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Test Report: Demonstration of BLU-26 Detection Systems for UXO Lao

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GICHD | UXO Lao | UNDP | MMG

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I. INTRODUCTION

During the period November 27, 2014 to December 20, 2014, UXO Lao undertook a detection trial in Sepon. The primary objective was to assess the suitability and the cost effectiveness of advanced detection systems for the detection of small ordnance. Specifically, the trial was focused on detection of a half BLU-26 at 25cm depth below the natural surface (the national standard of the Lao People's Democratic Republic (Lao PDR) as set by the National Regulatory Authority (NRA)). The Geneva International Centre for Humanitarian Demining (GICHD) along with Minerals and Metals Group, Lane Xang Minerals Limited (MMG LXML) and in cooperation with UXO Lao conducted and supported the detection trial.

A numbers of advanced systems were compared with each other as well as with systems currently used in Lao, on blind test sites. These tests were conducted in accordance with the guidelines from the CEN Workshop Agreement (CWA) 14747:2003 on standardized detector test procedures where applicable and as a 'blind test' - test in which the detector operator does not know details of the location or the depth or nature of the target(s) being sought.

II. MOTIVATION

Currently, most operations to clear UXO in Lao – and specifically BLU-26, are completed by the use of analogue metal detectors. Depending on location and conditions, either standalone detectors, or large array detection systems followed by standalone detectors used for pinpointing are employed. Such detectors rely solely on the ability of the operator to interpret audio, visual or motion alarms as indications that are then physically marked and manually excavated. A great proportion of these excavations turn out to be false negatives – scrap or contamination of various forms. In 2005 and 2006 UXO Lao collected data on fragmentation found during UXO clearance. Based on data from 2,550 individual clearance tasks where UXO was found, an average of 852 pieces of scrap were found for every item of UXO[1].

There are a number of systems in place globally that utilise various geophysical detection systems and methodologies which allow large areas of ground to be processed at a much faster speed, and, following detailed analysis of gathered data, excavations are only made on those readings that show the attributes of the specific UXO being searched for. The detector trial will provide data to UXO Lao so that a determination can be made as to whether an advanced system would provide significant positive benefit to the clearance process while being cost effective when compared to existing techniques. Simultaneously, it will allow many analogue detectors that are currently being employed in Laos to be compared to each other.

III. BACKGROUND

Lao PDR is the most heavily bombed nation in the world on a per capita basis. Between the years 1964 and 1973, the United States flew more than half a million bombing missions, delivering more than two million tons of explosive ordnance, in an attempt to block the flow of

[1] UXO Lao Operations Progress Database

North Vietnamese arms and troops through Laotian territory. The ordnance dropped includes more than 266 million sub munitions (known as “bombies” in Lao) released from cluster bombs.

Significant land battles, including those during the war for independence during the French colonial era and between the Pathet Lao and the Royal Lao forces, also contributed vast quantities of unexploded heavy bombs, rockets, grenades, artillery munitions, mortars, anti-personnel landmines, and improvised explosive devices.

It has been estimated that up to 30% of all ordnance did not explode[2]. Such unexploded ordnance (UXO) continues to remain in the ground, maiming and killing people, and hindering socio-economic development and food security.

The **Lao National Unexploded Ordnance Programme (UXO Lao)** is the national UXO clearance operator. The organisation works in nine of the most heavily impacted provinces. UXO Lao clears land for agriculture, community purposes (e.g. schools, hospitals, temples, and water supply) and other development activities.

The **National Regulatory Authority for the UXO/Mine Action Sector in the Lao PDR (NRA)** is a public institution of the Government of the Lao PDR. It is responsible for the regulation and coordination of all operators in the country that work towards reducing the impact of unexploded ordnance.

Subject to funding availability, UXO Lao is constantly looking for ways to improve clearance productivity and cost efficiency. This may involve testing/adopting of new technology or development of more efficient working processes. In recent years the Lao Government has given high priority to the clearance of so called Government Focal Areas (GFA), which are large areas of land allocated for resettlement or other socio-economic development. In response to this, UXO Lao is looking for technology that ensures reliable search based on the Lao national standard and that also has good search capabilities for UXO detection below the minimum depth, where applicable.

IV. TRIAL SUMMARY

During the period November 27, 2014 to December 20, 2014, a number of different analogue and digital detection systems were blind tested at three test areas. The target locations, orientations, depth distribution and level of contamination were unknown to all operators taking part in the trial. The test areas, which were prepared weeks in advance of the trials, were approximately ¼ ha in size. Each detection instrument was tested on the same sites and in precisely the same manner.

The test areas were blind seeded with inert half BLU-26 items at depths ranging from 5-40cm below natural surface (as measured to the top of the item). Test areas contained contamination at varying levels including scrap and fragmentation.

[2] http://nra.gov.la/uxoproblem.html

The systems have been evaluated based on the following key metrics (among others):

- Probability of detection and False alarm rate
- Productivity (sq-m per hour)
- Cost (cost per sq-m)

V. KEY TEST PERSONNEL

The following key personnel planned, directed, and supervised the trial activities:

- Michael Laneville, Senior Geophysicist, MMG LXML Sepon, michael.laneville@mmg.com
- Erik de Brun, Operations Consultant, GICHD, erik.debrun@rippledesign.com
- Jinno Ramos, Geophysicist, MMG LXML Sepon, jinno.ramos@mmg.com

The following key personnel supported the trial at various stages:

- Tim Lardner, Chief Technical Advisor to UXO Lao, UNDP Laos, tim.lardner@undp.org
- Mikael Bold, Advisor, Mechanical and Animal Detection Systems, GICHD, m.bold@gichd.org
- Marco Heuscher, QM Technical Advisor to UXO Lao, Sterling Int. marco@heuscher.com

VI. TEST SITES

The tests were based at the Sepon mine site, owned and operated by MMG LXML and located in Savannakhet province, Lao PDR. The test areas are shown in Figure 1. It should be noted that the soil in test areas 1 and 2 consisted of soil that was moved to these areas from mining pits as non-ore bearing 'waste'. The soil in these areas was dumped, graded and compacted with rollers approximately every 20cm and left to settle for 7-10 years.

A) TEST AREAS

Three controlled test areas were prepared well in advance of the testing. They included varying aspects of the following obstacles:

- Contamination of ordnance fragmentation and other metallic clutter.
- Highly mineralized soils.

The test areas were blind seeded with inert half BLU-26 items at depths ranging from 5-40cm below natural surface. Each test area is approximately 50 x 50 meters and had 50 (mostly) half BLU with a few full BLU test pieces in the 2,500 m^2 area. The depth and orientation of each item were recorded and position was measured using an RTK GPS. Each item was photographed before being emplaced and covered with soil. Test areas contain contamination at varying levels including scrap and fragmentation in order to simulate a typical clearance site in Laos, as best as possible. The sites were also selected to offer a range of soil conditions experienced in Laos.

The three test areas were chosen where it is thought that geophysical platforms may be viable; based on several features common to many such platforms including the use of wheels, skis and hand-carried arrays, controlled acquisition speeds and access to GPS. That is not to say that all test areas were flat and easily accessible; but rather that the range of terrain aimed to identify the limits of manoeuvrability of current digital systems (i.e. those used for typical range clearance activities in other countries). Each test area has an adjacent reference area of approximately 20 x 20 meters that was utilized for pre-test equipment shake out and test day equipment calibration.

Test area 1 and 2 are 50 x 50 meter areas and test area 3 was divided into two areas 3A and 3B where 3A is 30 x 50 meters and 3B is 20 x 50 meters. Table 1, shows the characteristics of each test area. A number from 1 to 3 was assigned for degree of difficulty of soil conditions (in terms of magnetic susceptibility), level of contamination and topography; where 1 was easiest and 3 was the most challenging.

Table 1: Test Area Characteristics

Test Area	Area (m^2)	# Targets	Soil Conditions	Contamination	Topography
1. Namkok West	2,496.58	50	2 – Weathered siltstone with minor surface clays and iron cementation in fractures.	3 – 6200 pieces of fragmentation.	2 – Gently varying terrain with many rocks and several small boulders strewn throughout. There were also a few small gullies of several meters long and 10-20cm deep. There was a small rise of approximately 3m in the middle of the area, creating a large lower area and smaller upper area.
2. Discovery West	2,496.23	50	2 – Highly weathered siltstone with rio-dacite porphopry and dolomite. Pisolithic ironstone also present.	2 – 4450 pieces of fragmentation.	3 – Generally flat area which was bisected by several gullies ranging from 20-120cm deep and several to tens of meters long; all in various directions. There was also a simulated rice paddy wall of approximately 25m length and 40cm in height.
3A. Discovery East	1,499.31	30	3 – Gossan ironstone capped siltstone and weathered clays, visible pyrite concentrations in siltstones.	1 – 2000 pieces of fragmentation.	2 – Generally flat area with tire ruts criss-crossing most of it. The ruts had been created several months earlier in the wet season when the area was muddy. The area was now dry and the ruts ranged from 4-30cm deep.

3B. Discovery East	998.74	20	1 – Highly weathered siltstones/clays; no iron and low silica content.	1 – 1000 pieces of fragmentation.	1 – Completely flat and smooth area.

The magnetic properties of the soils were measured with a Bartington magnetic susceptibility meter (MS2B) at 465 Hz and 4650 Hz in order to determine the frequency dependence of the soils. Susceptibility with high frequency dependence indicates areas where metal detector performance will be negatively affected.

Four samples from each of the three test areas were taken; one from each quadrant of the 50m x 50m grid (two samples from Area 3a and two from Area 3b). Each sample was measured two times and the averages are shown below; all units are in 10^{-5}.

Table 2: Magnetic Properties of the Test Areas

	Low Frequency (465 Hz)	High Frequency (4650 Hz)	Difference between LF and HF
Area 1 - NE	11.6	10.9	0.7
Area 1 - SE	68.0	64.5	3.5
Area 1 - SW	39.5	35.0	4.5
Area 1 - NW	93.0	75.0	18.0
Area 2 - NE	93.5	88.0	5.5
Area 2 - SE	30.0	27.5	2.5
Area 2 - SW	37.5	36.5	1.0
Area 2 - NW	41.0	36.5	4.5
Area 3A - NE	35.0	34.5	0.5
Area 3A - SE	564.5	523.0	41.5
Area 3B - SW	21.5	18.5	3.0
Area 3B - NW	3.4	2.6	0.8

Area 3a is notable for the most extreme ground conditions. Although only one of the two readings was significant, with a difference between low and high frequency measurements of more than 40 x 10^{-5}, (measured in SI units) these readings may not entirely capture the overall difficulty of the area. This area contains significant amounts of ironstone and several detectors, notably the Ebinger UPEX 740M, when operated by UXO Lao abandoned portions (522.2m2) of the area as they could not obtain reliable measurements. The UPEX 740 operated by HALO Trust, the Minelab F3 large head (MMG) and Vallon (UXO Lao) each declared portions of Area 3a unsearchable; 25.3m2, 20.7m2 and 20.7m2 respectively, although the Minelab F3 large head found 100% of targets to 40cm in the remaining area. All three instruments made by Geonics obtained some of their best results in Area 3a while not leaving out any of this area due to the high mineralization. Generally, metal detectors with ground compensation achieved better results than those without, which is not surprising. Digital systems, which typically record several channels in time-domain windows, attempt to remove signal generated from the soil in post processing of the data. The soil signal decay rate is approximately V=1/t which is much slower than the target decay rate of approximately $V=1/t^2$. Lao is known to have challenging soils as was described in previous metal detector trials such as Systematic Test and Evaluation of Metal Detectors (STEMD) trial in 2004, conducted by the Joint Research Centre of the European Commission (JRC). This issue of ground conditions is however further complicated by the issue of spatial variability where the soil response can change over tens of meters. Soil compensation techniques, which assume a constant soil response or even a gradual change, will have limited success in removing such effects from the measured signal.

In advance of the trials, UXO Lao staff visited with MMG staff to inspect several potential sites in the Sepon area in order to find test areas representative of challenging soil types and mineralization. This was done visually, as well as by walking random lanes in the test areas with a Vallon VMXC1 and a Foerster 4.032 API magnetometer to get a sense of the response and variability. Operators performed ground compensations and dug holes in multiple locations at each site to approximately 30cm and tested with sample BLU-26 targets in order to verify that soil types and mineralisation was as expected.

From a UXO Lao perspective, mineralized soil is certainly a key factor impacting on detector performance and productivity, but it is not the biggest challenge. The biggest impact on clearance productivity is caused by clutter contamination.

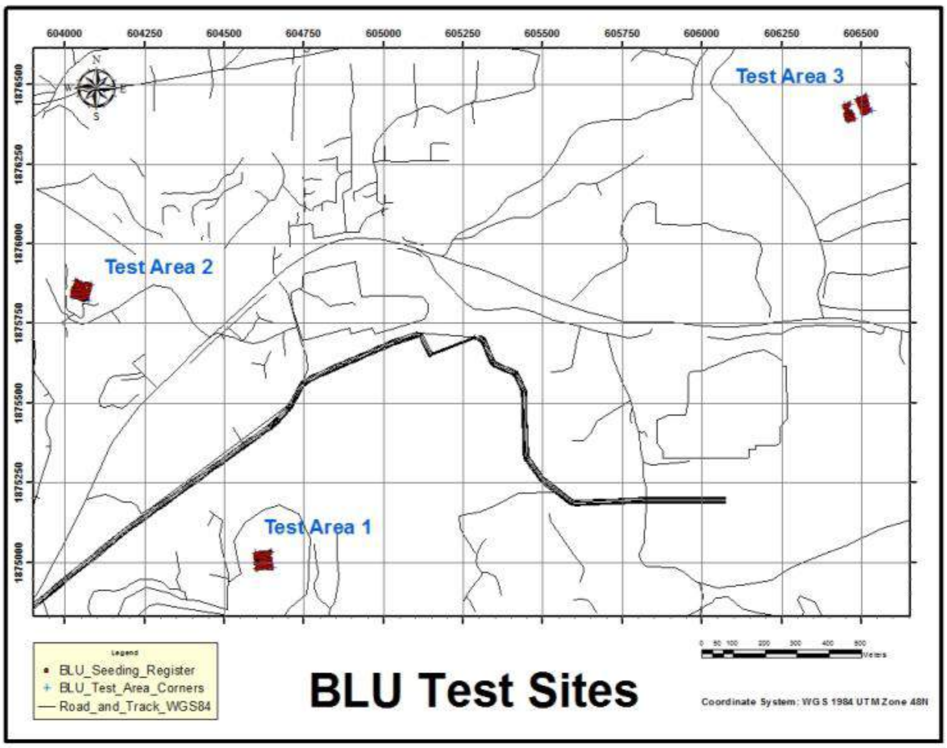

Figure 1: Map of Test Areas


Figure 2: Test Area 1 (Namkok West)


Figure 3: Test Area 1 (Namkok West) - Alternate View

Figure 4: Test Area 2 (Discovery West)

Figure 5: Test Area 3A (Discovery East)

Figure 6: Test Area 3B (Discovery East)

B) DEPTH TEST LANE

In addition, a separate test lane was set up to provide information about what level of detection is possible for larger items at deeper depths at the same detector settings used for the trials. This lane was 1m wide with items placed at 3m intervals and increasing depths with 3m of cleared ground at the start and end of the lane. This test lane was set up at Test site 2 – Discovery West and contained non-UXO test items of increasing size and increasing depths. The results of this test are included in this report for informational and reference purposes only and not included in the main test results.

The items placed in the depth test lane included steel hemispheres of 2”, 3”, 3.5”, 4” diameters and two sections of pipe measuring approximately 25cm long, 9cm outside diameter and 0.5cm thick. Each item had two samples, one placed lower than the next. The items and their depths are shown in the following two images. All hemispheres were placed concave upwards and the pipes were horizontal.

Figure 7: Depth Test Lane Targets

Figure 8: Additional Depth Test Lane Targets

C) TEST ITEMS

As discussed above, inert half BLU-26's were utilized along with varying fragmentation, but no additional metal was added to substitute for the fuse. Note that the condition of the BLU-26 items represent the full range and prevalence of those typically found in Laos.

Table 3: Distribution of test items by depth and physical condition (number of items)

Test Site	Full BLU good condit.	Half BLU good condition		Full BLU average condit.	Half BLU Average condition		Half BLU, old & slightly broken	Half BLU, old & badly broken	Total
Depth Range	**>25cm**	**<=25cm**	**>25cm**	**>25cm**	**<=25cm**	**>25cm**	**<=25cm**	**<=25cm**	
Site 1	3	11	18		7	8	3		50
Site 2	1	14	21	2	5		4	3	50
Site 3 A	1	8	10	1	3	4	3		30
Site 3 B	1	2	7		3	4	3		20
Total	**6**	**35**	**56**	**3**	**18**	**16**	**13**	**3**	**150**
	65%			**25%**			**11%**		**100%**

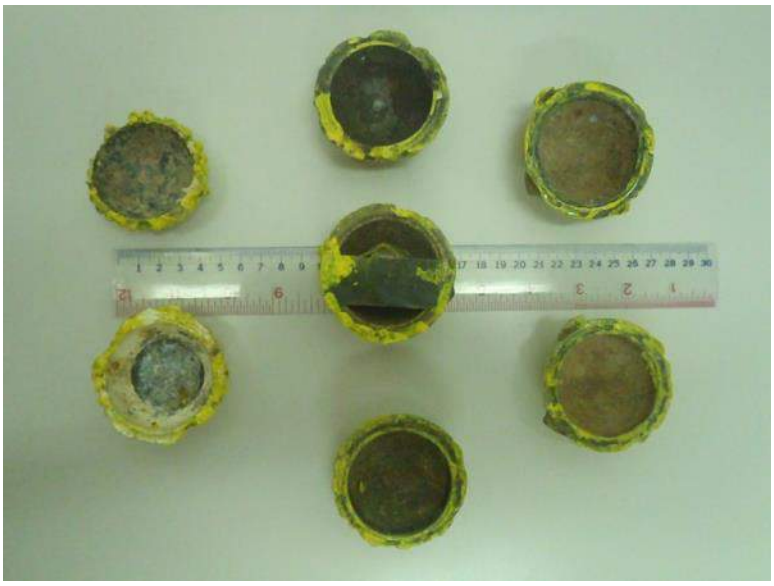

Figure 9: Half BLU 26 Inert Test Pieces - Inside View

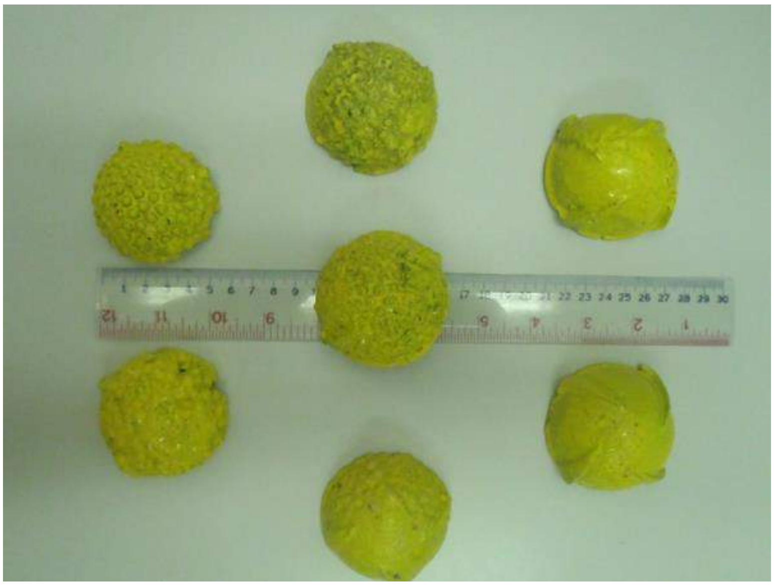

Figure 10: Half BLU 26 Inert Test Pieces - Outside View

Figure 11: Fragmentation

VII. TEST EQUIPMENT

A number of different operators and detection systems were used during the test. Below is a list (in the approximate order they were tested) of each piece of equipment and the operator that tested the equipment.

1. Aqua Survey, Inc. – Geonics EM47/63 HP
2. MMG - Minelab F3 Large head, YELLOW cap
3. UXO Lao – Vallon VMXC1
4. UXO Lao - Magnex 120 DATA LOGGER
5. UXO Lao - Upex 740M Analogue + Vallon VMXC1
6. UXO Lao - Upex 740M Data Logger
7. MMG - Minelab CTX 3030
8. MMG - Minelab F3 Small head, YELLOW cap
9. Golden West Humanitarian Foundation – MMDS (UPEX 740M)
10. HALO Trust - Upex 740M Analogue + EBINGER PIDD
11. MMG – Geonics EM61-BLU26 Array
12. MMG – Geonics EM61
13. GAP Explosive Ordnance Detection – ULTRATEM Mobile Detection System

VIII. TEST PROCEDURE

All participants and equipment were given two and a half days of equipment preparation time followed by four days in which to survey the three test areas. Each test area required one full day to complete (including data analysis if required) and the extra day was used as a reserve. The goal was to have a dig sheet (along with raw and processed data) submitted each day a given piece of equipment was tested. The dig sheets for analogue systems were simply the marked locations of anomalies, which were recorded with RTK GPS. Digital systems submitted a prioritized list of anomalies that could be further broken down into a list of those items thought to be UXO and a second list of items believed to not be UXO. This second 'response' list would allow test personnel to determine if items were detected by an instrument but the analyst excluded it from being picked as a UXO.

Access to an office space with an Internet connection was provided to all participants. Support and logistics such as local transport, accommodation, meals, personnel to assist with assembling, transporting, carrying equipment, surveying, translating, etc. was also provided.

The main priority for each system was to demonstrate ability to detect half BLU-26s that were seeded down to a depth of 25 cm, measured to the top of the item, as per the national standard of Lao PDR.

A) EQUIPMENT PREPARATION

Participants were shown all three test areas during the first day on site and were able to choose how and where they wanted to spend the remaining equipment preparation time. During equipment preparation no one was allowed to enter the official test areas and were required to stay at least 3 meters away from the test areas at all times. A 20 x 20 meter (approximate) calibration area adjacent to each test area was provided for pre-test equipment preparation and for pre-test calibration during testing. This area was cleared of metal down to 1 meter. Participants were given sample half BLU-26s and fragmentation similar to what has been used to seed the test areas. Marking pegs for lane/box setup, sticks for target marking, measuring tapes (2 x 50m) and lane ropes (200m) were also provided during the equipment preparation and test time.

B) TESTING

Demonstrators were given a fixed amount of time to setup, calibrate, and survey a given test area. Participants attempted to survey as much of the area as possible in the allotted time in exactly the same manner as they would on a live UXO site in terms of operating procedures. In this respect, they could choose their own survey direction and use of team members. If a team/system completed less than 66% of an area, the results for that area were not included in final analysis. Any area not surveyed was marked by the GPS survey team and noted in the daily observations.

<u>Digital Systems:</u>

Digital systems had a minimum of three (3) hours and at most four (4) hours to work in a given test area. For Quality Control (QC), digital systems resurveyed one line within the test area; as the first and last lines; in opposite directions. Surveying in the reference area and any QC activities were included in the total survey time. Participants utilizing digital systems had the test day afternoon (a maximum of four and a half (4.5) hours) to perform data analysis and produce a prioritized dig sheet in CSV format. It was acceptable for teams to utilize a field computer to review data or perform QC at the test site. Any time spent performing data analysis in the field was factored into the 4.5 hour data analysis time window. Some teams were unable to perform data analysis on site due to logistical issues. These teams performed data analysis from remote locations after testing had been completed but were still subjected to the strict time requirements (raw data was sent to the analyst at a designated time and results were uploaded within 4.5 hours).

Analogue Systems:

Analogue systems had a minimum of seven (7) hours and at most eight and a half (8.5) hours to work within a given area. Lunch was not included in this time. MMG, UXO Lao and HALO Trust conducted the analogue system testing and their teams were staffed and equipped as per normal operations. Operators were selected based on being qualified UXO technicians who were currently active with at least 6 months of continuous work directly before the trial. Each team represented the typical work force in terms of ability, age and sex in order to achieve unbiased results. For Quality Control (QC), Supervisors were required to perform 10% physical check per the national standard. They were required to use the same detector as the operator. Hence, the operator was not able to survey at that time. As indicated above, surveying in the reference area and QC was included in the total survey time. Teams were given coloured stakes to mark targets. As on a real clearance site, it was solely up to the operator's interpretation of the sound/LED/vibration from the detector to indicate where a target to be marked is located. A trial staff member recorded the location of all target markers with RTK GPS and that data constituted the (un-prioritized) dig sheet.

C) DIG SHEET DETAILS (FOR DATALOGGING SYSTEMS)

A single prioritized dig sheet was supplied within 4.5 hours of having access to the data. The sheet contained all possible targets in the test area (which included all potential UXO and clutter). The targets were given a unique target ID number with the highest confidence UXO targets being assigned the lowest target IDs. Each team supplied a cut-off number which separated items thought to be UXO from those thought to be non-UXO. Both lists were used for calculations of probability of detections, false alarm rates, etc.

Two lists were utilized to separate the ability of a system to measure the response of UXO from the analyst's ability to discriminate it as a UXO or non-UXO.

D) TEST TEAM DATA RECORDING

Test staff recorded the following data during each test day:

- Start and stop times for:
  - Pre-survey activities (safety briefing, equipment setup, calibration/tests, grid preparation, etc.)
  - Area survey (data collection / detector use)
  - Downtime (breaks, equipment checks, maintenance)
  - Post survey activities (Equipment breakdown)
- General test observations, method of surveying, marking, etc.
- Photographs of testing
- Detector information (make, model, serial number, software, settings)
- Name of participants (Detector operators, supervisor, etc.)

IX. TEST SCHEDULE

After the initial 2.5 days of setup and calibration time each piece of equipment was tested on one site per day. The following schedule shows all the testing that was conducted during the trial.

Table 4: Test Timeline

Date	Area 1	Area 2	Area 3
11/25/2014			Aqua Survey – Geonics EM47/63 HP
11/25/2014	MMG - Minelab F3 Large head, yellow cap		
11/26/2014		Aqua Survey – Geonics EM47/63 HP	
11/26/2014			MMG - Minelab F3 Large head, yellow cap
11/27/2014	Aqua Survey – Geonics EM47/63 HP		
11/27/2014		MMG - Minelab F3 Large head, yellow cap	
11/28/2014	UXO Lao – Vallon VMXC1		
11/28/2014			UXO Lao - Magnex 120 DATA LOGGER
11/29/2014			UXO Lao – Vallon VMXC1
11/29/2014		UXO Lao - Magnex 120 DATA LOGGER	
11/30/2014		UXO Lao – Vallon VMXC1	
11/30/2014	UXO Lao - Magnex 120 DATA LOGGER		
12/1/2014		UXO Lao - UPEX 740M Analogue + Vallon VMXC1	
12/1/2014	UXO Lao - UPEX 740M Data Logger		
12/2/2014			UXO Lao - UPEX 740M Analogue + Vallon VMXC1
12/2/2014		UXO Lao - UPEX 740M Data Logger	

Date	Area 1	Area 2	Area 3
12/3/2014	UXO Lao - UPEX 740M Analogue + Vallon VMXC1		
12/3/2014			UXO Lao - UPEX 740M Data Logger
12/4/2014		MMG - Minelab CTX 3030	
12/5/2014			MMG - Minelab CTX 3030
12/6/2014	MMG - Minelab CTX 3030		
12/7/2014		MMG - Minelab F3 Small head, yellow cap	
12/8/2014			MMG - Minelab F3 Small head, yellow cap
12/8/2014	Golden West – MMDS (UPEX 740)		
12/9/2014	MMG - Minelab F3 Small head, yellow cap		
12/9/2014			Golden West – MMDS (UPEX 740)
12/10/2014		Golden West – MMDS (UPEX 740)	
12/10/2014	HALO Trust - UPEX 740M Analogue + Ebinger PIDD		
12/11/2014		HALO Trust - UPEX 740M Analogue + Ebinger PIDD	
12/12/2014			HALO Trust - UPEX 740M Analogue + Ebinger PIDD
12/14/2014	MMG – Geonics EM61 BLU26 Array		
12/15/2014			MMG – Geonics EM61 BLU26 Array
12/16/2014		MMG – Geonics EM61 BLU26 Array	
12/19/2014	MMG – Geonics EM61		
12/19/2014			MMG – Geonics EM61

Date	Area 1	Area 2	Area 3
12/19/2014	GAP EOD – UltraTEM		
12/19/2014		GAP EOD – UltraTEM	
12/20/2014			GAP EOD – UltraTEM
12/21/2014		MMG – Geonics EM61	

X. RESULTS

The primary metrics used to judge system effectiveness and allow for comparison between systems were:

- Probability of detection (number of targets identified per opportunity) and False alarm rate (false alarms per square meter)
- Productivity (square meters per hour)
- Cost (cost per square meter)

A) PROBABILITY OF DETECTION AND FALSE ALARM RATE

One of the primary objectives of the test was to quantify the ability of each system to identify the maximum number of half BLU-26 targets while minimizing the number of non-BLU targets which would be required for investigation. Dig sheet locations were compared with the locations of seeded items in order to determine the horizontal positioning error. The basis for declaring that a system has properly detected a target is dependent on horizontal separation distance of the dig sheet target location and an actual seeded location – we call this *Distance to Target* and define successful detection for each type of system below.

$$\text{Detection is successful if } Distance\ to\ Target = \begin{cases} \leq 50\ cm, & Digital\ Systems \\ \leq 21.78\ cm, & Analogue\ Systems \end{cases}$$

For analogue systems the distance to target is calculated based on the definition provided in the CEN Workshop Agreement 14747 that states:

The circle around the target location whose radius is defined by this maximum distance is known as the detection halo. The radius of the detection halo shall be half of the maximum horizontal extent of the metal components in the target plus 100mm.

For our purposes, the distance to target must also include errors in measurement of the location of the indication. And since there is one measurement taken to mark the indication and one measurement taken to mark the actual seeded target, we must include two times the error in GPS measurement. For the BLU-26 target and with the RTK GPS used during the testing, the distance to target comes to 21.78 cm.

For the digital systems, the distance to target is set to 50 cm based on similar trials performed in the United States such as the Standardized UXO Technology Demonstrations. More information is provided on the Distance to Target calculations in Appendix B.

The following metrics have been calculated for two depth ranges: 0 to 25cm and 26 to 40cm:

1. Probability of detection: $PoD = \frac{\#\ of\ targets\ identified}{total\ \#\ of\ seeded\ targets}$
2. False Alarm Rate: $FAR = \frac{\#\ of\ false\ alarms}{m^2}$
3. The resulting receiver-operating characteristic (ROC) plots

For any system with a probability of detection less than 0.75, Productivity and Cost metrics will NOT be calculated.

B) PROBABILITY OF DETECTION AND FALSE ALARM RATE RESULTS

Below, the probability of detection, false alarm rate and receiver operator characteristic plots are shown for target depth ranges 0-25cm. For the data related to the depth range 25.1-40cm see Appendix D. As is customary for tests such as these, and as directed by the CWA, we also display error bars on the graphs to show the 95% confidence limits of the data. These limits indicate how confident we can be in the test results and the larger the error bar spread the less confidence we should have with a given set of data – this can be seen when looking at results for individual test areas, the fairly low number of actual targets to detect means that results have less likelihood of being representative of future operation. The method for calculating the 95% confidence limits for PoD and FAR is discussed more in Appendix C.

Shown below is the PoD for all systems for 0-25cm Depth, the [XX] after some of the system names indicates which set of data is being shown. The 'P' indicates preliminary data that was calculated in the 4.5 hours after each test day whereas 'F' indicates final data submitted with each equipment operators/manufacturers final report. The 'T' refers to the data being the prioritized list of targets and the 'R' refers instead to the reference list that indicates all possible readings from a given instrument. When comparing 'T' and 'R' it will be clear that sometimes the reference list allows for a greater PoD but at the cost of a higher FAR.

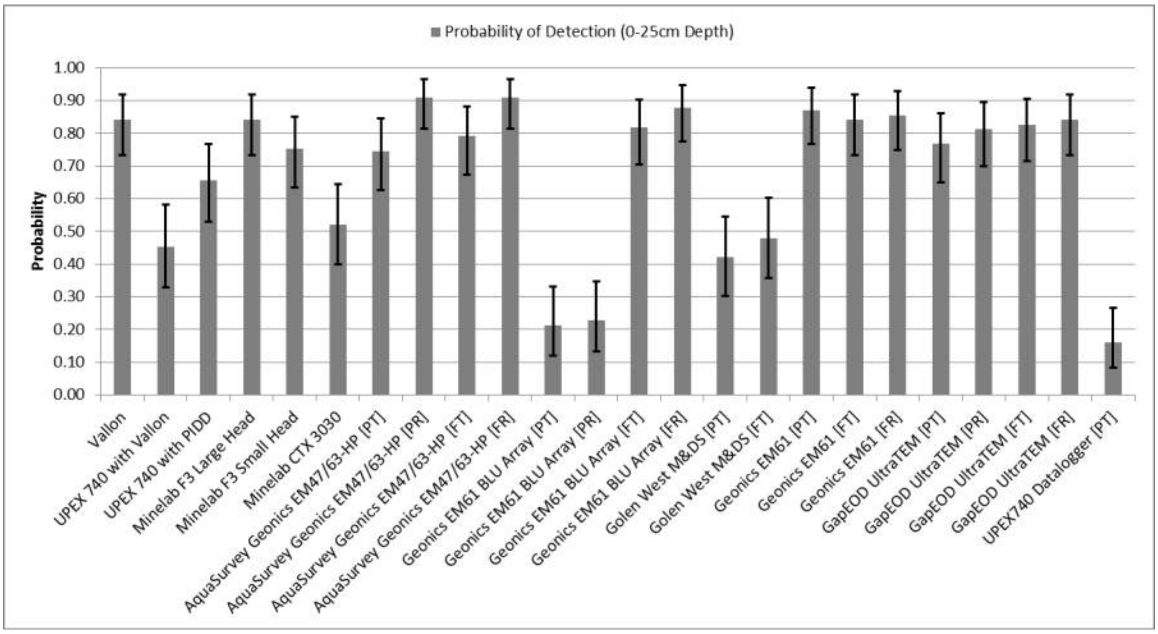

Figure 12: PoD for All System Results for Depth Range 0-25cm

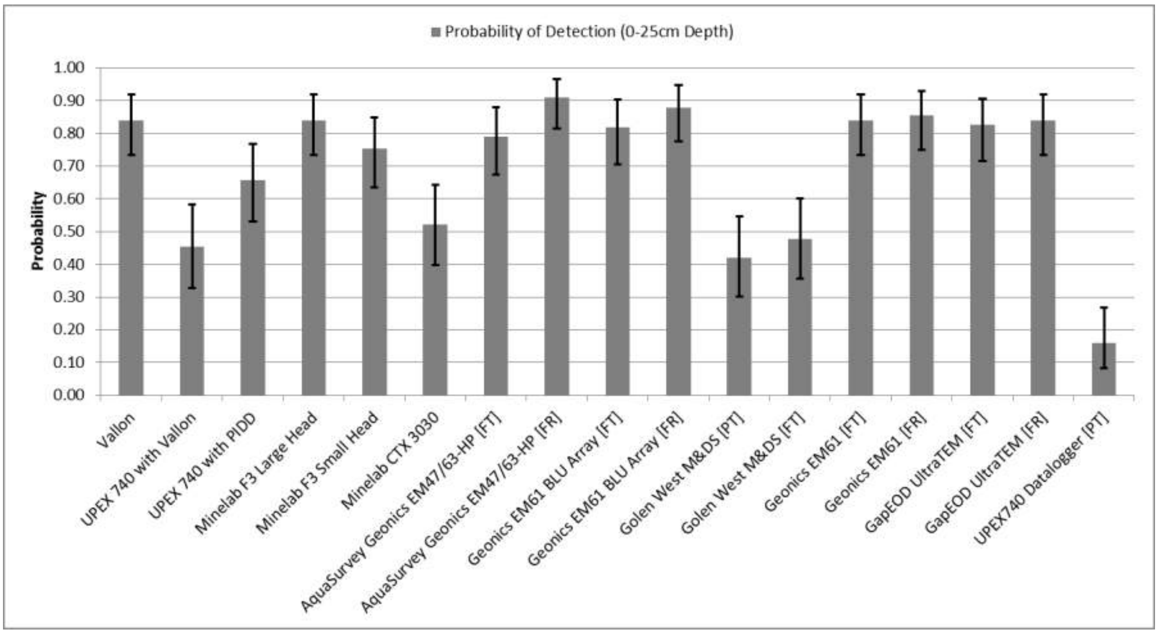

Figure 13: PoD for Final System Results for Depth Range 0-25cm

PoD Data for depth range 25.1-40cm can be found in Appendix D.

The False Alarm Rates for each All System and just Final System data is shown below:

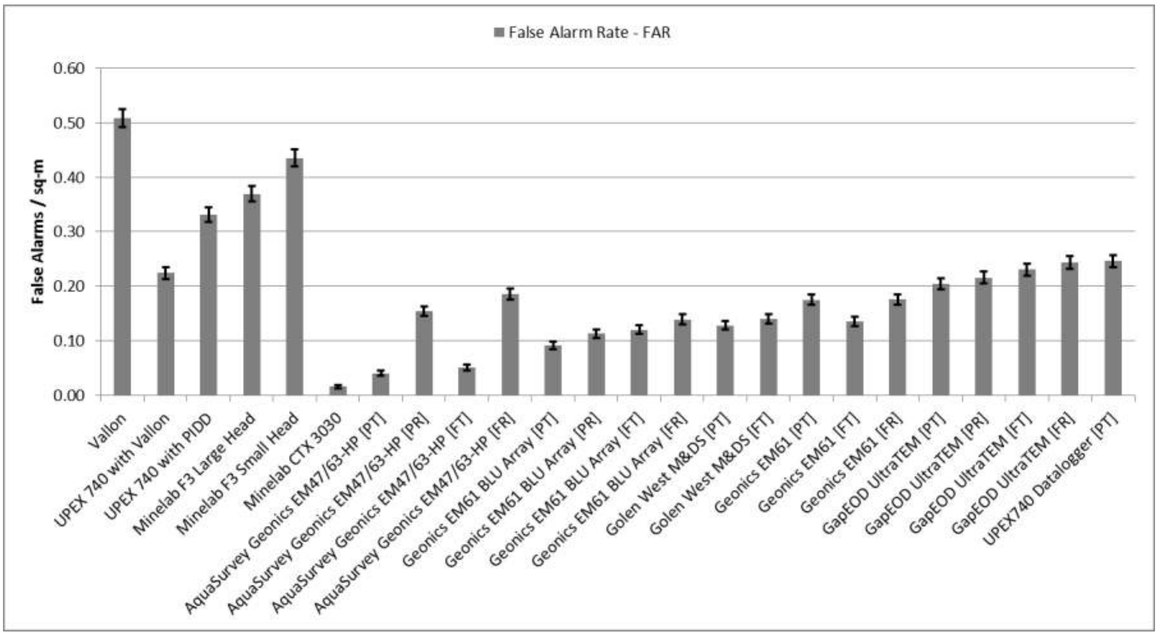

Figure 14: FAR for All System Data Across All Target Depths

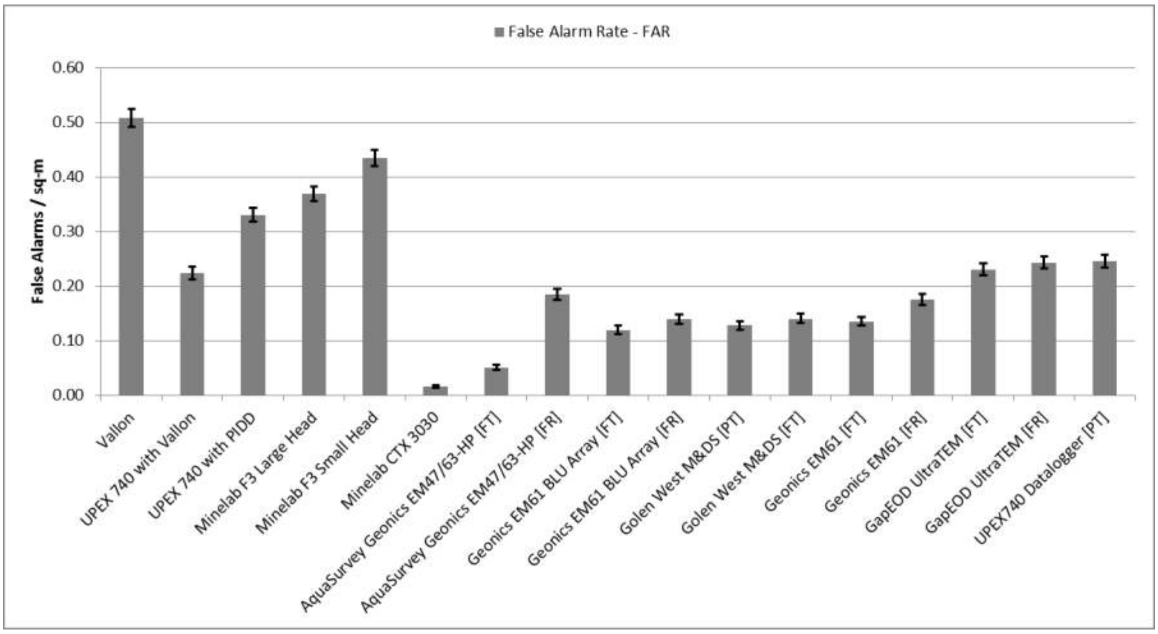

Figure 15: FAR for Final System Data Across All Target Depths

To truly get an appreciation for the data it is a common convention to look at the Receiver Operator Characteristic (ROC) plots to see the trade-off between PoD and False Alarm Rate. Equipment which plots in the upper left area represent ideal detectors; achieving a high probability of detection combined with a low false alarm rate. Moving to the upper right area are detectors that still achieve a high probability of detection but at the expense of increasing false alarms. Equipment whose data is located in the lower right area are obviously unsuitable as they fail to detect UXO while still detecting non-UXO. Equipment whose data is located in the lower left are also unsuitable for UXO clearance as the detection capability is too low. However, such equipment may find use in technical surveys where detection of every UXO is not necessarily the aim. Figure 16 shows the ROC for system final results (depth range 0-25cm):

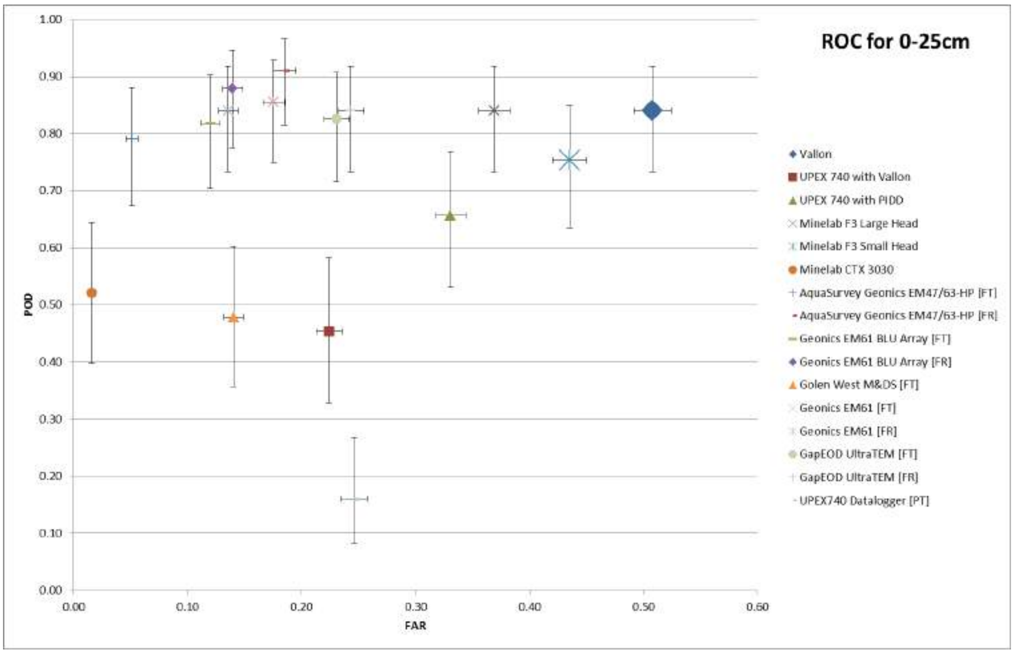

Figure 16: ROC for Final System Data for Depth Range 0-25cm

Figure 17 shows the ROC for those systems with an overall PoD greater than 0.75.

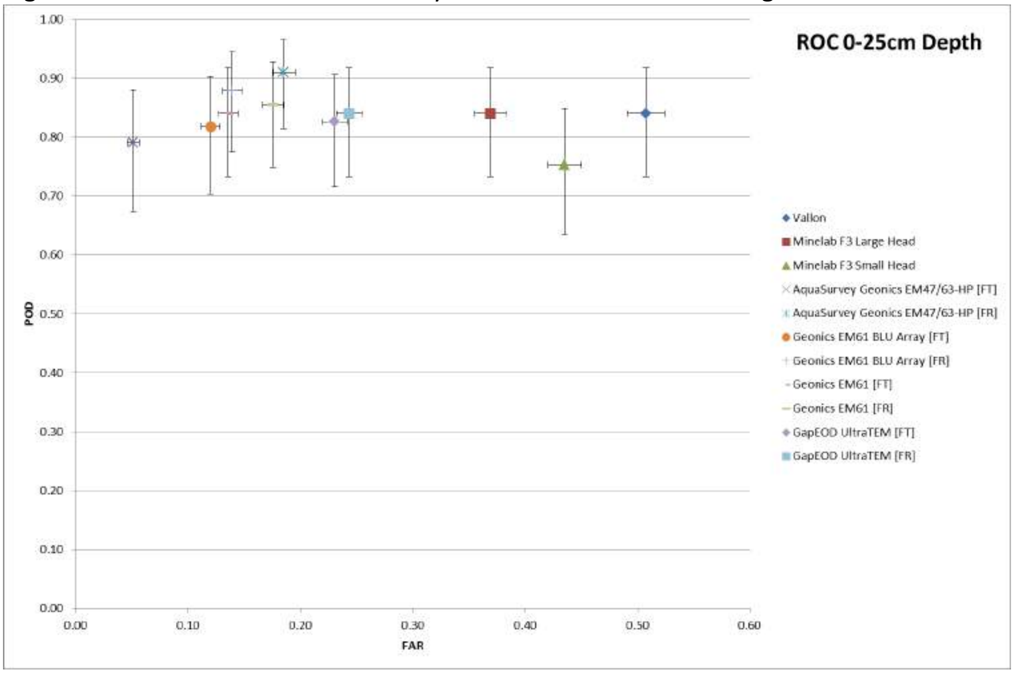

Figure 17: ROC for Systems with Overall PoD > 0.75 for Depth Range 0-25cm

Looking at each test area separately for all final system data and then just for systems with overall PoD (for all areas) greater than 0.75. It should be noted that the spread of FAR results is much higher in high contamination areas (0.01 – 0.81) than in low contamination areas (0.02 – 0.26).

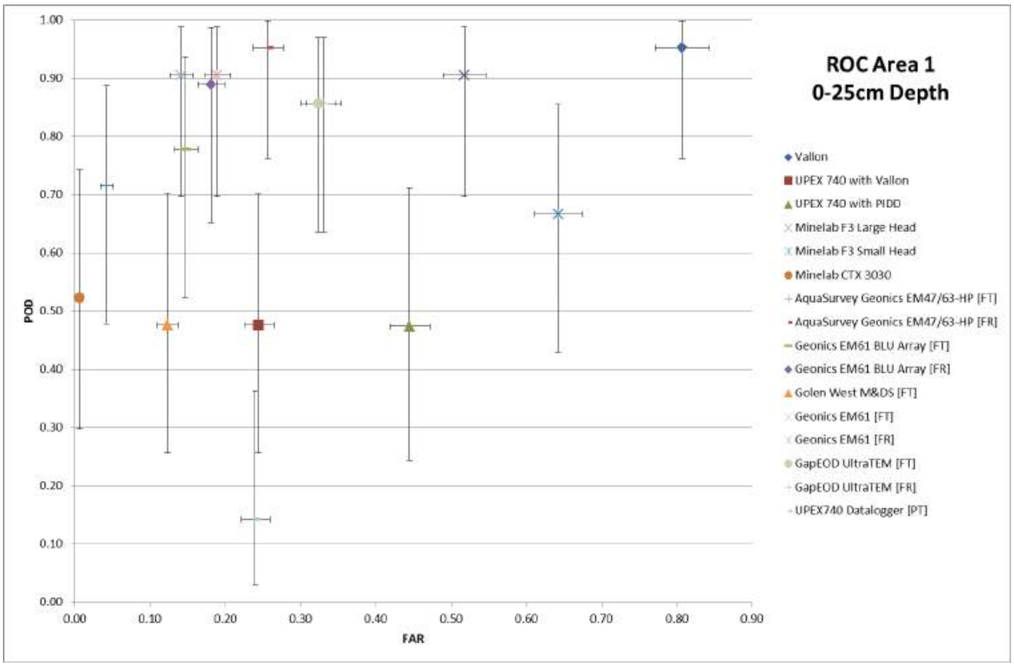

Figure 18: ROC for Final Systems Data for Depth Range 0-25cm in Area 1

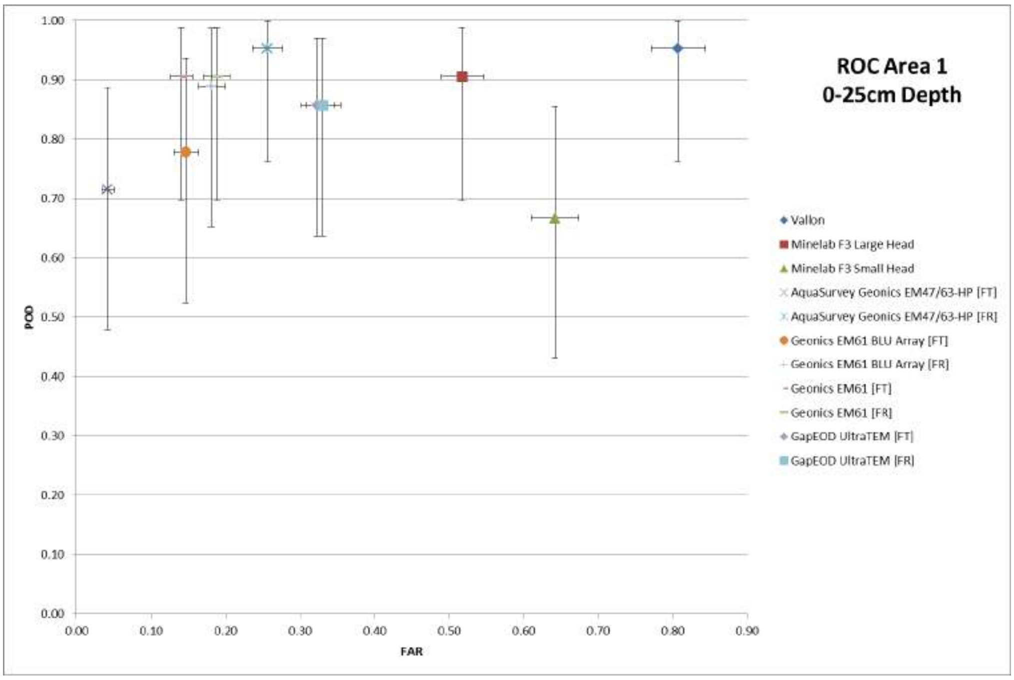

Figure 19: ROC for Systems with Overall PoD > 0.75 for Depth Range 0-25cm in Area 1

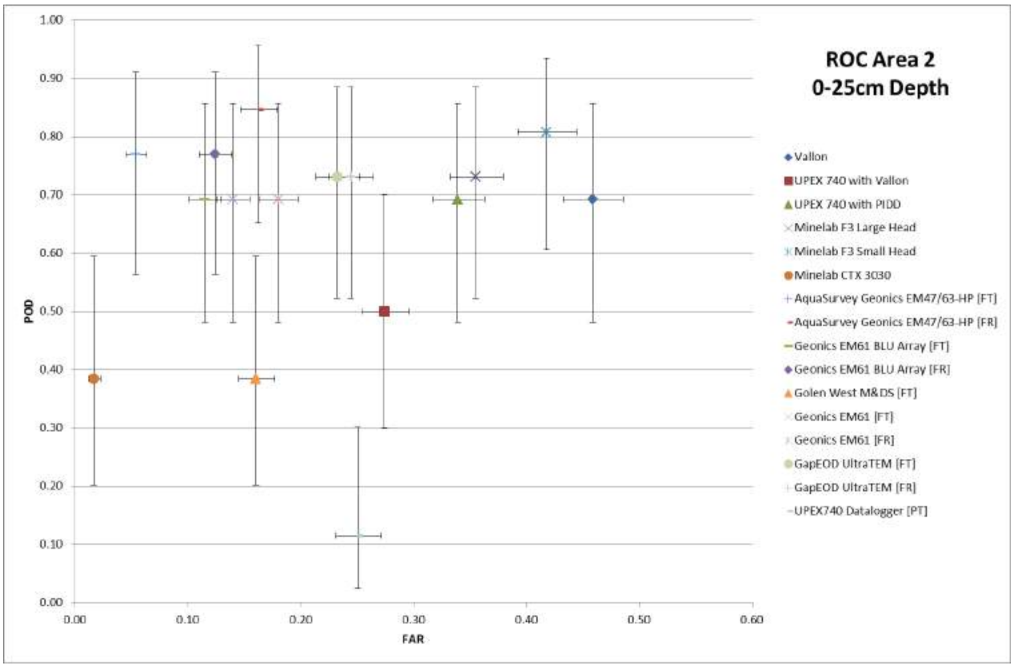

Figure 20: ROC for Final Systems Data for Depth Range 0-25cm in Area 2

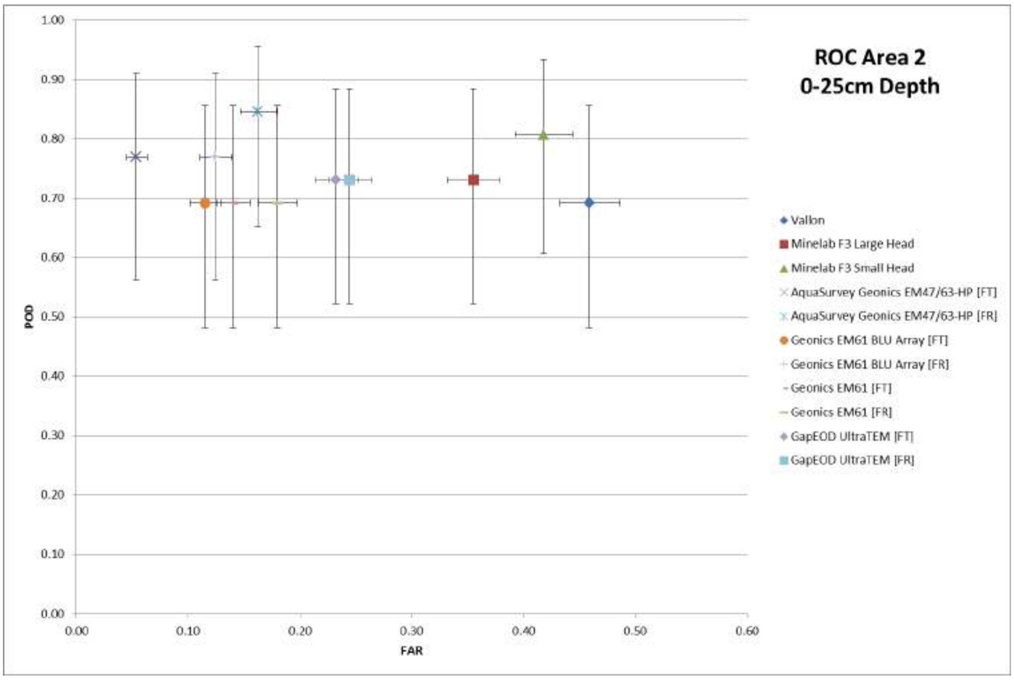

Figure 21: ROC for Systems with Overall PoD > 0.75 for Depth Range 0-25cm in Area 2

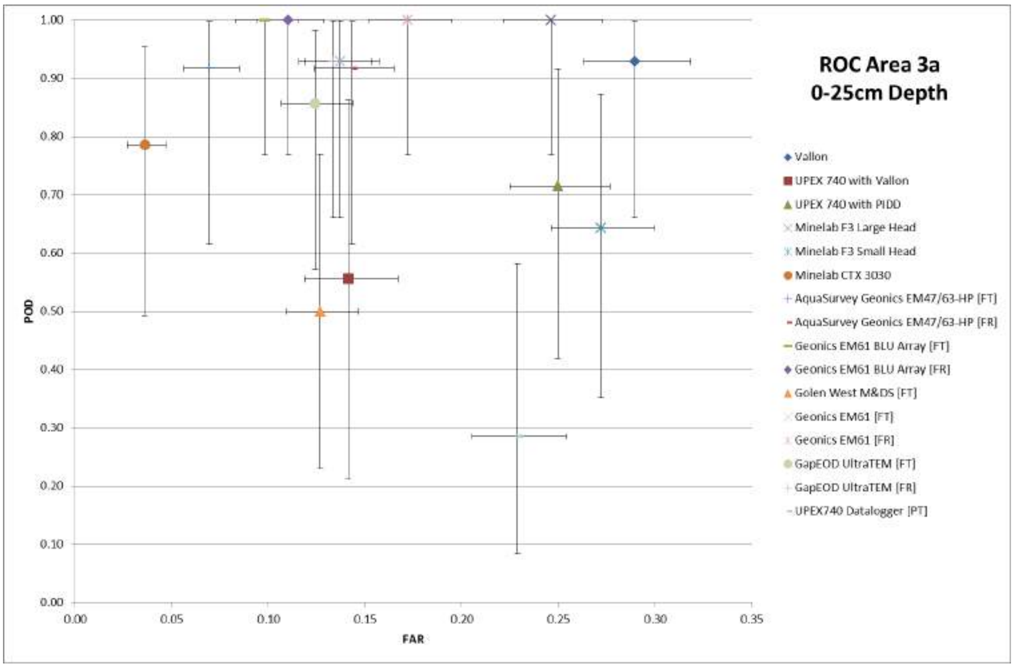

Figure 22: ROC for Final Systems Data for Depth Range 0-25cm in Area 3a

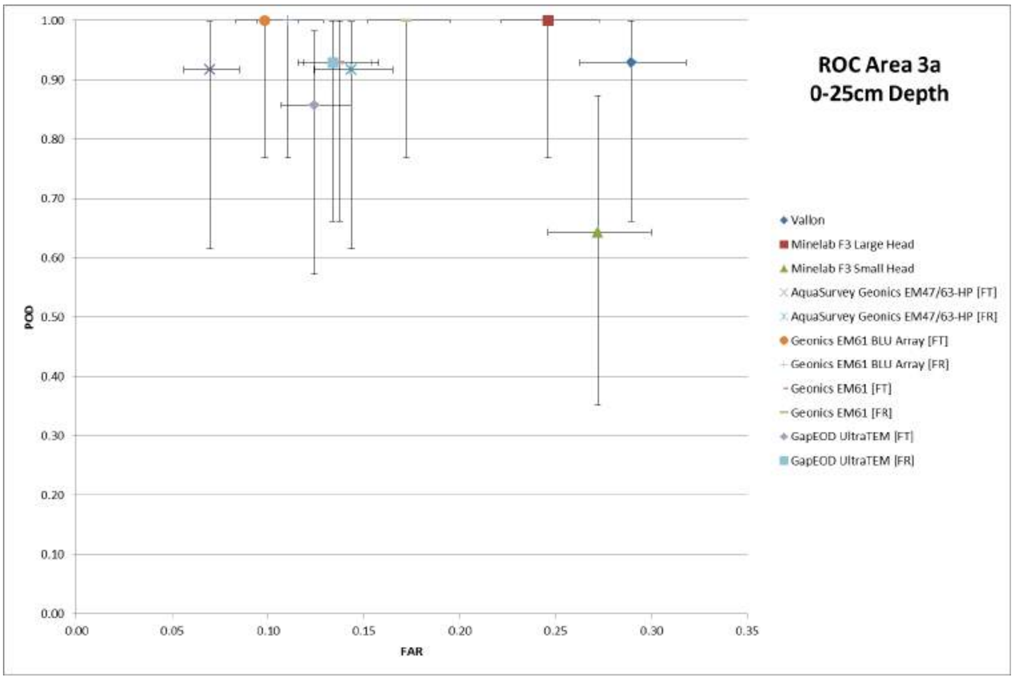

Figure 23: ROC for Systems with Overall PoD > 0.75 for Depth Range 0-25cm in Area 3a

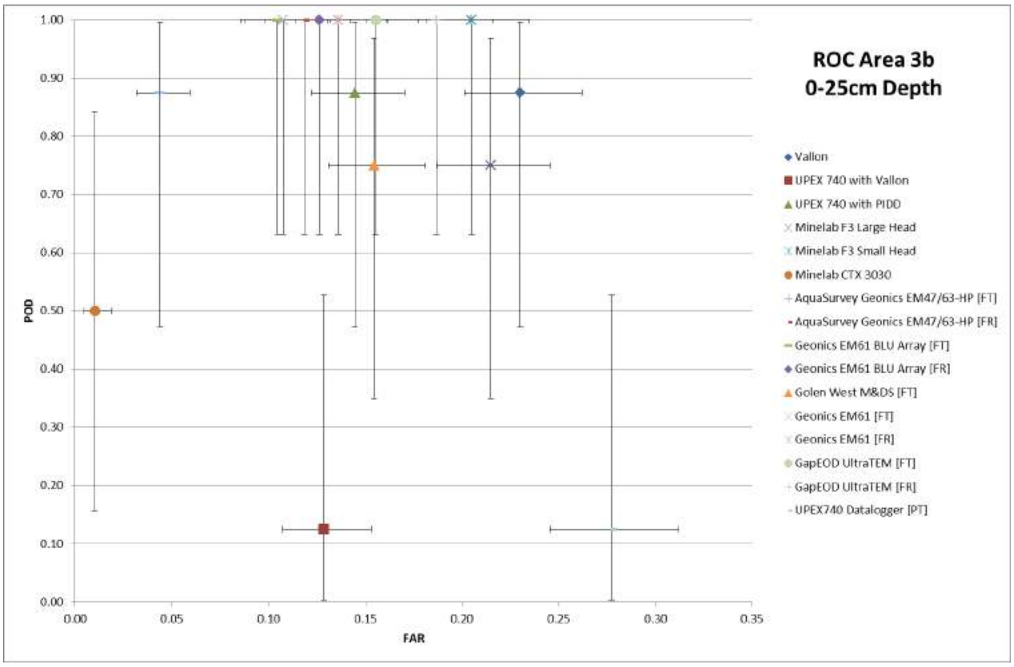

Figure 24: ROC for Final Systems Data for Depth Range 0-25cm in Area 3b

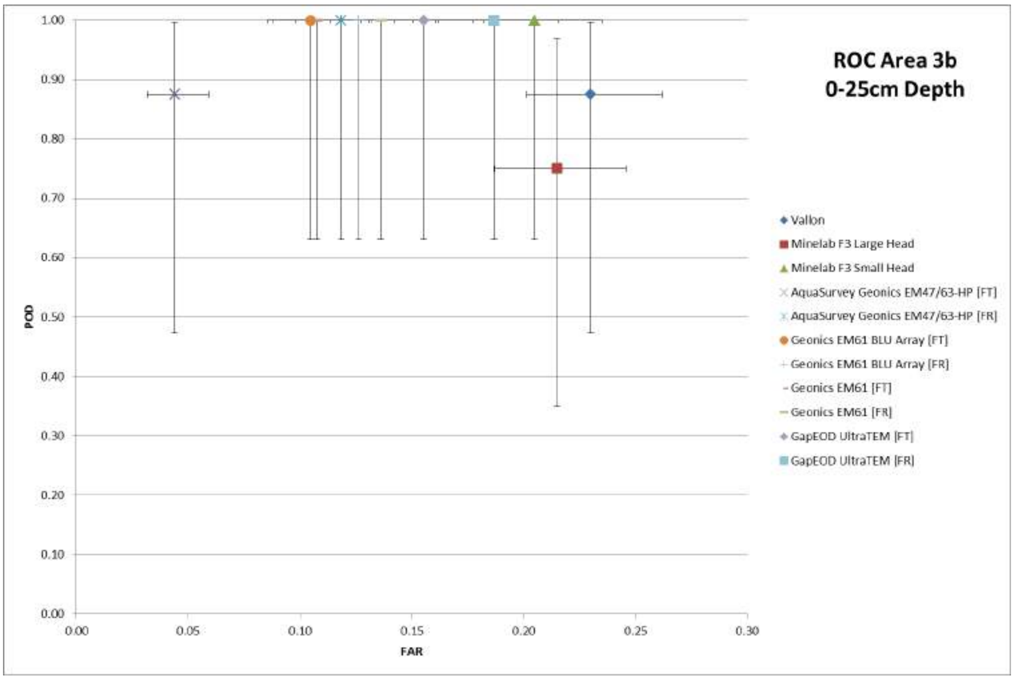

Figure 25: ROC for Systems with Overall PoD > 0.75 for Depth Range 0-25cm in Area 3b

Next we look at the mean and standard deviation of Positional Accuracy for each system:

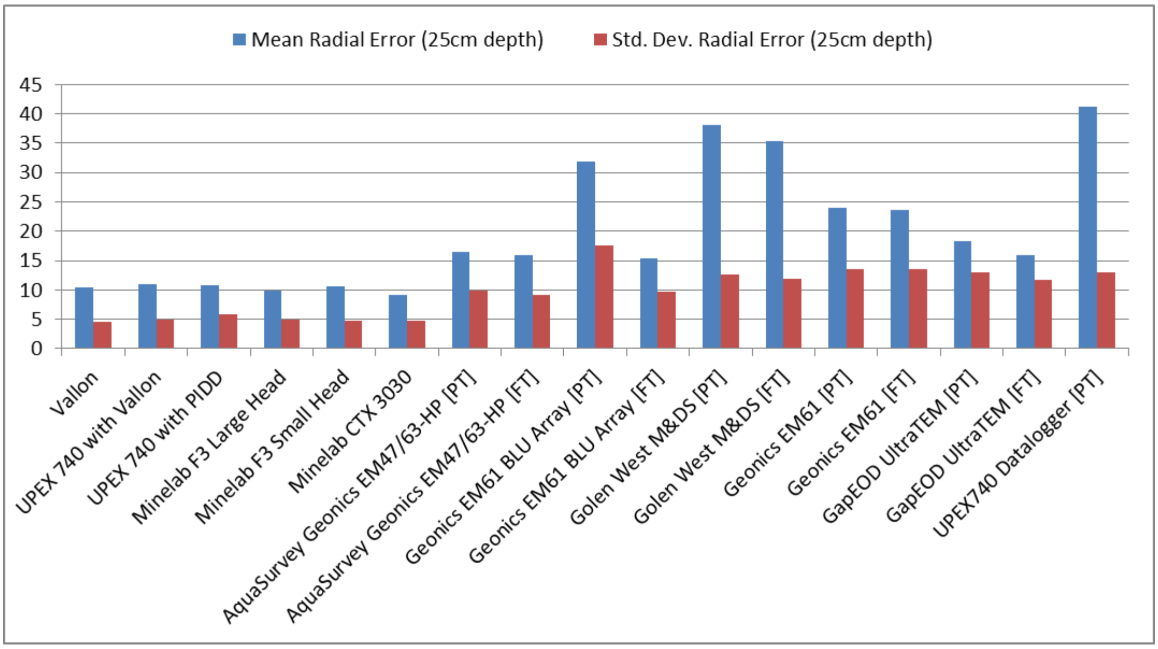

Figure 26: Mean and Standard Deviation of Positional Accuracy for Depth Range 0-25cm

C) PRODUCTIVITY

We can compare the systems that were tested during this trial by looking at how many square meters each system can clear in a given amount of time. For the purposes of this report, productivity is defined as the total square meters that UXO Lao (using appropriate resources to ensure max efficiency) could clear using a given system in one (1) hour. The term "clear" refers to multiple actions: survey of an area, data processing (for digital systems), and investigation (reacquiring dig sheet locations) and excavation of indications. It is important to note that the calculation of productivity is not just a direct calculation of how productive each system was during the trial, instead it is an attempt to extrapolate the potential productivity of each system if SOPs were setup to allow for the most reasonably efficient process possible. Obviously, this productivity calculation does not take into account all possible variables, but instead uses information collected during the test and reasonable assumptions to allow for a direct comparison of the systems evaluated. Lastly, productivity alone is only half of the story and this metric should always be examined in concert with the cost metric calculated in Section D.

A typical UXO Lao clearance team is made up of 10 members, 8 searchers, 1 team leader, and 1 medic. From a survey time and area standpoint, for analogue systems data is scaled to match the capabilities of a team (i.e. if 4 searchers surveyed 1000 m^2 in 4 hours during the test then 8 searchers would have been able to survey that same 1000 m^2 in 2 hours). For the digital systems, the as tested systems and scaled versions of those systems were examined. The scaling was still based on hand carried systems that are simply wider and contain more receivers. The wider arrays require additional searchers that are accounted for. The scaling is done to present a more realistic picture of what each of the digital systems would be able to accomplish during survey if utilized by UXO Lao in actual operations. Note that the medic is not counted as a resource during the survey portion of the clearance process because they are only required during excavation. For the investigation and excavation portion of the clearance effort, for both analogue and digital systems, the full team of 8 searchers has been used to determine a duration for each system.

To calculate productivity the total area surveyed by each system is divided by the total time required to survey, process data, and excavate indications. At first glance it seems logical to simply add the time required for survey, data processing (if applicable), and excavation to arrive at total time required to "clear" a given area. This is true when we look at costs, but not for productivity where we would want to work in the most efficient way that these systems could be applied. In practice it would not make sense to have resources waiting for one activity to be completed if there was an opportunity to work in parallel. In the case of a digital system, as soon as a reasonable section of one area (a box) has been surveyed one would want to start processing data. And, as soon as the data for the box had been processed we would want to begin excavation. When we think about working on larger areas or a group of many areas it becomes apparent quickly that the total time to "clear" all of that area is really the total time that the slowest step takes plus a small amount of survey time at the beginning and a small amount of excavation time at the end. So, to simplify, we can say that time required to "clear" any given area (when that area is part of a larger set of work) is the time it takes to complete the slowest portion of the clearance process. This simplification can also apply to analogue systems because the same efficiency gain is possible. If two teams are utilized (one team for survey and one team for excavation) then again the total time to "clear" a given area over a large area or multiple areas is just the time to complete the slowest portion of the clearance process.

Productivity is referred to by P_{RATE} with units of m^2 per hour.

$$P_{RATE} = \frac{A}{T}$$

The total survey area *A* was recorded for each system in m^2. The total time *T* (in hours) spent for each system doing survey, processing date, and excavating indications was calculated using the following equation:

$$T = MAX(T_{SUR\_TOT} + T_{PROC} + T_{EX\_TOT})$$

Where T_{SUR_TOT} is the total time spent during survey including equipment setup and breakdown and any QC activities. It was calculated by determining the number of effective days WD_{NUM} that the team would have spent to survey the total test area and then applying the appropriate amount of setup and breakdown time based on averaging time spent during setup and breakdown on each test day. Note that survey time is scaled with each analogue system to account for 8 searchers instead of the 4 that were used during testing.

$$T_{SUR\_TOT} = \begin{cases} (WD_{NUM} * WD_{HOURS}) * \frac{DM_{NUM\_TEST}}{DM_{NUM\_TEAM}}, & Analogue\ Systems \\ (WD_{NUM} * WD_{HOURS}), & Digital\ Systems \end{cases}$$

$$WD_{NUM} = \frac{T_{SUR}}{(WD_{HOURS} - (T_{SET} + T_{BR})}$$

Where WD_{HOURS} is the number of hours in a working day; for UXO Lao this is 6 hours because 1 hour of the full 8 hour day is set aside for lunch and 1 hour is usually required for travel. DM_{NUM_TEST} is the number of searchers used during the test and DM_{NUM_TEAM} is the number of searchers in the typical UXO Lao team that is 8. T_{SET} is the average time for daily setup and T_{BR} is the average time for daily breakdown.

T_{PROC} is the total time spent performing data processing for a given digital system and is a value of 0 hours for any analogue system.

Finally, T_{EX_TOT} is the total time spent investigating and excavating all indications given by a system (including false alarms). This value is calculated differently for analogue and digital systems. But, for both systems, we calculated the total time to investigate and excavate all indications and then divided by 8 searchers to set the value of T_{EX_TOT} at the team level.

$$T_{EX\_TOT} = \begin{cases} T_{EX\_TOT\_A}, & Analogue\ Systems \\ T_{EX\_TOT\_D}, & Digital\ Systems \end{cases}$$

Where $T_{EX\_TOT\_A}$, the total time spent investigating and excavating indications from the analogue systems is based on time to excavate the area directly around an indication (either for an actual target or false alarm) and the time to check that immediate area with a detector to ensure no other UXO is still present in the ground (potentially below the item or piece of scrap just removed). No time is spent rechecking the area before actually excavating soil because during the process of the analogue detector survey stakes were placed in the ground at the exact position that an indication was found and excavation would take place at that particular spot. Note that the time to check the area after excavation is actually part of the defined time for $T_{EX.}$

$$T_{EX\_TOT\_A} = \frac{T_{EX} * (Targets + FA)}{8\ Deminers}$$

In the above equation for $T_{EX\_TOT\_A}$, the term T_{EX} is the amount of time that it takes to excavate and remove a half BLU-26 or piece of scrap and search the immediate area with a detector after; determined to be 2 minutes (0.034 hours) based on testing performed by UXO Lao staff. The term *Targets* represents the total number of actual targets identified by an analogue system and the term *FA* is the total number of false alarms indicated by the analogue system.

For digital systems, the calculation of $T_{EX\_TOT\_D}$ is slightly more involved because the indications that are given by the digital systems are based on processed data and provided on a "dig sheet" that contains a set of coordinates that must be investigated. Due to the nature of the digital systems and data processing, each dig sheet coordinate is estimated to be within +/- 0.5 meters of an actual target (just like the detection halo as defined previously). What this means is that for each digital system indication (both actual targets and false alarms) a few things must take place:

1. The coordinate must be located using a GPS system
2. A 1x1m box (as determined by the +/- 0.5m accuracy of the dig sheet locations) must be searched with a handheld analogue detector around that location to account for the accuracy of the detector system, data processing, and GPS
3. All indications given by the handheld analogue detector must be excavated
4. And finally, after all excavation is complete the 1x1m box must be re-searched to ensure all items have been removed

The total investigation and excavation time for each digital system is given by the following equation:

$$T_{EX\_TOT\_D} = \frac{T_{EX\_TOT\_D\_FA} + T_{EX\_TOT\_D\_TARGETS}}{8\ Deminers}$$

Where $T_{EX\_TOT\_FA}$ is the time to investigate and excavate for false alarm indications and $T_{EX\_TOT\_TARGETS}$ is the time to investigate and excavate for actual target indications. The combined time for false alarm and target investigation and excavation is divided by 8 to set the value at the team level as with the analogue calculation. As shown below, the calculation for investigation and excavation time for false alarms versus targets is slightly different because for an actual target we must account for the target and the presence of scrap whereas with a false alarm all that must be found and excavated is scrap.

$$\begin{aligned} T_{EX\_TOT\_D\_FA} = & \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * S_{RATE\_A1})\right) * (FA_{A1}) \\ & + \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * S_{RATE\_A2})\right) * (FA_{A2}) \\ & + \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * S_{RATE\_A3a})\right) * (FA_{A3a}) \\ & + \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * S_{RATE\_A3b})\right) * (FA_{A3b}) \end{aligned}$$

$$\begin{aligned} T_{EX\_TOT\_D\_TARGETS} & \\ = & \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * (S_{RATE\_A1} + 1))\right) * Targets_{A1} \\ & + \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * (S_{RATE\_A2} + 1))\right) * Targets_{A2} \\ & + \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * (S_{RATE\_A3a} + 1))\right) * Targets_{A3a} \\ & + \left(T_{LOC} + (2 * T_{SEARCH\_D}) + (T_{EX} * (S_{RATE\_A3b} + 1))\right) * Targets_{A3b} \end{aligned}$$

In the above equations, T_{LOC} represents the time required to locate a coordinate with GPS. This was tested by MMG by locating over 500 different coordinate locations and it was determined that a single point can be found in 30 seconds (0.008 hours), including 10 minutes of breaks every hour. The term T_{SEARCH_D} refers to the time it takes to search a 1x1m box with a handheld analogue detector that is estimated to be 45 seconds (0.012 hours). S_{RATE_AX} is the expected number of pieces of scrap that would be found in a given 1x1m box in each of the test areas when using a handheld detector. Because an entire 1x1m box is searched for each digital system indication, all indications from that search will need to be excavated. S_{RATE_AX} is examined more below. The time required to excavate a single indication (T_{EX}) is multiply by the expected number of pieces of scrap that would be found in a given 1x1m box to determine the total amount of time spent digging. As seen above, when looking at false alarm indications we only need to account for the expected number of pieces of scrap in a given box, but when looking at actual target indications we also need to account for the fact that a piece of UXO is present in the box – hence T_{EX} is multiplied by S_{RATE_AX} + 1. The term FA_{AX} refers to the total number of false alarm indications given for each area by a given system and $Targets_{AX}$ is the number of actual target indications for each area.

When calculating the amount of scrap that would be expected in a 1x1m box (S_{RATE_AX}) in each test area we need to know the total number of piece of scrap seeded in each area, the amount of m^2 of each area, and the percentage of scrap that is actually detected by a typical analogue detector for the test areas. This last aspect is important since every piece of scrap in an area is not indicated by a typical analogue detector. Because we have detection and false alarm numbers from our testing for analogue detectors we can accurately calculate the percentage of scrap that would be expected to be found for each area.

$$S_{RATE\_AX} = \frac{\#\ of\ pieces\ of\ scrap\ in\ Area\ X}{\#\ of\ m^2\ in\ Area\ X} * 1.0m^2 * Scrap\ Detection\ Rate\ for\ Area\ X$$

For each area S_{RATE_AX} was determined as follows:

$$S_{RATE\_A1} = \frac{6200\ pieces\ of\ scrap}{2{,}496.58\ m^2\ in\ Area\ 1} * 1.0m^2 * 0.26 = 0.65$$

$$S_{RATE\_A2} = \frac{4450\ pieces\ of\ scrap}{2{,}496.23\ m^2\ in\ Area\ 2} * 1.0m^2 * 0.23 = 0.41$$

$$S_{RATE\_A3a} = \frac{2000\ pieces\ of\ scrap}{1{,}499.31\ m^2\ in\ Area\ 3a} * 1.0m^2 * 0.20 = 0.27$$

$$S_{RATE\_A3b} = \frac{1000\ pieces\ of\ scrap}{998.74\ m^2\ in\ Area\ 3b} * 1.0m^2 * 0.22 = 0.22$$

Where the Scrap Detection Rate (SDR) was determined by taking all false alarm rates for the Vallon and both Minelab F3 analogue detectors in each area and dividing by the total amount of scrap seeded in each area and then averaging across the 3 devices for each area as shown in Table 5.

Table 5: Determination of Scrap Detection Rate

		Vallon			**Minelab F3 Large Head**			**Minelab F3 Small Head**		
	Ave SDR	FA	Scrap	SDR	FA	Scrap	SDR	FA	Scrap	SDR
Area 1	**26%**	1943	6200	31%	1291	6200	21%	1602	6200	26%
Area 2	**23%**	1145	4450	26%	886	4450	20%	1043	4450	23%
Area 3a	**20%**	428	2000	21%	364	2000	18%	406	2000	20%
Area 3b	**22%**	229	1000	23%	214	1000	21%	204	1000	20%

D) PRODUCTIVITY RESULTS

Figure 27 shows the time each system took for survey, data processing, and indication investigation and excavation.

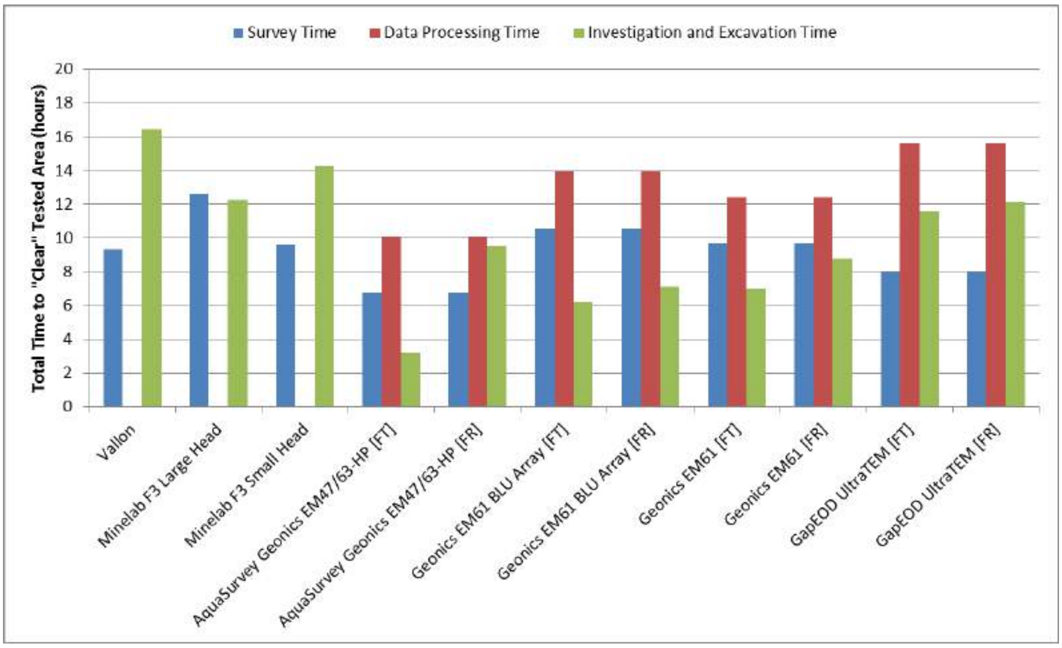

Figure 27: Time Required to "Clear" Tested Area for All As Tested Systems

Next, in Figure 28 the overall productivity rate for each system or how many m^2 can be cleared in 1 hour is shown for each of the As Tested systems.

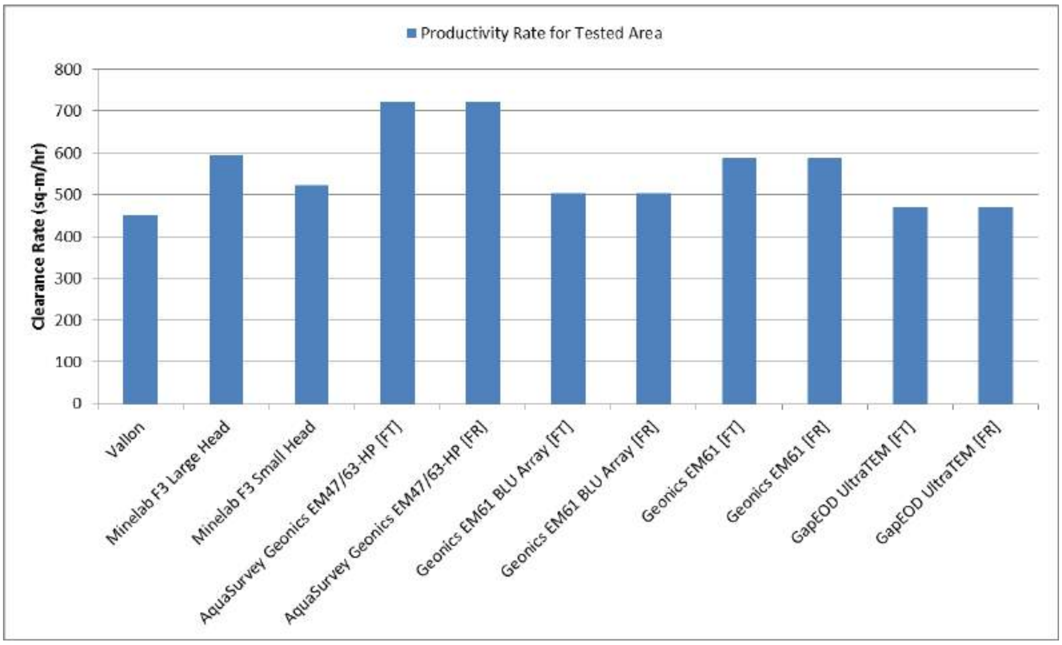

Figure 28: Productivity Rate (sq-m/hr) for All As Tested Systems

Next, data for scaled up digital systems is presented. As discussed in the previous section, just as the time to survey for the analogue systems was scaled to that of a full team, the survey times for the Geonics EM61 BLU Array, Geonics EM61, and the GAP EOD UltraTEM have been scaled based on modified equipment. This modified equipment is still representative of what can be purchased from the manufacturers and is all still hand carried. For each system a slightly wider array that included additional receivers was considered. It is important to note that the AquaSurvey equipment was not scaled because the system that was tested is the largest system they produce that can still be hand carried. New times for setup, breakdown, and survey time were estimated based on the new width of the equipment.

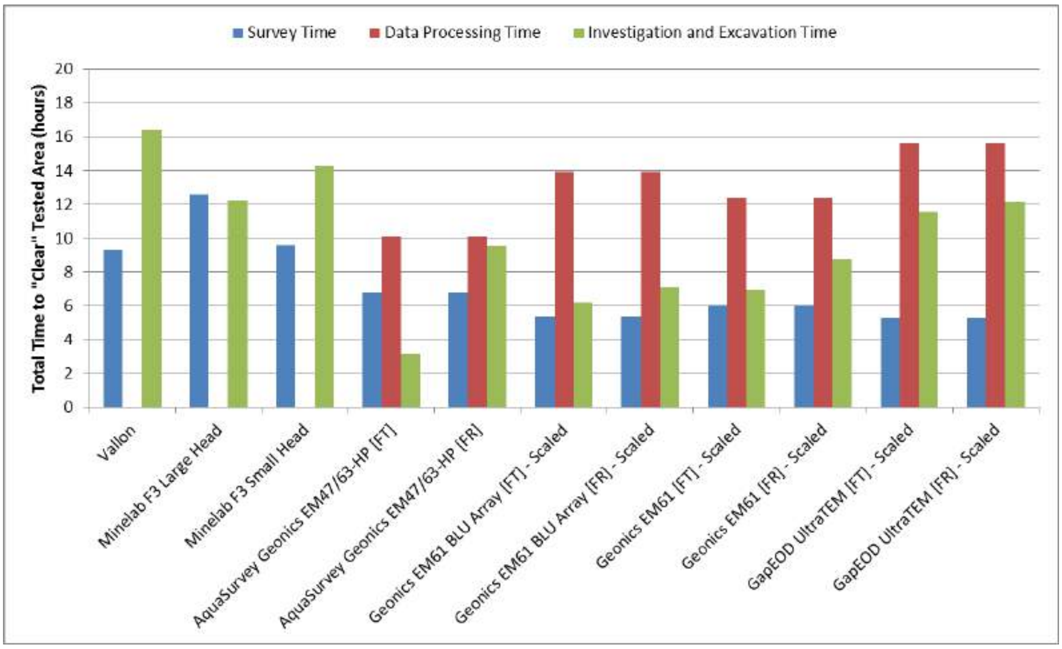

Figure 29: Total Time Required to "Clear" Tested Area for Scaled Systems

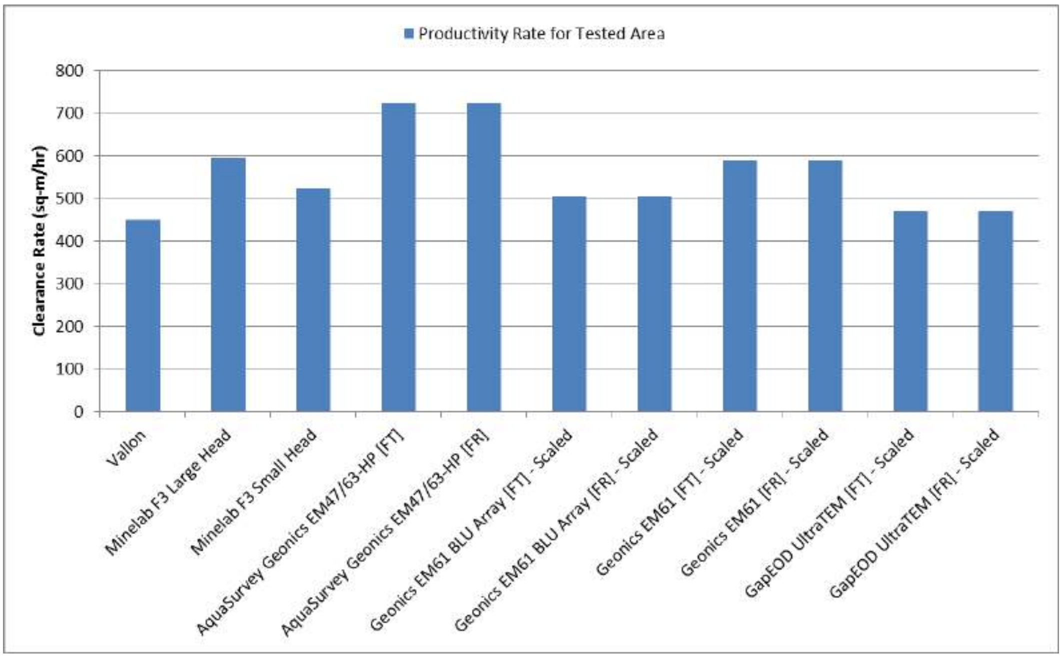

Figure 30: Productivity Rate (sq-m/hr) for Scaled Systems

Figure 29 shows that survey time is reduced for the scaled systems by 3-4 hours but the productivity rate does not change because data processing is still the slowest portion of the clearance process.

E) COST

Cost is another metric that we can use to compare different UXO detection systems. For cost, two different main parameters were examined: Fixed Cost and Operational Cost. Fixed Cost takes into account all costs associated with obtaining and preparing to use the equipment, including direct equipment cost, shipping cost to Laos, cost of any required support equipment such as GPS, operator training, etc. For Operational Cost, the test data will be used to calculate the cost to clear 1 square meter. As with Productivity, the term "clear" refers to the process of survey, data processing (if applicable), and indication investigation and excavation.

Fixed Cost:

See the table showing fixed costs in the next section. The table summarizes the fixed costs associated with each system and includes the cost for scaled up systems where applicable.

Operational Cost:

As introduced above, Operational Cost for each system will be calculated based on the cost to "clear" 1 square meter. As with Productivity, Operational Cost was examined on a team basis, meaning that when looking at a particular system the cost to clear was based on the total time to survey, process data (if applicable), and excavate indications and a full UXO Lao representative team consisting of 1 team leader, 8 searchers, and 1 medic (for the excavation portion only). Cost calculations of the survey and data processing portions of the clearance for digital systems was based on the actual number of searchers and other personnel involved in the testing. If a given digital system can survey the same area as an 8 person team with analogue detectors using only 2 searchers then the cost for survey will be substantially less for the digital system and will be represented in the Operational Cost calculation.

For some of the digital systems, both the as-tested and scaled versions of the systems were evaluated and it is important to note that as each of the digital systems is scaled (using survey time based on wider arrays) we also accounted for the additional resources needed to manage the larger equipment.

Operational cost rate is the cost for each system to clear a given area (in this case the total test area *A*) that was covered during the test divided by that area.

$$OpCostRate = \frac{OpCost}{A}$$

In the above equation, OpCost is the total cost for the clearance involving survey (C_{SUR}), data processing (C_{PROC}), and indication investigation and excavation (C_{EX}).

$$OpCost = C_{SUR} + C_{PROC} + C_{EX}$$

To calculate survey cost it's a simple matter of using the total survey time that we previously calculated and the hourly rate for each person participating in the survey. T_{SUR_TOT} is the total time to survey the area tested, TL_{NUM_SUR} is the number of team leaders involved in the survey, and DM_{NUM_SUR} is the total number of searchers involved in the survey. For the Analogue systems we use 8 as the number of searchers and 1 as the number of team leaders. For digital systems we use the actual number of searchers involved in the survey (or the number anticipated for each scaled system) and include 1 team leader. For both digital and analogue we include an additional searcher (the plus 1 in the excavation equation below) to represent the medic who receives the same salary as a searcher for the excavation portion of the clearance. TL_{HR} and DM_{HR} refer to the hourly cost for the team leader and searchers.

$$C_{SUR} = T_{SUR\_TOT} * \left(\left(TL_{NUM\_SUR} * TL_{HR} \right) + \left(DM_{NUM\_SUR} * DM_{HR} \right) \right)$$

$$TL_{HR} = \frac{\frac{\$448\ USD\ per\ month}{19.7\ working\ days} = \$22.74\ USD\ per\ working\ day}{6\ working\ hours\ per\ day} = \$3.79\ USD\ per\ hour$$

$$DM_{HR} = \frac{\frac{\$341\ USD\ per\ month}{19.7\ working\ days} = \$17.3\ USD\ per\ working\ day}{6\ working\ hours\ per\ day} = \$2.88\ USD\ per\ hour$$

To calculate the cost for data processing for each system, time spent performing data processing (for the analogue systems this is 0) is multiplied by the cost for a data processing personnel. Typically data processing is performed by an international staff member either onsite or remotely. It is important to note that we focused on an on-site or off-site international staff member who would be expected to already have the appropriate data processing tools (note that data processing software tools can be a significant expense).

In the equation below, T_{PROC} refers to the time spent processing data for the area tested and IN_{HR} is the hourly rate for an international staff member. Note that daily downtime for the international staff member is not included which is certainly not accurate but for the purposes of this analysis is not practical to make too many assumptions about how the data processing will be completed.

$$C_{PROC} = T_{PROC} * IN_{HR}$$

$$IN_{HR} = \frac{\$10,0000\ USD\ per\ month}{160\ hours\ per\ month} = \$62.5\ USD\ per\ hour$$

To calculate the cost for investigation and excavation of each test indication again the time for excavation is simply multiplied by the number of personnel and their hourly rates. For the investigation and excavation as with Productivity we are assuming a typical UXO Lao team with 8 searchers, 1 team leader, and 1 medic (with the same hourly rate as a searcher).

$$C_{EX} = T_{EX\_TOT} * \left((1\ Team\ Leader * TL_{HR}) + (9\ Searchers * DM_{HR})\right)$$

Finally, with all individual costs determined for survey, data processing, and indication investigation and excavation the Operational Cost Rate in USD per square meter can be determined.

F) COST RESULTS

Fixed Cost:

The following table summarizes the fixed costs associated with each system and includes the cost for scaled up systems where applicable. It is clear that there is a cost trade-off for scaling up a system.

Table 6: Digital System Fixed Costs

	AquaSurvey Geonics EM47/63-HP	Geonics EM61 BLU26 Array	Geonics EM61 BLU26 Array - Scaled System	Geonics EM61	Geonics EM61 - Scaled System	GapEOD UltraTEM	GapEOD UltraTEM - Scaled System
Basic Equipment	$81,500	$65,000	$110,000	$40,300	$70,000	$95,000	$110,000
Required RTK GPS *note that a range is presented because a second RTK GPS is required if excavation team works in parallel with survey team	$30,000 to $60,000	$30,000 to $60,000	$30,000 to $60,000	$30,000 to $60,000	$30,000 to $60,000	$30,000 to $60,000	$30,000 to $60,000
Operator Training (Equipment Handling for Survey Only)	$7,500	$7,500	$7,500	$7,500	$7,500	$14,000	$14,000
Shipping to Lao	not available	$1,550		$750		$1500	

Next, the total cost required to "clear" the tested area is shown. It is important to note that we capture only the cost of activities that occur on site, i.e. excluding cost of operations support services provided by the supporting headquarters and excluding the cost for commuting, consumables etc., therefore the these figures allow for relative comparison amongst tested systems, but are not suitable for comparison with the conventional cost per hectare or square meter. Figure 31, below, shows how the cost for the different required activities (survey, data processing, and indication investigation and excavation) add up to the total cost.

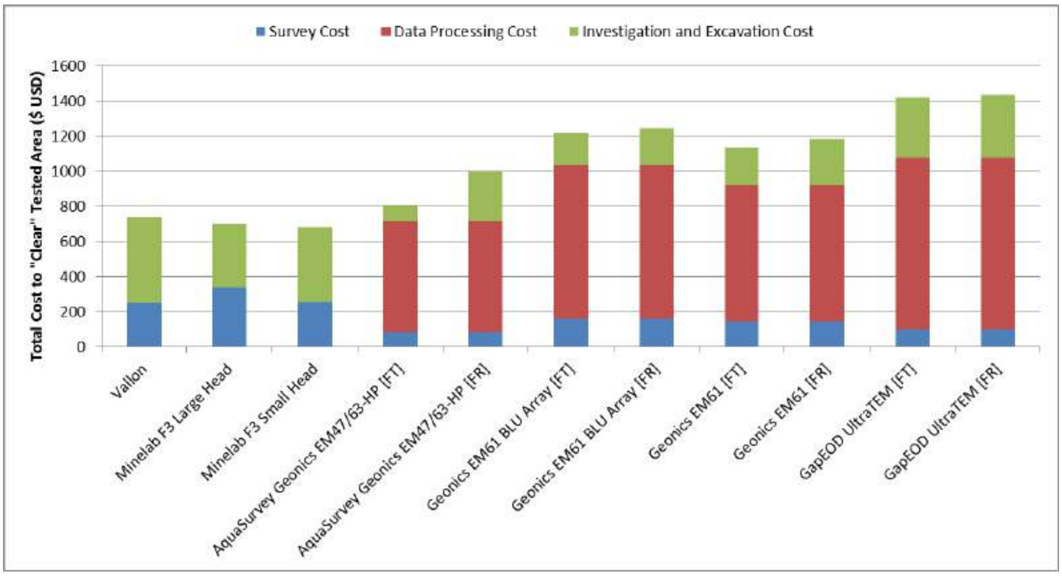

Figure 31: Total Cost Required to "Clear" Tested Area

Figure 32, the overall Operational Cost Rate for each system or how many USD is required to "clear" 1 m^2 of area is presented below.

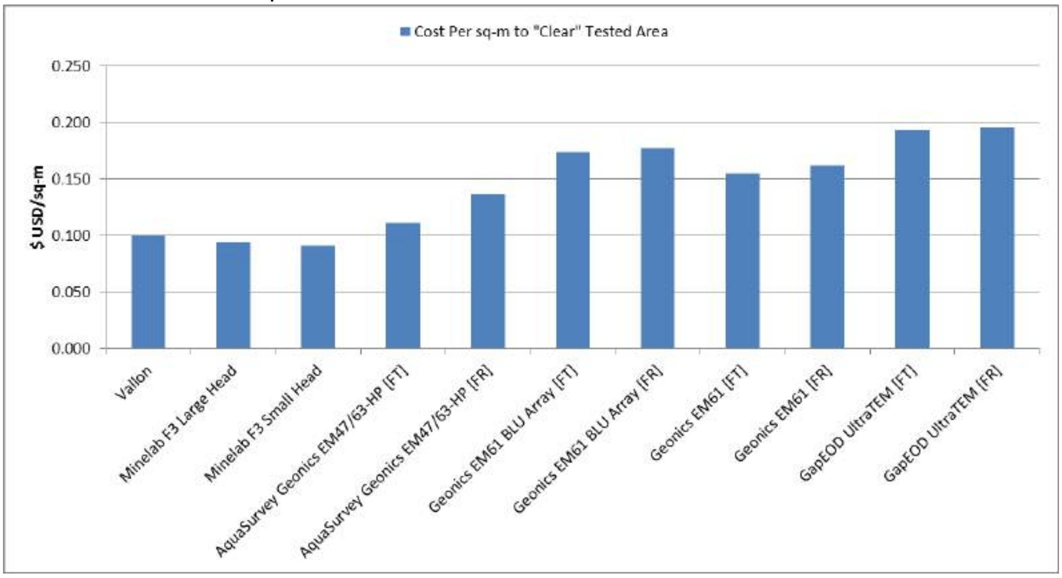

Figure 32: Operational Cost Rate

Next, the scaled system data for both cost to "clear" the tested area and operational cost rate is compared. For each scaled system, the number of support personnel required to handle the equipment was increased relative to how much wider the system became. So, even though there was a large decrease in the time required to survey, the cost decrease is not as significant due to the additional labour.

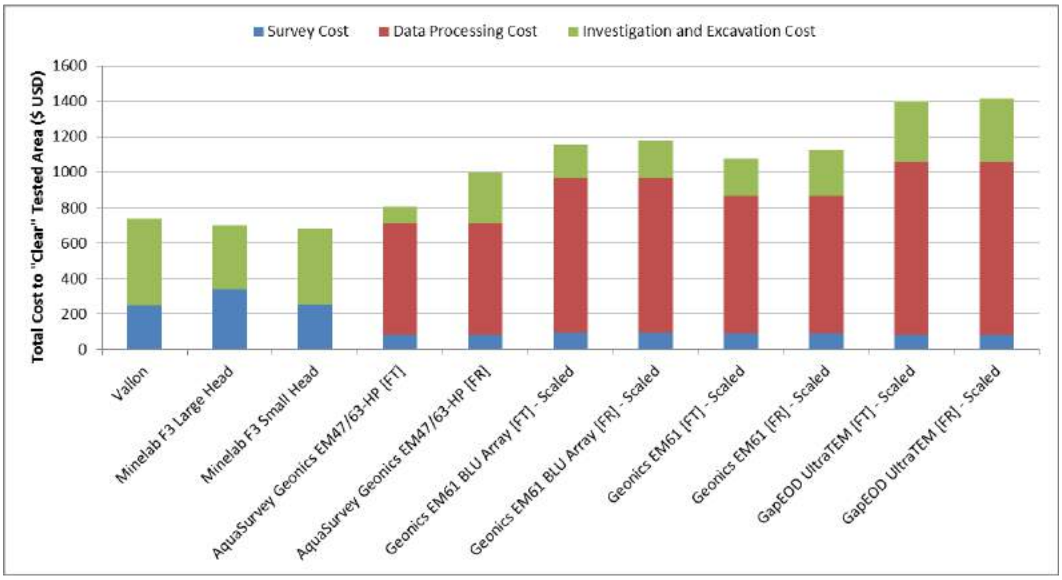

Figure 33: Total Cost Required to "Clear" the Tested Area with Scaled Systems

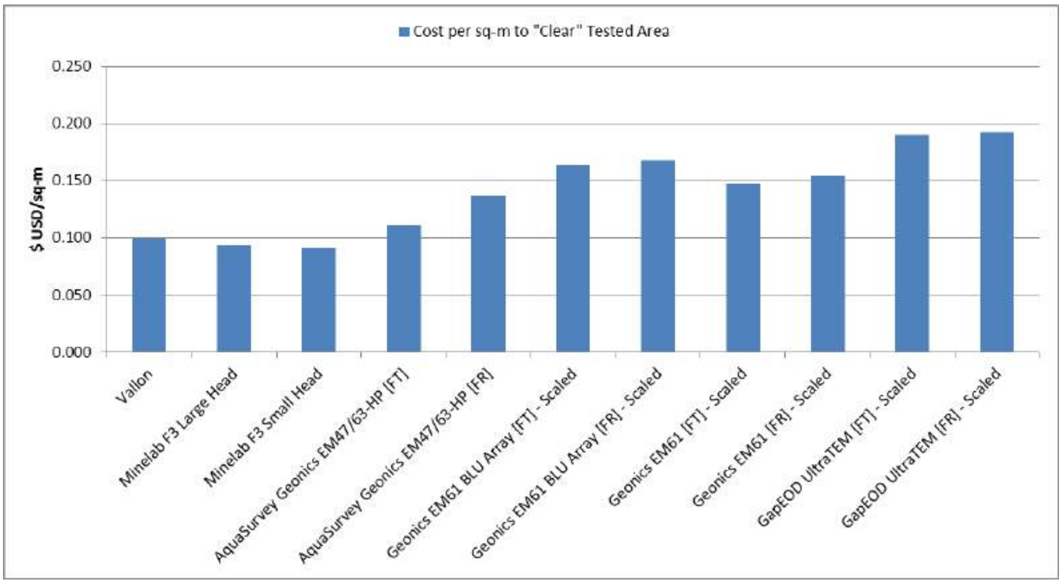

Figure 34: Operational Cost Rate for Scaled Systems

Another interesting way to look at the cost and productivity data is to view it relative to test area contamination level. The digital systems perform better relative to analogue systems in areas of high contamination when looking at the averaged data presented above. And while the productivity is better for digital systems relative to the analogue system due to much lower false alarm rates the cost per square meter is not significantly closer than in the averaged data. What is clear is that it is certainly worth performing more analysis that focuses on productivity and cost versus area contamination level.

G) DEEP ITEM TEST LANE RESULTS

As previously described, a short test lane at Area 2 was established and seeded with non-UXO items of increasingly larger sizes and depths in order to see if there was additional scope of detection beyond the primary goal of a half BLU-26 at 25cm.

For handheld detectors, four of each model was swept along the line by a separate operator. If they received a signal, they repeatedly swept over the target location and if they obtained a clear signal on four successive attempts, the target was considered to be identified. The trial observer declared targets identified or not. All four detectors were averaged so that a score of 1 implies that all four detectors located the target, while a score of 0.25 implies that only one of the four detected it.

The digital systems passed back and forth over the test lane in opposite directions. If a clear signal in the data was observed in both directions, a score of 1 was given, if it was only clear in one direction, a score of 0.5 was given. The results were added and expressed as a probability of detection. Note that due to logistical reasons, the Vallon and Ebinger UPEX 740M data logger were not tested.

Table 7: Depth Test Lane Results

Target ID	Target Location (meters from South end)	Item Description	Item Depth (meters to top)	Gap EOD - UltraTEM	Ebinger UPEX 740M (UXO Lao)	Geonics EM61 BLU-26 Array (MMG)	Golden West - MMDS	Geonics EM61 BLU-26 (MMG)	Geonics - EM47/53-HP (AquaSurvey)	Minelab CTX 3030 (MMG)	Ebinger PIDD (HALO Trust)	Minelab F3 Large Head (MMG)	Minelab F3 Small Head (MMG)
1	3	hemisphere - 2.5"	0.25	1	1	1	1	1	1	1	1	0.75	0.5
2	6	hemisphere - 2.5"	0.3	1	0	1	1	0.5	1	1	1	0.25	0.25
3	9	hemisphere - 3.5"	0.4	1	1	1	1	1	1	1	0.75	0.25	0.5
4	12	hemisphere - 3.5"	0.5	1	1	1	1	0	0	0.75	0.5	0	0
5	15	hemisphere - 4"	0.5	1	1	1	1	0	0	1	0.5	0	0
6	18	hemisphere - 4"	0.6	1	1	1	1	1	1	0	0.75	0	0
7	21	hemisphere - 4.5"	0.5	1	1	1	1	1	1	0.5	0.5	0.25	0.25
8	24	hemisphere - 4.5"	0.6	1	1	0	1	0.5	0	0	0.25	0	0
9	27	pipe	0.6	1	1	1	0	1	1	1	0.25	0.25	0.5
10	30	pipe	0.75	1	1	1	0	1	1	0	0.25	0.25	0
Probability of Detection				**1**	**0.9**	**0.9**	**0.8**	**0.7**	**0.7**	**0.6**	**0.6**	**0.2**	**0.2**

XI. DISCUSSION OF RESULTS

On average, the digital systems utilized during this trial achieved a higher PoD than the analogue detectors that are currently used in Laos. More notable, but not entirely unexpected, was that the average FAR for the digital systems was less than half that of the analogue detectors. The performances of the digital systems versus the analogue systems is of note considering the fact that most analogue systems have been in use in Laos for many years and during that time have undergone continuous improvement specific to the Lao context. Whereas the digital systems had little or no historic performance data that would have allowed for such refinement. A minimum standard for probability of detection (PoD) of 0.75 was determined to allow productivity and cost comparison between the subset of systems that were able to "effectively" locate targets throughout the test areas. By no means is this defining a PoD standard for UXO Lao, it is simply used as a way to focus on a refined group of systems with similarly high detection capabilities.

It is worth noting, that some of the digital systems were handled solely by Lao nationals, which is an indication that, with appropriate training and a competent team, digital systems could be handled by a local work force. However, the reliance on highly skilled staff to analyse the data is common to all evaluated systems. At present such highly skilled staff would most likely need to be foreign experts.

As mentioned above, productivity and cost metrics, were calculated only for systems that met a minimum PoD of 0.75. When looking at productivity, or how many sq-m a given system can "clear" in 1 hour, the AquaSurvey system stood out with values around 700 sq-m/hr as opposed to all other systems (both analogue and digital) being around 500 sq-m/hr. The analysis also highlighted how significant data processing time was even when survey and excavation time are reduced. We can also see that even though the number of False Alarms for the digital systems is much lower than for the analogue systems, due to the need to spend much more time for each digital system indication the actual total time for investigating and excavating all indications is not actually significantly reduced. And, when we use the reference list of indications from a given digital system instead of the prioritized target list the slight increase in PoD is accompanied by an increase in false alarms that add appreciable time to excavation.

When looking at the cost metric (cost to "clear" 1 sq-m), we see that the analogue systems had lower cost/sq-m than all of the digital systems and only the AquaSurvey system came close when utilizing just the prioritized target list which had a lower PoD than the analogue systems. But, it is important to note that PoD was much higher for the AquaSurvey system (as for a number of the other digital systems) when using the full reference list of indications. It is nothing new to see that PoD can be increased at the expense of additional false alarms and that this impact can be seen in the productivity and cost metrics. On average, the analogue systems had cost/sq-m of under $0.1 whereas the digital systems were mostly between 0.15 and 0.20 USD/sq-m.

Analogue detectors demonstrated a near constant average of 10cm in mean spatial accuracy while digital systems ranged from approximately 15 to 40cm with a clear correlation shown between smaller receivers providing increasing accuracy. Furthermore, analogue systems maintained this accuracy with the deeper BLU-26 targets while the accuracy of the digital systems degraded slightly at depth.

The UPEX 740M by Ebinger, which is widely used in Laos failed to meet the trial's minimum PoD standard. During the trial, this equipment was handled by experienced and current operators from multiple organizations, used in a variety of configurations, settings, in various soils and analogue and digital modes. Because the UPEX 740M in analogue mode was used with two different detectors for follow up localization; one of which achieved a high PoD on its own, the Vallon VMXC1; it is likely that the supplemental metal detector was not responsible for the low PoD. When looking at the equipment properties, the receiver size of 1m x 2m may be an area to focus on because a larger receiver will necessarily average signal responses over a larger area, thereby reducing the relatively small signal from the BLU. Delay and sensitivity settings must also be scrutinized as incorrect settings would lead to a reduced signal from not only small scrap but weak signals from BLUs at depth or in a poor physical state.

With respect to clutter rejection, the Minelab CTX3030, the only analogue detector demonstrated which is currently not actively used in Lao, showed significant potential. Although it did not meet the trial's minimum PoD standard, its exceptionally low false alarm ratio of less than 2 non-UXO identified for every correctly detected UXO certainly merits further investigation. It should be noted however that detectors that discriminate clutter by using target object signatures are likely not suitable for area clearance but rather are more suited to technical survey.

Below, we discuss each system that was part of the trial. Note that False Alarm Rates (FAR) are expressed per hectare and the reported numbers were generated by averaging across all of the trial sites.

AQUA SURVEY, INC. – GEONICS EM47/63 HP

This system was notable for its high PoD at both 25 and 40cm; 0.91 and 0.89 respectively, with a FAR of 1700.

This system was trialled by two international AquaSurvey staff with an average of 3.3 years of experience. Data was analysed by a third AquaSurvey staff onsite.

From a productivity and cost standpoint, it was by far the best performer of the digital systems examined with productivity approaching 700 sq-m/hour and cost of just over 0.1 USD/sq-m.

This was a customized system that synthesized higher power, faster acquisition rates and more time gates than the standard EM61-MK2A-HP system. This allowed for more complex data analysis where some amount of target discrimination was possible. The initial field target list of a total of 294 objects accounted for a PoD of 0.75 at 25cm, which represented the least amount of false alarms per UXO identified of any successful system demonstrated. However, to locate the next 11 UXO, over 1000 additional non-UXO would require investigation. This demonstrates both the potential and the difficulty of classification; the FAR typically increases significantly for a small raise in PoD at the top end. Although the PoD for both shallow and deeper items was very similar, the process of manual target classification appears to be a lot more challenging for items at greater depth.

MMG – GEONICS EM61 BLU-26 ARRAY

This system was notable for its high PoD at both 25 and 40cm; 0.88 and 0.92 respectively, with the lowest FAR, 1353, when comparing only the Response list (AquaSurvey has a better FAR when comparing Target Lists). Only two systems detected all seeded targets in highly mineralized soil, this system being one of them. The spatial accuracy of this system was the best of the digital systems with mean radial error of 15.45cm at targets above 25cm and 18.35cm for targets between 25 and 40cm. It tied for the best record in the deep item calibration lane by locating 9 of the 10 targets. Minor weaknesses exist with respect to manoeuvrability, which should be addressed in a production version.

For productivity it was on the lower end even when scaled up and for the cost metric it was one of the more expensive systems evaluated.

This system was trialled by a local crew of four operators who carried the equipment and one Lao supervisor who operated the data logger. The field team had an average of 4 years of experience and the data was analysed from abroad. Data analysis combined automated target picking supplemented by visual inspection of the data to refine the target list.

The actual equipment that was tested was a prototype of the now commercially available system. For the trial, its four circular receivers of 0.67m diameter were overlapped evenly and encircled by a transmitting cable. The system was connected to a standard EM61-MK2A-HP cart, which housed the console, battery and data logger (although that system's transmitter and receiver were not operating). Each receiver recorded two channels, early and late time gates.

Ahead of the first day of trials, the field crew had inadvertently connected the receivers from right to left instead of left to right. This was subsequently realized and corrected during the final data analysis and explains the large improvement in results between the two submissions.

MMG – GEONICS EM61

This system achieved a PoD at 25cm of 0.86, although decreasing to 0.70 at 40cm with a FAR of 1691.

From a cost and productivity standpoint this system had a slightly better than average productivity rate (~600 sq-m/hour) and a moderate cost of 0.15 USD/sq-m.

This system was trialled by a local crew of four operators who rotated carrying the equipment two at a time and one supervisor who operated the data logger. The field team had an average of 3.6 years of experience. This was a modified EM61-MK2A-HP system. The time gates were adjusted to exploit the rapid decay of the BLU-26 in the time domain. The two channels were used to compute a patent pending output channel, which did a reasonable job of reducing soil response effects and highlighting UXO targets.

The system was configured with hand-carried poles where the console and data logger were mounted to, rather than the standard wheeled configuration. This resulted in improved data quality although the 0.5m x 1m receiver size combined with 0.75m line spacing limited the system resolution and added to spatial errors of 23.7cm for 25cm targets. This system located 7 of the 10 buried items in the deep item test lane.

Data processing was performed off-site by experts from Geonics Ltd. Data analysis combined automated target picking supplemented by visual inspection of the data to refine the target list.

GAP EXPLOSIVE ORDNANCE DETECTION – ULTRATEM MOBILE DETECTION SYSTEM

This system achieved a PoD of 0.85 and 0.86 at 25cm and 40cm respectively, with a FAR of 2237. This system achieved a high spatial accuracy of 15.54cm and 18.57cm at 25 and 40cm respectively and tied for the best record on the deep item calibration lane by locating 9 out of 10 targets.

When looking at productivity and cost metrics, this system was the worst overall performer of the digital systems with the lowest productivity of less than 500 sq-m/hour and the highest cost of ~0.20 USD/sq-m.

It was operated by three local crew members with an average number of 2 years of experience plus an international supervisor to operate the acquisition computer and analyse the data.

This system included a lightweight frame of 6 small cubic receivers, each with three orthogonal coils, spaced approximately 25cm apart and encircled by a transmitting cable. It samples 30 different channels and the transmitter outputs up to 25A. It was carried by two operators while a third carried a backpack containing the acquisition computer, which was controlled by a tablet.

GOLDEN WEST HUMANITARIAN FOUNDATION – MMDS (UPEX740M)

This system achieved a PoD of 0.48 and 0.35 at 25cm and 40cm respectively, with a FAR of 1410. It located 8 of the 10 items on the deep item calibration lane.

This system is based on the UPEX 740M by Ebinger. It was operated by two international crew members with an average number of 15 years of experience. They also analysed the data. The system has advanced the standard product by creating an array and synchronizing three 1mx1m, two turn transmitter/receiver coils, integrating the system with GPS and logging data on custom made software. It was demonstrated in both a three coiled, wheeled cart and a two coiled, hand-carried configuration. Prior to data acquisition, the system was left to warm up for five minutes; was tilted or lifted off the ground and each coil was zeroed. A delay of 45 µs was used and the mode was 'LIN'. The coils remained 20cm above the ground.

While demonstrating versatility with the size, shape and numbers of receiver/transmitter configurations, the system failed to pass the minimum PoD standard of the trial. At 3.24m wide, the cart system covered a swath of 3m at a time, the largest of any equipment demonstrated. This may have been too wide as the system bounced side to side on uneven ground causing the array to 'roll' in the direction perpendicular to travel. Data analysis was mainly automated and all targets above a specified amplitude were selected.

UXO LAO – EBINGER UPEX 740M - DATALOGGER

This system achieved a PoD of 0.16 and 0.14 at 25cm and 40cm respectively, with a FAR of 1842.

The area was searched with two people operating the UPEX 740M, two people moving lane ropes and one supervisor. The average number of years of operator experience was 5.25 years. This system was deployed in a 1m x 2m wide configuration with the coincident transmitter/receiver coils in a figure eight formation. A delay of 75µs was used and the mode was 'LIN', the height was approximately 15-20cm above the ground and lines were spaced 1.5m apart.

Prior to surveying, the system was warmed up for ten minutes and tested with a half BLU-26 at a distance of 30cm. The crew surveyed lanes smoothly and at an even pace; necessary to geo-reference the grid once completed. They appeared however, to lack experience to use the equipment in data-logging mode; as was evidenced by one grid that had been set up incorrectly and had to be resurveyed as well as the detection score which, was the lowest of all equipment demonstrated. Performing local grids that are later geo-referenced may work for large UXO targets but is not ideal for small targets such as BLUs. The resulting spatial errors would quickly compound with larger grids when walking speeds, start/stop times are not precisely managed. Targets were picked solely based on maximum amplitude. This system is currently not in operational use at UXO Lao.

MMG – MINELAB F3 LARGE HEAD, YELLOW CAP
This metal detector was notable for a PoD of 0.84 and 0.85 at 25cm and 40cm respectively, with a FAR of 3333. While tying for the highest PoD among successful analogue detectors, it had the lowest FAR.

From a productivity and cost metric standpoint, this detector was a strong performer. It had one of the highest productivity rates over 600 sq-m/hr and one of the lowest cost rates at less than 0.10 USD/sq-m.

The area was searched as a 'one person per detector' drill with one area supervisor covering four searchers, one per 25m x 25m box. The average number of years of operator experience was 5.3 years. This metal detector was used with settings optimized for the detection of a BLU-26 to 25cm. The volume was 30 and the sensitivity 23, with standard ground compensation. The detectors were all ground balanced and tested on a half BLU-26 at 25cm depth before searching and after changing batteries. Lanes were one meter wide with 20cm overlap on each side. The search head was held approximately 15cm above the surface and all targets that met or exceeded five LEDs were marked for excavation.

The large search head covered ground relatively quickly and penetrated deep (as evidenced by the highest PoD at depth of analogue detectors). In strongly mineralized soil it performed much better than most of its analogue contenders. Keeping in mind that signals of one to four LEDs were discriminated during search, there seems to be potential for higher PoD, however, that is expected to incur a sharp increase of false alarms. In addition, as is typical with large search heads, the batteries were consumed quickly and needed replacing two or three times in a day. Other negative issues included replacing a unit that had malfunctioned in Area 3a and not being able to search a small area (20.7m^2) of highly mineralized soil in Area 3a.

Despite the large search head, pinpointing did not seem to suffer as its spatial accuracy was in line with other metal detectors. Pinpointing was achieved by tilting the search head and approaching the anomaly from multiple directions along the edge of the search head.

UXO LAO – VALLON VMXC1

This metal detector was notable for a PoD of 0.84 and 0.76 at 25cm and 40cm respectively, with a FAR of 4462. While tying for the highest PoD among successful analogue detectors, it had also the highest FAR.

For productivity and cost metrics, this detector had a lower than average productivity rate of less than 500 sq-m/hr but a low cost rate of 0.10 USD/sq-m.

The area was searched as a 'one person per detector' drill with one area supervisor covering four searchers, one per 25m x 25m box. The average number of years of operator experience was 12.3 years.

This metal detector was used on setting 8 and searched lanes one meter wide with 15cm overlap on each side while maintaining the search head approximately 7cm above the ground. The detectors were all ground balanced and tested on a half BLU-26 at 25cm depth before searching and after changing batteries. Negative issues included running out of time in Area 1, the most heavily contaminated area, replacing a unit that has malfunctioned in Area 1 and not being able to search in small area (20.7m^2) of highly mineralized soil in Area 3a.

Like the Minelab CTX 3030, the Vallon also has an object signature feature, though it is currently not applied for UXO Lao clearance operations for various reasons.

MMG – MINELAB F3 SMALL HEAD, YELLOW CAP

This metal detector achieved a PoD of 0.75 and 0.73 at 25cm and 40cm respectively, with a FAR of 3841.

From a productivity and cost metric standpoint, this detector was the best performer of the analogue systems with a productivity rate around average (500 sq-m/hr) and the best cost rate of any system tested at 0.09 USD/sq-m.

The area was searched as a 'one person per detector' drill with one area supervisor covering four searchers, one per 25m x 25m box. The average number of years of operator experience was 3 years.

This metal detector was used with settings optimized for the detection of a BLU-26 to 25cm. The volume was 36 and the sensitivity 27, with standard ground compensation. The detectors were all ground balanced and tested on a half BLU-26 at 20, 25 and 30cm depth before searching and after changing batteries. Lanes were one meter wide with 20cm overlap on each side. The search head was held approximately 15cm above the surface and all targets that met or exceeded five LEDs was marked for excavation. The small search head resulted in slightly slower searching than the large head version although the battery usage was better.

HALO TRUST – EBINGER 740M ANALOGUE + EBINGER PIDD

This metal detector achieved a PoD of 0.66 and 0.41 at 25cm and 40cm respectively, with a FAR of 2944.

The area was searched with two people operating the UPEX 740M; two people moving lane ropes and marking areas for follow up investigation with the PIDD; and one supervisor. The average number of years of operator experience was 1 year. This system was deployed in a 1m x 2m wide configuration with the coincident transmitter/receiver coils in a figure eight formation. A delay of 150µs was used and the mode was 'LIN', the height was approximately 20cm above the ground and lines were spaced 1.8m apart, providing 10cm of overlap on each lane.

Prior to surveying, the UPEX system was warmed up for ten minutes and tested with a half BLU-26 at a distance of 25cm after zeroing in a cleared area at 15-20cm above the ground. The PIDD was tested with a test piece supplied by the manufacturer at a distance of 35cm from the search head. It was then tested over the half BLU-26 at 25cm. Signals of 20 or greater on the UPEX 740M were marked with bamboo pegs and subsequently searched with the PIDD to isolate targets. This system failed to meet the minimum PoD requirements of the trial. A potential cause is the large array size which relates directly to a decrease in resolution of small objects. The receiver size of 1m x 2m may be an area to focus on because a larger receiver will necessarily average signal responses over a larger area, thereby reducing the relatively small signal from the BLU.

MMG – MINELAB CTX3030

This metal detector achieved a PoD of 0.51 and 0.35 at 25cm and 40cm respectively, with an extremely low FAR of 171.

The area was searched as a 'one person per detector' drill with one area supervisor covering four searchers, one per 25m x 25m box. The average number of years of operator experience was 3 years.

This metal detector was used with settings optimized for the detection of a BLU-26 to 25cm. The detectors have a range of adjustable settings and exploit the ability of the instrument to provide information to the operator about the ferrous and conductive nature of the signal being received. The detector can be set up to emit a tone when a certain combination of ferrous and conductive values have been measured while the threshold will blank over targets which are measured but do not fall inside the range of accepted signals. In this way, it was attempted to create a 'discrimination pattern', which provided a tone when the search head passed over a BLU-26 but a blanking tone when passed over fragmentation.

The detectors were all ground balanced and tested on a half BLU-26 at 25cm and 30cm and a second hole with fragmentation at 20cm depth before searching and after changing batteries. Lanes were one meter wide with 10cm overlap on each side. The search head was held approximately 5cm above the surface and all targets, which clearly fell inside the discrimination pattern, were marked for excavation.

This was the only analogue metal detector demonstrated which is currently not being used in Laos. The operators were UXO technicians working for MMG and had just 2.5 days of training;

enough to meet CWA guidelines but not ideal. During the training performed by the Minelab country representative, a method of pinpointing was devised to deal with the event that targets fell near to the discrimination pattern. This involved sweeping the search head over the target from multiple directions and at multiple angles. Only targets that repeatedly fell inside the discrimination pattern were marked for investigation. The ability to avoid time on the many pieces of non-UXO present allowed this team to complete the search in very short time. Although they missed almost half of the UXO in the test areas at 25cm deep, this detector showed significant potential due to the extremely low false alarm ratio; less than 2 non-UXO were identified for each UXO. If the discrimination pattern could be relaxed so that more targets were picked, the PoD may have passed the trial's minimum standard while maintaining a reasonably low FAR.

It should however be kept in mind that by discriminating steel fragmentation, the user has also discriminated any objects made almost entirely of steel such as bombs, rockets and mortars. If searching in an area where it is not known what types of UXO are present, the discrimination patterns used during this trial could not reliably detect such items. This limits the use of signature detectors to 'survey for specific evidence' only (e.g. Cluster Munition Remnant Survey).

UXO LAO – EBINGER 740M ANALOGUE + VALLON VMXC1

This metal detector achieved a PoD of 0.45 and 0.47 at 25cm and 40cm respectively, with a FAR of 1968.

The area was searched with two people operating the UPEX 740M, three people moving lane ropes and marking areas for follow up investigation with the Vallon, and one supervisor. The average number of years of operator experience was 7.3 years. This system was deployed in a 1m x 2m wide configuration with the coincident transmitter/receiver coils in a figure eight formation. A delay of 75µs was used and the mode was 'LIN', the height was approximately 15-20cm above the ground and lines were spaced 1.5m apart, providing 25cm of overlap on each lane. The Vallon was used in the same manner as previously described.

Prior to surveying, the UPEX system was warmed up for ten to fifteen minutes, held 20cm above the ground and zeroed in a cleared area before being tested with a half BLU-26 at a distance of 25cm. The Vallon was tested as previously described. Signals of 25 or greater on the UPEX 740M were marked with bamboo pegs and subsequently searched with the Vallon to isolate targets. This system failed to meet the minimum PoD standard set for the trial. A potential cause is the large array size which relates directly to a decrease in resolution of small objects. The comparatively good (and consistent) performance of the UPEX on the Deep Item Test Lane (second best PoD of 0.9) is in contrast with performance during the shallow search portion of the trial.

XII. CONCLUSIONS & RECOMMENDATIONS

The testing has produced some very informative results. The data collected during this test period will not only help UXO Lao in their clearance efforts but potentially other UXO clearance operations in other parts of the world. Some specific conclusions and recommendations follow:

General Conclusions:

1. A number of digital systems performed well, with a number achieving a higher probability of detection and less than half of the false alarm indications compared to the successful analogue systems tested. As such, they certainly should be considered as viable UXO detection systems. Going forward, it will be important to develop accreditation, operational standards, and QM processes for these systems.

   They do have a few drawbacks that need to be considered. Due to the requirement of having GPS, they need a relatively open view of the sky which limits where they can operate. They struggle in difficult terrain or where vegetation restricts access. They have large initial costs for both the equipment and training. In addition, our analysis indicates that they are much more expensive to operate and may only provide marginal improvement in productivity and PoD. It is clear that local staff would be able to handle a man-portable system, but data analysis would need to be significantly automated, sped up, and/or conducted by regional personnel rather than outsourced by foreign experts in order to be a cost effective option for UXO Lao. This does not appear to be likely in the foreseeable future.

   It is important to note that the digital systems were shown to offer some nice benefits from a quality control perspective. Several teams conducted preliminary quality control checks of the data while still in the field. And, in two instances, they identified areas without adequate coverage and we able to resurvey them immediately. Being able to quantify how much of the areas were covered, precisely what was left out, potential operator problems such as metallic interference, excessive walking speeds or incorrect handling of the equipment are valuable. And, the digital record created is defensible in terms of demonstrating that work has been carried out to an agreed standard. In addition, these systems scored well on probability of detection and had low false alarm rates largely by allowing the data analyst to determine what constitutes a "target" based on a repeatable process utilizing a multitude of parameters including but not limited to: minimum signal strength, inherent conductive properties, anomaly width, and calculated target size.

2. Unless the data processing costs associated with using digital systems are substantially reduced, analogue systems are likely to remain the preferred choice for organizations like UXO Lao.

3. Of the successful digital systems, the Aqua Survey system was by far the best performer from a productivity and cost standpoint with productivity approaching 700 sq-m/hour and cost of just over 0.1 USD/sq-m.

4. For all successful digital systems, target picking was less effective than one might have desired. The process either removed too many true positives (reducing PoD) or was not able to substantially reduce false alarms (maybe with the exception of the Geonics EM61 which was able to reduce false alarms by 22% with a PoD loss of only 0.02).

5. Digital systems, notably the UltraTEM by GapEOD and the EM61 BLU-26 Array appear to offer technology able to clear up to 75cm in a single pass. This could represent a cost effective option to search areas where excavation beyond the standard 25cm is required such as road building or construction.
6. Three of the analogue systems that were tested met the minimum PoD standard of 0.75. Of those, two had an average PoD of 0.84 up to 25cm, the Minelab F3 with large search head and the Vallon VMXC1. These systems did have high numbers of False Alarms but this ultimately did not negatively affect their productivity and cost rates – productivity was on average equivalent to most digital systems even when they were scaled, and their cost rate was significantly better than all digital systems evaluated. Special care must be taken to recognize mineralized soils and in those areas, additional testing and ground compensation measures should be undertaken to ensure adequate performance.
7. The UPEX 740M failed to meet the trial's minimum PoD standard in every configuration demonstrated, despite the experience of the staff using this equipment. The UPEX is currently utilized in Lao by several organizations and as such the results should be further investigated to determine all cause(s) of the poor performance.
8. The Minelab CTX 3030 produced interesting results and shows good potential as a technical survey tool. It had the lowest false alarm rate of any system tested but did not have a high probability of detection. Based on the results this detector should be further investigated to see if probability of detection could be increased even at the expense of increasing the false alarm rate. Again, it must be stated that the detector's ability to discriminate fragmentation from BLUs required the operator to be aware that the nature of UXO threat was indeed from BLUs and that the contamination was from steel fragmentation. Other types of UXO, which may be present, must be tested on before using this instrument to ensure they fall within the operator created discrimination pattern; else they may be missed.
9. Given what we know about the ground conditions in Lao (terrain, soil characteristics, and fragmentation contamination) and measurements taken at the test sites, the 4 test areas utilized during this trial were reasonably representative of ground conditions found throughout Lao (at least those areas that are open and relatively flat).

Some specific recommendations:

1. UXO Lao should conduct a simple desk study to look at how a digital detection system would fit with existing operations and what the true impact and cost would be over a period of years. This study would be an extension of the productivity and cost metric analysis performed as part of this trial. Actual areas of much greater size could be looked at and be directly compared to existing clearance processes to understand what productivity increase might be possible and what the true cost would be. This study should also take into account contamination level to determine if certain systems would be better suited to certain environments and terrain.
2. UXO Lao QM Department is advised to further investigate/analyse the results for the Ebinger UPEX 740M. Further testing in the same test areas utilized for this trial should be done with various loop sizes, settings, heights and along with non-blind testing to examine the effects of operator techniques. It is recommended that Ebinger technical staff handle

the equipment during the testing to ensure proper calibration and handling. It is further recommended that representatives from Ebinger and operational managers from selected organisations (i.e. UXO Lao, MMG, GICHD, etc.) are also present to observe calibration and handling and provide technical assistance.

3. UXO Lao should test the use of large search heads for the Vallon or optimize search techniques (e.g. higher stand-off distance from the ground with higher sensitivity setting) to improve clutter discrimination, which is the main problem of the Vallon.
4. UXO Lao should further investigate the Minelab CTX3030, with the goal of understanding the true capabilities of the system as related to technical survey and perhaps should conduct a technical survey focused trial where other systems are also examined.
5. Independent testing is crucial to advance detection technology and survey techniques as they relate to UXO clearance. It is recommended that UXO Lao, together with the NRA and other UXO clearance organizations within Laos support on-going testing of detection equipment. For instance, if a single test area of one hectare with approximately 500 targets (including all types of commonly found UXO) and appropriately representative conditions (terrain, soil, and fragmentation) was setup, existing equipment could utilize this area for continuous improvement, operational refresher training, and new systems could utilize the area for in-country qualification.
6. UXO Lao, together with the NRA and other UXO clearance organizations in Laos should work together to identify, test and approve one or more representative surrogate test items to represent the signal of a generic half BLU-26 at 25cm.

APPENDIX A. TEST EQUIPMENT

A number of different operators and detection systems were used during the test. Below is a list (in the approximate order they were tested) of each piece of equipment and the operator that tested the equipment. Please note that all descriptions were provided by manufactures documentation and sales material.

Aqua Survey, Inc. – Geonics EM63 HP

The equipment that was utilized during the trial by Aqua Survey is the Geonics EM63 HP Metal Detector. Its high power (10-25 Amperes), 16 time gates, full transient decay metrics and acquisition software leads to an increase in the probability of detecting UXO. The EM63 HP data processing software utilizes the full transient decay rates to characterize individual targets that allows for partial target discrimination. The system provides excellent spatial accuracy due to its ability to sample at 75-150 Hz. The EM63 HP can be configured to survey a swath from 1-4 meters wide. Configured at 4 meters the system can assess greater than 20 hectors per 8-hour workday when towed by a light truck or quad-all-terrain vehicle. A 2-meter wide system can be easily hand-carried (<20 kg) by two technicians.

All data is digitally collected thereby allowing all detected targets to be geopositioned via RTK DGPS to ±0.5 meters. The EM63 HP can also be used to support the detection of larger, more deeply buried targets with the use of ground transmit loops (20-40 square meters). However, the use and benefits of ground loops are not the point of this demonstration.

Aqua Survey, Inc. has trained technicians to successfully operate the field equipment in two weeks. The amount of time to become proficient with the use of processing software is highly dependent on the individual being trained. A trained geophysicist can master the program in hours. A totally untrained technician may be capable after a few weeks of training and practice (very dependent on the individual's aptitude).

Figure 35: Aqua Survey Geonics EM63 HP

MMG - Minelab F3 Large/Small head, YELLOW cap

The F3 incorporates all the features of Minelab's unique, proven and highly renowned Multi Period Sensing technology into Minelab's new BIPOLAR technology.

Effective: Capable of detecting all metal and minimum metal mines at full sensitivity regardless of the mineralised content of soil.
Rugged: Constructed from impact resistant materials and designed to survive in any operating environment.
Easy to Use: No complicated switches, dials or flashing lights to distract or confuse an operator.
Safe: Designed to prevent an operator accidentally reducing sensitivity - provision of a 'Confidence Tone' during operation and comprehensive Built-In-Test systems to monitor and confirm detector functionality.

Features:

- Selectable sensitivity through use of innovative 'Sensitivity Endcaps'
- Minimises risk of initiating magnetic influence mines
- Fully adjustable for operator comfort
- Fully enclosed and protected cables
- Simple to maintain and service
- Fast and accurate pinpointing
- Water resistant to 3 metres
- RS232 port for data logging
- Detachable Battery Pack
- Adjustable search head
- Improved battery life
- Simple to operate

Configurations:

F3 L (L ~ Light Emitting Diodes)
The F3 L is a modified F3, which includes an LED display, and volume controls located on top of the handle assembly.

F3 S & F3 LS (S ~ Sensitivity Adjustment)
The F3 S and F3 LS are modified F3 and F3 L detectors. The S configuration permits a user to customize the sensitivity of the detector via a laptop computer using Minelab supplied software. The advantage of the S configuration is the ability to maximize detector performance in specific ground conditions, against a specific mine threat and within areas of electromagnetic interference. The customized sensitivity is only functional when using a dedicated Yellow Endcap.

UXO Lao – Vallon VMXC1

The Vallon VMXC1 detector is based on the well-known mine detector VMH3CS (see separate entry). Larger search heads and a special UXO firmware, which is custom designed for different applications, offer a reliable and specific detection of ordnance, submunition and metal cased mines with less false alarms by other metallic waste.

With the highly effective automatic ground compensation, the VMXC1 is also recommended if the use of magnetometers is limited by mineralized soils.

- Ultra high detection range
- Highly effective automatic ground balance
- Metal alarm: audio, visual and vibration

- Length continuously adjustable
- Input for firmware upgrade
- Output for data acquisition
- Power supply: 3 ea. 1.5 V standard batteries, D-size, standard or rechargeable (NiMH)

UXO Lao - Upex 740 Analogue

The UPEX® 740 M PI large-loop detection system supports a fast search of large areas after metal objects of substantial size buried deep in the ground. Depending on the vegetation, areas of several ha can be surveyed with one unit within one day.

The UPEX® detects ferrous and non-ferrous metals as well as alloys. It is ideally suited for locating underground dumps, pipelines, stores, manholes and sewer shafts, UXOs, sunken vehicles and other metal objects of relatively large dimensions.

The system, which is widely used in forensic police work and Mine Action is easy to use, to train and surpasses the detection range and productivity of the conventional type of metal detectors with standard small halo search heads.

The UPEX® 740 M can suppress the indication of small metal scrap. This saves time for the excavation of unwanted small scrap.

UXO Lao - Upex 740 Data Logger

UPEX® 740 M supports digital mapping as the detection data can be recorded via a data output socket at the electronic box. The EPAD® data logger stores the values measured by the metal detector for subsequent processing, interpretation and conversion into a coloured-coded map. This version is in conformity with the requirements of GIS systems (geo-information systems) and supports IMSMA (Information Management System of Mine Action). The geo-referencing system allows a time wise separation of detection.

MMG - Minelab CTX 3030

The waterproof all-terrain CTX 3030 is the ultimate high performance TREASURE detector Discover more historical treasures with the most accurate target identification available. With a full colour LCD and advanced Target Trace discrimination you will find more treasure, even amongst junk littered areas, in all ground conditions.

Enjoy the freedom of wireless audio with the versatility of built-in speaker and headphone options. With Minelab's exclusive integrated GPS, you can navigate to your favourite locations and record your finds. Transfer your detecting information onto Google Maps using the XChange 2 PC application.

'Switch on and go' simplicity, five pre-set Search Modes and many automatic functions make it easy for the beginner to get started. Advanced features are easily accessible at the touch of a button for the experienced treasure hunter.

Main Features

- **Waterproof**: You can go detecting anywhere with this versatile TREASURE detector. You have the flexibility of land and underwater detecting as the CTX 3030 is waterproof* to 10 ft (3 m).

- **Wireless Audio**: Have the freedom to detect without your headphones being attached to your detector. With the WM 10 Wireless Module^ you have the choice of using the built-in speaker, supplied headphones or your own favourite headphones.
- **Ultimate FeCo Discrimination**: With Ferrous (Fe) and Conductivity (Co) target resolution, plus adjustable Tone ID Profiles, you can detect (accept) the targets you want to and ignore (reject) the rest. With Target Trace and Target Separation, you can identify multiple targets simultaneously for accurate detecting results.
- **Full Colour Display**: The full colour LCD clearly displays more target information than ever before and greatly enhances the CTX 3030's discrimination capabilities.
- **GPS Locating**: See where you have been, and where you are going, by using the Map screen and Navigation Tool.
    - GeoTrails show the ground that you have already covered.
    - Waypoints mark points of interest.
    - FindPoints mark your treasure locations.
    - GeoHunts record your entire detecting adventure.
- **PC Mapping (with Google Maps)**: Upload all of your detector settings and treasure locations to your PC using the XChange 2 application. Attach photos and text to your finds, group them into categories. View the locations on Google Maps. You can also download data to your detector for re-exploring favourite areas.
- **Quick Menus (and smart functions)**: Quick Menus give you easy access to 'on the go' adjustments. Smart functions (Sensitivity, Noise Cancel, Audio, Ground Balance) and a customisable User button allow fast changes to your most used controls while detecting.
- **Ergonomic Design**: The well balanced design has all the battery weight behind the armrest for comfortable detecting. The detector is fully adjustable to suit your needs.
- **Multi-Languages**: You can choose from 9 different languages: English, French, German, Italian, Polish, Portuguese, Russian, Spanish or Turkish.
- **Key Technologies**
    - FBS 2 uses multiple frequency transmission and coil-to-detector data communication to find more targets in variable ground conditions.
    - Smartfind 2 provides digital signal processing and precision FeCo discrimination, with colour target information, for the best target identification results.
    - GPSi has very high sensitivity for accurate recording of geo locations.
    - Wi-Stream creates very fast wireless audio with no loss of sound quality.

Golden West Humanitarian Foundation – MMDS (UPEX 740)

Golden West has modified the UPEX 740 made by Ebinger GmbH of Germany. It is a hand carried or cart mounted mapping and detection system based on single channel time domain electromagnetics and consists the following main components:

- 1 to 4 Ebinger UPEX 740 large loop detectors
- 1 Ebinger master power control module, power supply cable and (12V battery)
- 1 Modified Ebinger 4 data input cables to 1 data output cable module
- 1 Trimble Pro XRT-2 GNSS system with Omnistar HP/G2 differential service
- 2 Data acquisition laptop or tablet (Windows 7 Pro or Windows 8 Pro)

- 1 Golden West integrated analog to digital converter and Bluetooth module
- 1 Golden West GAMP Blue data acquisition software package
- 1 Golden West GAMP Dig mapping and data processing software
- 1 Golden West Sensor array frame package (3-7 sensor array frames) with carry straps
- 2 Golden West Instrument carry shelves
- 3 Golden West Backpacks
- 1 Golden West Sensor array push cart

There are several configurations including:

- A sensor array (100cm x 100cm x 2) with centre mounted GPS antenna. Productivity ~5000m2-6000m2 /hour depending on sensor array.
- A Cart mounted version. Sensor array (1200 mm Octagon x 2) with centre mounted GPS antenna. Productivity ~8000m2-10000m2/hour depending on sensor array.
- 2400 mm Octagon sensor array frame with centre mounted GPS antenna
- 200cm x 200cm square sensor array frame with centre mounted GPS antenna
- 100cm x 200cm rectangular sensor array frame (C8 and O8 configurations) with centre mounted GPS antenna
- 100cm x 100cm x 2 sensor array with centre mounted GPS antenna
- 50cm x 50cm x 4 sensor array with centre mounted GPS antenna

MMDS Packed for shipment minus wheels

Figure 36: Golden West Humanitarian Foundation - MMDS

MMG - Upex 740 Analogue + EBINGER PIDD

PIDD: UXO locator, interference compensation; The EBINGER PIDD metal detector is a new, unique design for successful searching for after metal objects buried in non-cooperative soil. The device is intended as a tool to support the detection of objects with a metal content larger than that of minimum amount of metal mines. The PIDD was designed as a rugged locator for use in humanitarian Mine Action.

MMG – Geonics BLU Array

The EM61-BLU26 Array prototype system is comprised of a multi-turn transmitter cable surrounding four overlapping induction coil sensors, a platform on which the transmitter loop and coil sensors plus GPS antenna mounting pole are attached, an EM61-MK2 HP (High Power) transmitter and two EM61-MK2 Electronics consoles (two coils are connected to each console), a Panasonic Toughbook computer for data acquisition and navigation, a 24V battery pack, plus interconnection cables. The Electronics consoles, battery pack and computer are mounted separately on a wheeled cart.

The EM61-BLU26 Array production system will use a lighter frame for mounting of the transmitter loop and receiver coils. Transmitter, electronics consoles, battery and computer will be mounted on two carrying poles attached to the platform. There will be no separate cart (as per the figure below).

MMG – Geonics EM61 (Modified)

The EM61-BLU26 system is comprised of a bottom and top frame (each 0.5 x 1.0 m in dimension and separated by vertical standoffs), two carrying poles, an EM61-MK2 HP (High Power) console with transmitter and receiver electronics, 24V battery pack, hand-held field computer for data acquisition and navigation, GPS antenna mount, and interconnection cables. The bottom coil includes both transmitter loop wire and induction coil sensor wire. The top frame serves only to support the carrying poles.

GAP Explosive Ordnance Detection – UltraTEM

GapEOD UltraTEM push-cart comprising the following components:

- Gap GeoPak LPTX-25 transmitter with in-built controller: The LPTX-25 is a battery-powered transmitter capable of transmitting up to 25 Amps. It has evolved from earlier prototype transmitters built and tested by Gap GeoPak. The internal controller is used to change the base-transmitter frequency and duty cycle of the transmitter. It is precisely synchronized to the 1 PPS signal from a GPS timing card. For the UltraTEM cart, the transmitter coil comprises multiple turns of 16 AWG wire laid as a 1.8 m x 1 m rectangular loop with a nominal current of 11 Amps.

- UltraTEM receiver; The Ultra data acquisition system (DAQ) is capable of simultaneously sampling up to 30 different channels. In the configuration proposed here five receiver cubes with dimensions of 10 cm x 10 cm x 10 cm will be interfaced to the DAQ. Each cube has three orthogonal coils to provide a total of fifteen receiver channels. The DAQ is synchronized with the 1 PPS signal from GPS, which allows it to operate independently of the transmitter.
- Trimble R10 GPS operating in Real-Time Kinematic with corrections obtained via the Client's base-station. A key advantage of the Trimble R10 series of GPS receivers is that they provide the capability to track both the standard GPS constellation of satellites as well as the GLONASS constellation. The increased number of satellites minimizes the chance that insufficient satellites are available to compute an accurate position in those areas with occluded sky view (such as in the steeper sections of the sites).

Figure 37: GAP EOD – UltraTEM

APPENDIX B. DISTANCE TO TARGET CALCULATION

As discussed in the results section, we define *Distance to Target* as the horizontal separation distance between the indicated target location and an actual seeded location.

For analogue systems, the CEN Workshop Agreement 14747, the field users guide for metal detector testing, provides a preliminary definition for this quantity which they call "detection halo":

The circle around the target location whose radius is defined by this maximum distance is known as the detection halo. The radius of the detection halo shall be half of the maximum horizontal extent of the metal components in the target plus 100mm.

We must also take into account an aspect of our testing procedure where we measure the location of analogue detector indications with a GPS and then compare to GPS measured locations of the actually seeded items. Because of this process, we must include two times the error in our GPS measurement. MMG performed a test with the RTK GPS that was utilized during the trial and determined that the GPS error was on average 4.29 cm.

So to determine *Distance to Target* we do the following:

$$Distance\ to\ Target = \frac{Max\ Horiz\ Extent\ of\ Metal\ in\ Target}{2} + 10cm + 2 * (GPS\ Error)$$

So,

$$Distance\ to\ Target = \frac{6.4cm}{2} + 10cm + 2 * 4.29cm = 21.78cm$$

For the digital systems, the *Distance to Target* is set to 50 cm based on previous testing experience and efforts. The 50 cm takes into account the fact that the dig location produced by a digital system is based on data processing.

APPENDIX C. CALCULATION OF 95% CONFIDENCE LIMITS

As discussed in the results section, we have included 95% confidence limits with our presentation of the data for both PoD and FAR. Per the CWA the following method was used to calculate those limits.

The upper and lower 95% confidence limits of the probability of detection can be computed using standard statistical tables that include the F distribution. From the CWA we know that:

$$PoD_{lower} = \frac{x}{x + (n - x + 1) * F_{1-\alpha/2, f_1, f_2}} \; where \; f_1 = 2(n - x + 1) \; and \; f_2 = 2x$$

$$PoD_{upper} = \frac{(x + 1) * F_{1-\alpha/2, f_1, f_2}}{n - x + (x + 1) * F_{1-\alpha/2, f_1, f_2}} \; where \; f_1 = 2(x + 1) \; and \; f_2 = 2(n - x)$$

Where *n* is the number of opportunities to detect a target, *x* is the number of correct detections, *1-α* is 95%, and F represents the F distribution function evaluated as shown above.

For the False Alarm Rate to calculate the 95% confidence limits we utilize the chi-squared distribution as follows:

$$FAR_{lower} = \frac{1}{2A} \chi^2{}_{\alpha/2, f} \; where \; f = 2y$$

$$FAR_{upper} = \frac{1}{2A} \chi^2{}_{1-\alpha/2, f} \; where \; f = 2(y + 1)$$

Where *y* is the total number of false alarms, *A* is the size of the area, *1-α* is 95%, and *X* represents the chi-squared Poisson distribution function.

To turn the 95% confidence limits into simple error bar we just calculate the difference between them and the trial value.

APPENDIX D. ADDITIONAL RESULTS – DATA TABLES

This appendix contains tabular results data starting with PoD.

This first table shows PoD data for all systems across each area and for all areas combined. The column labels are as follows: T25Ax refers to number targets available in Area x at depth range 0-25cm, D25Ax refers to the number of correct detections in area x for depth range 0-25cm, POD25Ax refers to the Probability of Detection for Area x at depth range 0-25cm, and ME25Ax and PE25Ax are the minus and plus error bars for the 95% confidence limits. The final 5 columns are the total values across all areas.

System	T25A1	D25A1	POD25A1	ME25A1	PE25A1	T25A2	D25A2	POD25A2	ME25A2	PE25A2	T25A3a	D25A3a	POD25A3a	ME25A3a	PE25A3a	T25A3b	D25A3b	POD25A3b	ME25A3b	PE25A3b	T25	D25	POD25	ME25	PE25
Vallon	21	20	0.95	0.19	0.05	26	18	0.69	0.21	0.16	14	13	0.93	0.27	0.07	8	7	0.88	0.40	0.12	69	58	0.84	0.11	0.08
UPEX 740 with Vallon	21	10	0.48	0.22	0.23	26	13	0.50	0.20	0.20	9	5	0.56	0.34	0.31	8	1	0.13	0.12	0.40	64	29	0.45	0.12	0.13
UPEX 740 with PIDD	19	9	0.47	0.23	0.24	26	18	0.69	0.21	0.16	14	10	0.71	0.30	0.20	8	7	0.88	0.40	0.12	67	44	0.66	0.13	0.11
Minelab F3 Large Head	21	19	0.90	0.21	0.08	26	19	0.73	0.21	0.15	14	14	1.00	0.23	0.00	8	6	0.75	0.40	0.22	69	58	0.84	0.11	0.08
Minelab F3 Small Head	21	14	0.67	0.24	0.19	26	21	0.81	0.20	0.13	14	9	0.64	0.29	0.23	8	8	1.00	0.37	0.00	69	52	0.75	0.12	0.10
Minelab CTX 3030	21	11	0.52	0.23	0.22	26	10	0.38	0.18	0.21	14	11	0.79	0.29	0.17	8	4	0.50	0.34	0.34	69	36	0.52	0.12	0.12
AquaSurvey Geonics EM47/63-HP [PT]	21	14	0.67	0.24	0.19	26	19	0.73	0.21	0.15	12	12	1.00	0.26	0.00	8	5	0.63	0.38	0.29	67	50	0.75	0.12	0.10
AquaSurvey Geonics EM47/63-HP [PR]	21	17	0.81	0.23	0.14	26	24	0.92	0.17	0.07	12	12	1.00	0.26	0.00	8	8	1.00	0.37	0.00	67	61	0.91	0.10	0.06
AquaSurvey Geonics EM47/63-HP [FT]	21	15	0.71	0.24	0.17	26	20	0.77	0.21	0.14	12	11	0.92	0.30	0.08	8	7	0.88	0.40	0.12	67	53	0.79	0.12	0.09
AquaSurvey Geonics EM47/63-HP [FR]	21	20	0.95	0.19	0.05	26	22	0.85	0.19	0.11	12	11	0.92	0.30	0.08	8	8	1.00	0.37	0.00	67	61	0.91	0.10	0.06
Geonics EM61 BLU Array [PT]	18	5	0.28	0.18	0.26	26	4	0.15	0.11	0.19	14	4	0.29	0.20	0.30	8	1	0.13	0.12	0.40	66	14	0.21	0.09	0.12
Geonics EM61 BLU Array [PR]	18	5	0.28	0.18	0.26	26	5	0.19	0.13	0.20	14	4	0.29	0.20	0.30	8	1	0.13	0.12	0.40	66	15	0.23	0.09	0.12
Geonics EM61 BLU Array [FT]	18	14	0.78	0.25	0.16	26	18	0.69	0.21	0.16	14	14	1.00	0.23	0.00	8	8	1.00	0.37	0.00	66	54	0.82	0.11	0.08
Geonics EM61 BLU Array [FR]	18	16	0.89	0.24	0.10	26	20	0.77	0.21	0.14	14	14	1.00	0.23	0.00	8	8	1.00	0.37	0.00	66	58	0.88	0.10	0.07
Golen West M&DS [PT]	21	10	0.48	0.22	0.23	26	7	0.27	0.15	0.21	14	6	0.43	0.25	0.28	8	6	0.75	0.40	0.22	69	29	0.42	0.12	0.12
Golen West M&DS [FT]	21	10	0.48	0.22	0.23	26	10	0.38	0.18	0.21	14	7	0.50	0.27	0.27	8	6	0.75	0.40	0.22	69	33	0.48	0.12	0.12
Geonics EM61 [PT]	21	19	0.90	0.21	0.08	26	19	0.73	0.21	0.15	14	14	1.00	0.23	0.00	8	8	1.00	0.37	0.00	69	60	0.87	0.10	0.07
Geonics EM61 [FT]	21	19	0.90	0.21	0.08	26	18	0.69	0.21	0.16	14	13	0.93	0.27	0.07	8	8	1.00	0.37	0.00	69	58	0.84	0.11	0.08
Geonics EM61 [FR]	21	19	0.90	0.21	0.08	26	18	0.69	0.21	0.16	14	14	1.00	0.23	0.00	8	8	1.00	0.37	0.00	69	59	0.86	0.11	0.07
GapEOD UltraTEM [PT]	21	19	0.90	0.21	0.08	26	17	0.65	0.21	0.17	14	9	0.64	0.29	0.23	8	8	1.00	0.37	0.00	69	53	0.77	0.12	0.09
GapEOD UltraTEM [PR]	21	19	0.90	0.21	0.08	26	17	0.65	0.21	0.17	14	12	0.86	0.29	0.13	8	8	1.00	0.37	0.00	69	56	0.81	0.11	0.08
GapEOD UltraTEM [FT]	21	18	0.86	0.22	0.11	26	19	0.73	0.21	0.15	14	12	0.86	0.29	0.13	8	8	1.00	0.37	0.00	69	57	0.83	0.11	0.08
GapEOD UltraTEM [FR]	21	18	0.86	0.22	0.11	26	19	0.73	0.21	0.15	14	13	0.93	0.27	0.07	8	8	1.00	0.37	0.00	69	58	0.84	0.11	0.08
UPEX740 Datalogger [PT]	21	3	0.14	0.11	0.22	26	3	0.12	0.09	0.19	14	4	0.29	0.20	0.30	8	1	0.13	0.12	0.40	69	11	0.16	0.08	0.11

Table 8: PoD Data for Each Area and Total for Depth Range 0-25cm

This table shows the same PoD data as above but for the depth range 25.1-40cm.

System	T40A1	D40A1	POD40A1	ME40A1	PE40A1	T40A2	D40A2	POD40A2	ME40A2	PE40A2	T40A3a	D40A3a	POD40A3a	ME40A3a	PE40A3a	T40A3b	D40A3b	POD40A3b	ME40A3b	PE40A3b	T40	D40	POD40	ME40	PE40
Vallon	27	18	0.67	0.21	0.17	24	18	0.75	0.22	0.15	16	13	0.81	0.27	0.15	12	11	0.92	0.30	0.08	79	60	0.76	0.11	0.09
UPEX 740 with Vallon	29	12	0.41	0.18	0.20	24	13	0.54	0.21	0.20	11	8	0.73	0.34	0.21	12	3	0.25	0.20	0.32	76	36	0.47	0.12	0.12
UPEX 740 with PIDD	24	11	0.46	0.20	0.21	24	9	0.38	0.19	0.22	16	6	0.38	0.22	0.27	12	5	0.42	0.27	0.31	76	31	0.41	0.11	0.12
Minelab F3 Large Head	29	27	0.93	0.16	0.06	24	15	0.63	0.22	0.19	16	16	1.00	0.21	0.00	12	11	0.92	0.30	0.08	81	69	0.85	0.10	0.07
Minelab F3 Small Head	29	19	0.66	0.20	0.17	24	15	0.63	0.22	0.19	16	13	0.81	0.27	0.15	12	12	1.00	0.26	0.00	81	59	0.73	0.11	0.09
Minelab CTX 3030	29	5	0.17	0.11	0.19	24	4	0.17	0.12	0.21	16	12	0.75	0.27	0.18	12	7	0.58	0.31	0.27	81	28	0.35	0.10	0.11
AquaSurvey Geonics EM47/63-HP [PT]	29	9	0.31	0.16	0.20	24	12	0.50	0.21	0.21	15	13	0.87	0.27	0.12	12	11	0.92	0.30	0.08	80	45	0.56	0.12	0.11
AquaSurvey Geonics EM47/63-HP [PR]	29	18	0.62	0.20	0.17	24	17	0.71	0.22	0.17	15	13	0.87	0.27	0.12	12	12	1.00	0.26	0.00	80	60	0.75	0.11	0.09
AquaSurvey Geonics EM47/63-HP [FT]	29	10	0.34	0.17	0.20	24	16	0.67	0.22	0.18	16	15	0.94	0.24	0.06	12	11	0.92	0.30	0.08	81	52	0.64	0.11	0.10
AquaSurvey Geonics EM47/63-HP [FR]	29	24	0.83	0.19	0.11	24	21	0.88	0.20	0.10	16	15	0.94	0.24	0.06	12	12	1.00	0.26	0.00	81	72	0.89	0.09	0.06
Geonics EM61 BLU Array [PT]	26	3	0.12	0.09	0.19	24	7	0.29	0.17	0.22	16	2	0.13	0.11	0.26	12	3	0.25	0.20	0.32	78	15	0.19	0.08	0.10
Geonics EM61 BLU Array [PR]	26	3	0.12	0.09	0.19	24	8	0.33	0.18	0.22	16	2	0.13	0.11	0.26	12	3	0.25	0.20	0.32	78	16	0.21	0.08	0.11
Geonics EM61 BLU Array [FT]	26	21	0.81	0.20	0.13	24	20	0.83	0.21	0.12	16	14	0.88	0.26	0.11	12	12	1.00	0.26	0.00	78	67	0.86	0.10	0.07
Geonics EM61 BLU Array [FR]	26	23	0.88	0.19	0.09	24	23	0.96	0.17	0.04	16	14	0.88	0.26	0.11	12	12	1.00	0.26	0.00	78	72	0.92	0.08	0.05
Golen West M&DS [PT]	29	7	0.24	0.14	0.19	24	7	0.29	0.17	0.22	15	2	0.13	0.12	0.27	12	6	0.50	0.29	0.29	80	22	0.28	0.09	0.11
Golen West M&DS [FT]	29	13	0.45	0.18	0.19	24	9	0.38	0.19	0.22	15	2	0.13	0.12	0.27	12	4	0.33	0.23	0.32	80	28	0.35	0.10	0.11
Geonics EM61 [PT]	29	20	0.69	0.20	0.16	24	19	0.79	0.21	0.14	16	9	0.56	0.26	0.24	12	12	1.00	0.26	0.00	81	60	0.74	0.11	0.09
Geonics EM61 [FT]	29	20	0.69	0.20	0.16	24	19	0.79	0.21	0.14	16	6	0.38	0.22	0.27	12	12	1.00	0.26	0.00	81	57	0.70	0.11	0.10
Geonics EM61 [FR]	29	20	0.69	0.20	0.16	24	19	0.79	0.21	0.14	16	6	0.38	0.22	0.27	12	12	1.00	0.26	0.00	81	57	0.70	0.11	0.10
GapEOD UltraTEM [PT]	29	25	0.86	0.18	0.10	24	22	0.92	0.19	0.07	16	7	0.44	0.24	0.26	12	12	1.00	0.26	0.00	81	66	0.81	0.10	0.08
GapEOD UltraTEM [PR]	29	25	0.86	0.18	0.10	24	22	0.92	0.19	0.07	16	7	0.44	0.24	0.26	12	12	1.00	0.26	0.00	81	66	0.81	0.10	0.08
GapEOD UltraTEM [FT]	29	26	0.90	0.17	0.08	24	21	0.88	0.20	0.10	16	10	0.63	0.27	0.22	12	11	0.92	0.30	0.08	81	68	0.84	0.10	0.07
GapEOD UltraTEM [FR]	29	27	0.93	0.16	0.06	24	21	0.88	0.20	0.10	16	10	0.63	0.27	0.22	12	12	1.00	0.26	0.00	81	70	0.86	0.09	0.07
UPEX740 Datalogger [PT]	29	4	0.14	0.10	0.18	24	6	0.25	0.15	0.22	16	1	0.06	0.06	0.24	12	0	0.00	0.00	0.26	81	11	0.14	0.07	0.09

Table 9: PoD Data for Each Area and Total for Depth Range 25.1-40cm

Here is the FAR data in tabular form. The column labels are as follows: FASAx refers to number of False Alarms in Area x, ASAx refers to the total area surveyed in area x, FARAx refers to the False Alarm Rate for Area x, and MEAx and PEAx are the minus and plus error bars for the 95% confidence limits.

System	FASA1	ASA1	FARA1	MEA1	PEA1	FASA2	ASA2	FARA2	MEA2	PEA2	FASA3a	ASA3a	FARA3a	MEA3a	PEA3a	FASA3a	ASA3b	FARA3b	MEA3b	PEA3b	FAS	AS	FAR	ME	PE
Vallon	1943	2408.73	0.81	0.04	0.04	1145	2496.23	0.46	0.03	0.03	428	1478.608	0.29	0.03	0.03	229	995.466	0.23	0.03	0.03	3745	7379	0.51	0.02	0.02
UPEX 740 with Vallon	608	2496.58	0.24	0.02	0.02	684	2496.23	0.27	0.02	0.02	138	977.151	0.14	0.02	0.03	126	979.9	0.13	0.02	0.02	1556	6950	0.22	0.01	0.01
UPEX 740 with PIDD	1110	2496.58	0.44	0.03	0.03	846	2496.23	0.34	0.02	0.02	368	1474.055	0.25	0.02	0.03	144	996.03	0.14	0.02	0.03	2468	7463	0.33	0.01	0.01
Minelab F3 Large Head	1291	2496.58	0.52	0.03	0.03	886	2496.23	0.35	0.02	0.02	364	1478.608	0.25	0.02	0.03	214	996.03	0.21	0.03	0.03	2755	7467	0.37	0.01	0.01
Minelab F3 Small Head	1602	2496.58	0.64	0.03	0.03	1043	2496.23	0.42	0.02	0.03	406	1492.75	0.27	0.03	0.03	204	995.83	0.20	0.03	0.03	3255	7481	0.44	0.01	0.02
Minelab CTX 3030	14	2496.58	0.01	0.00	0.00	41	2496.23	0.02	0.00	0.01	54	1499.31	0.04	0.01	0.01	10	994.357	0.01	0.01	0.01	119	7486	0.02	0.00	0.00
AquaSurvey Geonics EM47/63-HP [PT]	57	2494.85	0.02	0.01	0.01	81	2449.04	0.03	0.01	0.01	109	1353.32	0.08	0.01	0.02	47	979.16	0.05	0.01	0.02	294	7276	0.04	0.00	0.00
AquaSurvey Geonics EM47/63-HP [PR]	377	2494.85	0.15	0.01	0.02	410	2449.04	0.17	0.02	0.02	180	1353.32	0.13	0.02	0.02	152	979.16	0.16	0.02	0.03	1119	7276	0.15	0.01	0.01
AquaSurvey Geonics EM47/63-HP [FT]	104	2494.85	0.04	0.01	0.01	131	2449.04	0.05	0.01	0.01	94	1353.32	0.07	0.01	0.02	43	979.16	0.04	0.01	0.02	372	7276	0.05	0.01	0.01
AquaSurvey Geonics EM47/63-HP [FR]	639	2494.85	0.26	0.02	0.02	397	2449.04	0.16	0.02	0.02	194	1353.32	0.14	0.02	0.02	116	979.16	0.12	0.02	0.02	1346	7276	0.18	0.01	0.01
Geonics EM61 BLU Array [PT]	255	2204.04	0.12	0.01	0.02	279	2369.85	0.12	0.01	0.01	57	1477.54	0.04	0.01	0.01	54	974.34	0.06	0.01	0.02	645	7026	0.09	0.01	0.01
Geonics EM61 BLU Array [PR]	294	2204.04	0.13	0.01	0.02	354	2369.85	0.15	0.02	0.02	72	1477.54	0.05	0.01	0.01	72	974.34	0.07	0.02	0.02	792	7026	0.11	0.01	0.01
Geonics EM61 BLU Array [FT]	323	2204.04	0.15	0.02	0.02	272	2369.85	0.11	0.01	0.01	145	1477.54	0.10	0.02	0.02	102	974.34	0.10	0.02	0.02	842	7026	0.12	0.01	0.01
Geonics EM61 BLU Array [FR]	398	2204.04	0.18	0.02	0.02	294	2369.85	0.12	0.01	0.02	163	1477.54	0.11	0.02	0.02	123	974.34	0.13	0.02	0.02	978	7026	0.14	0.01	0.01
Golen West M&DS [PT]	218	2496.58	0.09	0.01	0.01	312	2484.89	0.13	0.01	0.01	246	1498.84	0.16	0.02	0.02	181	996.27	0.18	0.03	0.03	957	7477	0.13	0.01	0.01
Golen West M&DS [FT]	306	2496.58	0.12	0.01	0.01	398	2484.89	0.16	0.02	0.02	190	1498.84	0.13	0.02	0.02	154	996.27	0.15	0.02	0.03	1048	7477	0.14	0.01	0.01
Geonics EM61 [PT]	462	2453.3	0.19	0.02	0.02	439	2447.18	0.18	0.02	0.02	248	1457.56	0.17	0.02	0.02	129	948.83	0.14	0.02	0.03	1278	7307	0.17	0.01	0.01
Geonics EM61 [FT]	345	2453.3	0.14	0.01	0.02	342	2447.18	0.14	0.01	0.02	200	1457.56	0.14	0.02	0.02	102	948.83	0.11	0.02	0.02	989	7307	0.14	0.01	0.01
Geonics EM61 [FR]	462	2453.3	0.19	0.02	0.02	440	2447.18	0.18	0.02	0.02	251	1457.56	0.17	0.02	0.02	129	948.83	0.14	0.02	0.03	1282	7307	0.18	0.01	0.01
GapEOD UltraTEM [PT]	784	2451.96	0.32	0.02	0.02	485	2456.44	0.20	0.02	0.02	85	1466.31	0.06	0.01	0.01	145	985.58	0.15	0.02	0.03	1499	7360	0.20	0.01	0.01
GapEOD UltraTEM [PR]	822	2451.96	0.34	0.02	0.02	507	2456.44	0.21	0.02	0.02	104	1466.31	0.07	0.01	0.02	155	985.58	0.16	0.02	0.03	1588	7360	0.22	0.01	0.01
GapEOD UltraTEM [FT]	791	2452	0.32	0.02	0.02	570	2456.4	0.23	0.02	0.02	182	1466.3	0.12	0.02	0.02	153	985.6	0.16	0.02	0.03	1696	7360	0.23	0.01	0.01
GapEOD UltraTEM [FR]	810	2452	0.33	0.02	0.02	600	2456.4	0.24	0.02	0.02	196	1466.3	0.13	0.02	0.02	184	985.6	0.19	0.03	0.03	1790	7360	0.24	0.01	0.01
UPEX740 Datalogger [PT]	597	2496.58	0.24	0.02	0.02	625	2496.23	0.25	0.02	0.02	343	1499.31	0.23	0.02	0.03	277	998.74	0.28	0.03	0.03	1842	7491	0.25	0.01	0.01

Table 10: False Alarm Data for All Target Depth

APPENDIX D. ADDITIONAL RESULTS FOR TARGET DEPTH RANGE 25.1-40CM

This appendix contains additional results summarized in Probability of Detection, False Alarm Rate, and Receiver Operator Characteristic Plots.

Shown below is the PoD for all systems for 25.1-40cm Depth. As described in the results section, the [XX] after some of the system names indicates which set of data is being shown. The P indicates preliminary data that was calculated in the 4.5 hours after each test day whereas F indicates final data submitted with each equipment operators/manufacturers final report. And the T refers to the data being the prioritized list of targets and the R refers instead to the reference list that indicates all possible readings from a given instrument. When comparing T and R it will be clear that sometimes the reference list allows for a greater PoD but at the cost of a higher FAR.

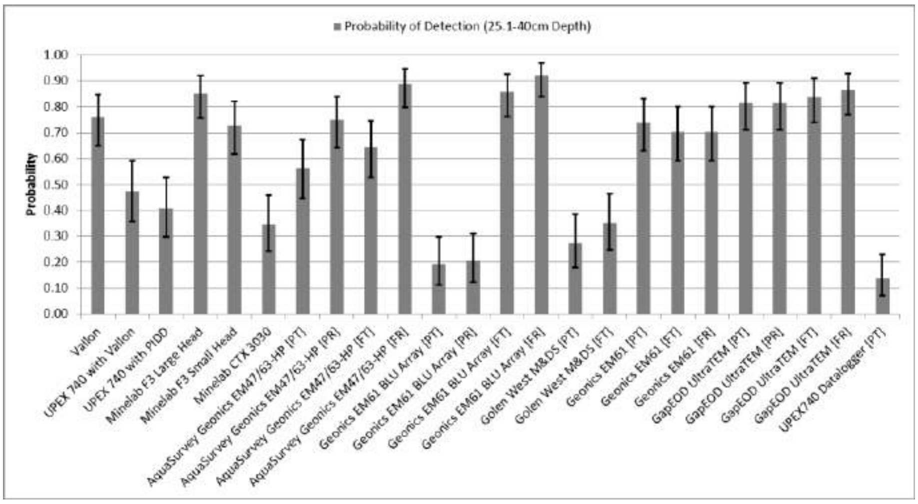

Figure 38: PoD for all System Data for Target Depth Range 25.1-40cm

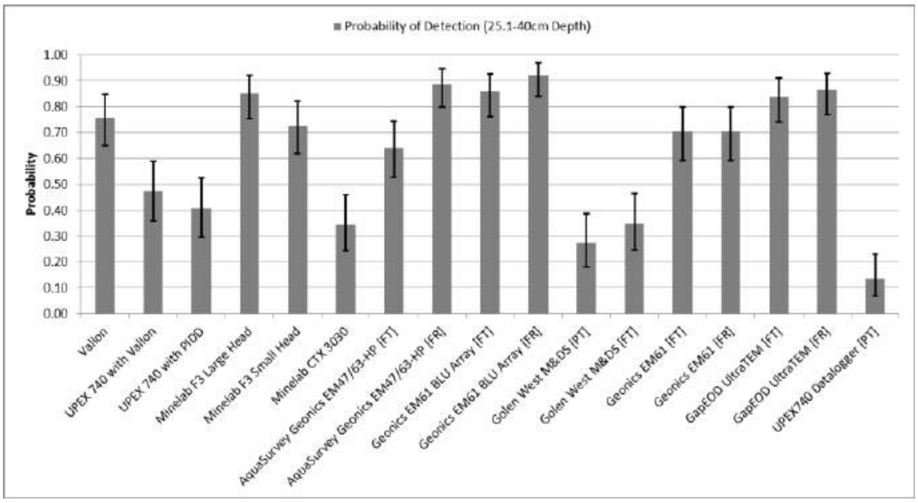

Figure 39: PoD for Final System Data for Target Depth Range 25.1-40cm

Below are a series of Receiver Operator Characteristic Plots for the target depth range 25.1-40cm. An overall ROC for final system and one for just systems with PoD greater than 0.75 is followed by plots for each area.

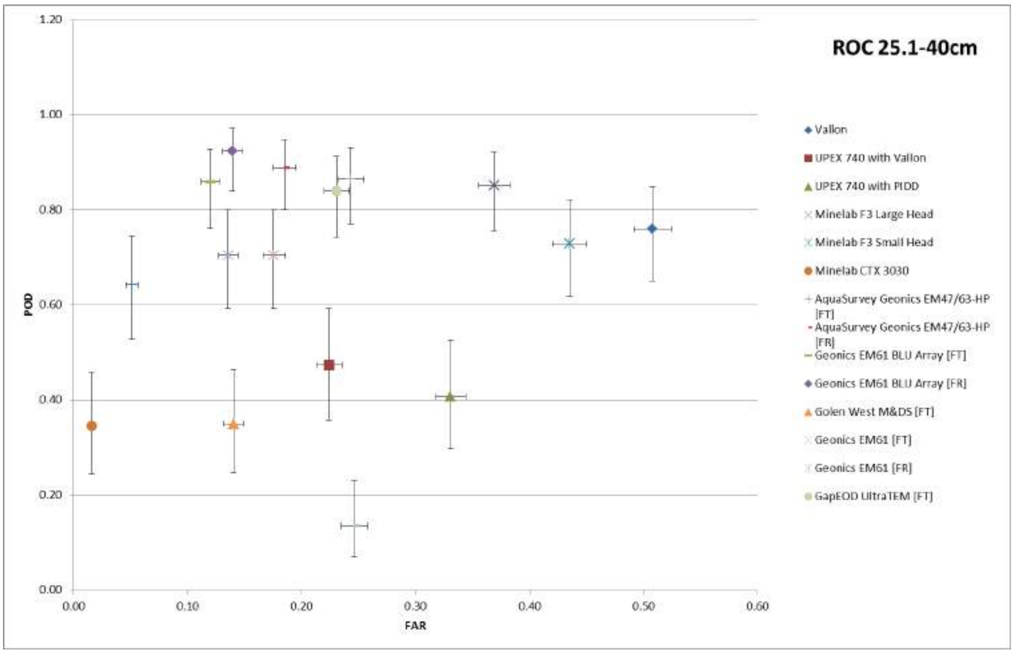

Figure 40: Overall ROC of Final System Data for Depth Range 25.1-40cm

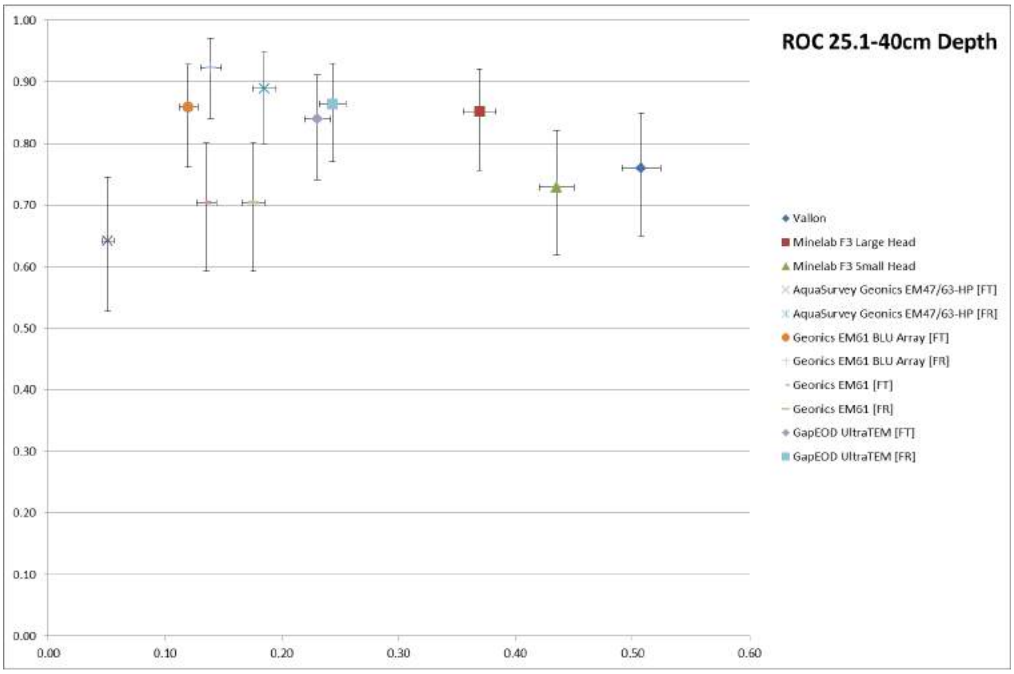

Figure 41: Overall ROC for Depth Range 25.1-40cm (Overall PoD > 0.75 above 25cm)

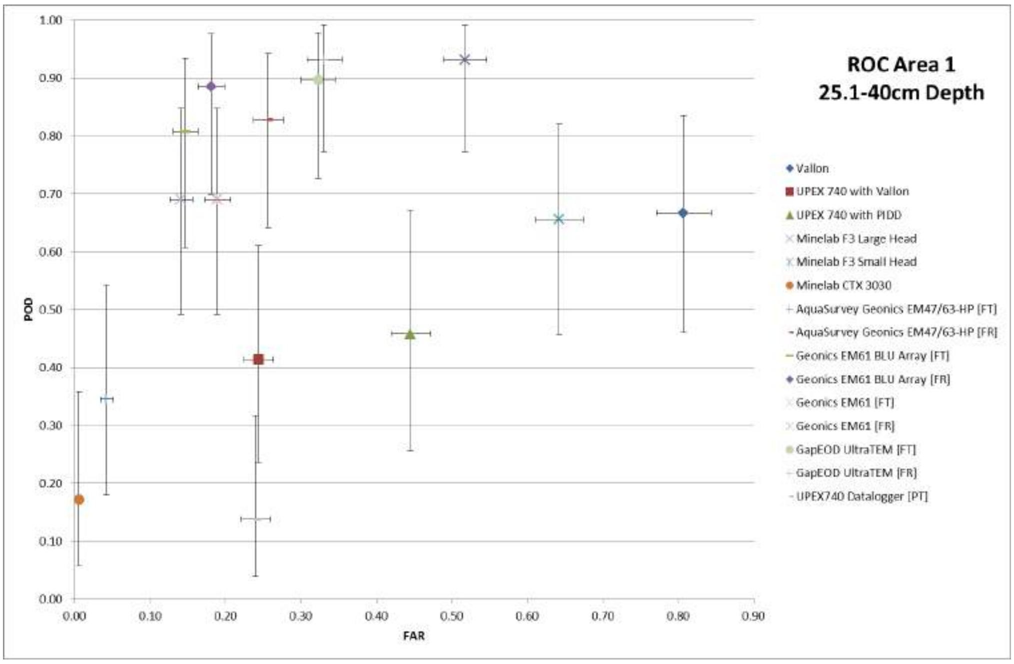

Figure 42: ROC of Final System Data for Depth Range 25.1-40cm in Area 1

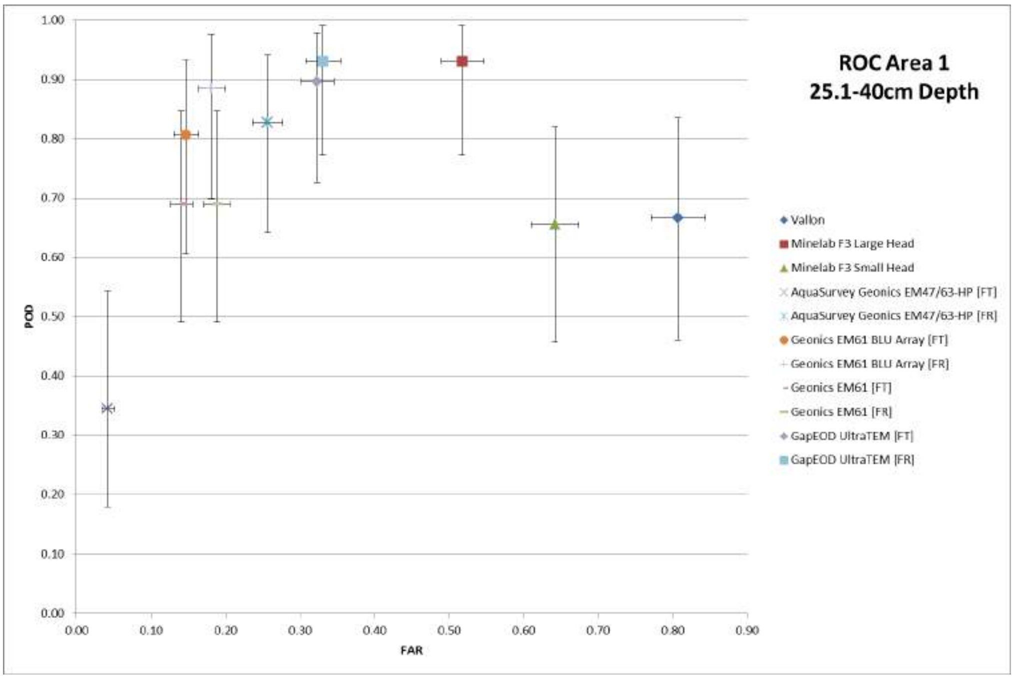

Figure 43: ROC for Depth Range 25.1-40cm (Overall PoD > 0.75 above 25cm) in Area 1

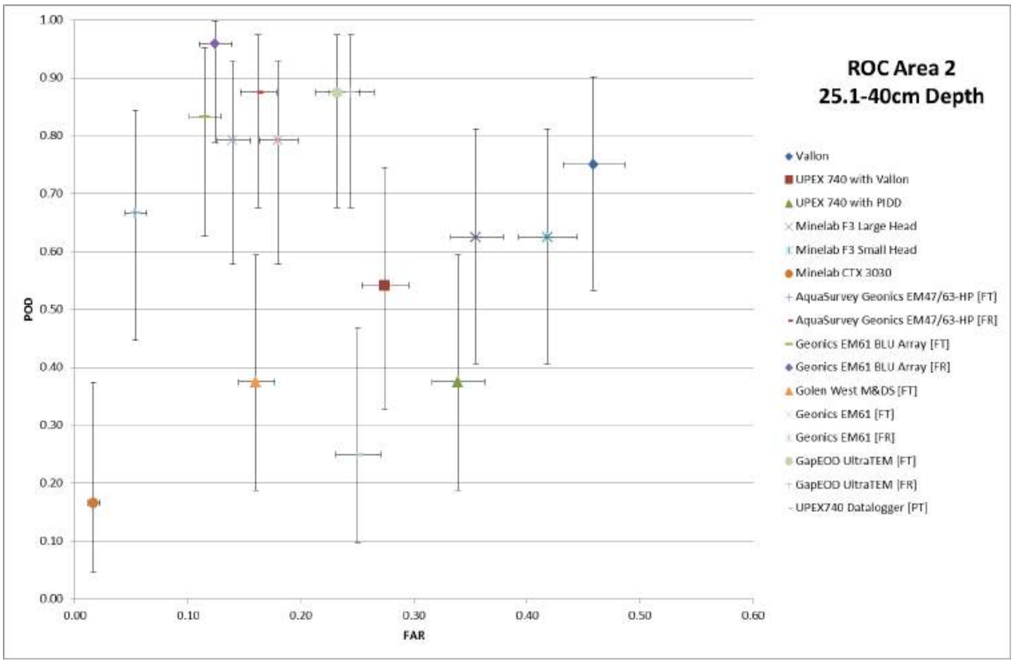

Figure 44: ROC of Final System Data for Depth Range 25.1-40cm in Area 2

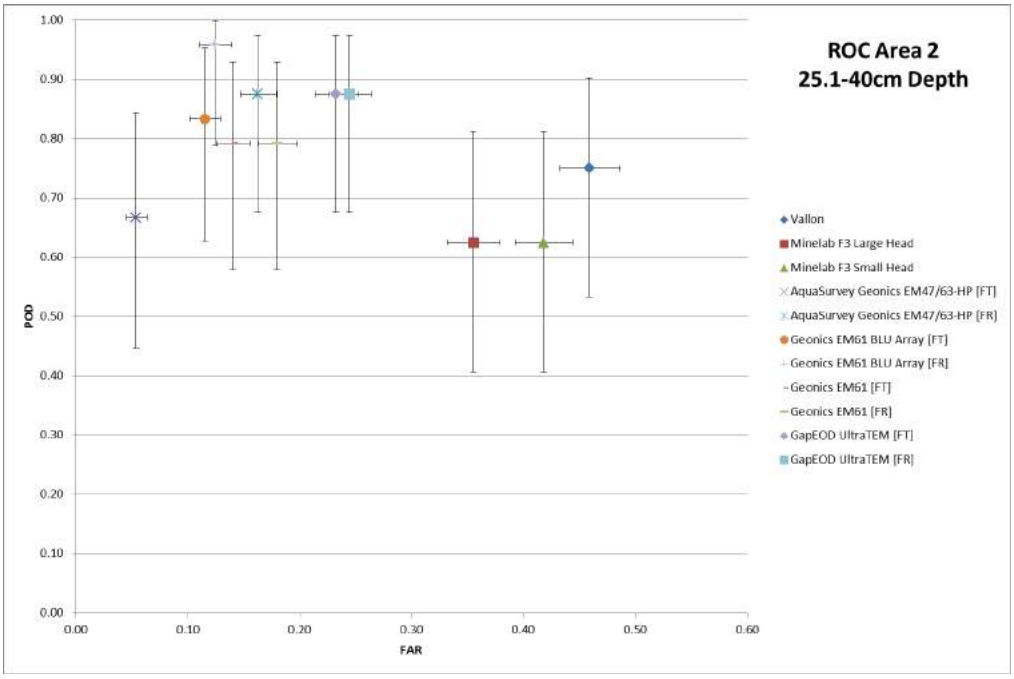

Figure 45: ROC for Depth Range 25.1-40cm (Overall PoD > 0.75 above 25cm) in Area 2

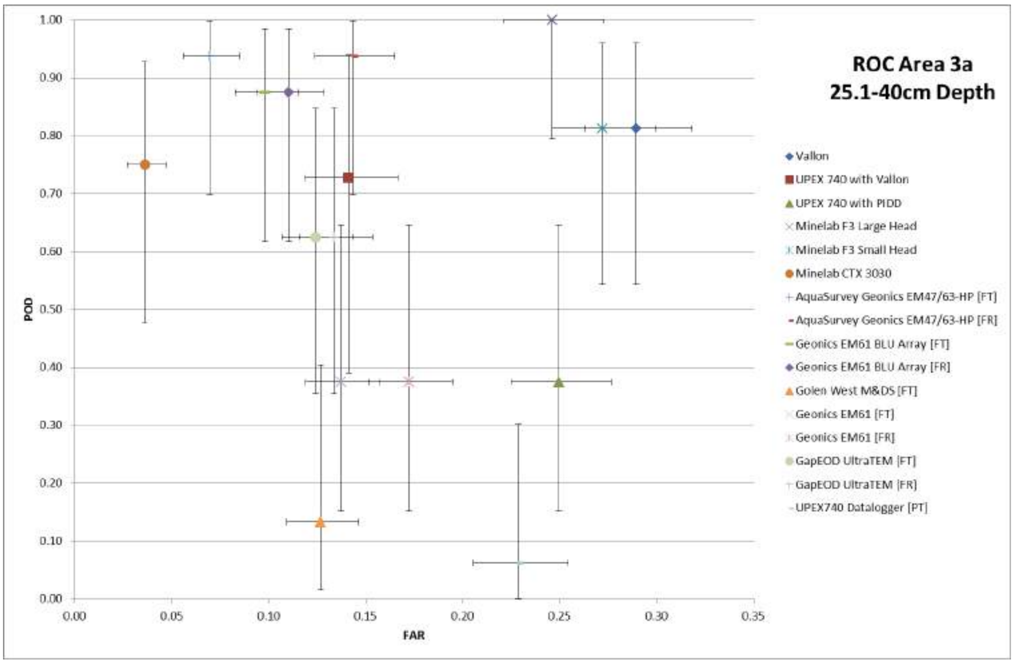

Figure 46: ROC of Final System Data for Depth Range 25.1-40cm in Area 3a

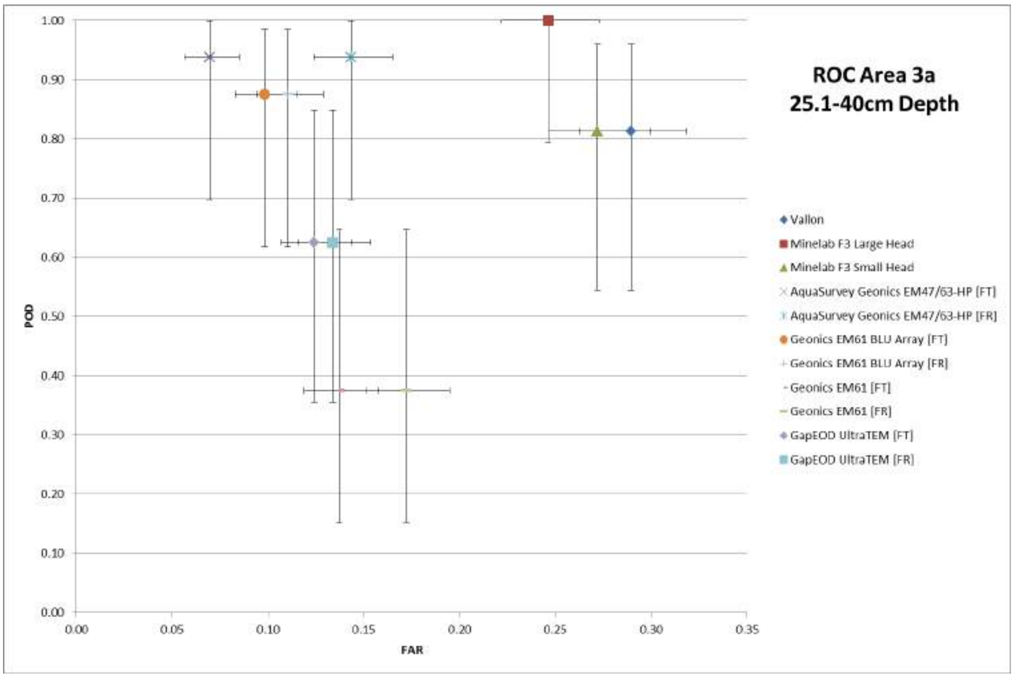

Figure 47: ROC for Depth Range 25.1-40cm (Overall PoD > 0.75 above 25cm) in Area 3a

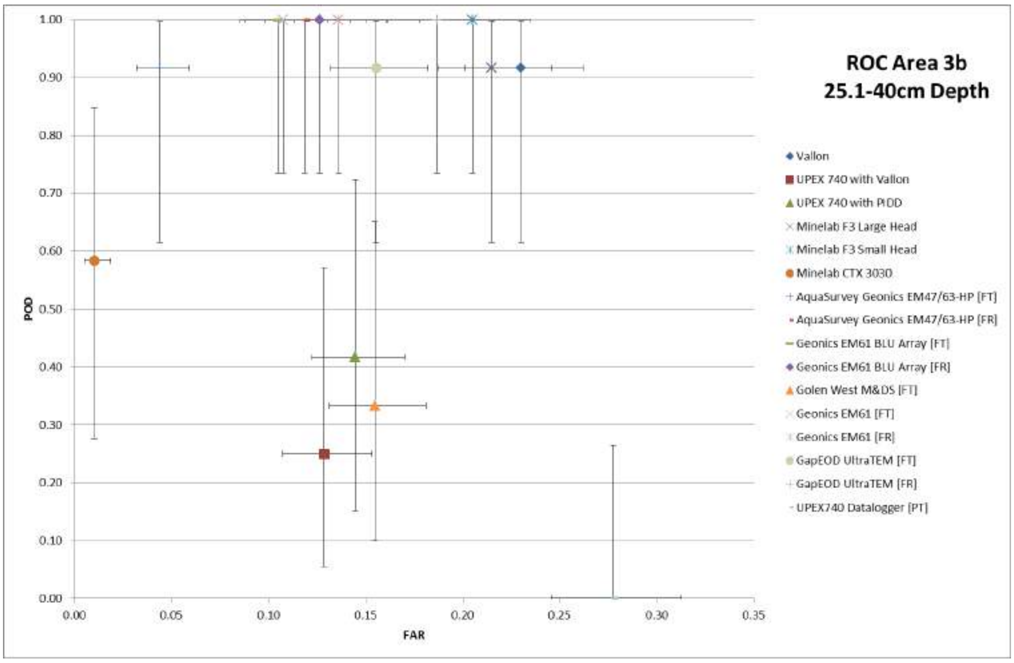

Figure 48: ROC of Final System Data for Depth Range 25.1-40cm in Area 3b

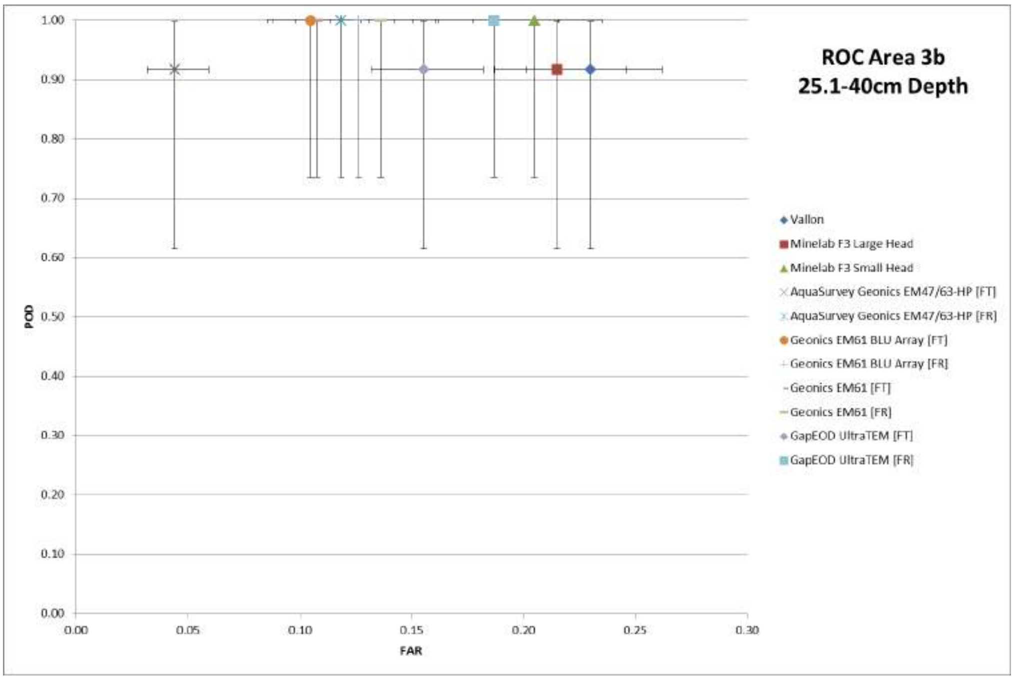

Figure 49: ROC for Depth Range 25.1-40cm (Overall PoD > 0.75 above 25cm) in Area 3b

Finally we show the mean and standard deviation of positional accuracy for the depth range 25.1-40cm.

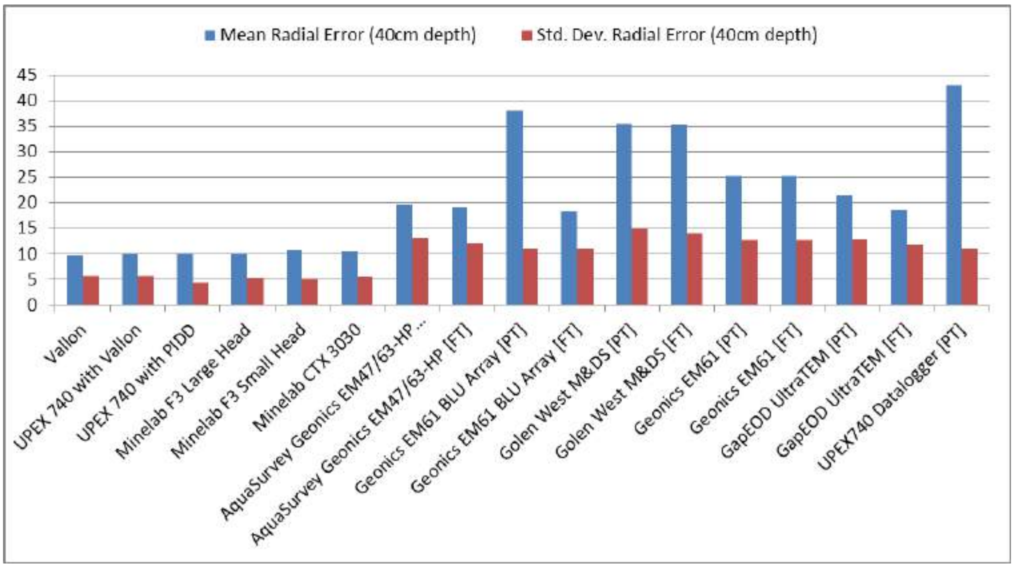

Figure 50: Mean and Standard Deviation of Positional Accuracy for Depth Range 25.1-40cm

APPENDIX E. TESTING PHOTOS

1. Aqua Survey, Inc. – Geonics EM47/63 HP

2. MMG - Minelab F3 Large head, YELLOW cap

3. UXO Lao – Vallon VMXC1

4. UXO Lao - Upex 740M Analogue + Vallon VMXC1

5. UXO Lao - Upex 740M Data Logger

6. MMG - Minelab CTX 3030

7. Golden West Humanitarian Foundation – MMDS (UPEX 740M)

8. HALO Trust - Upex 740M Analogue + EBINGER PIDD

9. MMG – Geonics EM61-BLU26 Array

10. MMG – Geonics EM61

11. GAP Explosive Ordnance Detection – ULTRATEM Mobile Detection System