taken on October 8th, 2006 starting at 15:21:49. The PC clock is synced to UTC at program entry.

Oct082006_152149.pps
Oct082006_152149.mark
Oct082006_152149.mkii
Oct082006_152149.nmea

Each data line is time stamped with the PC system clock to allow synchronization between files

| | |
|---|---|
| MMMDDYYYY_HHMMSS.mkii - | Output from Geonics EM61 MkII (Mode, Scale Factor, 4 channels, Tx current, battery voltage), 10 Hz. |
| MMMDDYYYY_HHMMSS.pps - | pulse per second (PPS) from GPS receiver, 1 Hz. |
| MMMDDYYYY_HHMMSS.nmea - | GPS output, Trimble PTNL,GGK sentence at 10 Hz (position) and UTC time tag from GPS receiver, "The time will be" message for next PPS, 1 Hz.. |
| MMMDDYYYY_HHMMSS.mark - | Fiducial markers recorded by operator, if used. |

EM61 MkII (.mkii) files:

```
D  FF        -980         697         631        1976      3420   12.75  55309.000  55309.050
D  FF        -980         698         631        1977      3423   12.75  55309.100  55309.150
D  FF        -979         698         629        1976      3414   12.75  55309.200  55309.250
D  FF        -980         698         629        1976      3408   12.75  55309.300  55309.350
D  FF        -980         698         629        1976      3412   12.75  55309.400  55309.450
```

First line:
D – Sensor Mode, 'D' is differential (3 gates on bottom coil, 1 gate on top coil), 'T' mode has 4 time gates on bottom coil
FF – Scale factor. Hexidecimal representation of range factors for 4 time gates. 'FF' corresponds to the highest range (100x) for all four time gates.
Channel 1
`-980 - -980 counts`
Channel 2
`697 - 697 counts`
Channel 3
`631 - 631 counts`
Channel T
`1976 - 1976 counts`
Tx Current
`3420 - 3420 counts`
Battery Voltage
`12.75 – 12.75 VDC`

`55309.000` – PC Time stamp for transmission of trigger character.
`55309.050` - PC Time stamp for receipt of data packet.

.PPS files:

```
55309.990
55310.990
55311.990
```

.NMEA files:

```
$PTNL,GGK,152149.00,100806,3423.76458565,N,11629.97525670,W,3,08,1.8,EHT766.6
92,M*6B  55309.040
$PTNL,GGK,152149.10,100806,3423.76458579,N,11629.97525721,W,3,08,1.8,EHT766.6
97,M*67  55309.130
UTC 06.10.08 15:21:50 58  55309.200
$PTNL,GGK,152149.20,100806,3423.76458753,N,11629.97525562,W,3,08,1.8,EHT766.6
96,M*6A  55309.230
```

Table A-1 – PTNL,GGK Message Fields[a]

| **Field** | **Meaning** |
|---|---|
| 1 | UTC of position fix |
| 2 | Date |
| 3 | Latitude |
| 4 | Direction of Latitude (N = North, S = South) |
| 5 | Longitude |
| 6 | Direction of Longitude (E = East, W = West) |
| 7 | GPS Fix Quality (0 = Invalid,1,2,3,4) |
| 8 | Number of Satellites in fix |
| 9 | DOP of fix |
| 10 | Ellipsoidal height of fix |
| 11 | M: ellipsoidal height is measured in meters |

[a] For further information, refer to the Trimble MS Series Operation Manual

.mark files:

Unused in this demonstration but follows the file format of the .PPS file.

Located data archives are ASCII files of the format:

For located, (demedianed) EM61 MkII data:

```
PC_Time (UTC, seconds since midnight)
X (UTM Zone X, NAD83, m) Easting
Y (UTM Zone X, NAD83, m) Northing
Z Height Above Ellipsoid (HAE, WGS84, m)
Heading (Referenced to Grid North, degrees)
Gate1_Fin (demedianed, mV)
Gate2_Fin (demedianed, mV)
```

```
Gate3_Fin (demedianed, mV)
Gate4_Fin (demedianed, mV)
Gate1_def (not demedianed, mV)
Gate2_def (not demedianed, mV)
Gate3_def (not demedianed, mV)
Gate4_def (not demedianed, mV)
```
where X is the appropriate UTM zone (11N for Victorville, CA)

Course over Ground (.COG) files:
Corresponding Course-Over-Ground (COG) Reports for Transect data will be ASCII files of the format:

```
X       (UTM Zone X, NAD83, m) Easting
Y       (UTM Zone X, NAD83, m) Northing
```
where X is the appropriate UTM zone (11N for Victorville, CA)

Static Survey Archive (.xyz) files:
Daily static calibration run data will be archived as geosoft .XYZ files of the format:

```
PC_Time (UTC, seconds since midnight)
X       (UTM Zone X, NAD83, m) Easting for GPS antenna
Y       (UTM Zone X, NAD83, m) Northing for GPS antenna
HAE     (WGS84, m) Height above Ellipsoid for GPS antenna
Gate1_Fin (demedianed, mV)
Gate2_Fin (demedianed, mV)
Gate3_Fin (demedianed, mV)
Gate4_Fin (demedianed, mV)
```
where X is the appropriate UTM zone (11N for Victorville, CA)

UX-Analyze Target List Example

The example is given in ASCII text file format. Actual delivery will be in Excel Spreadsheet format.

```
/ ---------------------------------------------------------------------------
---
/ CSV EXPORT [10/18/2006]
/ DATABASE   [c:\montaj~1\waapro~1\waavvm~1\PBR15_Anomalies.gdb]
/ ---------------------------------------------------------------------------
---
/
/fid,Fit_X,Fit_Y,Latitude,Longitude,Fit_Depth,Fit_Size,Fit_Coh,Fit_b1,Fit_b2,
Fit_b3,Fit_theta,Fit_phi,Fit_psi,Fit_chi2,Fit_Error,Comments,Comments_2
Line DAnomalies
0,546367.83,3806177.80,34.395976453,-
116.495551050,1.096,0.081,0.928,3.643,0.542,0.000,83.86,74.77,8.76,0.727,0,""
,""
1,546388.83,3806178.25,34.395979030,-
116.495321551,0.651,0.034,0.658,0.205,0.113,0.000,-
19.93,10.18,72.45,0.428,0,"",""
2,546459.59,3806178.67,34.395975854,-
116.494552376,0.265,0.024,0.921,0.105,0.003,0.000,75.40,48.51,-
7.77,0.550,0,"Partial Anomaly on Edge of Data.",""
```

3,546413.58,3806179.04,34.395984953,-
116.495049535,0.770,0.061,0.970,1.808,0.021,0.005,81.41,310.50,130.26,1.022,0
,"","""

## A.2 Data Storage and Archiving Procedures

Data was stored electronically during collection on a laptop hard drive. Approximately every two survey hours, the collected data was copied onto a USB data key and transferred to the data analyst. The data was moved onto the data analyst's computer. Raw data and analysis results are backed up from the data analyst's computer to optical media (CD-R or DVD-R) or magnetic media (external HDD) daily. These results are archived on an internal file server at NRL. The located data archives are distributed with all copies of the demonstration data report. All field notes / activity logs are written in ink and stored in archival laboratory notebooks. These notebooks are archived at NRL. Relevant sections are reproduced in the demonstration data report. Dr. Daniel Steinhurst is the POC for obtaining data and other information. His contact information is provided in Section 5 of this report.