KEMRON
ENVIRONMENTAL SERVICES

TRANSMITTAL MEMORANDUM

To: Distribution **Date:** 01/31/18

Subject: Field Work Variance 012 for Final, Work Plan, Munitions with Sensitive Fuzes Field Study, Former Fort Ord, California

DCN: SH4914-211

Attached please find the FWV 012, for the *Final, Work Plan, Munitions with Sensitive Fuzes Field Study, Former Fort Ord, California*.

Also included are the revised Advanced Geophysical Classification Munitions Response (AGCMR)-Quality Assurance Project Plan (QAPP) Standard Operating Procedures (SOPs) updated for use with the MetalMapper 2x2 and MetalMapper 2x2-specific Measurement Quality Objectives for Table 22 in the AGCMR-QAPP.

If you have any questions, please contact Kevin Siemann, Gilbane, at 831-824-2303.

Kemron Gilbane

FIELD WORK VARIANCE

Project Name/Number	Fort Ord	**WP**	CM-01
Applicable Document	*Final, Work Plan, Munitions with Sensitive Fuzes Field Study, Former Fort Ord, California* (OE-0888B) (KEMRON, 2017); *Final, Quality Assurance Project Plan, Superfund Response Actions, Former Fort Ord, California, Volume II, Munitions Response, Appendix B, Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan* (OE-0868B) (KEMRON, 2016)	**Date**	January 9, 2018

Problem Description:

The *Final, Work Plan, Munitions with Sensitive Fuzes Field Study, Former Fort Ord, California (OE-0888B) (KEMRON, 2017)* (FSWP) is designed to demonstrate the performance and capabilities of two digital geophysical mapping (DGM) systems for the identification of subsurface munitions and explosives of concern (MEC), specifically those with sensitive fuzes. Range 48 was originally selected for the field study because the historical subsurface removal information revealed a wide range of subsurface anomaly density. EM61 and OPTEMA data acquisition were completed as planned, but data analysis revealed a subsurface anomaly density too high to determine a density threshold at which the DGM systems can no longer resolve individual items. To meet the original objective of the field study, an additional study area was identified with a wide range of subsurface anomaly density, including concentrations lower than those in Range 48.

The FSWP also identified the White River Technologies One-Pass Time-domain ElectroMagnetic Array (OPTEMA) as the advanced electromagnetic induction (EMI) sensor system selected for the dynamic detection and cued advanced geophysical classification surveys associated with the field study. The OPTEMA is a research and development system that is approaching commercial production but is not yet available for field production work. The availability of the system for additional field study data acquisition is therefore limited and not logistically feasible at this time. An alternate advanced EMI sensor system is therefore necessary for the acquisition of additional DGM data to complete the field study.

Recommended solution:

Study grids in Unit 23 have been identified for field study data acquisition, processing and analysis, and intrusive investigation. The additional field study areas have been selected based on locations in Unit 23 where 40mm projectiles have been previously recovered during surface removal activities and where subsurface anomalies of various density ranges have been observed in previously acquired EM61 DGM data. The proposed field study grids are shown on Figure 1.

For comparison with the advanced classification results, subsurface anomalies will also need to be formally identified from the previously acquired EM61 DGM data in the new field study area and intrusively investigated. The proposed field study grids have been evaluated and have a complete EM61 data set. The approximate quantity of EM61 subsurface anomalies in the proposed field study grids, based on preliminary data analysis, is identified on Figure 1. Intrusive investigation will include all detected EM61 anomalies greater than 14mV (sum) and all anomalies detected by the advanced EMI sensor system utilizing an equivalent detection threshold, regardless of classification decision. It is anticipated that the majority of EM61 anomalies requiring subsurface investigation will coincide with anomalies identified by the advanced EMI sensor.

The Geometrics MetalMapper 2x2, an advanced EMI sensor, will be used. The MetalMapper 2x2 is a person-portable advanced EMI sensor designed for the detection and classification of buried metal objects and uses sensor elements similar to the OPTEMA but in a different geometry. The MetalMapper 2x2 is composed of four sensor elements arranged on 40-centimeter (cm) centers in a 2x2 array. Each sensor element consists of a 35-cm square transmit coil for target illumination with a 10-cm three-axis receive cube centered in the transmit coil. The transmitters are energized in sequence, and decay data are recorded with a 500 kHz sample rate after turn-off of the excitation pulse for each of the 12 (4 cubes with 3 axes each) receive channels. An illustration of the MetalMapper 2x2 sensor coil configuration is shown below.

Positioning of the MetalMapper 2x2 is accomplished using real-time kinematic global positioning system, and orientation is measured using a six-degree-of-freedom inertial measurement unit. The MetalMapper 2x2 is deployable as a person-portable system and will be utilized in this configuration for both dynamic detection and static classification surveys. Data files and processing and analysis procedures are equivalent to those of an OPTEMA investigation, except for separate dynamic data acquisition and static classification surveys with the MetalMapper 2x2. MetalMapper 2x2 and OPTEMA detection and classification capabilities have been demonstrated to be nearly identical through the Environmental Security Technology Certification Program (ESTCP) Live Site Demonstration program.

Impact on present and completed work:

Utilizing the MetalMapper 2x2 to acquire advanced EMI geophysical data in additional field study grids will allow completion of the Munitions with Sensitive Fuzes Field Study and fulfillment of the field study objective.

Recommended solution/disposition:

Incorporate this FWV as an appendix to the existing FSWP, and add MetalMapper 2x2-specific standard operating procedures and measurement quality objectives.

Clarification ☐ Minor Change ☐ Major Change ☒

Affects Budget Yes ☒ No ☐
Affects Schedule Yes ☒ No ☐

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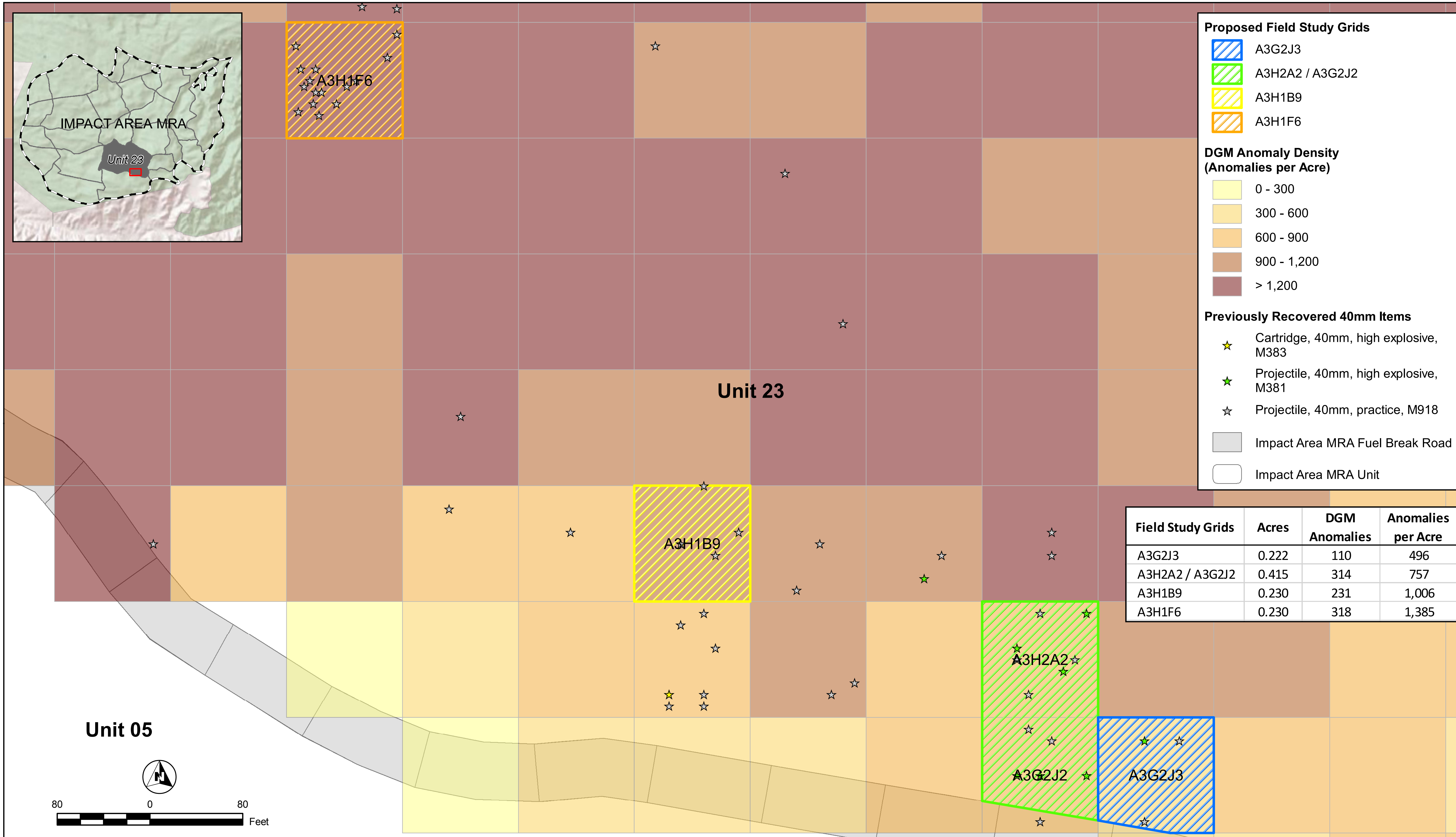

Field Study Grids	Acres	DGM Anomalies	Anomalies per Acre
A3G2J3	0.222	110	496
A3H2A2 / A3G2J2	0.415	314	757
A3H1B9	0.230	231	1,006
A3H1F6	0.230	318	1,385

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Munitions with Sensitive Fuzes Field Study Field Work Variance
Former Fort Ord, California

Figure 1
Proposed Unit 23 Field Study Grids

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1.1 Equipment Testing, Inspection and Quality Control (QAPP Worksheet #22)

This worksheet documents procedures for performing testing, inspections and quality control for all field equipment. References to the applicable DFWs and SOPs are included. Where appropriate, the failure response will proscribe a corrective action (CA). Otherwise, both an RCA and CA are required. MQOs developed specifically for use of the MetalMapper 2x2 system at Fort Ord are presented in this worksheet.

Detection (Dynamic) Survey (MetalMapper 2x2)

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
QC seed item placement	Place Subsurface QC Seeds/ SOP AGCMR-03/Blind Seed Firewall Plan (Appendix C of AGCMR-QAPP)	Evaluated for each QC seed item	QC Geophysicist / Final Seed Report	Each seed item has been buried away from the immediate vicinity of strong anomalies, the burial parameters have been recorded with 1-inch precision for locations, 2-inch precision for depths, and 10° precision for inclinations and azimuths, and a photograph has been taken of the item in place.	CA: Replace the seed item, if necessary, or reacquire burial parameter information prior to commencement of data acquisition activities.
Verify correct MetalMapper 2x2 assembly	Dynamic Detection Survey/ SOP AGCMR-01	Once following assembly	Data Acquisition Geophysicist/Assembly Checklist	As specified in SOP AGCMR-01, Assembly Checklist	CA: Make necessary adjustments and re-verify

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Initial sensor function test (five measurements over an emplaced IVS item, 1 with item directly under center of array and 1 each with item centered under each diagonal quadrant of the array). Derived polarizabilities for each measurement are compared to the classification library using UXA	Dynamic Detection Survey/ SOP AGCMR-01/ SOP AGCMR-08	Once following assembly	Data Acquisition Geophysicist/Assembly Checklist/Lead Data Processor	Library Match metric ≥ 0.95 for each of the five sets of inverted polarizabilities	CA: make necessary repairs/adjustments and re-verify
Initial sensor function test (five measurements over an emplaced IVS item, 1 with item directly under center of array and 1 each with item centered under each diagonal quadrant of the array). Modeled locations are compared to the known locations of the ISO for each measurement.	Dynamic Detection Survey/ SOP AGCMR-01/ SOP AGCMR-08	Once following assembly	Data Acquisition Geophysicist/Assembly Checklist/Lead Data Processor	Modeled location of each measurement is under the correct quadrant of the MetalMapper 2x2 sensor array	CA: make necessary repairs/adjustments and re-verify
Initial derived target position accuracy (IVS)	Dynamic Detection Survey/ SOP AGCMR-02/ SOP AGCMR-05/ SOP AGCMR-06	Once during initial system IVS test	Lead Data Processor and Gilbane Project Geophysicist/Initial IVS Technical Memorandum	All IVS item fit locations within 10 inches of ground truth locations	CA: make necessary repairs/adjustments and re-verify
Initial detection response amplitudes (IVS)	Dynamic Detection Survey/ SOP AGCMR-02/ SOP AGCMR-05/ SOP AGCMR-06	Once during initial system IVS test	Lead Data Processor and Gilbane Project Geophysicist/Initial IVS Technical Memorandum	Response amplitudes within 25% of predicted (or baseline) amplitudes	CA: make necessary repairs/adjustments and re-verify

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Ongoing derived target position precision (IVS)	Dynamic Detection Survey/ SOP AGCMR-02/ SOP AGCMR-05/ SOP AGCMR-06	Twice daily, at the beginning and end of data acquisition, as part of IVS testing	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	All IVS item fit locations within 10 inches of the average locations	RCA/CA
Ongoing detection response precision (IVS)	Dynamic Detection Survey/ SOP AGCMR-02/ SOP AGCMR-05/ SOP AGCMR-06	Twice daily, at the beginning and end of data acquisition, as part of IVS testing	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	Response amplitudes within 25% of the predicted response amplitude	RCA/CA
Down-line measurement spacing	Dynamic Detection Survey/ SOP AGCMR-05	Verified for each survey unit using existing UX Detect tools based upon monostatic Z coil data positions	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	98% ≤ 8 inches between successive measurements	RCA/CA CA assumption: Reacquire portions that fail
Coverage	Dynamic Detection Survey/ SOP AGCMR-05	Verified for each survey unit using existing UX Detect tools based upon GPS antenna positions	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	95% (or greater) of the line spacing within 2 ft., and 100% of the line spacing within 2.6 ft., with no unexplained data gaps.	RCA/CA CA assumption: Gaps require fill-in survey to achieve required coverage
Transmit current levels	Dynamic Detection Survey/ SOP AGCMR-05	Evaluated for each sensor measurement	Data Acquisition Geophysicist/failures noted in field log and tracking summary	Peak transmit current ≥ 5.5 amps	CA: reject data acquired with current levels outside of the acceptable range
Dynamic detection performance	Dynamic Detection Survey/ SOP AGCMR-05/ SOP AGCMR-06	Evaluated for each dataset	QC Geophysicist/tracking summary	All blind seed items detected and positioned within 16-inch radius of ground truth location	RCA/CA
Position data are valid (1 of 2)	Dynamic Detection Survey/ SOP AGCMR-05/ SOP AGCMR-06	Evaluated for each sensor measurement	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	GPS status flag indicates RTK fix	RCA/CA

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Position data are valid (2 of 2)	Dynamic Detection Survey/ SOP AGCMR-05/ SOP AGCMR-06	Evaluated for each sensor measurement	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	Orientation data valid Data input string checksum passes	RCA/CA

[1] Referenced SOPs are included in Appendix B of the AGCMR-QAPP

Classification (Cued) Survey (MetalMapper 2x2)

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
QC seed item placement	Place Subsurface QC Seeds/ SOP AGCMR-03	Evaluated for each QC seed item	QC Geophysicist / Final Seed Report	Each seed item has been buried away from the immediate vicinity of strong anomalies, the burial parameters have been recorded with 1-inch precision for locations, 2-inch precision for depths, and 10° precision for inclinations and azimuths, and a photograph has been taken of the item in place.	CA: Replace the seed item, if necessary, or reacquire burial parameter information prior to commencement of data acquisition activities.
Verify correct MetalMapper 2x2 assembly	Cued Classification Survey/ SOP AGCMR-01	Once following assembly	Data Acquisition Geophysicist/Assembly Checklist	As specified in SOP AGCMR-01, Assembly Checklist	CA: Make necessary adjustments and re-verify
Initial sensor function test (five measurements over an emplaced IVS item, 1 with item directly under center of array and 1 each with item centered under each diagonal quadrant of the array). Derived polarizabilities for each measurement are compared to the classification library using UXA	Cued Classification Survey/ SOP AGCMR-01/ SOP AGCMR-08	Once following assembly	Data Acquisition Geophysicist/Assembly Checklist/Lead Data Processor	Library Match metric ≥ 0.95 for each of the five sets of inverted polarizabilities	CA: make necessary repairs/adjustments and re-verify

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Initial sensor function test (five measurements over an emplaced IVS item, 1 with item directly under center of array and 1 each with item centered under each diagonal quadrant of the array). Modeled locations are compared to the known location of the schedule 80 small industry standard object (ISO 80) for each measurement.	Cued Classification Survey/ SOP AGCMR-01/ SOP AGCMR-08	Once following assembly	Data Acquisition Geophysicist/Assembly Checklist/Lead Data Processor	Modeled location of each measurement is under the correct quadrant of the MetalMapper 2x2 sensor array	CA: make necessary repairs/adjustments and re-verify
Initial IVS background measurement (five background measurements – 1 centered at the flag and 1 offset 15 inches (40cm) in each cardinal direction)	Cued Classification Survey/ SOP AGCMR-02/ SOP AGCMR-07/ SOP AGCMR-08	Once during initial system IVS test	Data Acquisition Geophysicist/Initial IVS Technical Memorandum/ Lead Data Processor	Decay amplitudes are below the selected background threshold at each offset background location	CA: reject/replace BG location
Initial derived polarizabilities accuracy (IVS)	Cued Classification Survey/ SOP AGCMR-02/ SOP AGCMR-07/ SOP AGCMR-08	Once during initial system IVS test	Lead Data Processor and Gilbane Project Geophysicist/Initial IVS Technical Memorandum	Library Match metric ≥ 0.9 for each set of inverted polarizabilities	RCA/CA
Initial derived target position accuracy (IVS)	Cued Classification Survey/ SOP AGCMR-02/ SOP AGCMR-07/ SOP AGCMR-08	Once during initial system IVS test	Lead Data Processor and Gilbane Project Geophysicist/Initial IVS Technical Memorandum	All IVS item fit locations within 5 inches of ground truth locations	RCA/CA

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Ongoing IVS background measurements	Cued Classification Survey/ SOP AGCMR-02/ SOP AGCMR-07/ SOP AGCMR-08	Twice daily as part of IVS testing	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	All decay amplitudes lower than project threshold and qualitatively agree with initial measurement	RCA/CA CA assumption: rejection of BG measurement (unless RCA indicates system failure)
Ongoing derived polarizabilities precision (IVS)	Cued Classification Survey/ SOP AGCMR-02/ SOP AGCMR-07/ SOP AGCMR-08	Twice daily as part of IVS testing	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	Library match to initial polarizabilities metric ≥ 0.9 for each set of three inverted polarizabilities	RCA/CA
Ongoing derived target position precision (IVS)	Cued Classification Survey/ SOP AGCMR-02/ SOP AGCMR-07/ SOP AGCMR-08	Twice daily as part of IVS testing	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	All IVS item fit locations within 5 inches of average of derived fit locations	RCA/CA
Initial measurement of production area background locations	Cued Classification Survey/ SOP AGCMR-04/ SOP AGCMR-08	Once per background location	Data Acquisition Geophysicist and Lead Data Processor/ tracking summary	All decay amplitudes lower than project threshold	CA: reject BG location and find alternate
Ongoing production area background measurement frequency	Cued Classification Survey/ SOP AGCMR-04/ SOP AGCMR-07	Evaluated for each background measurement	Data Acquisition Geophysicist/failures noted in field log and tracking summary	Time separation between background measurement and anomaly measurement < 2 hour	CA: reject data that does not have a corresponding background measurement recorded within acceptable time period
Ongoing production area background measurement	Cued Classification Survey/ SOP AGCMR-04/ SOP AGCMR-07/ SOP AGCMR-08	Evaluated for each background measurement	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	All decay amplitudes lower than project threshold and qualitatively agree with initial measurement	CA: background measurement rejected and reacquired

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Transmit current levels	Cued Classification Survey/ SOP AGCMR-07	Evaluated for each sensor measurement	Data Acquisition Geophysicist/failures noted in field log and tracking summary	Peak transmit current ≥ 5.5 amps	CA: reject data acquired with current levels outside of the acceptable range
Initial anomaly (flag) location interrogated	Cued Classification Survey/ SOP AGCMR-07/ SOP AGCMR-08	Evaluated for each flag position	Data Acquisition Geophysicist/failures noted in field log and tracking summary	For each anomaly, a measurement must be acquired with the center of the array within 12 inches of the flag location.	CA: Reacquire measurement at flag location
Position data are valid (1 of 2)	Cued Classification Survey/ SOP AGCMR-07	Evaluated for each sensor measurement	Data Acquisition Geophysicist/failures noted in field log and tracking summary	GPS status flag indicates RTK fix	RCA/CA
Position data are valid (2 of 2)	Cued Classification Survey/ SOP AGCMR-07/ SOP AGCMR-08	Evaluated for each sensor measurement	Data Acquisition Geophysicist/Lead Data Processor/tracking summary	Orientation data valid Data input string checksum passes	RCA/CA
Confirm inversion model supports classification (1 of 2)	Cued Classification Survey/ SOP AGCMR-08	Evaluated for all models derived from a measurement (i.e., single item and multi-item models)	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	Derived model response must fit the observed data with a fit coherence > 0.8	CA: If no valid model is derived, classify as inconclusive
Confirm inversion model supports classification (2 of 2)	Cued Classification Survey/ SOP AGCMR-08	Evaluated for derived target	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	Fit location estimate of item ≤ 15 inches from center of sensor	CA: If no target within 15 inch radius using multi-solver inversion, classify as inconclusive
Confirm all anomalies classified	Cued Classification Survey/ SOP AGCMR-08	Evaluated for each anomaly (flag) location	Lead Data Processor and Gilbane Project Geophysicist/tracking summary	100% of anomalies are classified as: TOI/ Non-TOI/Inconclusive	Documentation required identifying reason for missing data with RCA/CA if necessary. If data cannot be acquired, classify as inconclusive.

MQO	DFW/SOP Reference[1]	Frequency	Responsible Person/Report Method	Acceptance Criteria	Failure Response
Confirm reacquisition GPS accuracy and precision	Intrusive Investigation/ SOP AGCMR-09	Daily	Reacquisition Geophysicist/Daily Report	Benchmark positions repeatable to within 3 inches	CA: Make adjustments and re-verify
Confirm derived features match ground truth (1 of 2)	Intrusive Investigation/ SOP AGCMR-09	Evaluated for all recovered items	QC Geophysicist/QC reports	95% of recovered item positions < 10 inches from predicted position	RCA/CA
Confirm derived features match ground truth (2 of 2)	Intrusive Investigation/ SOP AGCMR-09	Evaluated for all recovered seed items	QC Geophysicist/QC reports	100% of predicted seed item positions < 10 inches from known position	RCA/CA
Classification performance	Intrusive Investigation/ SOP AGCMR-09	For each delivered dig list	QC Geophysicist/QC reports	100% of seed items classified as TOI	RCA/CA
Classification validation	Intrusive Investigation/ SOP AGCMR-09	For each delivered dig list	QC Geophysicist/QC reports	100% of predicted intrusively investigated non-TOI are confirmed to be non-TOI	RCA/CA

[1] Referenced SOPs are included in Appendix B of the AGCMR-QAPP

STANDARD OPERATING PROCEDURE AGCMR-01

Advanced EMI Sensor Assembly and Verification

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to describe the assembly of advanced electromagnetic induction (EMI) sensors for dynamic and cued advanced geophysical classification surveys and the process for verification that all components are correctly assembled, functioning properly, and capable of acquiring data of sufficient quality. This SOP describes Geometrics MetalMapper, U.S. Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS), and Geometrics MetalMapper 2x2 system assembly and verification. If other advanced EMI sensors are selected for use, this SOP will be updated to include assembly and verification details for those systems.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Advanced EMI sensor coupled with a real-time kinematic (RTK) global positioning system (GPS) and inertial measurement unit (IMU) for orientation measurements
- Hand tools, including wrenches, screw drivers, and optional cordless power drill with driver bits
- Zip ties (to secure TEMTADS and MetalMapper 2x2 wheels)
- Schedule 80 small industry standard object (ISO 80) or serialized ISO for operational testing
- Digital camera

2.1 Personnel and Qualifications

The following individuals will be involved in the assembly and verification of the MetalMapper:

- Data Acquisition Geophysicist
- Lead Data Processor (off-site)

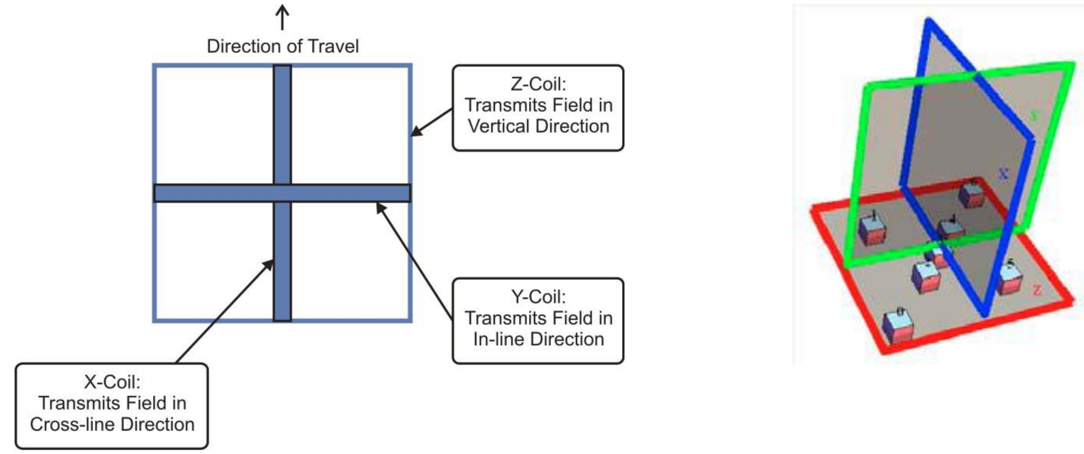
The qualifications for the Data Acquisition Geophysicist and the Lead Data Processor are listed in Worksheet 7 of the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP).

3 Procedures and Guidelines

3.1 Geometrics MetalMapper

The MetalMapper is an advanced electromagnetic induction sensor designed for the detection and classification of buried metal objects. The sensor consists of three orthogonal 1-meter (m) x 1-m transmit coils for target illumination and seven, three-axis receive cubes. It measures the decay curve up to 25 milliseconds (ms) after the transmitters are turned off for each of the 21 receiver coils, resulting in the recording of 63 different EM transients. The orientation of the three transmit coils and seven receive cubes is shown on **Figure 1**.

Figure 1. Orientation of MetalMapper transmit coils and receive cubes



The MetalMapper sampling parameters are programmable and therefore flexible to meet site-specific objectives. The decay curve of induced responses is typically measured to 8 ms after the transmitters are turned off with each of the 21 receiver coils, but a 25 ms decay curve will be used for this project based on the large targets of interest (TOI) which are the focus of the investigation.

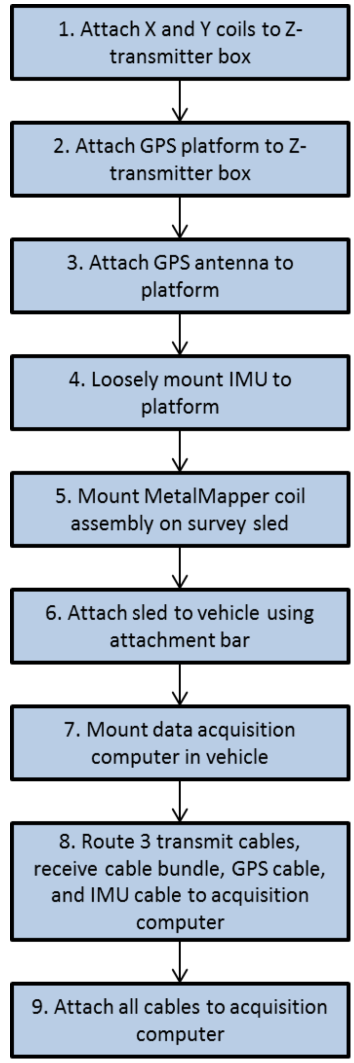
Positioning of the MetalMapper is accomplished using RTK GPS, and orientation is measured using a six-degree-of-freedom IMU. For proper functioning, the IMU must be mounted to the MetalMapper in the correct orientation.

3.1.1 Assemble the MetalMapper

MetalMapper assembly operations are described in the MetalMapper manual (Geometrics 2011), which is available for download from http://www.geometrics.com/files/metalmapper_manual_beta1.pdf. The detailed instructions contained in the manual should be followed precisely. The assembly steps are briefly described below and shown as a schematic overview on **Figure 2**.

1. Using the bolts and brackets provided, attach the X transmitter coil followed by the Y transmitter coil to the Z-transmitter box.
2. Attach the GPS platform legs to the Z-transmitter box and the GPS platform to the platform legs.
3. Securely attach the GPS antenna to the GPS platform.
4. Loosely attach the IMU to the GPS platform. The attachment will be secured after correct IMU orientation is verified.
5. Mount the MetalMapper coil assembly on the survey sled, cushioned with a partially-inflated truck tire inner tube to reduce shock to the sensor assembly, if necessary.
6. Mount one end of the attachment bar to the survey sled and the other end to the vehicle using the provided hitch mount.
7. Mount the data acquisition computer (DAC) in the vehicle so that it is accessible to the operator and can be easily seen during normal vehicle operations. Confirm that the operator's view of the sensor sled is not obstructed by the computer or display screen.
8. Route all cables (three transmit cables, the receive cable bundle, and the cables for the GPS and IMU) along the attachment bar to the acquisition computer. Secure the cables to the bar at several points.
9. Attach all cables to the marked connectors on the acquisition computer.

Figure 2. MetalMapper assembly overview



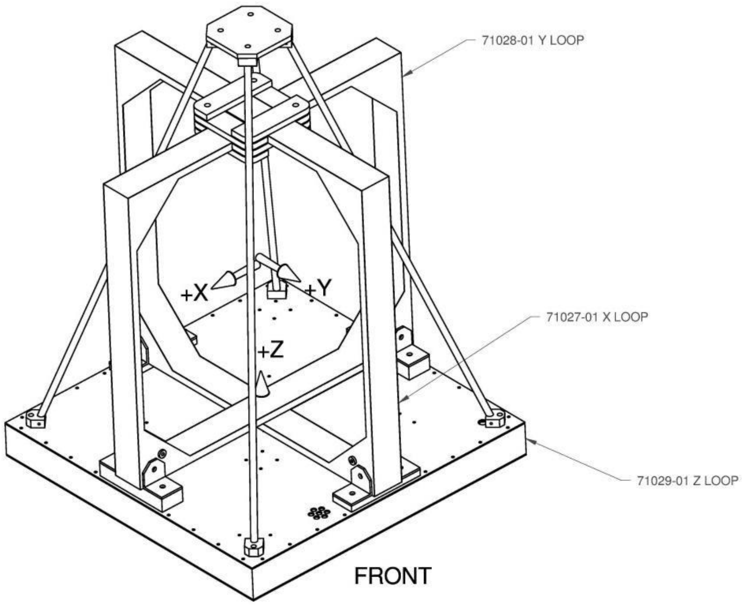
3.1.2 Verify MetalMapper Assembly

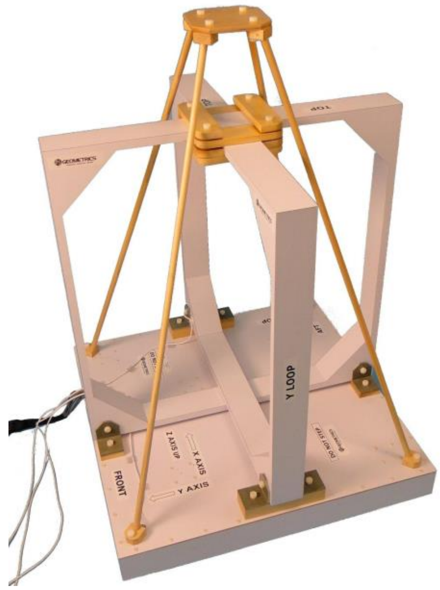
Successful data acquisition with the MetalMapper is dependent on proper assembly of the system. The following subsections describe the processes for verification that the sensor coils and IMU are properly oriented and the RTK GPS measurements are being received at the data acquisition computer (DAC).

3.1.2.1 Verify Orientation of the Transmit Coils

The correct orientation of the transmit coils and their polarities are shown on **Figure 3**. Visually verify that the assembled sensor matches this diagram.

Figure 3. Correct orientations and polarities of the three MetalMapper transmit coils

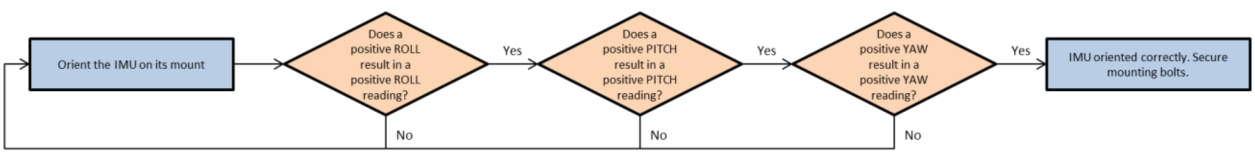




3.1.2.2 Verify Orientation of the IMU

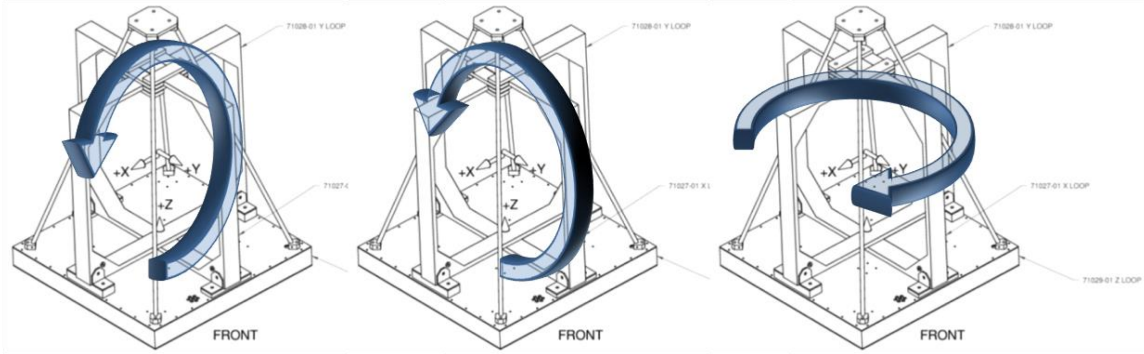
The procedure to verify the correct orientation of the IMU is shown on **Figure 4**, with detailed instructions following the figure.

Figure 4. Procedure for verification of IMU orientation



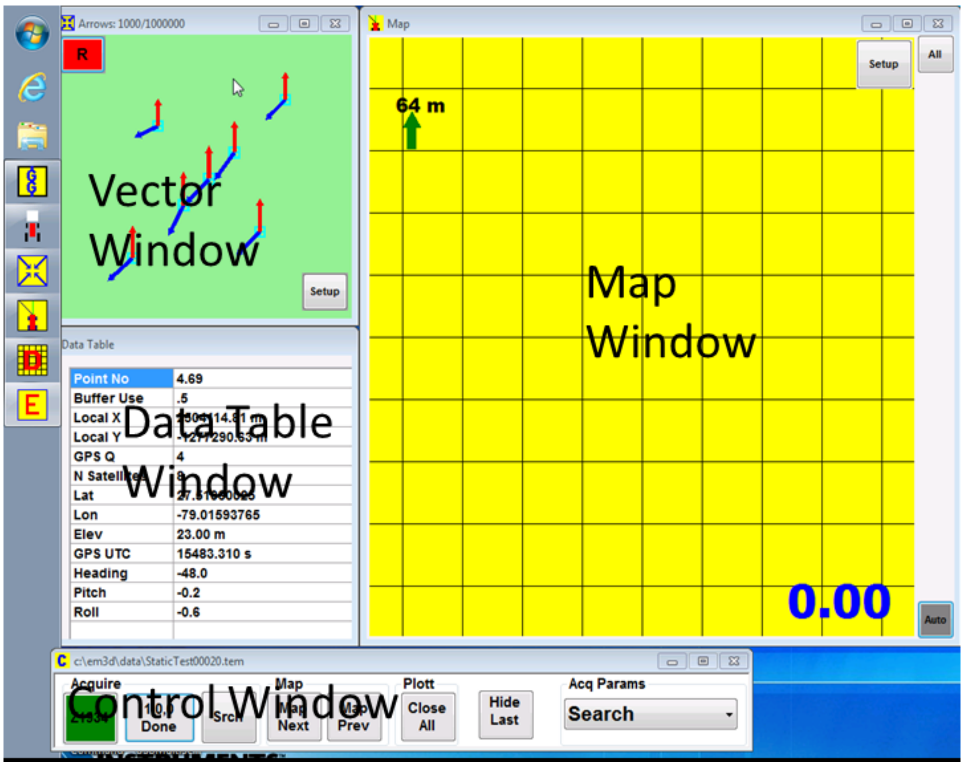
1. Standing behind the MetalMapper platform facing the direction of travel, rotate the IMU clock-wise around the along-track axis to produce a positive ROLL as shown on **Figure 5**. The primary data acquisition system window, including IMU displays, is shown on **Figure 6**. Verify that the data acquisition system records a positive ROLL. If it does not, reorient the IMU on its mount and test again.

Figure 5. Positive ROLL, PITCH, and YAW rotations of the IMU



Positive ROLL Positive PITCH Positive YAW

Figure 6. Default data acquisition system window



2. Standing on the side of the MetalMapper platform with the direction of travel to your right, rotate the IMU counter-clockwise around the cross-track axis to produce a positive PITCH as shown on **Figure 5**. The primary data acquisition system window, including IMU displays, is shown on **Figure 6**. Verify that the data acquisition system records a positive PITCH. If it does not, reorient the IMU on its mount and return to step 1.

3. Standing behind the MetalMapper platform facing the direction of travel, rotate the IMU clockwise around the vertical axis to produce a positive YAW as shown on **Figure 5**. The primary data acquisition system window, including IMU displays, is shown on **Figure 6**. Verify that the data acquisition system records a positive YAW (displayed as “heading” in the data acquisition system). If it does not, reorient the IMU on its mount and return to step 1.

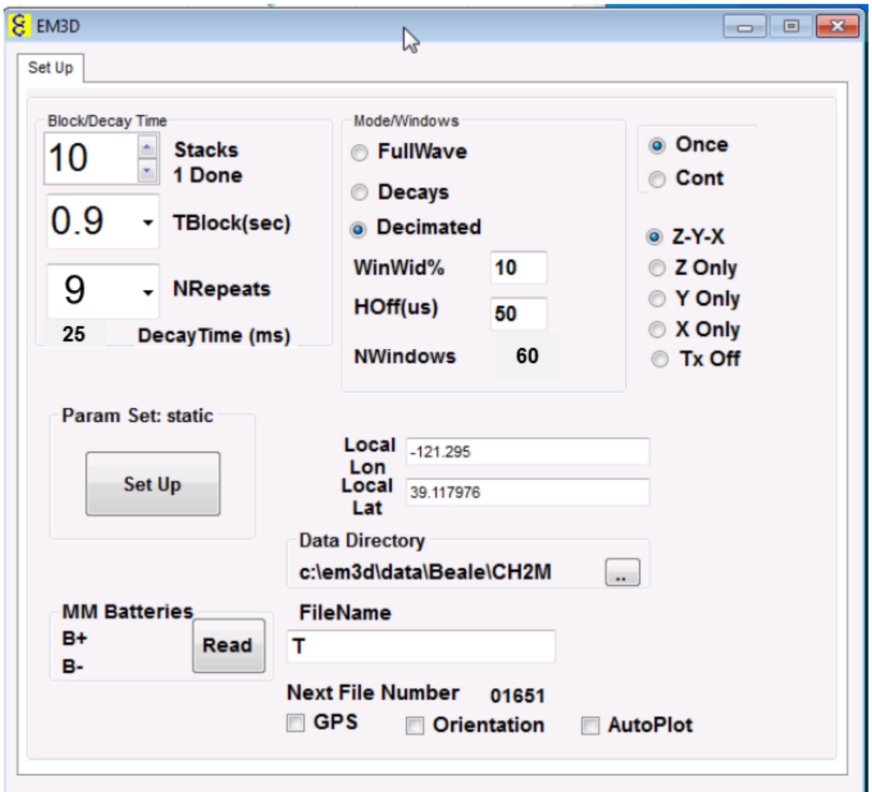
3.1.2.3 Verify Operation of the RTK GPS

Power on the GPS receiver and allow sufficient time to acquire a fixed position. Verify that GPS readings are being received at the DAC. The primary data acquisition system window, including the GPS position display, is shown on **Figure 6**.

3.1.2.4 Verify Data Acquisition Parameters

Verify that the project-specific data acquisition parameters are set in the MetalMapper data acquisition system by opening the data acquisition parameter control window, shown on **Figure 7**.

Figure 7. Data acquisition parameter control window

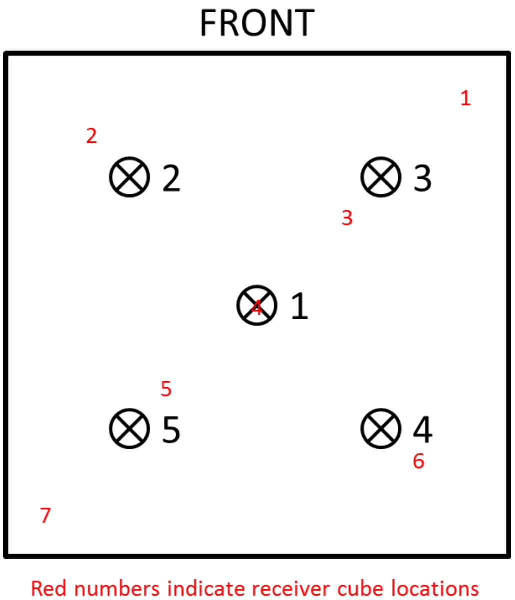


For Fort Ord advanced geophysical classification risk reduction activities, verify that the decay time is set to the long (25ms) window length, TBlock is set to 0.9 seconds, NRepeats is set to 9, and NWindows is set to 60. Different data acquisition parameters may be utilized depending on site-specific advanced classification objectives. These parameters will be defined in the Site-Specific Work Plan for each advanced geophysical classification activity.

3.1.2.5 Verify MetalMapper Operation

To verify operation of the MetalMapper, center the sensor platform over the blank location in the Instrument Verification Strip (IVS) and record a background measurement, verifying that the transmit current is within the expected range, as specified in Table 22 of the AGCMR-QAPP. Next, center the sensor platform over an IVS item with the IVS item directly under measurement position 1, as shown on **Figure 18**, and record a cued measurement. Position the sensor platform with the IVS item directly under measurement positions 2 through 5, recording a cued measurement at each position. Invert each of the five data sets and verify that the modeled location is under the correct quadrant of the MetalMapper sensor array and that the resulting polarizability decay curves match the library values for the IVS item with a match metric in accordance with that specified in Table 22 of the AGCMR-QAPP.

Figure 8. MetalMapper operation verification diagram



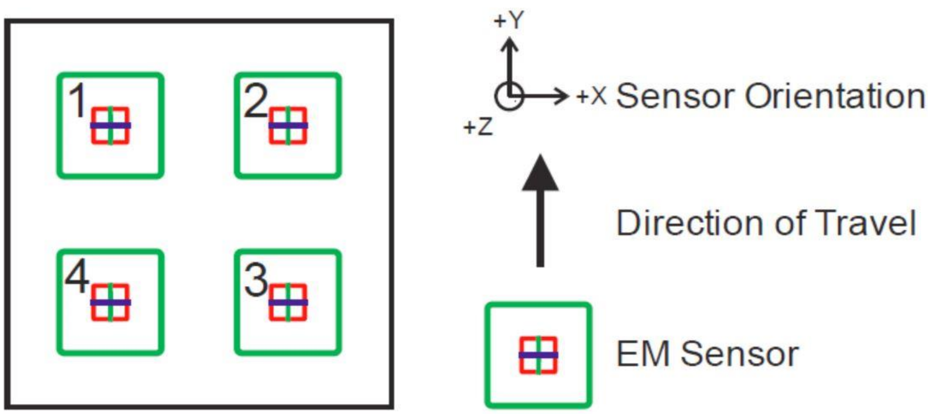
3.1.3 Photograph the MetalMapper System

Using a digital camera, photograph the assembled MetalMapper system for documentation of the MetalMapper assembly. Verify that the photographs depict the orientation of the MetalMapper relative to the tow vehicle and show the locations of the IMU sensor and GPS receiver.

3.2 Naval Research Laboratory TEMTADS MP 2x2

The TEMTADS is a person-portable advanced electromagnetic induction sensor designed for the detection and classification of buried metal objects. The sensor consists of four sensor elements arranged on 40-centimeter (cm) centers in a 2x2 array. Each sensor element consists of a 35-cm square transmit coil for target illumination with an 8-cm three-axis receive cube centered in the transmit coil. The transmitters are energized in sequence, and decay data are recorded with a 500 kHz sample rate after turn-off of the excitation pulse for up to 25 ms for each of the 12 (4 cubes with 3 axes each) receive channels. A schematic of the sensor coil configuration is shown on **Figure 9**.

Figure 9. Orientation of TEMTADS transmit coils and receive cubes



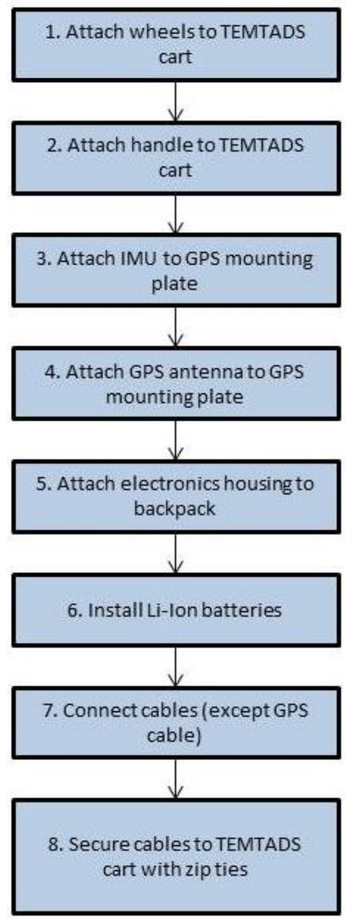
Positioning of the TEMTADS is accomplished using RTK GPS, and orientation is measured using a six-degree-of-freedom IMU. For proper functioning, the IMU must be mounted to the TEMTADS in the correct orientation. TEMTADS data acquisition is controlled from a tablet computer wirelessly-connected to the DAC, where acquired data are logged.

3.2.1 Assemble the TEMTADS

TEMTADS assembly operations are described in the TEMTADS User's Guide (NRL 2014). The detailed instructions contained in the manual should be followed precisely. The assembly steps are briefly described below and shown as a schematic overview on **Figure 10**.

1. Attach spacers and wheels to TEMTADS cart axels and secure with zip ties.
2. Attach handle to TEMTADS cart.
3. Attach the IMU to the GPS mounting plate.
4. Attach the GPS antenna to the GPS mounting plate.
5. Attach the electronics housing to the backpack using webbed belting material.
6. Place two lithium-ion (Li-Ion) batteries in the backpack battery compartment box.
7. Connect the transmitter data cable, transmitter power cable, receiver cable, CPU power cable, and IMU cable assembly to the interconnect panels on the data acquisition computer (DAC). The GPS cable will be connected after booting the computer.
8. Secure all cables to the cart with zip ties.

Figure 10. TEMTADS assembly overview



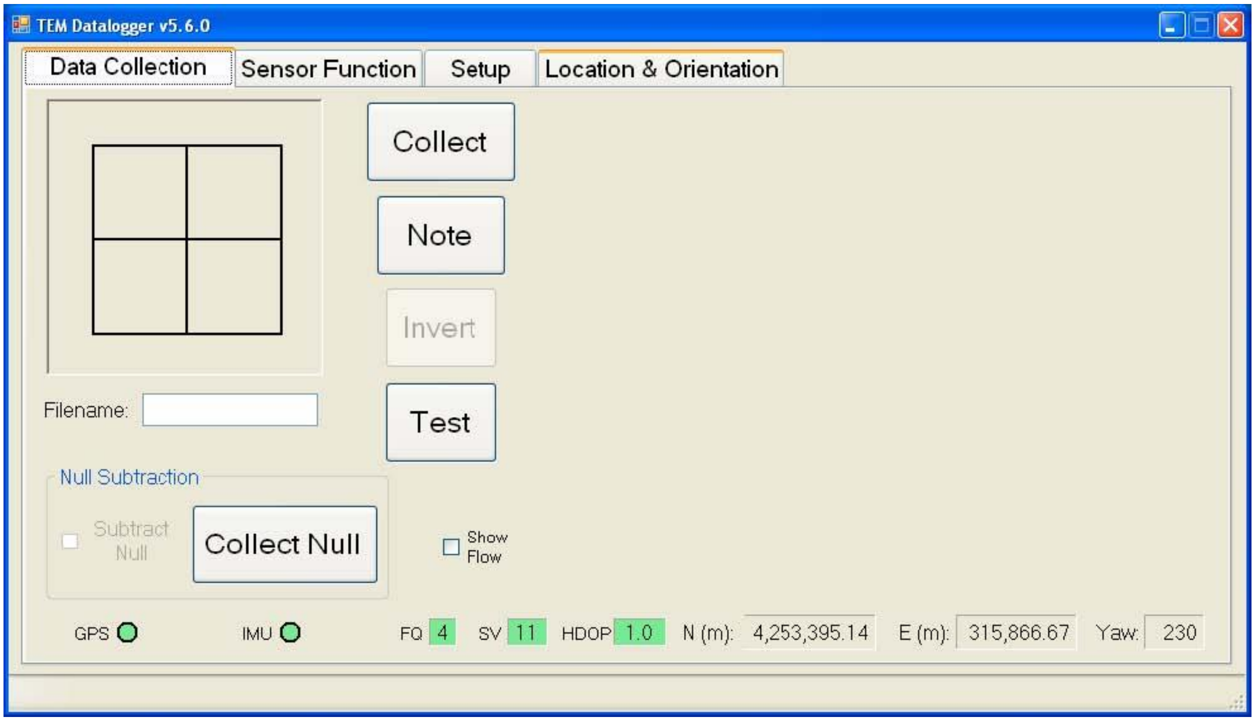
3.2.2 Verify TEMTADS Assembly

Successful data acquisition with the TEMTADS is dependent on proper assembly of the system. The following subsections describe the processes for verification of correct system assembly and reception of IMU, GPS, and data measurements at the DAC.

Prior to system assembly verification, confirm that the GPS cable is disconnected from the DAC. To begin assembly verification, turn the DAC main power switch to the "On" position. Power on the tablet computer and establish a remote desktop connection (RDC) to the DAC. After the RDC is established, connect the GPS cable to the DAC.

Start the *TEM DataLogger* application by selecting and holding the application icon on the desktop. When the contextual menu opens, select "Open". The *TEM DataLogger* interface is shown on **Figure 11**.

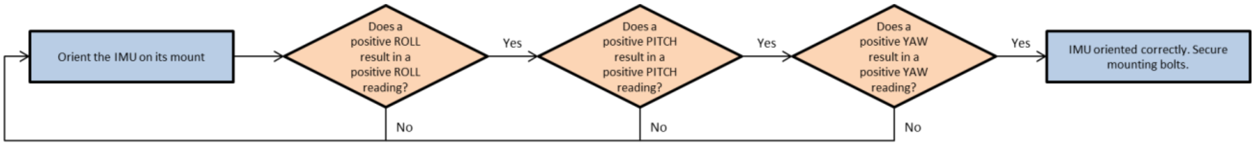
Figure 11. *TEM DataLogger* Interface



3.2.2.1 Verify Orientation of the IMU

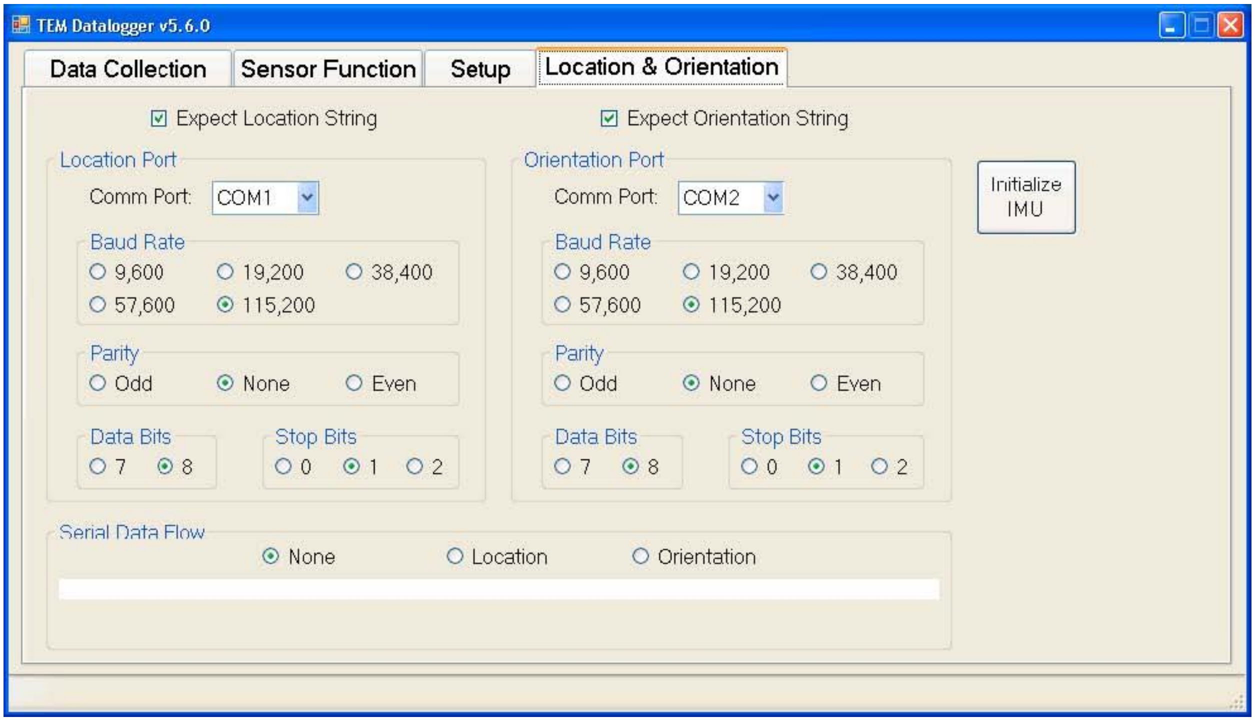
The procedure to verify the correct orientation of the IMU is shown on **Figure 12**, with detailed instructions following the figure.

Figure 12. Procedure for verification of IMU orientation



Data acquisition parameters related to location and orientation sensors are accessible from the "Location & Orientation" tab in the *TEM DataLogger* interface. To enable logging of IMU and GPS information, check the corresponding "Expect…" checkboxes, as shown on **Figure 13**.

Figure 13. ***TEM DataLogger*** **Location and Position Window**

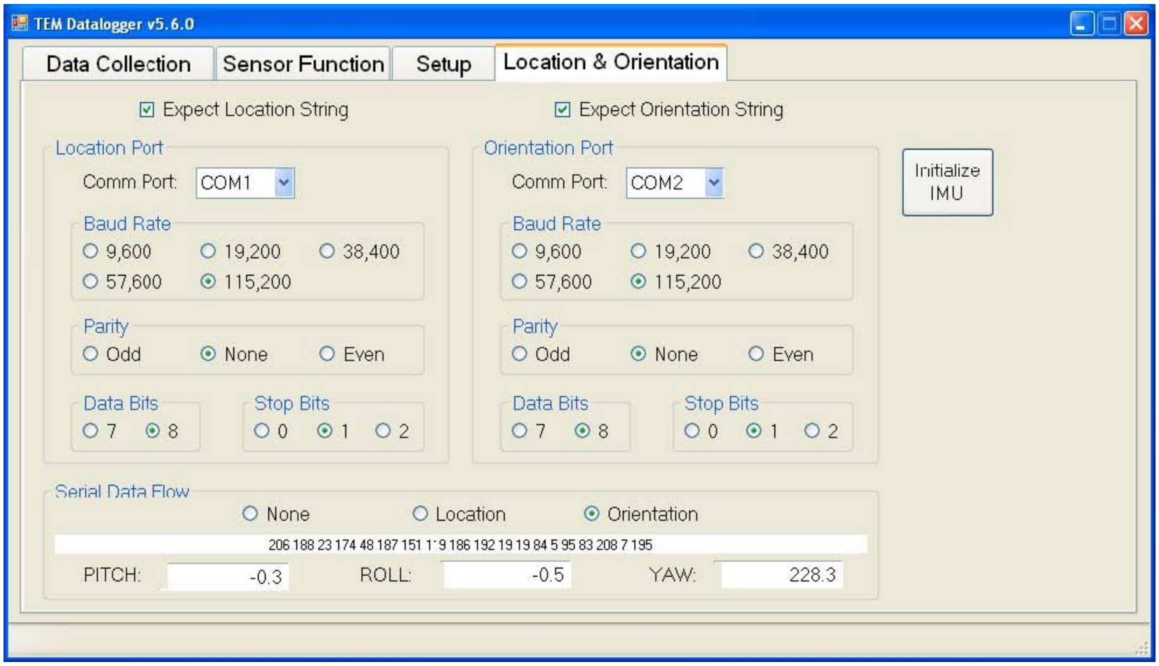


1. Standing behind the TEMTADS platform facing the direction of travel, rotate the system clockwise around the along-track axis to produce a positive ROLL as shown on **Figure 14**. Select the "Orientation" radio button in the "Location and Orientation" interface to observe the IMU orientation data flow, as shown on **Figure 15**. Verify that the data acquisition system measures a positive ROLL. If it does not, reorient the IMU on its mount and test again.

Figure 14. Positive ROLL, PITCH, and YAW rotations of the IMU

Positive ROLL Positive PITCH Positive YAW

Figure 15. ***TEM DataLogger* Orientation Display**

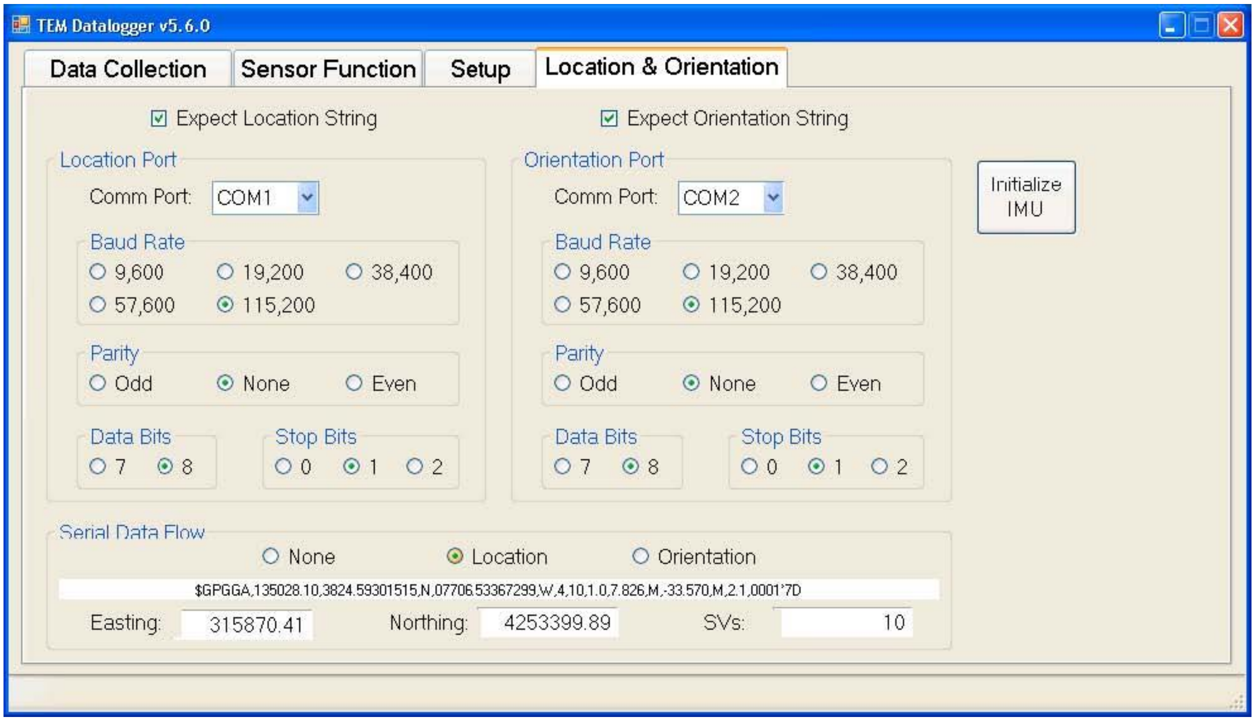


2. Standing on the side of the TEMTADS platform with the direction of travel to your right, rotate the system counter-clockwise around the cross-track axis to produce a positive PITCH as shown on **Figure 14**. Verify that the data acquisition system records a positive PITCH. If it does not, reorient the IMU on its mount and return to step 1.
3. Standing behind the TEMTADS platform facing the direction of travel, rotate the system clockwise around the vertical axis to produce a positive YAW as shown on **Figure 14**. Verify that the data acquisition system records a positive YAW. If it does not, reorient the IMU on its mount and return to step 1.

3.2.2.2 Verify Operation of the RTK GPS

Power on the GPS receiver and allow sufficient time to acquire a fixed position. Select the “Location” radio button in the “Location and Orientation” interface to observe the GPS positional data flow, as shown on **Figure 16**. Verify that GPS readings are being received at the DAC.

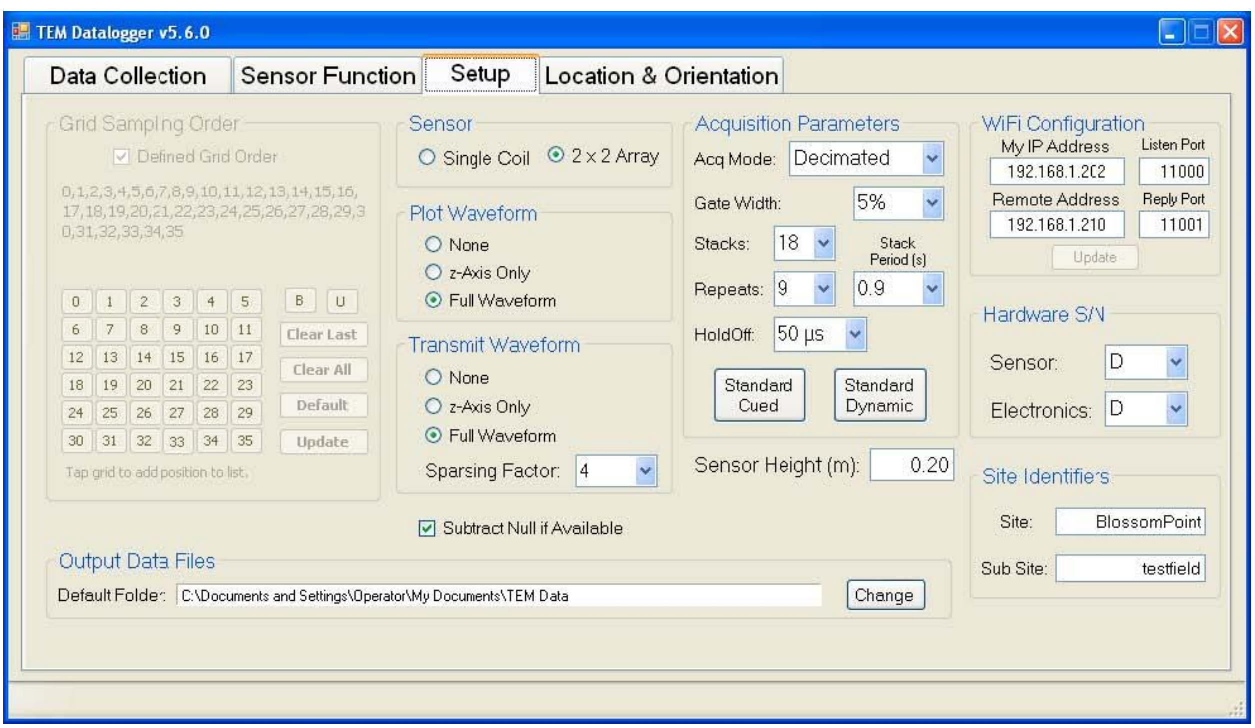
Figure 16. *TEM DataLogger* Location Display



3.2.2.3 Verify Data Acquisition Parameters

Verify that the project-specific data acquisition parameters are set in the TEMTADS data acquisition system by selecting the "Setup" tab in the *TEM DataLogger* interface, shown on **Figure 17**.

Figure 17. *TEM DataLogger* Setup Window



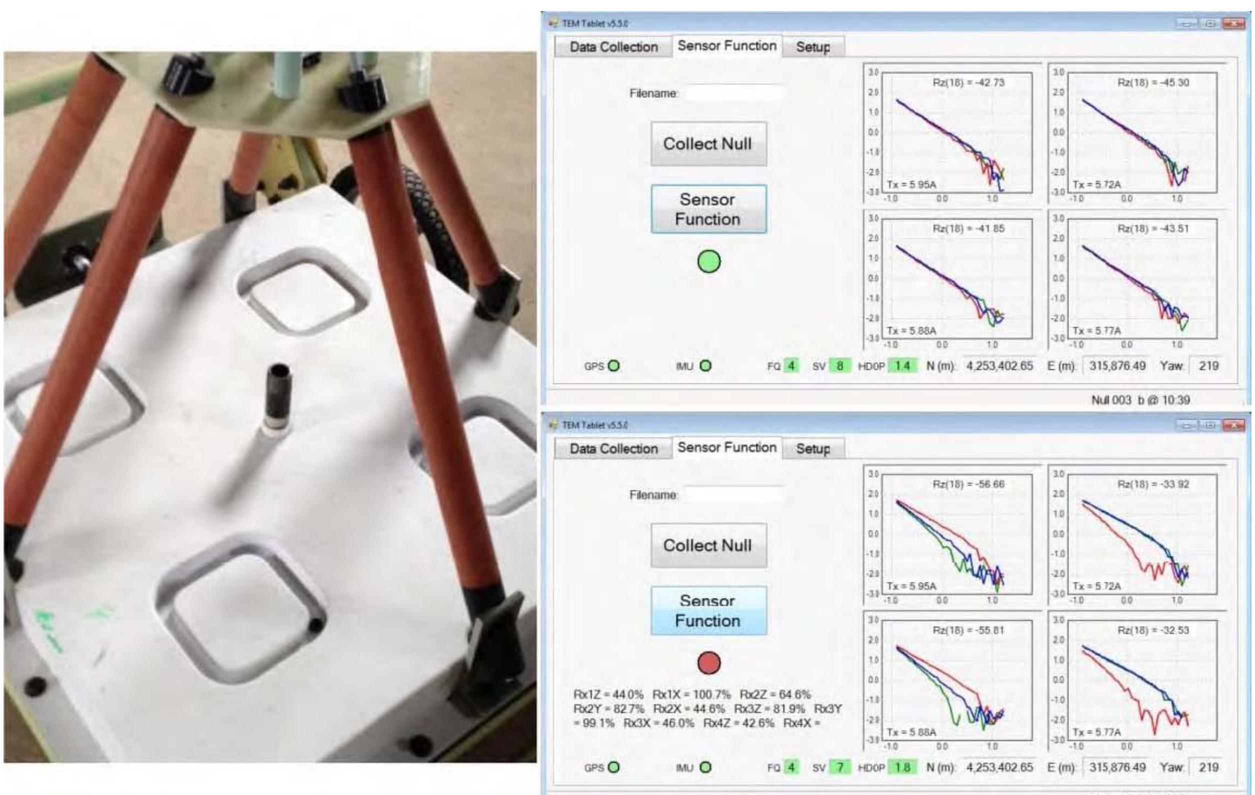
The default data collection parameters for dynamic TEMTADS data acquisition are: 0.033 seconds, 3 repeats, 1 stack, decimated decays, 50 µs holdoff time, with 20% gate widths. These parameters result in a 2.78 ms decay time, 19 time gates per decay, and a total data collection time of 133 milliseconds. The default data collection parameters for cued TEMTADS data acquisition are: 0.9 seconds, 9 repeats, 18 stacks, decimated decays, 50 µs holdoff time, with 5% gate widths. These parameters result in a 25 ms decay time, 122 time gates per decay, and a total data collection time of 1 minute. If the data acquisition parameters differ from the default parameters for a specific advanced geophysical classification activity, the modified parameters will be defined in the Site-Specific Work Plan for that activity.

3.2.2.4 Verify TEMTADS Operation

To verify operation of the TEMTADS, open the "Sensor Function" tab in the data acquisition interface and perform a sensor function test as follows. If the "Sensor Function" tab is not available, follow the alternate TEMTADS operation verification process below.

Position the TEMTADS sensor in a location known to be clear of buried metal, such as the clear position in the IVS. Record a background measurement from the "Sensor Function" window of the data acquisition software. Without moving the sensor, mount the schedule 80 small industry standard object (ISO80) test item in the depression on the top of the TEMTADS sensor platform as shown on **Figure 18**. Record the sensor function measurement. If the results agree with the reference values, a green LED is displayed. If they do not agree, a red LED is displayed and a summary of the incorrect results is displayed.

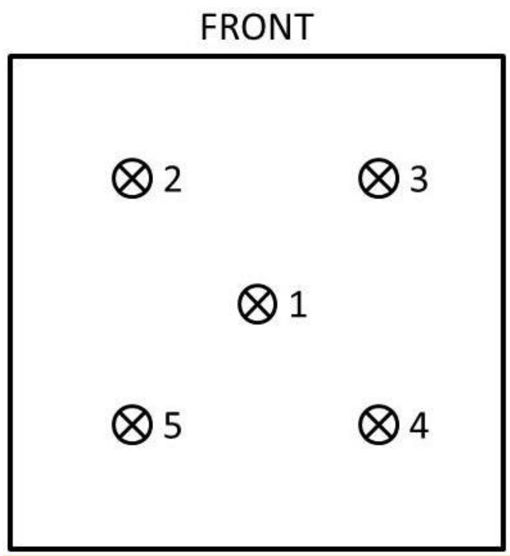
Figure 18. TEMTADS Sensor Function Test



Alternatively, if no reference response exists for the combination of hardware and data acquisition parameters being used, verify operation of the TEMTADS by conducting a system function test as follows.

Center the sensor platform over the blank location in the IVS and record a background measurement, verifying that the transmit current is within the expected range, as specified in Table 22 of the AGCMR-QAPP. Next, center the sensor platform over an IVS item with the IVS item directly under measurement position 1, as shown on **Figure 19**, and record a cued measurement. Position the sensor platform with the IVS item directly under measurement positions 2 through 5, recording a cued measurement at each position. Invert each of the five data sets and verify that the modeled location is under the correct quadrant of the TEMTADS sensor array and that the resulting polarizability decay curves match the library values for the IVS item with a match metric in accordance with that specified in Table 22 of the AGCMR-QAPP.

Figure 19. TEMTADS operation verification diagram



3.2.3 Photograph the TEMTADS System

Using a digital camera, photograph the assembled TEMTADS system for documentation of the TEMTADS assembly. Verify that the photographs depict the locations of the IMU sensor and GPS receiver.

3.3 Geometrics MetalMapper 2x2

The MetalMapper 2x2 is the successor to the MetalMapper and features a smaller, lighter platform that is easier to deploy as a person-portable advanced classification system. The design of the MetalMapper 2x2 is based on the NRL TEMTADS but utilizes upgraded electronics and cabling to provide a more reliable and rugged system. The MetalMapper 2x2 can be deployed as a person-portable or vehicle-towed system. The data acquisition software operates on a tablet PC or laptop, and data files are written in a self-describing open-source HDF5 format that can be seamlessly integrated with recent versions of the Geosoft Oasis Montaj UX-Analyze data inversion and classification package.

The MetalMapper 2x2 uses time domain electromagnetic (TDEM) principles to induce electrical currents in buried metallic objects and then measures the effects of those currents in receivers on the surface. It is comprised of four transmitter coils oriented in a 2 by 2 square. Each transmitter coil is approximately 35 cm by 35 cm in size. Located in the center of each transmitter coil is a 10 cm by 10 cm x 10 cm receiver cube, each one containing three orthogonal coils to measure the fields resulting in 12 different receiver coils. The receiver coils are oriented in 3-dimensions. The center-to-center distance of each receiver cube is approximately 40 cm. The transmitter coils are powered using a bi-polar half duty cycle, and the time decays of the subsurface currents (transients) are measured during the time that the transmitter coils are off. The sensors are mounted on a platform that is typically 20 cm above the ground surface. A GPS and IMU are mounted on a tower centered above the sensor platform. The transmitter electronics and batteries are mounted on a backpack carried by the operator. The system is operated from a tablet computer running the MetalMapper software. A cartoon of the MetalMapper 2x2 system is shown on **Figure 20**, and a schematic of the sensor coil configuration is shown on **Figure 21**.

Figure 20. MetalMapper 2x2 sensor platform with top cover removed and fully assembled

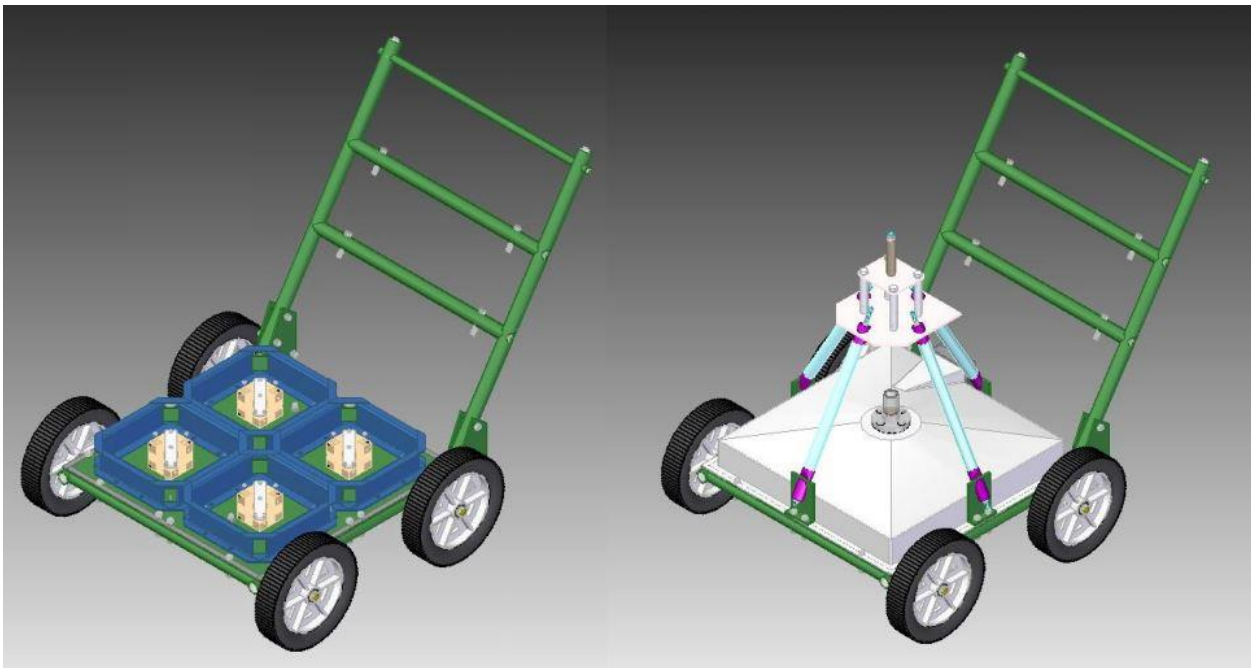
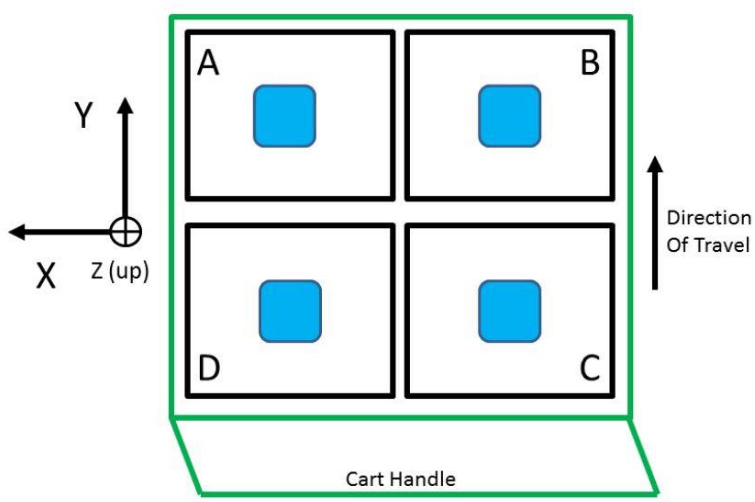


Figure 21. Orientation of MetalMapper 2x2 transmit coils and receive cubes



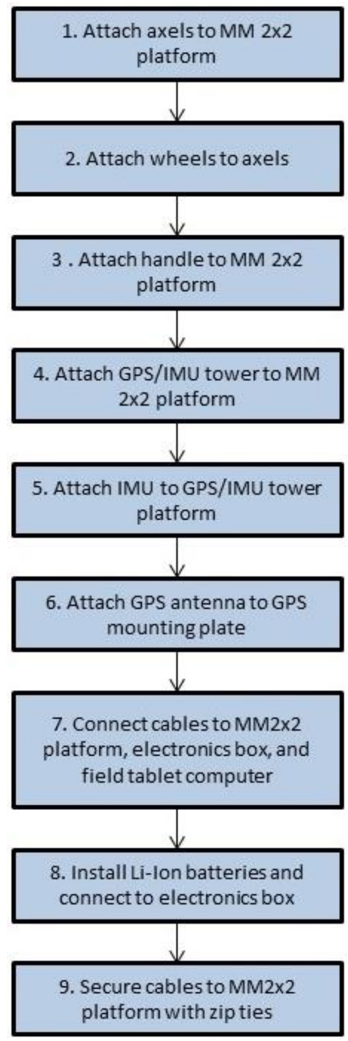
Positioning of the MetalMapper 2x2 is accomplished using RTK GPS, and orientation is measured using a six-degree-of-freedom IMU. To ensure correct orientation, the IMU is fixed inside a box mounted to the GPS antenna tower.

3.3.1 Assemble the MetalMapper 2x2

MetalMapper 2x2 assembly operations are described in the MetalMapper 2x2 Operations Manual (Geometrics 2017). The detailed instructions contained in the manual should be followed precisely. The assembly steps are briefly described below and shown as a schematic overview on **Figure 22**.

1. Attach axels to MetalMapper 2x2 platform.
2. Attach spacers and wheels to axels and secure with zip ties.
3. Attach handle to MetalMapper 2x2 platform.
4. Attach the GPS/IMU tower to MetalMapper 2x2 platform.
5. Attach the IMU to the underside of the GPS/IMU tower platform.
6. Attach the GPS antenna to the GPS mounting plate.
7. Connect the transmitter and receiver cables to the electronics box on the backpack and the cable junction box on the rear of the MetalMapper 2x2 platform. Connect the GPS serial cable to the DB-9 serial port on the IMU box. Connect the IMU cable to the round connector on the IMU box. Connect ruggedized Ethernet cable to the RJ45 connectors on the side of the electronics box and the field tablet computer.
8. Place the Li-Ion battery pack in the backpack battery compartment pouch and connect the battery power cable to the electronics box.
9. Secure all cables to the cart with zip ties.

Figure 22. MetalMapper 2x2 assembly overview

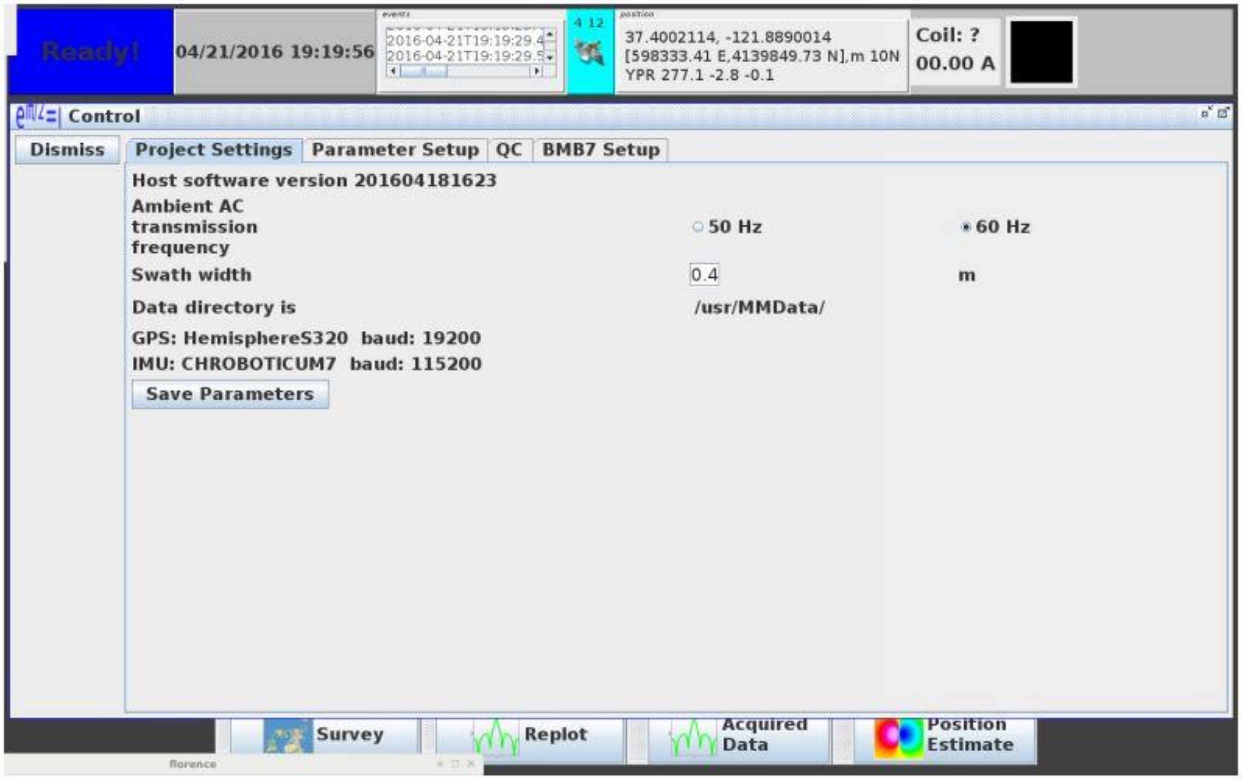


3.3.2 Verify MetalMapper 2x2 Assembly

Successful data acquisition with the MetalMapper 2x2 is dependent on proper assembly of the system. The following subsections describe the processes for verification of correct system assembly and reception of IMU, GPS, and data measurements at the DAC.

To begin assembly verification, power on the tablet computer (the electronics box will start up upon connecting the batter power cable) and launch the *MetalMapper 2x2* software by clicking the MetalMapper.sh icon on the desktop. After the software connects to the electronics and the software and hardware are successfully communicating, the *MetalMapper 2x2* interface will display “Ready” in blue, as shown on **Figure 23**.

Figure 23. *MetalMapper 2x2* Interface

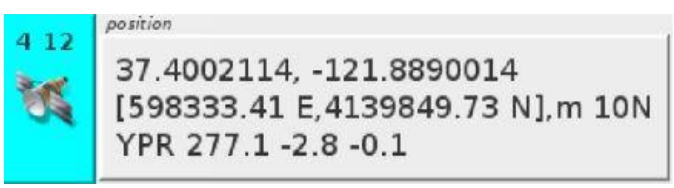


A status bar is always shown at the top of the *MetalMapper 2x2* interface, displaying, from left to right, the date and time, the event log, GPS status, and position and IMU information.

3.3.2.1 Verify Operation of the RTK GPS

Power on the GPS receiver and allow sufficient time to acquire a fixed position. The GPS status indicator displays the GPS status value followed by the quantity of satellites from which the position information is derived, as shown on **Figure 24**. A GPS quality status of 4, accompanied by a picture of a satellite, indicates GPS measurements with fixed RTK correction. A GPS quality status of 2 indicates GPS measurements without RTK correction. Click on the GPS status window to display the entire GPS data string. Verify that fixed RTK GPS readings are being received by the software and that GPS positions are updating.

Figure 24. *MetalMapper 2x2* GPS Status and Location Display



3.3.2.2 Verify Operation of the IMU

YAW, PITCH, and ROLL information from the IMU are displayed on the *MetalMapper 2x2* location display, as shown on **Figure 24**. The YAW is corrected for magnetic declination, which is automatically calculated through a magnetic declination look-up table when the software receives location information from the GPS receiver.

Standing behind the MetalMapper 2x2 platform facing the direction of travel, rotate the system to the right (clock-wise around the vertical axis) to produce a positive YAW, as shown on **Figure 25**. Verify that the first value (Y) on the *MetalMapper 2x2* location display measures a positive YAW change.

Figure 25. Positive YAW, PITCH, and ROLL Rotations

Standing behind the MetalMapper 2x2 platform facing the direction of travel, tilt the front of the system up to produce a positive PITCH, as shown on **Figure 25**. Verify that the second value (P) on the *MetalMapper 2x2* location display measures a positive PITCH change.

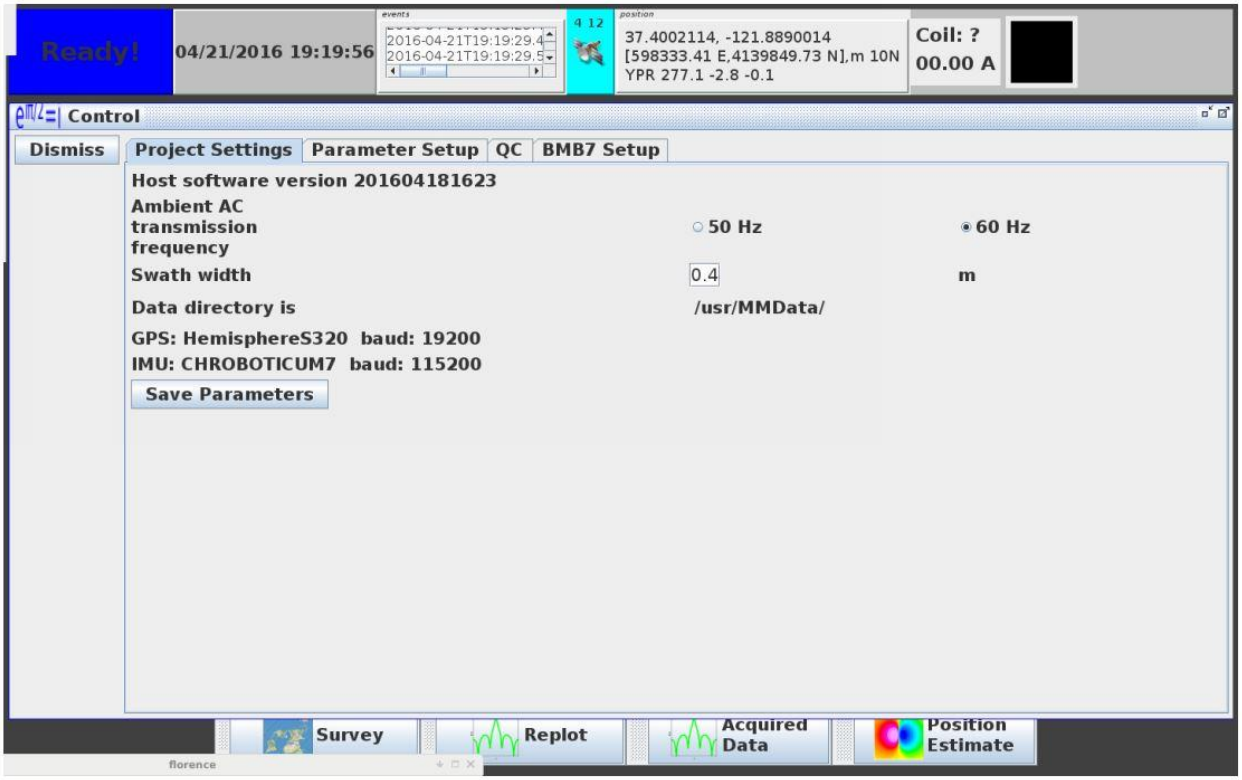
Standing behind the MetalMapper 2x2 platform facing the direction of travel, tilt the system to the right (clock-wise around the along-track axis) to produce a positive ROLL, as shown on **Figure 25**. Verify that the third value (R) on the *MetalMapper 2x2* location display measures a positive ROLL change.

3.3.2.3 Verify Data Acquisition Parameters

Open the Project Settings tab in the *MetalMapper 2x2* software Control window to verify the following system parameters, as shown on **Figure 26**:

- Ambient AC Transmission Frequency: Select 60 Hz frequency to filter powerline electrical interference.
- Swath width: Enter 0.4 meters for the swath width during dynamic data acquisition.
- Data directory: Set the path for the storing acquired data on the computer. Each project will create a new directory under the main directory, and each GeoID will have its own subdirectory within the project directory.
- GPS: Verify that GPS information, including baud rate, is correct. Changes may be made in the “EquipmentConfiguration.xml” file.
- IMU: Verify that IMU information, including baud rate, is correct. Changes may be made in the “EquipmentConfiguration.xml” file. The standard MetalMapper 2x2 utilizes a Microstrain 3DM-GX4-25 IMU that updates at 115200 baud.

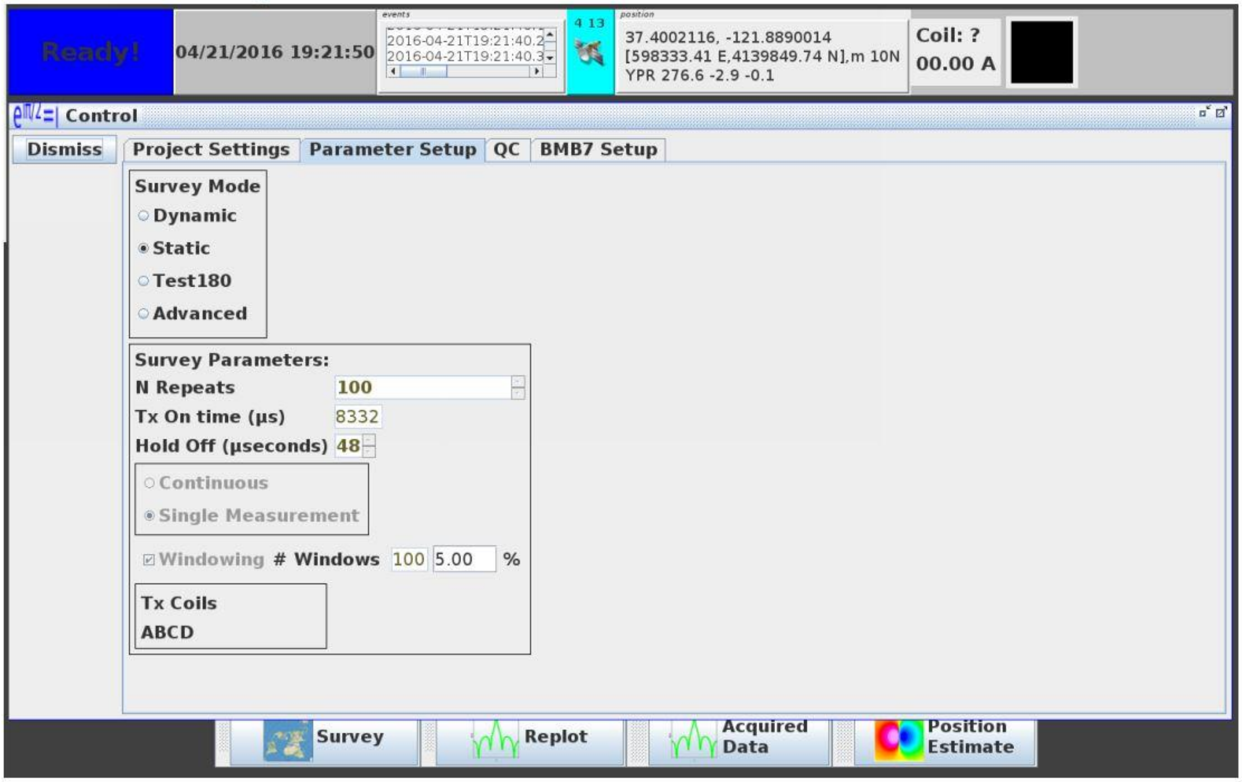
Figure 26. ***MetalMapper 2x2*** **Project Settings Interface**



Open the Parameter Setup tab in the *MetalMapper 2x2* software Control window to verify the survey mode, as shown on **Figure 27**. In most instances, either the Dynamic or Static survey mode should be selected. These survey modes include default parameters that cannot be changed by the operator. The Test180 mode is used for instrument troubleshooting and should not be selected during regular operation. The Advanced Measurement mode allows custom selection of data acquisition parameters and should be used only with the approval of the Project Geophysicist. If the data acquisition parameters differ from the default parameters for a specific advanced geophysical classification activity, the modified parameters will be defined in the Site-Specific Work Plan for that activity. The following parameters are displayed on the Parameter Setup interface:

- N Repeats: Number of repeated measurements stacked during each acquisition.
- Tx On Time: Time (in microseconds) that current is sent through the transmitter.
- Hold Off: Time (in microseconds) that the receivers record after the transmitter is turned off.
- # Windows: Percentage by which each successive window grows during the windowing of the data.

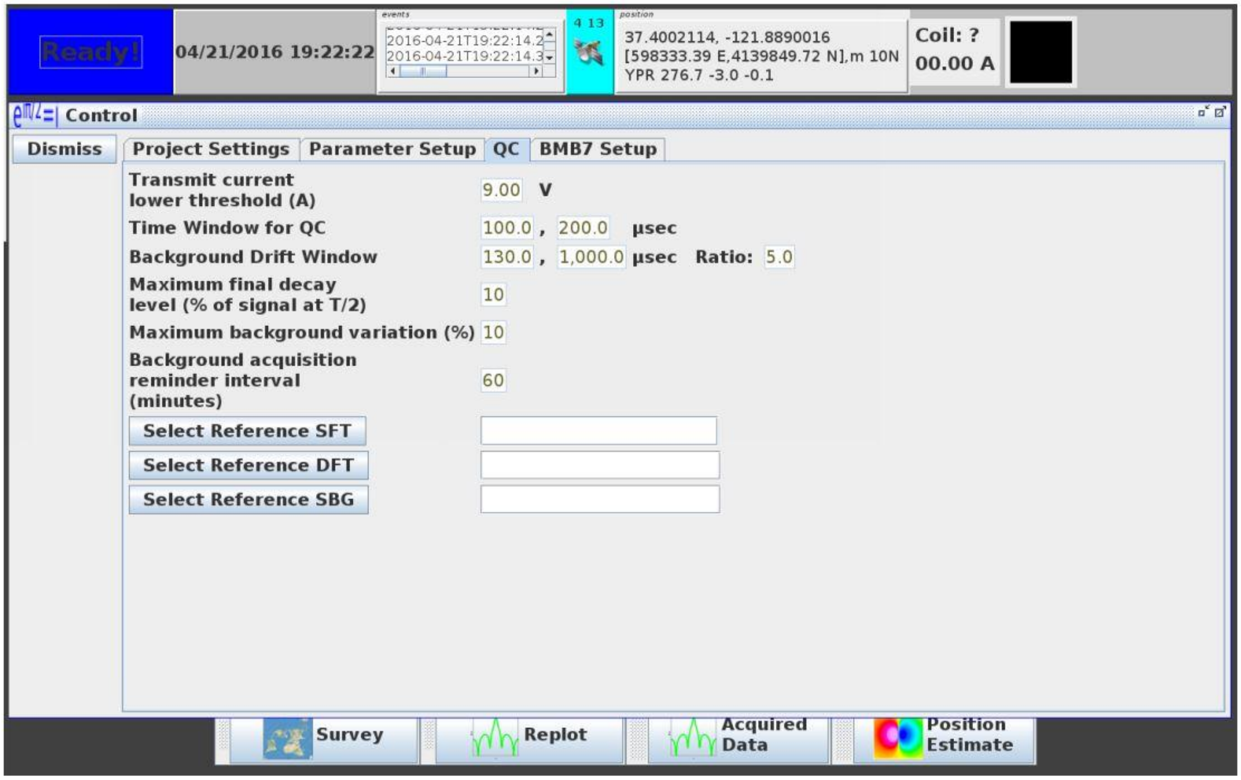
Figure 27. *MetalMapper 2x2* Parameter Setup Interface



Open the QC tab in the *MetalMapper 2x2* software Control window to verify the following QC settings and automated system alerts, as shown on **Figure 28**:

- Transmit current lower threshold (A): Transmit current level where the operator will be warned about low battery level. Lithium batteries display the same voltage throughout their discharge cycle, so battery level is monitored by current.
- Time Window for QC: Time window (in microseconds) used to compare Z-component amplitudes during the instrument function tests.
- Background Drift Window: Time window (in microseconds) used to compare Z-component amplitudes for drift from reference background measurement. The ratio is the allowed change in background amplitude before a warning is displayed.
- Background acquisition reminder interval: Time (in minutes) at which the software will remind the operator to acquire a background measurement.
- Select Reference SFT/DFT/SBG: Locations of static function test (SFT), dynamic function test (DFT), and static background (SBG) reference data files with which to compare daily function test results (see Section 3.3.2.4).

Figure 28. ***MetalMapper 2x2*** **QC Settings Interface**



3.3.2.4 Verify MetalMapper 2x2 Operation

Prior to data acquisition, perform a SFT or DFT in an area free of nearby metallic objects to verify system operation. The measured function test data are directly compared to the test results of a known reference standard measurement. The reference measurement is performed on a serialized ISO reference standard at the factory under controlled conditions and represents the ideal instrument response. The static and dynamic reference measurements are stored in the master SFT and DFT files in the following directory:

/usr/MMData/InstrumentFunctionTest/

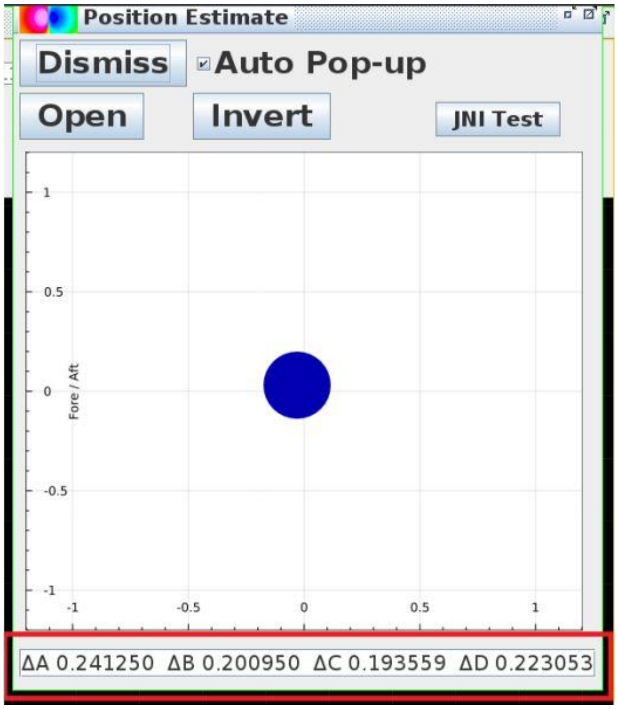
The “Time Window for QC” settings in the QC tab specify the time gates for the acquired measurements that will be compared to the known reference measurement (**Figure 28**). The MetalMapper 2x2 SFT and DFT routines will compare the amplitude of the signals on each channel within the selected time gates. If the measured amplitudes are within 20% of the known reference amplitudes for each channel, the instrument will pass the function test. Values greater than 20% difference will cause the sensor function test to fail.

To perform a SFT, select “Static Mode” in the Parameter Setup interface and open the Survey window. Perform a static background measurement (SBG) in an area free of known metallic interference. The SFT measurement requires a SBG measurement immediately prior to the SFT. Immediately after acquiring the SBG, place the serialized ISO test object in its holder centered directly above the sensor platform, with the etched Geometrics logo up and forward, as shown on **Figure 29**. It is important the serialized ISO is well-seated in the holder. A tilted or misplaced ISO will result in SFT failure. Select “Functional Test” as the measurement type and acquire a measurement. The software will display a warning if the known reference file has not been loaded in the QC tab and will indicate if the completed test passes or fails.

Figure 29. ***MetalMapper 2x2*** **Function Test with Serialized Reference Standard**

After the functional test measurement has been acquired, the measured data will be compared to the data in the known reference file. The results of the comparison will be displayed as a delta value for each receiver cube (A, B, C, D) in the Position Estimate window, as shown on **Figure 30**. The Position Estimate of the ISO item should be centered at 0,0. A successful function test will display delta values for each receiver cube below 2.000. If the delta value for any receiver cube is greater than 2.000, a failure notification will appear, and the function test must be repeated. Prior to repeating the function test, verify that the correct SFT reference file is selected in the QC menu, the ISO reference standard is properly placed in the holder, and the background and function test measurements are acquired in the same location free of known metallic interference. A new SFT file will be created in the GeoID folder with the file increment increased by 01. If, after troubleshooting these issues, the instrument continues to fail the SFT, contact the factory for more information.

Figure 30. ***MetalMapper 2x2*** **Function Test Result with Successful Delta Values**



To perform a DFT, select “Dynamic Mode” in the Parameter Setup interface and open the Survey window. Perform dynamic background measurement (DBG) in an area free of known metallic interference for approximately 20 seconds. Immediately after acquiring the DBG, place the serialized ISO test object in its holder centered directly above the sensor platform, with the etched Geometrics logo up and forward, as shown on **Figure 29**. It is important the serialized ISO is well-seated in the holder. A tilted or misplaced ISO will result in DFT failure. Select “Functional Test” as the measurement type and acquire a measurement for approximately 20 seconds. The software will display a warning if the known reference file has not been loaded in the QC tab and will indicate if the completed test passes or fails.

If the DFT fails, follow the troubleshooting steps previously described for an SFT failure.

3.3.3 Photograph the MetalMapper 2x2 System

Using a digital camera, photograph the assembled MetalMapper 2x2 system for documentation of the MetalMapper 2x2 assembly. Verify that the photographs depict the locations of the IMU sensor and GPS receiver.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data consists of the MetalMapper Manual (Geometrics 2011), which is available for download from http://www.geometrics.com/files/metalmapper_manual_beta1.pdf., the TEMTADS User’s Guide (NRL 2014), or the MetalMapper 2x2 Operations Manual (Geometrics 2017).

4.2 Output Data

Output data consist of the five MetalMapper or TEMTADS static verification measurements over the IVS item described in Section 3.1.2.5 and Section 3.2.2.4 or the TEMTADS or MetalMapper 2x2 function test results described in Section 3.3, photographs of the assembled sensor system described in Section 3.1.3, Section 3.2.3, and Section 3.3.2.4, and the completed Advanced EMI Sensor Assembly Quality Control (QC) Checklist in Attachment 1 of this SOP. Data files from the five static verification measurements over the IVS item or the MetalMapper 2x2 function test measurements will be saved along with the inversion results and library match metric for each of the measurements. The Advanced EMI Sensor Assembly QC Checklist will be completed, signed, and filed with the assembled system photographs as documentation of correct system assembly.

5 Quality Control

This definable feature of work is completed only during the preparatory QC phase, and only preparatory QC checks will therefore be performed. QC consists of performing the inspections listed on the Preparatory Advanced EMI Sensor Assembly Checklist that is included as Attachment 1 to this SOP. The checklist will be completed by the Data Acquisition Geophysicist and reviewed by the QC Geophysicist. The QC Geophysicist will document the implementation of this SOP in the Daily QC Report.

5.1 Measurement Performance Criteria (MPC)

The measurement quality objectives (MQO) for this task, as presented in Worksheet 22 of the AGCMR-QAPP, include verification of correct system assembly as shown on the completed Advanced EMI Sensor Assembly Checklist and by an IVS item library match metric and modeled location within the measurement performance criteria MPC for each of the five sets of inverted polarizability decay curves from the static verification measurements over the IVS item described in Section 3.1.2.5 and Section 3.2.2.4 and MetalMapper 2x2 function tests described in Section 3.3.2.4. Advanced EMI sensor system performance will not be verified on the instrument verification strip (IVS) (SOP AGCMR-02) until documentation that the MQO for system assembly have been completed as described below.

6 Reporting

Achievement of the advanced EMI system assembly MPC, detailed in Worksheet 22 of the AGCMR-QAPP, will be documented by the Data Acquisition Geophysicist by completion of the Advanced EMI Sensor Assembly Checklist in Attachment 1 to this SOP and will be verified by the QC Geophysicist in the Daily QC Report.

The delivered data package for the assembled and tested advanced EMI system will include the following:

- A brief description of the assembly and test process along with the photographs taken in Section 3.1.3, Section 3.2.3, or Section 3.3.3 included in the IVS letter report
- The completed Advanced EMI Sensor Assembly Checklist signed by the Data Acquisition Geophysicist verifying the assembly and orientation tests described above
- The inversion results from the five static verification measurements over the IVS item overlain over the library polarizabilities for the IVS item
- A plot of the modeled locations of each of the five static verification measurements over the IVS item
- Verification documentation in the Daily QC Report

7 References

Geometrics, 2011. *MetalMapper Manual, Preliminary*. July 10. Available for download from http://www.geometrics.com/files/metalmapper_manual_beta1.pdf.

Geometrics, 2017. *MetalMapper 2x2 Operations Manual, Rev 1.01*.

U.S. Naval Research Laboratory, 2014. *User's Guide, TEMTADS MP 2x2 Cart, v2.00*. May 27.

Attachment 1

Preparatory Advanced EMI Sensor Assembly Checklist

Preparatory Advanced EMI Sensor Assembly Checklist

This checklist is to be completed by the Data Acquisition Geophysicist during assembly and initial testing of the advanced EMI sensor and reviewed and verified by the QC Geophysicist.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist Initials
1. Qualifications	Are the qualifications of the Data Acquisition Geophysicist and the Lead Data Processor in accordance with AGCMR-QAPP Worksheet 7?		
2. Assembly	Has the advanced EMI sensor been assembled in accordance with the published instructions and in the sequence specified in Section 3.1.1, Section 3.2.1, or Section 3.3.1?		
3. Assembly: Transmit coil verification	Has the orientation of the transmit coils been verified to be correct (Section 3.2.1 – for MetalMapper system only)?		
4. Testing: IMU orientation verification	Have the procedure and tests for verification of the IMU orientation been completed (Section 3.1.2.2, Section 3.2.2.1, or Section 3.3.2.1)?		
5. Testing: GPS verification	Have the procedure and tests for verification of the GPS assembly been completed (Section 3.1.2.3, Section 3.2.2.2, or Section 3.3.2.2)?		
6. Testing: Data acquisition parameters verification	Have data acquisition parameters been verified (Section 3.1.2.4, Section 3.2.2.3, or Section 3.3.2.3)?		
7. Testing: ISO-80 placement	Has an IVS item been used for testing and was it placed as specified in Section 3.1.2.5, Section 3.2.2.4, or Section 3.3.2.4?		
8. Testing: System functioning	Has the advanced EMI system been tested over the IVS item in all five locations (Section 3.1.2.5, Section 3.2.2.4)? Record the library match metric and correct modeled location for each of the five inversions below: 1. ______________________________ 2. ______________________________ 3. ______________________________ 4. ______________________________ 5. ______________________________ Alternatively, has a TEMTADS sensor function test been conducted as specified in Section 3.2.2.4 or a MetalMapper 2x2 sensor function test (Section 3.3.2.4)?		
9. Photograph the assembled system	Have photographs of the assembled advanced EMI system been taken (Section 3.1.3, Section 3.2.3, or Section 3.3.3)?		
10. MPC documentation	Have the MPC for advanced EMI system assembly been achieved in accordance with AGCMR-QAPP Worksheet 22?		

Data Acquisition Geophysicist: ____ Date: _________________

Lead Data Processor: ____ Date: _________________

STANDARD OPERATING PROCEDURE AGCMR-02

Advanced EMI Sensor Instrument Verification Strip

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when verifying the operation of an advanced electromagnetic induction (EMI) sensor system prior to and during site surveys. The instrument verification strip (IVS) is constructed of buried industry standard objects (ISO). During the IVS process, the advanced EMI sensor system measures the response of each item in the IVS, and these responses are subsequently compared to a library of expected responses to verify and document proper functioning of the system. This SOP describes Geometrics MetalMapper, Geometrics MetalMapper 2x2, and U.S Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS) IVS operations. If other advanced EMI sensors are selected for use, this SOP will be updated to include IVS details for those systems.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Advanced EMI sensor coupled with a real-time kinematic (RTK) global positioning system (GPS) and inertial measurement unit (IMU) for orientation measurements
- Two industry standard objects (ISO) to construct the IVS
- Hand tools, including shovels, pike axes, breaker bars, etc. to construct the IVS
- Data processing computer suitable for and equipped to run the UX-Analyze Advanced module of Geosoft's Oasis Montaj geophysical processing environment

2.1 Personnel and Qualifications

The following individuals will be involved in verifying correct operation of the advanced EMI sensor system at the IVS:

- Data Acquisition Geophysicist
- Lead Data Processor
- QC Geophysicist
- UXO Personnel[1]

The qualifications for the Data Acquisition Geophysicist and the Lead Data Processor are listed in Worksheet 7 of the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP).

3 Procedures and Guidelines

3.1 Advanced EMI Sensor Systems

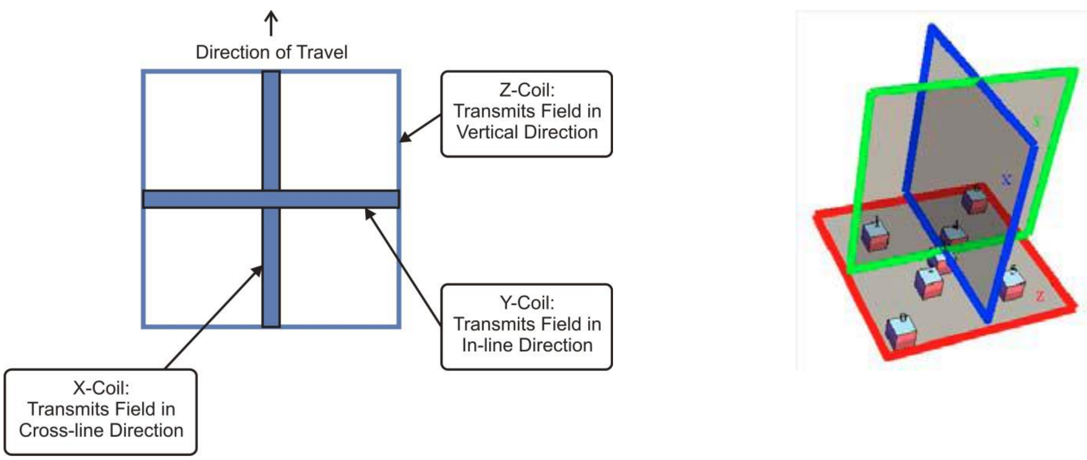
3.2.1 Geometrics MetalMapper

The Geometrics MetalMapper is an advanced EMI sensor designed for the detection and classification of buried metal objects. The sensor consists of three orthogonal 1-meter by 1-meter transmit coils for target illumination and seven, three-axis receive cubes. It measures the decay curve up to 25 milliseconds (ms)

[1] UXO personnel will be responsible for overall daily site access and safety aspects of the project, compiling health and safety documents, conducting daily safety briefings, and performing munitions and explosives of concern avoidance, as needed, in the field. Information on the specific qualifications for various UXO personnel support roles can be found in the project Health and Safety Plan.

after the transmitters are turned off with each of the 21 receiver coils, resulting in the recording of 63 different EM transients. The orientation of the three transmit coils and seven receive cubes is shown on **Figure 1**. The MetalMapper sampling parameters are programmable and therefore flexible to meet site-specific objectives. The decay curve of induced responses is typically measured to 8 ms after the transmitters are turned off for each of the 21 receiver coils, but a 25 ms decay curve may be used for individual advanced geophysical classification projects, depending on site-specific objectives. Data acquisition parameters will be defined in the Site-Specific Work Plan for each advanced geophysical classification activity.

Figure 1. Orientation of MetalMapper transmit coils and receive cubes

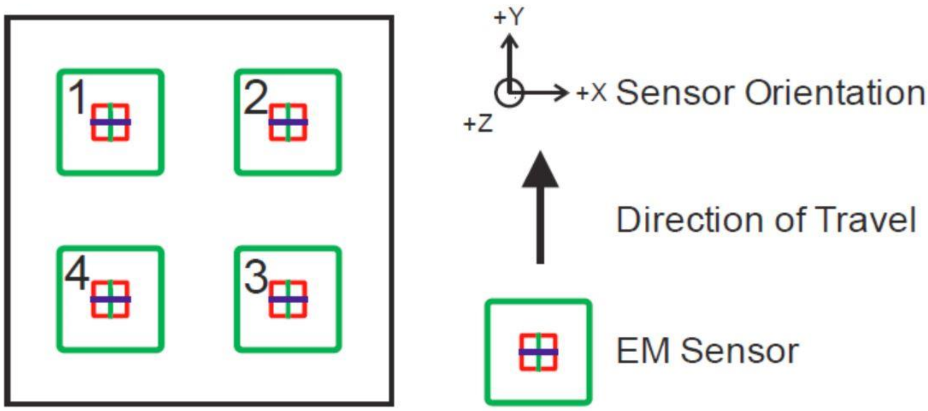


Positioning of the MetalMapper is accomplished using RTK GPS, and orientation is measured using a six-degree-of-freedom inertial measurement unit (IMU). Combining the sensor orientation and location measurements in this manner typically results in derived target locations within 6 inches (15 centimeters) of the ground truth.

3.2.2 Naval Research Laboratory TEMTADS MP 2x2

The TEMTADS is a person-portable advanced electromagnetic induction sensor designed for the detection and classification of buried metal objects. The sensor consists of four sensor elements arranged on 40-centimeter (cm) centers in a 2x2 array. Each sensor element consists of a 35-cm square transmit coil for target illumination with an 8-cm three-axis receive cube centered in the transmit coil. The transmitters are energized in sequence, and decay data are recorded with a 500 kHz sample rate after turn-off of the excitation pulse for up to 25 ms for each of the 12 (4 cubes with 3 axes each) receive channels. A schematic of the sensor coil configuration is shown on **Figure 2**.

Figure 2. Orientation of TEMTADS transmit coils and receive cubes



Positioning of the TEMTADS is accomplished using RTK GPS, and orientation is measured using a six-degree-of-freedom IMU. For proper functioning, the IMU must be mounted to the TEMTADS in the correct orientation. TEMTADS data acquisition is controlled from a tablet computer wirelessly-connected to the DAC, where acquired data are logged.

3.2.3 Geometrics MetalMapper 2x2

The MetalMapper 2x2 is the successor to the MetalMapper and features a smaller, lighter platform that is easier to deploy as a person-portable advanced classification system. The design of the MetalMapper 2x2 is based on the NRL TEMTADS but utilizes upgraded electronics and cabling to provide a more reliable and rugged system. The MetalMapper 2x2 can be deployed as a portable-portable or vehicle-towed system. The data acquisition software operates on a tablet PC or laptop, and data files are written in a self-describing open-source HDF5 format that can be seamlessly integrated with recent versions of the Geosoft Oasis Montaj UX-Analyze data inversion and classification package.

The MetalMapper 2x2 uses time domain electromagnetic (TDEM) principles to induce electrical currents in buried metallic objects and then measures the effects of those currents in receivers on the surface. It is comprised of four transmitter coils oriented in a 2 by 2 square. Each transmitter coil is approximately 35 cm by 35 cm in size. Located in the center of each transmitter coil is a 10 cm by 10 cm x 10 cm receiver cube, each one containing three orthogonal coils to measure the fields resulting in 12 different receiver coils. The receiver coils are oriented in 3-dimensions. The center-to-center distance of each receiver cube is approximately 40 cm. The transmitter coils are powered using a bi-polar half duty cycle, and the time decays of the subsurface currents (transients) are measured during the time that the transmitter coils are off. The sensors are mounted on a platform that is typically 20 cm above the ground surface. A GPS and IMU are mounted on a tower centered above the sensor platform. The transmitter electronics and batteries are mounted on a backpack carried by the operator. The system is operated from a tablet computer running the MetalMapper software. A cartoon of the MetalMapper 2x2 system is shown on **Figure 3**, and a schematic of the sensor coil configuration is shown on **Figure 4**.

Figure 3. MetalMapper 2x2 sensor platform with top cover removed and fully assembled

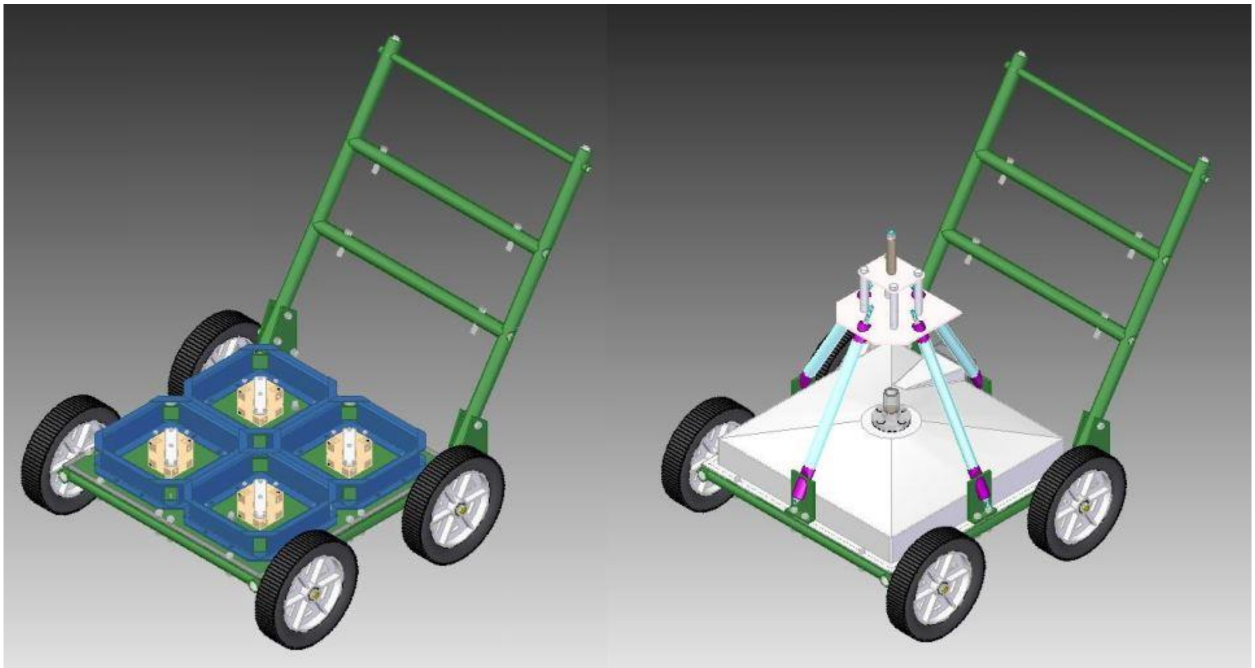
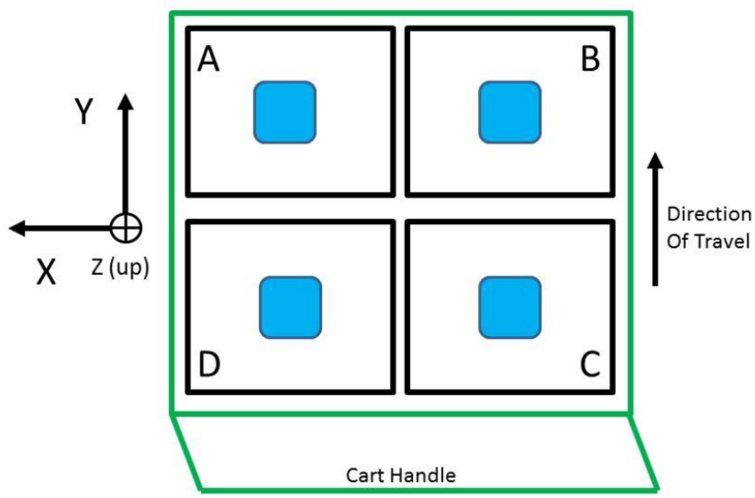


Figure 4. Orientation of MetalMapper 2x2 transmit coils and receive cubes



Positioning of the MetalMapper 2x2 is accomplished using RTK GPS, and orientation is measured using a six-degree-of-freedom IMU. To ensure correct orientation, the IMU is fixed inside a box mounted to the GPS antenna tower.

3.2 Instrument Verification Strip Construction

Verification of the advanced EMI sensor system is accomplished using an IVS. Multiple IVS locations may be constructed during the project for efficiency of data acquisition. The constructions details and verification procedures described in this document apply to each IVS location.

3.2.1 Location and Configuration of the Instrument Verification Strip

IVS locations will be identified during initial site reconnaissance by the DGM field team. The IVS should be established in an area that is easily accessible, not prone to flooding and other weather-related incidents, and is determined to be relatively free of subsurface metal objects. The IVS for advanced geophysical classification surveys will include two ISO and one 'blank' location, where nothing is buried.

3.2.2 Instrument Verification Strip Objects

Seed objects for the IVS will be small schedule 80 ISO, medium schedule 40 ISO, or large schedule 40 ISO, depending on sizes of the site-specific TOI. **Table 1** lists the specifications for the three sizes of ISO, photographs of which are presented on **Figure 5**.

Table 1. Industry standard objects characterized for use as munitions surrogates

Item	Nominal Pipe Size	Outside Diameter	Length	Part Number[1]	Schedule
Small ISO 80	1 inch	1.315 inches	4 inches	4550K226	80
Medium ISO 40	2 inches	2.375 inches	8 inches	44615K529	40
Large ISO 40	4 inches	4.500 inches	12 inches	44615K137	40

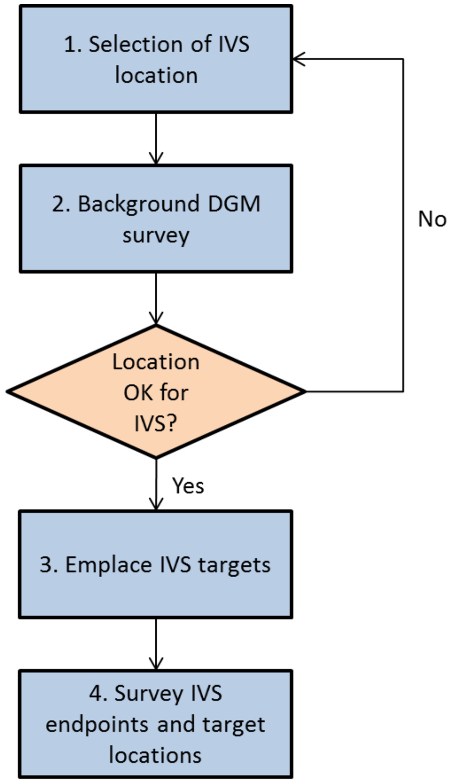
[1] Part number from McMaster-Carr supplier (http://www.mcmastercarr.com/)

Figure 5. Small, medium, and large ISO

3.2.3 Instrument Verification Strip Emplacement

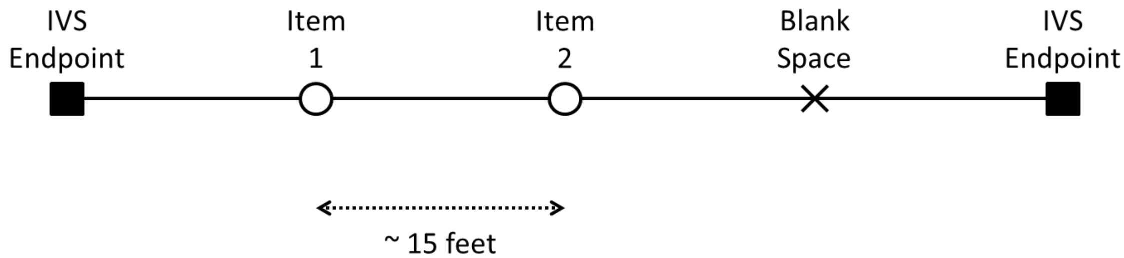
Figure 6 illustrates the overall IVS process and the procedures to be followed during the siting, and emplacement of the IVS. Detailed descriptions of each step are described in the following section.

Figure 6. IVS siting and emplacement



1. An IVS location will be selected with preference for the following (although none of the conditions are vital for IVS success):
   - Terrain, geology, and vegetation similar to that of a majority of the survey area
   - Geophysical noise conditions similar to those expected across the survey area
   - Large enough site to accommodate all necessary IVS tests and equipment and for adequate spacing (at least 3-m separation and preferably greater) of the ISO items to avoid ambiguities in data evaluation
   - Readily accessible to project personnel
   - Close proximity to the actual survey site (if not within the site)
2. A dynamic background DGM survey will be performed with the advanced EMI sensor or other DGM instrument using RTK GPS. The purpose of the background survey is to document the suitability of the location (e.g. few existing anomalies), and verify that IVS targets are not seeded near existing anomalies. The data from this IVS pre-survey will be processed and provided to the Project Geophysicist and QC Geophysicist for evaluation.
3. After determination that the IVS area is free of significant subsurface anomalies or contains only anomalies that are clearly identified and can be avoided during seeding, one ISO will be buried horizontally, perpendicular to the transect, and one will be buried vertically, both at depths below ground surface (measured to the center of mass of the ISO) determined to provide adequate signal to noise ratio for detecting the targets. The generalized diagram of the seeded IVS transect is presented as **Figure 7**.

Figure 7. Example IVS layout



On-site personnel will bury the IVS targets using shovels to dig the holes to the appropriate depths for burial of the seed items in coordination with the QC Geophysicist. UXO personnel will implement MEC avoidance procedures using analog instruments during installation, if necessary. The background survey data and anomaly avoidance techniques will be reviewed so that transect start and end stakes and seed items are not placed on top of or near existing anomalies. IVS construction personnel will bury the ISO and record the following information:

- Transect endpoints
- Blank space location
- Target type with unique seed item identifier and photograph of item (with a whiteboard displaying its identity depth, and orientation)
- Target emplacement location
- Target emplacement depth
- Target emplacement orientation

4. The holes will then be backfilled with soil to the original ground surface grade, and a wooden survey stake or other suitable non-metallic marker will be placed at each buried item location as well as at the blank location, start and end points of the IVS survey line. Wooden stakes will not extend more than 3 inches above the ground surface to prevent interference with the advanced EMI sensor when passing over them.

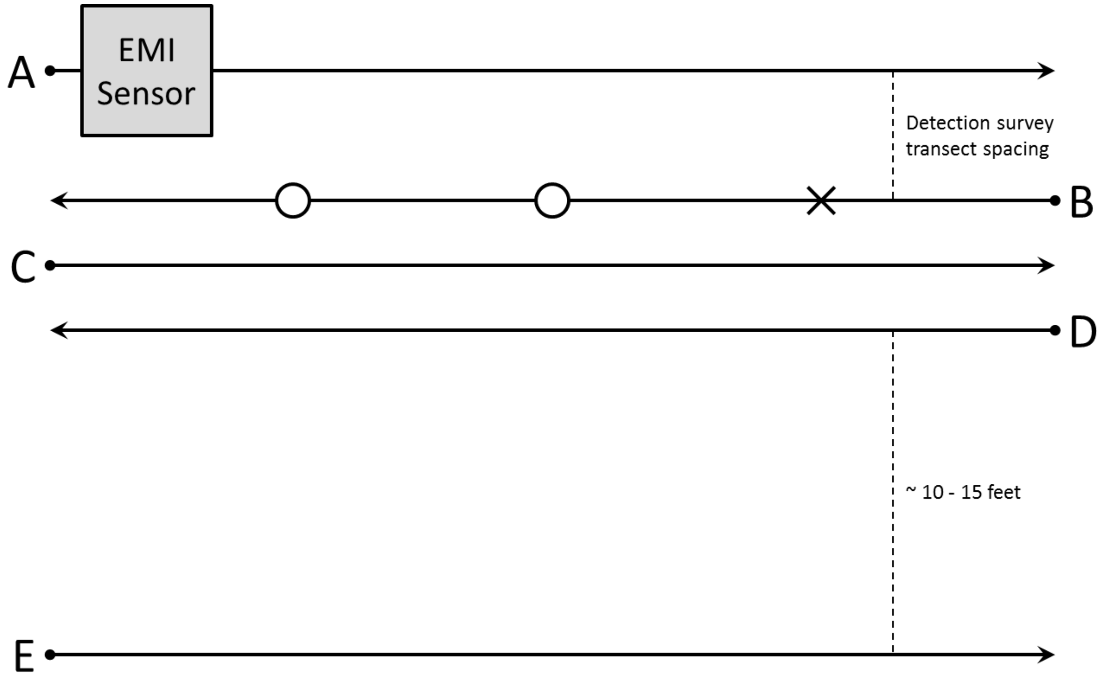
3.3 Initial Instrument Verification Strip Survey

Prior to acquiring dynamic or cued production data, the advanced EMI sensor will be assembled and tested in accordance with SOP AGCMR-01, and the initial IVS survey will be completed in dynamic and/or cued mode, depending on the nature of the advanced EMI sensor survey.

3.3.1 Initial Dynamic Instrument Verification Strip Survey

During the initial dynamic IVS survey, advanced EMI sensor data will be acquired along four transects over the seeded IVS and along one background transect, as illustrated on **Figure 8**. Three of the dynamic transects will be acquired at the intended detection survey line spacing – one transect directly over the IVS items, one transect to the left of the seeded transect, and one transect to the right of the seeded transect. The fourth dynamic transect will be offset from the seeded item transect by ½ the intended detection survey line spacing as an assessment of the detection capability of targets located between survey lines. The background transect will be offset 10-15 feet from the seeded IVS transect.

Figure 8. Initial Dynamic IVS survey transect locations



The raw .tem files and converted .csv files or raw HDF5 files for each transect will be delivered to the data processor, who will process the data in the same manner as the detection survey data. The data processor will verify successful achievement of the initial dynamic IVS survey measurement performance criteria (MPC) described in Worksheet 22 of the AGCMR-QAPP by performing the following data quality verifications:

- Verify that all IVS item fit locations are within the ground truth location offset allowance specified in the AGCMR-QAPP
- Verify that all IVS item response amplitudes are within the predicted amplitude response window specified in the AGCMR-QAPP

If the MPC have not been met, the QC Geophysicist will initiate a root cause analysis (RCA) to determine the source of the discrepancy. If modifications to the instrument or procedures can be made so that the MPC can be met, these modifications will be made. If the MPC cannot be met, the Project and QC Geophysicists will meet with the project team to discuss potential resolutions.

After verification that the dynamic IVS survey MPC (initial or modified) have been met, the dynamic IVS survey will be complete, and the advanced EMI sensor and operators will be verified for detection data acquisition.

3.3.2 Initial Cued Instrument Verification Strip Survey

During the initial cued IVS survey, advanced EMI sensor data will be acquired over each of the item positions in the IVS, including the background location (blank space). The raw .tem files and converted .csv files or raw HDF5 files for each measurement will be delivered to the data processor, who will process the data in the same manner as the cued survey data. The data processor will verify successful achievement of the initial cued IVS survey MPC described in Worksheet 22 of the AGCMR-QAPP by performing the following data quality verifications:

- Examine the data from each IVS location and verify that all measured decays are valid

- Use the measurement over the blank space to background-correct cued data points, and invert the corrected data
- Verify that the resulting polarizabilities match the expected library values in accordance with the match metric specified in the AGCMR-QAPP
- Verify that the horizontal fit locations are within the IVS seed item location offset allowance specified in the AGCMR-QAPP

If the initial MPC have not been met, the QC Geophysicist will initiate an RCA to determine the source of the discrepancy. If modifications to the instrument or procedures can be made so that the MPC can be met, these modifications will be made. If the MPC cannot be met (e.g., the initial background decay amplitudes are too large), the Project and QC Geophysicists will meet with the project team to discuss potential resolutions.

After verification that the cued IVS survey MPC (initial or modified) have been met, the cued IVS survey will be complete, and the advanced EMI sensor and operators will be verified for cued data acquisition.

3.3.3 Daily Instrument Verification Strip Survey

Twice each day during dynamic or cued data acquisition operations, IVS data will be acquired with the advanced EMI sensor. The daily IVS surveys will be conducted prior to beginning data acquisition activities and following completion of data acquisition activities.

When dynamic surveys are being conducted, the daily IVS survey will consist of the acquisition of a single line over the IVS items. The raw .tem files and converted .csv files or raw HDF5 files for the transect will be delivered to the data processor, who will process the data in the same manner as the detection survey data. The data processor will verify successful achievement of the daily dynamic IVS survey MPC described in Worksheet 22 of the AGCMR-QAPP by performing the following data quality verifications:

- Verify that all IVS item fit locations are within the ground truth location offset allowance specified in the AGCMR-QAPP
- Verify that all IVS item response amplitudes are within the predicted amplitude response window specified in the AGCMR-QAPP

When cued surveys are being conducted, the daily IVS survey will consist of the acquisition of cued data over each of the item positions in the IVS, including the background location. The raw .tem files and converted .csv files or raw HDF5 files for each measurement will be delivered to the data processor, who will process the data in the same manner as the cued survey data. The data processor will verify successful achievement of the daily cued IVS survey MPC described in Worksheet 22 of the AGCMR-QAPP by performing the following data quality verifications:

- Examine the data from each IVS location and verify that all measured decays are valid
- Verify that the background decay amplitudes are lower than project threshold and qualitatively agree with the initial measurement
- Use the measurement over the blank space to background-correct cued data points, and invert the corrected data
- Verify that the resulting polarizabilities match the expected library values in accordance with the match metric specified in the AGCMR-QAPP
- Verify that the horizontal fit locations are within the IVS seed item location offset allowance specified in the AGCMR-QAPP

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for this SOP are the locations and identities of the IVS items, the dynamic response values for each item, and the library polarizabilities for each item.

4.2 Output Data

Output data consist of the dynamic measurements over the IVS items described in Sections 3.3.1 and 3.3.3, the cued measurements over the IVS items described in Sections 3.2.2 and 3.3.3, and the QC checklists in Attachments 1 - 5 of this SOP. The test measurement data will be saved along with the dynamic IVS data and the cued inversion results and library match metric for each IVS measurement. The QC checklists will be completed, signed, and filed as documentation of system performance.

5 Quality Control

5.1 IVS Quality Control

Dynamic and/or cued IVS measurements are performed throughout the project and therefore require preparatory, initial, and follow-on QC checks. Performance of the required QC checks will be documented by the Data Acquisition Geophysicist or Lead Data Analyst on the Preparatory, Initial and Follow-on QC checklists in Attachments 1 - 5 of this SOP. Successful completion of these procedures will be verified by the QC Geophysicist in the daily Geophysics QC Report.

- The Preparatory QC Checklist covers the construction of the IVS and preparation of the advanced EMI sensor prior to the first IVS tests. This checklist is completed once per IVS.
- The Initial Dynamic IVS Checklist covers the initial IVS tests to demonstrate proper functioning of the advanced EMI sensor system prior to performing dynamic data acquisition.
- The Initial Cued IVS Checklist covers the initial IVS tests to demonstrate proper functioning of the advanced EMI sensor system prior to performing cued data acquisition.
- The Follow-on Dynamic Daily IVS Checklist documents the twice-daily IVS tests that are performed each morning prior to beginning dynamic data acquisition and following completion of dynamic data acquisition.
- The Follow-on Cued Daily IVS Checklist documents the twice-daily IVS tests that are performed each morning prior to beginning cued data acquisition and following completion of cued data acquisition.
- The QC checks in Attachments 1 - 5 will be performed as part of IVS procedure. In addition, instrument-specific start-up and function checks for the advanced EMI sensor system will also be performed at start-up prior to data acquisition activities, including IVS data acquisition.
- Achievement of the IVS MQO will be verified by the Field Geophysicist and QC Geophysicist on their QC checklists.
- During review of the initial and follow-on data packages, the data processor will overlay the polarizabilities of each IVS target from all cued measurements to observe the time variation of the inverted results. Should an issue be detected (such as a data trend indicating a MPC limit is being approached) or a MQO not be met, a comprehensive RCA will be conducted and a corrective action determined.

5.2 Measurement Quality Objectives

The MQO for the IVS are presented in Worksheet 22 of the AGCMR-QAPP. The advanced EMI sensor will not be used for production area data acquisition until it is able to meet initial IVS MQO or until the project team agrees on modifications to the MQO. If ongoing IVS MQO are not met, a comprehensive RCA will be performed and a corrective action determined.

6 Reporting

System verification at the IVS will be documented through the completion of the preparatory, initial, and follow-on QC Checklists in Attachments 1 - 5. The IVS construction and implementation will be documented in an IVS Technical Memorandum. Copies of the completed Advanced EMI Sensor Assembly Checklist (from SOP AGCMR-01), the Preparatory and Initial Checklists (from this SOP), and/or the Advanced EMI Sensor Dynamic Data Acquisition Checklist (from SOP AGCMR-05) and the Advanced EMI Sensor Cued Data Acquisition Checklist (from SOP AGCMR-07) will be included as attachments to the IVS Technical Memorandum. A follow-on QC Checklist will be completed by the Data Acquisition Geophysicist and Lead Data Processor each time IVS data are acquired during the production survey, and copies will be included with the advanced geophysical classification report at the completion of the project.

Attachment 1

Preparatory IVS Construction Checklist

Preparatory IVS Construction Checklist

This checklist is to be completed by the Data Acquisition Geophysicist during construction of the IVS and reviewed and verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist Initials
1. Qualifications	Are the qualifications of the Data Acquisition Geophysicist and the Lead Data Processor in accordance with AGCMR-QAPP Worksheet 7?		
2. IVS construction	Has an appropriate location for the IVS been selected (Sections 3.2.1 and 3.2.3, Step 1)?		
3. IVS construction	Have appropriate IVS seed targets been selected (Section 3.2.2)?		
4. IVS construction	Has the background geophysical survey been performed (Section 3.2.3, Step 2)?		
5. IVS construction	Have the IVS seed targets been buried appropriately (Section 3.2.3, Step 3)?		
6. IVS construction	Has the required IVS construction information (Section 3.2.3, Step 3) been recorded for inclusion in the IVS Letter Report?		
7. IVS construction	Have the IVS seed target holes been backfilled and marked (Section 3.2.3, Step 4)?		

Data Acquisition Geophysicist: ___________________________________ Date: _____________

Lead Data Processor: ____ Date: _____________

Attachment 2
Initial Dynamic IVS Checklist

Initial Dynamic IVS Checklist

This checklist is to be completed by the Data Acquisition Geophysicist and the Lead Data Processor during the initial demonstration of the advanced EMI sensor dynamic performance on the IVS and reviewed and verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist or Lead Data Processor Initials
1. Preparation	Has the SOP AGCMR-02 Preparatory Checklist been successfully completed?		
2. Preparation	Have the advanced EMI sensor start-up procedures and the Advanced EMI Sensor Dynamic Data Acquisition Checklist (from SOP AGCMR-05) been successfully completed?		
3. Data acquisition	Has the IVS data been acquired in accordance with Section 3.3.1?		
4. Data processing	Has the data been processed in accordance with Section 3.3.1?		
5. Data analysis	Have the IVS item horizontal fit locations been verified to be within the IVS seed item horizontal fit offset allowance specified in the AGCMR-QAPP?		
6. Data analysis	Have the IVS item response amplitudes been verified to be within the predicted amplitude response window specified in the AGCMR-QAPP?		
7. MPC documentation	Have the MPCs for the initial dynamic IVS survey been achieved in accordance with AGCMR-QAPP Worksheet 22?		

Data Acquisition Geophysicist: ______________________________ Date: ____________

Lead Data Processor: ____________________________________ Date: ____________

Attachment 3

Initial Cued IVS Checklist

Initial Cued IVS Checklist

This checklist is to be completed by the Data Acquisition Geophysicist and the Lead Data Processor during the initial demonstration of the advanced EMI sensor cued performance on the IVS and reviewed and verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist or Lead Data Processor Initials
1. Preparation	Has the SOP AGCMR-02 Preparatory Checklist been successfully completed?		
2. Preparation	Have the advanced EMI sensor start-up procedures and the Advanced EMI Sensor Cued Data Acquisition Checklist (from SOP AGCMR-07) been successfully completed?		
3. Data acquisition	Has the IVS data been acquired in accordance with Section 3.3.2?		
4. Data processing	Has the data been processed in accordance with Section 3.3.2?		
5. Data analysis	Has the data acquired on the blank space been verified to be suitable for use as background (Section 3.3.2)?		
6. Data analysis	Have the background decay amplitudes been verified to be below the selected threshold (Section 3.3.2)?		
7. Data analysis	Has the background data from the blank space been used to correct the target data sets and to invert the data (Section 3.3.2)?		
8. Data analysis	Have the resulting polarizabilities been verified to match the expected library values in accordance with the match metric specified in the AGCMR-QAPP (Section 3.3.2)?		
9. Data analysis	Have the horizontal fit locations been verified to be within the IVS seed item horizontal fit offset allowance specified in the AGCMR-QAPP?		
10. MPC documentation	Have the MPCs for the initial cued IVS survey been achieved in accordance with AGCMR-QAPP Worksheet 22?		

Data Acquisition Geophysicist: ____________________________________ Date: _______________

Lead Data Processor: ____ Date: _______________

Attachment 4

Follow-on Dynamic Daily IVS Checklist

Follow-On Dynamic Daily IVS Checklist

This checklist is to be completed by the Data Acquisition Geophysicist and Data Processor during each dynamic IVS survey (twice each day during data acquisition operations, prior to beginning data acquisition and following completion of data acquisition) and reviewed and verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist or Data Processor Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Have the advanced EMI sensor start-up procedures and the Advanced EMI Sensor Dynamic Data Acquisition Checklist (from SOP AGCMR-05) been successfully completed?		
3. Data acquisition	Has the IVS data been acquired in accordance with Section 3.3.3?		
4. Data processing	Has the data been processed in accordance with Section 3.3.3?		
5. Data analysis	Have the IVS item horizontal fit locations been verified to be within the IVS seed item horizontal fit offset allowance specified in the AGCMR-QAPP?		
6. Data analysis	Have the IVS item response amplitudes been verified to be within the predicted amplitude response window specified in the AGCMR-QAPP?		
7. MPC documentation	Have the MPCs for the dynamic daily IVS survey been achieved in accordance with AGCMR-QAPP Worksheet 22?		

Field Geophysicist: ______________________________________ Date: ____________

Lead Data Processor: ____________________________________ Date: ____________

Attachment 5

Follow-on Cued Daily IVS Checklist

Follow-on Cued Daily IVS Checklist

This checklist is to be completed by the Data Acquisition Geophysicist and Data Processor during each cued IVS survey (twice each day during data acquisition operations, prior to beginning data acquisition and following completion of data acquisition) and reviewed and verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist or Data Processor Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Have the advanced EMI sensor start-up procedures and the Advanced EMI Sensor Cued Data Acquisition Checklist (from SOP AGCMR-07) been successfully completed?		
3. Data acquisition	Has the IVS data been acquired in accordance with Section 3.3.3?		
4. Data processing	Has the data been processed in accordance with Section 3.3.3?		
5. Data analysis	Has the background data from the blank space been used to correct and invert the target data (Section 3.3.3)?		
6. Data analysis	Have the resulting polarizabilities been verified to match the expected library values in accordance with the match metric specified in the AGCMR-QAPP (Section 3.3.3)?		
7. Data analysis	Have the IVS item horizontal fit locations been verified to be within the IVS seed item horizontal fit offset allowance specified in the AGCMR-QAPP?		
8. MPC documentation	Have the MPCs for the cued daily IVS survey been achieved in accordance with AGCMR-QAPP Worksheet 22?		

Field Geophysicist: ____ Date: ______________

Lead Data Processor: ____ Date: ______________

STANDARD OPERATING PROCEDURE
AGCMR-03

Quality Control Seeding for Advanced Geophysical Classification

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON
ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when emplacing quality control (QC) seed items in the production area in preparation for dynamic or cued advanced electromagnetic induction (EMI) sensor digital geophysical mapping.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Inert munitions and/or industry standard objects (ISO) as seed items
- Hand tools including shovels, pick axes, breaker bars, etc. to emplace the seed items
- Excavators if required by the production seed plan

2.1 Personnel and Qualifications

The following individuals will be involved in emplacing QC seed items:

- QC Geophysicist, or designee
- UXO Personnel[1]
- Real-time kinematic global positioning system (RTK GPS) operator

The minimum qualifications for the QC Geophysicist are listed in Worksheet 7 of the AGCMR-QAPP.

3 Procedures and Guidelines

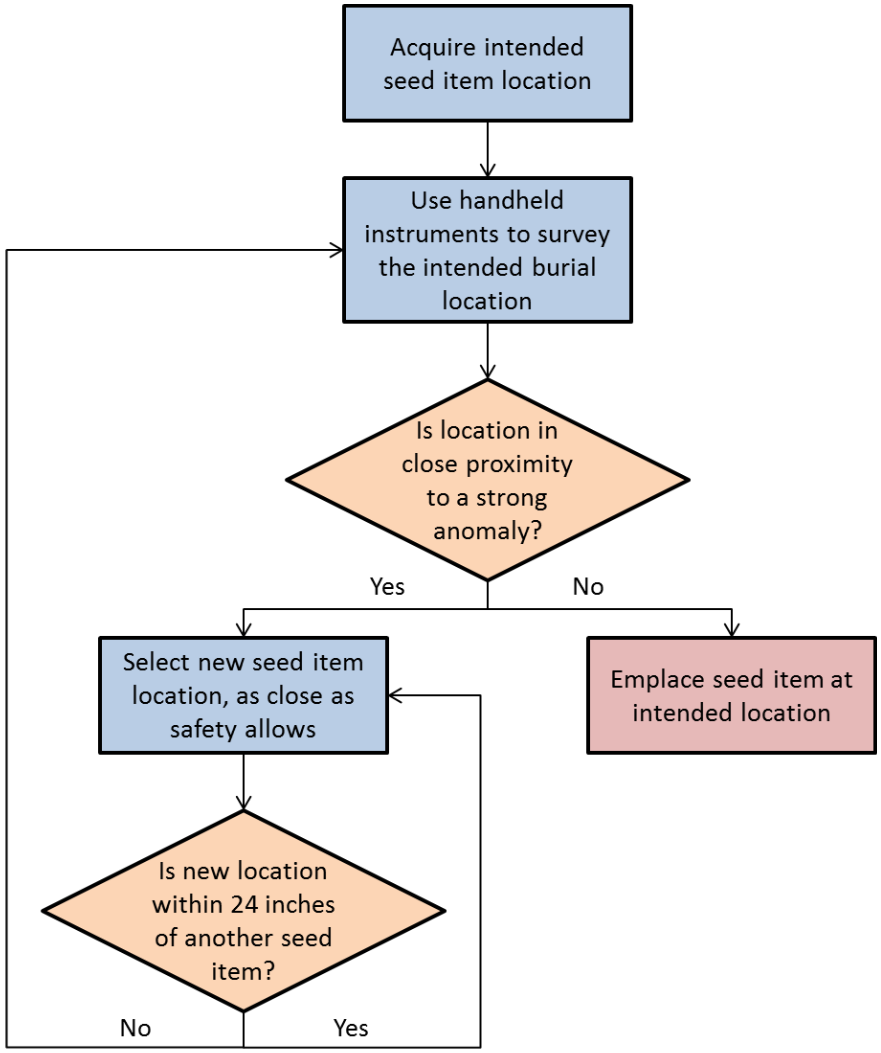
The production area seed plan provides a list of seed identities, locations, depths, and orientations. When emplacing the seeds, the emplacement team will employ anomaly avoidance techniques as described in Section 3.1 and use the emplacement procedure described in Section 3.2.

3.1 Anomaly Avoidance

It is likely that the survey area will contain metallic items or electromagnetically active geology. These will produce anomalies in data collected with a magnetometer or electromagnetic induction instrument. The emplacement team should avoid emplacing seeds in the immediate vicinity of strong anomalies. **Figure 1** describes the process that will be used to avoid strong anomalies when emplacing a seed. First, the emplacement team will acquire the seed item's intended location. The team will then use a hand-held detector to survey within the immediate vicinity of the intended location. If there are no strong anomalies in the immediate vicinity, the team will emplace the seed at the intended location. If, however, the intended location is in the immediate vicinity of any strong anomaly, the team will select a new location for the seed, as close as safety allows. The new location should not be within the immediate vicinity of any strong anomaly or within 5 feet of another seed item.

[1] UXO personnel will be responsible for overall daily site access and safety aspects of the project, compiling health and safety documents, conducting daily safety briefings, and performing munitions and explosives of concern avoidance, as needed, in the field. Information on the specific qualifications for various UXO personnel support roles can be found in the project Health and Safety Plan.

Figure 1. Anomaly avoidance during QC seed item emplacement



3.2 Seed Emplacement

Advanced geophysical classification will attempt to reconstruct the physical parameters of buried targets, such as location, depth, inclination, azimuth, and size. It is therefore critical for the success of the project that the actual locations of the buried seed items are surveyed as accurately and precisely as possible. To that end, the emplacement team should dig in a fashion to minimize seed migration (e.g., settling) after burial.

The QC seed item list specifies the intended burial parameters of each seed item. The intended locations are given to 1 inch precision, the intended depths to 2 inch precision, and the intended inclinations and azimuths to 10 degree precision. All locations should be acquired as accurately and precisely as possible using RTK GPS before digging begins, to maximize anomaly avoidance.

The QC seed item list is a guide for seed emplacement, but the emplacement team may allow small deviations from the intended burial parameters. Variations from the intended burial parameters must be documented by recording the actual burial parameters as accurately and precisely as possible. The emplacement team should adjust the inclination angles of the seed items to ensure at least 2 inches of soil covering the shallowest point of each seed item.

After emplacing a seed item in the ground, but before covering it with soil, the following information should be accurately recorded:

- The x, y, and z coordinates for the center of mass of the seed item
- The depth of the seed item, measured as the vertical distance from the bottom of a straight edge placed across the opening of the hole down to the center of the seed
- A photograph of the seed item, showing its serial number and a ruler or similar scale

For each seed item, the emplacement team should also complete the following:

- Ensure the seed item is marked with blue paint to identify it as inert
- Rebury any metallic items that were found in the hole along with the seed
- Replace soil in the hole as completely as possible
- Level the burial location
- Replace the grass plug over the burial location, if possible

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for this SOP consists of the QC seed item list, which contains the intended locations, depths, and orientations of each seed item.

4.2 Output Data

Output data consists of the final production area seed report. The report includes of a brief narrative describing the seed item emplacement and a discussion of significant deviations from the seed plan. The bulk of the report consists of a seed location table that includes the "as emplaced" identity, location, depth, and orientation of each emplaced seed item accompanied by a photograph of the item in the ground before being covered.

5 Quality Control

5.1 Measurement Quality Objectives

The MQO for QC seeding for advanced geophysical classification is presented in Worksheet 22 of the AGCMR-QAPP and specifies verification that all seed items have been emplaced with the specified precision. Advanced EMI sensor data acquisition will not be conducted until conformance with this MQO has been documented as described below.

6 Reporting

QC seeding for advanced geophysical classification will be documented through the completion of the Preparatory Quality Control Seeding for Advanced Geophysical Classification Checklist in Attachment 1. The preparatory QC checklist for this SOP will be completed by the QC Geophysicist. Production area seeding will also be documented in the production area seed report as described in Section 4.2.

Attachment 1

Preparatory Quality Control Seeding for Advanced Geophysical Classification Checklist

Preparatory Quality Control Seeding for Advanced Geophysical Classification Checklist

This checklist is to be completed by the QC Geophysicist following completion of production area seeding. The QC Geophysicist will observe the emplacement of production area seed items and will document the successful completion of this checklist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Qualifications	Are the qualifications of the QC Geophysicist in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Have appropriate QC seed items been selected and procured?		
3. Seed emplacement	Have the target seed items been buried appropriately, measured, photographed, and backfilled?		
4. Reporting	Has the production area seed report been prepared in accordance with Section 4.2?		

QC Geophysicist: ____ Date: ______________

STANDARD OPERATING PROCEDURE
AGCMR-04

Advanced EMI Sensor Background Measurement Acquisition

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when selecting the locations for background measurements using an advanced electromagnetic induction (EMI) sensor system for geophysical classification and verifying the usability of the resulting background data. This SOP describes background data acquisition with the Geometrics MetalMapper, Geometrics MetalMapper 2x2, and U.S Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS) systems. If other advanced EMI sensors are selected for use, this SOP will be updated to include background data acquisition details for those systems.

The observed signal in a cued advanced EMI sensor measurement includes the following three components:

- the EMI response of the buried target
- the self-signature of the sensor system
- any response from the ambient environment in which the target is buried

The objective of acquiring background measurements is to independently measure the last two contributors to the overall EMI response. These “non-target” values can then be subtracted from the overall signal response to isolate the signal response from only the unknown object being evaluated. For the background removal process to be successful, the background measurements must be acquired in an area free of buried metal objects and with geologic conditions representative of the location of the unknown items. Background measurements must also be acquired throughout the survey day because environmental changes such as significant changes in geologic/soil conditions, ambient temperature, or background moisture (morning dew evaporating, rain showers passing through, etc.), or significant changes to the sensor itself (cable replacement, new GPS antenna, etc.) will cause the environmental or sensor contribution to the background reading to change.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Advanced EMI sensor coupled with a real-time kinematic (RTK) global positioning system (GPS) and inertial measurement unit (IMU) for orientation measurements
- Data processing computer suitable for and equipped to run the UX-Analyze Advanced module of Geosoft’s Oasis Montaj geophysical processing environment

2.1 Personnel and Qualifications

The following individuals will be involved in advanced EMI sensor background measurement acquisition and evaluation:

- Data Acquisition Geophysicist
- QC Geophysicist
- Lead Data Processor

The minimum qualifications for the Data Acquisition and QC Geophysicists, and the Lead Data Processor are listed in Worksheet 7 of the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP).

3 Procedures and Guidelines

Background measurements will be acquired immediately prior to the onset of data acquisition, immediately following data acquisition, and throughout the survey day at maximum intervals of 2 hours. Multiple geographic locations may be required to document the response of near-surface soils present at the site. Background measurements involve positioning the sensor and acquiring static measurements over a pre-identified set of background locations. In combination with SOPs for advanced EMI sensor assembly (SOP AGCMR-01) and testing at the IVS (SOP AGCMR-02), background data are acquired and used to correct the cued advanced EMI sensor data that are acquired as described in SOP AGCMR-07.

Prior to cued data collection, including the acquisition of background measurements, the correct operation of the geophysical sensor and navigation and orientation systems must be verified at the IVS as described in SOP AGCMR-02. This will be verified by completion of the Follow-on QC checklist attached to SOP AGCMR-02.

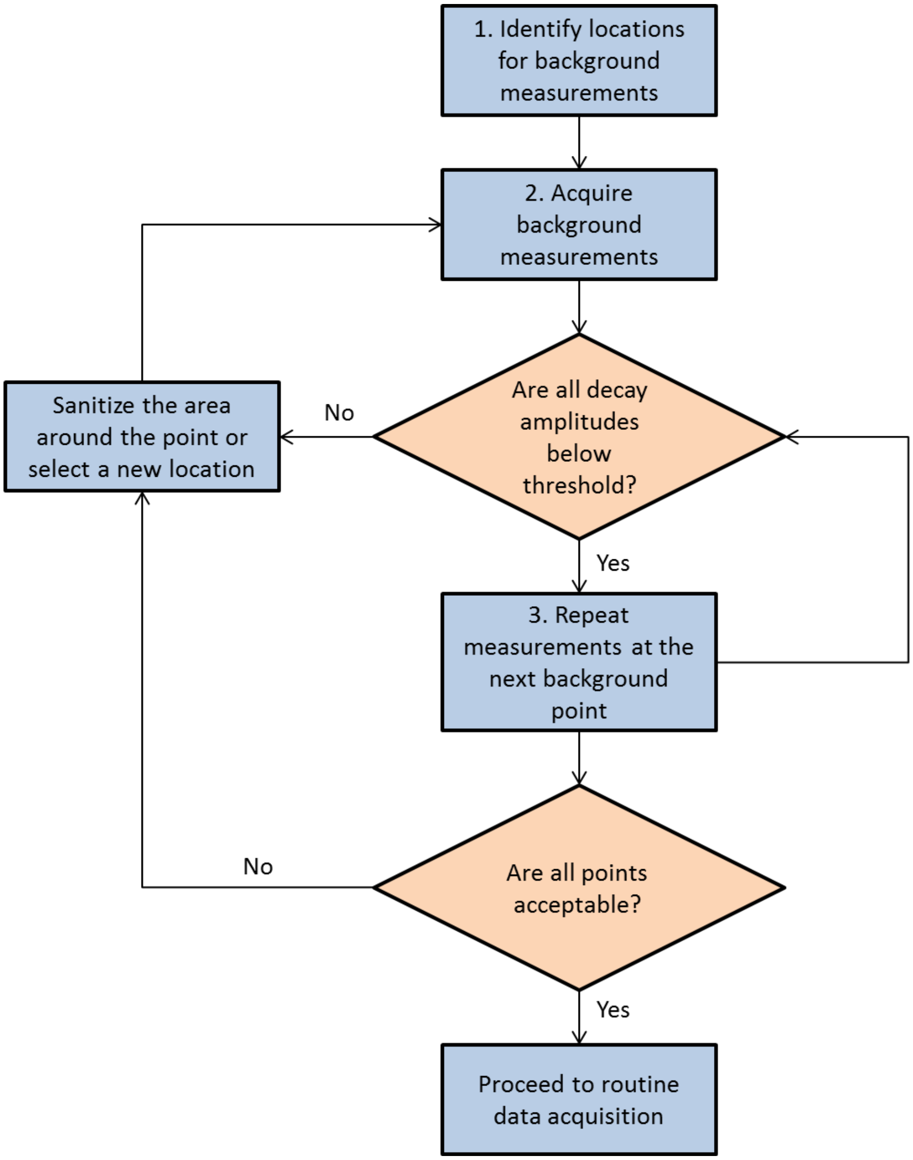
3.1 Choose Background Measurement Locations and Verify Their Suitability

One or more locations for background measurements will be planned at each site. The number and location of the background measurements will be influenced by the following considerations:

- The background measurements should be acquired at locations that are similar to that of the production survey area with regard to geophysical noise, terrain, geology, and vegetation. If these factors change appreciably, additional background measurements, taken at more representative locations, will be required.
- The background measurements should be collected at locations free of buried metal objects. If a suitable object-free area cannot be identified from the existing detection data, attempts should be made to create a clear 5-foot square area by locating and removing all metal objects. Once sanitized, the background measurements should be acquired in the clear area.
- For efficiency, background measurements should be acquired in areas that are close to the survey area to minimize travel time.
- Data from the dynamic survey will be used to assist in selection of initial background locations

Once an adequate number of background locations have been identified, an initial cued measurement should be acquired over each background location in turn as illustrated on **Figure 1**.

Figure 1. Choosing and verifying background measurement locations



The following is a description of each step shown above:

1. **Identify locations for background measurements.** Initial locations for background measurement are chosen most easily by referencing the detection survey data to guide the geophysicist to suitable locations that satisfy the considerations noted above.
2. **Acquire background measurements.** Once an adequate number of initial locations have been identified, a set of initial measurements should be collected over each background location as follows:
    a. Center the advanced EMI sensor over the location chosen as a background point. Mark the corners of the sensor with non-metallic pin flags to allow the same location to be occupied again for future background readings.
    b. Record a cued advanced EMI sensor measurement at the potential background location.

   c. Verify that the signal amplitude for the measured decay is below the background threshold chosen for the project. If higher amplitude decays are observed, the location should be inspected and any metal contamination removed. Alternatively, another nearby location can be chosen.
   d. Document if the location is verified for future use during the production survey as a background measurement location.

3. **Repeat measurements at the next background point.** Continue this process at each of the chosen initial locations until their suitability for background measurements has been verified.
4. **Proceed to routine data acquisition.** After verification of each background measurement location, the measurements will serve as baseline values for future background measurements at each point.

3.2 Acquire Background Measurements throughout the Survey Day

Background locations will be stored in the advanced EMI sensor data acquisition computer to assist in navigating each location. Background measurements will be acquired immediately prior to the onset of data acquisition, immediately following data acquisition, and throughout the survey day at maximum intervals of 2 hours. Background measurement frequency can be increased if the Project Geophysicist or Field Team Leader determines that changes to the sensor or natural environment may have caused the sensor or environmental contribution to the background reading to change. Specific documentation of changes to the sensor or environment and the reasons for additional background readings is critical to guide the Data Processor in choosing the correct background for each cued data measurement.

The procedure for acquiring background measurements during cued data acquisition is as follows:

1. Return the sensor to a previously verified background measurement location and position the sensor as closely as possible to the initial location and orientation.
2. Acquire a cued background measurement.
3. Evaluate the decay amplitudes and transmitter current levels. Decay amplitudes must be below the background threshold. If there are noticeable deviations or changes in the decays, document in the field notes any environmental changes that may be responsible and repeat the background measurement if necessary.

The Data Processor will compare the measured decays to previous measurements at this location. If there are significant deviations in the measured amplitudes or character of the decay curves, the Data Processor will determine if the background measurements are acceptable or if they must be rejected.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for this SOP includes an initial list of background locations, identified from the detection survey data. After verification of the background the locations, they become the final background location list.

4.2 Output Data

Output data consist of the cued background measurement data acquired at each background location and the QC checklists in Attachments 1 - 3 of this SOP. The background measurement data described in Section 3.1 will be saved for each background location. The QC checklists will be completed, signed, and filed as documentation of system performance.

5 Quality Control

5.1 Background Quality Control

Background measurements are acquired throughout the project and therefore require preparatory, initial, and follow-on QC checks. Performance of the required QC checks will be documented by the Data Acquisition Geophysicist and Lead Data Processor on the Preparatory, Initial and Follow-on QC checklists in Attachments 1 - 3 of this SOP. Successful completion of these procedures will be verified by the QC Geophysicist in the Geophysics Daily QC Report.

- The Preparatory QC Checklist (Attachment 1) will be completed to document the identification of background locations.
- The Initial QC Checklist (Attachment 2) will be completed to document responses at each initial background location.

Background measurements acquired throughout the duration of the advanced EMI sensor survey verify that the sensor is functioning properly and that the geophysical field team is collecting data of adequate quality. After initial verification of background measurement locations, daily data acquisition activities require only follow-on QC inspections, which are documented as follows:

- The operating software automatically logs the responsible geophysicist's identification in each data file. By acquiring the data, and thereby taking responsibility for it, the geophysicist certifies compliance with the requirements of this SOP.
- The QC Geophysicist will observe background data acquisition each morning and afternoon of data acquisition activities and document the observation in the Daily Geophysics QC Report.
- The Data Acquisition Geophysicist will also maintain a field log, which will be reviewed daily by the QC Geophysicist to note issues that potentially affect data quality.

Achievement of the background measurement measurement performance criteria will be documented by the Data Acquisition Geophysicist and verified by the QC Geophysicist in the Geophysics Daily QC Report. During review of each background measurement, the Data Processor will overlay the measured decays from all previous measurements at that location to observe any variation. Should variations be observed that are not the result of changing environmental conditions documented by the field crew, a comprehensive root cause analysis will be performed and corrective actions determined.

5.2 Measurement Quality Objectives (MQO)

The MQO for background measurements are presented in Worksheet 22 of the AGCMR-QAPP. Measured backgrounds will not be used to correct field advanced EMI sensor data until the MQO are met or the project team agrees on modifications to the MQO.

6 Reporting

Background measurement acquisition will be documented through the completion of the preparatory, initial, and follow-on QC Checklists in Attachments 1 – 3 by the Data Acquisition Geophysicist and Lead Data Processor. The Preparatory Inspection Checklist (Attachment 1) will document the selection and preparation of the background measurement locations. The Initial Inspection Checklist (Attachment 2) will document the initial background measurements acquired at each background location. The Follow-on Checklist (Attachment 3) will document the routine background measurements acquired at maximum 2-hour intervals throughout the production survey. The QC Geophysicist will observe the acquisition of background measurements and will document completion of all checklists in the Daily Geophysics QC Report. Copies will be included with the advanced geophysical classification project report at the completion of the project.

Attachment 1

Preparatory Background Measurement Acquisition Checklist

Preparatory Background Measurement Acquisition Checklist

This checklist is to be completed by the Data Acquisition Geophysicist during selection and preparation of background measurement locations. Successful completion of the process will be verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Background area selection	Do the selected background locations have similar geophysical noise, terrain, geology and vegetation as the production survey area they represent (Section 3.1)?		
3. Background area selection and preparation	Are the selected background locations free of buried metal objects or has a 5-foot square area been sanitized (Section 3.1)?		
4. Background area selection	Are the selected background locations sufficiently close to the production area to minimize travel (Section 3.1)?		

Data Acquisition Geophysicist: ___________________________________ Date: ______________

Attachment 2

Initial Background Measurement Acquisition Checklist

Initial Background Measurement Acquisition Checklist

This checklist is to be completed by the Data Acquisition Geophysicist and the Lead Data Processor during initial data acquisition at each background measurement location. Successful completion of the process will be verified by the QC Geophysicist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Data Acquisition Geophysicist or Lead Data Processor Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Has the Preparatory Advanced EMI Sensor Assembly Checklist (SOP AGCMR-01) been successfully completed?		
3. Preparation	Has the Follow-on IVS QC checklist (SOP AGCMR-02) been successfully completed?		
4. Data acquisition	Has the advanced EMI sensor been properly centered on each background location, and have the corners of the sensor been marked with non-metallic pin flags (Section 3.1, Step 2)?		
5. Data acquisition	Have all signal amplitudes for measured decays been verified to be below the selected threshold (Section 3.1, Step 2)?		
6. MPC documentation	Have the MPCs for background measurement acquisition been achieved in accordance with AGCMR-QAPP Worksheet 22?		

Data Acquisition Geophysicist: ______________________________________ Date: _______________

Lead Data Processor: ____ Date: _______________

Attachment 3

Follow-on Background Measurement Acquisition Checklist

Follow-on Background Measurement Acquisition Checklist

This checklist is to be completed by the QC Geophysicist daily during background measurement acquisition activities. The operating software automatically logs the responsible geophysicist's identification in each data file. By acquiring background data, and thereby taking responsibility for it, the geophysicist certifies compliance with the requirements of this SOP. The QC Geophysicist will observe the background measurement acquisition process at least twice per day and will document the successful completion of this checklist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Has the Preparatory Advanced EMI Sensor Assembly Checklist (SOP AGCMR-01) been successfully completed?		
3. Preparation	Has the Follow-on Daily Cued IVS Checklist (SOP AGCMR-02) been successfully completed?		
4. AM field observation	Has the AM field observation been performed? Time:_________ Background #s:_______________		
5. PM field observation	Has the PM field observation been performed? Time:_________ Background #s:_______________		
6. Field Documentation	Has the QC Geophysicist reviewed the day's data acquisition with the Data Acquisition Geophysicist and reviewed the field log? Have any technical issues been noted?		
7. MPC documentation	Have the MPCs for background measurement acquisition been achieved in accordance with AGCMR-QAPP Worksheet 22?		

QC Geophysicist: ____ Date: _______________

STANDARD OPERATING PROCEDURE
AGCMR-05

Advanced EMI Sensor Dynamic Data Acquisition

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when performing dynamic surveys using an advanced electromagnetic induction (EMI) sensor for target detection. This SOP describes cued data acquisition with the Geometrics MetalMapper, Geometrics MetalMapper 2x2, and U.S Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS) systems. If other advanced EMI sensors are selected for use, this SOP will be updated to include cued data acquisition details for those systems.

Advanced EMI sensor dynamic data acquisition involves navigating the sensor along pre-determined transects designed to meet the project target of interest (TOI) detection performance objectives. The detection objectives and transect spacing for individual projects and survey areas are identified in the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP) and Site-Specific Work Plans.

The signal measured by the advanced EMI sensor is composed of the following three individual components:

1. the EMI response of buried metallic targets,
2. the self-signature of the sensor system, and
3. the response from the ambient environment in which the target is buried.

To isolate responses associated with discrete buried metal objects, a background model comprised of the sensor system self-signature and the ambient environment response must be derived and removed from the raw data. The remaining leveled signal data are used as inputs into a detection algorithm that identifies anomalous responses due to potential TOI, which are then mapped and selected for further investigation or removal. Details of the processing and analysis of dynamic advanced EMI sensor data are covered in SOP AGCMR-06.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Advanced EMI sensor coupled with a real-time kinematic global positioning system (RTK GPS) and inertial measurement unit (IMU) for orientation measurements
- Data processing computer suitable for and equipped to run the UX-Analyze Advanced module of Geosoft's Oasis Montaj geophysical processing environment

2.1 Personnel and Qualifications

The following individuals will be involved in dynamic advanced sensor data acquisition and evaluation:

- QC Geophysicist
- Data Acquisition Geophysicist
- Lead Data Processor

The minimum qualifications for the Data Acquisition and QC Geophysicists and the Lead Data Processor are listed in Worksheet 7 of the AGCMR-QAPP.

3 Procedures and Guidelines

3.1 Survey Grid Preparation

Survey grid preparation involves marking the site boundaries and survey transects required to achieve the coverage specified in the Site-Specific Work Plan. Start- and endpoints of individual transects, as well as intermediate points along each transect, will be physically measured and marked or entered into a real-time navigation system such that the sensor can be precisely navigated along the desired transect.

3.2 Daily Function Test Measurements

Daily function test measurements will be conducted at the IVS prior to the start of daily data acquisition to confirm that all transmit and receive components of the advanced EMI sensor are operational. The daily function test will consist of a static measurement acquired over the IVS background location (blank space) followed by a static measurement acquired in the same location with a schedule 80 small industry standard object centered under (or above) the sensor.

3.3 Daily IVS Survey

Twice daily during dynamic data acquisition activities (prior to the start of daily data acquisition and following the completion of daily data acquisition) a dynamic IVS survey will be performed as described in SOP AGCMR-02.

3.4 Dynamic Data Acquisition

Dynamic survey utilizing an advanced EMI sensor involves acquiring data along transects across the survey area. In combination with SOPs for advanced EMI sensor assembly (SPO AGCMR-01) and testing at the IVS (SOP AGCMR-02), dynamic data is collected along each transect at the spacing defined in the AGCMR-QAPP or Site-Specific Work Plan. Data acquisition is controlled by the Data Acquisition Geophysicist with the EM-3D software, which allows the user to assign a numerical ID to each transect line and start and stop data acquisition at the beginning and end of each transect. When an obstacle is encountered along a transect, the obstacle can be avoided by either altering the path of the transect or by stopping data acquisition and resuming with a new transect ID after the obstacle has been passed. Data gaps resulting from obstacles should be recorded in the field notes and submitted to the data processor. Data gaps resulting from line spacing greater than the defined acceptable spacing will be identified by the data processor and provided to the Data Acquisition Geophysicist for recollection. Data acquisition will be performed using the following steps:

1. **Power-on and test the sensor.** After starting the geophysical and navigation systems, a function test is performed prior to every data collection event, as described in Section 3.2. The data acquisition software is monitored during data acquisition to ensure that all data streams (EMI, GPS, and IMU) are valid and being recorded.

2. **Navigate and acquire data along transects.** Navigation along transects is performed visually with the assistance of markers, which are placed at the discretion of the Data Acquisition Geophysicist or by real-time navigation using the data acquisition software. Physical transect markers may include, but are not limited to, ropes, tapes, spray paint, or flags. Coverage may be monitored by marking the track of the inside wheels as the sensor moves along a transect. Positioning in the data file is captured through the use of the RTK-GPS system and the IMU.

3. **Verify the integrity and quality of the acquired data.** During data acquisition, the integrity and quality of the data will be verified by the Data Acquisition Geophysicist by inspection of the advanced EMI sensor data acquisition display to ensure the following:

    - Data acquisition starts and stops in coordination with the beginning and end of each transect
    - Each transect is assigned a unique numerical identifier (ID), in sequential order
    - The amplitude responses measured by each receiver coil appear reasonable and responses are not flat-lined or overly saturated

4. **Verify complete coverage of survey area.** 100% coverage surveys will require appropriate line spacing (presented in the AGCMR-QAPP and Site-Specific Work Plan). Data gaps resulting from obstacles or inaccessible terrain will be marked and verified by the data acquisition geophysicist. Data gaps exceeding the MQOs described in AGCMR-QAPP Worksheet 22 will be reacquired using RTK GPS and recollected.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

The following input data are required for performing a dynamic advanced EMI sensor survey:

- Site boundary coordinates
- IVS transect start and end point locations.

4.2 Output Data

Output data consist of the following:

- Dynamic advanced EMI sensor IVS data
- Dynamic advanced EMI sensor survey area data
- Daily function test data
- Field notes, including scanned pdf images of hand-written notes or digitally-recorded notes, as well as a digital spreadsheet containing data filenames as delivered and rectified field notes (in which differences between original field notes and delivered digital filenames and are resolved)

5 Quality Control

Quality Control (QC) of the dynamic data acquisition activities is limited to qualitative assessments of data quality and survey area coverage. Quantitative QC and assessment of the collected daily function test, IVS, and survey area data will be performed during data processing and analysis, as described in SOP AGCMR-06. The preparatory and initial QC checks for this SOP are performed during testing of the advanced EMI sensor at the IVS (SOP AGCMR-02). SOP AGCMR-02 verifies that the system is working properly and that the data acquisition team is acquiring data of adequate quality. Therefore, the acquisition of dynamic advanced EMI sensor survey data requires only follow-on QC inspections, which are documented as follows:

- The operating software automatically logs the identification of the Data Acquisition Geophysicist in each data file. By acquiring the data, and thereby taking responsibility for it, the Data Acquisition Geophysicist certifies compliance with the requirements of this SOP.
- The QC Geophysicist will observe data acquisition periodically and document the observation in the Daily Geophysics QC Report.

- The Data Acquisition Geophysicist will maintain a field log, which will be reviewed daily by the Data Processor to note issues that potentially affect data quality.

Daily data packages containing the geophysical data from that day will be reviewed by the Data Processor to ensure that the measurement quality objectives (MQO) are being achieved. A comprehensive root cause analysis will be performed, including a corrective action, if the Data Processor or QC Geophysicist determines that the MQO are not being met or if a trend toward the MQO limits is observed.

5.1 Measurement Quality Objectives

The MQO for acquisition of dynamic advance EMI sensor data are presented in Worksheet 22 of the AGCMR-QAPP. The advanced EMI sensor will not be used for production area data acquisition until it is able to meet these MQO or until the project team agrees on modifications to the MQO.

6 Reporting

Acquisition of dynamic advanced EMI sensor data will be documented through the completion of the follow-on QC checklist in Attachment 1. The follow-on checklist for this SOP will be completed by the QC Geophysicist to document the successful completion of equipment start-up and the IVS (SOP AGCMR-02) and the periodic observation of data acquisition. The completion of all checklists will be documented by the QC Geophysicist in the Daily Geophysics QC Report, and copies will be included with the advanced geophysical classification project report at the completion of the project.

Attachment 1

Follow-on Advanced EMI Sensor Dynamic Data Acquisition Checklist

Follow-on Advanced EMI Sensor Dynamic Data Acquisition Checklist

This checklist is to be completed by the QC Geophysicist during data acquisition activities. The operating software automatically logs the identification of the Data Acquisition Geophysicist in each data file. By acquiring the data, and thereby taking responsibility for it, the Data Acquisition Geophysicist certifies compliance with the requirements of this SOP. The QC Geophysicist will periodically observe the data acquisition process and will document the successful completion of this checklist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Has the Preparatory Advanced EMI Sensor Assembly Checklist (SOP AGCMR-01) been successfully completed?		
3. Function Tests	Were function tests performed, and did all function tests meet the MQOs in accordance with AGCMR-QAPP Worksheet 22?		
4. IVS Tests	Were dynamic surveys conducted over the IVS items at the start and end of the day with exceptions noted in the field notes?		
5. Sensor Navigation	Were valid dynamic data acquired along the intended transects with any exceptions or gaps in coverage noted in the field notes?		
6. Data Measurements	Was the advanced EMI sensor system transmit current monitored with any exceptions noted in the field notes?		
7. Field observation	Has the field observation been performed? Time:_________ Anomaly #s:________________		
8. Field documentation	Has the QC Geophysicist reviewed the day's data acquisition with the Field Geophysicist and reviewed the Field Geophysicist's log? Have any technical issues been noted?		
9. MPC documentation	Have the MPCs for dynamic advanced EMI sensor data acquisition been achieved in accordance with AGCMR-QAPP Worksheet 22?		

QC Geophysicist: ____ Date: _______________

STANDARD OPERATING PROCEDURE
AGCMR-06

Advanced EMI Sensor Dynamic Data Processing and Analysis

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON
ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when processing and analyzing dynamic survey data acquired by an advanced electromagnetic induction (EMI) sensor for target detection. Dynamic surveys include the acquisition of dynamic data over predetermined transects. Dynamic data are also acquired over instrument verification strip (IVS) targets for quality control (QC) verification. This SOP details the steps required to verify the quality of the acquired dynamic data and to process the data to detect targets in the subsurface. This SOP describes data processing and analysis of Geometrics MetalMapper, Geometrics MetalMapper 2x2, and U.S Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS) data. If other advanced EMI sensors are selected for use, this SOP will be updated to include cued data processing and analysis details for those systems.

The detection objectives and transect spacing for individual projects and survey areas are identified in the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP) and Site-Specific Work Plans. Processing the dynamic data involves processing and assessing daily function tests and instrument verification strip (IVS) surveys, leveling the raw data to remove EMI signal due to the self-signature of the sensor systems and the ambient EMI soil response, and target selection. Function test measurements and IVS surveys are conducted during initial setup of the advanced EMI sensor and on a daily basis to verify correct operation and functionality of the dynamic survey system.

The signal measured by the advanced EMI sensor is composed of the following three individual components:

1. the EMI response of buried metallic targets,
2. the self-signature of the sensor system, and
3. the response from the ambient environment in which the target is buried.

To isolate responses associated with discrete buried metal objects, a background model comprised of the sensor system self-signature and the ambient environment response must be derived and removed from the raw data. The remaining leveled signal data are used as inputs into a detection algorithm that identifies anomalous responses due to potential TOI, which are then mapped and selected for further investigation or removal.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Data processing computer suitable for and equipped to run the UX-Analyze Advanced (UXA) module of Geosoft’s Oasis Montaj geophysical processing environment

2.1 Personnel and Qualifications

The following individuals will be involved in the processing and analysis of dynamic advanced EMI sensor data for target detection:

- Data Acquisition Geophysicist
- Lead Data Processor
- QC Geophysicist

The minimum qualifications for the Data Acquisition and QC Geophysicists and the Lead Data Processor are listed in Worksheet 7 of the AGCMR-QAPP.

3 Procedures and Guidelines

This section describes the procedures used to process dynamic advanced EMI sensor data including positioning and leveling of the data, processing and selecting target anomalies, and verification of the data quality through processing and assessment of daily QC measurements.

3.1 Advanced EMI Sensor Dynamic Data Processing

Advanced EMI sensors are composed of multiple transmit (Tx) and receive (Rx) coils in different orientations and positions within the sensor platform. As each Tx coil transmits, the response is measured at every Rx coil, resulting in measured data that is composed of numerous Tx/Rx combinations. This rich dataset provides the advantage of advanced EMI sensors over traditional geophysical sensors but also necessitates more involved and time-consuming processing and analysis of the data. Typical advanced EMI sensor detection surveys therefore utilize only the monostatic Z-component EMI measurements. This means that rather than analyzing every Tx/Rx combination, only the response at the Rx coil associated with the transmitting Tx coil (monostatic) and only the Tx and Rx coils oriented horizontally (Z-component) are used.

The processing of dynamic advanced EMI sensor data involves the following steps:

- Data import and QC
- Data positioning and background removal
- Target selection

3.1.1 Data Import and Initial QC

Advanced EMI sensor data files are imported into a Geosoft database in UXA, where they are inspected and assessed against the measurement quality objectives (MQO) described in Worksheet 22 of the AGCMR-QAPP and the Site-Specific Work Plan. The following data quality indicators are reviewed:

- Transmit current
- Global positioning system (GPS) fit quality
- Inertial measurement unit (IMU) data
- EMI response signal not saturated

Data measurements that do not meet the MQOs are identified and flagged by a series of scripts that maintain the chronologic integrity of the EMI data but prevent the out-of-specification data from being mapped and used for detection.

3.1.2 Data Positioning and Leveling

Coordinate positions are automatically assigned to the EMI measurements based on the GPS antenna location, platform geometry and platform attitude data (from the IMU). A site-specific de-median filter is applied to the raw data to derive a model that estimates the background response at the site. This background model is then subtracted from the raw data to provide a leveled data set with the background response component removed.

3.1.3 Target Selection

After leveling the data to remove the background response, the leveled data is gridded and mapped for target selection. Traditional anomaly selection is based almost entirely on signal response amplitude. Using the response amplitude of the monostatic Z-component of the advanced EMI sensor data as a detection metric is similar to traditional EM61 response amplitude detection. After the data have been leveled and gridded, the peak detection algorithm in Oasis Montaj is used to extract locations of all grid response peaks greater than the project detection threshold. These target anomaly locations are reviewed by the data processor, and manual additions and deletions may be made to the target list. The target list is reviewed by the QC Geophysicist prior to finalization.

3.2 Advanced EMI Sensor Data Quality Verification

Verification of the advanced EMI sensor data quality is accomplished through the processing and assessment of daily QC measurements. Daily function tests (described in SOP AGCMR-05) and IVS surveys (described in SOP AGCMR-02) are performed to verify the operation of the sensor system and the quality of the measured data. The processing and assessment of these daily tests is described below.

3.2.1 Function Test Measurement Processing

A function test measurement (described in SOP AGCMR-05) is performed prior to each data acquisition session to confirm that all Tx and Rx components of the advanced EMI sensor are functioning properly. The data from each function test are assessed relative to the MQO presented in AGCMR-QAPP Worksheet 22. Worksheet 22 also identifies the actions to be taken if function tests do not meet the MQO. Dynamic data associated with failed function tests will not be used for target detection until these MQO are met, or until the project team agrees on modifications to the MQO, and may need to be reacquired.

3.2.2 Daily IVS Survey Processing

Twice daily during dynamic data acquisition activities (prior to the start of daily data acquisition and following the completion of daily data acquisition) a dynamic IVS survey is performed as described in SOP AGCMR-02. The IVS survey data are positioned, leveled, and processed in the same manner as the detection survey data described in Section 3.1.2. The data from each IVS survey are assessed relative to the MQO presented in AGCMR-QAPP Worksheet 22. Worksheet 22 also identifies the actions to be taken if Daily IVS surveys do not meet the MQO. Dynamic data associated with failed daily IVS surveys will not be used for target detection until these MQO are met, or until the project team agrees on modifications to the MQO, and may need to be reacquired.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for processing dynamic advanced EMI sensor data include the following:

- Raw dynamic advanced EMI sensor data files (daily function test data, daily dynamic IVS survey data, and dynamic detection survey data)
- Minimum amplitude response detection threshold (from the AGCMR-QAPP or Site-Specific Work Plan)

4.2 Output Data from Data Verification

Output data from the verification of daily dynamic advanced EMI sensor data quality include the following:

- QC report including documentation of performance relative to Worksheet 22 of the AGCMR-QAPP for the following:
    - Daily IVS results
    - Daily Function test results

4.3 Output Data from Detection Data Processing and Analysis

Output data from the processing and analysis of dynamic advanced EMI sensor detection data include the following:

- Mapped detection metric data (monostatic Z-component amplitude) in ASCII (x,y,z) format
- Target anomaly list with unique target ID and X and Y coordinates
- Geosoft databases for processed advanced EMI sensor data and identified targets
- QC seed detection results
- Description of processing approach details, including leveling and target selection procedures, to be included in the final report

5 Quality Control

Dynamic advanced EMI sensor data verification and analysis requires follow-on QC inspections that will be documented on the Follow-on Advanced EMI Sensor Dynamic Data Verification Checklist and Follow-on Advanced EMI Sensor Dynamic Data Processing and Analysis Checklist that are included as Attachments 1 and 2 to this SOP. The checklists will be completed by the QC Geophysicist and documented in the Daily QC Report.

5.1 Measurement Quality Objectives

The MQO for dynamic advanced EMI sensor data processing and analysis are presented in Worksheet 22 of the AGCMR-QAPP (including MQO for daily IVS and function test performance as well as for detection data quality). Performance relative to the MQO will be assessed during the processing and analysis of the data. Dynamic advanced EMI sensor data will not be used for target detection until these MQO are met or until the project team agrees on modifications to the MQO.

6 Reporting

Verification of dynamic advanced EMI sensor data processing and analysis will be documented through the completion of the follow-on QC checklists in Attachments 1 and 2. The follow-on checklists for this SOP will be completed by the QC Geophysicist and documented in the Daily Geophysics QC Report, and copies will be included with the final report at the completion of the project. The final advanced geophysical classification report will detail the specific approach to classification including final library make-up, cut-off threshold, cluster analysis approach and results, and feature space analysis approach and results.

Attachment 1
Follow-on Advanced EMI Sensor Dynamic Data Verification Checklist

Follow-on Advanced EMI Sensor Dynamic Data Verification Checklist

This checklist is to be completed by the QC Geophysicist for each daily advanced EMI sensor data verification event during dynamic data acquisition activities. The QC Geophysicist will document the successful completion of this checklist in the Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Function tests	Has the functionality of the advanced EMI sensor components been verified for each dynamic data acquisition event using function tests, and did the function test results meet the associated MQO from AGCMR-QAPP Worksheet 22?		
2. IVS tests	Has the functionality of the advanced EMI sensor system been verified for each dynamic data acquisition event using IVS survey collected on the same day, and have the IVS survey results met the associated MQO from AGCMR-QAPP Worksheet 22 and the SOP AGCMR-02 Follow-On Daily Cued IVS Checklist?		
3. Reporting	Have daily data quality results been reported in the QC Report?		

QC Geophysicist: ____ Date: ______________

Attachment 2

Follow-on Advanced EMI Sensor Dynamic Data Processing and Analysis Checklist

Follow-on Advanced EMI Sensor Dynamic Data Processing and Analysis Checklist

This checklist is to be completed by the QC Geophysicist for each daily advanced EMI sensor dynamic data processing event. The QC Geophysicist will document the successful completion of this checklist in the Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Data validity	Were invalid data, based on transmit current, GPS fit quality, IMU data quality, and EMI response range, for each data acquisition event identified and rejected?		
2. Coverage	Were gaps in data coverage due to down-line and across-line sampling identified and accounted for?		
3. Data leveling (background removal)	Was the background model inspected prior to leveling the raw data, and was the leveling process reviewed by the QC Geophysicist?		
4. Target selection	Was the final target list reviewed by the data processor and the QC Geophysicist?		
5. Reporting	Have the following documents been completed, reviewed, and delivered? • Mapped detection metric data • Target anomaly list • Geosoft databases for processed advanced EMI sensor data and identified targets • QC seed detection results		

QC Geophysicist: ____ Date: _____________

STANDARD OPERATING PROCEDURE
AGCMR-07

Advanced EMI Sensor Cued Data Acquisition

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when acquiring cued measurements using an advanced electromagnetic induction (EMI) sensor for geophysical classification. Cued data acquisition involves navigating the sensor to the precise anomaly location, collecting static, advanced EMI sensor data at this location, and verifying the integrity and validity of the collected data. Verification includes using the sensor data to derive an estimate of the target position relative to the center of the sensor. If this position estimate falls outside a predetermined threshold, the sensor will be repositioned, and a second data acquisition event will be performed. This SOP describes cued data acquisition with the Geometrics MetalMapper, Geometrics MetalMapper 2x2, and U.S Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS) systems. If other advanced EMI sensors are selected for use, this SOP will be updated to include cued data acquisition details for those systems.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Advanced EMI sensor coupled with a real-time kinematic global positioning system (RTK GPS) and inertial measurement unit (IMU) for orientation measurements
- The target list with unique IDs and locations to be investigated
- Data processing computer suitable for and equipped to run the UX-Analyze Advanced module of Geosoft's Oasis Montaj geophysical processing environment

2.1 Personnel and Qualifications

The following individuals will be involved in cued advanced EMI data acquisition and evaluation:

- QC Geophysicist
- Data Acquisition Geophysicist
- Lead Data Processor

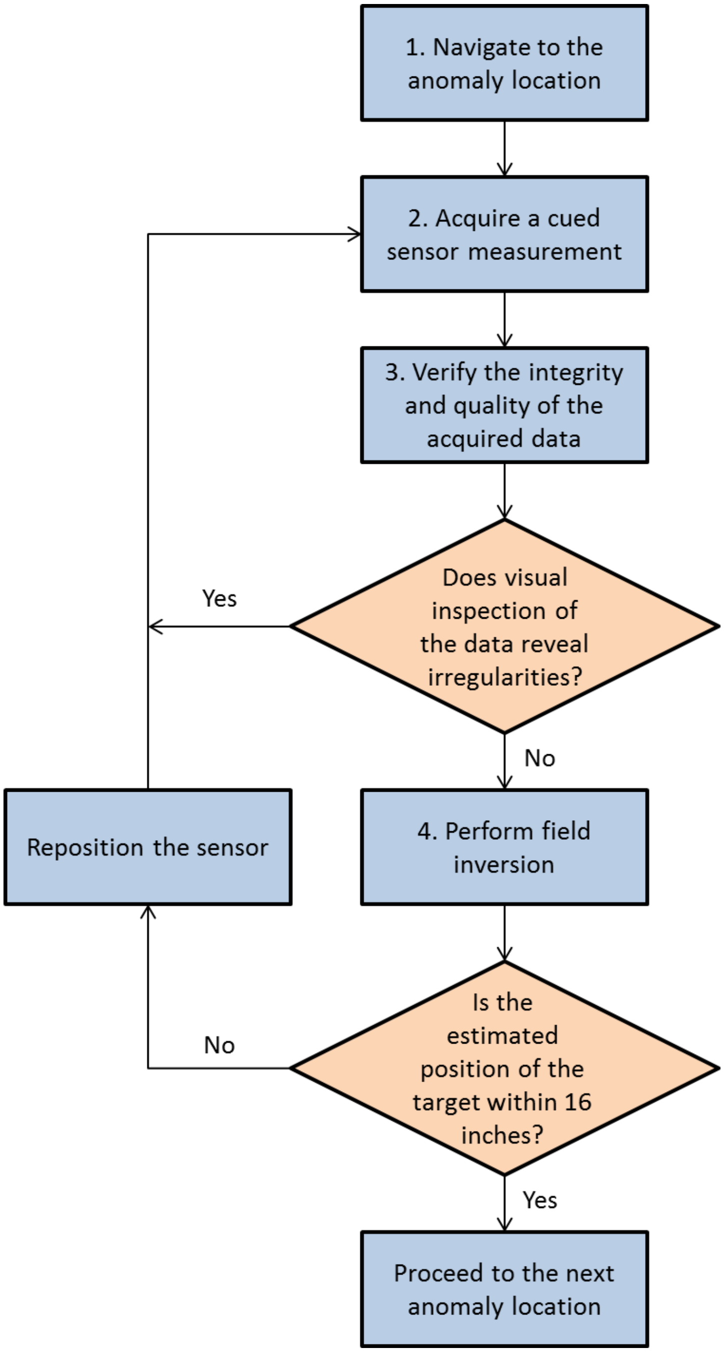
The minimum qualifications for the Data Acquisition and QC Geophysicists and the Lead Data Processor are listed in Worksheet 7 of the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP).

3 Procedures and Guidelines

Cued investigation for advanced geophysical target classification involves positioning the advanced EMI sensor and acquiring static measurements over a pre-identified set of anomalies. In combination with SOPs for advanced EMI sensor assembly (SOP AGCMR-01), testing at the instrument verification strip (IVS) (SOP AGCMR-02) and background measurement acquisition (SOP AGCMR-04), a set of static data measurements are acquired using the advanced EMI sensor over each anomaly. At each anomaly, data acquisition will be performed in accordance with the steps shown on **Figure 1**.

Prior to cued data acquisition, the correct operation of the geophysical sensor and navigation and orientation systems must be verified at the IVS as described in SOP AGCMR-02. This will be verified by completion of the Follow-on Cued Daily IVS Checklist attached to SOP AGCMR-02.

Figure 1. Cued data acquisition process



The following is a description of each step shown above:

1. **Navigate to the anomaly location**. Anomaly locations will be loaded into the advanced EMI sensor data acquisition computer (or physically marked) prior to data acquisition operations to allow navigation to each anomaly location through the use of the RTK GPS positioning system and the data acquisition software. The initial measurement will be recorded at the provided anomaly location as indicated by precisely aligning the center of the sensor over the provided anomaly location.

2. **Acquire a cued sensor measurement**. Initiate the acquisition of a measurement. During data acquisition, the sensor must remain stationary, and all external sources of electromagnetic signals must be kept away from the sensor.

   Any metal associated with the sensor and deployment mechanism (e.g., console, support structures) that cannot be reasonably distanced from the sensor must be kept in the same physical location with respect to the sensor as during background measurements.

3. **Verify the integrity and quality of the acquired data.** Immediately after data acquisition, the integrity and quality of the data will be verified by the operator by inspection of the data acquisition screen to ensure the following:

   - The data acquisition cycle completed properly
   - The transmit current for each transmitter was within the acceptable range specified in the AGCMR-QAPP
   - The decay curves measured by each receiver coil appear reasonable (i.e., decay curve displays are not 'flat-lined')
   - GPS and IMU information have been recorded

4. **Perform a field inversion**. Valid inversion results require that the target is located within 16 inches of the center of the sensor array for most advanced EMI sensor surveys. The initial target horizontal position may be significantly offset from the center of the sensor for the following reasons:

   - Positioning errors in the initial detection survey
   - Imprecision in the derivation of the anomaly position from the detection survey data
   - Imprecision in the reacquisition of the anomaly
   - Imprecision in positioning the sensor
   - The presence of multiple anomaly sources in relatively close proximity

   This step includes performance of an in-field inversion and inspection of the results to verify that the estimated horizontal target location is within 16 inches of center of the sensor array. After initiating the in-field inversion algorithm, an estimate of the target location relative to the center of the sensor array is provided. If the offset is greater than 16 inches, position the sensor over the target location estimate provided by the in-field inversion (visually or using the RTK GPS data) and repeat **Steps 2** and **3**.

   This recollection should only be performed once. Assuming the repositioning was performed accurately, if the subsequent position estimate is still greater than 16 inches from the center of the sensor array, the cause is likely to be multiple anomaly sources, and additional data collection and data analysis may be required after further analysis by the Data Processor.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for this SOP includes an anomaly list consisting of anomaly IDs and location coordinates to load into the advanced EMI sensor data acquisition computer (or previously-flagged anomaly locations).

4.2 Output Data

Output data consist of one raw sensor data file (.tem or .hdf5) for each anomaly measured. The data files will be transferred daily (or more often as dictated by site procedures) to the Data Processor.

5 Quality Control

The preparatory and initial QC checks for this SOP are performed during testing of the advanced EMI sensor at the IVS (SOP AGCMR-02). SOP AGCMR-02 verifies that the advanced EMI sensor is working properly and that the field geophysical team is acquiring data of adequate quality. Therefore, the acquisition of cued advanced EMI sensor data requires only follow-on QC inspections, which are documented as follows:

- The operating software automatically logs the identification of the Data Acquisition Geophysicist in each data file. By acquiring the data, and thereby taking responsibility for it, the Data Acquisition Geophysicist certifies compliance with the requirements of this SOP.
- The QC Geophysicist will observe data acquisition periodically and document the observation in the Daily Geophysics QC Report.
- The Data Acquisition Geophysicist will maintain a field log, which will be reviewed daily by the Data Processor to note issues that potentially affect data quality.

Daily data packages containing the geophysical data from that day will be reviewed by the Data Processor to ensure that the measurement quality objectives (MQO) are being achieved. A comprehensive root cause analysis will be performed, including a corrective action, if the Data Processor or QC Geophysicist determines that the MQO are not being met or if a trend toward the MQO limits is observed.

5.1 Measurement Quality Objectives

The MQO for acquisition of cued target measurements are presented in Worksheet 22 of the AGCMR-QAPP. The advanced EMI sensor will not be used for production area data acquisition until it is able to meet these MQO or until the project team agrees on modifications to the MQO.

6 Reporting

Acquisition of cued target measurements will be documented through the completion of the follow-on QC checklist in Attachment 1. The follow-on checklist for this SOP will be completed by the QC Geophysicist to document the successful completion of equipment start-up and the IVS (SOP AGCMR-02) and the periodic observation of data acquisition. The completion of all checklists will be documented by the QC Geophysicist in the Daily Geophysics QC Report, and copies will be included with the advanced geophysical classification project report at the completion of the project.

Attachment 1

Follow-on Advanced EMI Sensor Cued Data Acquisition Checklist

Follow-on Advanced EMI Sensor Cued Data Acquisition Checklist

This checklist is to be completed by the QC Geophysicist during data acquisition activities. The operating software automatically logs the identification of the Data Acquisition Geophysicist in each data file. By acquiring the data, and thereby taking responsibility for it, the Data Acquisition Geophysicist certifies compliance with the requirements of this SOP. The QC Geophysicist will periodically observe the data acquisition process and will document the successful completion of this checklist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Qualifications	Are the same geophysical personnel being used as in SOP AGCMR-01? If not, are the qualifications of the new personnel in compliance with the requirements of AGCMR-QAPP Worksheet 7?		
2. Preparation	Has the Preparatory Advanced EMI Sensor Assembly Checklist (SOP AGCMR-01) been successfully completed?		
3. Preparation	Has the Follow-on Daily Cued IVS Checklist (SOP AGCMR-02) been successfully completed?		
4. Field observation	Has the field observation been performed? Time:_________ Anomaly #s:________________		
5. Field observation	Have background measurements been acquired at appropriate background locations and time intervals in accordance with Worksheet 22?		
6. Field documentation	Has the QC Geophysicist reviewed the day's data acquisition with the Field Geophysicist and reviewed the Field Geophysicist's log? Have any technical issues been noted?		
7. MPC documentation	Have the MPCs for cued advanced EMI sensor data acquisition been achieved in accordance with AGCMR-QAPP Worksheet 22?		

QC Geophysicist: ____ Date: _______________

STANDARD OPERATING PROCEDURE AGCMR-08

Advanced EMI Sensor Cued Data Processing and Analysis

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 3

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when processing and analyzing cued measurements acquired by an advanced electromagnetic induction (EMI) sensor for geophysical classification. Cued surveys include the acquisition of cued data over predetermined anomaly locations and background measurements. Cued data are also acquired over instrument verification strip (IVS) targets for quality control (QC) verification. This SOP details the steps required to verify the quality of these measurements, process the acquired data to derive features related to the physical characteristics of the anomaly sources, and use these features to classify the targets. This SOP describes data processing and analysis of cued Geometrics MetalMapper, Geometrics MetalMapper 2x2, and U.S Naval Research Laboratory (NRL) TEMTADS MP 2x2 (TEMTADS) data. If other advanced EMI sensors are selected for use, this SOP will be updated to include cued data processing and analysis details for those systems.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Data processing computer suitable for and equipped to run the UX-Analyze Advanced (UXA) module of Geosoft's Oasis Montaj geophysical processing environment

2.1 Personnel and Qualifications

The following individuals will be involved in the processing and analysis of cued MetalMapper data for advanced analysis and classification:

- Data Acquisition Geophysicist
- Lead Data Processor
- QC Geophysicist

The minimum qualifications for the Data Acquisition and QC Geophysicists and the Lead Data Processor are listed in Worksheet 7 of the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP).

3 Procedures and Guidelines

3.1 Data Verification

3.1.1 Data Conversion

Raw advanced EMI sensor data files in .tem format must be converted to ASCII.csv format prior to data processing and analysis. The conversion is accomplished using TEM2CSV, a purpose-built software utility. The TEM2CSV conversion window is shown on **Figure 1**.

Figure 1. TEM2CSV utility for conversion of raw advanced EMI sensor .tem files to ASCII .csv file format

The coordinate system, coordinate correction and file prefix must be set to project specific parameters prior to selecting files for conversion. The output .csv filenames must contain the anomaly ID in the last part of the filename, for example, if the file name is Test_1020_11.csv, the ID would be 11.

Any cued measurement documented in the field notes as having the incorrect anomaly ID logged during data acquisition must have the filename corrected to contain the correct ID, and the anomaly ID field in the .csv file must be updated to that value. The anomaly ID cannot be corrected in the .tem file.

The background measurement filename should not be entered in the TEM -> CSV dialog. This correction will be applied later using UXA.

Raw advanced EMI sensor data files in HDF5 format do not require conversion prior to data processing and analysis.

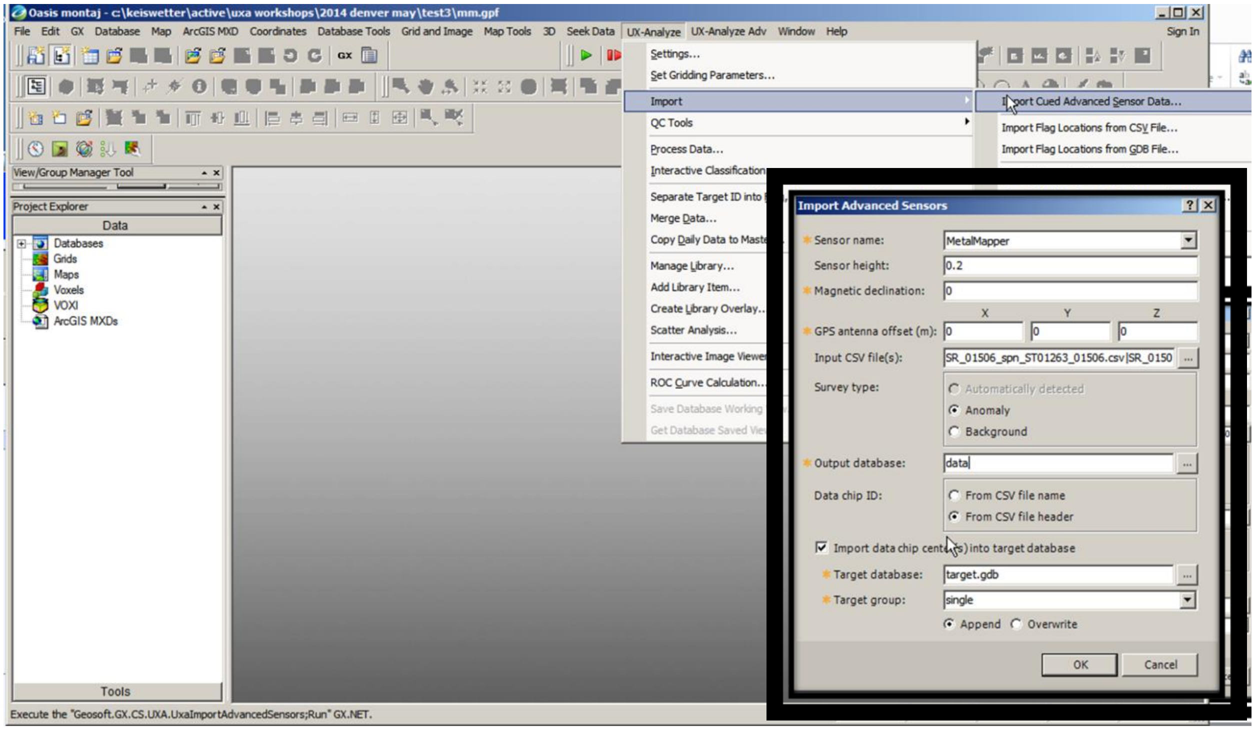
3.2.2 Data Import and Initial Data Checks

Data processing and analysis are conducted using the UXA module within Geosoft's Oasis Montaj geophysical processing environment. Prior to importing advanced EMI sensor data, the data processor specifies general settings in UXA to define the data acquisition parameters for the survey, including settings such as survey mode (static or dynamic), database names, and distance units). After initial setup of the UXA project, the data processor imports data into the following four separate databases:

- Cued background measurement data
- Background features
- Cued anomaly measurement data
- Target features

Cued advanced EMI sensor data is imported into separate databases for anomaly and background measurements using import routines in UXA, as shown on **Figure 2**. The target features database initially contains the locations of each surveyed anomaly but will subsequently be populated with summaries of the derived feature and classification information for each target. The background features database initially contains the locations of each background measurement but will subsequently be populated with statistics and quality control check values.

Figure 2. UX-Analyze Advanced data import window



After importing the cued data, the data processor verifies the quality of the measurements against the measurement quality objectives (MQO) provided in Worksheet 22 of the AGCMR-QAPP for the following characteristics:

- Transmit (Tx) current within limits
- Global positioning system (GPS) fix quality
- Valid inertial measurement unit (IMU) data
- EMI response signal not saturated
- Offset of acquisition location from flag/anomaly list location

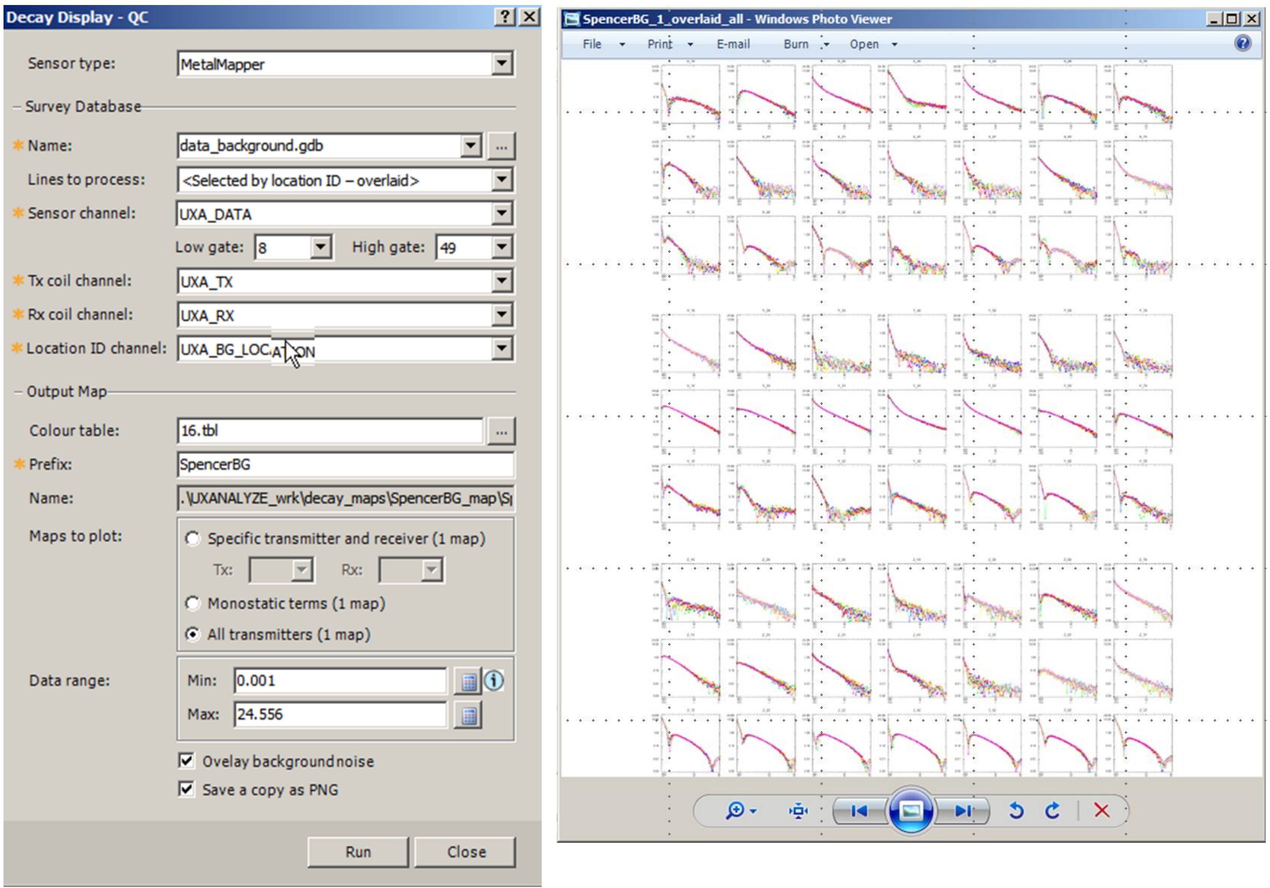
3.2.3 Background Corrections

Background corrections are used to remove the portions of the measured response that are caused by the advanced EMI sensor system and the soil response from the measured anomaly data. Background measurements are acquired at locations selected from the detection survey data that are verified to be free of metal. Each background measurement is also verified as suitable prior to using it for background correction of the target measurement data as described in SOP AGCMR-04 Section 3.1.

3.2.3.1 Background Location Verification

The data processor verifies the suitability of each background location by analyzing a set of 5 measurements taken at the intended location: one measurement at the location and one each with the sensor offset by 15 inches in each cardinal direction, as described in SOP AGCMR-04. The background measurements are analyzed using the UXA decay display utility and considered valid if the signal amplitudes for all measured decays are below the threshold chosen for the project. Images of the decay curves are saved for presentation in a background summary report. The UXA decay display utility is shown on **Figure 3**.

Figure 3. UX-Analyze Advanced decay display utility and example decay comparison plot



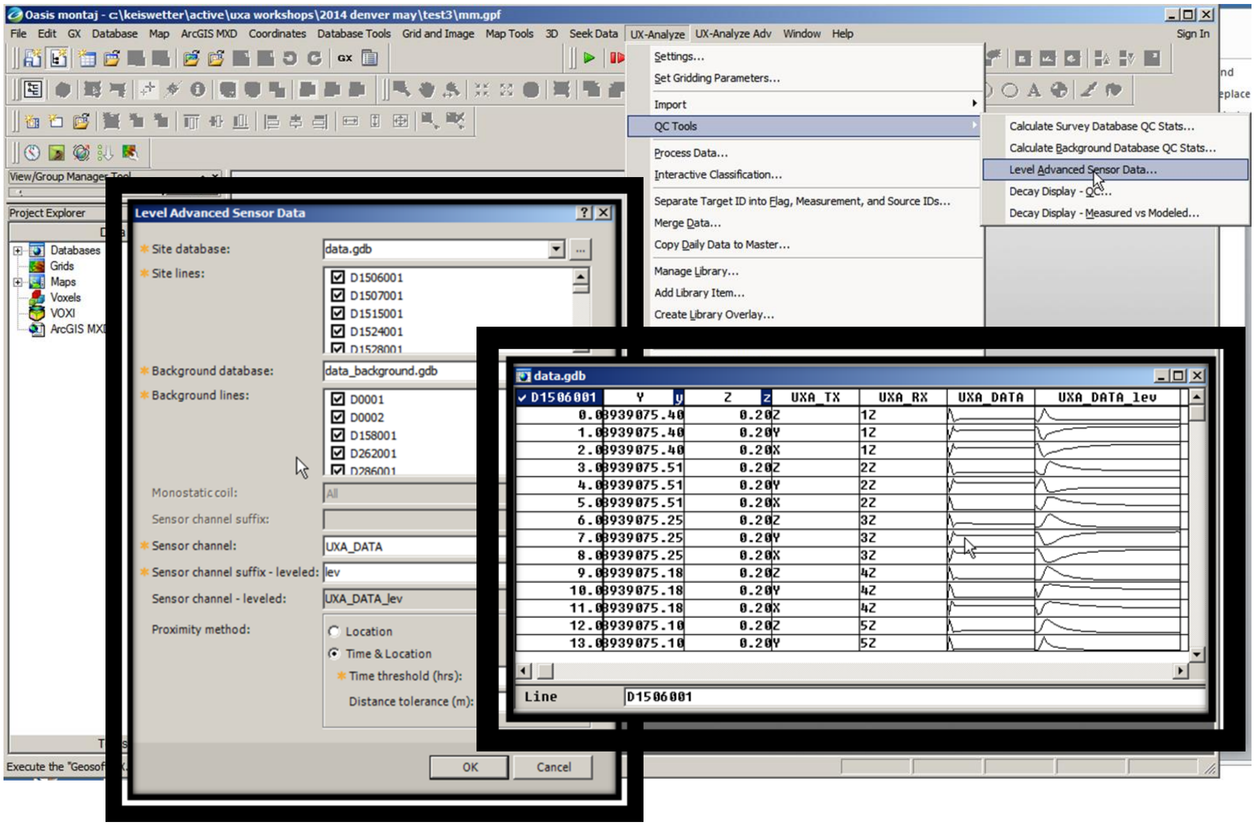
3.2.3.2 Background Measurement Verification

The data processor verifies each individual background measurement prior to its use for background correction. Each background measurement is qualitatively compared to the initial background verification measurement at that location using the UXA decay display QC utility and all decays are checked to be lower than the project threshold. Images of the decay curves are saved for presentation in a background summary report. Invalid measurements are removed from the background database to ensure that they are not used.

3.2.3.3 Background Corrections

After verification that individual background measurements are valid, the data processor subtracts the appropriate background correction from each target data measurement using the UXA level advanced sensor data utility. The background correction utility identifies the closest background (chronologically and spatially) to each target measurement. Only background corrections acquired within 2 hours of a target measurement are used to correct that measurement to ensure that background data measurements are most likely to mimic target measurement conditions. The background- corrected data are stored in the “UXA_Data_Lev” channel in the database and will be used for the subsequent inversion processes to derive target features. This data channel is not populated for those target measurements that do not have a suitable background measurement within the 2 hour time limit. The UXA level advanced sensor data utility is shown on **Figure 4**.

Figure 4. UX-Analyze Advanced Level advanced sensor data utility



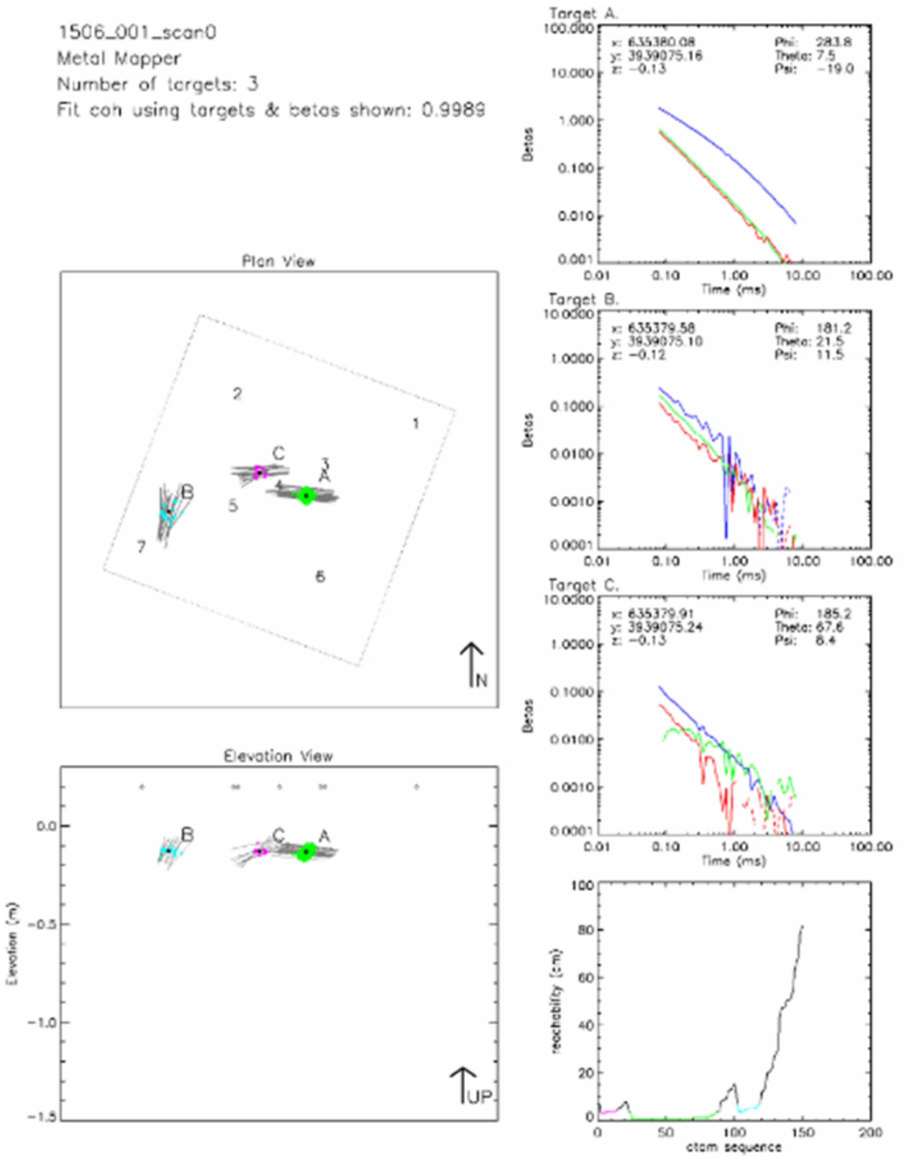
3.2.4 Target Feature Estimation

After background corrections are applied, the data processor estimates the intrinsic and extrinsic features for the target anomalies using the UXA process data interface. UXA applies single-target and multi-target inversion routines to determine the parameters of a target (single-target inversion), or of a group of targets (multi-target inversion), that would produce responses that closely match the observed responses. These parameters include extrinsic parameters (location and orientation) as well as the intrinsic parameters related to the object size, shape and composition. The intrinsic parameters, in the form of principal axis polarizabilities, also known as betas (β), are used for classification. Size and decay parameters at specific time gates are also calculated.

As the names suggest, the single-target inversion solves for a single target as the anomaly source, and the multi-target inversion assumes that the measured anomaly is the result of multiple targets. The multi-target solver not only presupposes multiple sources but will also produce a number of candidate realizations of targets. Each candidate realization proposes a configuration of targets whose modeled response reasonably fits the observed data. For example, one candidate realization may have three targets, while a second candidate realization for the same measurement may have two or four targets. This process reflects the fact that, with an unknown number of potential targets of different sizes and shapes, a number of different models can closely match the observed data. A separate fit coherence value, which measures the degree of fit to the observed data, is derived for each multiple-target candidate realization as well as for the single target model.

An example inversion fit summary is shown on **Figure 5**.

Figure 5 Example UX-Analyze Advanced inversion fit summary



Model results will only be used for classification if they meet the MQO in Worksheet 22 of the AGCMR-QAPP to verify that they are of sufficient quality to support classification.

3.2.5 Review of Processed and Modeled Data

A preliminary library match using the single source modeled parameters is performed as part of data verification to assist in determining the usability of the data and ensure that cued advanced geophysical classification survey MQOs have been satisfied.

Graphic decision plots that display a summary of measured and modeled data associated with each cued measurement are evaluate along with the targets feature database for the following:

- Tx current
- GPS fix is valid
- IMU reading is valid or correctable based on field notes
- Offset from flag is within MQO
- Fit error is acceptable
- Fit coherence is within MQO
- Size and decay are reasonable
- Library match is successful

If any readings fail to meet the MQOs a request for recollection will be sent to the field crew along with the reason, such as a request for the instrument to be located closer to the apparent source.

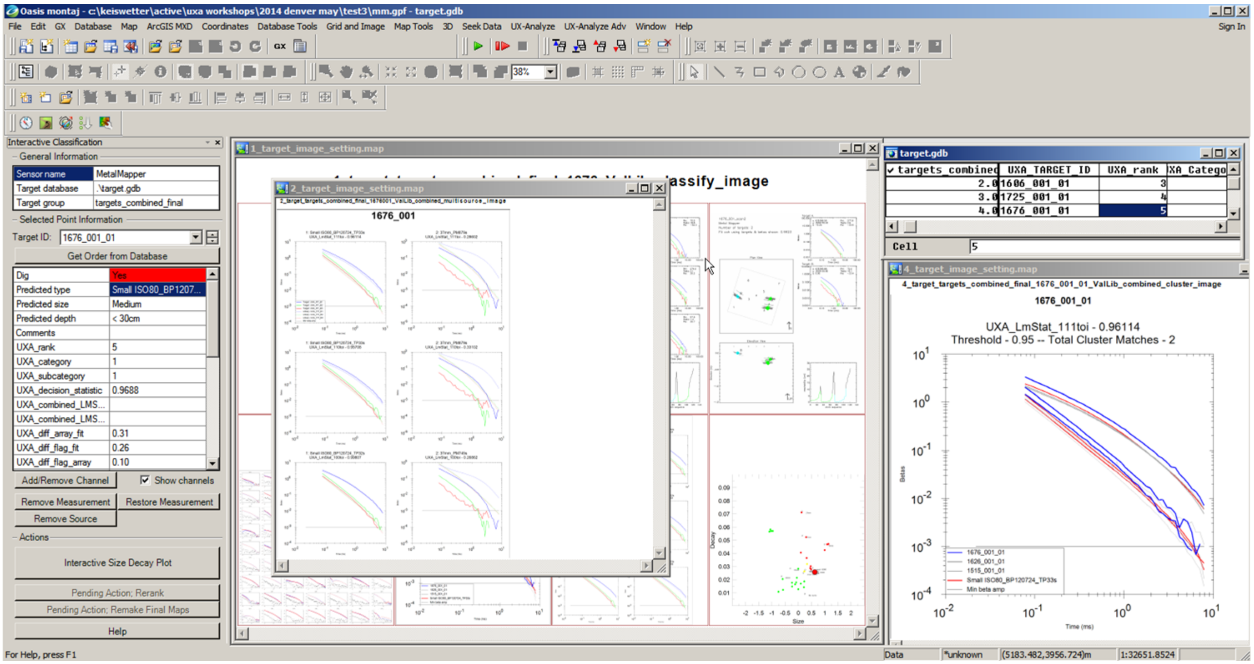
3.4 Daily IVS Survey

At the beginning and at the end of each day of data acquisition, cued measurements are acquired at each IVS target location, as described in SOP AGCMR-02. The IVS measurements are processed as described above, and the derived features are assessed against the MQO presented in Worksheet 22 of the AGCMR-QAPP. The results are documented and summarized in a QC report to accompany the classification list.

3.5 Classification

Advanced geophysical classification of targets is based upon objective, quantitative criteria. Using these criteria, a prioritized list is created with high likelihood targets of interest (TOI) placed at the top of the list (just after digs classified as "cannot analyze") and high likelihood non-TOI placed at the bottom of the list. "Cannot analyze" targets are those for which the measured data cannot support a confident classification decision. Because these targets cannot confidently be identified as non-TOI, they must be excavated. The primary method for classification is library matching, supplemented by cluster analysis and feature space analysis. The UXA interactive classification utility display shown on **Figure 6** provides an example of the data outputs that are considered in the classification decision metric.

Figure 6. UX-Analyze Advanced interactive classification utility



3.5.1 Library Matching

Advanced geophysical classification is based primarily on the fit metric (values from 0.0 to 1.0, with 1.0 representing a perfect match) generated by UXA during a comparison of the β values estimated for each surveyed target and the β values of the items in the munitions library developed for the project. The comparison is performed via the library match utility in UXA. The fit metric is a measure of the fit correlation between a target and the library entry that best fits that target, with higher values indicating a better fit between the target and the corresponding item in the library. The library fit analysis matches the following four combinations of βs to those of the candidate library TOI:

- β1, β1/β2, β1/β3
- β1, β1/β2
- β1/β2, β1/β3
- β1

The confidence metrics for each fit combination are averaged to derive a decision metric.

Single- and multi-source models are used during the inversion process for each flagged location. The results of all the models are compared against the library signatures, and the most conservative result, aka the result that is most similar to a TOI, is saved. Once completed, the targets are ranked, or ordered, from TOI to non-TOI according to their library-match comparison values. Library-match comparison values below the project decision metric threshold, which is nominally around 0.8, are considered non-TOI.

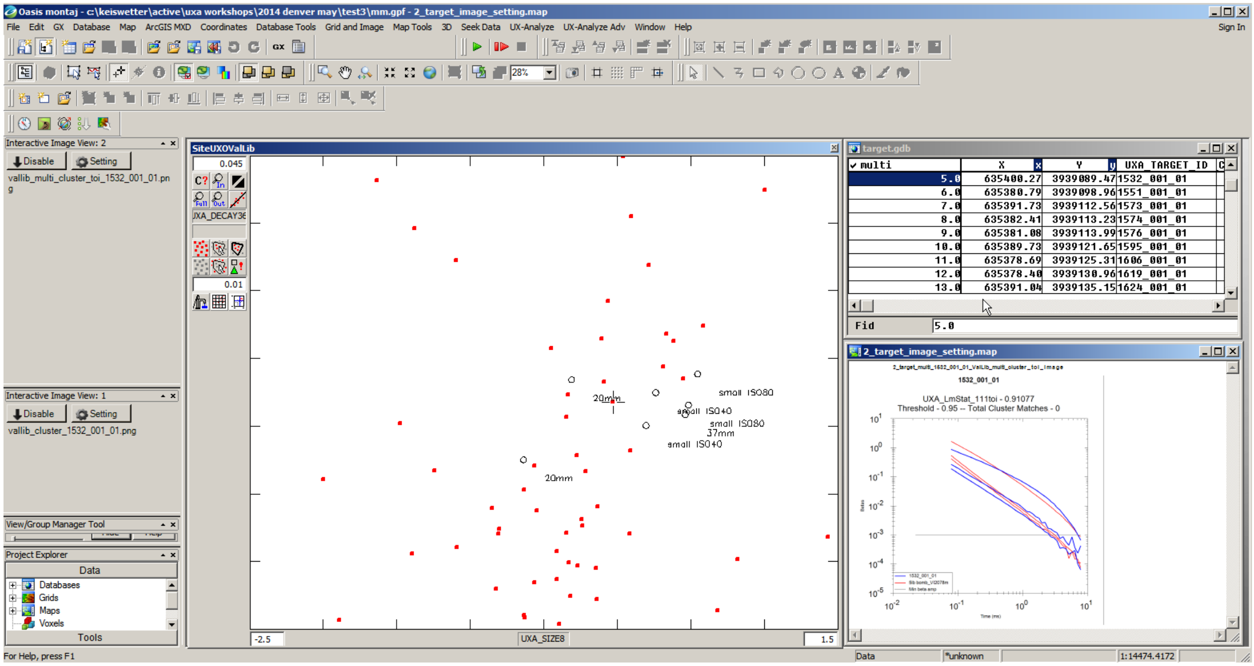
The intrusive investigation results of the training digs identified by the analyst as well as decision metrics derived for other known TOI (IVS and QC seed items) are used to finalize the decision metric threshold.

3.5.2 Cluster Analysis/Feature Space Analysis

Cluster analyses are performed using the UXA scatter analysis utility to identify clusters of anomalies with similar β signatures. The same library matching method as described above is used. However, instead of using a known TOI signature library, a “self-match” of each measured anomaly is performed.

Cued measurements with a confidence metric above the selected cluster threshold are identified and reviewed along with a size-decay feature space plot to determine if they represent a grouping of unique signatures that may represent a TOI that is not contained in the initial library. For each identified cluster, the data processor selects a representative sample to be intrusively investigated as part of the training data. If the intrusive investigation identifies a potentially hazardous item that should be on the TOI list, a representative signature is placed in the site-specific library, and the library matching process is repeated to ensure that all items with similar β signatures are classified as TOI. An example of the UXA scatter analysis results is shown on **Figure 7**.

Figure 7. Example UX-Analyze Advanced scatter analysis results



Individual items that do not match any library items but have β signatures that indicate large, axially-symmetric, thick-walled objects are identified and investigated as part of the training data and added to the library if they are identified as TOI.

3.5.3 Library Validation and Site-Specific Munitions Library

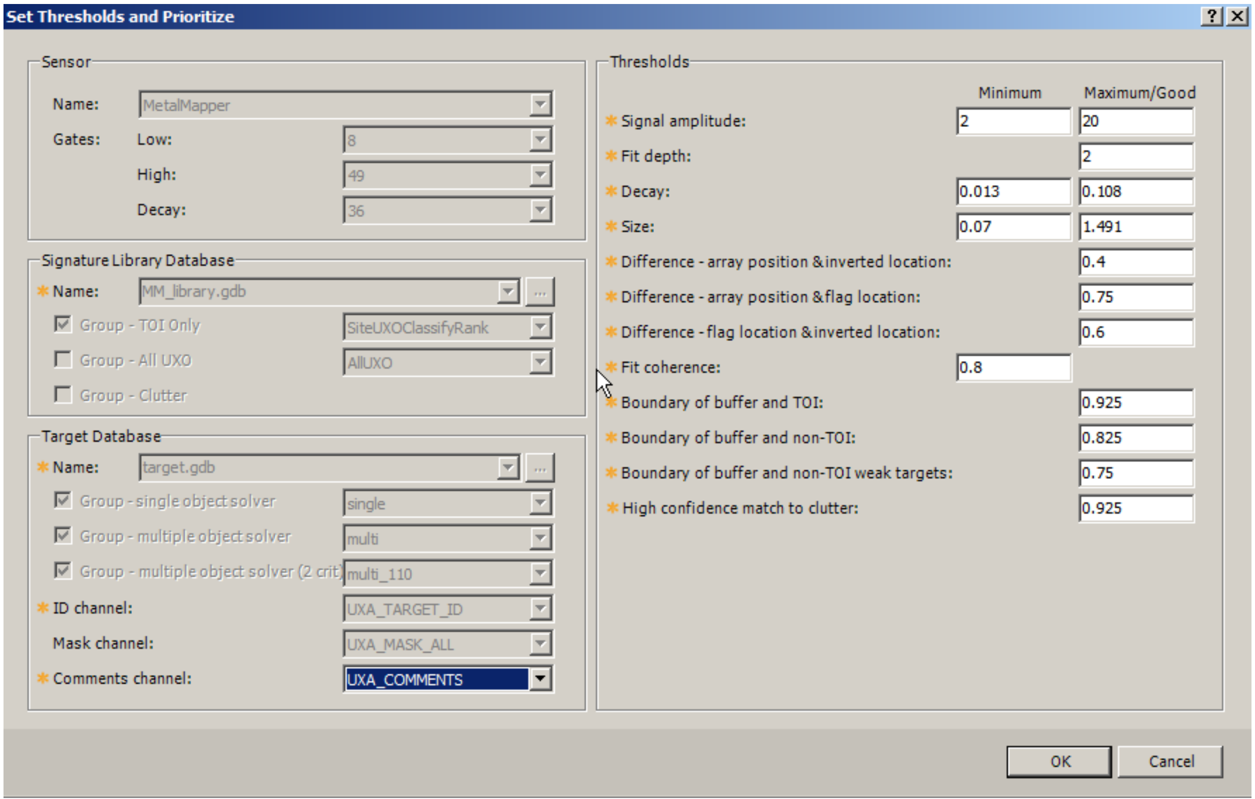
A site-specific library of βs for candidate munitions items identified in the conceptual site model (CSM) is used for classification. Intrinsic parameters for items listed in the CSM not confirmed to be in the existing munitions library will be derived from test measurements prior to the start of the advanced geophysical classification process and added to the library.

3.5.4 Threshold Selection and Classification Expressions

Initial threshold selection values will be evaluated during preliminary library matching and cluster analysis and will incorporate system performance observed at the test pit and IVS. A partial ranked list of approximately the first two weeks of survey data will be generated to demonstrate the initial thresholds and classification expressions to ensure the process is accurately classifying QC seed items. The classification expressions contain the logic for sorting the ranked target list; initial expressions are provided with the UXA module and can be customized to best suit the project goals. Further refinement of the analysis process may occur at this time, and details of the classification process will be documented in a target classification report.

3.5.5 Classify and Rank

The UXA tool to perform advanced geophysical classification and ranking of targets allows for user input of selected thresholds and applies the selected classification expressions to rank the targets.



All single and multi-solver results will be consolidated into a ranked list with a single entry for each anomaly ID on the target list within the target features database. Decision plots displaying measured and modeled data along with the target features database will be reviewed with the interactive classification tool by the data processor to refine the sorting of the prioritized target list. This function is run twice each time a prioritized list is generated. The first iteration ranks the targets and generates plots for the data processor to review and the second incorporates data processor comments to refine the sorting of the list.

3.5.6 Generate Prioritized Target List

A preliminary ranked list containing all anomalies will be delivered to the QC Geophysicist to determine if all relevant MQOs (including QC seed classification) have been met, and a final review of the ranked list will be performed to generate the prioritized target list. Every investigated target will be included on the prioritized list and will be classified as TOI, non-TOI, or cannot analyze and sorted based on their likelihood to be TOI. All targets in the cannot analyze and TOI categories will be selected for intrusive investigation. The target classification report will include descriptions and values for all thresholds and classification expressions used to generate interim and final ranked target lists.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for this SOP include the following:

- A list of target anomalies including identifier (ID) and position (X, Y)
- A list of verified background locations (ID, X, Y)
- A list of IVS item locations (ID, X, Y)
- Advanced EMI sensor measurement data including those for target anomalies, daily IVS measurements, background measurements, and function tests
- Field notes for all data collection activities
- Site-specific munitions library signatures and/or test pit measurements of intended site-specific library items

4.2 Output Data for Data Verification

Output data include the following:

- QC report including documentation of performance relative to Worksheet 22 of the AGCMR-QAPP for the following:
    - IVS results
    - Function test results
    - Background measurements
    - Target anomaly measurements
- Geosoft databases for target measurement data, background measurement data, target features and background features

4.3 Output Data for Data Analysis

- Prioritized target list
- Target classification report
- Revised data validation plan
- Geosoft databases for target measurement data, background measurement data, target features, and background features
- Supporting documents for classification (.png images)

5 Quality Control

Cued advanced EMI sensor data verification and analysis requires follow-on QC inspections that will be documented on the Follow-on Advanced EMI Sensor Cued Data Verification Checklist and Follow-on Advanced EMI Sensor Cued Data Analysis Checklist that are included as Attachments 1 and 2 to this SOP. The checklists will be completed by the QC Geophysicist and documented in the Daily QC Report.

5.1 Measurement Quality Objectives

The MQO for advanced EMI sensor data processing and analysis are presented in Worksheet 22 of the AGCMR-QAPP (including MQO for daily IVS and function test performance as well as for individual measurement metrics). Performance relative to the MQO will be assessed during the processing and analysis of the data. Cued advanced EMI sensor data will not be used to classify targets until these MQO are met or until the project team agrees on modifications to the MQO.

6 Reporting

Verification of advanced EMI sensor data processing and analysis will be documented through the completion of the follow-on QC checklists in Attachments 1 and 2. The follow-on checklists for this SOP will be completed by the QC Geophysicist and documented in the Daily Geophysics QC Report, and copies will be included with the advanced geophysical classification report at the completion of the project. The final advanced geophysical classification report will detail the specific approach to classification including final library make-up, cut-off threshold, cluster analysis approach and results, and feature space analysis approach and results.

Attachment 1

Follow-on Advanced EMI Sensor Cued Data Verification Checklist

Follow-on Advanced EMI Sensor Cued Data Verification Checklist

This checklist is to be completed by the QC Geophysicist for each daily MetalMapper data verification event during data acquisition activities. The QC Geophysicist will document the successful completion of this checklist in the Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Background locations	Have background locations been verified to be free of localized anomaly sources (from SOP AGCMR-04 Initial Background Measurement Acquisition Checklist)?		
2. Background measurements	Has the Data Processor reviewed the day’s background measurements and verified them to be within the MQO defined limits?		
3. IVS tests	Has the functionality of the advanced EMI sensor system been verified for each measurement using IVS tests collected on the same day, and have all associated IVS tests passed the associated MQO (from SOP AGCMR-02 Follow-On Daily Cued IVS Checklist)?		
4. Sensor navigation	Have valid RTK GPS data been collected with the sensor positioned over the initial detected anomaly location with any exceptions noted in the processing notes?		
5. Sensor orientation	Have valid IMU data been collected or manually documented orientation incorporated with any exceptions noted in the processing notes?		
6. Cued measurements	For each cued measurement used for advanced geophysical classification (including background measurements), have the MQO related to transmit current and receiver decay data been met?		
7. Cued measurements	Has the background correction been applied?		
8. Cued measurements	Have the initial single source inversion and preliminary library match performed?		
9. Reporting	Have anomalies with cued data that has passed verification been listed as complete and anomalies requiring resurvey been added to the redo list?		

QC Geophysicist: ____ Date: _____________

Attachment 2

Follow-on Advanced EMI Sensor Cued Data Analysis Checklist

Follow-on Advanced EMI Sensor Cued Data Analysis Checklist

This checklist is to be completed by the QC Geophysicist for each MetalMapper advanced geophysical data classification event. The QC Geophysicist will document the successful completion of this checklist in the Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Feature Extraction	Has background corrected data been modeled with the single and multi-source inversion routines to extract model parameters? Are the inversion parameters (e.g., time gates) documented?		
2. Feature Extraction	Have the derived models for each classified anomaly been verified to fit the observed data with a fit coherence that meets the MQO with exceptions added to the dig list as cannot analyze (dig)?		
3. Feature Extraction	Have all targets classified as TOI or non-TOI been verified to have a fit position offset from the center of the array that meets the MQO?		
4. Cluster Analysis	Has cluster analysis using self-match of polarizations been performed using the parameters specified in Worksheet 22?		
5. Library Verification	Did the initial library contain examples of all TOI and other potential TOI? Was down-selection performed to reduce unnecessary library entries?		
6. Classify and rank	Is the ranking logic valid? Are applicable expressions, variables and thresholds specified?		
7. Threshold selection	Are all QC seeds correctly classified?		
8. Complete dig list	Are all anomalies on the dig list classified to meet the MQO? (Interim dig lists should identify which anomalies have not yet been classified; final dig list must include all anomalies with a classification decision).		
9. Reporting	Does the advanced geophysical classification report describe the classification approach and identify the decision thresholds used to place an item on the non-TOI list?		

QC Geophysicist: ____ Date: ______________

STANDARD OPERATING PROCEDURE
AGCMR-09

Anomaly Reacquisition and Intrusive Investigation

Advanced Geophysical Classification Activities
Former Fort Ord, California

Revision 2

December 2017

KEMRON ENVIRONMENTAL SERVICES

1 Purpose and Scope

The purpose of this standard operating procedure (SOP) is to identify the means and methods to be employed when reacquiring and intrusively investigating targets classified from advanced electromagnetic induction (EMI) sensor data. Reacquisition includes navigating to each target and marking the location for intrusive investigation. Intrusive investigation includes excavating and removing the anomaly source, documenting the investigation results, and verifying that the targeted anomaly source has been removed. This SOP details the steps required to accurately flag selected target locations, intrusively investigate and remove the identified anomaly sources, sufficiently document the intrusive investigation process and results, and verify the success of the removal operation.

2 Personnel, Equipment, and Materials

This section describes the personnel, equipment and materials required to implement this SOP. The following is a list of required equipment and materials:

- Real-time kinematic (RTK) global positioning system (GPS) receiver
- Tablet field computer equipped with intrusive investigation forms for recording intrusive investigation results
- Hand tools including shovels, pick axes, breaker bars, etc. to conduct intrusive investigation operations
- Digital camera

2.1 Personnel and Qualifications

The following individuals will be involved in the reacquisition and intrusive investigation of targets classified from cued advanced EMI sensor data:

- Reacquisition Geophysicist
- UXO Technician II
- UXO Dig Team (1 UXO Technician III, 1 UXO Technician II, and 2 UXO Technician Is)

3 Procedures and Guidelines

Anomalies to be reacquired and intrusively investigated will include those identified as TOI and cannot analyze as well as those selected as part of the validation process.

3.1 Reacquisition

Anomalies selected for intrusive investigation will be reacquired by a reacquisition team composed of one geophysicist and one UXO Technician II. The reacquisition team will navigate to the location of each anomaly to be intrusively investigated using an RTK GPS and will place a non-metallic survey flag at the modeled target location derived through the data processing and classification process. The anomaly ID will be written in indelible marker on the survey flag. The reacquisition team will take care to reacquire each target location with accuracy within 1 inch.

3.2 Intrusive Investigation

After reacquisition of the anomalies selected for intrusive investigation, each anomaly will be intrusively investigated in accordance with the *Final Quality Assurance Project Plan, Former Fort Ord, California, Volume II, Appendix A, Munitions and Explosives of Concern Remedial Action* (QAPP) with exceptions described below. The initial anomalies to be investigated will be those selected as threshold verification digs in order to determine whether certain signatures should be added to the classification library from the cluster analysis and to verify the appropriate threshold (see the draft Advanced Geophysical Classification Validation Plan in Appendix D). After completion of the threshold verification digs, the intrusive team will proceed to investigate the remainder of the anomalies identified on the dig list. The final set of anomalies to be investigated will be those selected as part of the validation process approved in the final Advanced Geophysical Classification Validation Plan.

Due to the precision of advanced EMI sensor data and modeling results, as well as to the nature of advanced geophysical classification surveys, where non-TOI metallic items are purposely left in the ground, intrusive investigations will be conducted with different procedures than those of intrusive investigations based on standard DGM. Each excavation will be conducted only in the immediate vicinity of the reacquired target location, with an approximate search radius of 10 inches. The investigation will proceed until the predicted item (or a metallic item of comparable size and shape) is recovered or until the excavation depth has reached 12 inches below the predicted depth (to the center of mass of the target item).

3.3 Post-Investigation Anomaly Resolution

Post-investigation anomaly resolution will be verified by comparing the modeled classification results (predicted item identity and depth) to the actual intrusive investigation results. Any anomaly investigated from the validation dig list and identified as a TOI will trigger a root cause analysis and corrective action, as appropriate. Documentation of the intrusive investigation results and anomaly resolution will be performed in accordance with the QAPP, with exceptions discussed below.

4 Data Management

The following sections describe the input data needed to perform this SOP and the resulting output data.

4.1 Input Data Required

Input data required for this SOP include the following:

- A dig list containing target identifiers (ID) with a modeled anomaly source location (X,Y), depth, and identity for each target

4.2 Output Data

Output data include the following:

- Digitally-recorded intrusive investigation results including the following:
  - Recovered item identity
  - Specific type and model of MEC or MD, if possible
  - Precisely-measured recovery depth, within 1 inch, to the center of mass of the recovered item
  - Recovery orientation
  - Offset of recovered item from predicted location, within 1 inch
- Photograph of recovered item
- QC report including documentation of performance relative to Worksheet 22 of the Advanced Geophysical Classification for Munitions Response Quality Assurance Project Plan (AGCMR-QAPP) for the following:
  - Daily verification of reacquisition RTK GPS accuracy and precision

- Recovered item locations match predicted positions within MQO tolerance
- Recovered item depths match predicted depths
- Predicted seed item locations match known positions within MQO tolerance
- All seed items are classified as TOI and recovered
- Validation of classification results – all intrusively investigated non-TOI are confirmed to be non-TOI

5 Quality Control

Reacquisition and intrusive investigation require follow-on QC inspections that will be documented on the Follow-on Advanced EMI Sensor Reacquisition Checklist and the Follow-on Advanced EMI Sensor Intrusive Investigation Checklist that are included as Attachments 1 and 2 to this SOP. The checklists will be completed by the Reacquisition Geophysicist and the QC Geophysicist, respectively. Successful completion of these procedures will be documented by the QC Geophysicist in the Geophysics Daily QC Report.

5.1 Measurement Quality Objectives

The MQO for advanced EMI sensor reacquisition and intrusive investigation are presented in Worksheet 22 of the AGCMR-QAPP. Performance relative to the MQO will be assessed during reacquisition and intrusive investigation activities. Resolution of classified targets will not be considered complete until these MQO are met or until the project team agrees on modifications to the MQO.

6 Reporting

Documentation of intrusive investigation results will be entered on digital dig sheet forms in the dig team's tablet computer and will include recovered item identity, a detailed description of specific features and variety of MEC, if applicable, the precisely-measured recovery depth, and the recovery orientation. Photographs will be taken of recovered items. Recovered items will be compared to the predicted item identity and modeled burial depth to verify that the correct item was recovered from the excavation location and to validate the advanced geophysical classification process. Verification of reacquisition and intrusive investigation activities will be documented through the completion of the Follow-on Advanced EMI Sensor Reacquisition Checklist and the Follow-on Advanced EMI Sensor Intrusive Investigation Checklist that are included as Attachments 1 and 2 to this SOP. The checklists will be completed by the Reacquisition Geophysicist and the QC Geophysicist, respectively. Successful completion of these procedures will be documented by the QC Geophysicist in the Geophysics Daily QC Report.

Attachment 1

Follow-on Advanced EMI Sensor Reacquisition Checklist

Follow-on Advanced EMI Sensor Reacquisition Checklist

This checklist is to be completed by the Reacquisition Geophysicist for each cued advanced EMI sensor reacquisition event. The QC Geophysicist will document the successful completion of this checklist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	Reacquisition Geophysicist Initials
1. Reacquisition GPS accuracy and precision	Has the RTK GPS performance been verified by conducting a static position check on a local benchmark position?		
2. Reacquisition accuracy	Have all reacquired targets been located with accuracy within 1 inch?		
3. Reacquisition completeness	Have all targets identified for intrusive investigation been reacquired?		
4. Reacquisition completeness	Have all target locations been marked with pin flags clearly displaying their unique target IDs?		

Reacquisition Geophysicist: ____ Date: ______________

Attachment 2

Follow-on Advanced EMI Sensor Intrusive Investigation Checklist

Follow-on Advanced EMI Sensor Intrusive Investigation Checklist

This checklist is to be completed by the QC Geophysicist for each advanced EMI sensor intrusive investigation event. The QC Geophysicist will document the successful completion of this checklist in the Daily Geophysics QC Report.

QC Step	QC Process and Guidance Reference	Yes/No	QC Geophysicist Initials
1. Intrusive investigation completeness	Have all targets identified for intrusive investigation been excavated?		
2. Intrusive investigation reporting	Have complete descriptions been recorded for each recovered item?		
3. Intrusive investigation reporting	Have accurate recovery depth measurements, to the center of mass of the recovered item, been recorded for each recovered item?		
4. Intrusive investigation reporting	Have recovery orientations been recorded for each recovered item?		
5. Intrusive investigation reporting	Have accurate recovery offsets been recorded?		
6. Intrusive investigation reporting	Have photographs been taken of each recovered item?		
7. Modeled location validation	Have recovered item locations been verified to match predicted positions within MQO tolerance?		
8. Modeled depth validation	Have recovered item depths been verified to match predicted depths?		
9. Classification validation	Have all seed items been classified as TOI and recovered?		
10. Modeled location validation	Have all predicted seed item locations been verified to match known positions within MQO tolerance?		
11. Classification validation	Have modeled advanced geophysical classification results (predicted item identity and depth) been compared to the actual intrusive investigation results?		
12. Classification validation	Have all intrusively investigated non-TOI been verified to be non-TOI?		

QC Geophysicist (or designee): ___________________________________ Date: _____________