FINAL
MRS-16 GEOPHYSICAL PROVE-OUT REPORT
FORMER FORT ORD, CALIFORNIA

TOTAL ENVIRONMENTAL RESTORATION CONTRACT
CONTRACT NO. DACW05-96-D-0011, CTO 16

Submitted to:

U.S. Department of the Army
Corps of Engineers
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Revision 1

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Acronyms and Abbreviations

AS	analytic signal
cm	centimeter(s)
DGM	digital geophysical mapping
DID	Data Item Description
DQO	data quality objective
EM	electromagnetic
EM1	EM Unit 1
EM2	EM Unit 2
EM3	EM Unit 3
EM61-MK2	Geonics EM61-MK2 time domain electromagnetic metal detector
FAR	false alarm rate
G858	Geometrics G-858G cesium vapor magnetometer
GPO	Geophysical Prove-Out
GPS	global positioning system
MAG	magnetic
MEC	munitions and explosives of concern
mm	millimeter(s)
mV	milliVolts
mph	mile(s) per hour
MRS	Munitions Response Site
nT	nanoTesla(s)
nT/ft	nanoTesla(s) per foot
ODDS	Ordnance Detection and Discrimination Study
QC	quality control
RTK	real-time kinematic
Sum4	sum of the four leveled EM61-MK2 data channels
TDEM	time-domain electromagnetic
USACE	U.S. Army Corps of Engineers

1.0 Introduction

This Geophysical Prove-Out (GPO) Report addresses the geophysical equipment and survey technique evaluations performed by Shaw Environmental, Inc. (Shaw) at the Former Fort Ord, located near Marina, California, north of Monterey (Figure 1). This work was performed on behalf of the U.S. Army Corps of Engineers (USACE), Sacramento District, under Prime Contract Number DACW05-96-D-0011, Contract Task Order 16. The fieldwork was conducted from April 25, 2006, through May 24, 2006. Plots and summaries are included in Tables 1 – 21. These equipment evaluations were performed to assess and compare site-specific performance and detection capabilities of electromagnetic (EM) and magnetic (MAG) instrumentation for the munitions and explosives of concern (MEC) digital geophysical mapping (DGM) surveys planned for site Munitions Response Site (MRS) -16 at former Fort Ord. Additionally, this GPO evaluation serves as a tool for procedural and instrumentation quality control (QC). The DGM was conducted at Ordnance Detection and Discrimination Study (ODDS) Known 1 and 2 and Unknown 1 and 2 test plots (Figure 2). In accordance with the USACE Munitions Response Data Item Description (DID) MR-005-05A requirements, this report provides the following information:

- Color maps of the geophysical data
- Summary of the GPO results
- Proposed geophysical equipment, techniques, and methodologies
- Justification for recommendations

This GPO evaluation utilized the existing ODDS Plots; therefore the following items available in Parson's Final ODDS Report are not provided here:

- Photographs of seeded items
- Pre-seed maps

The GPO was conducted in accordance with the *Draft Work Plan, MRS-16 Munitions and Explosives of Concern Removal, Former Fort Ord, California* (Work Plan) (Shaw, 2006). The procedures for DGM at MRS-16 will be revised as necessary in the Final Work Plan based on the results of the GPO described herein.

2.0 Geophysical Prove-Out Test Grids

The GPO was conducted at the ODDS plots in the Badger Flats area of Fort Ord. The ODDS plots are seeded test plots constructed specifically to evaluate a variety of geophysical instruments' abilities to detect MEC items likely to be found at Fort Ord in a controlled atmosphere representative of Fort Ord site conditions. Shaw used the ODDS plots for the geophysical prove-out to test the capabilities of arrays of Geonics EM61-MK2 time domain electromagnetic metal detector (EM61-MK2) and Geometrics, Inc., G-858G (G858) magnetometers to detect seeded MEC items buried at varying depths in local site conditions. The location of the ODDS plots is shown on Figure 2. Site photographs can be found in Appendix A.

Four of the five ODDS plots were surveyed - Known Plots 1 and 2 and Unknown Plots 1 and 2. Each plot was 100-feet by 180-feet and consisted of generally flat pastures covered with waist-height grass. Overhead views were obstruction-free. The 5th plot was overgrown with vegetation and was located on a hill side. The approval for vegetation removal could not be obtained at the time of the GPO survey. The 5th plot will be surveyed if the proper approval for vegetation clearance can be obtained.

2.1 Seeded Items

The seeded items range from projectiles [e.g. 25 millimeter (mm), 35 mm, 37 mm, 75 mm, 90 mm, 105 mm, 2.36 inch rockets and 3 inch mortars] to grenades, MEC fragments and signal illuminations (e.g. M125, M126 and M127). These items were buried at a variety of inclinations and azimuths at burial depths ranging from 6 to 48 inches. These types of items and these depths are representative of the MEC encountered at Fort Ord ranges and simulate site conditions. The detectability of these items under these conditions will be used to develop parameters for the production surveys. A number of (backfilled) empty holes are also located within the ODDS plots. See Tables 1 and 2 and Appendix B for a full description of the seeded items, their locations, orientations, and depths.

2.2 GPO Test Grid As-Built Maps

Figures 3 and 4 show the buried seed items and empty backfilled holes for Known Plot 1 and Known Plot 2, respectively. The location data were obtained from published information which has been compiled in Tables 1 and 2. The known plots have been subdivided into quadrants where each quadrant has been seeded with specific items as follows (reference should be made to the maps for the specific number, location, orientation, and depth of seeded items).

Known Plot 1

- Quadrant A (northwest) – no seeded MEC items buried
- Quadrant B (northeast) – no seeded MEC items, 7 empty backfilled holes
- Quadrant C (southwest) – Generally smaller seeded MEC items (e.g. 35 mm, 37 mm, hand grenades, illuminators, etc.)
- Quadrant D (southeast) – Generally smaller seeded MEC items, MEC scrap, metal debris, and empty backfilled holes

Known Plot 2

- Quadrant A (northwest) – Generally mid-size (e.g. 25 mm to 90 mm) seeded MEC items
- Quadrant B (northeast) – Mostly larger (e.g. 75 mm to 105 mm) seeded MEC items
- Quadrants C and D (southwest and southeast) – all types of seeded MEC items, MEC scrap, metal debris, and empty holes

3.0 Instrumentation

The following sections describe the instruments used during the GPO at the ODDS Plots at Ft Ord. The deployment strategies for these systems are described in more detail in Section 4.0. It should be noted that Shaw used the same equipment used by Parsons Infrastructure and Technology (during their GPO and production surveys) to conduct this present GPO at the Odds Plots.

3.1 Geophysical Instruments

3.1.1 Geometrics G-858G

Gradiometer and total field MAG survey data were obtained using an array of four G858s. The G858 is an optically pumped cesium vapor instrument that measures the intensity of the earth's magnetic field in nanoTeslas (nT). At Fort Ord, the total MAG field intensity is approximately 48,600 nT, with an inclination of about 60 degrees down and a declination of about 14.34 degrees east.

The G858s were mounted on a man-towed, non-metallic cart. The sensors were mounted 2 feet apart in both the vertical and horizontal directions. They formed a square face such that total field and gradient data could be collected concurrently. The surveys were conducted with the lower sensors mounted 12 inches above the ground.

The diurnal drift of the earth's magnetic field undergoes low-frequency diurnal variations associated with the earth's rotation, generally referred to as magnetic drift. A Geometrics G856 was used as a stationary base station to record and monitor the diurnal drift over the course of the magnetometer surveys. The MAG data recorded by the base station were used to correct any magnetic drift occurring during the MAG survey.

3.1.2 Geonics EM61-MK2

The EM61-MK2 is a four-channel, high-sensitivity time-domain electromagnetic (TDEM) sensor designed to detect shallow ferrous and nonferrous metallic objects with good spatial resolution and minimal interference from adjacent metallic features. The EM61-MK2 consists of two 1- by 0.5-meter rectangular coils stacked 40 centimeters (cm) apart with the source/receiver coil located below a second receiver coil. A square wave EM pulse is generated with "time on" (positive and negative) and "time off" cycles. This induces subsurface eddy currents with an associated secondary magnetic field. The decay of the secondary magnetic fields is measured during "time off" cycles and stored as an milliVolts (mV) response. By measuring the decay at "late times" the system can distinguish between natural earth materials and buried metal (ferrous and nonferrous) as the secondary field in metallic objects decays at a much slower rate than earth materials. Although the EM61-MK2 is capable of measuring a differential, calculated as the voltage difference between the top and bottom coils, for this project, data were recorded at four time gates from the bottom coil. The responses at these four specified time gates are recorded and displayed by an integrated system data logger.

An array of three EM61-MK2s mounted on a non-metallic cart, towed by a Dodge Dakota, was used to acquire EM data at the ODDS test grids. The three units were mounted in parallel, narrow end forward, such that the center-to-center coil spacing was 2.0 feet and the bottoms of the coils were set at the standard Geonics height of 40 cm above the ground.

Since this GPO was performed, it was decided to use a tractor for a tow vehicle. The GPO will be conducted to demonstrate that no degradation in data quality will occur with this change in deployment.

3.2 Leica Real-Time Kinematic Global Positioning System

Real-time kinematic (RTK) global positioning system (GPS) uses a base station that is set up based on a known position. Once the base station is established, it determines its location using satellites and then applies a correction based on the offset from the known coordinates at the location. This correction is then used by a rover that is in direct communication with the base station through a radio link. The rover must be within 6 to 10 miles of the base station. At longer distances, line of sight is required; at shorter distances (as in this survey); line of sight is not required. RTK GPS is capable of taking survey-grade measurements in real time and providing immediate accuracy to within 1 to 4 cm. The Leica SR530 series RTK GPS was used for data collection in the ODDS plots.

4.0 Geophysical Prove-Out Procedures

4.1 Survey Modes

Full coverage was achieved through deploying the sensor system and collecting sub-parallel survey lines such that across-track sensor measurements were spaced 2 feet apart. The track marks of the arrays, augmented by spray paint marks as needed, were used by field personnel to guide the successive paths of each traverse to ensure full coverage of the ODDS plots. RTK GPS was used for navigation. To minimize turn-arounds of the sensor arrays, the four ODDS plots were surveyed as a single area. The individual plots were extracted from the final processed xyz files.

Only towed or man-pushed sensor arrays were tested at the ODDS plot. Man-portable single sensor systems will be tested if required for the MRS-16 DGM.

Raw instrumentation and processed data for the G858 and EM61-MK2 surveys are included in Appendix C.

4.2 Calibration Tests

An area that was tested and established as having “no noise” was used as a calibration test area outside of the GPO test grid for instrument calibration and QC checks before and after data collection with both the G858 and EM61-MK2 geophysical instruments. As described in DID MR-005-05A, the following calibration tests were performed:

- Static Background Test
- Static Spike Test
- Personnel Test
- Cable Shake Test
- Azimuthal Test (MAG only)
- Octant Test (MAG only)
- Height Optimization (MAG only)
- 6-Line Test

All instrumentation calibration QC tests were performed as specified in the Work Plan. The standard calibration QC tests, test frequencies and metrics are summarized in Table 15. The DID metrics were generally achieved although a higher standard deviation of measurements was observed for static measurements from the lower MAG sensor due to trembling/vibration of the lower sensor proximal to the soils. The QC results and DID metrics are discussed in Section 6.1. Calibration data files are also included in Appendix C, and the Sensor and Navigation QC Logs are presented in Appendix D. Field logs are provided in Appendix E.

4.3 G858 Magnetic Survey

The G858 was deployed in vertical gradient and horizontal modes using the Parsons sensor array cart. The vertical sensor separation between the two sensors was 2 feet with the sensors mounted at 12 and 36 inches above the ground. The offset from the GPS antenna to the magnetometers was measured and used for data positioning. The measured GPS antenna offset was x = -1.08 feet and 1.08 feet - and y = 0 feet to magnetometers 1 and 2, respectively. Data were collected with both sensors in the vertical position, with the bottom sensor approximately 12 inches above the ground surface. For the ODDS grids, data were collected with a line spacing of 2 feet. Lines spacing was achieved by following the track marks from previous lines. Sensor measurements were collected every 0.1 seconds. The navigation data streamed from the rover unit into the field laptop. The gradiometer and navigation data were stored for subsequent downloading at the end of the day.

For the purpose of this study, the MAG and gradient data were collected concurrently. Rather than covering the grids twice, the data were collected in the vertical gradient configuration, and the lower MAG sensor data were used for the total field MAG analysis.

The data were collected along north-south traverses which spanned all four ODDS plots.

4.4 EM61-MK2 Electromagnetic Survey

The EM61-MK2 array consisted of 3 sets of coils mounted on a cart with fixed distances with respect to each other. The cart was towed by a Dodge Dakota pick-up truck. EM61-MK2 data were collected with the GPS antenna mounted centered above the center EM unit 1 (EM1) using the following GPS-sensor offsets:

Sensor	X offset	Y offset
EM1	0	0
EM2	2.0 feet	-2.0 feet
EM3	-2.0 feet	-2.0 feet

Data were collected along the same traverses described for MAG data collection with line spacings of approximately 2 feet. Sensor measurements were collected every 0.1 seconds. The navigation data streamed from the rover unit and EM61-MK2 to a data acquisition laptop. The four-channel EM and navigation data were stored in the laptop and were downloaded following the field activities.

5.0 Geophysical Data Processing

The following summarizes the processing procedures and parameters used on the ODDS plot data. Data processing logs are provided in Appendix F. A report detailing the use of a tractor as a tow vehicle is provided in Appendix G. Two white papers detailing advanced processing techniques are provided in Appendix H.

5.1 G858 Data Processing and Target Selection

5.1.1 G858 Data Processing

The MAG data, including both the survey and base station data, were downloaded to a laptop computer in the field using Geometrics Magmap 2000® software. The data were verified and backed up prior to G858 system demobilization. Magmap 2000® was used to remove drop outs and to perform the sensor offset position corrections. RTK GPS positions were collected in geographic latitude/longitude coordinates and converted in Magmap 2000® to Universal Transverse Mercator Zone 10N WGS84 coordinates for intermediate xyz files. These coordinates were subsequently converted to North American Datum 1983 California State Plane Zone 4, US Survey feet coordinates in Geosoft. Subsequent to data review, Geosoft was used for additional spike removal and further data processing. Spike rejection using a standard Geosoft non-linear filter with a width of 1 and tolerance of 0 and a 1-point (MAG sensor 1) and a 2-point (MAG sensor 2) lag correction were also performed.

Gradients were calculated by subtracting the top sensor reading from the bottom sensor readings and dividing by the 2-foot sensor separation.

Geosoft was used to generate the analytic signal (AS) for both total field and gradient data. The AS data plots (Figures 15, 17, 20, 22, 25, 27, 30, and 32) are provided for both the total field and gradient data. Calculating the AS on gradient data approximates the leveled AS of the total field [the closeness of the approximation depends on the sensor heights (upward and downward continuation), separation, and the orientation of the local field]. The data were gridded using a minimum curvature routine with a grid size of 0.5 feet.

5.1.2 G858 Target Selection

Analysis of the GPO data resulted in the determination that geologic noise, background levels, and terrain responses dominated the target selection criteria. These parameters appeared to be best controlled through the use of thresholds at this early stage of the project, which resulted in the focus on thresholds for general target selection.

Targets were auto-picked in UXDetect® from the calculated AS data. Targets were merged with a radius of 2 feet for the total field and gradient data. The target locations were reviewed and manually adjusted by a Shaw geophysicist during target QC using both the AS and the dipolar total field data.

Because of the MAG noise levels and noise/anomaly densities encountered, thresholds were established based on an evaluation of the noise levels and the detection of the known location seed items in each GPO plot. We believe this approach maximizes the detection ability while minimizing the numbers of false positives being detected. These thresholds and GPO background noise levels are listed as follows:

MAG Picking Thresholds and Background Levels

Sensor		Value
Total Field AS	Threshold (nT/ft)	7
	Background (nT/ft)	1.6
Vertical Gradient	Threshold (nT/ft)	3
	Background (nT/ft)	1.0

nT/ft = nanoTesla(s) per foot.

Discussion and assessment of the target selection criteria is presented in Section 6.1. Target lists and analyses for the total field and magnetic gradient data sets are discussed in Section 6.2.

5.2 EM61-MK2 Data Processing and Target Selection

5.2.1 EM61-MK2 Data Processing

All EM61-MK2 data were downloaded to a laptop computer in the field. The data sets were verified and subsequently backed up prior to system demobilization. Geosoft's Oasis Montaj® and UXDetect® were used for post-processing, target picking, analysis, and map creation. The data were merged and xyz files generated using Shaw software. The data were leveled using a 100-point drift correction, and a 0-, 2.5- and 4.5-point lag corrections, for sensors EM1, EM Unit 2 (EM2) and EM Unit 3 (EM3) respectively. The four leveled data channels were summed in a sum of the four leveled EM61-MK2 data channels (Sum4) channel for gridding and interpretation. Based on assessment of the data and noise levels, the sum of channels provided the best signal to noise ratio. This can be easily seen in the profile data over a 37 mm target depicted in Figure 34 (see page 6-8). The data were then gridded using a minimum curvature routine with a grid size of 0.5 feet.

5.2.2 EM61-MK2 Target Selection

Thresholds were selected that would minimize the amount of target picks without excluding items of interest. The targets were automatically selected using the Blakely method within UXDetect®. The threshold was established based on an evaluation of the noise levels and the detection of the known location seed items in order to maximize detection performance while minimizing the number of false positives being detected. It was determined that using the Sum4 channel enhanced the signal to noise ratio resulting in fewer overall targets. The picking thresholds are listed as follows:

EM61-MK2 Picking Threshold and Background Levels

Sensor	Value
EM61-MK2 Sum4 Threshold (mV)	14
Sum4 Background (mV)	3.8

Discussion and assessment of the target selection criteria is presented in Section 6.1. Target lists and analyses for the EM data sets are discussed in Section 6.3.

Targets were merged using a 2-foot search radius. The targets were then reviewed by a Shaw geophysicist and adjusted as needed. Target lists and analyses for the EM61-MK2 data sets are discussed in Section 6.3.

6.0 Results

The DGM data quality objectives (DQOs) are discussed in Section 6.1, followed by the interpretative results for the G858 MAG and EM61-MK2 data in Sections 6.2 and 6.3, respectively.

6.1 Data Quality Objectives

The following sections discuss the DID DQOs and general DQOs specified for the Fort Ord project.

6.1.1 Background Noise

The metric for background noise will be determined based on the GPO data. The Background Noise Levels table presents the background noise, calculated as the mean of the peak clipped data, were observed during the GPO.

Background Noise Levels

Instrument	Data	Value	Units
EM61-MK2	Channel 1	1.9	mV
	Channel 2	0.8	mV
	Channel 3	0.6	mV
	Channel 4	0.3	mV
	Sum4	3.8	mV
MAG (G858)	Total Field	48671 ± 1	nT
	Residual of Total Field	9.1	nT
	Vertical Gradient	± 1	nT/ft

6.1.2 Mean Speed

The metric for mean speed is less than 3 miles per hour (mph). Average along-track speeds were slightly greater than 2 mph; 2.03 mph for the EM array and 2.05 mph for the mag array. The metric of 3 mph was not exceeded during the GPO except on a local point-to-point basis where the "instantaneous" motion of the prism or receiver due to sway was not indicative of the sensor velocity.

6.1.3 Along-Track Spacing

The metric for along-track spacing is less than 0.6 feet with cumulative gaps of less than 2 percent. Along-track spacing during the GPO was within the metric for the RTK GPS data, which sampled positions at a true 10-hertz rate. EM data were sampled at approximately 0.3 foot increments and the magnetic data were also sampled at approximately 0.3 feet increments. Cumulative gaps were approximately .07 percent, below the 2 percent specification.

6.1.4 Cross-Track Spacing

The metrics for cross-track spacing are less than 2 feet, not to exceed 2.5 feet, excluding gaps due to obstructions. This metric is very aggressive for non-flat terrain conditions. Data track maps for each GPO for both G858 magnetometer and EM61-MK2 surveys are shown in Figures 5 through 12. The following summarizes cross-track spacing for each GPO site:

- Known 1: Good repeatable coverage was achieved for both MAG and EM data with only minor local cross-track spacing deviations including one line gap in the EM data (Figures 5 and 6, respectively).
- Known 2: Good repeatable coverage was achieved for both MAG and EM data with only minor local cross-track spacing deviations (Figures 7 and 8, respectively).
- Unknown 1: Good repeatable coverage was achieved for both MAG and EM data with only minor local cross-track spacing deviations (Figures 9 and 10, respectively).
- Unknown 2: Good repeatable coverage was achieved for both MAG and EM data with only minor local cross-track spacing deviations including minor line gaps in the EM data (Figures 11 and 12, respectively).

6.1.5 Latency Correction

The metric for latency correction is no visible chevron effects on the data maps. Latency corrections were generally low (0 to 4.5 points). Lag corrections were applied such that chevron effects were not visible in the processed data.

6.1.6 Data Quality

Profile data showed no systematic or sporadic equipment noise excluding occasional magnetometer drop outs and data spikes. Background levels were generally low creating a high (good) signal to noise ratio.

6.1.7 Data Leveling

The metric for data leveling consists of achieving consistent processing parameters and methods for all data sets. A UXDetect® 100 point rolling drift correction was applied for leveling. Magnetic data were diurnally corrected using the static base station data.

6.1.8 Anomaly Selection

The metric for anomaly selection will be determined based on the GPO data in consultation with USACE for inclusion in the MRS-16 Work Plan. Analysis of the GPO data site conditions resulted in a determination that geologic noise, background levels, and terrain responses at each test site dominated the anomaly selection criteria. Processing of the data was generally straightforward due to the low level of geologic noise. Multiple factors were considered, including signal power threshold, noise levels on each data channel, anomaly densities and geometries, decay curves and channel summing (for EM data), and AS (for MAG data). For EM data, 24 of 30 known targets were detected at Known 1 (Table 3) and 26 of 34 known targets were detected at Known 2 (Table 6). For MAG total field data, 24 of 30 and 26 of 34 known targets were detected at Known Plots 1 and 2 respectively (Tables 4 and 7). The gradient data detected 22 of 30 and 21 of 34 targets at Known Plots 1 and 2 respectively (Tables 5 and 8).

6.1.9 Known Location Calibration Positional Check

The metric for known location calibration positional check is less than 0.5 feet. Navigation control at known point calibration was performed on all RTK GPS setups. All were within 0.5 feet.

6.1.10 Dynamic Calibration Positional Check

The metric for dynamic calibration positional check is based on cumulative errors not to exceed 2 feet. Section 4.2 discusses the 6-Line and 2-Line calibration tests which are summarized in Table 15. Lag-corrected replicate line peaks show cumulative positional errors of less than or equal to 2 feet. Of the 16 corner hubs on the GPO plots, all were located within the boundaries of their associated anomalies. Due to uncertainties in calculation of the targeted peak response (EM) or inflection point (MAG) location related to data point distribution, grid size, and interpolation uncertainties, the metric is considered to have been achieved as long as the coordinates lie unambiguously within the associated anomaly.

6.1.11 Known Location QC Items

The metric for known location QC items is within 2 feet of their known locations. Assessment of buried seed item locations versus target anomaly pick locations at the GPO sites, which is discussed in Sections 6.2 (G858) and 6.3 (EM61-MK2), indicates that the seed items are being located within 2 feet of their known locations.

6.1.12 Reacquisition

The metrics for reacquisition is that seed items must be within 2 feet of their interpreted location and 95 percent must lie within a 3.28 foot radius of their original dig sheet location. The targets were reacquired using the GPS and EM61-MK2 unit. Of the 53 targets reacquired only one target (562) was offset by more than 2 feet (Tables 19 and 20). The offset to 562 was 2.5 feet which is still within the 3.28 foot radius specification. Reacquisition recommendations based on the GPO results are discussed in Section 7.5 for incorporation into the Geophysical Investigation Plan.

6.1.13 False Positives

The metric is for false positives to be kept to a minimum. As part of the detection analysis, an approximation of a false positive rate has been calculated based on the number of seed-item targets and the number of non-seed item targets (including blind seed items). This is not a true false positive rate because the non-seed item target anomalies have not been excavated and we do not know what they represent, nor do we know the number and location of blind seed items. These approximated rates significantly overstate the actual false positive rates because it assumed that all non-seed item target anomalies are false positives. The definition of a false positive in DID MR-005-05 is "anomalies reacquired by the Contractor result(ing) in no detectable metallic material recovered during excavations, calculated as a running average for the sector." As there is no way to calculate a true false positive rate without excavating all the non-target anomalies, we have calculated these overly conservative approximate rates using the available data. It is believed that the blind seed items are likely detected and are among the targets that have not been correlated to the known items.

6.2 G858 Magnetometer Results

6.2.1 Total Field Magnetic Data

The total field data are presented in the figures as follows:

- Total field MAG data are shown in Figures 14, 19, 24 and 29 for Known Plots 1 and 2 and Unknown Plots 1 and 2, respectively.
- AS data calculated from the total field response data are shown in Figures 15, 20, 25 and 30 for Known Plots 1 and 2 and Unknown Plots 1 and 2, respectively.

Tables 4, 7, 10 and 13 list the targets selected for each of the four plots. Tables 3 and 6 also show the location and correlation with different seed items picked from total field data for both of the known item plots. Summary target selection, analysis information, and target grading for total field MAG data sets are presented in Table 21. The total field survey results are summarized as follows:

- Known Plot 1. 81 percent—25 of the 31 seed items were detected. The 7 empty holes are not included in the seed item number. A total of 101 targets were identified, resulting in a false alarm rate (FAR) of 76 percent. Two signals illuminations buried at 12 inches, three 35 mm projectiles buried at 12, 18 and 24 inches and one 2.36 inch projectile buried at 24 inches were not detected. One MK-2 practice hand grenade seed item that was not detected is located just outside the area on the western boundary of Quadrant C. Note that the 35 mm projectiles at 18 and 24 inches are deeper than the detection metric of depth to 11 times the target's diameter.
- Known Plot 2. 76 percent—26 of the 34 seed items were detected. A total of 159 targets were identified, resulting in a FAR of 84 percent. One signal illumination

buried at 12 inches, two 25 mm projectiles buried at 18 and 24 inches, one 3-inch stokes mortar buried at 40 inches, one 37 mm buried at 24 inches, one 75 mm Shrapnel case buried at 36 inches and 2 frag targets buried at 12 inches were not detected. Note the 25 mm, 3 inch stokes mortar, 37 mm and 75 mm Shrapnel MK1 case were at depths below the depth detection metric.

- Unknown Plot 1. 144 targets were detected. No further analysis can be made since no seed item information is available for this plot.
- Unknown Plot 2. 163 targets were detected. No further analysis can be made since no seed item information is available for this plot.

6.2.2 Magnetic Gradient Data

The gradiometer survey data and selected targets are presented in the following figures:

- Gradient data are shown in Figures 16, 21, 26 and 31 for Known Plots 1 and 2 and Unknown Plots 1 and 2, respectively.
- AS data calculated from the gradient data are shown in Figures 17, 22, 27 and 32 for Known Plots 1 and 2 and Unknown Plots 1 and 2, respectively.

Targets picked from gradiometer data are labeled numerically on the maps. Tables 5, 8, 11 and 14 list the targets selected for each of the four plots. Tables 4 and 7 also show the location and correlation with different seed items on the known item plots. Summary target selection, analysis information, and target grading for magnetic gradient data sets are presented in Table 21. The magnetic gradient survey results are shown as follows:

- Known Plot 1. 74 percent—23 of the 31 seed items were detected. The 7 empty holes are not included in the seed item number. A total of 43 targets were identified, resulting in a FAR of 63 percent. Two frag targets buried at 12 inches, three 35 mm projectiles buried at 12, 12 and 24 inches and 1 grenade rifle M9 head buried at 18 inches were not detected. One MK-2 practice hand grenade seed item that was not detected is located just outside the area on the western boundary of Quadrant C.
- Known Plot 2. 62 percent—21 of the 34 seed items were detected. A total of 46 targets were identified, resulting in a FAR of 54 percent. Four frag targets buried at 12 inches, two 25 mm projectiles buried at 18 and 24 inches and two 37 mm projectiles buried at 24 inches were not detected. The 25 and 37 mm projectile targets were buried deeper than their respective detection depth metrics.
- Unknown Plot 1. 81 targets were detected. No further analysis can be made since no seed item information is available for this plot.
- Unknown Plot 2. 84 targets were detected. No further analysis can be made since no seed item information is available for this plot.

6.3 EM61-MK2 Electromagnetic Results

The EM61-MK2 GPO test grid data are provided as Figures 13, 18, 23 and 28 for Known Plots 1 and 2 and Unknown Plots 1 and 2, respectively.. The targets picked from each respective EM data set are shown relative to the seeded item locations and are superimposed on the sum of the 4 time gates data. Tables 3, 6, 9, and 12 list the EM data target picks for each of the four plots. The locations and associations to the known seed items are included in Tables 2 and 5. Summary target selection, analysis information, and target grading for both MAG and EM data sets are presented in Table 21. The EM61-MK2 survey results are summarized as follows:

- Known Plot 1. 84 percent—26 of the 31 seed items were detected. The 7 empty holes are not included in the seed item number. A total of 108 targets were identified, resulting in a FAR of 76 percent. Two frag targets buried at 12 inches and three 35 mm projectiles buried at 12, 12 and 24 inches. One MK-2 practice hand grenade seed item that was not picked is located just outside the western boundary of Quadrant C.
- Known Plot 2. 79 percent—26 of the 34 seed items were detected. A total of 120 targets were identified, resulting in a FAR of 74 percent. Four frag targets buried at 12 inches, two 25 mm projectiles buried at 18 and 24 inches and two 37 mm projectiles buried at 24 inches were not detected. The 25 and 37 mm projectile targets were buried deeper than their respective detection depth metrics.
- Unknown Plot 1. 147 targets were detected. No further analysis can be made since no seed item information is available for this plot.
- Unknown Plot 2. 161 targets were detected. No further analysis can be made since no seed item information is available for this plot.

The EM target selections correlate extremely well with the known seeded item locations. Several additional targets, not attributed to any known seed items, were selected in each EM data set. These targets are likely blind seed items and/or preexisting metallic items, as the grids were not cleared prior to seed item burial. This leads to higher apparent FARs. Additionally, the reacquisition errors of all targets picked in both EM data sets fall within the criteria outlined in the Work Plan (Shaw, 2006).

In an effort to reduce the FAR, the Parson's lowpass filtering and 3 mV thresholds, as discussed in their Ft Ord reports are likely candidates for use given their success. Tests of their parameters have shown that to get equivalent results to Parson's using a threshold of 2.2 mV is required. However this may increase the numbers of targets. More investigation will be done.

6.4 Analysis of Results

As required by DID MR-005-05A, the geophysical data were graded to allow comparison of the sensor data. Table 21 summarizes the grading of each data set for both MAG and EM data. The

EM61-MK2 surveys had higher probability of detections (with a moderate FAR) than either the MAG total field or vertical gradient surveys.

The MAG data failed to detect a number of the seeded items, some of which are buried beyond the depth of 11 times the diameter of the item.

The target picks from the total field MAG and gradiometer data are similar. This is expected as the data essentially measure the same property. However, the magnetic data had more picks. This may be attributed to the total field data being inherently noisier than gradient data.

Total field data typically produce anomalies that are greater in area than the gradient anomalies but with higher background noise levels. Target reacquisition is also difficult for both the gradient and total field magnetic surveys because the AS data are calculations rather than responses observed directly from the field instrument. Persistent (nontransient) short wavelength total field and gradient responses from nonhomogenous distributions of ferro-magnetic minerals/aggregates (hot rocks) are inherently more difficult to resolve from "background" conditions. The gradient data is more effective in increasing the signal to noise ratio due to mitigation of transient noises and generally longer wavelength nontransient geologic noises, which are not necessarily the dominant components of the background noise levels at these sites. In this case, the gradient data seem to be slightly more effective in resolving the anomalies from the seed items.

Aside from data collection issues, gradiometer and MAG data require more processing steps and more involved interpretation to produce target lists than EM data. Additional processing steps are required for picking targets from MAG and gradient data, including calculating the AS. Generally, the picked targets must be adjusted manually in order to accurately locate them on the inflection point of the dipolar anomaly, which may or may not be apparent in the data, depending on the complexity of the magnetic signature and the proximity of the targets. Figures 33, 34, and 35 illustrate the profiles generated by each instrument over a 37 mm Projectile buried at 18 inches. The simplicity of selecting the same target in the EM data set compared to the gradient and total field MAG data is demonstrated in these figures. The EM data show a definite peak directly at the target location, whereas the gradient and MAG data show a complex profile at the same location.

Figure 33. EM61 Profile Over 37 mm Projectile at 18 Inches

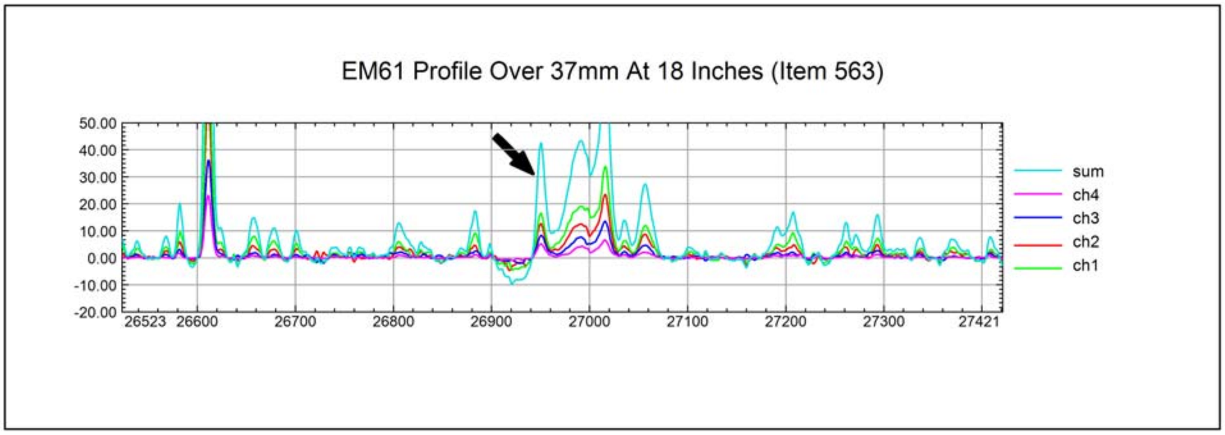


Figure 34. Gradiometer Profile Over 37 mm Projectile at 18 Inches

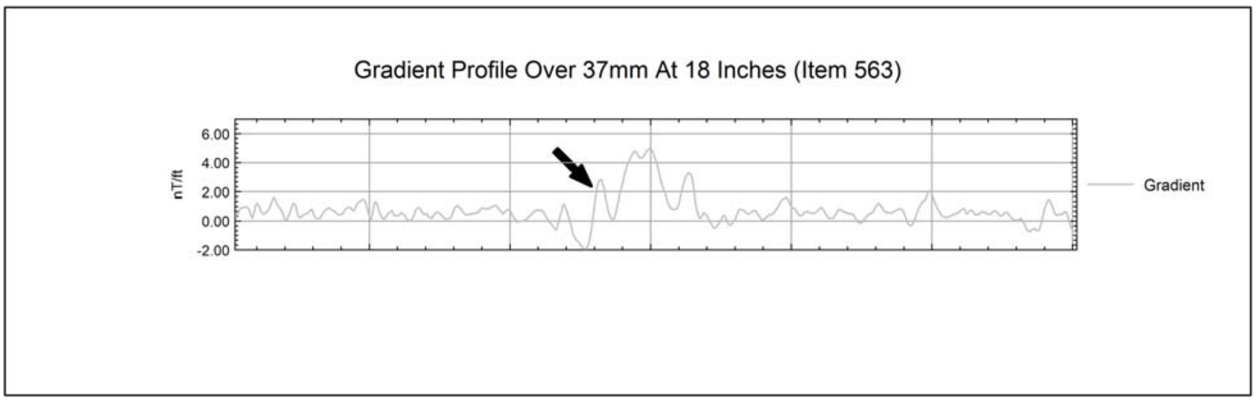
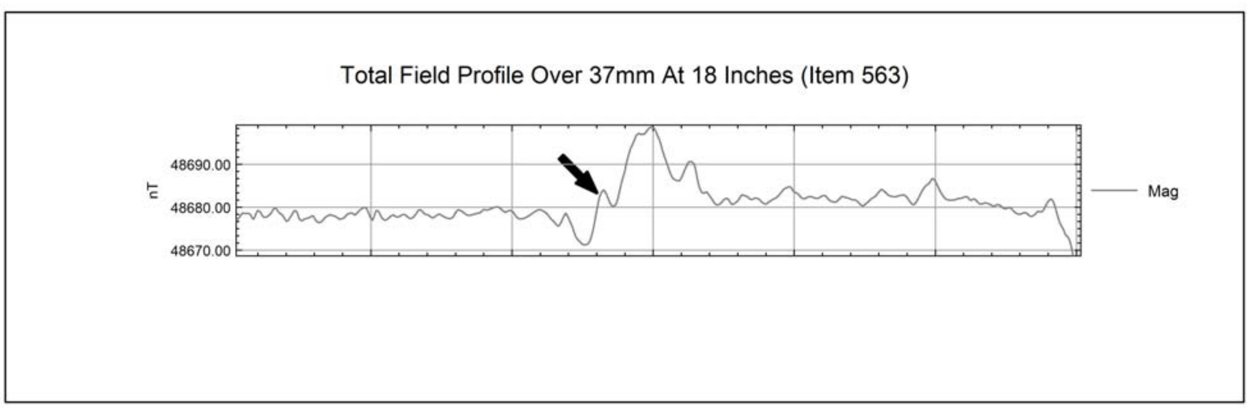


Figure 35. Total Field Profile Over 37 mm Projectile at 18 Inches



Review of the detection depths at Known Plots 1 and 2 shows that the EM data detected the targets at depths meeting or exceeding the 11 times the depth metric as described in the DIDs. The exceptions are the signals illuminations, MK-2 grenade, the M7 2.36 inch practice rocket and the 90 mm projectile. They were detected, however, no judgment is made regarding these targets since these seeded items' burial depths did not meet or exceed the performance objective depth. In three incidences the EM detected seeded items to depths greater than the vertical gradient – 37 mm projectile, 25 mm projectile, and 75 mm shrapnel MK1 case. The EM also detected the 75 mm shrapnel case to depths deeper than the total field mag. The total field mag and the vertical gradient data did not detect targets deeper than the EM.

The EM61-MK2 data at Known Plots 1 and 2 detected most of the targets, meeting or exceeding the depth specifications

The vertical gradient data at Known Plots 1 and 2 detected most of the targets, meeting or exceeding the depth specifications. The 25 mm projectile was not detected and the 75 mm shrapnel MK1 was detected to 30 inches rather than the 32 inch specification.

The total field magnetic data at Known Plots 1 and 2 also detected most of the targets, meeting or exceeding the depth specifications. The 81 mm mortar was detected outside the 2 foot search radius and the 75 mm shrapnel MK1 was detected to 30 inches rather than the 32 inch specification.

Exceptions regarding the detection depths are the signals illumination, MK-2 grenade, the M7 2.36 inch practice rocket, and the 90 mm projectile. No judgment is made regarding these targets since these seeded items' burial depths did not meet or exceed the performance objective depth. They were however detected. Tables 16, 17, and 18 present the type and percentage of items detected at various depths for each type of sensor.

7.0 Recommendations

7.1 Selected DGM Survey Equipment

For the DGM project at MRS-16 an array of three EM61-MK2s survey system integrated with the Leica RTK GPS is recommended. This recommendation is based on the following factors:

- The EM61-MK2 is capable of identifying all "known" seeded items within DID specifications.
- The MAG and vertical gradient surveys had lower seed item detection rates in Known Plot 1.
- Target picking and reacquisition meet project specifications.
- The system is well suited to collecting data given the project site conditions.
- The EM61-MK2 provides more accurate and convenient target reacquisition.
- EM61-MK2 sensors are not restricted to ferrous metal and are insensitive to ferro-magnetic (hot) rocks.
- Target picking is easier because target anomalies are generally located directly over the buried metal; AS generation adds uncertainty in locating targets, particularly in dense target areas.
- The seed items that were not detected by the EM61-MK2 were buried close to, or below, the performance depth of 11 times the diameter of the target. These data will be used to determine depths where detection drops off and will be compared to production data as a tool for target selection.
- Target reacquisition is quicker and more efficient with the EM61-MK2, as the anomaly values posted on the target lists will closely resemble those found in the field reacquisition and are not dependent on daily field variations.

7.2 Contingency DGM Equipment

The vertical gradient magnetic sensor configuration will be used in areas where the EM61-MK2 data collection is not appropriate. It was found during previous DGM work by other contractors that at Fort Ord, power lines greatly affect the EM data quality and the gradient data provides superior results. Evaluations of both systems in areas close to power lines will need to be completed before DGM in these areas proceed.

7.3 Recommendations for DGM Survey Procedures

Digital geophysical mapping using the EM61-MK2 and RTK GPS demonstrated during the GPO will be utilized for production surveys. All instrumentation will be field-tested prior to initiation of the production surveys. Other recommendations for production work based on the GPO results are addressed in the following sections.

7.3.1 Grid Surveys

It is anticipated that DGM with 100-percent coverage can be achieved.

7.4 Recommendations for DGM Data Processing and Target Selection

7.4.1 Data Processing

Geonics EM61-MK2 TDEM metal detector data processing procedures demonstrated during the ODDS plots surveys appear to be sufficient to meet the target detection criteria established for the project.

7.4.2 Target Selection

Threshold-based target selection criteria for the EM61-MK2 sum of channels data was most effective at detecting the GPO seed items and achieving an optimal "apparent" False Positive rate (real rate not known due to blind seeds and unremoved buried items). Given that there is a high likelihood of collecting both EM and magnetic data with the EM being the primary data for the DGM all the recommended thresholds are presented and are as follows:

Recommended Picking Thresholds Based on ODDS Plot Results

Sensor	Threshold
EM61-MK2 Sum4 Threshold (mV)	14
Analytic Signal from Gradient Data Threshold (nT/ft)	3
Analytic Signal from T.F. Magnetic Threshold (nT/ft)	7

7.5 Recommendations for Target Reacquisition

Anomaly reacquisition was performed using a single EM61-MK2 integrated with a Leica RTK GPS for navigation. The success achieved (meeting DIDs requirements) indicate that this configuration of instrumentation is appropriate for the production surveys. However, near the power lines, where magnetic or gradient data may be collected, the use of same (magnetic) sensor is recommended.

We note that data from arrayed EM61-MK2 sensors has generally shown slightly higher signal-to-noise ratios than single units, apparently due to synchronization and overlap of the primary EM pulses transmitted. For reacquisition, which is only practical for single EM61-MK2s, the observed target reacquisition responses may vary slightly.

8.0 References

Shaw Environmental, Inc. (Shaw), 2006. *Draft Work Plan, MRS-16 Munitions and Explosives of Concern Removal, Former Fort Ord, California*