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Prepared for:  
U.S. ARMY ENVIRONMENTAL CENTER  
ABERDEEN PROVING GROUND, MD 21010-5401

U.S. ARMY DEVELOPMENTAL TEST COMMAND  
ABERDEEN PROVING GROUND, MD 21005-5055

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| <b>14. ABSTRACT</b><br>This report documents the efforts of Tetra Tech Ec, Inc. to detect and discriminate inert unexploded ordnance (UXO) using a Dual Acoustic and Magnetometer Array. Testing was conducted at ATC, Standardized Shallow Water UXO Technology Demonstration Site. A description of the tested system and an estimate of survey costs along with the analysis of the system performance are provided.                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                    |                                     |                                              |                                                                   |                                                  |  |
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## SECTION 1. GENERAL INFORMATION

### 1.1 BACKGROUND

Technologies under development for the detection and discrimination of munitions and explosives of concern (MEC), i.e., unexploded ordnance (UXO) and discarded military munitions (DMM), require testing so their performance can be characterized. Technologies under development for the detection and discrimination of UXO require independent testing so their performance can be characterized. To that end, the U.S. Army Aberdeen Test Center (ATC) located at Aberdeen Proving Ground (APG), Maryland, has developed a Standardized Shallow Water Test Site. This site provides a controlled environment containing varying water depths, multiple types of ordnance and clutter items, as well as navigational and detection challenges. Testing at this site is independently administered and analyzed by the government for the purposes of characterizing technologies, tracking performance during system development, and comparing the performance and costs of different systems.

The Standardized UXO Technology Demonstration Site Program is a multi-agency program spearheaded by the U.S. Army Environmental Center (USAEC). ATC and the U.S. Army Corps of Engineers Engineering, Research and Development Center (ERDC) provide programmatic support. The Environmental Security Technology Certification Program (ESTCP), the Strategic Environmental Research and Development Program (SERDP), and the Army Environmental Quality Technology Program (EQT) provided funding and support for this program.

### 1.2 OBJECTIVE

The objective of the Shallow Water Standardized UXO Technology Demonstration Site is to evaluate the detection and discrimination capabilities of existing and emerging technologies and systems in a shallow water environment. Specifically:

- a. To determine the demonstrator's ability to survey a shallow water area, analyze the survey data, and provide a prioritized "Target List" with associated confidence levels in a timely manner.
- b. To determine both the detection and discrimination effectiveness under realistic scenarios that varies ordnance, clutter, and bathymetric conditions.
- c. To determine cost, time, and manpower requirements needed to operate the technology.

### 1.3 CRITERIA

The scoring criteria specified in the Environmental Quality Technology - Operational Requirements Document (EQT-ORD) (app D, ref 1) for: A(1.6.a): UXO Screening, Detection and Discrimination document are presented in Table 1-1. Very little information was available on the capabilities of shallow water detection systems when these criteria were developed. However, they were used in the design of the test site, and the five metrics were used to measure system performance in this report.

TABLE 1-1. SCORING CRITERIA

| <b>Metric</b>   | <b>Threshold</b>                                                                                                   | <b>Objective</b>                                                                                                    |
|-----------------|--------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|
| Detection       | 80% ordnance items buried to 1 foot and under 8 feet (2.4 m) of water at a standardized site detected              | 95% ordnance items buried to 4 feet and under 8 feet (2.4 m) of water at a standardized site detected               |
| Discrimination  | Rejection rate of 50% of emplaced non-UXO clutter at a standardized site with a maximum false negative rate of 10% | Rejection rate of 90% of emplaced non-UXO clutter at a standardized site with a maximum false negative rate of 0.5% |
| Reacquisition   | Reacquire within 1 meter                                                                                           | Reacquire within 0.5 meter                                                                                          |
| Cost Rate       | \$4,000 per acre                                                                                                   | \$2,000 per acre                                                                                                    |
| Production Rate | 5 acres per day                                                                                                    | 50 acres per day                                                                                                    |

The ATC shallow water site was designed to evaluate the threshold-detection level of a range of ordnance at the 1-foot + 8-foot requirement. Limited information is available at the objective-detection level. All other measured results will be evaluated against both criteria levels.

#### 1.4 APG SHALLOW WATER SITE INFORMATION

##### 1.4.1 Location

The Aberdeen Area of APG is located in the northeast portion of Maryland on the western shore of the Chesapeake Bay in Harford County. The Shallow Water Test Site is located within a controlled range area of APG.

##### 1.4.2 Soil Type

The area chosen for the shallow water test site was known as Cell No. 3 in a dredge-spoil field. The cell bottom is primarily composed of sediment removed from the Bush River. This is a freshwater site.

##### 1.4.3 Test Areas

a. The test site contains five areas: calibration grid, blind test grid, littoral, open water, and deeper water. Additional detail on each area is presented in Table 1-2. A schematic of the calibration lanes is shown in Figure 1.

TABLE 1-2. TEST AREAS

| Area             | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Calibration Grid | The calibration area contains 15 projectiles, 3 each 40, 60, 81, 105, and 155 mm. One of each projectile type is buried at the projectile diameter to depth ratio shown in Figure 1. This area is designed to provide the user with a sensor library of detection responses for the emplaced targets and an understanding of their resistivity prior to entering the blind test fields. Two “clutter-cloud” target scenarios have been constructed adjacent to this area (fig. 1).                    |
| Blind Grid       | The blind grid contains 644 detection opportunities. Each grid cell is 2 by 2 m <sup>2</sup> . At the center of each cell is either an ordnance item, clutter, or nothing. Surrounding the blind grid on three sides are 3.6-kg (8-lb) shot puts, buried 0.3-meters deep in the sediment. The shot puts can be used as a navigational/ Global Positioning System (GPS) check. The GPS coordinates for the center of each grid and the shot put locations are provided to the vendor prior to testing. |
| Littoral         | This is a sloping area on one side of the pond with vegetation growing into the water line. Water depth ranges from 0.3 to 1.8 meters. It contains a variety of navigational and detection challenges.                                                                                                                                                                                                                                                                                                |
| Open Water       | The open water scenario contains a variety of navigational, detection, and discrimination challenges. Water depth varies from 1.8 to 3.4 meters.                                                                                                                                                                                                                                                                                                                                                      |
| Deeper Water     | The water depth in this area varies between 3.4 and 4.3 meters.                                                                                                                                                                                                                                                                                                                                                                                                                                       |

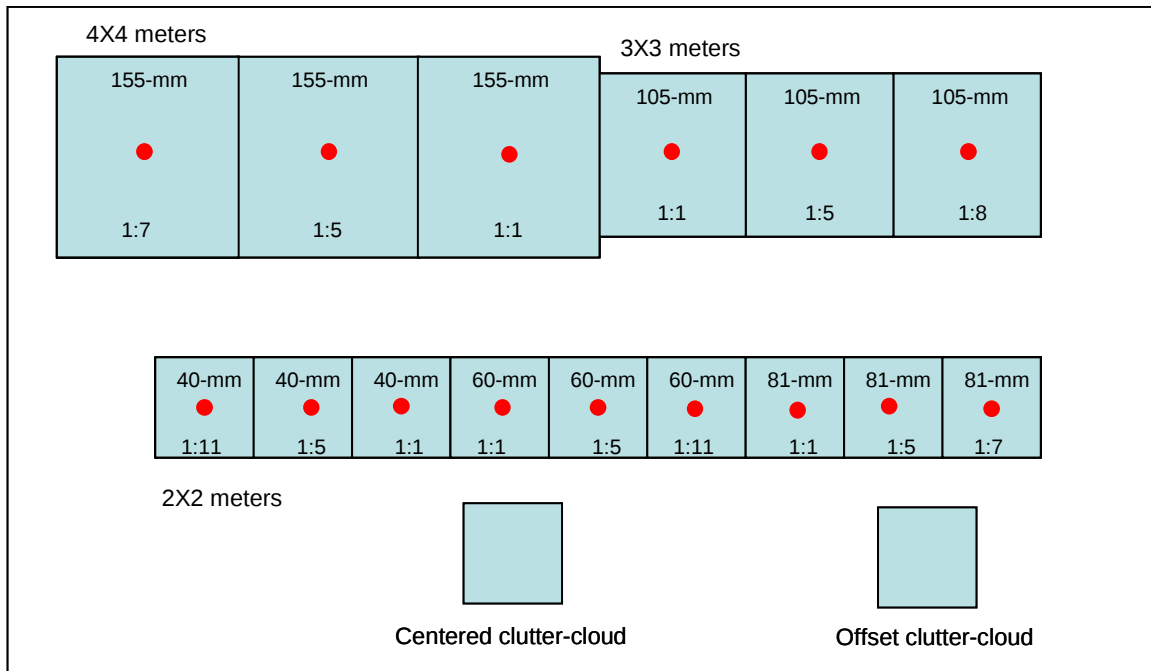


Figure 1. Schematic of the calibration grid.

b. The water depth at this facility during testing is maintained such that the calibration and blind grid areas meet the 2.4-meters (8 ft) detection criterion specified in paragraph 1.3. The test site is approximately 2.8 hectares (6.9 acres) in size.

## 1.5 GROUND-TRUTH TARGETS

The ground truth is comprised of both inert ordnance and clutter items. The inert ordnance items are listed in Table 1-3. All items were located in storage sites at APG. The items have not been fired or degaussed.

Clutter items fit into one of three categories: ferrous, nonferrous, and mixed-metals. The ferrous and nonferrous items have been further divided into three weight zones as shown in Table 1-4 and distributed throughout all test areas. Most of this clutter is comprised of ordnance components; however, there are also industrial scrap metal and cultural items as well. The mixed-metals clutter is comprised of scrap ordnance items or fragments that have both a ferrous and nonferrous component and could reasonably be encountered in a range area. The mixed-metals clutter was placed in the open water area only.

TABLE 1-3. INERT ORDNANCE TARGETS

| Description            | Length,<br>mm | Diameter,<br>mm | Aspect<br>Ratio, W/L | Weight, g |
|------------------------|---------------|-----------------|----------------------|-----------|
| 40-mm L70 Projectile   | 208           | 40              | 0.1923               | 965       |
| 60-mm Mortar M49A2     | 185           | 60              | 0.3243               | 975       |
| 81-mm Mortar M374      | 528           | 81              | 0.1534               | 3969      |
| 81-mm Mortar M821      | 510           | 81              | 0.1588               | 3338      |
| 105-mm Projectile M1   | 445           | 105             | 0.2360               | 13834     |
| 155-mm M107 Projectile | 684           | 155             | 0.2266               | 41731     |
| 8-inch M104/106        | 856           | 203             | 0.2371               | 89811     |

TABLE 1-4. CLUTTER WEIGHT RANGES

| Clutter Type | Weight Range in Grams |             |        |
|--------------|-----------------------|-------------|--------|
|              | Small                 | Medium      | Large  |
| Ferrous      | 10 to 510             | 511 to 2200 | > 2201 |
| Nonferrous   | 10 to 270             | 275 to 800  | > 801  |

## SECTION 2. SYSTEM UNDER TEST

### 2.1 DEMONSTRATOR INFORMATION

Tetra Tech, as part of their Broad Agency Announcement (BAA) submittal (app D, ref 2), provided the information in paragraphs 2.2 through 2.7 in their detailed test plan. ATC's comments on the demonstrated system are provided in paragraph 2.8.

### 2.2 SYSTEM DESCRIPTION

A unique system that contains acoustic and magnetic geophysical technology was used. The two acoustic systems were selected in order to be able to identify metal objects on the pond bottom as well as in the shallow pond sediments (through acoustic reflectivity). The acoustic technologies consist of a Sound Metrics Corporation dual frequency imaging and Specialty Devices, Inc., sub-bottom profiler. The proposed magnetic technology was selected to confirm visual indications with the acoustic systems and provide information on the presence of ferrous objects that are potentially out of the detection "window" of the acoustic systems (i.e., buried in the pond sediments). The technology consists of two GEM Systems optically pumped potassium gradiometers (GSMP-40) (fig. 2). Positioning will be accomplished with multiple Leica 1230 Differential Global Positioning System (DGPS) systems, and a Starlink LB-5 swath guidance system was used for system navigation.

The marine vessel that was used for this survey is comprised of two 12-foot fiberglass Jon boats attached together, side by side, with fiberglass supports. There is a space of 2 feet between the boats where the two acoustic technologies are mounted. Several fiberglass poles that extend to a height of approximately 4 to 5 feet were used for GPS antenna mounts. A second fiberglass vessel 8 feet in length supports the magnetic gradiometer system (MGS) array and is pushed 15 to 20 feet ahead of the main vessel. The primary marine vessel is powered by two electric motors. The detection platform is shown in Figure 3.

Two GEM GSMP-40 potassium gradiometers (two sensors per gradiometer) were used in the MGS array. The array geometry consisted of three sensors in a triangular configuration, and one sensor "trailing" the triangular array in a separate horizontal plane. The unique geometric design of the four-sensor MGS allowed the total magnetic field for each sensor to be measured, as well as six magnetic gradients. There were also four analytic signal measurements in two geometric planes that could be automatically calculated from the total field and gradient measurements. The four analytic signal combinations were used to delineate complex magnetic anomalies (e.g., representative of cluttered areas) into their individual constituents so that the anomaly locations are more representative of the individual items present.



Figure 2. GEM GSMP-40 potassium gradiometers array.



Figure 3. Tetra Tech shallow water UXO detection platform.

The increased sensitivity of the MGS over conventional magnetometer systems permits it to be used at or very near the surface of the water, ensuring accurate and precise measurement coordinates using DGPS and efficient data acquisition logistics.

A GEM Systems base station magnetometer was positioned in a magnetically quiet area not more than 0.5 miles from the survey area. The base station magnetometer was used to monitor the geomagnetic field intensity so that these naturally occurring changes could be removed from the data acquired with the MGS array.

The Sound Metrics Corporation High frequency Imaging Sonar (HFIS) (fig. 4) dual frequency imaging sonar operates at 1.1 and 1.8 MHz. For this project, the instrument was used to acquire acoustic image data at 1.8 MHz at a maximum range of 30 meters from the mount location. The x-y-z position of the HFIS unit was determined using a National Marine Electronics Association (NMEA) GPRMC string from a Leica GPS system antenna mounted directly above the HFIS instrument. This permits the image data to be integrated with the Multiple Frequency Sub-Bottom Profiler (MFSBP) and MGS data during analysis.



Figure 4. Sonar platform.

The MFSBP system is also deployed on the main acquisition platform at a slight offset ( $< 1$  m) from the Leica GPS unit. When metal is encountered at higher frequencies (e.g.,  $> 24$  KHz) the acoustic “reflectivity” of the received signal can be very large compared to the surrounding sediments. The contrast between the metal items of interest and the “background” sediments is maximized when the pond sediments are comprised of soft, lower density grains and particles.

The environmental characteristics of the shallow water detection site (SWDS) permit the use of GPS used in real-time kinematic (RTK) DGPS mode. Due to the unique NMEA code strings required for the acoustic, magnetic, and navigation instrumentation, three to four GPS units and a GPS base station are necessary.

The raw position data for all GPS systems was recorded, and if necessary, post-processed to eliminate potential data gaps.

Navigation was performed using a Starlink LB-5 swath guidance system.

## 2.3 DEMONSTRATOR POC AND ADDRESS

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email: [timothy.deignan@tteci.com](mailto:timothy.deignan@tteci.com)

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## 2.4 DEMONSTRATOR'S SITE SURVEYING METHOD

The spatial sample density (line spacing and data recording interval) will be based on the results of the calibration lane data. It was anticipated that a survey line spacing of approximately 3 to 5 feet and the following instrument recording intervals would be sufficient to detect the items of interest for this project:

### Recording Intervals

GPS 4 to 5 Hz  
MGS 15 to 20 Hz  
HFIS 14 to 20 Hz  
MFSBP (samples digitized at 100 KHz)

## 2.5 DEMONSTRATOR QC AND QA

Prior to and at the end of each data acquisition session, a portion of the calibration lane was surveyed, and the data used as a known "benchmark" for the sensitivity and repeatability of the MGS, HFIS, and MFSBP systems. This procedure provided information on the timing systems used in the recording of the magnetic and DGPS equipment so that any latency could be removed from the data during the data processing phase.

At the conclusion of each acquisition session, a portion of the track path from that session was surveyed a second time for QC purposes

## 2.6 DATA PROCESSING DESCRIPTION

The processed data for each area (i.e., calibration lane, blind grid, open water, littoral, and deep water) was evaluated with respect to anomaly characteristics of each sensor used (e.g., signal intensity, visual identification through HFIS, anomaly size and shape, signal gradients, "noise," and spatial sample density) in order to identify UXO-like items.

Specifically, the HFIS data was used to visually identify the characteristics (length, orientation, overall visual properties, and coordinate position) of items on the pond bottom. The MFSBP data was used to identify the coordinates, distance, and acoustic reflectivity of metal items that existed above and below the pond sediments. The MGS array data provided information on the characteristics of the ferrous metal items present in terms of their distance, ferrous mass, and magnetic dipole direction.

Geosoft Oasis Montaj was used as the data interpretation platform. Color-coded images of the MGS and MFSBP data were generated and compared to the coordinate locations of items visually identified using the HFIS data. The coordinate location of the item was digitized and classified by the interpreter and then output to a dig sheet in the required format.

## 2.7 DEMONSTRATOR'S SITE PERSONNEL

Project Geophysicist: Mr. Tim Deignan

Data Acquisition Specialists: Adam Maiers  
Brian Corbett

## 2.8 ATC'S SURVEY COMMENTS

Overall, the design of the three-boat system and the instrumentation distribution among the boats was well thought out.

The two electric motors that propelled the three-boat system did not have enough thrust to keep the boat on track in windy conditions. Replacing the two electric motors with a single 3.3-HP gasoline engine solved this problem.

Writable compact disks (CD-R) with the data files from the imaging sonar along with the minimally processed (raw) magnetometer data were provided at the completion of the survey. The final data submission (dig-list) was based on magnetometer data only. Tetra Tech provided the following explanation (app D, ref 3):

“We were unable to fully use all of the data from the five frequency sub-bottom profilers because of software limitations for that particular system (we requested data be available in a certain SEG-Y format for all five frequencies - the vendor is still trying to correctly get this task completed by writing new software using a third party vendor). During data analysis, we used the system depth information and the current software "depthpic"...to view the different frequencies, determine the approximate pond bottom, and correlate this information with the magnetic data. When (and if) the software can convert the multi-frequency data correctly, I expect that we have sufficient x-y data coverage of the area and expanded software analysis tools (as compared to depthpic software) to increase the overall usability of the data.

We did use the data from the DIDSON imaging sonar to select potential items and correlate with the magnetic data; however, it appears that there are extremely few or no metal items that were intended to exist on the pond bottom, however, we do not know this for sure since we do not have the truth data. Basically, the imaging sonar is (and was) implemented to detect items on the pond bottom.”

Tetra Tech's pairing of acoustic and metal detecting instrumentation is a unique approach to underwater MEC detection. Problems with acoustic data interpretation, as described above, and detection limitations of the magnetometer array, as described later in this report, show that this particular application of a dual-sensor system was not very successful in terms of underwater MEC detection.

The magnetometer configuration and mounting platform appears better suited for surveying in very shallow water ( $\leq 1$  meter) areas. Detection and discrimination results from the three unbounded test areas show this system performed best in the littoral area.

## SECTION 3. SURVEY COST ANALYSIS

### 3.1 DATES OF SURVEY

The Tetra Tech Inc. Dual Acoustic and Magnetometer Array was tested from 24 through 29 October 2005.

### 3.2 SITE CONDITIONS

#### 3.2.1 Atmospheric Conditions

An ATC weather station located adjacent to the test site recorded the average temperature and precipitation on an hourly basis for each day of operation. The temperatures listed in Table 3-1 represent the average temperature from 0700 through 1700. The hourly weather logs used to generate this summary are provided in Appendix B.

#### 3.2.2 Water Conditions

Water conditions were monitored using a TIDALITE IV Portable Tide Gauge System<sup>®</sup>. Data recorded include: water depth and temperature, significant wave height based on the average 1/3 wave height seen over the test period using the Draper/Tucker analysis method, and the full-wave frequency calculated by full-wave mean crossing detection. The values displayed in Table 3-1 were averaged from 0700 through 1700. Detailed information is provided in Appendix B.

TABLE 3-1. SITE CONDITION SUMMARY

| <b>Date 05</b> | <b>Air<br/>Temperature,<br/>°C</b> | <b>Wind,<br/>km/h</b> | <b>Water<br/>Temperature,<br/>°C</b> | <b>Water Depth,<br/>m<sup>a</sup></b> | <b>Significant<br/>Wave<br/>Height, m</b> | <b>Wave<br/>Frequency,<br/>Hz</b> |
|----------------|------------------------------------|-----------------------|--------------------------------------|---------------------------------------|-------------------------------------------|-----------------------------------|
| Oct 24         | 11.5                               | 9.7                   | 12.79                                | -0.02                                 | 0.04                                      | 0.14                              |
| Oct 25         | 7.6                                | 9.0                   | 12.00                                | -0.09                                 | 0.10                                      | 0.04                              |
| Oct 26         | 10.3                               | 8.0                   | 11.44                                | 0.06                                  | 0.18                                      | 0.05                              |
| Oct 27         | 9.1                                | 4.6                   | 11.85                                | -0.25                                 | 0.05                                      | 0.04                              |
| Oct 29         | 8.6                                | 4.4                   | 11.57                                | -0.12                                 | 0.07                                      | 0.04                              |

<sup>a</sup> Variance between the required 2.4 meter test depth and actual test conditions.

### 3.3 SURVEY ACTIVITIES

The information contained in this section provides an estimate of the time needed and costs associated with surveying an area with this demonstrator's system. This includes data on equipment setup and calibration, site survey and any resurvey time, and downtime due to system malfunctions and maintenance requirements.

### 3.3.1 Survey Times

a. A government representative monitored and recorded all on-site activities. These activities are grouped into one of eleven categories. The first eight categories are chargeable to the system while the last three are not. Categorizing these activities provides insight into the technical and logistical aspects of the system. The times recorded in each category are then matched with the number of demonstrator personnel, assigned skill levels and a consistent (across vendor) salary to produce an estimate of the survey costs.

(1) Initial setup/mobilization. Starts at the time when the demonstrator's equipment arrives at the survey site and stops when the system is ready to acquire data.

(2) Daily setup/close-up. Monitors time spent mounting and dismounting the equipment each day.

(3) Instrument calibration. Records the amount of time used for daily quality assurance checks, i.e., sensors, GPS data, survey data quality, etc.

(4) Collecting data. Time spent surveying the test area.

(5) Downtime (non-survey time) due to equipment/data checks. Covers time spent trouble shooting equipment or verifying survey tracks.

(6) Downtime (non-survey time) due to equipment failure. Examples are replacing damaged cables, lost communication with base station, or any other failure that prevents surveying. Some weather related failures would fall into this category for example light-emitting diode (LED) displays darken by the sun, wind creating waves too high to survey in, etc.

(7) Downtime (non-survey time) due to maintenance. Battery replacement and memory downloads are typical examples.

(8) Demobilization. Commencement action once the demonstrator has completed the survey and concluded the final on-site check of the test data and ends when the equipment and personnel are ready to leave the site.

(9) Non-chargeable downtime for breaks and lunch. The demonstrator's company policy sets this standard.

(10) Non-chargeable downtime for weather related causes (i.e., lightning, high wet-bulb heat index, and similar events).

(11) Non-chargeable downtime due to ATC range operating requirements. Danger zone conflicts, lack of support personnel, equipment or other ATC caused delays.

b. Appendix C contains the daily log sheets. Table 3-2 summarizes that information to provide insight into the operational, maintenance, and logistical aspects of the system.

TABLE 3-2. TIME ON SITE

| Date, 05                                          | Oct 24 | Oct 25 | Oct 26 | Oct 27 | Oct 28 | Oct 29 | Activity Totals, hr |
|---------------------------------------------------|--------|--------|--------|--------|--------|--------|---------------------|
| <b>Activity</b> (daily times recorded in minutes) |        |        |        |        |        |        |                     |
| Initial setup                                     | 435    |        |        |        |        |        | 7.3                 |
| Daily setup/close-up                              | 60     | 120    | 170    | 185    | 110    | 165    | 13.5                |
| Instrumentation calibration                       | 55     | 280    | 50     |        | 65     | 45     | 8.3                 |
| Data collection                                   |        | 60     | 180    | 155    | 335    | 310    | 17.3                |
| Equipment/data checks                             |        |        |        |        |        |        | 0.0                 |
| Equipment failure                                 |        | 25     | 120    | 115    | 50     | 20     | 5.5                 |
| Maintenance                                       |        |        |        |        |        |        | 0.0                 |
| Demobilization                                    |        |        |        |        |        | 80     | 1.3                 |
| Breaks and lunch                                  |        | 45     |        |        |        |        | 0.8                 |
| Weather related                                   |        |        |        |        |        |        | 0.0                 |
| ATC downtime                                      |        |        |        |        |        |        | 0.0                 |
| <b>Daily Total, hr</b>                            | 9.2    | 8.8    | 8.7    | 7.6    | 9.3    | 10.3   |                     |

Note: Task times have been rounded to 5-minute increments.

### 3.3.2 On-Site Data Collection Costs

The times associated with the 11 activities have been reduced into the three basic components of the evaluation: initial setup, site survey, and pack-up (demobilization). Note that site survey time includes daily setup/stop time, collecting data, breaks/lunch, downtime due to equipment/data checks or maintenance, downtime due to failure, and downtime due to weather. This combines the actual survey cost with the demonstrator's associated on-site overhead costs.

A standardized estimate for labor costs associated with this effort was then calculated using the following job categories: "supervisor" (\$95.00/hr), "data analyst" (\$57.00/hr), and "site support" (\$28.50/hr). The estimated costs are shown in Table 3-3.

TABLE 3-3. CALCULATED SURVEY COSTS

|                      | No. People | Hourly Wage | Hours | Cost              |
|----------------------|------------|-------------|-------|-------------------|
| <b>Initial Setup</b> |            |             |       |                   |
| Supervisor           | 1          | \$95.00     | 7.3   | \$693.50          |
| Data Analyst         | 1          | \$57.00     | 7.3   | \$416.10          |
| Site Support         | 1          | \$28.50     | 7.3   | \$208.05          |
| <b>Subtotal</b>      |            |             |       | <b>\$1,317.65</b> |
| <b>Site Survey</b>   |            |             |       |                   |
| Supervisor           | 1          | \$95.00     | 45.4  | \$4,313.00        |
| Data Analyst         | 1          | \$57.00     | 45.4  | \$2,587.80        |
| Site Support         | 1          | \$28.50     | 45.4  | \$1,293.90        |
| <b>Subtotal</b>      |            |             |       | <b>\$8,194.70</b> |

TABLE 3-3 (CONT'D)

|                            | No. People | Hourly Wage | Hours | Cost              |
|----------------------------|------------|-------------|-------|-------------------|
| Demobilization             |            |             |       |                   |
| Supervisor                 | 1          | \$95.00     | 1.3   | \$123.50          |
| Data Analyst               | 1          | \$57.00     | 1.3   | \$74.10           |
| Site Support               | 1          | \$28.50     | 1.3   | \$37.05           |
| <b>Subtotal</b>            |            |             |       | <b>\$234.65</b>   |
| <b>Total On-site Costs</b> |            |             |       | <b>\$9,747.00</b> |

### 3.4 COST ANALYSIS

The data collection process described above provides an on-site cost guide to compare the performance of this vendor with any other that has demonstrated at the shallow water site. It is not a true indicator of survey costs. Many other expenses have not been included: travel costs, per Diem, off-site data processing and analysis, company overhead, profit, etc.

Calculating the area surveyed is done by plotting the raw GPS coordinates then combining the sensor swath (line spacing and associated overlap).

To determine the number of acres surveyed per day, the total number of hours spent at the test site (table 3-2) is divided by 8 (converts to 8-hour days). The number of acres is then divided by the number of 8-hour days. The cost per acre is determined by dividing the total survey costs (table 3-3) by the same number of acres. This information is summarized in Table 3-4

TABLE 3-4. SURVEY COSTS

|                                       |         |
|---------------------------------------|---------|
| Area Surveyed (Acres <sup>a</sup> )   | 5.57    |
| Time on-site (8-hr days)              | 6.7     |
| Calculated survey cost (U.S. dollars) | \$9,748 |
| Acres per day                         | 0.83    |
| Cost per acre                         | \$1750  |

<sup>a</sup> Acre = 4047 meters<sup>2</sup>

Tetra Tech's survey costs are compared with the EQT-ORD criteria in Table 3-5.

TABLE 3-5. TEST RESULTS - CRITERIA COMPARISON

| Metric          | Threshold        | Objective        | TetraTech          |
|-----------------|------------------|------------------|--------------------|
| Cost Rate       | \$4,000 per acre | \$2,000 per acre | \$1,750 per acre   |
| Production Rate | 5 acres per day  | 50 acres per day | 0.83 acres per day |

## SECTION 4. TECHNICAL PERFORMANCE RESULTS

### 4.1 AREA SURVEYED

#### 4.1.1 Calculated Area

a. Both the test and scoring methodologies require the demonstrator to survey 100 percent of each of the four test areas (blind grid, open water, littoral, and deeper water). Scoring a partially surveyed area alters the ordnance and clutter sample sizes, and test area boundaries and decreases the statistical confidence in the performance statements made for that area. Allowing partial scoring decreases the validity of performance comparisons made between multiple test areas for a single demonstrator and comparisons made between multiple demonstrators for a single test area.

b. Realizing that some systems may not be able to survey 100 percent of a given test area, a ranking system was established. The percent coverage for a given test area is determined by first plotting the raw GPS coordinates combined with the sensor swath (line spacing and associated overlap), calculating the area surveyed, and then comparing that surveyed area to the total test area.

$$\frac{\text{Section Surveyed}}{\text{Test Area Size}} \times 100 = \% \text{ surveyed}$$

c. The demonstrator's system is always scored against the complete ground truth for a given test area regardless of the percentage covered.

#### 4.1.2 Area Assessment

The ranking system and survey results are presented in Table 4-1.

TABLE 4.1. SURVEY RANKING SYSTEM AND RESULTS

| Ranking System |               | Survey Results |                | Data Usage                                                                                                                                        |
|----------------|---------------|----------------|----------------|---------------------------------------------------------------------------------------------------------------------------------------------------|
| % Area Covered | Ranking       | Test Area      | % Area Covered |                                                                                                                                                   |
| 95 to 100      | Met           | Blind Grid     | 100            | Direct comparison between systems and areas.                                                                                                      |
|                |               | Open Water     | 99             |                                                                                                                                                   |
|                |               | Deeper Water   | 98             |                                                                                                                                                   |
| 90 to 94       | Generally met |                |                | Comparison between systems and areas. A small negative bias is contained in the reported numbers (bias not quantified in this report).            |
| 50 to 89       | Partially met | Littoral       | 88             | Reported, not compared between systems or areas. A large negative bias is contained in the reported numbers (bias not quantified in this report). |
| 0 to 49        | Not met       |                |                | Not scored/not reported.                                                                                                                          |

## 4.2 SYSTEM SCORING PROCEDURES

a. The scoring entities used in this program are predicated on knowing the composition and location of every detectable item in an area. The deeper water area is the one exception. Ground-truth targets were placed in this area without a pre-survey and clearing operation. Therefore, only the system's probability of detection ( $P_d$ ) is evaluated in this area.

b. The best indicator of survey performance is the blind grid. This area provides a statically valid, controlled environment in which the demonstrator must provide a response (ordnance, clutter, or blank) at each of the 644 locations. Comparison of the response and discrimination lists to the ground truth in this area both determines the range of ordnance the system can reliably detect and establishes the baseline to which system performance in all other test areas is measured.

c. The scoring terms and definitions along with an explanation of the receiver operating characteristics (ROC) curve development and the Chi-square analysis used in this report are in Appendix C.

d. Demonstrator performance is scored in two stages: response and discrimination.

e. The response stage scoring evaluates the ability of the demonstrator's system to detect emplaced ground-truth targets without regard to discriminating ordnance from clutter. In this stage, the GPS locations and signal strengths of all anomalies that the demonstrator has deemed sufficient for further investigation and/or processing are reported. This list is generated with minimal processing, i.e., associating signal strength with GPS location, and includes only signals that are above the system noise level.

f. The discrimination stage evaluates the demonstrator's ability to segregate ordnance from clutter. The same GPS locations reported in the response stage anomaly list are evaluated based on the demonstrator's discrimination process (para 2.1.5). A discrimination stage list is generated and prioritized based on the demonstrator's determination that an anomaly is more likely to be ordnance rather than clutter. Typically, higher output values indicate a higher confidence that an ordnance item is present at a specified location. The demonstrator then specifies the threshold value for the prioritized ranking that provides optimum system performance. This value is the discrimination stage threshold.

g. Both the response and discrimination lists contain an identical number of potential target locations. They differ only in the priority ranking of the declarations.

h. Within both of these stages, the following entities are measured:

(1)  $P_d$ .

(2) Probability of false positive ( $P_{fp}$ ).

(3) Probability of background alarm ( $P_{ba}$ )/background alarm rate (BAR).

#### 4.2.1 ROC curves

Based on the entire range of ground-truth targets used at this site, ROC curves were generated for both the response and discrimination stages. In both stages, the probability of detection versus false alarm rates is plotted. False alarms are divided into two groups; those anomalies that correspond to emplaced clutter items, thereby measuring the  $P_{fp}$ , and anomalies that do not correspond to any known item, termed background alarms ( $P_{ba}$ ) in the blind grid area and BAR in all other areas.

The ROC curves for the response and discrimination stages for all areas surveyed are shown in Figures 5 through 10. Horizontal lines illustrate the system performance at the demonstrator's recommended noise level during the response stage, or discrimination threshold level in the discrimination stage. The point where the curve crosses the horizontal line defines the subset of targets the demonstrator recommends digging.

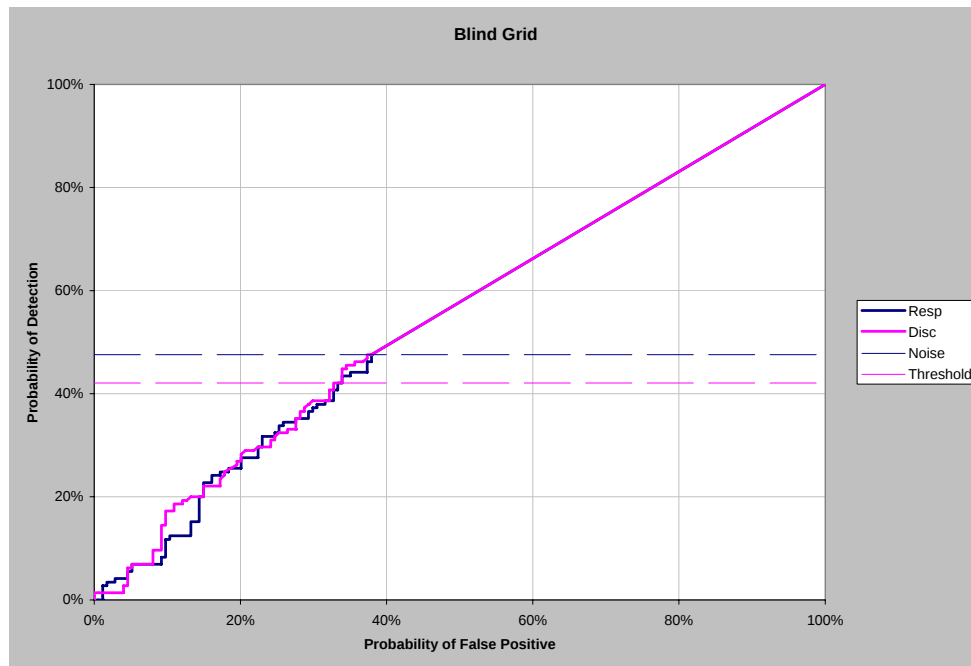


Figure 5. Blind grid  $P_d$  versus  $P_{fp}$ .

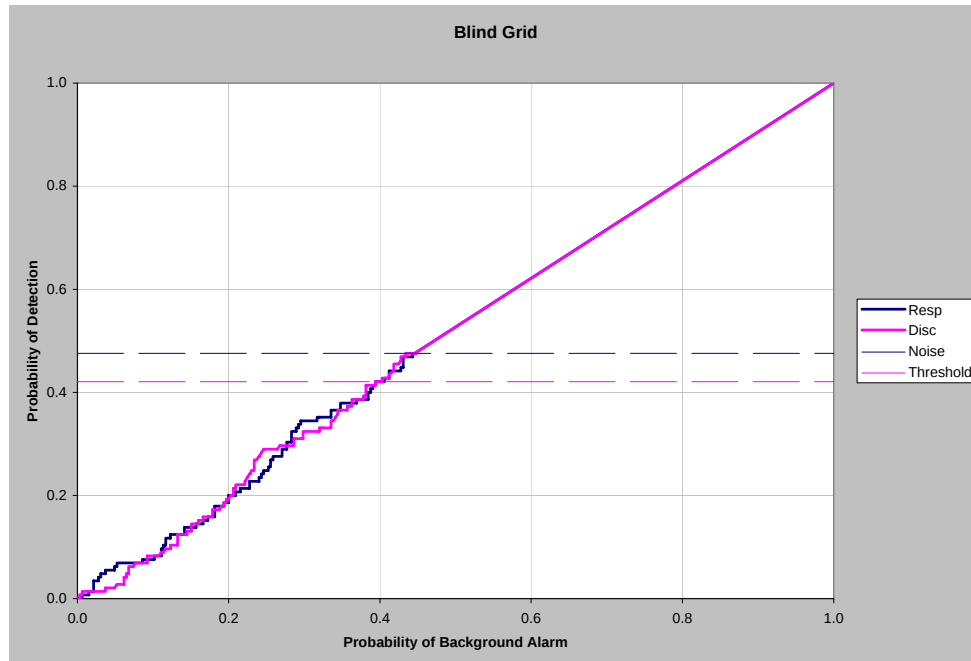


Figure 6. Blind grid  $P_d$  versus  $P_{ba}$ .

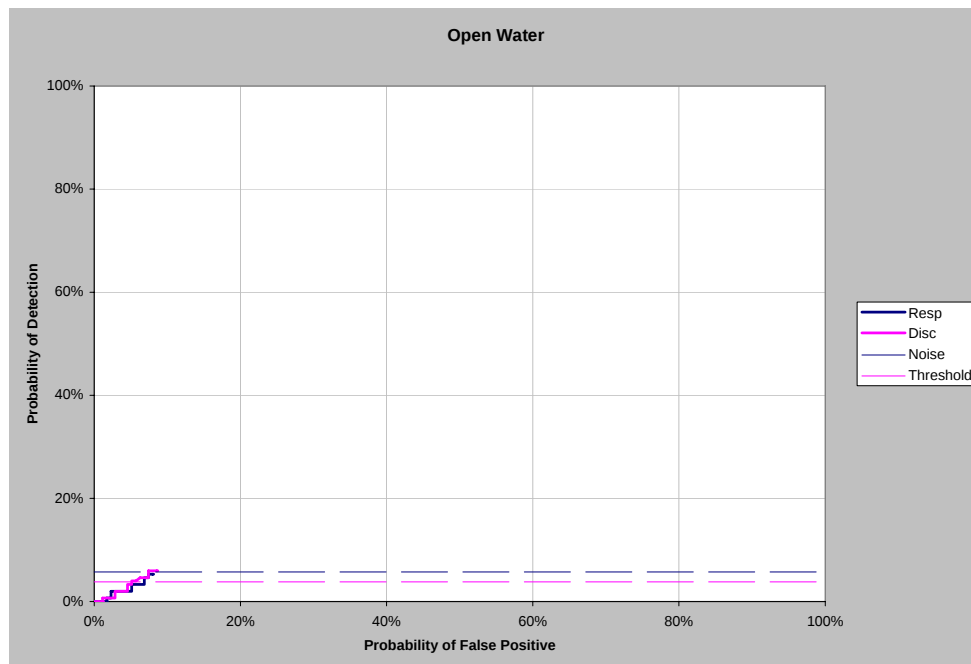


Figure 7. Open water  $P_d$  versus  $P_{fp}$ .

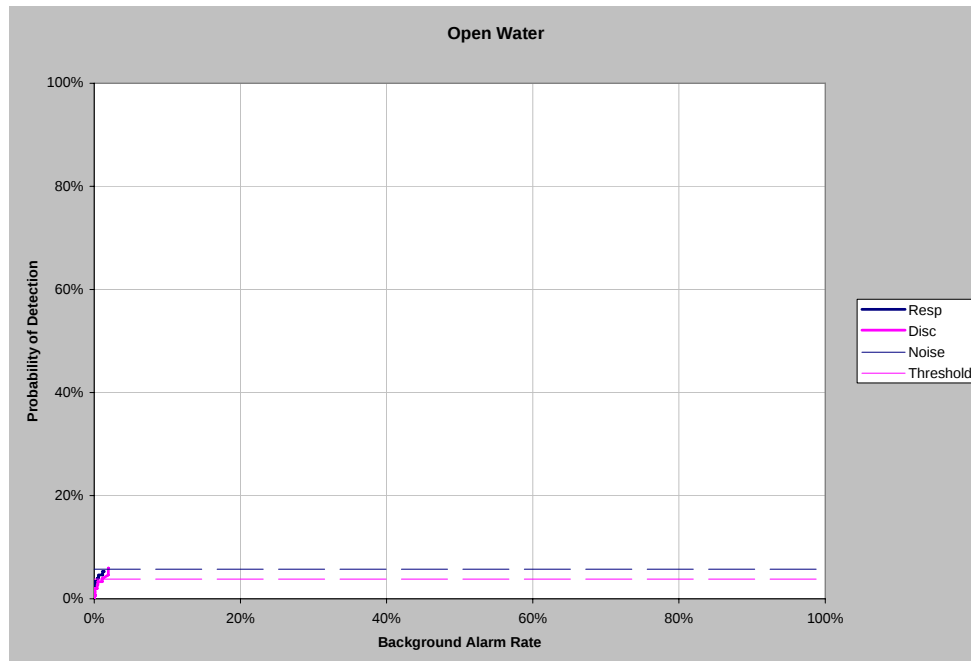


Figure 8. Open water  $P_d$  versus BAR.

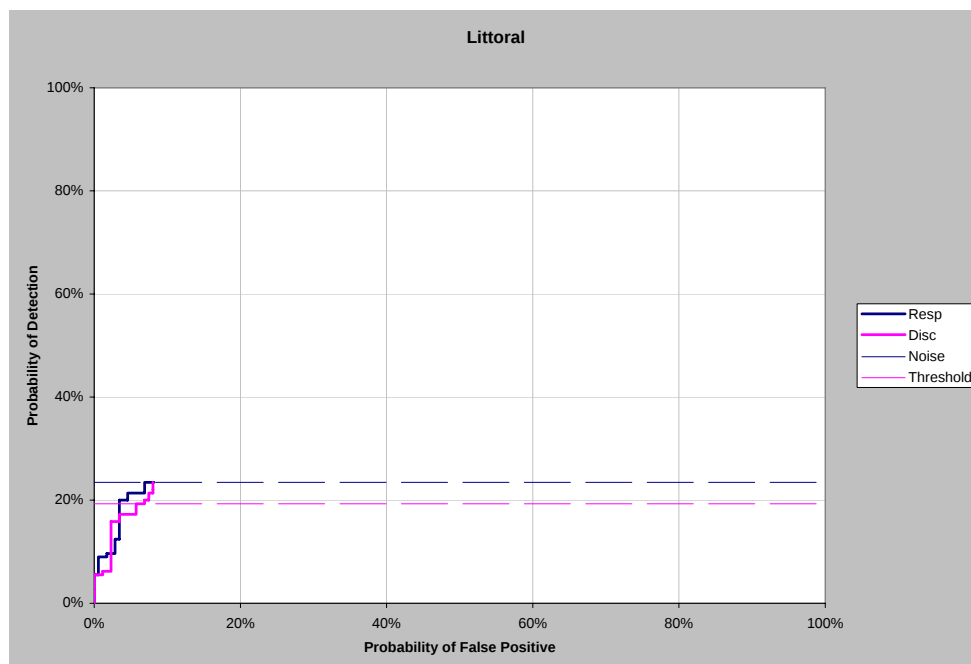


Figure 9. Littoral  $P_d$  versus  $P_{fp}$ .

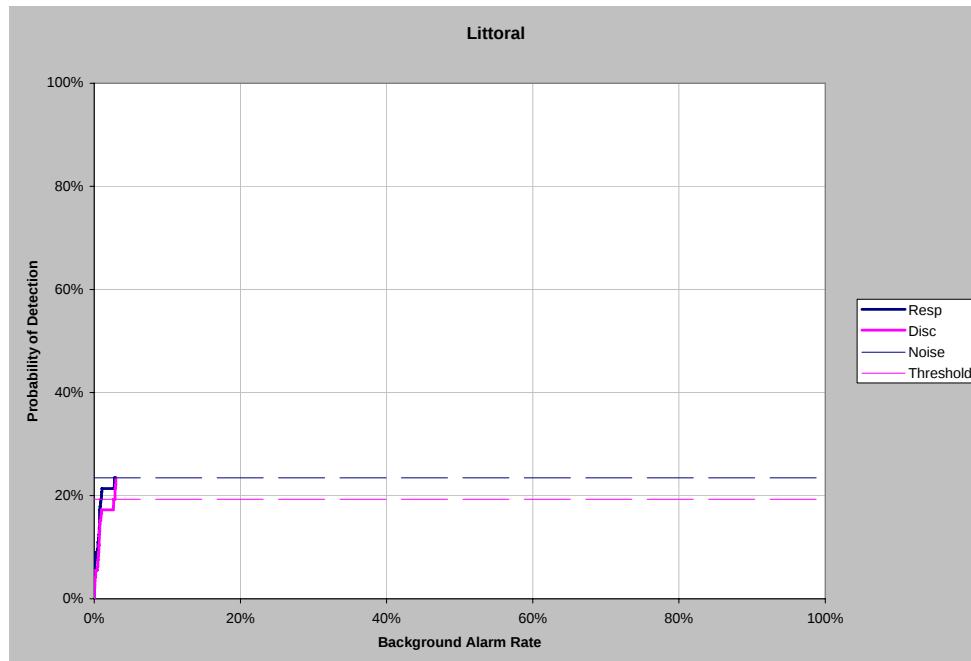


Figure 10. Littoral  $P_d$  versus BAR.

#### 4.2.2 Detection Results

Detection results, broken out by stage, area surveyed, and ordnance size are in Table 4-2. The results by size indicate how well the demonstrator did at detecting/discriminating ordnance of a given caliber. Overall results summarize ordnance detection over a given area. All values were calculated assuming the number of detections is a binomially distributed random variable. These results are reported at the 90-percent reliability/95-percent confidence levels unless otherwise noted

TABLE 4-2. SYSTEM DETECTION SUMMARY

| Metric                                                                                          | Overall | By Projectile Caliber |       |       |        |        |        |
|-------------------------------------------------------------------------------------------------|---------|-----------------------|-------|-------|--------|--------|--------|
|                                                                                                 |         | 40 mm                 | 60 mm | 81 mm | 105 mm | 155 mm | 8 inch |
| Blind Grid                                                                                      |         |                       |       |       |        |        |        |
| Response Stage                                                                                  |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 47.6%   | 58.6%                 | 41.4% | 51.7% | 37.9%  | 48.3%  |        |
| P <sub>d</sub> Lower 90% Confidence                                                             | 42.0%   | 45.0%                 | 28.8% | 38.4% | 25.7%  | 35.1%  |        |
| P <sub>fp</sub>                                                                                 | 37.9%   |                       |       |       |        |        |        |
| P <sub>fp</sub> Lower 90% Confidence                                                            | 33.1%   |                       |       |       |        |        |        |
| P <sub>ba</sub>                                                                                 | 44.6%   |                       |       |       |        |        |        |
| Discrimination Stage                                                                            |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 42.1%   | 44.8%                 | 37.9% | 44.8% | 37.9%  | 44.8%  |        |
| P <sub>d</sub> Lower 90% Confidence                                                             | 36.6%   | 31.9%                 | 25.7% | 31.9% | 25.7%  | 31.9%  |        |
| P <sub>fp</sub>                                                                                 | 32.8%   |                       |       |       |        |        |        |
| P <sub>fp</sub> Lower 90% Confidence                                                            | 28.1%   |                       |       |       |        |        |        |
| P <sub>ba</sub>                                                                                 | 39.7%   |                       |       |       |        |        |        |
| Open Water                                                                                      |         |                       |       |       |        |        |        |
| Response Stage                                                                                  |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 5.7%    | 10.3%                 | 6.9%  | 3.4%  | 6.9%   | 2.9%   | 0.0%   |
| P <sub>d</sub> Lower 90% Confidence                                                             | 3.5%    | 3.9%                  | 1.8%  | 0.4%  | 1.8%   | 0.3%   | 0.0%   |
| P <sub>fp</sub>                                                                                 | 7.4%    |                       |       |       |        |        |        |
| P <sub>fp</sub> Lower 90% Confidence                                                            | 5.1%    |                       |       |       |        |        |        |
| BAR m <sup>-2</sup>                                                                             | 0.020   |                       |       |       |        |        |        |
| Discrimination Stage                                                                            |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 3.8%    | 3.4%                  | 6.9%  | 3.4%  | 3.4%   | 2.9%   | 0.0%   |
| P <sub>d</sub> Lower 90% Confidence                                                             | 2.0%    | 0.4%                  | 1.8%  | 0.4%  | 0.4%   | 0.3%   | 0.0%   |
| P <sub>fp</sub>                                                                                 | 4.9%    |                       |       |       |        |        |        |
| P <sub>fp</sub> Lower 90% Confidence                                                            | 3.1%    |                       |       |       |        |        |        |
| BAR m <sup>-2</sup>                                                                             | 0.012   |                       |       |       |        |        |        |
| Littoral Region                                                                                 |         |                       |       |       |        |        |        |
| Response Stage                                                                                  |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 23.4%   | 10.3%                 | 3.4%  | 17.2% | 44.8%  | 41.4%  |        |
| P <sub>d</sub> Lower 90% Confidence                                                             | 18.9%   | 3.9%                  | 0.4%  | 8.6%  | 31.9%  | 28.8%  |        |
| P <sub>fp</sub>                                                                                 | 8.0%    |                       |       |       |        |        |        |
| P <sub>fp</sub> Lower 90% Confidence                                                            | 5.5%    |                       |       |       |        |        |        |
| BAR m <sup>-2</sup>                                                                             | 0.030   |                       |       |       |        |        |        |
| Discrimination Stage                                                                            |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 19.3%   | 10.3%                 | 3.4%  | 17.2% | 34.5%  | 31.0%  |        |
| P <sub>d</sub> Lower 90% Confidence                                                             | 15.1%   | 3.9%                  | 0.4%  | 8.6%  | 22.6%  | 19.7%  |        |
| P <sub>fp</sub>                                                                                 | 6.9%    |                       |       |       |        |        |        |
| P <sub>fp</sub> Lower 90% Confidence                                                            | 4.5%    |                       |       |       |        |        |        |
| BAR m <sup>-2</sup>                                                                             | 0.028   |                       |       |       |        |        |        |
| Deeper Water                                                                                    |         |                       |       |       |        |        |        |
| Response Stage                                                                                  |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 6.9%    |                       |       |       |        | 6.9%   |        |
| P <sub>d</sub> Lower 90% Confidence                                                             | 1.8%    |                       |       |       |        | 1.8%   |        |
| Discrimination Stage                                                                            |         |                       |       |       |        |        |        |
| P <sub>d</sub>                                                                                  | 6.9%    |                       |       |       |        | 6.9%   |        |
| P <sub>d</sub> Lower 90% Confidence                                                             | 1.8%    |                       |       |       |        | 1.8%   |        |
| Response Stage Noise Level: 0.1 for all areas                                                   |         |                       |       |       |        |        |        |
| Recommended Discrimination Threshold: Blind Grid =3    Open Water, Littoral and Deeper Water =1 |         |                       |       |       |        |        |        |

#### 4.2.3 System Discrimination

Using the demonstrator's recommended setting, the items that were detected and correctly classified as ordnance were further evaluated as to whether the demonstrator could correctly identify the ordnance type. The list of ground-truth ordnance items was provided to the demonstrator prior to testing.

Tetra Tech's "dig-list" discriminated between ordnance and clutter, but not between ordnance types. The latter was an optional requirement.

#### 4.2.4 System Effectiveness

Efficiency and rejection rates were calculated to quantify the discrimination ability at two specific points of interest on the ROC curve: at the point where no decrease in  $P_d$  is suffered (i.e., the efficiency is by definition equal to one) and the operator-selected threshold. These values are presented in Table 4-3.

TABLE 4-3. EFFICIENCY AND REJECTION RATES

|                        | Efficiency | False Positive Rejection Rate | Background Alarm Rejection Rate |
|------------------------|------------|-------------------------------|---------------------------------|
| <b>Blind Grid</b>      |            |                               |                                 |
| At operating point     | 0.88       | 0.14                          | 0.11                            |
| With no loss of $P_d$  | 1.00       | 0.02                          | 0.03                            |
| <b>Open Water</b>      |            |                               |                                 |
| At operating point     | 0.67       | 0.33                          | 0.40                            |
| With no loss of $P_d$  | 1.00       | 0.13                          | 0.02                            |
| <b>Littoral Region</b> |            |                               |                                 |
| At operating point     | 0.82       | 0.14                          | 0.06                            |
| With no loss of $P_d$  | 1.00       | 0.00                          | 0.01                            |

#### 4.2.5 Chi-Square Analysis

Chi-square 2 by 2 Contingency Test for comparison between ratios was used to compare performance across test areas with regard to  $P_d^{\text{res}}$ ,  $P_d^{\text{disc}}$ ,  $P_{\text{fp}}^{\text{res}}$ , and  $P_{\text{fp}}^{\text{disc}}$ , efficiency, and false alarm rejection rate. A one-sided Chi-square significance test at the 0.05 significance level was used to compare the survey results from the blind grid to both the open water and littoral areas. A two-sided test at the 0.10 significance level was used to compare the open water results to those obtained in the littoral zone. The intent of the comparison was to determine if the features introduced in each test site had a degrading effect on the performance of the sensor system. These results are presented in Table 4-4.

TABLE 4-4. CHI-SQUARE SIGNIFICANCE TEST RESULTS

| Metric                                               | Overall | By Projectile Caliber |       |       |        |        |
|------------------------------------------------------|---------|-----------------------|-------|-------|--------|--------|
|                                                      |         | 40 mm                 | 60 mm | 81 mm | 105 mm | 155 mm |
| <sup>a</sup> Blind Grid - Open Water Comparison      |         |                       |       |       |        |        |
| P <sub>d</sub> <sup>res</sup>                        | SIG     | SIG                   | SIG   | SIG   | SIG    | SIG    |
| P <sub>d</sub> <sup>disc</sup>                       | SIG     | SIG                   | SIG   | SIG   | SIG    | SIG    |
| P <sub>fp</sub> <sup>res</sup>                       | SIG     |                       |       |       |        |        |
| P <sub>fp</sub> <sup>disc</sup>                      | SIG     |                       |       |       |        |        |
| Efficiency                                           | Not     |                       |       |       |        |        |
| Rejection rate (R <sub>fp</sub> )                    | Not     |                       |       |       |        |        |
| <sup>a</sup> Blind Grid - Littoral Region Comparison |         |                       |       |       |        |        |
| P <sub>d</sub> <sup>res</sup>                        | SIG     | SIG                   | SIG   | SIG   | Not    | Not    |
| P <sub>d</sub> <sup>disc</sup>                       | SIG     | SIG                   | SIG   | SIG   | Not    | Not    |
| P <sub>fp</sub> <sup>res</sup>                       | SIG     |                       |       |       |        |        |
| P <sub>fp</sub> <sup>disc</sup>                      | SIG     |                       |       |       |        |        |
| Efficiency                                           | Not     |                       |       |       |        |        |
| Rejection rate (R <sub>fp</sub> )                    | Not     |                       |       |       |        |        |
| <sup>b</sup> Open Water - Littoral Comparison        |         |                       |       |       |        |        |
| P <sub>d</sub> <sup>res</sup>                        | LR      | Not                   | Not   | Not   | LR     | LR     |
| P <sub>d</sub> <sup>disc</sup>                       | LR      | Not                   | Not   | Not   | LR     | LR     |
| P <sub>fp</sub> <sup>res</sup>                       | Not     |                       |       |       |        |        |
| P <sub>fp</sub> <sup>disc</sup>                      | Not     |                       |       |       |        |        |
| Efficiency                                           | Not     |                       |       |       |        |        |
| Rejection rate (R <sub>fp</sub> )                    | Not     |                       |       |       |        |        |
| SIG = Significant      Not = Not Significant         |         |                       |       |       |        |        |

<sup>a</sup> One-sided comparison performed at the 0.05 significance level.

<sup>b</sup> Two-sided comparison performed at the 0.10 significance level. The greater (better performance area) of the two areas is noted when a significant difference is detected.

#### 4.2.6 Location Accuracy

The data points in the following scatter-graphs represent the coordinates of ordnance items in the open water and littoral test areas that were first detected in the response stage within a 0.5-meter radius of their true positions, then correctly identified as ordnance in the discrimination stage. The maximum error represents the 0.5-meter detection limit. The mean error represents the statistical mean of the sample considered.

A visual assessment of the littoral graph indicates location error is a randomly distributed as opposed to a systematic error. The open water graph does not contain enough data to make an analysis or statement regarding location accuracy.

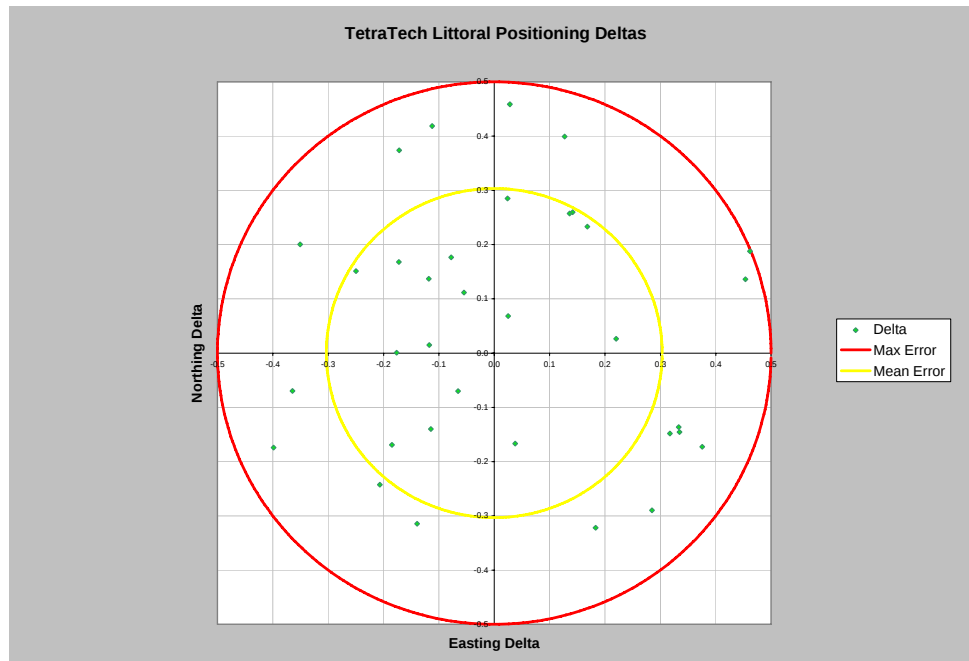


Figure 11. Tetra Tech littoral positional deltas.

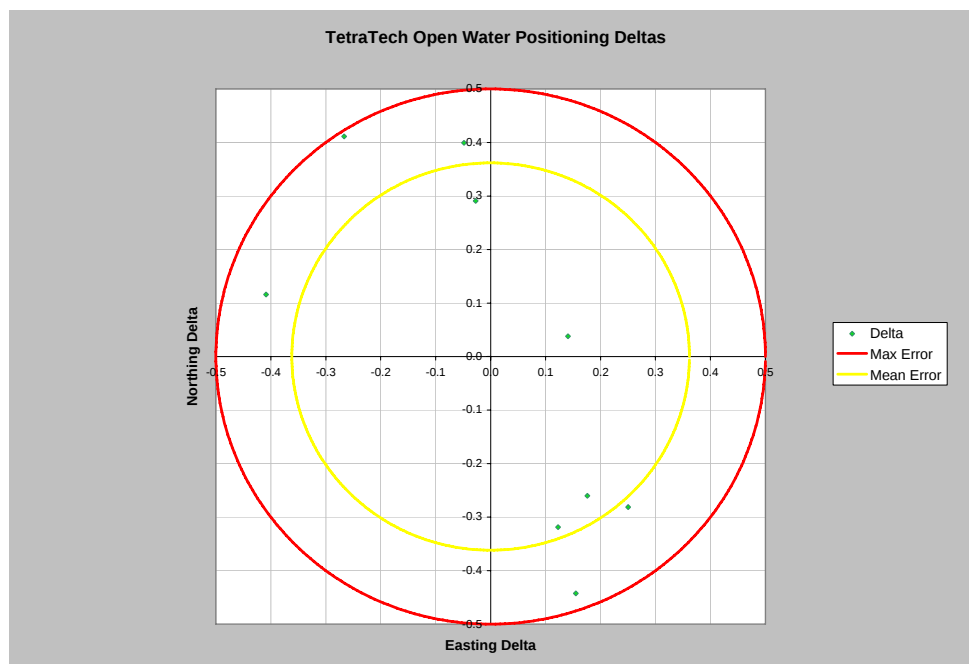


Figure 12. Tetra Tech open water positional deltas.

The comparison between the results obtained during testing and the EQT-ORD criteria are presented in Table 4-5.

TABLE 4-5. TEST RESULTS - CRITERIA COMPARISON

| <b>Metric</b>  | <b>Threshold</b>                                                       | <b>Objective</b>                                                       | <b>Tetra Tech by Area</b>                                                                                                        |       |
|----------------|------------------------------------------------------------------------|------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|-------|
| Detection      | 80% ordnance items buried to 1 foot and under 8 feet (2.4 m) of water. | 95% ordnance items buried to 4 feet and under 8 feet (2.4 m) of water. | Blind Grid                                                                                                                       | 47.6% |
|                |                                                                        |                                                                        | Open Water                                                                                                                       | 5.7%  |
|                |                                                                        |                                                                        | Littoral                                                                                                                         | 23.4% |
| Discrimination | Rejection rate of 50% of emplaced non-UXO clutter.                     | Rejection rate of 90% of emplaced non-UXO clutter.                     | Blind Grid                                                                                                                       | 14%   |
|                |                                                                        |                                                                        | Open Water                                                                                                                       | 33%   |
|                |                                                                        |                                                                        | Littoral                                                                                                                         | 14%   |
|                | Maximum false negative rate of 10%.                                    | Maximum false negative rate of 0.5%.                                   | Not assessed. An analytical procedure is not available to address this criterion.                                                |       |
| Reacquisition  | Reacquire within 1 meter.                                              | Reacquire within 0.5 meter.                                            | The reported detection values are based on ordnance items identified within 0.5meters of the georeferenced ground-truth targets. |       |

Note: The blind grid and open water areas are in general accordance with the threshold requirements.

## SECTION 5. APPENDIXES

# APPENDIX A. TEST CONDITIONS LOG

## ATMOSPHERIC CONDITIONS

| Date<br>mm/dd/yy | Time,<br>EDT | Average<br>Wind<br>Direction,<br>deg | Average<br>Wind<br>Speed,<br>km/h | Wind Direction<br>Average<br>Standard<br>Deviation, deg | Peak Wind<br>Speed,<br>km/h | Average<br>Temperture,<br>°C |
|------------------|--------------|--------------------------------------|-----------------------------------|---------------------------------------------------------|-----------------------------|------------------------------|
| 10/24/05         | 0700         | 71                                   | 6.1                               | 19                                                      | 13.0                        | 8.7                          |
|                  | 0800         | 66                                   | 6.1                               | 19                                                      | 13.8                        | 8.7                          |
|                  | 0900         | 66                                   | 6.9                               | 21                                                      | 18.3                        | 9.4                          |
|                  | 1000         | 66                                   | 8.5                               | 25                                                      | 24.0                        | 11.1                         |
|                  | 1100         | 66                                   | 10.0                              | 25                                                      | 25.1                        | 11.6                         |
|                  | 1200         | 76                                   | 11.3                              | 27                                                      | 26.1                        | 12.8                         |
|                  | 1300         | 74                                   | 11.3                              | 25                                                      | 26.9                        | 12.9                         |
|                  | 1400         | 76                                   | 10.0                              | 26                                                      | 26.1                        | 12.9                         |
|                  | 1500         | 74                                   | 12.7                              | 25                                                      | 31.2                        | 13.1                         |
|                  | 1600         | 59                                   | 12.6                              | 22                                                      | 26.2                        | 12.7                         |
|                  | 1700         | 61                                   | 11.7                              | 23                                                      | 29.1                        | 12.3                         |
| 10/25/05         | 0700         | 4                                    | 8.4                               | 17                                                      | 24.9                        | 7.5                          |
|                  | 0800         | 351                                  | 9.4                               | 16                                                      | 27.4                        | 7.6                          |
|                  | 0900         | 337                                  | 9.3                               | 15                                                      | 26.1                        | 7.6                          |
|                  | 1000         | 342                                  | 8.4                               | 20                                                      | 25.4                        | 7.5                          |
|                  | 1100         | 333                                  | 9.1                               | 18                                                      | 28.5                        | 7.3                          |
|                  | 1200         | 345                                  | 11.5                              | 16                                                      | 35.2                        | 7.4                          |
|                  | 1300         | 344                                  | 10.9                              | 17                                                      | 33.1                        | 7.7                          |
|                  | 1400         | 344                                  | 9.3                               | 17                                                      | 29.6                        | 7.8                          |
|                  | 1500         | 343                                  | 8.8                               | 16                                                      | 25.6                        | 7.7                          |
|                  | 1600         | 335                                  | 6.7                               | 16                                                      | 24.1                        | 7.7                          |
|                  | 1700         | 340                                  | 6.9                               | 17                                                      | 20.6                        | 7.6                          |
| 10/26/05         | 0700         | 319                                  | 6.5                               | 18                                                      | 21.7                        | 6.1                          |
|                  | 0800         | 289                                  | 5.6                               | 20                                                      | 18.3                        | 5.8                          |
|                  | 0900         | 276                                  | 6.4                               | 17                                                      | 17.7                        | 6.4                          |
|                  | 1000         | 293                                  | 5.8                               | 21                                                      | 20.3                        | 8.3                          |
|                  | 1100         | 305                                  | 8.0                               | 21                                                      | 27.8                        | 10.2                         |
|                  | 1200         | 304                                  | 8.5                               | 19                                                      | 31.4                        | 11.3                         |
|                  | 1300         | 301                                  | 8.5                               | 20                                                      | 29.3                        | 12.3                         |
|                  | 1400         | 295                                  | 10.1                              | 19                                                      | 30.1                        | 12.7                         |
|                  | 1500         | 300                                  | 9.7                               | 22                                                      | 30.9                        | 13.2                         |
|                  | 1600         | 299                                  | 9.1                               | 20                                                      | 29.1                        | 13.4                         |
|                  | 1700         | 291                                  | 9.3                               | 19                                                      | 28.8                        | 13.3                         |
| 10/27/05         | 0700         | 298                                  | 1.4                               | 24                                                      | 6.1                         | 2.7                          |
|                  | 0800         | 352                                  | 1.0                               | 19                                                      | 7.4                         | 2.5                          |
|                  | 0900         | 332                                  | 2.9                               | 30                                                      | 14.0                        | 5.1                          |
|                  | 1000         | 330                                  | 5.4                               | 19                                                      | 20.0                        | 8.3                          |
|                  | 1100         | 337                                  | 5.6                               | 18                                                      | 17.4                        | 10.1                         |
|                  | 1200         | 325                                  | 4.6                               | 24                                                      | 14.3                        | 11.3                         |
|                  | 1300         | 314                                  | 4.7                               | 27                                                      | 16.1                        | 12.4                         |
|                  | 1400         | 336                                  | 6.2                               | 21                                                      | 20.0                        | 12.4                         |
|                  | 1500         | 336                                  | 7.5                               | 22                                                      | 21.2                        | 12.1                         |
|                  | 1600         | 326                                  | 7.0                               | 17                                                      | 21.2                        | 11.7                         |
|                  | 1700         | 314                                  | 4.2                               | 20                                                      | 14.8                        | 11.2                         |

(CONT'D)

| <b>Date<br/>mm/dd/yy</b> | <b>Time,<br/>EDT</b> | <b>Average<br/>Wind<br/>Direction,<br/>deg</b> | <b>Average<br/>Wind<br/>Speed,<br/>km/h</b> | <b>Wind Direction<br/>Average<br/>Standard<br/>Deviation, deg</b> | <b>Peak Wind<br/>Speed,<br/>km/h</b> | <b>Average<br/>Temperture,<br/>°C</b> |
|--------------------------|----------------------|------------------------------------------------|---------------------------------------------|-------------------------------------------------------------------|--------------------------------------|---------------------------------------|
| <b>10/28/05</b>          | 0700                 | 13                                             | 4.3                                         | 10                                                                | 12.4                                 | 4.9                                   |
|                          | 0800                 | 16                                             | 3.4                                         | 12                                                                | 10.8                                 | 4.8                                   |
|                          | 0900                 | 57                                             | 1.9                                         | 38                                                                | 8.2                                  | 4.4                                   |
|                          | 1000                 | 19                                             | 3.0                                         | 39                                                                | 10.8                                 | 6.2                                   |
|                          | 1100                 | 30                                             | 4.9                                         | 26                                                                | 16.3                                 | 8.8                                   |
|                          | 1200                 | 67                                             | 3.6                                         | 49                                                                | 12.4                                 | 10.3                                  |
|                          | 1300                 | 49                                             | 3.4                                         | 55                                                                | 13.8                                 | 11.1                                  |
|                          | 1400                 | 325                                            | 4.6                                         | 34                                                                | 16.4                                 | 11.1                                  |
|                          | 1500                 | 328                                            | 6.1                                         | 18                                                                | 16.7                                 | 11.3                                  |
|                          | 1600                 | 345                                            | 7.3                                         | 18                                                                | 20.3                                 | 11.1                                  |
|                          | 1700                 | 353                                            | 5.4                                         | 28                                                                | 22.8                                 | 10.9                                  |
| <b>10/29/05</b>          | 0700                 | 328                                            | 2.6                                         | 17                                                                | 10.1                                 | 4.1                                   |
|                          | 0800                 | 325                                            | 3.8                                         | 16                                                                | 13.2                                 | 4.6                                   |
|                          | 0900                 | 341                                            | 5.4                                         | 19                                                                | 15.6                                 | 5.3                                   |
|                          | 1000                 | 354                                            | 6.1                                         | 17                                                                | 18.8                                 | 6.6                                   |
|                          | 1100                 | 5                                              | 6.3                                         | 21                                                                | 20.9                                 | 8.4                                   |
|                          | 1200                 | 350                                            | 8.0                                         | 19                                                                | 24.8                                 | 9.5                                   |
|                          | 1300                 | 343                                            | 8.2                                         | 19                                                                | 23.5                                 | 9.2                                   |
|                          | 1400                 | 330                                            | 7.8                                         | 20                                                                | 28.6                                 | 9.6                                   |
|                          | 1500                 | 315                                            | 8.4                                         | 20                                                                | 26.9                                 | 9.6                                   |
|                          | 1600                 | 325                                            | 10.1                                        | 20                                                                | 33.3                                 | 10.2                                  |
|                          | 1700                 | 320                                            | 8.4                                         | 20                                                                | 29.1                                 | 10.4                                  |

The water conditions during the Tetra Tech survey are shown in Figures A-1 through A-5.

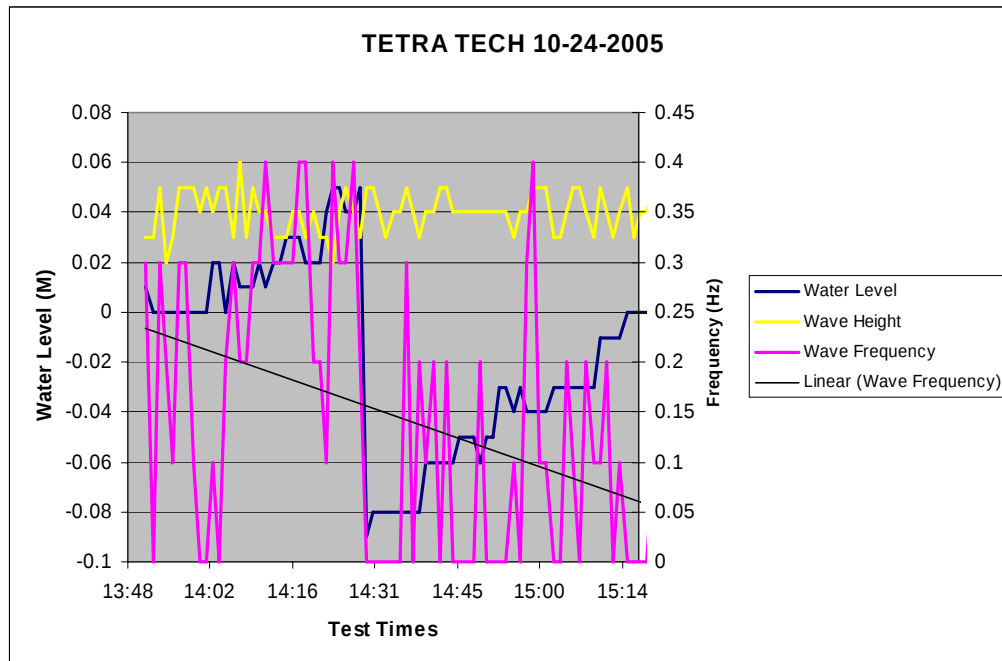


Figure A-1. Water conditions on 24 October 2005.

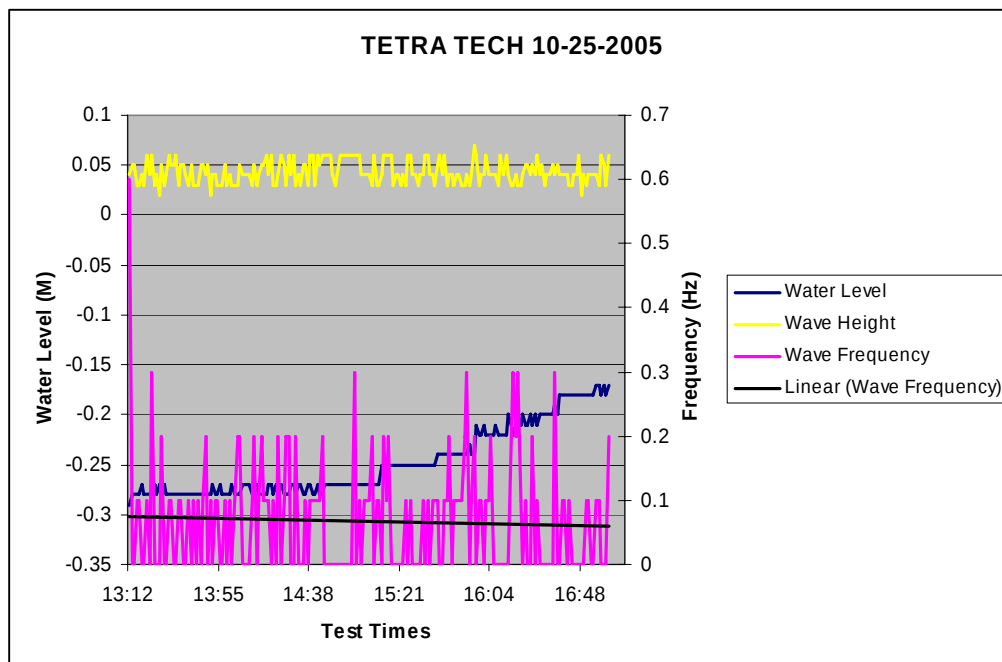


Figure A-2. Water conditions on 25 October 2005.

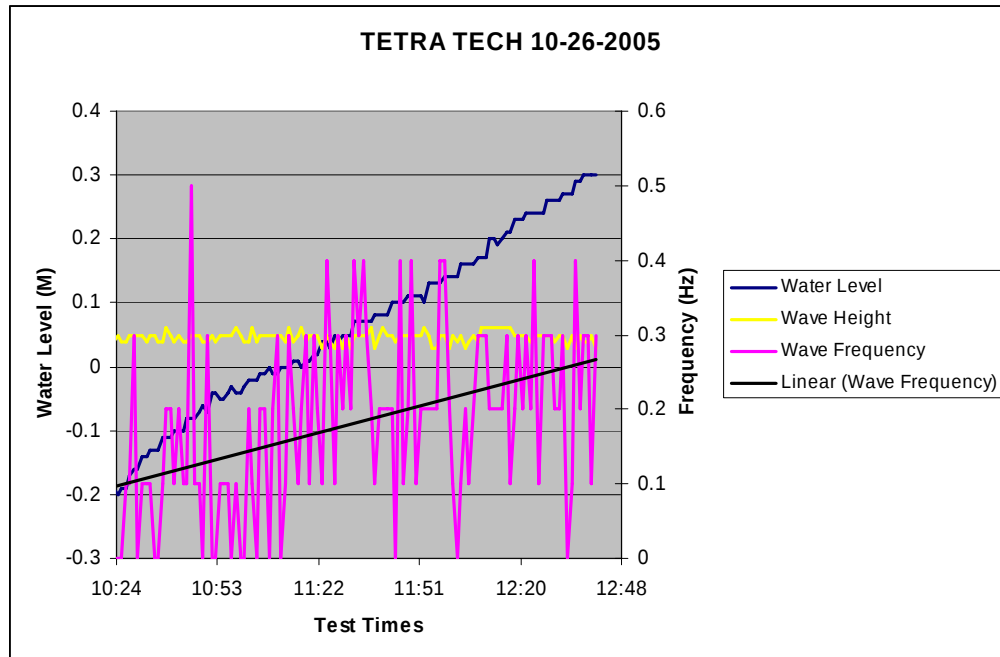


Figure A-3. Water conditions on 26 October 2005.

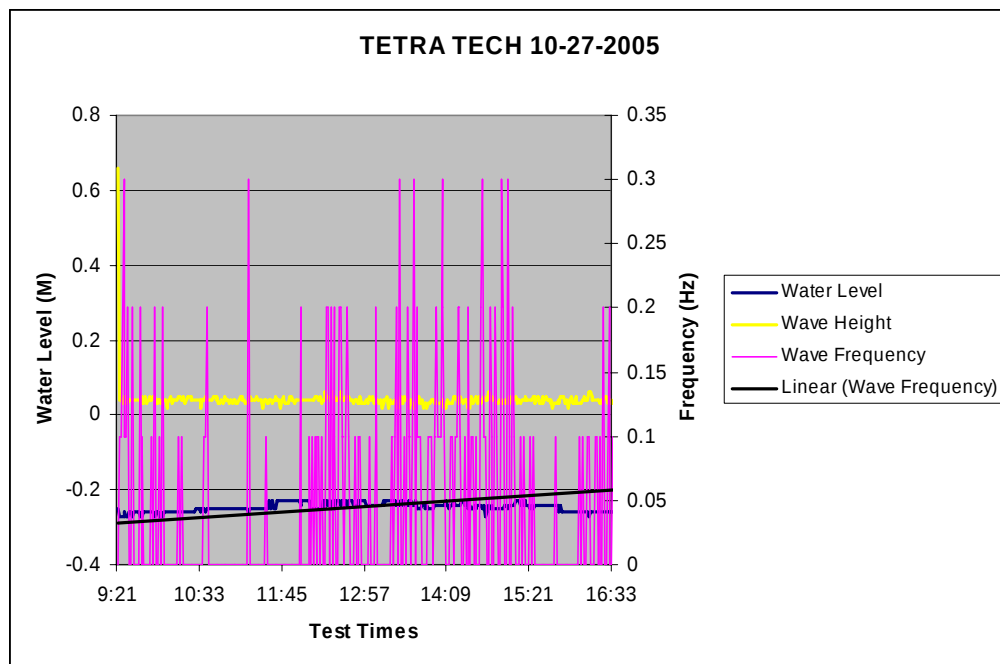


Figure A-4. Water conditions on 27 October 2005.

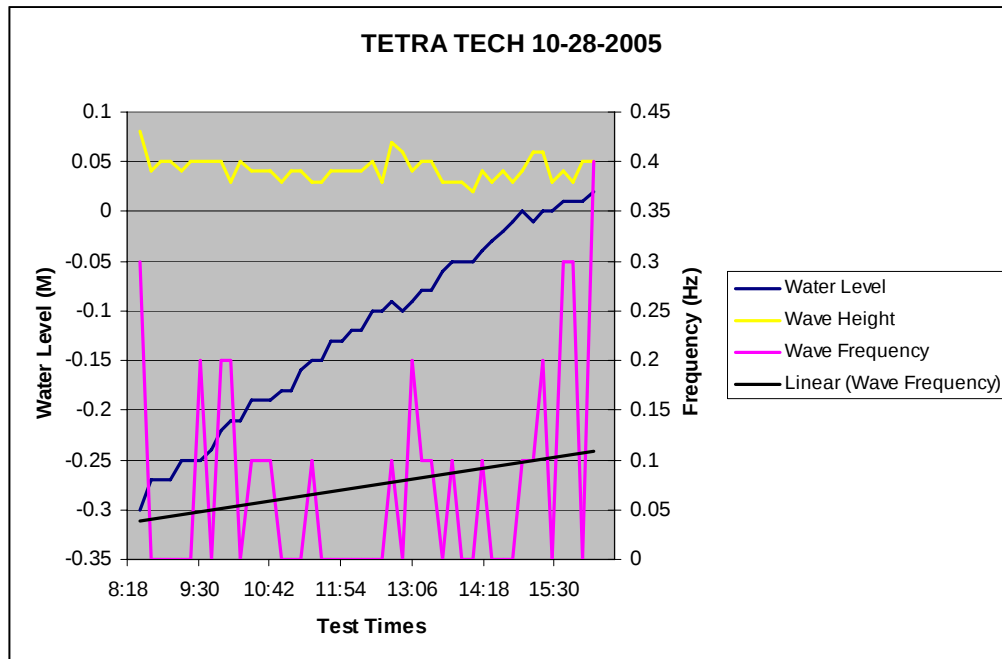


Figure A-5. Water conditions on 28 October 2005.

Water conditions for 29 October 2005 were lost due to an instrumentation malfunction.

| Company: Tetra Tech EC, Inc |      |                                                                                                              | Personnel: Tim Deignan, Adam Maiers, Brian Corbett |            |
|-----------------------------|------|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------|------------|
| Date: 10/24/2005            |      |                                                                                                              |                                                    |            |
| Start                       | Stop | Remarks                                                                                                      | Activity                                           | Chargeable |
| 0840                        | 0850 | Arrived at site. Safety briefing.                                                                            | Safety briefing                                    | 0          |
| 0850                        | 1030 | Walked area, began setup, waited on a truck to arrive with additional equipment.                             | Initial setup                                      | 100        |
| 1030                        | 1345 | Truck arrived, off loaded equipment. Continued setup.                                                        | Initial setup                                      | 195        |
| 1345                        | 1405 | Tested the imaging sonar in the pond.                                                                        | Calibration                                        | 20         |
| 1405                        | 1625 | Returned to the dock, began installing magnetometers.                                                        | Initial setup                                      | 140        |
| 1625                        | 1700 | MAGS installed. Out on the water for reading check. Seemed to follow same path taken during the sonar check. | Calibration                                        | 35         |
| 1700                        | 1800 | Packed up for the day. Left site.                                                                            | Daily close-up                                     | 60         |

| <b>Date: 10/25/2005</b> |             |                                                                                                                                                                                                                            |                    |                   |
|-------------------------|-------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|-------------------|
| <b>Start</b>            | <b>Stop</b> | <b>Remarks</b>                                                                                                                                                                                                             | <b>Activity</b>    | <b>Chargeable</b> |
| 0800                    | 0915        | Arrived at site - bailed rain out of the boat. Currently raining. One cable needs to be changed based on the QC check. Constructed a makeshift shelter from the rain for the equipment and operators.                      | Daily setup        | 75                |
| 0915                    | 0945        | Setup and QC check on background unit.                                                                                                                                                                                     | Calibration        | 30                |
| 0945                    | 1355        | Calibration lane and "quit" area of pond surveyed as part of the QC checks.                                                                                                                                                | Calibration        | 250               |
| 1355                    | 1450        | Break.                                                                                                                                                                                                                     | Lunch              | 45                |
| 1450                    | 1515        | The electric motors had a difficult time with today's wind. Conducted a short test using the facility 6-horsepower outboard motor to see if it produced too much interference for use with this system. The answer is yes. | Downtime equipment | 25                |
| 1515                    | 1615        | Surveyed using the two electric motors.                                                                                                                                                                                    | Survey             | 60                |
| 1615                    | 1700        | Cleaned up. Left site.                                                                                                                                                                                                     | Daily close- up    | 45                |

| Company: Tetra Tech EC, Inc |      |                                                                                                                                                                             | Personnel: Tim Deignan, Adam Maiers, Brian Corbett |            |
|-----------------------------|------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|------------|
| Date: 10/26/2005            |      |                                                                                                                                                                             |                                                    |            |
| Start                       | Stop | Remarks                                                                                                                                                                     | Activity                                           | Chargeable |
| 0800                        | 1000 | Arrived at site/setup.                                                                                                                                                      | Daily setup                                        | 120        |
| 1000                        | 1050 | Taking background readings.                                                                                                                                                 | Calibration                                        | 50         |
| 1050                        | 1145 | Surveyed.                                                                                                                                                                   | Survey                                             | 55         |
| 1145                        | 1315 | Returned to dock. One magnetometer had stopped working. Called GEM Systems technical support - fixed the problem on-site.                                                   | Downtime equipment                                 | 90         |
| 1315                        | 1345 | Resumed survey.                                                                                                                                                             | Survey                                             | 30         |
| 1345                        | 1350 | Same magnetometer stopped working. Reconfigured to survey with 3 instead of 4 magnetometers.                                                                                | Downtime equipment                                 | 5          |
| 1350                        | 1500 | Surveyed.                                                                                                                                                                   | Survey                                             | 70         |
| 1500                        | 1525 | Changed motor batteries. TT will order a 3.3 horsepower gas motor to propel the boat. The two electric motors are insufficient to maneuver the system when there is a wind. | Downtime equipment                                 | 25         |
| 1525                        | 1550 | Surveyed.                                                                                                                                                                   | Survey                                             | 25         |
| 1550                        | 1640 | Cleaned up. Left site.                                                                                                                                                      | Daily close-up                                     | 50         |

| <b>Date: 10/27/2005</b> |             |                                                                                        |                    |                   |
|-------------------------|-------------|----------------------------------------------------------------------------------------|--------------------|-------------------|
| <b>Start</b>            | <b>Stop</b> | <b>Remarks</b>                                                                         | <b>Activity</b>    | <b>Chargeable</b> |
| 0700                    | 0745        | Off site this morning; additional maintenance was performed on potassium magnetometer. | Downtime equipment | 45                |
| 0810                    | 1030        | Arrived at site. Reconfigured for a gas motor.                                         | Daily setup        | 140               |
| 1030                    | 1215        | Surveyed.                                                                              | Survey             | 105               |
| 1215                    | 1315        | Refueled. Other problems - networking.                                                 | Downtime equipment | 60                |
| 1315                    | 1445        | Surveyed.                                                                              | Survey             | 30                |
| 1445                    | 1455        | Refueled.                                                                              | Downtime equipment | 10                |
| 1455                    | 1615        | Surveyed.                                                                              | Survey             | 20                |
| 1615                    | 1700        | Cleaned up. Left site.                                                                 | Daily close-up     | 45                |

| Company: Tetra Tech EC, Inc |      |                                                                                                                                      | Personnel: Tim Deignan, Adam Maiers, Brian Corbett |            |
|-----------------------------|------|--------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------|------------|
| Date: 10/28/2005            |      |                                                                                                                                      |                                                    |            |
| Start                       | Stop | Remarks                                                                                                                              | Activity                                           | Chargeable |
| 0810                        | 0920 | Arrived on site, began setup.                                                                                                        | Daily setup                                        | 70         |
| 0920                        | 1000 | Experimentation: relocated GPS head above magnetometers to see what the signal may look like at different heights. Mounted GPS head. | Calibration                                        | 40         |
| 1000                        | 1015 | “Walk-away” check.                                                                                                                   | Calibration                                        | 15         |
| 1015                        | 1215 | Surveyed.                                                                                                                            | Survey                                             | 120        |
| 1215                        | 1220 | Refueled.                                                                                                                            | Downtime equipment                                 | 5          |
| 1220                        | 1320 | Surveyed.                                                                                                                            | Survey                                             | 60         |
| 1320                        | 1330 | Taking measurements of GPS/MAG configuration for data processing.                                                                    | Calibration                                        | 10         |
| 1330                        | 1530 | Surveyed. Filled in gaps caused by wind during the first days of testing.                                                            | Survey                                             | 120        |
| 1530                        | 1535 | Refueled.                                                                                                                            | Downtime equipment                                 | 5          |
| 1535                        | 1610 | Surveyed.                                                                                                                            | Survey                                             | 35         |
| 1610                        | 1650 | Problem with sensor No. 1 will continue working on it overnight.                                                                     | Downtime equipment                                 | 40         |
| 1650                        | 1730 | Cleaned up. Left site.                                                                                                               | Daily close-up                                     | 40         |

| <b>Date: 10/29/2005</b> |             |                                                                                                                     |                    |                   |
|-------------------------|-------------|---------------------------------------------------------------------------------------------------------------------|--------------------|-------------------|
| <b>Start</b>            | <b>Stop</b> | <b>Remarks</b>                                                                                                      | <b>Activity</b>    | <b>Chargeable</b> |
| 0750                    | 0915        | Arrived on site, began setup. Reconnected MAG that was worked on last night. Can survey without it using 3 sensors. | Daily setup        | 85                |
| 0915                    | 0945        | Sensor checked.                                                                                                     | Calibration        | 30                |
| 0945                    | 1115        | Surveyed.                                                                                                           | Survey             | 90                |
| 1115                    | 1125        | Refueled.                                                                                                           | Downtime equipment | 10                |
| 1125                    | 1345        | Surveyed.                                                                                                           | Survey             | 140               |
| 1345                    | 1355        | Refueled.                                                                                                           | Downtime equipment | 10                |
| 1355                    | 1415        | Surveyed.                                                                                                           | Survey             | 20                |
| 1415                    | 1430        | Reviewed data.                                                                                                      | Calibration        | 15                |
| 1430                    | 1530        | Surveyed. Concentrated on shallow side of the littoral zone. The 2 sonar units were put in the boat.                | Survey             | 60                |
| 1530                    | 1650        | Demobilization. Left site.                                                                                          | Demobilization     | 80                |

## APPENDIX C. TERMS AND DEFINITIONS

### GENERAL DEFINITIONS

**Anomaly:** Location of a system response deemed to warrant further investigation by the demonstrator for consideration as an emplaced ordnance item.

**Detection:** An anomaly location that is within  $R_{\text{halo}}$  of an emplaced ordnance item.

**Munitions and Explosives Of Concern (MEC):** Specific categories of military munitions that may pose unique explosive safety risks, including UXO as defined in 10 USC 101(e)(5), DMM as defined in 10 USC 2710(e)(2) and/or munitions constituents (e.g. TNT, RDX) as defined in 10 USC 2710(e)(3) that are present in high enough concentrations to pose an explosive hazard.

**Emplaced Ordnance:** An ordnance item buried by the government at a specified location in the test site.

**Emplaced Clutter:** A clutter item (i.e., non-ordnance item) buried by the government at a specified location in the test site.

**$R_{\text{halo}}$ :** A pre-determined radius about the periphery of an emplaced item (clutter or ordnance) within which a location identified by the demonstrator as being of interest is considered to be a response from that item. For the purpose of this program, a circular halo 0.5 meters in radius will be placed around the center of the object for all clutter and ordnance items less than 0.6 meters in length. When ordnance items are longer than 0.6 meters, the halo becomes an ellipse where the minor axis remains 1 meter and the major axis is equal to the projected length of the ordnance onto the ground plane plus 1 meter.

**Response Stage Noise Level:** The level that represents the point below which anomalies are not considered detectable. Demonstrators are required to provide the recommended noise level for the Blind Grid test area.

**Discrimination Stage Threshold:** The demonstrator selects the threshold level that they believe provides optimum performance of the system by retaining all detectable ordnance and rejecting the maximum amount of clutter. This level defines the subset of anomalies the demonstrator would recommend digging based on discrimination.

**Binomially Distributed Random Variable:** A random variable of the type which has only two possible outcomes, say success and failure, is repeated for  $n$  independent trials with the probability  $p$  of success and the probability  $1-p$  of failure being the same for each trial. The number of successes  $x$  observed in the  $n$  trials is an estimate of  $p$  and is considered to be a binomially distributed random variable.

## RESPONSE STAGE DEFINITIONS

Response Stage Probability of Detection ( $P_d^{\text{res}}$ ):  $P_d^{\text{res}} = (\text{No. of response-stage detections}) / (\text{No. of emplaced ordnance in the test site})$ .

Response Stage False Positive ( $fp^{\text{res}}$ ): An anomaly location that is within  $R_{\text{halo}}$  of an emplaced clutter item.

Response Stage Probability of False Positive ( $P_{fp}^{\text{res}}$ ):  $P_{fp}^{\text{res}} = (\text{No. of response-stage false positives}) / (\text{No. of emplaced clutter items})$ .

Response Stage Background Alarm: An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open water or littoral scenarios that is outside  $R_{\text{halo}}$  of any emplaced ordnance or emplaced clutter item.

Response Stage Probability of Background Alarm ( $P_{ba}^{\text{res}}$ ): Blind Grid only:  $P_{ba}^{\text{res}} = (\text{No. of response-stage background alarms}) / (\text{No. of empty grid locations})$ .

Response Stage Background Alarm Rate ( $BAR^{\text{res}}$ ): Open water only:  $BAR^{\text{res}} = (\text{No. of response-stage background alarms}) / (\text{arbitrary constant})$ .

Note that the quantities  $P_d^{\text{res}}$ ,  $P_{fp}^{\text{res}}$ ,  $P_{ba}^{\text{res}}$ , and  $BAR^{\text{res}}$  are functions of  $t^{\text{res}}$ , the threshold applied to the response-stage signal strength. These quantities can, therefore, be written as  $P_d^{\text{res}}(t^{\text{res}})$ ,  $P_{fp}^{\text{res}}(t^{\text{res}})$ ,  $P_{ba}^{\text{res}}(t^{\text{res}})$ , and  $BAR^{\text{res}}(t^{\text{res}})$ .

## DISCRIMINATION STAGE DEFINITIONS

Discrimination: The application of a signal processing algorithm or human judgment to response-stage data that discriminates ordnance from clutter. Discrimination should identify anomalies that the demonstrator has high confidence correspond to ordnance, as well as those that the demonstrator has high confidence correspond to non-ordnance or background returns. The former should be ranked with highest priority and the latter with lowest.

Discrimination Stage Probability of Detection ( $P_d^{\text{disc}}$ ):  $P_d^{\text{disc}} = (\text{No. of discrimination-stage detections}) / (\text{No. of emplaced ordnance in the test site})$ .

Discrimination Stage False Positive ( $fp^{\text{disc}}$ ): An anomaly location that is within  $R_{\text{halo}}$  of an emplaced clutter item.

Discrimination Stage Probability of False Positive ( $P_{fp}^{\text{disc}}$ ):  $P_{fp}^{\text{disc}} = (\text{No. of discrimination stage false positives}) / (\text{No. of emplaced clutter items})$ .

Discrimination Stage Background Alarm: An anomaly in a blind grid cell that contains neither emplaced ordnance nor an emplaced clutter item. An anomaly location in the open water or littoral scenarios that is outside  $R_{\text{halo}}$  of any emplaced ordnance or emplaced clutter item.

Discrimination Stage Probability of Background Alarm ( $P_{ba}^{disc}$ ):  $P_{ba}^{disc} = (\text{No. of discrimination-stage background alarms})/(\text{No. of empty grid locations})$ .

Discrimination Stage Background Alarm Rate ( $BAR^{disc}$ ):  $BAR^{disc} = (\text{No. of discrimination-stage background alarms})/(\text{arbitrary constant})$ .

Note that the quantities  $P_d^{disc}$ ,  $P_{fp}^{disc}$ ,  $P_{ba}^{disc}$ , and  $BAR^{disc}$  are functions of  $t^{disc}$ , the threshold applied to the discrimination-stage signal strength. These quantities can, therefore, be written as  $P_d^{disc}(t^{disc})$ ,  $P_{fp}^{disc}(t^{disc})$ ,  $P_{ba}^{disc}(t^{disc})$ , and  $BAR^{disc}(t^{disc})$ .

## RECEIVER-OPERATING CHARACTERISTIC (ROC) CURVES

ROC curves at both the response and discrimination stages can be constructed based on the above definitions. The ROC curves plot the relationship between  $P_d$  versus  $P_{fp}$  and  $P_d$  versus  $BAR$  or  $P_{ba}$  as the threshold applied to the signal strength is varied from its minimum ( $t_{min}$ ) to its maximum ( $t_{max}$ ) value.<sup>1</sup> Figure A-1 shows how  $P_d$  versus  $P_{fp}$  and  $P_d$  versus  $BAR$  are combined into ROC curves. Note that the “res” and “disc” superscripts have been suppressed from all the variables for clarity.

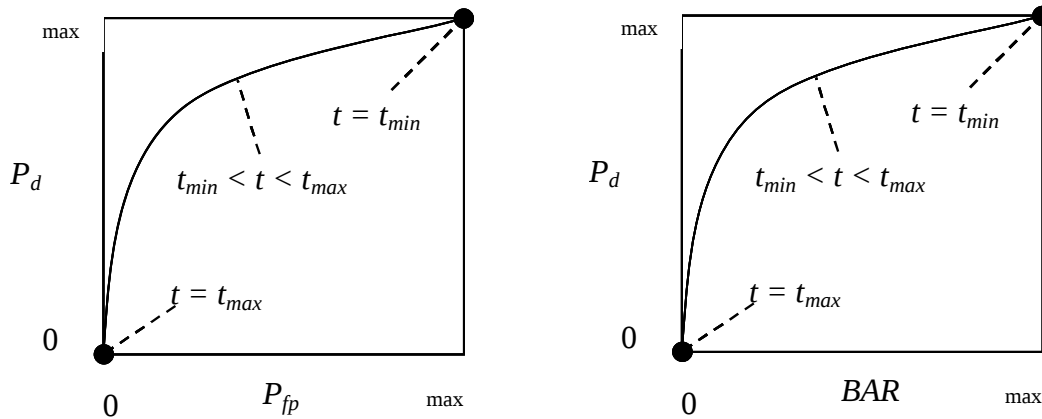


Figure A-1. ROC curves for open-site testing. Each curve applies to both the response and discrimination stages.

<sup>1</sup>Strictly speaking, ROC curves plot the  $P_d$  versus  $P_{ba}$  over a predetermined and fixed number of detection opportunities (some of the opportunities are located over ordnance and others are located over clutter or blank spots). In an Open Water scenario, each system suppresses its signal strength reports until some bare-minimum signal response is received by the system. Consequently, the Open Water ROC curves do not have information from low signal-output locations, and, furthermore, different contractors report their signals over a different set of locations on the ground. These ROC curves are thus not true to the strict definition of ROC curves as defined in textbooks on detection theory. Note, however, that the ROC curves obtained in the Blind Grid test sites are true ROC curves.

## METRICS TO CHARACTERIZE THE DISCRIMINATION STAGE

The demonstrator is also scored on efficiency and rejection ratio, which measure the effectiveness of the discrimination stage processing. The goal of discrimination is to retain the greatest number of ordnance detections from the anomaly list, while rejecting the maximum number of anomalies arising from non-ordnance items. The efficiency measures the amount of detected ordnance retained by the discrimination, while the rejection ratio measures the fraction of false alarms rejected. Both measures are defined relative to the entire response list, i.e., the maximum ordnance detectable by the sensor and its accompanying false positive rate or background alarm rate.

Efficiency (E):  $E = P_d^{disc}(t^{disc})/P_d^{res}(t_{min}^{res})$ : measures (at a threshold of interest), the degree to which the maximum theoretical detection performance of the sensor system (as determined by the response stage  $t_{min}$ ) is preserved after application of discrimination techniques. Efficiency is a number between 0 and 1. An efficiency of 1 implies that all of the ordnance initially detected in the response stage was retained at the specified threshold in the discrimination stage,  $t^{disc}$ .

False Positive Rejection Rate ( $R_{fp}$ ):  $R_{fp} = 1 - [P_{fp}^{disc}(t^{disc})/P_{fp}^{res}(t_{min}^{res})]$ : measures (at a threshold of interest) the degree to which the sensor system's false positive performance is improved over the maximum false positive performance (as determined by the response stage  $t_{min}$ ). The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all emplaced clutter initially detected in the response stage were correctly rejected at the specified threshold in the discrimination stage.

Background Alarm Rejection Rate ( $R_{ba}$ ):

Blind Grid:  $R_{ba} = 1 - [P_{ba}^{disc}(t^{disc})/P_{ba}^{res}(t_{min}^{res})]$

Open water:  $R_{ba} = 1 - [BAR^{disc}(t^{disc})/BAR^{res}(t_{min}^{res})]$

Measures the degree to which the discrimination stage correctly rejects background alarms initially detected in the response stage. The rejection rate is a number between 0 and 1. A rejection rate of 1 implies that all background alarms initially detected in the response stage were rejected at the specified threshold in the discrimination stage.

## CHI-SQUARE COMPARISON EXPLANATION:

The Chi-square test for differences in probabilities (or 2 x 2 contingency table) is used to analyze two samples drawn from two different populations to see if both populations have the same or different proportions of elements in a certain category. More specifically, two random samples are drawn, one from each population, to test the null hypothesis that the probability of event A (some specified event) is the same for both populations (ref 4, pages 144 through 151).

A one-sided 2 x 2 contingency table is used in the Shallow Water Site Program to compare each area (Open Water, Littoral, Deep Water) to the Blind Grid since each area introduces a water feature that makes it potentially more difficult to survey than the Blind Grid. The one-sided 2 x 2 contingency table is used to determine if there is reason to believe that the proportion

of ordnance correctly detected/discriminated by demonstrator X's system is significantly degraded by the more challenging feature introduced. A two-sided 2 x 2 contingency table is used to compare performance between any two of the test sites other than the Blind Grid, to determine if there is reason to believe that the proportion of ordnance correctly detected/discriminated by demonstrator X's system is significantly different between those two test sites.

The test statistic of the 2 x 2 contingency table is the Chi-square distribution with one degree of freedom. For the one-sided test, a significance level of 0.05 is chosen which sets a critical decision limit of 3.84 from the Chi-square distribution with one degree of freedom. It is a critical decision limit because if the test statistic calculated from the data exceeds this value, the two proportions tested will be considered significantly different. If the test statistic calculated from the data is less than this value, the two proportions tested will be considered not significantly different.

An exception must be applied when either a 0 or 100 percent success rate occurs in the sample data. The Chi-square test cannot be used in these instances. Instead, Fischer's Exact Test is used and the critical decision limit is the chosen significance level, which is 0.05 for one-sided tests and 0.10 for two-sided tests. With Fischer's test, if the test statistic (p-value) is less than the critical value, then the null hypothesis of similar performance is rejected in favor of the alternative hypothesis: significantly greater than for the one-sided case or significantly different for the two-sided case.

Shallow-water UXO Detection Test Site examples, where blind grid results are compared to those from the open water and littoral sites and the non-grid sites (open water and littoral) are compared to each other as follows. It should be noted that a significant result does not prove a cause and effect relationship exists between the change in survey area and sensor performance; however, it does serve as a tool to indicate that one data set reflects relatively degraded system performance of a large enough scale than can be accounted for merely by chance or random variation. Note also that a result that is not significant indicates that there is not enough evidence to declare that anything more than chance or random variation within the same population is at work between the two data sets being compared.

Demonstrator X achieves the following overall results after surveying each of the three areas using the same system (results indicate the number of ordnance detected divided by the number of ordnance emplaced):

|                     | Blind Grid    | Open water | Littoral    |
|---------------------|---------------|------------|-------------|
| $P_d^{\text{res}}$  | 100/100 = 1.0 | 8/10 = .80 | 20/33 = .61 |
| $P_d^{\text{disc}}$ | 80/100 = 0.80 | 6/10 = .60 | 8/33 = .24  |

$P_d^{\text{res}}$ : BLIND GRID versus OPEN WATER. Using the example data above to compare probabilities of detection in the response stage, all 100 ordnance out of 100 emplaced ordnance items were detected in the blind grid while 8 ordnance out of 10 emplaced were detected in the open water. Fischer's test must be used since a 100 percent success rate occurs in the data. Fischer's test uses the four input values to calculate a test statistic (p-value) of 0.0075 that is

compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.80) is considered to be significantly less at the 0.05 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and degradation in performance, it does indicate that the detection ability of demonstrator X's system seems to have been degraded in the open water relative to results from the blind grid using the same system.

$P_d^{disc}$ : BLIND GRID versus OPEN WATER. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 emplaced ordnance items were correctly discriminated as ordnance in blind grid testing while 6 out of 10 emplaced ordnance items were correctly discriminated as such in open water testing. Those four values are used in the Chi-square Contingency Test to calculate a test statistic of 1.12. Since the test statistic is less than the critical value of 3.84, the two discrimination stage detection rates are considered to be not significantly different at the 0.05 level of significance.

$P_d^{res}$ : BLIND GRID versus LITTORAL. Using the example data above to compare probabilities of detection in the response stage, 100 out of 100 and 20 out of 33 are used to calculate a test statistic ( $< 0.000$ ) that is compared against the critical value of 0.05. Since the test statistic is less than the critical value, the smaller response stage detection rate (0.61) is considered to be significantly less at the 0.05 level of significance.

$P_d^{disc}$ : BLIND GRID versus LITTORAL. Using the example data above to compare probabilities of detection in the discrimination stage, 80 out of 100 and 8 out of 33 emplaced ordnance items were correctly discriminated as such in open water testing. Those four values are used to calculate a test statistic of 32.01. Since the test statistic is greater than the critical value of 3.84, the smaller discrimination stage detection rate (0.24) is considered to be significantly less at the 0.05 level of significance.

$P_d^{res}$ : OPEN WATER versus LITTORAL. Using the example data above to compare probabilities of detection in the response stage, 8 out of 10 and 20 out of 33 are used to calculate a test statistic of 0.56. Since the test statistic is less than the critical value of 2.71, the two response stage detection rates are considered to be not significantly different at the 0.10 level of significance.

$P_d^{disc}$ : OPEN WATER versus LITTORAL. Using the example data above to compare probabilities of detection in the discrimination stage, 6 out of 10 and 8 out of 33 are used to calculate a test statistic of 2.98. Since the test statistic is greater than the critical value of 2.71, the two discrimination stage detection rates are considered to be significantly different at the 0.10 level of significance. While a significant result does not prove a cause and effect relationship exists between the change in survey area and change in performance, it does indicate that the ability of Demonstrator X to correctly discriminate seems to have been degraded by features of the littoral area relative to results from the open water using the same system.

## APPENDIX D. REFERENCES

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3. *Email*: 6 July 2006, sent from Mr. Timothy Deigan ([timothy.deigan@tteci.com](mailto:timothy.deigan@tteci.com)) to Mr. Gary Rowe ([gary.rowe@atc.army.mil](mailto:gary.rowe@atc.army.mil)) regarding SWDS Scoring.
4. Practical Nonparametric Statistics, W.J. Conover, John Wiley & Sons, 1980, pages 144 through 151.

## APPENDIX E. ABBREVIATIONS

|                 |   |                                                                           |
|-----------------|---|---------------------------------------------------------------------------|
| APG             | = | Aberdeen Proving Ground                                                   |
| ATC             | = | U.S. Army Aberdeen Test Center                                            |
| BAA             | = | Broad Agency Announcement                                                 |
| BAR             | = | background alarm rate                                                     |
| DGPS            | = | Differential Global Positioning System                                    |
| DMM             | = | discarded military munitions                                              |
| EQT             | = | Army Environmental Quality Technology Program                             |
| EQT-ORD         | = | Environmental Quality Technology - Operational Requirements Document      |
| ERDC            | = | U.S. Army Corps of Engineers Engineering, Research and Development Center |
| ESTCP           | = | Environmental Security Technology Certification Program                   |
| GPS             | = | Global Positioning System                                                 |
| HFIS            | = | High Frequency Imaging Sonar                                              |
| LED             | = | light-emitting diode                                                      |
| MEC             | = | munitions and explosives of concern                                       |
| MEDTC           | = | Military Environmental Technology Demonstration Center                    |
| MFSBP           | = | Multiple Frequency Sub-Bottom Profiler                                    |
| MGS             | = | magnetic gradiometer system                                               |
| NMEA            | = | National Marine Electronics Association                                   |
| $P_{ba}$        | = | probability of background alarm rate                                      |
| $P_d$           | = | probability of detection                                                  |
| $P_d^{disc}$    | = | probability of detection, discrimination stage                            |
| $P_d^{res}$     | = | probability of detection, response stage                                  |
| $P_{fp}$        | = | probability of false positive                                             |
| $P_{fp}^{disc}$ | = | probability of false positive, discrimination stage                       |
| $P_{fp}^{res}$  | = | probability of false positive, response stage                             |
| POC             | = | point of contact                                                          |
| QA              | = | quality assurance                                                         |
| QC              | = | quality control                                                           |
| ROC             | = | receiver operating characteristics                                        |
| RTK             | = | real-time kinematic                                                       |
| SERDP           | = | Strategic Environmental Research and Development Program                  |
| USAEC           | = | U.S. Army Environmental Center                                            |
| UXO             | = | unexploded ordnance                                                       |

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