ERDC/EL TR-06-11

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Environmental Quality Technology Program

Aberdeen Proving Ground GEM-3 Data Collection

Hollis H. Bennett, Jr., Tere A. DeMoss, Morris P. Fields, Ricky A. Goodson, and John Cliff Morgan

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Final report

Approved for public release; distribution is unlimited.

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Abstract: This report documents the analysis of the standard GEM-3-98 and the enhanced GEM-3-E sensor systems. The data were collected for the Advanced UXO Detection/Discrimination Technology Demonstration at the U.S. Army Aberdeen Proving Ground (APG), Aberdeen, MD. The data collection effort was conducted under sponsorship of the Department of Army Research and Development DOE4 (BA4) program. The analysis was conducted under sponsorship of the Department of Army Research and Development DOE3 (BA2/3) program. This post-demonstration analysis focuses on the usability of sensor systems, evaluates the noise level of the data collected, and examines improvements in target detection/discrimination, and positioning errors of the systems. The stability of the system is evaluated through histograms and statistical measurements of data collected during the technology demonstration. Based on findings of the characteristics of the collected data and initial work performed on target detection/discrimination, target detection/discrimination techniques are applied and evaluated. The statistical variability of the amplitude, in-phase, and quadrature measurements on classification performance was also examined.

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Preface

This report describes efforts conducted under the sponsorship of the Environmental Quality Technology (EQT) Program A (1.6.a), Unexploded Ordnance (UXO) Screening, Detection, and Discrimination Management Plan, Test and Evaluation (BA4) Major Thrust Area II, UXO Technology Demonstration, Work Unit "Hand Held UXO Detector, Design Demonstration and Validation." The work documented in this report was performed during the period 8 September through 12 September 2003. This project was funded through the EQT program previously cited. Dr. M. John Cullinane was Technical Director, Military Works Environmental Engineering and Cleanup, Environmental Laboratory (EL), U.S. Army Engineer Research and Development Center (ERDC), for EQT UXO work.

John H. Ballard, EL, and George Robitaille, U.S. Army Environmental Center (USAEC), were program managers of the Environmental Quality Technology Program A (1.6.a) during the execution of this project. Hollis "Jay" Bennett, EL, was responsible for planning, participated in the field demonstration activities, and directed the analysis of the results. Bennett, Jose L. Llopis, Morris P. Fields, and John Cliff Morgan, EL, executed the field demonstrations. Llopis was responsible for the daily log records. Bennett, Morgan, Fields, Ricky A. Goodson, and Tere A. DeMoss, EL, and R. Eddie Melton, JAYA, assisted with data analysis. The review and recommendations provided by Aberdeen Test Center (ATC) are gratefully acknowledged.

This project was performed under the general supervision of Dr. David J. Tazik, Chief, Ecosystems Evaluation and Engineering Division, EL, and Dr. Elizabeth C. Fleming, Director, EL.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
acres	0.4047	hectares
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
inches	0.0254	meters
miles (U.S. statute)	1,609.347	meters
miles per hour	0.44704	meters per second
pounds (mass)	0.45359237	kilograms

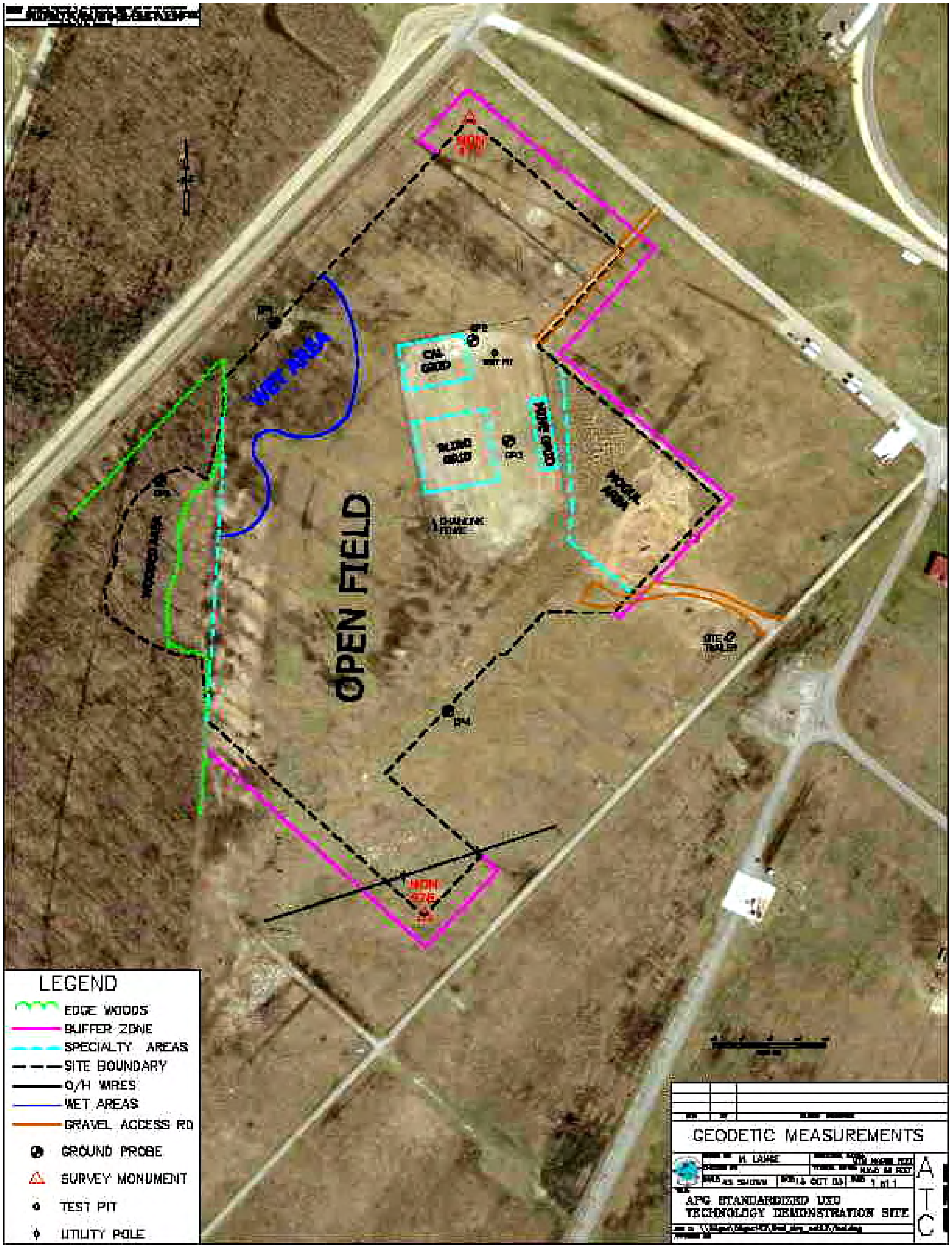
1 Introduction

This report documents the analysis of the time domain electromagnetic detectors by Geophex, Ltd., the standard GEM-3-98 and the enhanced GEM-3-E sensor systems. The data were collected for the Advanced UXO Detection/Discrimination Technology Demonstration at the U.S. Army Aberdeen Proving Ground (APG), Aberdeen, Maryland. The data collection effort was conducted under the Department of Army Research and Development DOE4 (BA4) Technology Demonstration Program. Data analysis was conducted under the Department of Army Research and Development DOE3 (BA3) Program. Post-demonstration analysis focused on the functionality of sensor systems, evaluation of the noise level in the data collected, improvements in target detection and discrimination, and positioning accuracy of the systems. The stability of the system was evaluated through histograms and statistical measurements of data collected during the technology demonstration. Based on findings of the characteristics of the collected data (Cespedes 2001, ERDC 2002) and initial work performed on target detection and discrimination (Miller et al. 2001), target detection and discrimination techniques were applied and evaluated.

This project addressed the Environmental Quality Technology (EQT) Program thrust area entitled “UXO Technology Demonstration, Work Unit “UXO Detection Design Demonstration and Validation.” This was Task 1 under this work unit. The objective was to evaluate enhancements made to the GEM-3 system.

Test site description

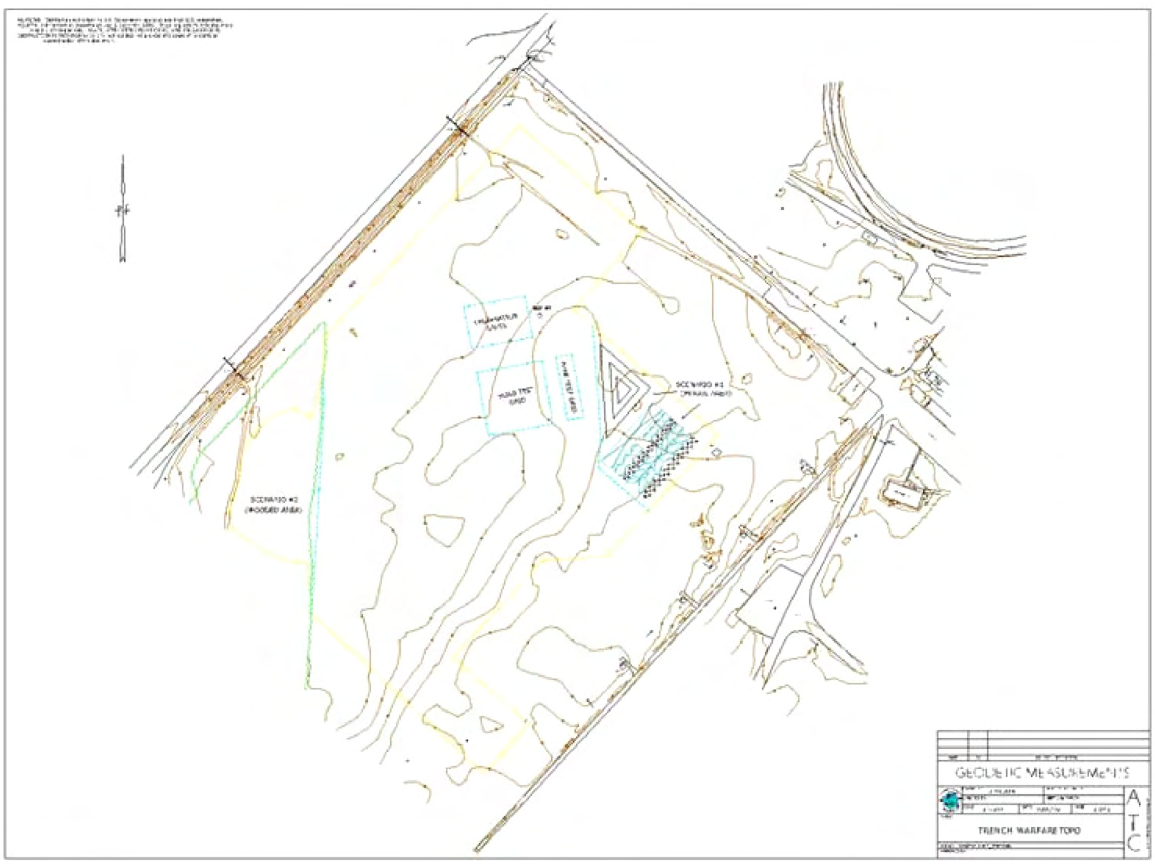
The APG Standardized UXO Technology Demonstration Site is located within a secured range area of the APG. The APG is located approximately 30 miles northeast of Baltimore, MD, at the northern end of the Chesapeake Bay. The Standardized UXO Demonstration Site encompasses 17 acres and is composed of upland and lowland flats, woods, and wetlands (see Figure 1). The layout descriptions are as follows:



a. Aerial view of layout

Figure 1. APG Standardized UXO Technology Demonstration Site (Continued).

b. Oblique view



c. Topographic view

Figure 1. (Concluded).

1. Calibration Lanes – 0.12 hectares (0.30 acres)
2. Blind Test Grid – 0.19 hectares (0.48 acres)
3. Open Field – 5.54 hectares (13.68 acres)
4. Scenario 1. Moguls – 0.53 hectares (1.50 acres)
5. Scenario 2. Wooded Area – 0.55 hectares (1.35 acres)

Description of data collection equipment

The GEM-3 system, manufactured by Geophex, Ltd., is a multi-frequency frequency domain electromagnetic (FDEM) system (Won et al. 1997). The GEM-3 sensor head contains three concentric coils (Figure 2). The outer coil (TX) is used as a transmitter, an inner low power transmitting coil is used as a bucking coil (BX) that creates a null area, and the innermost coil, located in the null area, is used as a receiver coil (RX). Hence, the two transmit coils create a central magnetic cavity that produces zero output to the inner receiver coil. For a frequency domain operation, the GEM-3 prompts for a set of desired transmitter frequencies. Built-in software converts this into a digital "bit-stream," which is used to construct the desired transmitter waveform. This bit-stream represents the instruction on how to generate a complex waveform that contains all frequencies specified by the operator. The basic GEM-3 Package consists of a 64-cm-diameter sensing head, handle boom, console with display unit, and battery charger. Standard software includes WinGEMv3, Windows-based operation software. The optional GEM-3 with 96-cm head, due to its size, must be mounted on a cart.

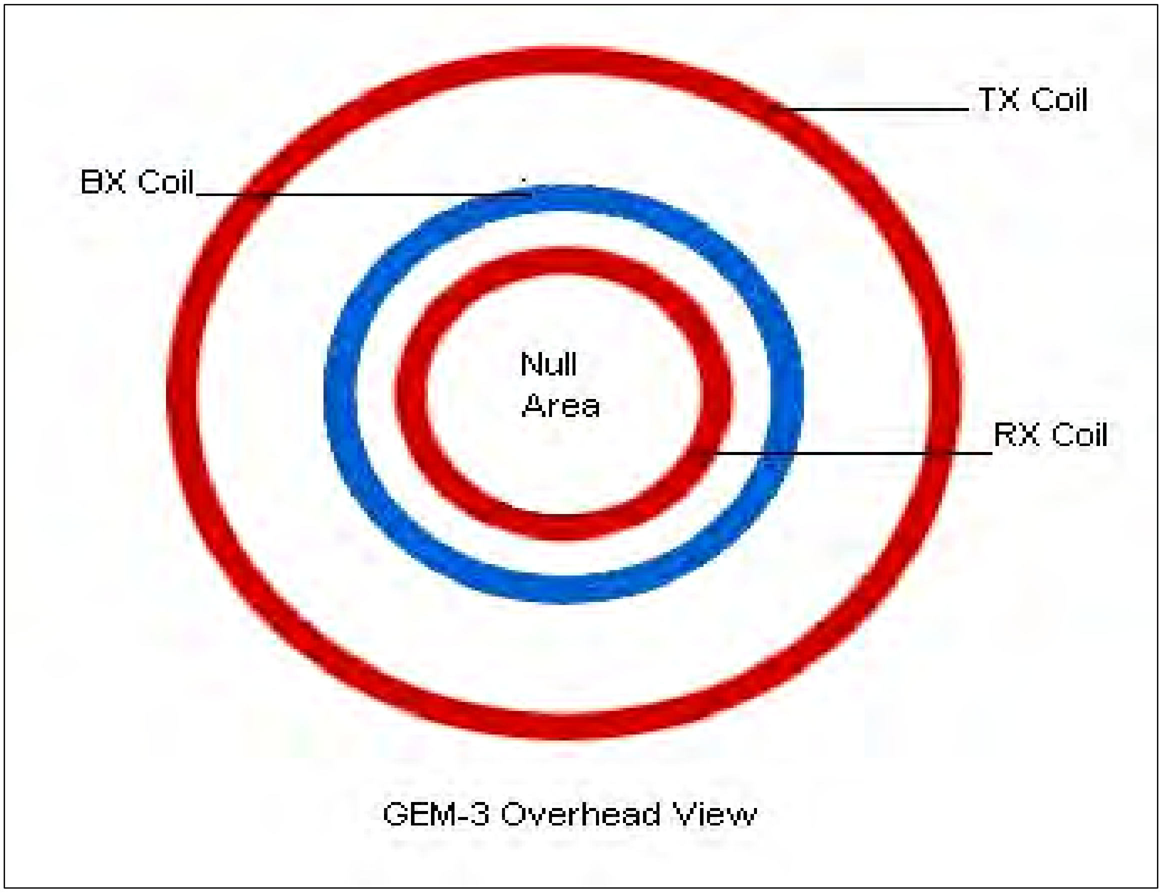


Figure 2. Schematic diagram of GEM-3-E, showing its internal construction.

2 Standardized UXO Technology Demonstration Site

Areas and grids of the Standardized UXO Technology Demonstration Site

The APG Blind Test Grid (BTG), as shown in Figure 3, consisted of a 3000-m^2 area. The BTG contained the same type of munitions found in the Calibration Lanes and the Open Field Site. Clutter items included non-UXO targets such as metal scrap, wood, and rocks. The calibration portion of the test site consisted of 19 lanes, 17 of which contained six identical munitions buried in various orientations and at three different depths. One lane contained four steel spheres buried at a depth of 0.5 to 2 m. Another lane contained two (30- and 61-cm diameter) circular steel plates buried at 0.3 and 0.9 m, respectively. A third lane contained 15- and 30-cm diameter copper wire loops (12, 16, 18, and 20 gauge) buried at 0.3 m depth. The wire loop, which will give a standard signature, can be used to calibrate the signature the detection instrument receives. If an installation has site-specific munitions that are not part of the Standardized Target, extra calibration lanes can be added.

Figure 3. Aerial view of the APG Blind Grid test area.

Munitions that are generally rectangular (aspect ratio not equal to one) were placed into the ground in six orientations and at three different depths. Munitions that are generally round (aspect ratio of one) were buried at three different depths. A 3.6-kg steel ball (diameter of 8.9 cm) was buried 15 cm deep at each end of the Calibration Lanes to provide a uniform signature that could be identified when looking at the raw data. The dig list for the GEM-3-98 and the enhanced GEM-3-E is shown in Appendix A.

Weather conditions

An Aberdeen Test Center weather station, located approximately 2 miles west of the test site, was used to record hourly average temperature and precipitation for each day of operation. The hourly weather logs used to generate this summary are provided in Appendix B.

Field conditions

ERDC personnel surveyed the Blind Grid on 10 September 2003. The calibration lane and blind grid had several muddy areas from rain before the field investigations. The climate during the data collection for Monday through Thursday was sunny. Rain on Friday, 12 September 2003, made extremely wet field conditions, as shown in Figure 4. On the last afternoon of the survey, some heavy rain, with winds gusting up to 20 mph, made conditions difficult.

Soil moisture

Three soil probes were placed at various locations of the site to capture soil moisture data: open field, open field lowland (wet), and open field scenario No. 1 wooded area. Measurements were collected in percent moisture and were taken twice daily (morning and afternoon) from five different soil layers, as seen in Table 1, from each probe. The average moisture content was calculated by averaging the morning and afternoon measurements for each layer of each probe for the duration of the field operations in the Blind Grid.

Figure 4. Survey on the last day in inclement weather.

Table 1. Soil moisture data summary.

Layer in inches and centimeters	Average Moisture Content, %	Standard Deviation, %
0 to 6 (0 - 15 cm)	39.81	0.29
6 to 12 (15 – 31 cm)	38.14	0.41
12 to 24 (31 – 61 cm)	8.46	0.67
24 to 36 (61 – 91 cm)	5.41	0.76
36 to 48 (91 – 122 cm)	85.53	1.08

Field Activities

Setup and mobilization

These activities included initial mobilization and daily equipment preparation and break down. A four-person crew took approximately 5 hr initially for setup and mobilization. Daily equipment preparation took 2 hr. Daily start/stop activities totaled 1 hr for the Blind Grid.

Calibration

ERDC personnel collected data for approximately 2 hr in the calibration lane on 9 September. ERDC personnel also collected data in the calibration test pit on 11 September using the 14 standard inert ordnance targets as shown in Figure 5. No other calibration was done while surveying the Blind Grid.

Figure 5. The GEM-3-E being calibrated over the pit.

Equipment maintenance and data checks

Equipment maintenance and data checks accounted for 10 min of site usage time while surveying in the Blind Grid.

Equipment failure or repair

No equipment failures occurred while surveying in the Blind Grid. The actual problems were with the prototype pushcart. The fiberglass or composite bolts used to anchor the wheels to the platform were stripping after minimal use. This equipment failure accounted for 50 min of downtime on 9 September.

3 System Descriptions

GEM-3-E system description

The GEM-3-E is a broadband, programmable electromagnetic (EM) sensor. It consists of a circular sensor, a three-button user interface or Personal Data Assistant (PDA) graphical interface, the electronics console, and the WinGEM software. The sensor is available in three different sizes. The 40- and 64-cm sensors come mounted on a boom for handheld operation, whereas the 96-cm sensor is usually mounted on a cart.

GEM-3-E specifications

- Multiple-frequency operation: up to 15 frequencies.
- Frequency band: 330 to 47,970 Hz.
- Coil configurations: horizontal coplanar.
- Battery: standard 12-V notebook computer battery (B905S).
- Battery life: ~4 hr.
- Weight: 9 lb (4 kg).
- Basic output: in-phase and quadrature response in parts per million (ppm).
- PC software: WinGEM2K.
- Positioning: utilizing GPS data.

GEM-3-E configuration

The GEM-3-E Cart system as used at APG consisted of the 96-cm head with the data acquisition box, an iPAQ PDA controller unit, and a Trimble 4700 GPS rover. The GPS rover was removed from the backpack and secured to a mast centered above the GEM-3-E sensor head. The controller was attached to the GEM-3-E adjacent to the iPAQ (see Figure 5). The frequencies used during the data collection were 90, 210, 390, 750, 1470, 2910, 5850, 11430, 21690 and 41,010 Hz.

GEM-3-98 description

The GEM-3 "circa 1998" is a multi-frequency frequency domain electromagnetic (FDEM) system (Won et al. 1998, Geophex 1998). The GEM-3-98 consists of a circular sensor, a three-button user interface, the electronics console, and WinGEM software. It is a handheld device with a 40-cm sensor head attached to a boom. This system allows the user to select up to seven frequencies between 30 Hz and 24 kHz in steps of 60 Hz. The system was developed by Geophex, Ltd., with improvements funded by the Army's Small Business Innovation Research (SBIR) Phase II program and was operated by Geophex during the Jefferson Proving Ground technology demonstration. Geophex performed the initial target detection.

GEM-3-98 specifications

- Multiple-frequency operation: up to 7 frequencies.
- Frequency band: 30 to 23,970 Hz.
- Coil configurations: horizontal coplanar.
- Battery: proprietary 12 V NiCd.
- Battery life: ~6 hr.
- Weight: 5 lb (2 kg).
- Basic output: in-phase and quadrature response in parts per million (ppm).
- PC software: WinGEM.
- Positioning: post-collection synchronization.

GEM-3-98 configuration

The GEM-3-E cart was used to acquire data with both instruments. The GEM-3-E cart was fitted with a 96-cm plywood holder with a cut-out section to accommodate the 40-cm head of the GEM-3-98. This kept the sensor centered on the cart. The data acquisition box and the LCD controller unit and the Trimble 4700 GPS rover were attached in the same place as on the GEM-3-E. The GPS rover was removed from the backpack and secured to a mast centered above the GEM-3-98 sensor head. The GPS controller was attached to the GEM-3 next to the GEM-3 controller. The frequencies used during the data collection were 90, 150, 330, 930, 2790, 8190, and 20010 Hz.

Initial runs showed that the internal memory of the GEM-3-98 was only able to store 8 to 10 lines of data before downloading was necessary. Because of this limitation, a second configuration was developed. A laptop computer was attached to the GEM-3-98 by using a serial port link to eliminate the need to stop and download the data. This configuration is shown in Figure 6. However, it was necessary for an additional person to carry the laptop. This allowed the data to be collected without excessive breaks in acquisition.

Figure 6. GEM-3-98 wheel support ropes with add-on laptop computer.

Positioning system

Specifications

GPS was collected using a Trimble Pathfinder 4700 series rover and base station for differential GPS (DGPS). The rover GPS antenna was mounted on a mast located above the center of the head on both GEM units. The moving accuracy of the DGPS for this system was on the order of 2 cm. However, owing to the rotation of the mast above the wheels, errors of 10 cm or greater were experienced.

Configuration

The same GPS units were used on both instruments, but there is a difference between the two acquisitions. The GEM-3-98 has an input port for the integration of GPS data into the data stream. For the GEM-3-E, data were logged on both the internal memory of the GPS and the GEM-3-E. Data were only logged in the GPS on the GEM-3-98 acquisition runs.

4 Data Collection Procedure

Survey setup

Data were collected over both the calibration grid and the blind grid areas using both instruments. These areas have lanes designating the possible locations of targets. These lanes are marked with sections of PVC pipe driven into the ground at 1-m intervals. A 50-m tape was laid at both ends of the areas to designate the line spacing. Also, white nylon lines were used to mark the lines every 2 m. By lining up with the wheels alternating either on the line or straddling it, the operator can get 0.5-m spacing. Figure 7 shows data being collected (the marked lines are visible in this photo).

Figure 7. GEM-3-E with ropes marking survey grid lines.

Quality assurance/quality control procedures

There were a number of standard measures that the ERDC team used to ensure the quality assurance/quality control (QA/QC) of the data produced during the field investigation. Inspection of coverage maps was the first step. The data were corrected for GPS drift and viewed in pseudo 3-D to look at the quality of the sensor positioning response. Statistical analysis was also used to determine the signal statistics of the data, and calibration sources responses were analyzed to quantify data drift.

Coverage maps

The first QA/QC function was to examine the spatial distribution of the acquired data to ensure that the survey area was adequately covered. After each data acquisition lane, data were acquired and downloaded; a line path plot was generated. The plot was generated to verify that no significant gaps were present in the newly acquired data or between the new data and the previously acquired data. When all the data for an area were collected, a coverage map of the area was generated using Geosoft's UX-Detect software module. A grid of a user-selected ground resolution was created and the number of survey points that pass through each grid was counted. It is displayed on a color-coded map in the next chapter. Grids with a value of zero, which was displayed in white, indicate gaps in the area coverage at the resolution being displayed. A coverage map was generated for each instrument at two resolutions: 0.5 m, which was the nominal line spacing for this data collection effort, and 0.75 m. If the survey lines were walked perfectly and no positioning error was present, then the 0.5-m coverage map would show 100% coverage. Because of imperfections in the data acquisition process, some small gaps in coverage may appear in the 0.5-m coverage maps; however, these gaps should disappear in the 0.75-m coverage map. Gaps in the 0.75-m coverage map indicate significant departure from the desired coverage. The coverage maps for each system are presented in Chapter 5.

GPS corrections

GPS was collected using a Trimble Pathfinder 4700 series rover and base station for differential GPS. In this configuration, the accuracy is between 2 and 10 cm.

Because of an internal lag between the synchronization of the input port on the GEM-3-E and the output of the DGPS system, it is necessary to correct the merged data stream to ensure that the position data and the measured electro-magnetic data are correctly co-located. Values observed for the magnitude of this drift are typically in a range from 0.5 to 1.5 sec, and it is thought to be caused by either the initial states of the buffers in the two instruments or in the overhead requirements for raw data processing. It was observed that once a correction value was found, the data continued to be corrected until the instrument was restarted.

Each data collection run was started with a calibration and synchronization procedure to determine the length of the lag. The instrument was placed on a calibration item, such as a ferrite core, when the DGPS streaming position data and the data acquisition on both GEM 3 devices were started. The instrument was moved forward a couple of meters and stopped (see Figure 8). After a brief hesitation, it was rolled back across the item to a couple of meters behind the item and stopped. Finally, the sensor was moved back across the item and into the grid to begin the data collection run.

Figure 8. Collecting data over the calibration pit site.

Data were collected for each of the 14 test items in the test pit area next to the calibration lanes; 0.5-in. (1.27-cm) plywood was placed over the hole to allow both GEM-3 devices to be rolled over the items without having to completely fill in the hole before data could be collected. Ordnance items were positioned in the pit to give 0, 45, 90, and 180° angles of elevation as shown in Figure 9. These data were used for training and discrimination processing.

Figure 9. 105-mm projectile in the calibration pit.

Figure 10 shows an idealized data set from which the speed of the sensor, and the sensor response, are normalized and plotted on the same graph. The initial speed of the sensor is at zero and the sensor response is at a maximum. As the sensor is pushed off the item, the sensor response declines and the sensor speed rises.

For this example, the change in speed from the sensor lags the decrease in sensor response. Measurement along the time axis will give the value of the lag, and this can be used to shift the data so that the two streams are synchronized, as shown in Figure 11.

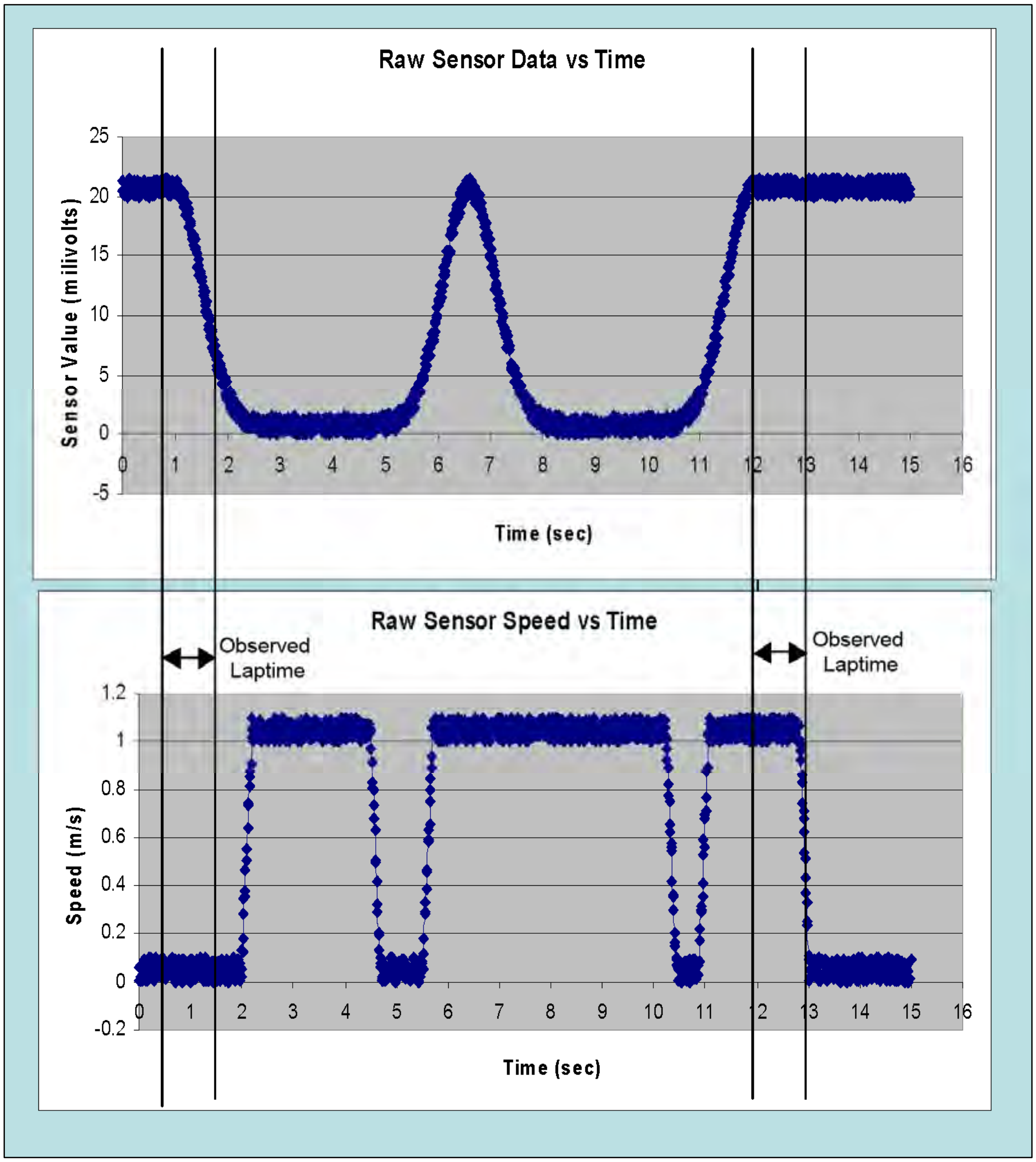


Figure 10. Idealized uncorrected sensor speed and sensor response versus time.

Once the data are synchronized, there is an additional check to ensure the correctness of the drift. If the data are plotted on a surface map with x, y, the color of the point as sensor response, and with the drift corrected, then all three passes over of the item will appear as a single anomaly on the graph. Data not synchronized will shift anomalies and will make them appear larger than they actually are. An example of raw data for the passes over an item can be seen in Figure 12. After the correction, the seemingly multiple targets converge into larger features shown in Figure 13. This represents a truer picture of detection.

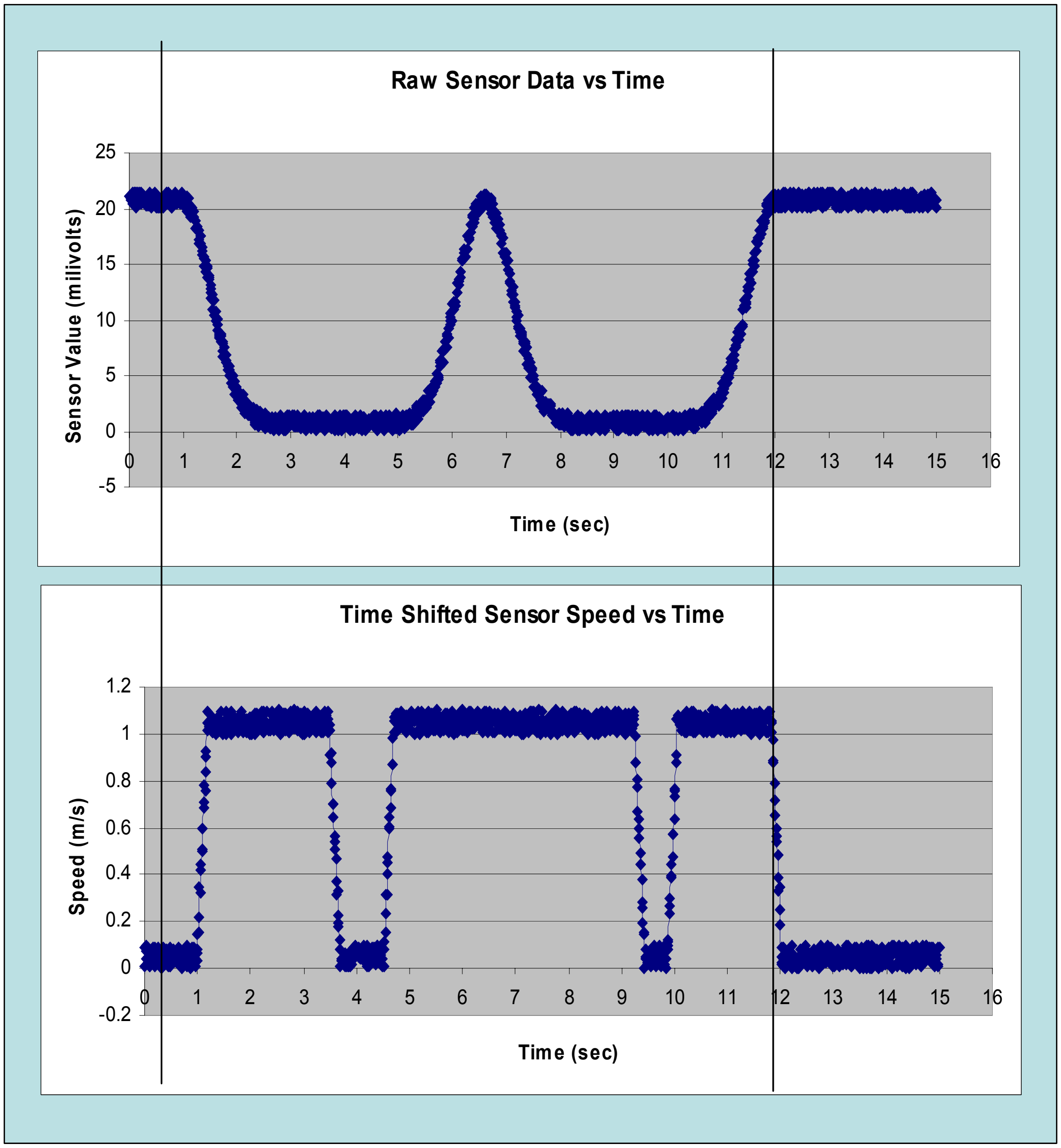


Figure 11. Idealized corrected sensor speed and sensor response versus time.

Drift correction

A common problem encountered when collecting geophysical data is instrument drift (see Figure 14). The GEM-3-E signal level varies with time during a data collection due to changes in temperature and power output from the batteries. The Geosoft UX-Detect drift correction algorithm was applied to the data collected with both GEM-3 systems, at APG, to compensate for this drift. This algorithm calculates the average value for each block of data of a user-specified size and subtracts the average from all the points in the block. A user-specified percentage of points at the high

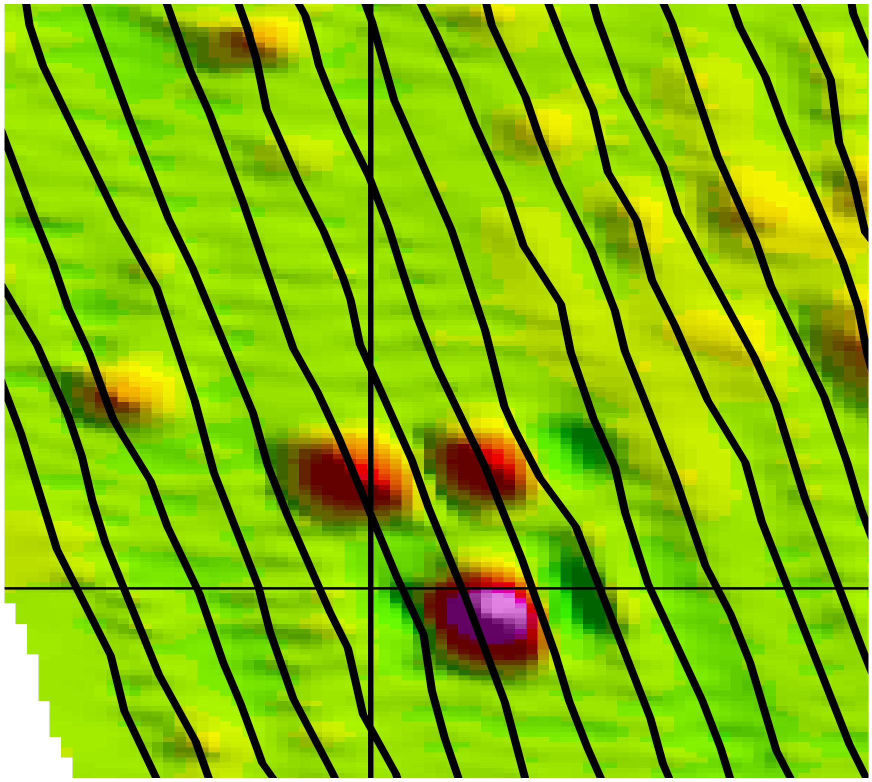


Figure 12. GEM-3-E raw data for the passes over an anomaly before lag correction.

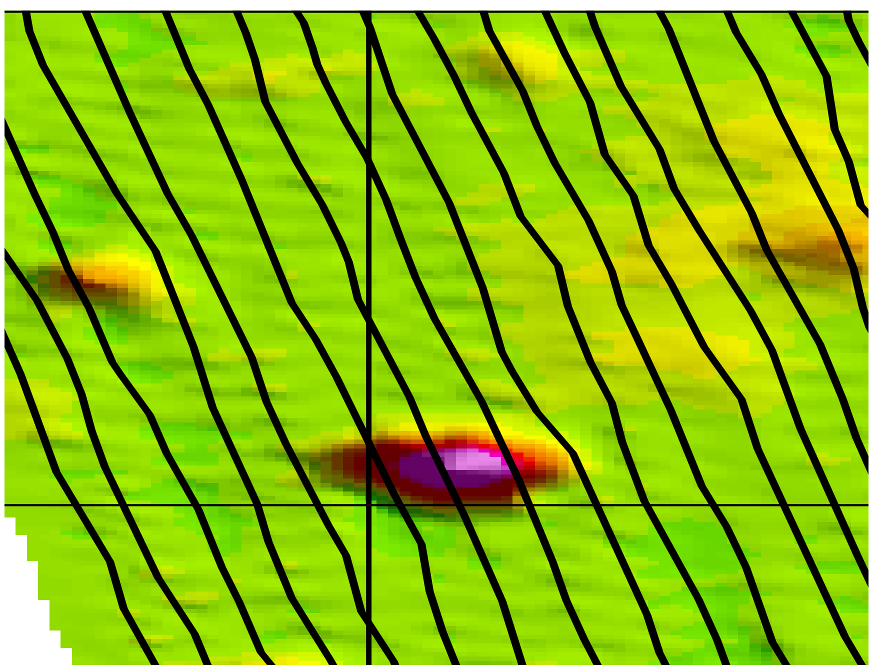


Figure 13. GEM-3-E data for the passes over an anomaly after lag correction.

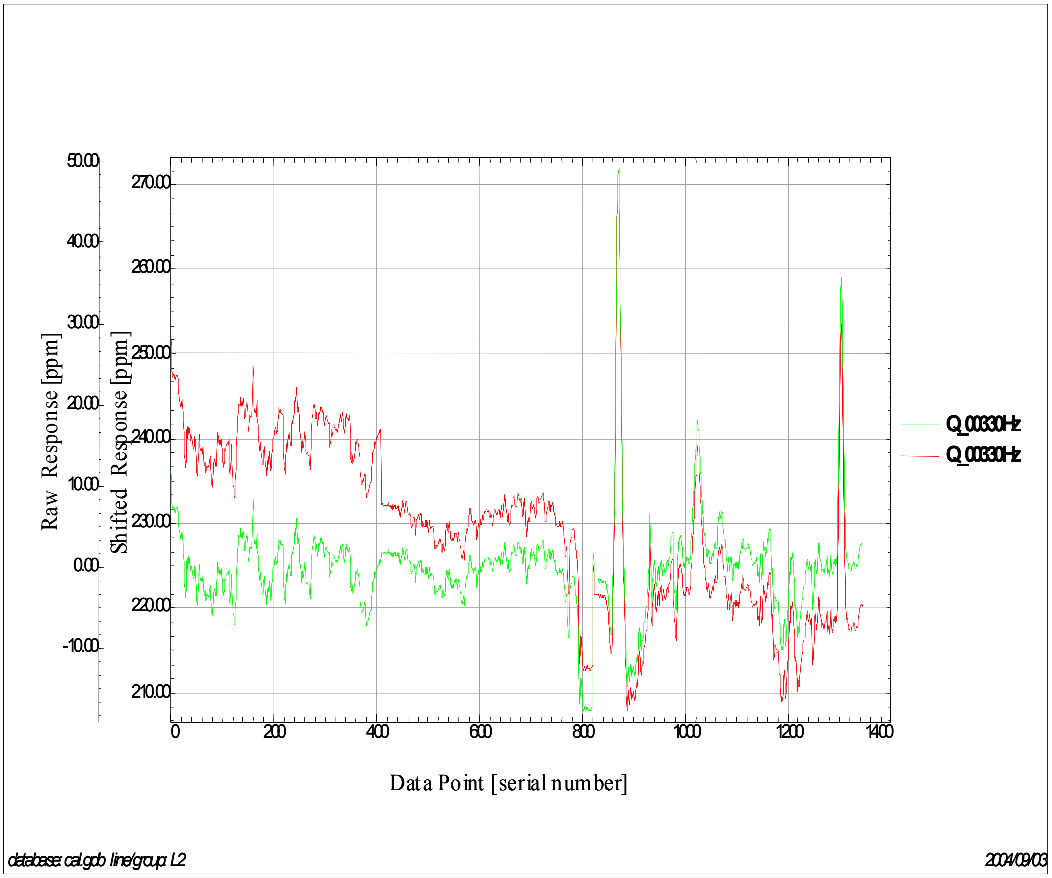


Figure 14. GEM-3-E (330HZ) corrected (green) and uncorrected (red) signal levels.

or low end of the range of values, or both, are excluded from the calculation of the average so that the presence of targets in the data block does not skew the average. Ideally, only background points will be included in the average calculation; however, this can be difficult to achieve in areas where targets are densely located. Figure 14 shows a single channel of data for one survey line before and after drift correction.

The uncorrected data, shown in red, have a significant downward drift, which is no longer present in the corrected data that are shown in green. Drift correction is performed on each data channel independently.

5 Data Collection

GEM-3-E

System operation

The GEM-3-E cart was positioned with the sensor head directly over the ferrite core. When data acquisition was initiated, the system was left over a ferrite core for 2 to 3 seconds to allow the system to “warm-up.” The cart was rolled backwards off the core then run back over the core twice. This gave a definite start and stop so any time lag in the GPS could be corrected.

The GEM-3-E was rolled into position for the next data acquisition lane. Once the GEM-3-E was positioned on the correct line, the operator started data collection and walked down the lane. At the end of every lane, the data acquisition was stopped and the lane number was advanced.

Data storage

There are two GEM-3-E data storage systems available. The data were either stored on the data acquisition module or on a PocketPC.

When the data were stored on the data acquisition module, they were downloaded to the computer by using the WinGEM2K software via a serial port connection. The data acquisition module was powered on and the WinGEM2K software was initiated. From the tool bar, the download data was selected. The file was named and a download location was selected.

When the data were stored on the PocketPC, the interface and data storage location was downloaded using a different procedure. The PocketPC was disconnected from the GEM-3-E and connected to the laptop by either the USB or infrared connections. The ActiveSync program was activated and the files were automatically downloaded to the sync file location. These files were then copied or moved to a new directory for further analysis.

GPS sensor data integration

A GEM-3-E input port was used to integrate GPS data. Care was taken to synchronize the data streams and to remove lag, which was discussed in the QA/QC Procedures section, GPS Corrections subsection.

Coverage maps

The gridded coverage maps of the GEM-3-E are as follows: Figure 15 shows the line path covered by the GEM-3-E. Small gaps appeared in the 0.5-m grid coverage map, as shown in Figure 16, but disappeared with a resolution of 0.75 m for the grid (see Figure 17). This indicates that, while there were a few departures from the nominal line spacing of 0.5 m, none of them were very large.

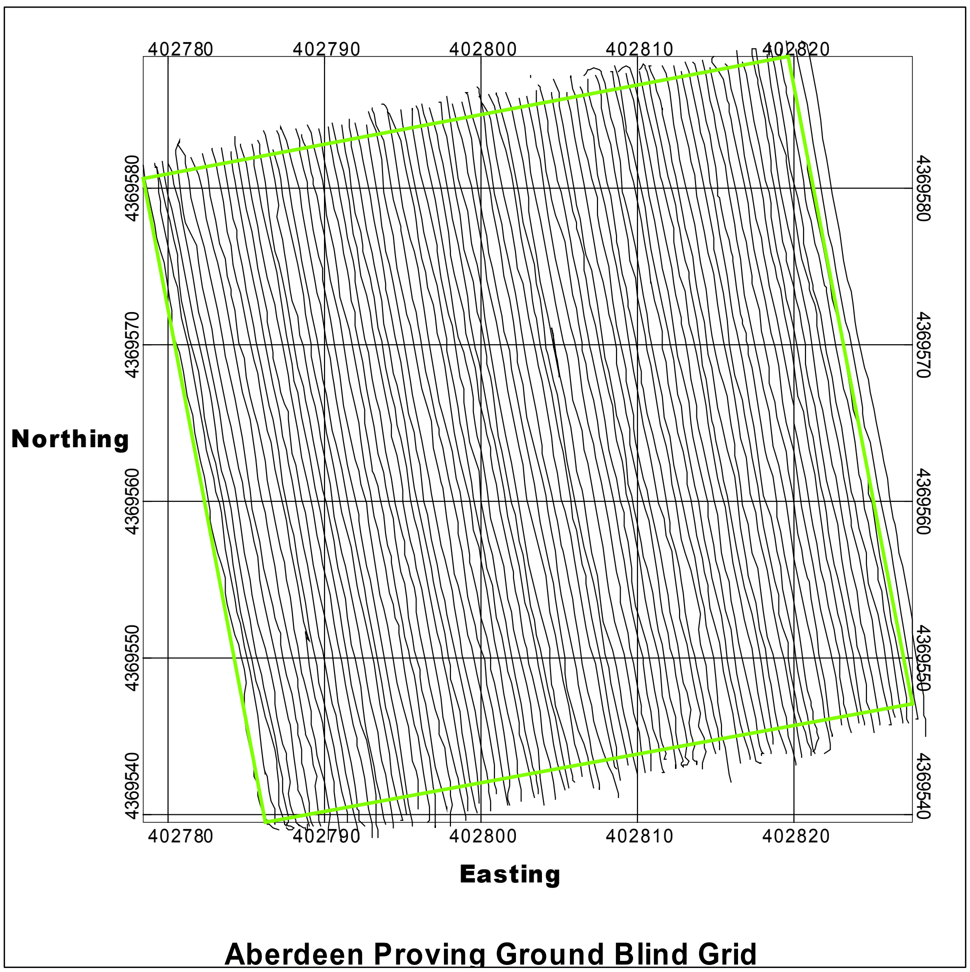


Figure 15. GEM-3-E site traverses.

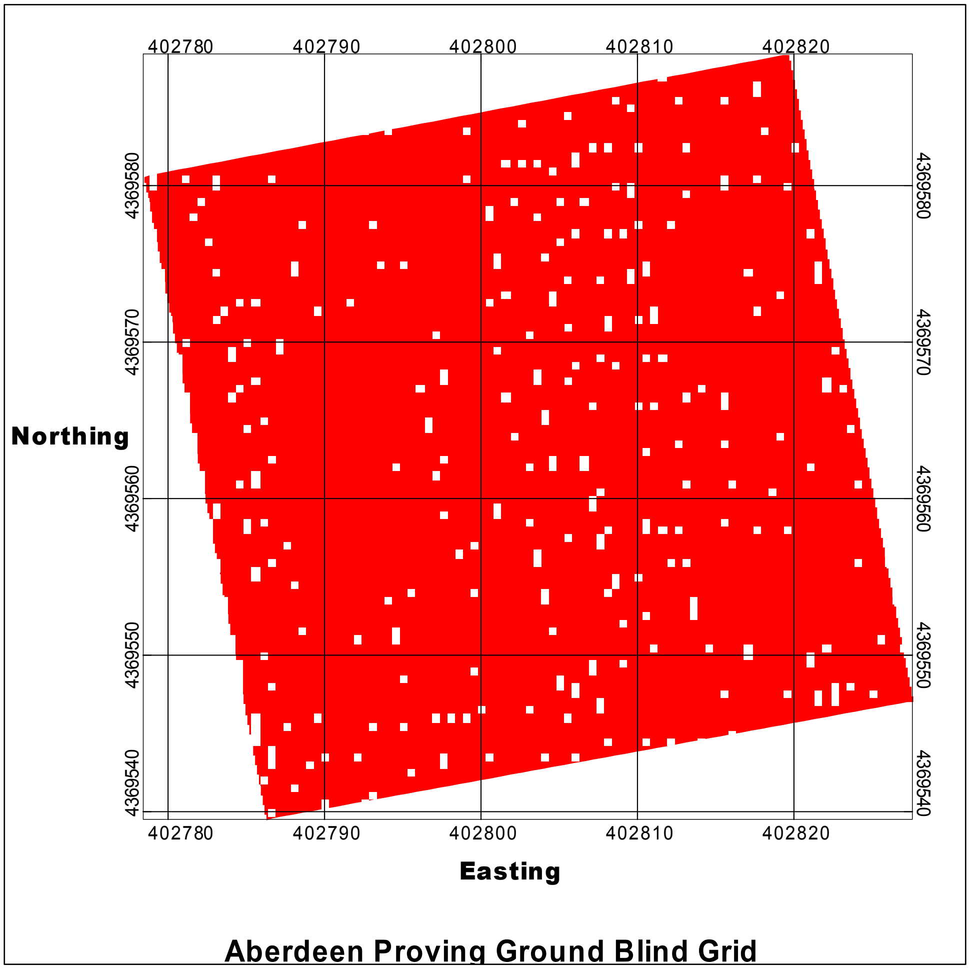


Figure 16. GEM-3-E coverage map with 0.5-m grid spacing.

GEM-3-98

System operation

The GEM-3 "circa 1998" cart was positioned with the sensor head directly over the ferrite core. When data acquisition was initiated, the system was left over a ferrite core for 2 to 3 seconds to allow the system to "warm-up." The cart was rolled backwards off of the core then run back over the core twice. This procedure established a start and stop to facilitate time lag correction in the GPS data. This action also produced data and GPS synchronization points.

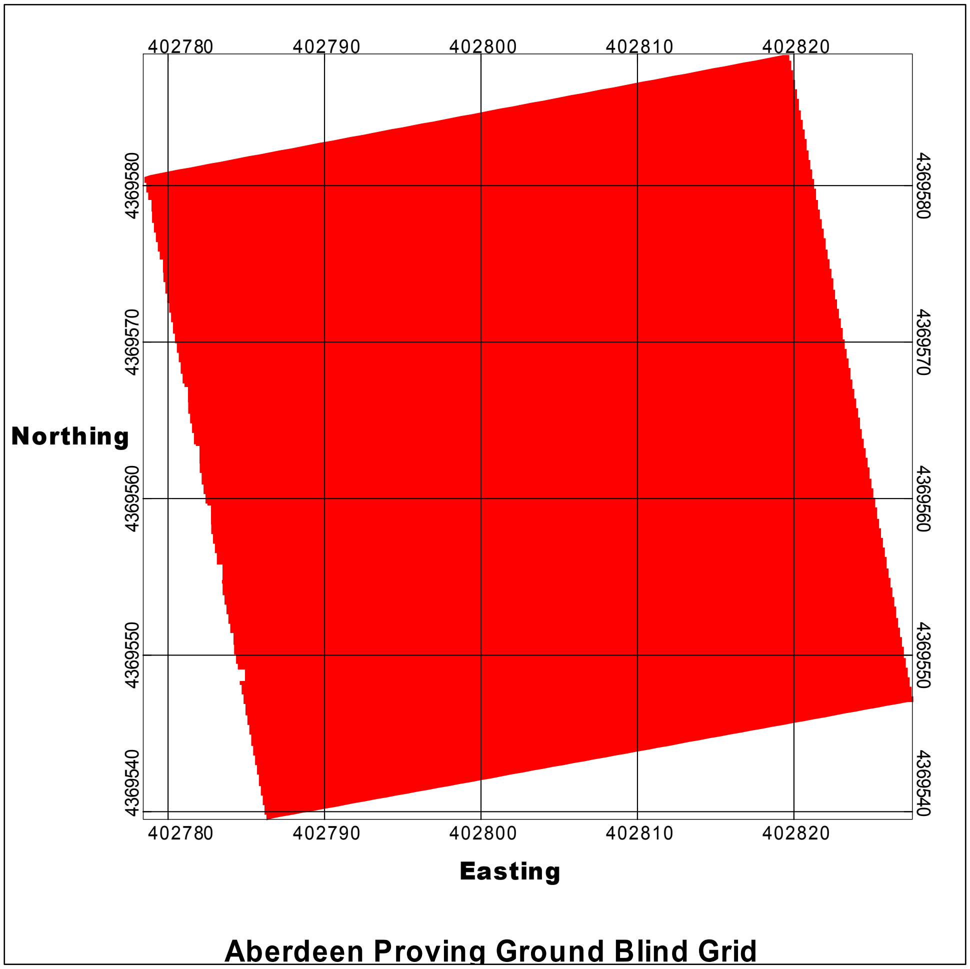


Figure 17. GEM-3-E coverage map with 0.75-m grid spacing.

The older GEM-3-98 was rolled into position for data acquisition. Once the GEM-3-98 was positioned on the correct lane, the operator started walking down the lane. Unlike the GEM-3-E cart, the older GEM-3-98 was not stopped at the end of every lane; data were taken continuously.

After every eighth or tenth lane, data were collected over a ferrite core to provide a synchronized reference point for GPS drift correction.

Data storage

Using the first configuration discussed in the GEM-3-98 System Description section, data were collected into the GEM-3-98 acquisition module. This module was connected via a serial port to a laptop computer. The WinGEM software was initiated, the download button on the tool bar was selected, a file named was assigned, and a download location was selected. Once the file was downloaded, data were deleted from the module. The

GPS data were stored on a data card in the GPS controller and a new GPS file was initiated for each GEM-3-98 data file. The GPS file was copied from the card onto a laptop and the data file was converted using GPS software.

This process was very time consuming. It took almost as long to download data as to collect data. So, the system configuration and download procedure were modified. The addition of a laptop to the configuration allowed the WinGEM software, via a serial cable connected to the data acquisition module, to control the system. This configuration allowed the data to be collected directly onto the laptop computer hard-drive, which eliminated the need to download data. The target file was given a name in the download directory and data acquisition was initiated. Once a lane traverse was completed, the data acquisition was stopped, and the file saved. GPS data were downloaded from the GPS rover and stored on the laptop with a name linked to the sensor response data file.

GPS sensor data integration

The GPS was outputting data at 1 Hz while the GEM-3-98 was outputting data between 3 and 4 Hz. Using the known position of calibration items and lane markers in the grid, the GPS data and sensor response data were synchronized using the analysis procedure outlined in the QA/QC Procedures section, GPS Corrections subsection. It is necessary to interpolate the GPS data when merging the GEM-3-98 data with the GPS data. Additional steps of position interpolation, based on the kinematics in the GPS data and on non-integer data acquisition timing, were addressed using custom Visual Basic routines to synchronize the data.

Coverage maps

Because of bad weather that degraded equipment mobility, it was difficult to maintain the 0.5 lane spacing. The actual mapped path of coverage is shown in Figure 18. This is illustrated, by the large number of white grids, in the 0.5-m grid coverage map, Figure 19. In this case, there were grids with a value of zero in the 0.75-m coverage map (Figure 20), indicating significant gaps in coverage.

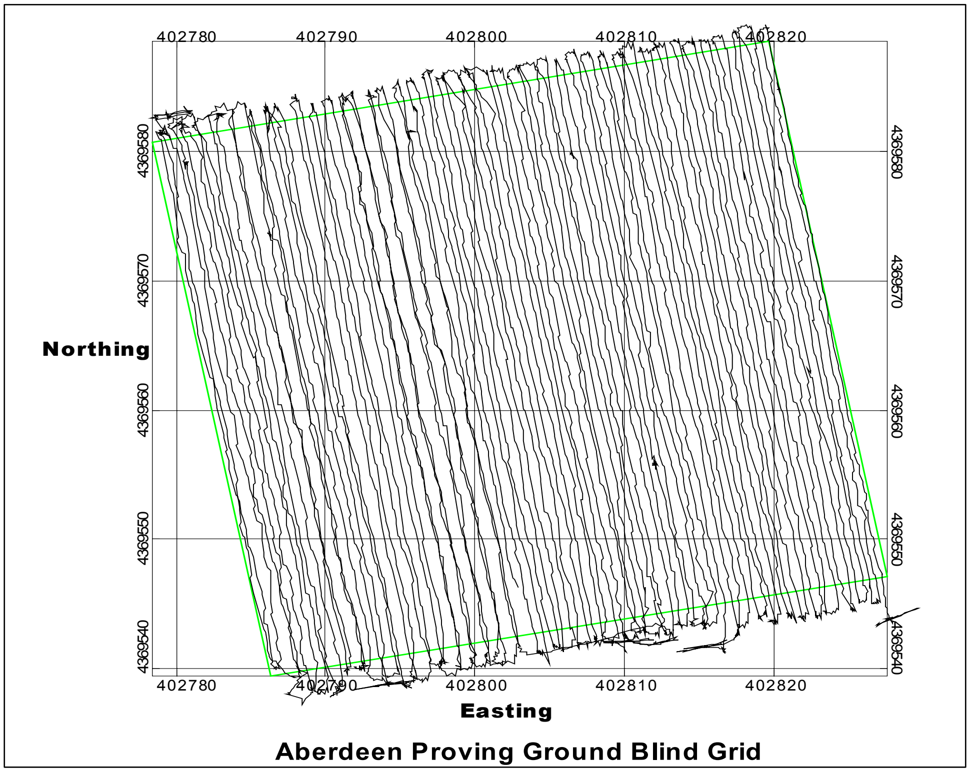


Figure 18. GEM-3-98 site traverses.

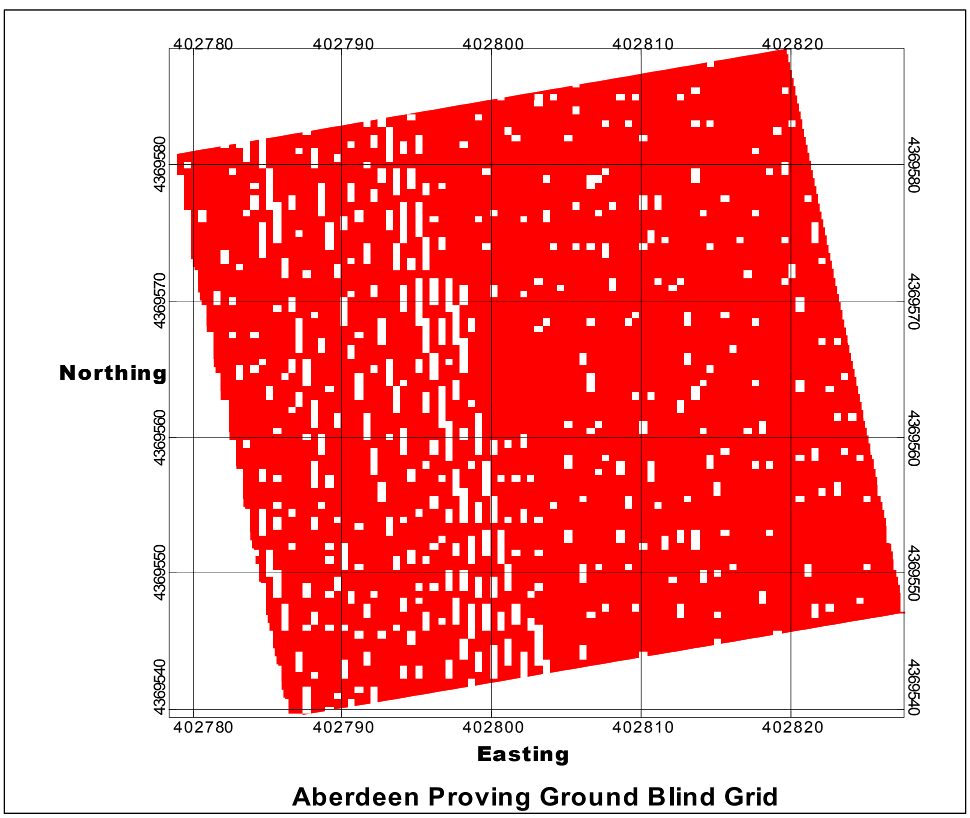


Figure 19. GEM-3-98 coverage map with 0.5-m grid spacing.

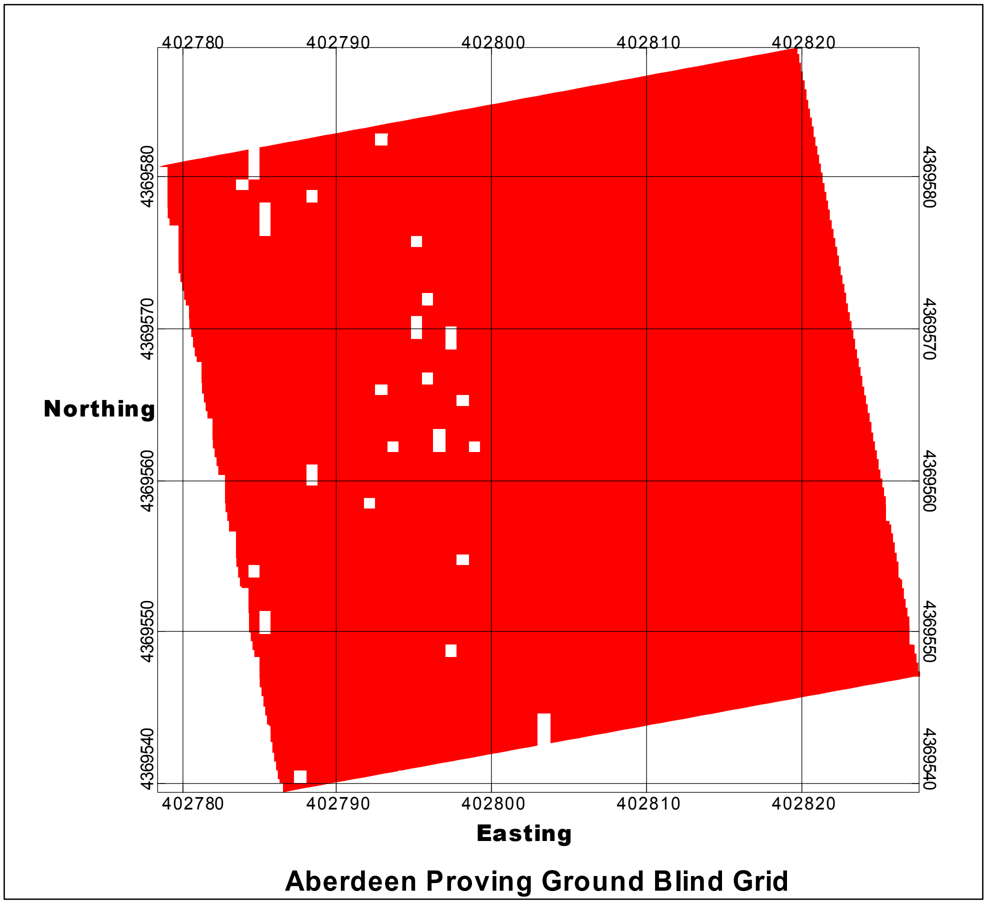


Figure 20. GEM-3-98 coverage map with 0.75-m grid spacing.

6 System Evaluation

Scoring the GEM-3-E

The scoring results obtained from the U.S. Army Aberdeen Test Center (ATC) for the GEM-3-E (USAEC 2004a) (*http://aec.army.mil/usaec/technology/uxo-record141.pdf*) are provided in Table 2. The values for response stage were repeated for discrimination stage on ATC form, even though discrimination results were not sent to ATC. The following variables definitions were obtained from the ATC website (see Appendix C):

BA^{disc}	A discrimination-stage location outside R_{halo} of any emplaced ordnance or emplaced clutter item
$P_{ba}{}^{disc}$	= (/3 of BA^{disc})/(# of empty grid locations)
$P_{det}{}^{dsc}$	= (# of discrimination-stage detections)/(# of emplaced ordnance in the test site).
$P_{det}{}^{res}$	= (# of response-stage detections)/(# of emplaced ordnance in the test site).
$P_{fp}{}^{res}$	= (# of response-stage false positives)/(# of emplaced clutter items).
Emplaced Clutter	A clutter item (i.e., nonordnance item) buried by the government at a specified location in the test site.
Emplaced Ordnance	An inert ordnance item buried by the government at a specified location in the test site.
Discrimination Stage	The ability to correctly identify ordnance as such, and to reject clutter. For the same locations as in the RESPONSE STAGE anomaly column, the DISCRIMINATION STAGE column contains the output of the algorithms applied in the discrimination-stage processing. This column is prioritized based on the confidence that an ordnance item is present at the specified location. For electronic

	signal processing, priority ranking is based on algorithm output. For other systems, priority ranking is based on human judgment. The demonstrator also selects the threshold that provides optimum system performance, (i.e., that retains all the detected ordnance and rejects the maximum amount of clutter).
Response Stage	The ability of the demonstrator's system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. The RESPONSE STAGE provides the location and signal strength of all anomalies deemed sufficient to warrant further investigation and/or processing as potential emplaced ordnance items. This list is generated with minimal processing (e.g., this list will include all signals above the system noise threshold). As such, it represents the most inclusive list of anomalies.

Results for the Blind Grid test are broken out by size, depth, standard, and nonstandard ordnance (Table 2). The standard column of Table 2 represents the following ordnance: 20-mm, 40-mm, M42, BLU-26, BDU-28, 57-mm, MK118, 60-mm, 81-mm, M230, 105-mm, and 155-mm. The nonstandard column is reporting on the other ordnances buried at APG test site. Results by size and depth include both standard and nonstandard ordnance. The results by size show how well the demonstrator did at detecting and discriminating ordnance of a certain caliber range. The results are relative to the number of ordnances emplaced. Depth is measured from the closest point of anomaly to the ground surface.

The RESPONSE STAGE results are derived from the list of anomalies above the demonstrator-provided noise level. The results for the DISCRIMINATION STAGE are derived from the demonstrator's recommended threshold for optimizing UXO field cleanup by minimizing false digs and maximizing ordnance recovery. The lower 90% confidence interval (CI) on probability of detection and probability of false positive was calculated assuming that the number of detections and false positives

Table 2. Enhanced GEM-3-E/Pushcart – ATC report scores.

Metric	Overall	Standard	Non-standard	By Size			By Depth, m		
				Small	Medium	Large	<0.3	0.3≤1	≥1
RESPONSE STAGE									
P_d	0.60	0.65	0.45	0.60	0.55	0.60	0.80	0.50	0.00
P_d L90%CI	0.50	0.57	0.32	0.48	0.42	0.35	0.68	0.36	0.00
P_{fp}	0.65						0.60	0.70	0.60
P_{fp} L90%CI	0.57						0.49	0.58	0.25
P_{ba}	0.05								
DISCRIMINATION STAGE									
P_d	0.60	0.65	0.45	0.60	0.55	0.60	0.80	0.50	0.00
P_d L90%CI	0.50	0.57	0.32	0.48	0.42	0.35	0.68	0.36	0.00
P_{fp}	0.65						0.60	0.70	0.60
P_{fp} L90%CI	0.57						0.49	0.58	0.25
P_{ba}	0.05								

are binomially distributed random variables. All results in Table 2 have been rounded to protect the ground truth. However, lower confidence limits were calculated using actual results.

Scoring of GEM-3-98

The scoring results obtained from the ATC for the GEM-3-98 are provided in Table 3 (USAEC 2004b). Definitions for Table 3 are the same as those used for Table 2.

Limitations of the GEM-3-E and the GEM-3-98

The most significant limitation found in both systems was the inability to detect targets below a depth of 1 m. This is indicated by a zero value for "Pd" in Tables 2 and 3 when targets are located deeper than 1 m, which was the threshold selected for this study. The lack of ruggedness of the system could limit its use for operational site characterization.

Comparison of the GEM-3-E to the GEM-3-98

Initial detection procedures

A very simple target detection procedure was applied to compare the data-sets of the GEM-3-E and GEM-3-98 systems. After latency and drift

Table 3. Standard GEM-3-98/Pushcart – ATC report scores.

Metric	Overall	Standard	Non-standard	By Size			By Depth, m		
				Small	Medium	Large	<0.3	0.3≤1	≥1
RESPONSE STAGE									
P_d	0.25	0.30	0.15	0.20	0.25	0.30	0.40	0.15	0.00
P_d L90%CI	0.18	0.23	0.06	0.13	0.16	0.12	0.28	0.06	0.00
P_{fp}	0.30						0.40	0.20	0.20
P_{fp} L90%CI	0.24						0.31	0.11	0.02
P_{ba}	0.05								
DISCRIMINATION STAGE									
P_d	0.25	0.30	0.15	0.20	0.25	0.30	0.40	0.15	0.00
P_d L90%CI	0.18	0.23	0.06	0.13	0.16	0.12	0.28	0.06	0.00
P_{fp}	0.30						0.40	0.20	0.20
P_{fp} L90%CI	0.24						0.31	0.11	0.02
P_{ba}	0.05								

corrections were applied to each data file, the data acquired by each system in the Blind Grid were merged into a single database. Next, the Q_{sum} channels for each system were gridded at a spatial resolution of 10 cm using Geosoft Oasis Montaj software. Peak detection was performed on the grids by applying the Blakely Test using the Geosoft UX-Detect module. The output of this procedure was a list of target coordinates, which were converted to the grid cell designations required by the Blind Grid scoring format and submitted to the ATC for scoring.

Analysis of signal strength

A signal-to-noise ratio (SNR) was calculated for each GEM-3 system for each target in the calibration area to compare their ability to detect anomalies. Initially, the peak response of each target was compared to its immediate background to compute the SNR. However, it became evident that, owing to the dense spacing of the targets in the calibration area, it was impossible to get background data around many of the larger targets that were not influenced by the target. Therefore, a single area with no targets was selected to use to get background statistics (mean and standard deviation) that were used in the SNR calculation for all targets. The procedure used to calculate the SNR for each target was as follows:

1. Extract the data in a 2-m window centered on the target's location obtained from the calibration area ground truth file.
2. For each data point in the extracted window of data, create three new data channels – the sum of the in-phase data magnitudes for all frequencies (In-phase Magnitude), the sum of the quadrature data magnitudes for all frequencies (Quadrature Magnitude), and the sum of the in-phase and quadrature magnitudes for all frequencies (Total Magnitude).
3. Find the peak Total Magnitude response and all points to either side of the peak with a magnitude of at least ½ of the peak and average them. The corresponding points in the In-phase magnitude and Quadrature Magnitude channels are also averaged.

The SNR for each of the three magnitude channels was 20 times the base 10-logarithm of the ratio of the average target response (from step 3) to the standard deviation of the background.

The difference between the two systems was evaluated using the amplitude, quadrature, and in-phase SNR (see Table 4). The first comparison of the GEM-3-E with the GEM-3-98 used the 8-lb shotput because there were 64 of the shotputs in the calibration site, all emplaced at a depth of 0.2 m. In comparing the combined SNR (Amplitude) of the two systems, it is noted that the GEM-3-E had a decibel (dB) return in low 40s while the GEM-3-98 had a dB return in the low 30s. The mean difference between the GEM-3-E and the GEM-3-98 for the SNR of the amplitude response was approximately 9 dB. Also, the mean difference between the GEM-3-E and the GEM-3-98 for the SNR of the in-phase response was approximately 12.5 dB higher. However, the mean difference between the GEM-3-E and the GEM-3-98 for the SNR of the quadrature was approximately 1 dB. This indicates that the quadrature SNR of the GEM-3-98 system was higher by 1 dB than the SNR of the GEM-3-E systems.

A one-sample T-test was performed on this difference to test the hypothesis that the two instruments delivered the same amplitude response against the alternative that there exists a significant difference between these two machines. The data in Table 5 for the 8-lb shotput were used because of the small sample sets in the other items. The significant difference was measured using a p-value calculated by the T-test in the statistical computer software package SPSS. If the p-value is less than the chosen

Table 4. Standard verses enhanced test—8-lb shotput.

Response	Amplitude		In-phase		Quadrature	
	GEM-3-98	GEM-3-E	GEM-3-98	GEM-3-E	GEM-3-98	GEM-3-E
Number	64	64	64	64	64	64
Minimum	20.7662	30.8529	18.3818	32.9140	25.4520	23.9828
Maximum	31.9105	40.6314	30.2613	42.3916	36.2402	34.6369
Mean	27.7611	36.9422	25.9058	38.5565	31.9877	31.2592
Standard Deviation	2.5511	1.5030	2.616	1.5432	2.4861	1.5405

Table 5. Standard verses enhanced—Single T-test SNR of the GEM-3-E minus the SNR of the GEM-3-98.

8-lb Shotput	(GEM-3-E) – (GEM-3-98) = Difference		
Response	Amplitude	Quadrature	In-phase
T-test value	36.797	-2.883	42.908
Degrees of freedom	63	63	63
Significance p value for (2-tailed test)	<0.0001	0.005	<0.0001
Mean Difference	10.2701	-0.7285	12.6507
95% Confidence Interval of the Difference			
Lower	9.712386	-1.2334	12.0615
Upper	10.827872	-0.2235	13.2399

alpha level of an allowed error in our answer, then the null hypotheses is rejected. For this report, significantly different will be when the p-value is less than 0.05 and the t-value is positive for the difference in the two instruments amplitudes. As the amplitude difference between these machines was significant for the 64 samples of 8-lb shotput, the alternative hypothesis is accepted for the two instruments showing that the GEM-3-E is performing better than the GEM-3-98 (Table 5).

In comparing the SNR of the in-phase and quadrature from the GEM-3-98, the quadrature SNR is approximately 20% greater than the in-phase SNR. This indicates that the GEM-3-98 was calibrated by the manufacturer to have a stronger signal strength in the quadrature return for this system. The comparison of the in-phase and quadrature SNRs for the GEM-3-E indicates that the quadrature SNR is approximately 20% less than the in-phase SNR. This indicates that the GEM-3-E was calibrated by the manufacturer to produce a stronger signal strength in the in-phase return for this system.

The following observations were made from the SNR data in Appendix A using two constraints: the depth of item not greater than 1 m and the peak distance from UXO location be less than 0.3 m. The largest amplitude response, which is the combined SNR from Appendix A, is shown in Table 6.

The following figures show histograms of the diffrences between the GEM-3-E and the GEM-3-98 using SNR data in Appendix A. To avoid very weak signals and systematic error in the measurements, a subset of the data was extracted for analysis. This subset consists of the data meeting two contrainsts: the depth of the item is 1 m or less, and the peak distance from UXO location is less than 0.3 m. The histograms imply an improvement in the overall performance of the GEM-3-E over the GEM-3-98.

The histograms demonstrate that the GEM-3-E has an enhanced SNR perfomance over the GEM-3-98. This is illustrated in Figure 21, which shows that the 95% confidence interval does not capture the value of zero and the alternative hypothesis of H_a (mean is greater than zero is accepted; it displayed a better SNR for the enhanced version). Figure 22 shows no improvement in the SNR for quadrature measurements; there was not enough evidence to reject the null hypothesis H_o: that the two system's means are the same. Figure 23 shows that the majority of the measurements for the in-phase portion of the signal displayed a better SNR for the enhanced version. As the 95% confidence interval does not capture the mean value of zero, then the H_o is rejected for the alternative hypothesis that the mean is greater than zero, meaning that the GEM-3-E performed better than the GEM-3-98.

Table 7 lists the strongest response for each system by the inclincation of the UXO, the depth of the UXO, and the type of munition. The table illustrated that neither system dominated over the other system in showing inclination of the UXO.

Table 6. Standard verses enhanced test—target where SNR was strongest response for each type of munition.

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98	GEM-3-E
					Strongest Amplitude Response	
					SNR	SNR
1	12 gauge 30-cm loop	0.25	0 az	0	44.5651	53.6466
5	16 gauge 30-cm loop	0.25	0 az	0	39.1485	50.7217
13	18 gauge 30-cm loop	0.25	0 az	0	40.8052	50.0885
17	20 gauge 30-cm loop	0.25	0 az	0	37.3868	45.8748
	12-lb shotput	0.5	0 az	n/a	11.5074	23.8394
23	20-mm M55	0.1	0 az	90	18.2164	20.1434
28	40-mm MK II	0.3	0 az	45	13.5827	22.3874
34	40-mm M385	0.1	0 az	45	25.4262	29.4372
43	M42	0.15	0 az	90	11.1950	
44		0.15	n/a	−90		20.6452
50	BLU-26	0.1	0	n/a	28.1214	30.8297
55	BDU-28	0.1	0 az	−45	25.8688	
57		0.1	n/a	−90		29.9095
61	57-mm M86	0.4	0 az	−45	9.3574	
63		0.4	n/a	−90		20.0480
68	MK 118 Rockeye	0.3	0 az	−45		19.9576
69		0.3	0 az	90	12.4090	
83	81-mm M374	0.5	n/a	−90	7.5851	19.8373
88	2.75 M230	0.5	0 az	90	15.0458	24.7893
75	60-mm M49A3	0.5	0 az	90	7.8118	18.6239
95	30-m steel plate	0.5	0	0	22.8362	37.6686
97	60-m steel plate	0.5	0	0	44.5662	57.9743
100	105-mm M456 HEAT	0.4	0 az	−45	18.1921	31.4040
106	105-mm M60	0.9	0 az	−45		13.8873
108		0.9	n/a	−90	9.4657	
113	155-mm M483A1	0.9	0 az	90	7.7706	18.2412
118	M14 AP mine	0.01	0	0	3.4092	13.9670
119	VS 50 AP mine	0.05	0	0	94.9130	
120	VS 50 AP mine	0.1	0	0		13.6594
122	T62 AT mine	0.2	0	0	52.0503	59.9406
124	VS 2.2 AT mine	0.2	0	0	−0.1666	10.3157
143	8-lb shotput	0.2	0	n/a	31.9105	
170		0.2	0	n/a		40.6314

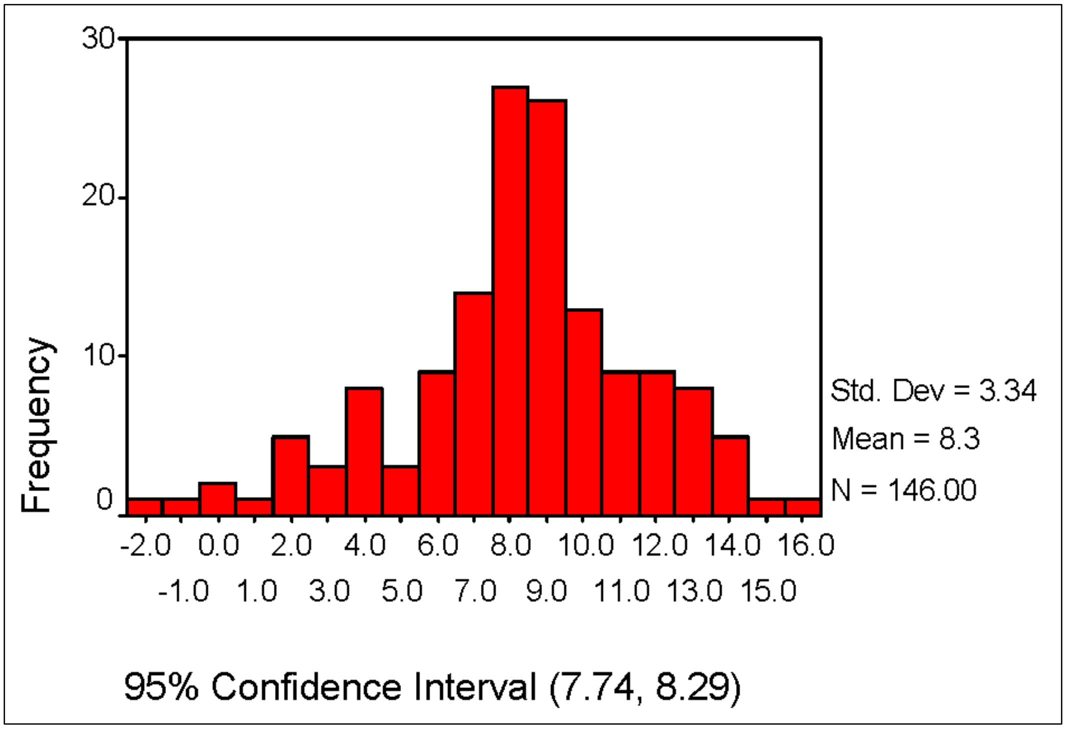


Figure 21. Histogram of combination SNR of GEM-3-E minus GEM-3-E
(H_0: mean is equal to zero or no difference).

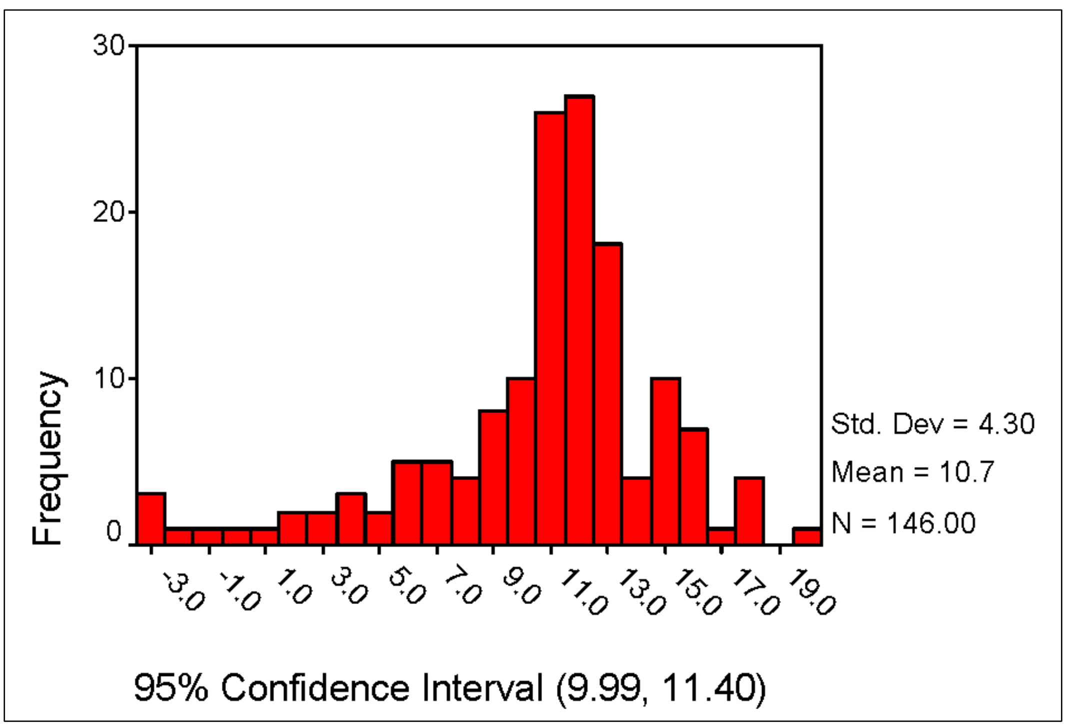


Figure 22. Histogram of quadrature SNR of GEM-3-E minus GEM-3-E
(H_0: mean is equal to zero or no difference).

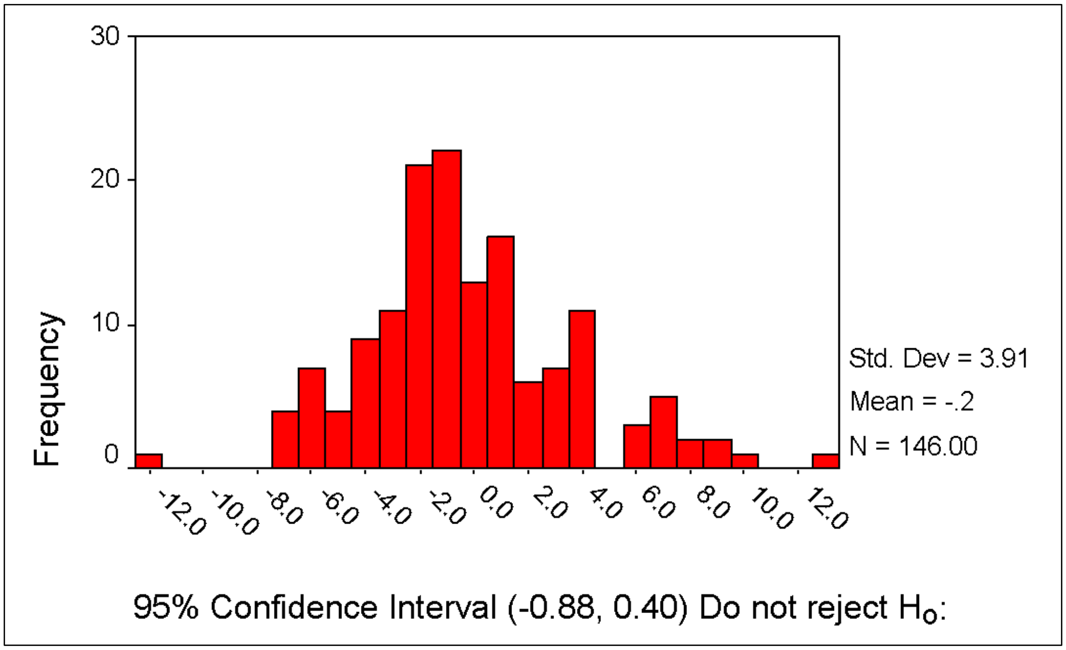


Figure 23. Histogram of in-phase SNR of GEM-3-E minus GEM-3-E (H_o: mean is equal to zero or no difference).

Table 7. Standard verses enhanced test—target where SNR was strongest response for each type of munition.

Inclination	Depth	Type of Munition	System	GEM-3-E	GEM-3-98
90	0.1	20-mm M55	Both	X	X
	0.15	M42	GEM-3-98		X
	0.3	MK 118 Rockeye	GEM-3-E	X	
	0.5	2.75 M230	Both	X	X
	0.5	60-mm M49A3	Both	X	X
	0.9	155-mm M483A1	Both	X	X
−90	0.1	BDU-28	GEM-3-E	X	
	0.15	M42	GEM-3-E	X	
	0.4	57-mm M86	GEM-3-E	X	
	0.5	81-mm M374	Both	X	X
	0.9	105-mm M60	GEM-3-98		X
45	0.1	40-mm M385	Both	X	X
	0.3	40-mm MK II	Both	X	X
−45	0.1	BDU-28	GEM-3-98		X
	0.3	MK 118 Rockeye	GEM-3-E	X	
	0.4	57-mm M86	GEM-3-98		X
	0.4	105-mm M456 HEAT	Both	X	X
	0.9	105-mm M60	GEM-3-E	X	
0	0.01	M14 AP mine	Both	X	X
	0.05	VS 50 AP mine	GEM-3-98		X
	0.1	VS 50 AP mine	GEM-3-E	X	
	0.2	T62 AT mine	Both	X	X
	0.2	VS 2.2 AT mine	Both	X	X
	0.25	12 gauge 30-cm loop	Both	X	X
	0.25	16 gauge 30-cm loop	Both	X	X
	0.25	18 gauge 30-cm loop	Both	X	X
	0.25	20 gauge 30-cm loop	Both	X	X
	0.5	30-cm steel plate	Both	X	X
	0.5	60-cm steel plate	Both	X	X

7 Conclusions

The following observations were made at the conclusion of this study:

1. The ERDC team experienced down time due to the malfunction of the pushcart. The wheels became dislodged repeatedly from the pushcart during operations.
2. Manpower to operate the GEM-3-E or the GEM-3-98 increased because of the axle failures.
3. The most significant limitation of both systems was the inability to detect targets below a depth of 1 m, which was the threshold selected by this study.
4. The mean difference between the GEM-3-E and the GEM-3-98 for the SNR of the amplitude response was approximately 9 dB. Also, the mean difference between the GEM-3-E and the GEM-3-98 for the SNR of the in-phase response was approximately 12.5 dB higher.
5. The mean difference between the GEM-3-E and the GEM-3-98 for the SNR of the quadrature was approximately –1 dB which indicates that the quadrature SNR of the GEM-3-98 system was higher by 1 dB than the SNR of the GEM-3-E systems.
6. The GEM-3-E performed better than the GEM-3-98 as demonstrated by amplitudes for 64 samples of 8-lb shotput.
7. The in-phase signal in the calibration lane was greater for the GEM-3-E over the older GEM-3-98; the quadrature signal did not show a clear improvement in this enhanced model. The magnitude of the in-phase response for the GEM-3-E was three times greater than the magnitude of the quadrature. The magnitude of the quadrature for the GEM-3-98 was 10% greater than the magnitude of the in-phase.
8. Ferrite core calibration performed on both systems verified that the in-phase response was level which indicated that both systems were properly calibrated.

8 Recommendations

The authors recommend the following actions for future studies:

1. Confirm that in-phase component was calibrated and that the quadrature component was balanced with respect to the in-phase before data is completed.
2. The Geophex cart in its current configuration should not be used until reliability of the cart is demonstrated.
3. The addition of nylon or glass bearings to the wheel will likely alleviate axle failure during detection operations.
4. Adding a team member to carry the laptop computer will minimize the total time to complete detection with the GEM-3-98.

References

Cespedes, E. R. (2001). *Advanced UXO detection/discrimination technology demonstration - U.S. Army Jefferson Proving Ground, Madison, Indiana*. ERDC/EL TR-01-20, Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Geophex, Ltd. 1998. *GEM-3 instruction manual*. Raleigh, NC: Geophex, Ltd.

Miller, J., T. Bell, D. Keiswetter, and D. Wright. 2001. Feature-based characterization of UXO-like targets using broadband electromagnetic induction. In *UXO Forum 2001 Proceedings*, New Orleans, LA.

U.S. Army Environmental Center (USAEC). 2004a. *Standardized UXO technology demonstration site blind grid scoring record no. 141*. U.S. Army Corps of Engineers, Engineer Research and Development Center, Commander, U.S. Army Environmental Center, ATTN: SFIM-AEC-PCT, Aberdeen Proving Ground, MD 21010-5401, March.

_____. 2004b. *Standardized UXO technology demonstration site blind grid scoring record no. 142*. U.S. Army Corps of Engineers, Engineer Research and Development Center, Commander, U.S. Army Environmental Center, ATTN: SFIM-AEC-PCT, Aberdeen Proving Ground, MD 21010-5401, March.

U.S. Army Engineer Research and Development Center. (2002). *Analysis of GEM-3 data from the advanced UXO detection/discrimination technology demonstration – U.S. Army Jefferson Proving Ground, Madison, Indiana*. TR-02-25. Washington, DC.

Won, I. J., D. A. Keiswetter, D. R. Hanson, E. Novikova, and T. M. Hall. 1997. GEM-3: A monostatic broadband electromagnetic induction sensor. *Journal of Environmental and Engineering Geophysics* 2(1):53–64.

Won, I. J., K. Keiswetter, and E. Novikova. 1998. Electromagnetic induction spectroscopy. *Journal of Environmental and Engineering Geophysics* 3(1):27-40.

Appendix A: Dig List

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98				GEM-3-E			
					Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR	Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR
1	12 gauge 30-cm loop	0.25	0 az	0	0.1484	43.9290	43.8549	44.5651	0.0820	56.3217	43.6998	53.6466
2	12 gauge 30-cm loop	0.25	0 az	90	0.0728	4.5995	5.7390	5.5872	0.2149	7.6432	2.0135	6.6545
3	12 gauge 15-cm loop	0.25	0 az	0	0.0995	28.3588	27.3970	28.9164	0.0557	40.5749	28.1415	37.9218
4	12 gauge 15-cm loop	0.25	0 az	90	0.1519	3.5793	6.8367	5.1109	0.0682	0.4704	2.7784	4.2857
5	16 gauge 30-cm loop	0.25	0 az	0	0.1560	38.2374	40.3051	39.1485	0.0695	53.1542	42.3133	50.7217
6	16 gauge 30-cm loop	0.25	0 az	90	0.3332	6.5785	8.3711	7.7242	0.1007	14.0226	2.6610	11.6567
7	16 gauge 15-cm loop	0.25	0 az	0	0.1134	23.6032	25.1588	24.4386	0.0287	36.6240	26.0769	34.2406
8	16 gauge 15-cm loop	0.25	0 az	90	0.1886	3.3486	6.8940	4.9108	0.1408	8.4838	5.1885	9.0768
9	12-lb shotput	0.5	0 az	0	0.1741	9.8687	15.1203	11.5074	0.1477	25.2925	18.4732	23.8394
10	12-lb shotput	1	0 az	0	0.1441	8.2663	7.8006	8.8932	0.0246	4.8011	4.5066	6.8397
10	12-lb shotput	1	0 az	0	0.1441	8.2663	7.8006	8.8932	0.0246	4.8011	4.5066	6.8397
11	12-lb shotput	1.5	0 az	0	0.2001	4.6146	5.0660	5.4262	0.2539	4.6721	6.9111	8.6605
12	12-lb shotput	2	0 az	0	0.3276	3.2594	6.6911	4.8436	0.3014	5.1812	5.5653	7.5143
13	18 gauge 30-cm loop	0.25	0 az	0	0.1692	39.6691	43.0011	40.8052	0.1770	52.2841	42.7365	50.0885
14	18 gauge 30-cm loop	0.25	0 az	90	0.0776	2.9414	3.6123	3.8231	0.0402	0.4343	11.9276	12.5518
15	18 gauge 15-cm loop	0.25	0 az	0	0.0505	24.2623	27.3536	25.3514	0.0884	37.4086	28.2972	35.3070
16	18 gauge 15-cm loop	0.25	0 az	90	0.3275	5.7576	9.7967	7.0880	0.1735	4.1416	4.8150	7.0461
17	20 gauge 30-cm loop	0.25	0 az	0	0.1398	35.8408	40.9181	37.3868	0.0718	47.6824	39.7591	45.8748
18	20 gauge 30-cm loop	0.25	0 az	90	0.1551	10.3992	12.1836	11.2666	0.2695	13.3404	12.0228	15.0243
19	20 gauge 15-cm loop	0.25	0 az	0	0.1571	19.9728	24.8409	21.4628	0.1185	31.6039	24.7544	30.1181
20	20 gauge 15-cm loop	0.25	0 az	90	0.0954	0.3416	8.1107	3.4497	0.0462	0.5720	1.6134	3.6420
21	20-mm M55	0.1	0 az	45	0.0604	6.0423	15.4334	9.3857	0.0539	13.8000	12.3638	14.9195

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98				GEM-3-E			
					Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR	Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR
22	20-mm M55	0.1	0 az	-45	0.2993	10.2912	15.8240	11.9732	0.2026	17.0465	11.7301	16.1273
23	20-mm M55	0.1	0 az	90	0.1711	16.6210	21.8769	18.2164	0.1398	20.8793	15.9890	20.1434
24	20-mm M55	0.1	n/a	-90	0.1591	15.4988	22.7328	17.7450	0.0871	19.4638	16.1156	19.4691
25	20-mm M55	0.2	0 az	0	0.0949	9.3166	13.8581	11.0779	0.3233	24.0775	17.2216	22.6023
26	20-mm M55	0.2	90 az	0	0.0726	6.5412	9.6440	7.6418	0.1035	7.6486	3.5480	7.6169
27	8-lb shotput	0.2	0		0.2665	27.0176	33.0136	28.8412	0.1560	37.6016	31.1486	36.2487
28	40-mm MK II	0.3	0 az	45	0.2066	10.7422	19.3354	13.5827	0.1217	22.1589	19.2376	22.3874
29	40-mm MK II	0.3	0 az	-45	0.1308	2.8972	10.8374	5.5896	0.1993	14.9803	11.7859	15.1088
30	40-mm MK II	0.3	0 az	90	0.2982	7.3507	18.1151	11.3199	0.1464	20.0536	18.1098	20.8286
31	40-mm MK II	0.3	n/a	-90	0.3204	4.0514	11.1610	6.3124	0.3009	13.0971	12.6764	14.8656
32	40-mm MK II	0.6	0 az	0	0.1204	1.0266	-1.3624	1.5354	0.3083	11.6239	6.3571	10.7647
33	40-mm MK II	0.6	90 az	0	0.3261	-7.9370	16.8505	7.7889	0.2719	10.4357	4.0254	9.1868
34	40-mm M385	0.1	0 az	45	0.0806	25.0833	20.5925	25.4262	0.0995	32.3913	16.2545	29.4372
35	40-mm M385	0.1	0 az	-45	0.1128	22.1145	17.6347	22.4579	0.0829	31.8810	13.8658	28.8423
36	40-mm M385	0.1	0 az	90	0.1128	22.9899	19.2689	23.3656	0.1284	30.0634	15.4364	27.2069
37	40-mm M385	0.1	n/a	-90	0.0255	19.4070	15.3695	19.7713	0.0340	29.0409	16.2073	26.3568
38	40-mm M385	0.2	0 az	0	0.0927	13.2228	7.4715	13.5345	0.0973	24.7364	10.8973	21.9585
39	40-mm M385	0.2	90 az	0	0.1156	15.3749	11.7424	15.7565	0.0971	26.0984	13.5881	23.4398
40	8-lb shotput	0.2	0		0.0507	27.9992	34.4517	29.9653	0.0714	38.6896	31.9343	37.2348
41	M42	0.15	0 az	45	0.1038	4.1123	10.5408	6.1094	0.0620	17.4950	13.5354	17.1872
42	M42	0.15	0 az	-45	0.1181	7.8100	12.7688	9.3244	0.1241	17.4381	7.6920	15.2045
43	M42	0.15	0 az	90	0.0835	9.6363	14.6337	11.1950	0.0633	21.6654	11.6576	19.3812
44	M42	0.15	n/a	-90	0.0745	9.6868	13.7820	11.0013	0.0807	22.7938	13.4062	20.6452
45	M42	0.35	0 az	0	0.0769	6.3910	8.0256	7.2506	0.0732	16.1972	7.7096	14.6096
46	M42	0.35	90 az	0	0.1234	5.5481	9.4312	6.8350	0.0982	18.7204	7.1252	16.1841
47	BLU-26	0.1	0		0.0930	25.6184	31.8919	27.5296	0.1885	31.3081	25.1190	30.0505
48	BLU-26	0.1	0		0.1450	22.0869	28.7095	24.1199	0.1999	30.7689	23.7936	29.2624
49	BLU-26	0.1	0		0.1751	23.4327	29.2280	25.1871	0.1801	30.3715	23.7055	28.9484
50	BLU-26	0.1	0		0.0689	25.8693	33.1175	28.1214	0.1450	31.7705	26.3971	30.8297
51	BLU-26	0.2	0		0.0254	11.8448	15.8582	13.1456	0.2308	19.9664	15.8550	19.6271
52	BLU-26	0.2	0		0.1248	9.7462	16.3424	11.9191	0.2699	18.7310	12.4240	17.4346
53	8-lb shotput	0.2	0		0.2732	26.9225	33.1094	28.8015	0.1300	37.5589	30.1233	35.8935
54	BDU-28	0.1	0 az	45	0.2273	14.0376	23.1117	17.1573	0.2406	24.5340	15.8329	22.6986
55	BDU-28	0.1	0 az	-45	0.0983	24.7783	27.7852	25.8688	0.1170	31.1297	21.7999	28.9880
56	BDU-28	0.1	0 az	90	0.2552	13.5513	25.0353	17.9298	0.0525	25.4131	21.7429	25.2476
57	BDU-28	0.1	n/a	-90	0.1720	24.8194	25.2706	25.5141	0.0988	32.6219	19.5292	29.9095

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98 Peak Dist From UXO	GEM-3-98 In-phase SNR	GEM-3-98 Quadrature SNR	GEM-3-98 Comb SNR	GEM-3-E Peak Dist From UXO	GEM-3-E In-phase SNR	GEM-3-E Quadrature SNR	GEM-3-E Comb SNR
58	BDU-28	0.2	0 az	0	0.0872	12.7388	15.0654	13.7006	0.1362	23.4894	10.1602	20.7854
59	BDU-28	0.2	90 az	0	0.2040	12.8868	15.6474	13.9347	0.0832	23.8357	12.8216	21.3920
60	57-mm M86	0.4	0 az	45	0.3137	4.5587	13.3773	7.7746	0.2060	14.8410	12.9935	15.7669
61	57-mm M86	0.4	0 az	-45	0.2487	6.2868	15.2862	9.3574	0.0801	19.4196	15.4681	19.1384
62	57-mm M86	0.4	0 az	90	0.3149	4.8500	15.9513	9.0447	0.2505	16.5004	17.0440	18.9483
63	57-mm M86	0.4	n/a	-90	0.2982	3.7669	13.7977	7.4463	0.1310	18.8651	17.5832	20.0480
64	57-mm M86	0.91	0 az	0	0.2498	-4.4434	3.0270	-1.9416	0.1904	8.8505	2.2570	7.8838
65	57-mm M86	0.91	90 az	0	0.1360	-1.5821	0.3306	-0.6446	0.3086	10.9784	-1.0580	8.4093
66	8-lb shotput	0.2	0		0.2301	26.9588	32.2525	28.5647	0.1310	39.0056	31.1229	37.2096
67	MK 118 Rockeye	0.3	0 az	45	0.3094	6.3752	4.6640	6.8937	0.1536	21.0668	-0.5182	17.9654
68	MK 118 Rockeye	0.3	0 az	-45	0.2857	7.9126	6.5234	8.4646	0.0669	23.0923	0.0291	19.9576
69	MK 118 Rockeye	0.3	0 az	90	0.2296	10.1617	17.3985	12.4090	0.2278	16.7936	5.6092	14.4027
70	MK 118 Rockeye	0.3	n/a	-90	0.3392	1.3437	7.4630	3.4758	0.2627	15.9735	3.0072	13.4284
71	MK 118 Rockeye	0.6	0 az	0	0.1694	1.7506	-0.2444	2.3108	0.1360	13.8149	2.1498	11.3836
72	MK 118 Rockeye	0.6	90 az	0	0.3260	1.9973	5.3229	3.2620	0.2071	11.9906	3.0827	9.9678
73	60-mm M49A3	0.5	0 az	45	0.1789	-1.8178	2.7435	-0.2974	0.0888	8.7083	11.9442	13.2624
74	60-mm M49A3	0.5	0 az	-45	0.0813	1.2878	8.9077	3.8587	0.1926	15.2290	12.7147	15.6776
75	60-mm M49A3	0.5	0 az	90	0.2380	5.7816	12.2829	7.8118	0.1423	17.2603	16.2149	18.6239
76	60-mm M49A3	0.5	n/a	-90	0.2414	3.0159	12.0255	6.0875	0.1506	4.9723	13.0345	13.8181
77	60-mm M49A3	1	0 az	0	0.1171	-0.6061	0.3172	0.2659	0.2921	8.2666	6.0116	9.1140
78	60-mm M49A3	1	90 az	0	0.1220	4.7665	3.5213	5.3378	0.2144	8.8010	0.7309	7.2060
79	8-lb shotput	0.2	0		0.0719	28.4966	35.2835	30.5784	0.2733	38.6503	32.1680	37.2873
80	81-mm M374	0.5	0 az	45	0.1870	4.8221	8.9495	6.1970	0.1929	17.7746	16.1782	18.7650
81	81-mm M374	0.5	0 az	-45	0.2226	5.6764	7.5602	6.7726	0.2811	17.5253	15.2690	18.1433
82	81-mm M374	0.5	0 az	90	0.1086	2.5111	3.1157	3.3150	0.2175	11.0042	9.8726	12.3734
83	81-mm M374	0.5	n/a	-90	0.1715	4.1497	13.8008	7.5851	0.1104	19.8610	16.4520	19.8373
84	81-mm M374	1.5	0 az	0	0.2096	6.4770	1.3006	6.8361	0.1674	6.6035	5.3379	7.9313
85	81-mm M374	1.5	90 az	0	0.3352	13.4900	6.5244	13.7743	0.3089	12.9314	0.8304	10.5298
86	2.75 M230	0.5	0 az	45	0.1345	7.5944	11.5427	9.2039	0.1795	21.7342	20.4805	22.9347
87	2.75 M230	0.5	0 az	-45	0.1301	7.9602	16.0616	10.6775	0.3311	24.3556	21.8262	24.7893
88	2.75 M230	0.5	0 az	90	0.0303	11.9595	21.1228	15.0458	0.0171	27.8424	24.9445	28.0689
89	2.75 M230	0.5	n/a	-90	0.1429	10.8536	17.5174	13.0042	0.0957	24.7940	21.9067	25.0337

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98				GEM-3-E			
					Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR	Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR
90	2.75 M230	1.2	0 az	0	0.1367	8.7179	4.4295	9.1419	0.1498	16.2272	1.2633	13.3604
91	2.75 M230	1.2	90 az	0	0.1823	9.0666	3.4609	9.3836	0.3090	16.4117	1.6199	13.5547
92	8-lb shotput	0.2	0		0.1584	26.3676	32.2266	28.1407	0.1880	38.6638	31.5266	37.0867
93	8-lb shotput	0.2	0		0.1333	26.0636	32.5203	28.0315	0.1725	38.3084	30.8133	36.6229
94	8-lb shotput	0.2	0		0.1537	29.7894	35.4988	31.5166	0.2014	40.9311	33.5791	39.2878
95	30 -cm steel plate	0.5	0	0	0.0934	21.8897	24.1407	22.8362	0.1288	40.2559	28.3295	37.6686
96	30 -cm steel plate	1	0	0	0.0436	8.5710	6.8697	9.2905	0.1458	18.6553	7.5236	16.2547
97	60 -cm steel plate	0.5	0	0	0.1472	44.0836	42.1819	44.5662	0.0842	60.8586	45.8850	57.9743
98	60 -cm steel plate	1	0	0	0.2133	21.5786	17.7018	21.9507	0.1194	39.1624	24.2297	36.2823
99	105-mm M456 HEAT	0.4	0 az	45	0.1189	8.2366	12.0274	9.5161	0.3046	21.9461	16.8140	21.1167
100	105-mm M456 HEAT	0.4	0 az	-45	0.2093	15.5632	23.6991	18.1921	0.2113	31.9189	27.5325	31.4040
101	105-mm M456 HEAT	0.4	0 az	90	0.1780	4.4234	9.3526	5.9921	0.3006	20.0834	14.2898	18.9745
102	105-mm M456 HEAT	0.4	n/a	-90	0.2103	12.2433	21.3948	15.3291	0.2007	28.1231	25.0179	28.2512
103	105-mm M456 HEAT	0.8	0 az	0	0.2152	3.1192	8.8754	4.8863	0.1526	18.0225	14.3954	17.8772
104	105-mm M456 HEAT	0.8	90 az	0	0.2666	6.8014	17.7780	10.8669	0.2382	12.3851	12.6091	14.6111
105	105-mm M60	0.9	0 az	45	0.2648	4.3532	14.7080	8.1648	0.3391	12.4499	8.0154	12.2417
106	105-mm M60	0.9	0 az	-45	0.2096	6.5902	13.7841	9.0486	0.0803	12.0393	11.7550	13.8873
107	105-mm M60	0.9	0 az	90	0.2433	7.0918	11.6712	8.7739	0.3089	7.3211	9.2028	10.7723
108	105-mm M60	0.9	n/a	-90	0.0723	8.4369	8.7348	9.4657	0.2638	7.1542	10.0603	11.4182
109	105-mm M60	1.8	0 az	0	0.1190	8.0963	10.4256	9.1771	0.0854	0.2939	-0.6887	1.7450
110	105-mm M60	1.8	90 az	0	0.1721	8.3086	12.5661	9.6828	0.1088	-0.1204	3.5136	4.7926
111	155-mm M483A1	0.9	0 az	45	0.0407	5.4832	7.5462	6.7815	0.1527	15.0041	11.6827	15.1587
112	155-mm M483A1	0.9	0 az	-45	0.2776	6.9912	6.0583	7.6180	0.0738	17.1146	13.4356	16.9576
113	155-mm M483A1	0.9	0 az	90	0.2752	7.4156	2.4066	7.7706	0.1200	16.8334	15.8815	18.2412
114	155-mm M483A1	0.9	n/a	-90	0.0998	7.5397	0.9726	7.8437	0.2229	9.6446	10.9190	12.6314
115	155-mm M483A1	2	0 az	0	0.2926	8.0226	7.9985	8.8727	0.2140	8.0889	4.8370	8.1574

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98				GEM-3-E			
					Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR	Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR
116	155-mm M483A1	2	90 az	0	0.2904	6.5403	-0.3019	6.8580	0.2860	4.1346	9.8483	10.8512
117	M14 AP mine	0.05	0	0	0.3100	-0.3355	5.4595	1.6213	0.1866	7.4007	12.6685	13.7931
118	M14 AP mine	0.01	0	0	0.0802	-1.3313	10.3444	3.4092	0.1969	8.9864	12.4562	13.9670
119	VS 50 AP mine	0.05	0	0	0.2372	1.6109	11.0101	4.9130	0.0211	7.8921	11.9947	13.4037
120	VS 50 AP mine	0.1	0	0	0.1306	-2.4878	8.3129	1.6295	0.2849	6.6238	12.6295	13.6594
121	T62 AT mine	0.1	0	0	0.1989	49.4397	54.0321	50.8664	0.2002	61.1359	52.7454	59.2088
122	T62 AT mine	0.2	0	0	0.1518	50.8611	54.4431	52.0503	0.2188	62.0064	53.0300	59.9406
123	VS 2.2 AT mine	0.1	0	0	0.3112	-2.1861	2.9494	-0.4631	0.3033	1.0778	3.4237	5.0509
124	VS 2.2 AT mine	0.2	0		0.1238	-1.8102	3.0724	-0.1666	0.1221	-4.1041	9.7395	10.3157
125	8-lb shotput	0.2	0		0.1059	28.4801	34.4610	30.2910	0.0602	37.6825	30.1364	35.9818
126	8-lb shotput	0.2	0		0.2988	25.3696	30.6862	26.9833	0.0711	37.2976	29.7582	35.5987
127	8-lb shotput	0.2	0		0.1767	27.0159	33.0574	28.8492	0.0827	37.7943	30.9985	36.3258
128	8-lb shotput	0.2	0		0.1960	26.8033	32.8841	28.6479	0.0657	37.3991	30.8911	36.0274
129	8-lb shotput	0.2	0		0.2278	26.9755	32.5533	28.6664	0.0461	38.5146	31.4884	36.9718
130	8-lb shotput	0.2	0		0.0586	28.2194	34.6911	30.1980	0.0690	37.6294	30.9068	36.1853
131	8-lb shotput	0.2	0		0.0714	27.9300	33.1949	29.5278	0.0864	39.2138	31.4435	37.4489
132	8-lb shotput	0.2	0		0.1171	26.8808	33.4583	28.8893	0.1066	37.8178	31.1097	36.3784
133	8-lb shotput	0.2	0		0.0788	26.2679	32.1260	28.0405	0.1620	37.7164	31.0798	36.3014
134	8-lb shotput	0.2	0		0.1420	26.8027	32.9127	28.6575	0.1292	38.2361	31.5861	36.8163
135	8-lb shotput	0.2	0		0.2253	27.7386	33.3900	29.4495	0.2335	38.8635	32.0269	37.3819
136	8-lb shotput	0.2	0		0.2771	23.7648	29.6450	25.5452	0.1087	37.0949	30.4793	35.6864
137	8-lb shotput	0.2	0		0.3072	26.1884	32.0424	27.9606	0.1409	38.1698	31.1320	36.6233
138	8-lb shotput	0.2	0		0.1290	26.4717	33.4360	28.6186	0.0872	39.2318	32.5487	37.8007
139	8-lb shotput	0.2	0		0.1431	29.3180	35.0135	31.0416	0.1669	41.5450	33.9156	39.8207
140	8-lb shotput	0.2	0		0.1391	25.9387	32.6400	27.9919	0.2230	37.9691	31.3443	36.5577
141	8-lb shotput	0.2	0		0.0410	30.0028	35.5742	31.6893	0.1431	41.3421	33.4787	39.5516
142	8-lb shotput	0.2	0		0.1465	28.5415	33.8905	30.1630	0.0636	39.9596	31.8188	38.0938
143	8-lb shotput	0.2	0		0.1324	30.2613	35.7052	31.9105	0.1494	41.7173	33.8028	39.9126
144	8-lb shotput	0.2	0		0.1917	27.4783	32.7931	29.0902	0.0999	38.8614	31.1221	37.1054
145	8-lb shotput	0.2	0		0.2769	25.9172	32.5911	27.9595	0.0739	37.8957	31.3152	36.4992
146	8-lb shotput	0.2	0		0.1040	26.5445	32.1839	28.2520	0.2792	37.7312	30.3690	36.0862
147	8-lb shotput	0.2	0		0.1010	27.7533	33.8144	29.5903	0.0665	36.9549	30.5984	35.6364
148	8-lb shotput	0.2	0		0.1761	19.0900	26.1774	21.2829	0.0202	34.3081	26.8643	32.6380
149	8-lb shotput	0.2	0		0.3041	22.2523	28.9078	24.2883	0.1809	36.7727	29.3900	35.1204
150	8-lb shotput	0.2	0		0.2307	23.5762	31.5528	26.1236	0.1189	38.8219	30.9293	37.0233

Target ID	Description	Depth	Orientation/ Inclination		GEM-3-98				GEM-3-E			
					Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR	Peak Dist From UXO	In-phase SNR	Quadrature SNR	Comb SNR
151	8-lb shotput	0.2	0		0.2706	23.6019	30.1958	25.6179	0.2088	38.6189	31.3273	36.9938
152	8-lb shotput	0.2	0		0.2329	25.2751	31.3584	27.1190	0.1600	38.3208	31.0511	36.7025
153	8-lb shotput	0.2	0		0.0348	27.4162	33.2385	29.1810	0.1023	39.1763	31.9571	37.5732
154	8-lb shotput	0.2	0		0.1725	28.2149	34.4093	30.0963	0.1553	38.9383	31.7675	37.3510
155	8-lb shotput	0.2	0		0.3225	29.6141	36.2402	31.6421	0.2034	40.4030	33.2013	38.8053
156	8-lb shotput	0.2	0		0.0763	26.9083	33.0210	28.7613	0.0091	38.9984	31.9644	37.4533
157	8-lb shotput	0.2	0		0.1201	27.9309	34.0863	29.7980	0.2320	39.6484	32.0871	37.9434
158	8-lb shotput	0.2	0		0.1681	26.4268	32.1343	28.1541	0.0924	38.8354	31.4127	37.1709
159	8-lb shotput	0.2	0		0.0978	27.3562	32.6137	28.9518	0.0729	39.3132	30.4395	37.2656
160	8-lb shotput	0.2	0		0.0825	27.7765	33.7425	29.5827	0.1715	39.5662	32.1946	37.9173
161	8-lb shotput	0.2	0		0.1269	26.4819	32.9501	28.4526	0.1341	37.8192	30.6164	36.2212
162	8-lb shotput	0.2	0		0.2770	27.5541	32.3727	29.0565	0.1199	38.5718	31.3298	36.9626
163	8-lb shotput	0.2	0		0.2392	25.3267	31.6218	27.2396	0.1625	37.9662	29.9696	36.1411
164	8-lb shotput	0.2	0		0.2378	22.1405	27.7710	23.8460	0.1670	38.0362	30.5359	36.3489
165	8-lb shotput	0.2	0		0.2176	18.3818	25.9692	20.7668	0.0886	38.4012	31.4750	36.8902
166	8-lb shotput	0.2	0		0.3014	25.1034	30.2194	26.6616	0.1087	40.1173	32.2238	38.3179
167	8-lb shotput	0.2	0		0.1810	23.5601	30.1519	25.5736	0.1188	36.3605	29.5623	34.8913
168	8-lb shotput	0.2	0		0.3356	18.6893	25.4520	20.7662	0.1561	39.5038	31.5044	37.6796
169	8-lb shotput	0.2	0		0.2370	22.4626	27.8637	24.1028	0.2844	40.3017	31.3169	38.2284
170	8-lb shotput	0.2	0		0.0893	24.3992	31.2731	26.5122	0.1063	42.3916	34.6369	40.6314
171	8-lb shotput	0.2	0		0.1102	22.9907	27.1561	24.3216	0.0430	38.8831	29.5452	36.7316
172	8-lb shotput	0.2	0		0.2332	23.1710	29.4996	25.0976	0.2523	39.2256	30.3672	37.1815
173	8-lb shotput	0.2	0		0.1463	20.1815	25.8272	21.8969	0.0800	32.9140	23.9828	30.8529
174	8-lb shotput	0.2	0		0.1542	24.6160	30.3691	26.3582	0.1099	39.2057	31.5873	37.4850
175	8-lb shotput	0.2	0		0.2813	25.7509	31.7043	27.5534	0.1641	40.9396	33.6994	39.3303
176	8-lb shotput	0.2	0		0.1351	24.5460	30.8614	26.4658	0.2196	38.3463	31.7554	36.9466
177	8-lb shotput	0.2	0		0.0989	24.4063	30.9184	26.3919	0.1231	36.9399	30.5427	35.6068
178	8-lb shotput	0.2	0		0.0367	26.0292	32.7444	28.0857	0.0810	38.5138	32.4070	37.2843
179	8-lb shotput	0.2	0		0.1137	26.9311	33.4388	28.9153	0.0614	38.6013	32.3176	37.3081
180	8-lb shotput	0.2	0		0.1761	23.5299	30.2687	25.5952	0.1440	36.8085	30.8615	35.6380

Appendix B: Weather Data from Phillips Airfield

Date	Time, EDST	Average Temperature, ºF	Maximum Temperature, ºF	Minimum Temperature, ºF	RH, %	Precipitation, in.
09/08/2003	00:00	61.0	61.8	60.1	97.90	0.00
09/08/2003	01:00	61.2	61.5	60.6	98.20	0.00
09/08/2003	02:00	61.0	61.5	60.4	98.10	0.00
09/08/2003	03:00	60.4	60.9	59.7	98.40	0.00
09/08/2003	04:00	59.3	60.1	58.6	98.70	0.00
09/08/2003	05:00	58.2	59.3	57.2	99.00	0.00
09/08/2003	06:00	57.4	58.6	56.4	99.20	0.00
09/08/2003	07:00	60.4	64.8	57.5	98.10	0.00
09/08/2003	08:00	68.5	71.6	64.4	84.60	0.00
09/08/2003	09:00	73.5	75.3	71.3	71.23	0.00
09/08/2003	10:00	76.6	77.7	74.9	62.32	0.00
09/08/2003	11:00	77.8	78.7	77.0	60.46	0.00
09/08/2003	12:00	79.0	80.2	78.1	59.18	0.00
09/08/2003	13:00	80.4	81.9	79.4	57.91	0.00
09/08/2003	14:00	80.6	81.8	79.8	58.38	0.00
09/08/2003	15:00	80.5	81.2	80.1	58.38	0.00
09/08/2003	16:00	80.2	81.0	79.5	60.65	0.00
09/08/2003	17:00	78.0	80.0	76.3	71.41	0.00
09/08/2003	18:00	75.7	77.5	73.6	80.40	0.00
09/08/2003	19:00	74.7	75.3	74.0	78.12	0.00
09/08/2003	20:00	74.2	75.0	73.2	79.00	0.00
09/08/2003	21:00	72.5	73.3	71.8	84.40	0.00
09/08/2003	22:00	71.6	72.6	70.4	79.33	0.00
09/08/2003	23:00	69.8	70.7	69.0	81.60	0.00
09/09/2003	00:00	68.7	69.4	67.8	83.40	0.00
09/09/2003	01:00	68.1	68.8	67.2	85.00	0.00
09/09/2003	02:00	68.3	68.9	67.5	85.00	0.00
09/09/2003	03:00	66.7	67.8	65.4	89.20	0.00
09/09/2003	04:00	65.4	65.9	64.9	91.30	0.00
09/09/2003	05:00	65.1	65.5	64.6	91.50	0.00
09/09/2003	06:00	64.8	65.2	64.5	90.80	0.00
09/09/2003	07:00	65.9	67.0	64.6	88.30	0.00

Date	Time, EDST	Average Temperature, ºF	Maximum Temperature, ºF	Minimum Temperature, ºF	RH, %	Precipitation, in.
09/09/2003	08:00	67.8	69.5	66.3	83.40	0.00
09/09/2003	09:00	70.1	71.7	69.0	70.97	0.00
09/09/2003	10:00	72.2	73.0	71.1	54.28	0.00
09/09/2003	11:00	73.0	73.9	72.5	50.62	0.00
09/09/2003	12:00	73.7	74.6	72.8	54.56	0.00
09/09/2003	13:00	74.6	75.5	73.9	54.94	0.00
09/09/2003	14:00	75.3	76.2	74.2	51.99	0.00
09/09/2003	15:00	75.0	75.5	74.2	51.57	0.00
09/09/2003	16:00	74.2	74.8	73.6	51.04	0.00
09/09/2003	17:00	73.3	74.1	72.3	52.62	0.00
09/09/2003	18:00	71.3	72.7	69.6	55.50	0.00
09/09/2003	19:00	68.7	70.0	67.6	58.99	0.00
09/09/2003	20:00	67.0	68.2	66.0	60.90	0.00
09/09/2003	21:00	65.3	66.5	64.5	67.22	0.00
09/09/2003	22:00	64.3	65.1	62.6	71.86	0.00
09/09/2003	23:00	62.4	63.9	60.4	78.16	0.00
09/10/2003	00:00	59.7	60.7	58.6	84.10	0.00
09/10/2003	01:00	58.3	59.0	57.6	88.80	0.00
09/10/2003	02:00	57.1	58.2	56.3	92.90	0.00
09/10/2003	03:00	56.9	57.5	56.5	93.50	0.00
09/10/2003	04:00	57.4	58.2	56.6	92.00	0.00
09/10/2003	05:00	56.3	57.0	55.7	93.90	0.00
09/10/2003	06:00	55.7	56.3	55.0	95.40	0.00
09/10/2003	07:00	58.1	60.8	55.3	91.90	0.00
09/10/2003	08:00	62.6	65.2	60.5	83.20	0.00
09/10/2003	09:00	66.0	67.3	64.8	75.33	0.00
09/10/2003	10:00	67.7	70.2	66.3	70.47	0.00
09/10/2003	11:00	70.7	72.0	69.0	64.24	0.00
09/10/2003	12:00	71.3	73.4	69.0	61.69	0.00
09/10/2003	13:00	72.3	74.6	70.6	58.95	0.00
09/10/2003	14:00	74.0	75.2	72.7	54.73	0.00
09/10/2003	15:00	74.9	75.9	74.0	52.57	0.00
09/10/2003	16:00	75.5	76.2	74.6	50.60	0.00
09/10/2003	17:00	75.8	76.6	74.9	49.73	0.00
09/10/2003	18:00	73.8	75.3	71.2	55.60	0.00
09/10/2003	19:00	66.8	71.6	63.6	75.62	0.00
09/10/2003	20:00	62.7	64.3	61.4	88.00	0.00
09/10/2003	21:00	60.5	61.9	59.4	93.50	0.00

Date	Time, EDST	Average Temperature, ºF	Maximum Temperature, ºF	Minimum Temperature, ºF	RH, %	Precipitation, in.
09/10/2003	22:00	59.0	60.1	58.4	95.20	0.00
09/10/2003	23:00	58.5	59.1	58.1	95.90	0.00
09/11/2003	00:00	57.2	58.4	56.6	96.90	0.00
09/11/2003	01:00	56.5	57.2	55.6	98.00	0.00
09/11/2003	02:00	56.1	56.6	55.7	97.30	0.00
09/11/2003	03:00	58.7	61.6	55.8	91.80	0.00
09/11/2003	04:00	58.0	60.8	56.3	91.90	0.00
09/11/2003	05:00	58.2	60.1	56.9	93.20	0.00
09/11/2003	06:00	57.2	58.8	55.9	93.80	0.00
09/11/2003	07:00	59.1	63.2	56.5	89.70	0.00
09/11/2003	08:00	65.8	68.7	63.0	74.54	0.00
09/11/2003	09:00	70.4	71.8	68.5	65.84	0.00
09/11/2003	10:00	72.9	74.0	71.7	60.09	0.00
09/11/2003	11:00	74.5	75.7	73.4	56.62	0.00
09/11/2003	12:00	76.6	77.6	75.2	53.00	0.00
09/11/2003	13:00	77.9	79.0	77.2	48.50	0.00
09/11/2003	14:00	78.8	79.6	77.9	46.95	0.00
09/11/2003	15:00	79.4	80.0	78.8	48.09	0.00
09/11/2003	16:00	79.5	80.0	79.0	49.18	0.00
09/11/2003	17:00	78.9	79.6	78.2	52.35	0.00
09/11/2003	18:00	76.9	78.5	74.9	54.67	0.00
09/11/2003	19:00	72.8	75.5	69.6	62.78	0.00
09/11/2003	20:00	69.3	70.6	67.6	69.00	0.00
09/11/2003	21:00	68.1	70.0	67.0	71.02	0.00
09/11/2003	22:00	68.8	69.5	67.4	67.03	0.00
09/11/2003	23:00	68.5	69.4	68.0	65.01	0.00
09/12/2003	00:00	68.0	68.6	67.2	68.17	0.00
09/12/2003	01:00	67.2	68.0	66.6	76.66	0.00
09/12/2003	02:00	66.5	67.1	66.0	83.30	0.00
09/12/2003	03:00	66.3	66.8	65.8	85.50	0.00
09/12/2003	04:00	66.0	66.5	65.3	85.00	0.00
09/12/2003	05:00	65.6	66.2	65.1	85.20	0.00
09/12/2003	06:00	65.1	65.6	64.6	87.00	0.00
09/12/2003	07:00	65.4	66.1	64.9	87.10	0.00
09/12/2003	08:00	66.1	66.7	65.8	83.80	0.00
09/12/2003	09:00	67.2	68.0	66.4	78.45	0.00
09/12/2003	10:00	67.7	68.2	67.4	74.80	0.00
09/12/2003	11:00	68.2	69.3	67.6	72.55	0.00

Date	Time, EDST	Average Temperature, ºF	Maximum Temperature, ºF	Minimum Temperature, ºF	RH, %	Precipitation, in.
09/12/2003	12:00	69.6	70.2	68.8	67.15	0.00
09/12/2003	13:00	67.4	69.0	64.7	68.94	0.00
09/12/2003	14:00	63.1	65.1	62.0	89.10	0.16
09/12/2003	15:00	62.7	63.3	62.0	94.10	0.13
09/12/2003	16:00	62.5	63.4	61.8	95.40	0.04
09/12/2003	17:00	63.7	64.4	63.1	94.70	0.06
09/12/2003	18:00	64.2	64.5	63.8	94.10	0.00
09/12/2003	19:00	64.6	65.2	64.2	93.10	0.00
09/12/2003	20:00	64.9	65.2	64.5	93.90	0.02
09/12/2003	21:00	65.1	65.7	64.7	94.60	0.01
09/12/2003	22:00	65.7	66.1	65.1	94.60	0.13
09/12/2003	23:00	65.8	66.4	65.3	95.60	0.00

Appendix C: Definitions from ATC Website

Anomaly	Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.
Azimuth	Positive clockwise direction of the ordnance nose from magnetic North.
BA^{disc}	A discrimination-stage location outside R_{halo} of any emplaced ordnance or emplaced clutter item.
BAR^{disc}	= (# of BA^{disc})/(test area).
BA^{res}	An anomaly from the response stage outside R_{halo} of any emplaced ordnance or emplaced clutter item.
BAR^{res}	= (# of BA^{res})/(test area).
Blind Test Grid	A matrix of squares. Center of each grid block may be a target, a piece of clutter, or nothing to test demonstrator detection system performance.
Calibration Lane	Contains targets from the standardized target list at 7 primary orientations to allow the demonstrator to develop a library on his detection system performance against known targets and location.
Clutter	Clutter items may include fragments of military munitions which have functioned as designed or were recovered from areas where munitions have been intentionally destroyed and have no explosive, pyrotechnic or chemical filler; steel; aluminum; magnetic rock; or copper.
Degaussing	Removing any remnant magnetic moments from ordnance targets.

Demonstrator	Vendor, user, developer of UXO detection and discrimination technologies.
Detection	An anomaly location that is within R_{halo} of an emplaced ordnance item.
Dip	Angle of inclination; Nose up (+), Nose down (-).
Discrimination	The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter.
Discrimination Stage	The ability to correctly identify ordnance as such, and to reject clutter. For the same locations as in the RESPONSE STAGE anomaly column, the DISCRIMINATION STAGE column contains the output of the algorithms applied in the discrimination stage processing. This column is prioritized based on the determination that an anomaly location is likely to contain ordnance. Thus, higher output values are indicative of higher confidence that an ordnance item is present at the specified location. For electronic signal processing, priority ranking is based on algorithm output. For other systems, priority ranking is based on human judgment. The demonstrator also selects the threshold that provides optimum system performance, (i.e., that retains all the detected ordnance and rejects the maximum amount of clutter).
Efficiency (E)	$= P_{det}^{disc}(t^{disc})/P_{det}^{res}(t_{min}^{res})$; Measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage t_{min}) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage, t^{disc}.

Emplaced Clutter	A clutter item (i.e., nonordnance item) buried by the government at a specified location in the test site.
Emplaced Ordnance	An inert ordnance item buried by the government at a specified location in the test site.
FAR	False identification of target in a empty grid cell.
FAR^{res}	= (# of BA^{res})/(# of opportunities).
fp^{disc}	A discrimination-stage location within R_{halo} of an emplaced clutter item.
fp^{res}	An anomaly location that is within Rhalo of an emplaced clutter item.
Large Ordnance	Caliber of ordnance greater than 81-mm (includes 105-mm HEAT, 105-mm projectile, 155-mm projectile, 500-lb bomb).
Medium Ordnance	Caliber of ordnance greater than 40-mm and less than or equal to 81-mm (includes 57-mm projectile, 60-mm mortar, 2.75-inch Rocket, MK 118 Rockeye, 81-mm mortar).
NAD83 Datum	Expressed as an Easting/Northing UTM number.
Open Field Site	Minimum 4 hectares site with a myriad of clutter, range simulations, and targets to test demonstrator detection system performance under real field-type conditions.
$P_{ba}{}^{disc}$	= (# of BA^{disc})/(# of empty grid locations).
$P_{det}{}^{disc}$	= (# of discrimination-stage detections)/(# of emplaced ordnance in the test site).
$P_{det}{}^{res}$	= (# of response-stage detections)/(# of emplaced ordnance in the test site).

P_{fp}^{res}	= (# of response-stage false positives)/(# of emplaced clutter items).
R_{BA}	= 1 - [$BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})$]; Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.
R_{fp}	= 1 - [$P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})$]; Measures (at a threshold of interest), the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage t_{min}). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.
R_{halo}	A predetermined radius about the center of the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. If multiple declarations lie within R_{halo} of any item (clutter or ordnance), the declaration with the highest signal output within the R_{halo} is utilized.
Raw Sensor Data	Preprocessed or minimally processed data for each grid square or open field area.
Response Stage	The ability of the demonstrator's system to detect emplaced targets without regard to ability to discriminate ordnance from other anomalies. The RESPONSE STAGE provides the location and signal strength of all anomalies deemed sufficient

	to warrant further investigation and/or processing as potential emplaced ordnance items. This list is generated with minimal processing (e.g., this list will include all signals above the system noise threshold). As such, it represents the most inclusive list of anomalies.
ROC Curve	Receiver Operating Characteristic curve provides the only useful and valid means of comparing performance among sensor/algorithm combinations and for determining the efficacy of algorithm or technology advancements.
Small Ordnance	Caliber of ordnance less than or equal to 40-mm (includes 20-mm projectile, 40-mm projectile, submunitions BLU-26, BDU-28, and M42).
Standardized Site	Made up of three areas - Calibration Lanes/ Ground Test Pit, a Blind Test Grid, and an Open Field Site designed to test the demonstrator detection systems under various test parameters.
Standardized Target	A military munition which contains no energetic material. These items pose no imminent threat. However, will remain under the control of the Standardized UXO Technology Demonstration Site On-Site Project Manager as issued by the ATC Project Manager.
Threshold	The limit, set on a system's discrimination stage, which defines the difference between what is considered to be ordnance and what is considered nonordnance. Only those signals that exceed (or fall below, depending on the signal strength polarity) the threshold are considered to result from ordnance.

Target Repository	Located at Aberdeen Proving Ground, MD. Managed by the ATC Target Repository Standardized UXO Technology Demonstration Site Program Manager. Thirteen types of standardized targets are available for loan.
Unexploded Ordnance	A military munition that contains explosive or pyrotechnic (UXO) charge and has been primed, fuzed, armed or otherwise prepared for action and which has been fired, placed, dropped, launched or projected, and remains unexploded by design or malfunction. An item of explosive ordnance which has failed to function as designed or has been abandoned, discarded or improperly disposed of and is still capable of functioning, causing damage to personnel or material. These can be, but are not limited to high-explosive warheads, rocket motors, practice munitions with spotting charges, torpedoes, artillery and mortar ammunition, grenades, incendiary munitions, electro-explosive devices and propellant-actuated devices. Fuzes with live explosive boosters or detonators are classified as UXO. All UXO are potentially dangerous and cannot be released for public use without being rendered safe (neutralized, vented, detonated, decontaminated or demilitarized).