FINAL

US Army Corps of Engineers®

UNDERWATER CHARACTERIZATION INNOVATIVE TECHNOLOGY DEMONSTRATION

PLUM TREE ISLAND, VA

Prepared by
U.S. Army Engineering & Support Center, Huntsville

October 14, 2009

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PLUM TREE ISLAND, VA

_____	__October 14, 2009____
USAESCH – Senior Geophysicist **Kelly Enriquez**	**Date**
_____	__October 14, 2009____
USAESCH –Geophysicist **Elise Goggin**	**Date**
_____	__October 14, 2009____
USAESCH – Geotech Branch Chief **Arthur Dohrman**	**Date**

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1. INTRODUCTION

This report describes the survey performed nearshore of the former Plum Tree Island Bombing Range from 12-19 July 2009.During this survey, data were collected in transects to demonstrate an underwater electromagnetic metal detector and the survey was designed to aid in the proof of technology for the underwater adaptation of the EM61S-MK2. Therefore, the focus of this report will be on the performance of the new technology and the ability to determine geophysical anomaly densities in the study area.

1.1 BACKGROUND

Plum Tree Island is situated on the southwestern corner of the Chesapeake Bay near the City of Poquoson, Virginia. It was owned by the Department of Defense from 1917-1972 and it was used for aerial bombardment and gunnery practice into the late 1950's. In 1972 it was transferred to the United States Fish and Wildlife Service. Today Plum Tree Island is one of four National Wildlife Refuges in the Eastern Virginia Rivers National Wildlife Refuge Complex.

This site was chosen for this project because it provides a shallow marine environment with sandy bottom characteristics that has a high probability of the presence of munitions and explosives of concern (MEC). On shore cleanup efforts, guided by the results of geophysical transects and grids identified a wide variety of MEC and munitions debris (MD), including small arms, 50 pound bombs, five inch rockets and Jet Assisted Take Off (JATO) bottles (Fig. 1). A shoreline sweep for surface items also uncovered 263 JATO bottles, along with occasional bomb and rocket parts.

Figure 1 JATO Bottle

1.2 OBJECTIVES

The primary objective of this project is to demonstrate an effective technology capable of detecting geophysical anomalies that could be associated with military munitions in shallow marine environments, including intact MEC, MD and remnants of targets. A secondary purpose

of this study is to demonstrate the use of Visual Sample Plan (VSP) software as a tool for locating the target based on elevated anomaly densities.

1.3 REPORT ORGANIZATION

This introduction section provides a brief overview of the geophysical survey operation. Section 2 describes the technical aspects of the system with limited details about the various components and subsystems. Section 2 also describes the different components of the data processing and presents a summary of the quality control used during this project. Section 3 presents and discusses the results of the geophysical surveys and highlights the capabilities of Visual Sample Plan (VSP). Conclusions and recommendations are recorded in Section 4.

2. TECHNICAL APPROACH

2.1 OVERVIEW

The geophysical system is comprised of the Geonics EM61S-MK2 coil and electronics fitted into a fiberglass body capable of being towed behind a boat. The EM tow-body (a.k.a. the fish) was collaboratively designed by the U.S. Army Corps of Engineers, Science Applications International Corporation (SAIC) and Brooke Ocean Technology USA. A SeaView digital video camera attached to the top of the tow-body provided real-time underwater footage of the survey line. Waterton Surveying and Engineering was contracted to provide a 21 foot boat to be utilized for the data collection. The boat was equipped with a Trimble GPS system that was used along with HYPACK software for navigation purposes. A Novatel 600 GPS was also set up for synchronization with the geophysical data. Excluding the boat driver, the crew ranged from two to four Army Corps personnel who all worked together to observe the tow system, monitor incoming data and watch the live video stream.

2.2 SITE DESCRIPTION

Figure 2 shows the Virginia coast along with a close-up of Plum Tree Island with the approximate survey boundary indicated in red. The depths in this area range from 3 to 26 feet, with most of the survey area around 5-9 feet. Depths of up to 26 feet are observed in the maintained channel south of Plum Tree Island. Tides in this area are semi-diurnal with a mean tidal range of 2.4 ft. In general, tides had a minimal affect on data acquisition except along the survey lines closest to shore which could not be surveyed during low tide. The sea floor is predominately sand and mud with patches of seaweed. An unobstructed view of the sky in all areas that were surveyed provided adequate GPS satellite coverage during the survey.

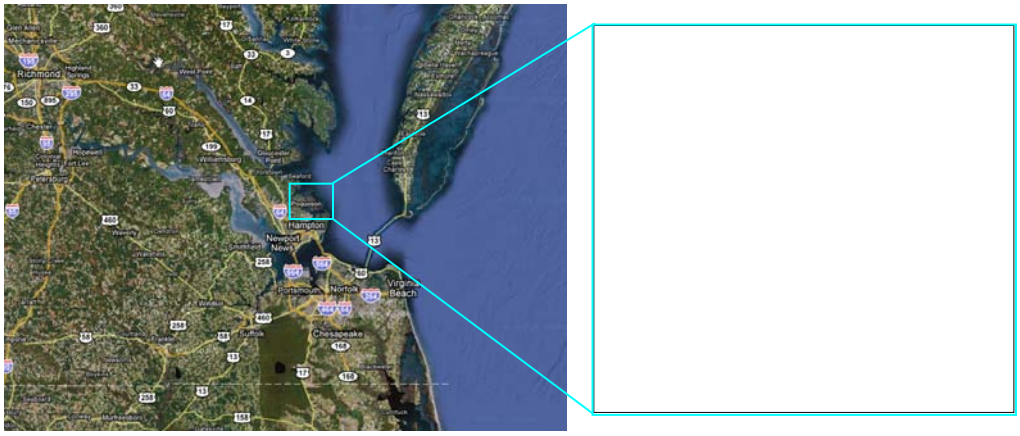

Figure 2 The Virginia coast with a close-up of Plum Tree Island: Survey boundary shown in red extends approx. 1 mile from shoreline

2.3 GEOPHYSICAL DATA COLLECTION METHODS

2.3.1 Side Scan Sonar Data

Side-scan sonar data were collected prior to the survey described in this report. Data were collected by USACE – Norfolk District. Post-processing of the data identified potential obstacles to the EM towbody which were loaded into the boat's HYPACK survey plan. However, many of the obstacles identified in the side-scan sonar data were from crab traps, and the positioning of active traps would often change on a daily basis.

2.3.2 Navigation and Positioning Equipment

The contractor's Trimble GPS system was the primary navigation tool. There were several times when this system failed for unknown reasons, and during these times the boat driver would attempt to maintain a constant heading while the system rebooted. Location information was also being recorded by the Novatel GPS system for synchronization with the digital electromagnetic data. The EM towbody was attached to the boat by approximately 15 meters of rope and cable. Therefore, to account for the spatial difference between the GPS antenna and the coil, the GPS data were offset by 15 meters to estimate the sensor location. The actual offset distance likely varied some, dependent on water depth and offset from the center of the boat due to currents, seas or turns. For this survey, exact positions of anomalies were not critical. Instead, good precision between data points and a positional accuracy of a few meters was considered to be sufficient to meet the project objectives. During processing the GPS data were smoothed, spikes were edited out, and positions were interpolated to fill GPS gaps whenever possible.

2.3.3 Underwater TDEM System

TDEM data were collected using the marine configuration of the Geonics EM61S-MK2 (Fig. 3). The fiberglass housing incorporates a streamlined profile that allows it to be towed through the water column, just above the sea floor. Skids along the sides of the body allow for some contact with the ground. This prototype was designed to be neutrally buoyant and to be towed above the seafloor. However, when the towbody was being pulled by the boat, it became positively buoyant, which also caused it to occasionally flip. After initial difficulties in the field, it was

decided that the best way to maintain a constant acquisition height was to drag the body along the bottom like a sled. A more detailed description of this issue is discussed in section 2.3.6. All data were recorded on a ruggedized laptop using Geometrics MagLog software.

Figure 3 Fiberglass housing for the underwater electromagnetic metal detector.

2.3.4 Underwater Digital Video System

A SeaView Underwater Video Camera was attached to the top of the fish to provide real-time footage of the underwater terrain. The video stream was fed to a portable multimedia center. After extended use, the viewing screen would go black and the device would have to be restarted to regain the visual. It is assumed that this is the result of heat sensitivity. During acquisition it was believed that the video was still recording during these "blackouts," but after reviewing the recordings it was determined that while in most cases it did continue to record, there were several instances where it did not. At this time the only hypothesis to explain these gaps in video data is from inadvertent unplugging of the AC adapter to the video unit. During the time when footage was recorded, video quality varied. This is discussed further in Section 2.5.2.

2.3.5 Boat and Tow System

The 21 foot boat acquired through Waterton Surveying and Engineering adequately met the project needs (Fig 4). However, future deployments will be aided by having a boat with additional features such as cleats, a davit and winch system. Trial and error at the start of the survey resulted in several improvements to aid with towing the fish. A make-shift tow point was created on top of the boat cabin using a two by four and ropes. Several safety precautions were taken and the system was reinforced to ensure that if it failed no one would be hurt. The fish was towed using a bridal connected to the two tow points on the front of the skids. The bridal then connected to a single, 15 meter tow rope that was attached to the tow point. All instrument cables were taped to the tow line every .25 meters to prevent tension on the connectors. The fish

was deployed by slowly lowering it over the edge of the boat and into the water while maintaining tension on the tow-rope to prevent it from flipping over. The task of hauling the fish in manually was difficult, especially after weight was added and on days with increased seas. It took at least two or three people to pull the fish out of the water and onto the boat deck.

Figure 4 A view of the boat captured by the video camera on top of the fish

2.3.6 Problems and Solutions

Problems that arose during data collection and solutions implemented included the following:

- Noise in the data due to the power supply.
  - During the initial day of acquisition it was discovered that the power inverter was creating high frequency noise in the EM data. To eliminate this noise the inverter was removed from the system and power was obtained directly from the 12 volt batteries or, at times, from a power strip connected to a generator. This reduced the noise but did not eliminate it completely.
- Difficulty keeping the fish on or close to the sea floor at reasonable speeds (greater than 1.5 knots).
  - The height of the fish above the sea floor is a critical variable that must be kept to a minimum in order to adequately characterize metallic objects and at a constant height to minimize noise. Several ideas were discussed as means to sink the fish, but the final solution was to fill PVC tubes with lead shot and attach them to the fish as well as the tow cable. Fifteen pounds of lead shot were added to the bottom of the tow fish. Another forty pounds were added to the tow cable approximately 5 meters in front of the towfish tow point. About another fifteen pounds of gravel in a PVC tube were also added to the tow cable. The total amount of weight added was roughly 70 lbs. The added weight allowed the speed to be increased from < 1 knot to between 2 and 3 knots, but it also increased the amount of friction between the fish and the seafloor which lead to extreme erosion of the fiberglass body and skids (Fig. 5). To minimize fiberglass erosion and maintain high production rates, tow speeds between 2 and 2.4 knots were used. During

the final survey day, the wear on the towbody became so great that survey speed was slowed to about 1.5 knots. Design modifications intended to improve the functionality and durability of the body are currently being considered.

Figure 5 Damage to the fish. The center spine and skids took the most abuse but the body was also scratched. A layer of duct tape was added to provide minimal protection.

- Wave or weight induced porpoising of the fish. This resulted in inconsistent survey height and coil alignment which increased noise in the data.
  - This problem was not solved in the field but was greatly reduced by the added weight on the tow cable. However the added weight likely coupled the towfish to the boat, which added noise into the system on days when seas were increased. This phenomenon has been observed during side-scan sonar surveys. The key is to find the minimum weight needed to keep the towfish on the seafloor. Also, the high position of the tow point on the tow fish and the weight on the tow cable pulling the towfish nose in a downward direction likely enhanced its instability. Porpoising is most likely the prominent source of noise in the data. Larger skids, better weight distribution and a skid on the tow cable mounted forward of the towfish to align the cable with the towfish tow points will likely help to reduce the noise and erosion of the fiberglass. Large down-planes on the fish or a deflector wing on the cable may also help solve this issue.
- Tendency of the fish to flip over in the water.
  - Special care had to be taken when deploying the fish so that it would not flip over. This resulted in a waste of time and energy. This problem was addressed by adding weight to the bottom of the towfish skids.

2.4 QUALITY CONTROL

Before data collection began, the sensor was tested to ensure that it could detect metal. The informal test consisted of collecting data with and without metal over the coil. This test was carried out prior to the initial deployment of the fish as well as several times throughout the

duration of the survey. Further QC tests were carried out while data were being collected to ensure that the sensor was still functioning correctly. These tests consisted of throwing a screwdriver or drill bit attached to a rope so that it would pass under the coil while data was being acquired. The crew member monitoring the incoming data stream was responsible for confirming the detection of the metal.

A repeat line was also completed on the first day of the survey along a 1.4 mile line segment. Anomaly counts from the repeat line segments were 35 anomalies/acre and 60 anomalies/acre respectively. This variation is in part due to inability to maintain positioning of both the boat relative to the transect line and the towfish height above the seafloor. On the first day of survey the boat had to maintain lower speeds because weight had not yet been added to the towfish. With lower speeds it was difficult to overcome the effects of waves and currents to keep the cross-track error to a minimum. Also, part of the repeat line segment went through the harbor channel, which reached a depth of up to 24 feet, and was not easily reached by the towfish particularly before weights were added. However, both line segments resulted in an anomaly count well above background.

2.5 DATA PROCESSING

2.5.1 Electromagnetic Data

The digital EM geophysical data were recorded on a field PC and merged with the corrected GPS positioning data using MagMap software. Once the data were merged, Geosoft Oasis Montaj software was used to level data and pick anomalies along profiles. Anomalies were picked individually by comparing the signals of channels 1 through 4. There was no standard threshold value defined for these data sets because the level of noise was extremely high and varied from day to day. Professional judgment was used to assess background and manually select anomalies. Since the purpose of this survey was to detect evidence of areas with concentrated munitions use, all anomalies possibly associated with small pieces of fragments and larger pieces of metal were selected by the geophysical analyst. The signal was considered to be anomalous if its amplitude was distinctly higher than the surrounding noise and it was consistent through all four channels. After the qualified anomalies had been picked, the field notes were reviewed and targets were removed for various reasons. Justification for target removal included snagged crab pots and intentional QC metal detection tests. Data were converted to ESRI shapefile format and additional data analysis was performed in ArcGIS.

2.5.2 Digital Video Recordings

Over 60 hours of digital video footage were recorded on this survey. This footage was not originally scoped in the survey plan, but was added to test the concept and learn how to improve it for future missions. For the purpose of time management not all of the footage was reviewed, and due to a variety of factors a large portion of the footage was unusable. These factors, shown in Figure 6, included low water visibility, vegetation covering the lens, and inappropriate camera angle.

Figure 6 Images show examples different challenges collecting underwater footage. From left to right: low visibility; vegetation covering the lens; camera angled too far down for monitoring to take place at high speeds; camera angled too high and low visibility.

To reduce the amount of time spent observing the usable footage, anomalies were selected from the data profiles and the time stamp was used to localize the footage of interest. This was difficult because the data times were not in sync with the video recording times and the offset was not constant. Field notes were relied on to match video files with the appropriate data. If a crab trap was viewed (Fig. 7) the associated anomalies were removed from the target list.

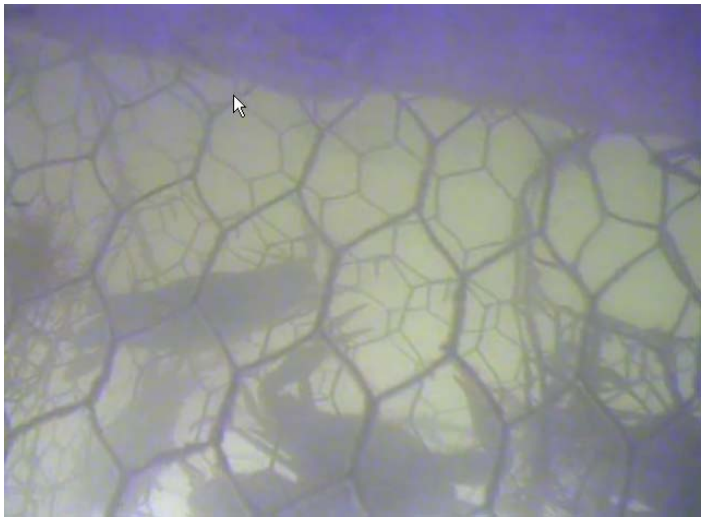

Figure 7 An encounter with a crab trap

2.5.3 Side Scan Data

The USACE processed all side scan data and picked targets of interest. They provided jpeg images of each target and associated metadata including position, length, width, and height. The positions of the targets were plotted along with the anomalies from the EM data in Arc GIS (Fig. 8). In locations where a side scan target was coincident with an EM anomaly, the anomaly was masked where the side scan image showed a crab trap (Fig. 9).

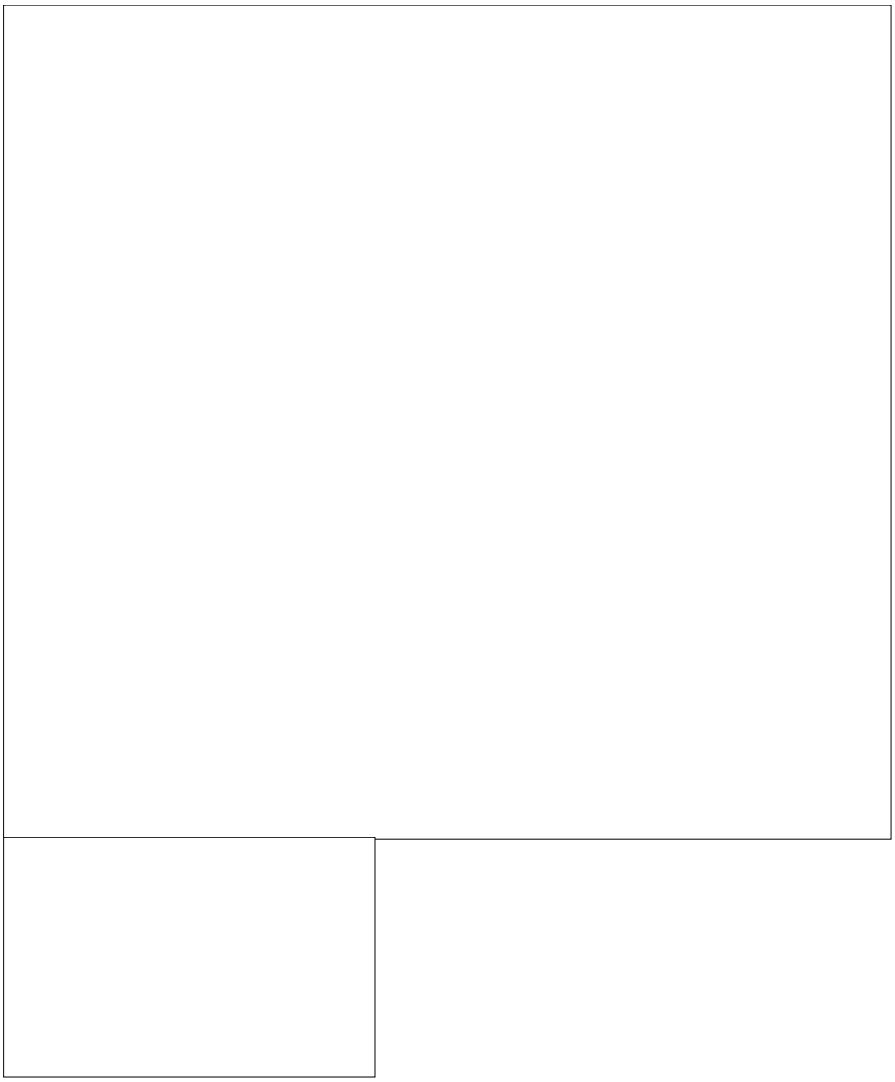

Figure 8 The locations of the final anomaly picks from the EM data as well as the locations of the side scan targets

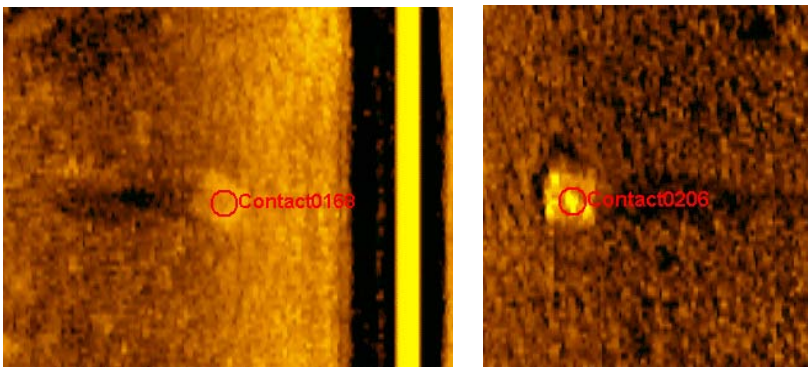

Figure 9 Example side scan images of a crab traps

3. RESULTS

3.1 GIS DATA ANALYSIS

The Arc GIS database for this project contains, among other features, the final anomalies and the transect paths. A contoured anomaly density map can be created using the point density analysis tool from Spatial Analyst. The algorithm determines the anomaly densities by calculating a magnitude per unit area from the anomalies that fall within a given neighborhood around each cell. The user can select the shape and size of the neighborhood to control the generated output. Figure 10 illustrates how anomaly density contours make it easy to highlight the target area of interest within the survey boundaries.

Figure 10 Anomaly density contour map generated in ArcGIS

3.2 VISUAL SAMPLE PLAN (VSP)

VSP is designed to perform statistical and graphical tests of distribution assumptions and provide a visual interface that can be utilized by a non-statistician. This software can aid in both the planning and analysis phases of a project. In this study VSP was used to assess the probability of traversing a target based on actual transect lines, and locate target areas based on elevated anomaly density.

3.2.1 Target Selection Based on Elevated Anomaly Density

VSP uses a process similar to that of the Spatial Analyst Tool in Arc GIS. A circular search window identifies areas where the anomaly density is significantly greater than the designated background density. To do this it requires the following user inputs (colors refer to Figure 12):

- A shape file of the Survey area = Light blue
- XY Transect data and width covered by the transect = Red lines, 1 meter width
- XY anomaly data = Blue crosses (The anomaly data used for this analysis has had all anomalies determined to be associated with crab traps removed.)
- Assumed background anomaly density = 10 anomalies/acre
    - An explanation as to why this value is so much higher than the density values reported in the GIS model will follow.
- Window size = 300 to 500 meters
    - The window size was chosen based on experimenting with different values and selecting the most appropriate. Larger window size may provide less defined targets, but it is also is less susceptible to being skewed by outliers.

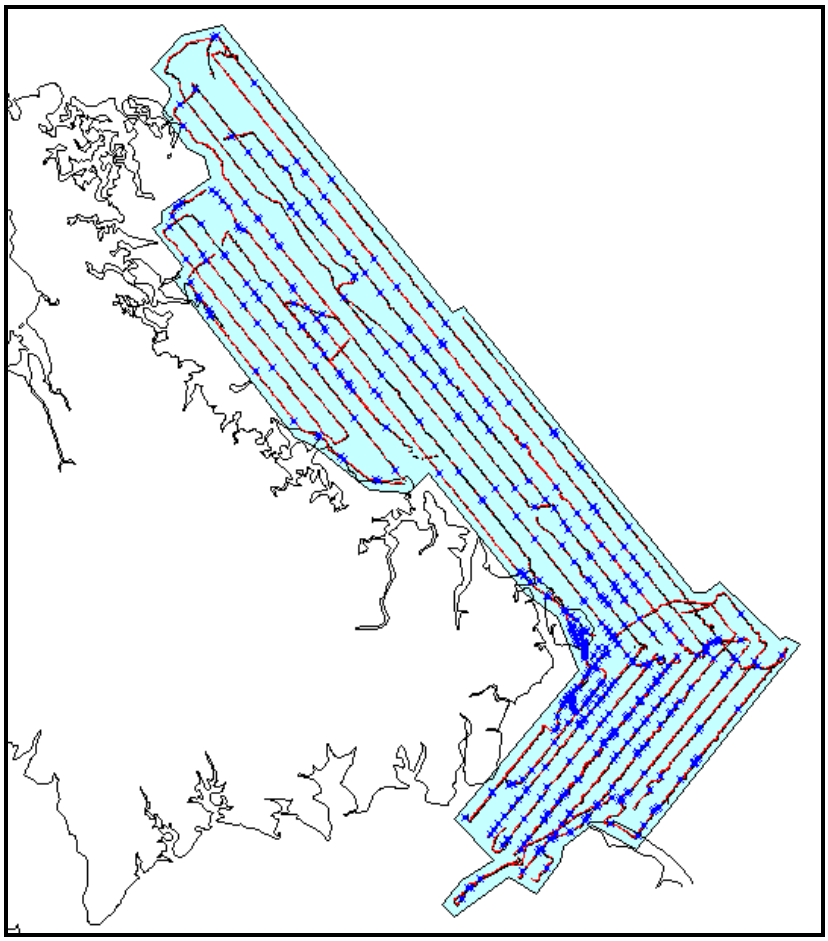

Figure 12 Survey area with transects (red) and final anomalies (blue) plotted in VSP.

The searching window moves in increments of 1/6 its diameter along the transect lines and the anomaly density is evaluated in each window. Figure 13 shows the results of using a 300, 400 and 500 meter window for this analysis. VSP also generates a histogram to show the frequency of the various densities (Fig. 14). This helps to justify the initial background anomaly hypothesis.

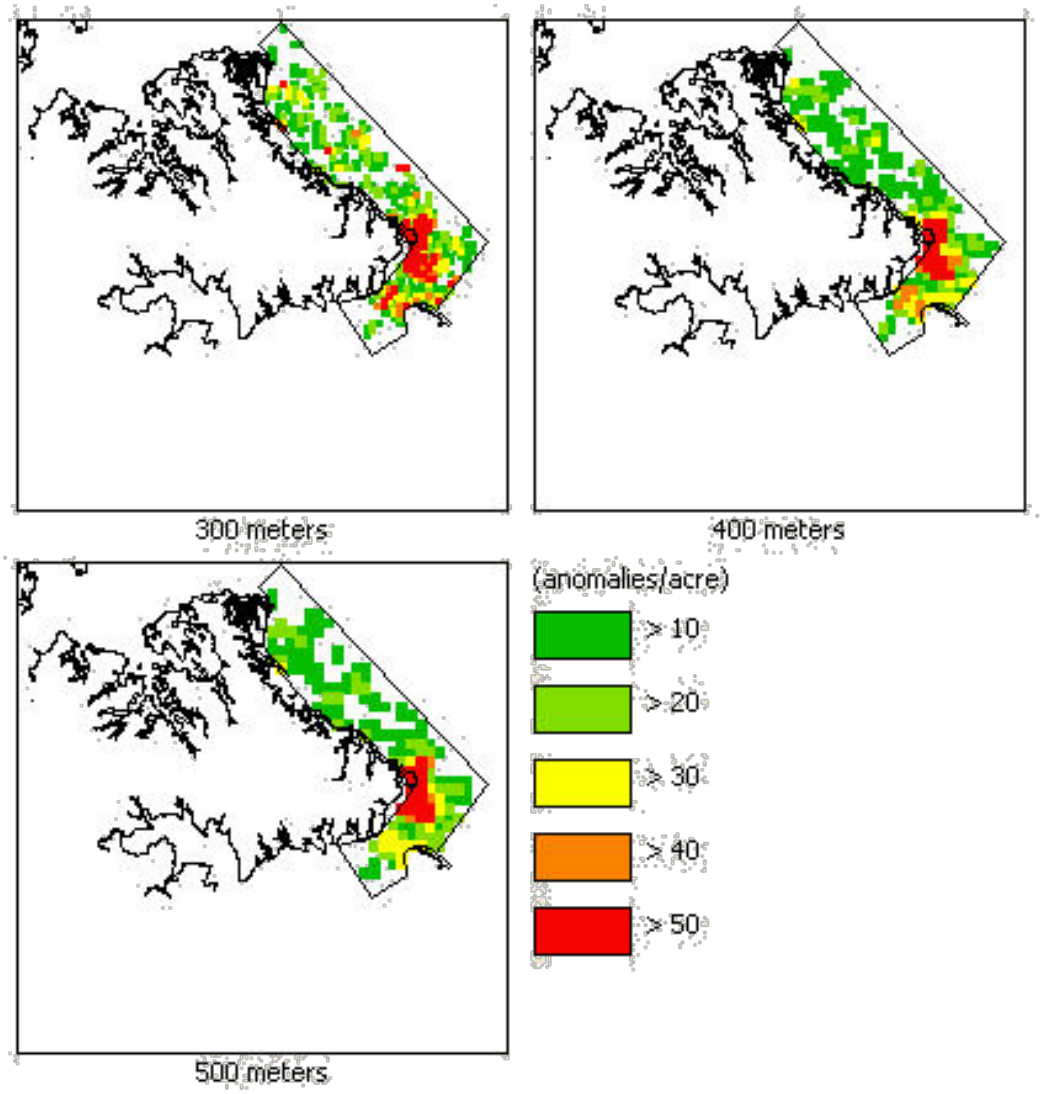

Figure 13 Anomaly density analysis using three different window sizes ranging from 300 to 500 meters

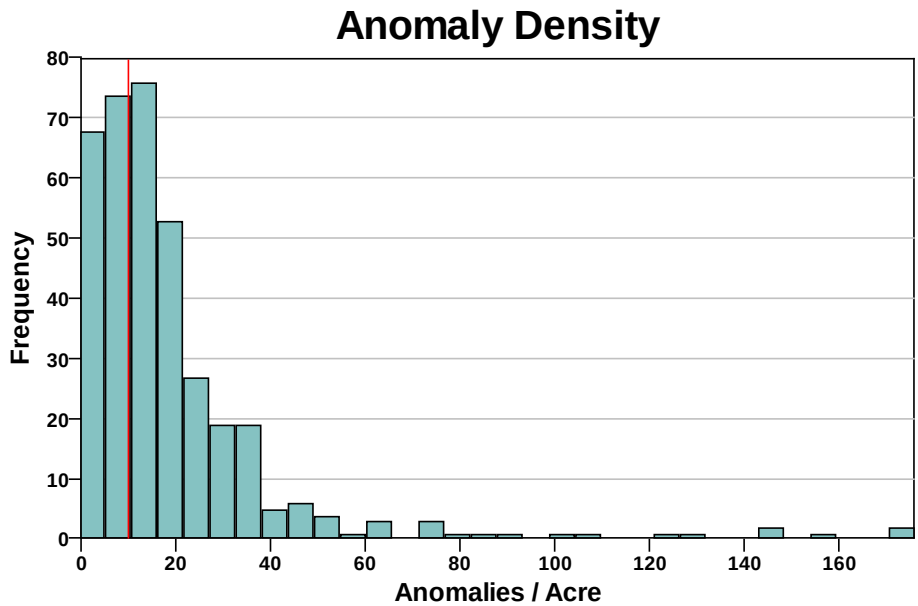

Figure 14 Histogram shows the frequencies for various anomaly densities within the survey area. The red line indicates the chosen background density of 10 anomalies/acre.

3.2.2 Overall Statistics

Table 1 lists the overall statistics calculated by VSP. The anomaly density is generated using the transect area and the total potential anomalies are calculated by applying this density to the total survey area.

Total Survey Area:	4308.75 Acres
Transect Area:	26.66 Acres
Detected Anomalies in Transect Area:	522
Average Anomaly Density (Survey):	20.70 /Acre
Total Potential Anomalies (Survey):	89206

Table 1 Survey Statistics generated in VSP

3.3 GIS/VSP COMPARISON

From section 3.2 it is evident that the anomaly densities calculated in ArcGIS and VSP differ by at least an order of magnitude. The densities generated by the Spatial Analyst Tool range from 0.22 anomalies per acre to greater than 1.4 anomalies per acre while those generated in VSP fall in the range of 10 anomalies per acre to greater than 50 anomalies per acre. The main reason for

this discrepancy is the way in which the survey areas are dealt with in the respective algorithms. The Spatial Analyst Tool assumes 100% coverage for the survey area, meaning that it does not take into account that data were only collected on the specified transects. VSP on the other hand calculates the densities based only on the area covered by the transect lines and then extrapolates this value to predict the total number of anomalies for the entire survey area (See 3.2.3). Applying a factor of 161.66 to the ArcGIS density data, which is the ratio of the transect area to the overall survey area, helps mitigate the difference between ArcGIS and VSP results. After applying the survey area factor, values from the ArcGIS density analysis ranged from 0 to 215 anomalies/acre.

While the values generated by the two software packages varied, the general shape of the density regions did not. Figure 15 shows a side-by-side comparison of the density analysis created in each program. The similarities seen here increase the confidence in both algorithms' ability to detect elevated anomaly levels.

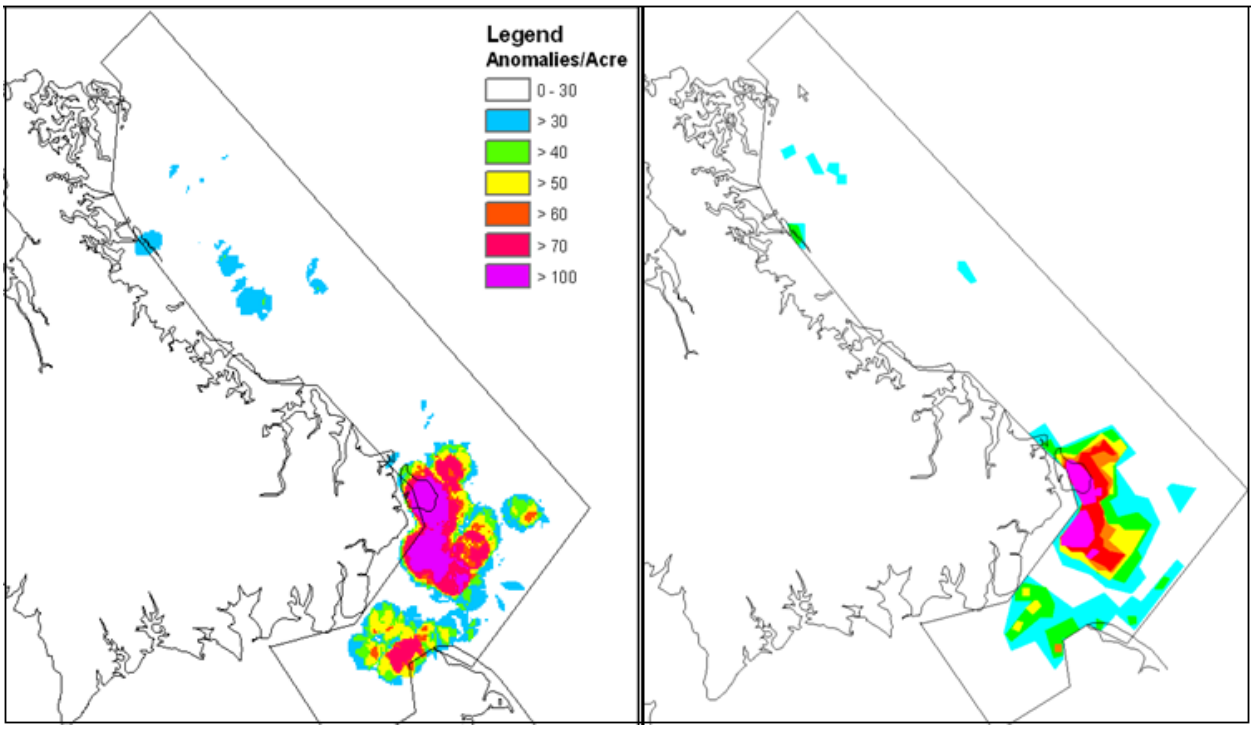

Figure 15 Comparison of the anomaly density contours produced using the Spatial Analyst Tools in ArcGIS (left) and the target detection tools in VSP (right). Note that the color scale is the same for both images.

3.4 VISUAL SUPPORT OF MEC PRESENCE

After reviewing the film and the side scan images, no MEC or MD can be positively identified. Figures 16 and 17 show examples from each media that could possibly be either MEC or MD. All of the side scan contacts in Figure 16 were located near an anomaly in the electromagnetic data. As mentioned in Section 2.5.2 there were difficulties with matching the time stamps between the video and the geophysical data so it cannot be concluded if the items in Figure 17

are associated with the geophysical anomalies. There is no way to verify that these items are MEC or MD other than retrieval.

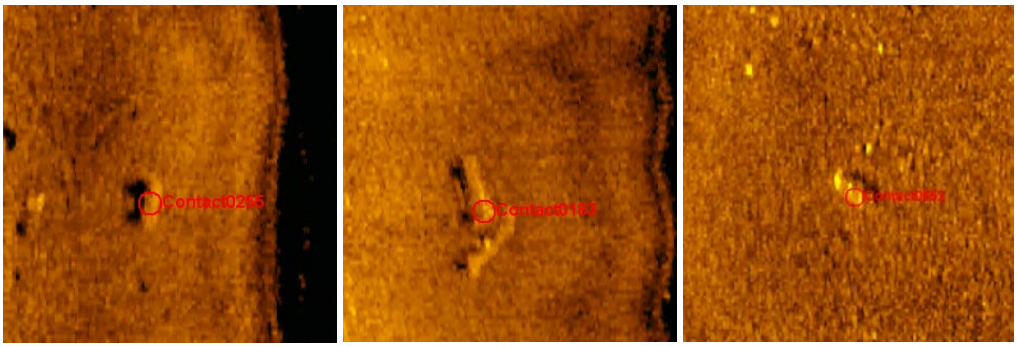

Figure 16 Side scan images of possible MEC or MD

Figure 17 Items seen in the underwater video footage. Note that the two images are not at the same scale.

Figure 18 Possible MEC/MD locations comprised of the final EM anomalies and the side scan contacts. All anomalies determined to be associated with crab traps have been removed and all side scan targets associated with crab traps and pier pilings have been removed.

3.5 COMPARISON TO LAND SURVEY

During land and beach munitions response surveys throughout the former Plum Tree Island Bombing Range a significant number of JATO bottles (Fig. 1) were found. Many of these bottles are located in the vicinity of the presumed nearshore target area based on VSP analysis of marine geophysical data (Fig. 19). Additionally, results from digs along several land-based transects show small clusters that are within a mile of other potential target areas based on VSP analysis (Fig. 20).

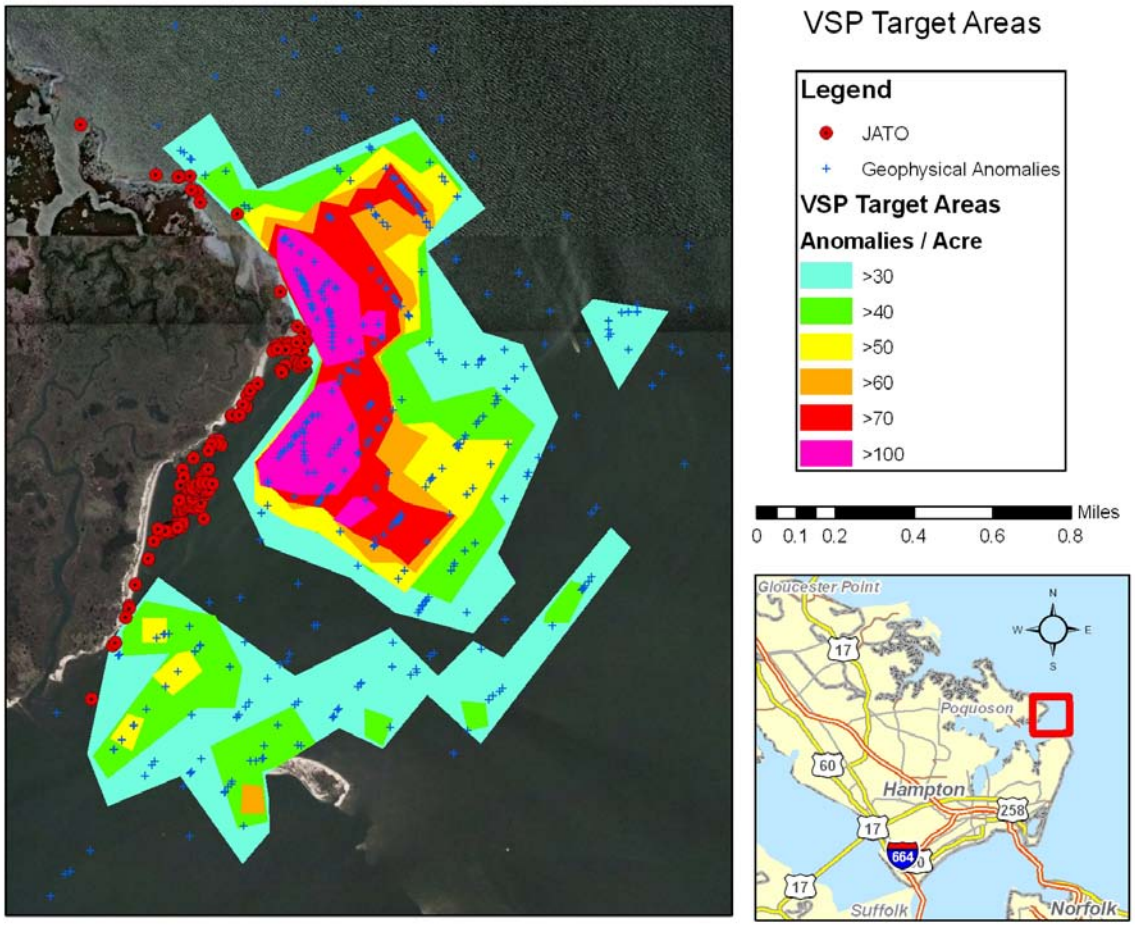

Figure 19 Location of JATO bottles relative to VSP target areas

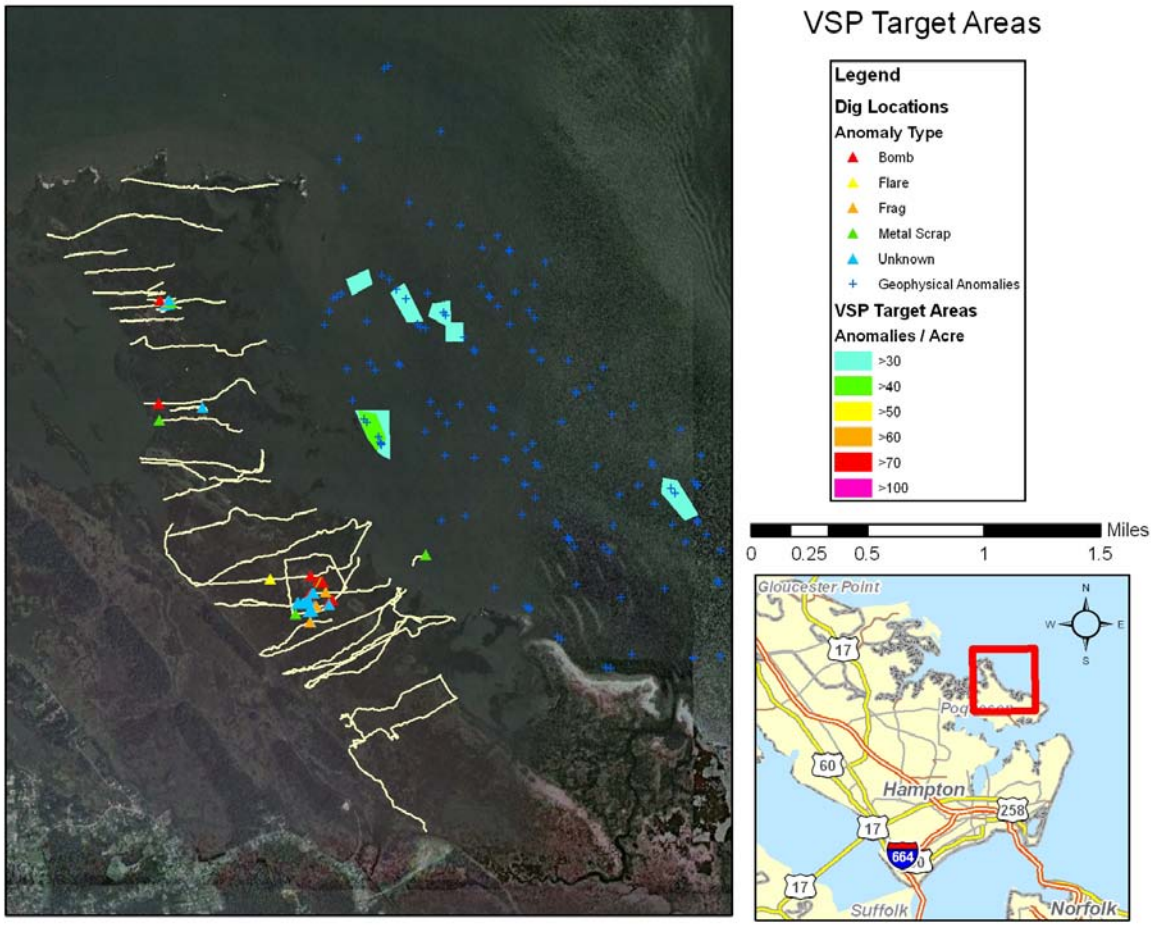

Figure 20 Land-based dig results relative to VSP target areas

4. CONCLUSIONS AND RECOMENDATIONS

Overall, the objectives of this survey have been met. The quality control metal detection test discussed in Section 2.4 is the primary evidence that the underwater electromagnetic equipment was able to detect metal. The coherent nature of the anomaly density maps also supports the notion that metal was being successfully detected.

As for the second objective, Sections 3.2 and 3.3 clearly illustrate the abilities of VSP to locate areas of interest based on elevated anomaly densities. The tools in VSP are preferable to those in ArcGIS because they account for the limited area covered by transects, however this can be mitigated in ArcGIS by factoring in the actual area surveyed. VSP was also able to increase the confidence in the coverage by verifying that the transects used in the Plum Tree Island survey would most likely be able to detect a circular target with a 100 meter radius.

4.1 Recommendations

While the Plum Tree Island Project proof of technology was a success, there is always room for improvement. To reduce the amount of time spent on data collection the problems stated in Section 2.3.6 should be addressed. For instance, to address issues such as porpoising and wear encountered from towing the system on the seafloor it may be necessary to reengage with the design team. Another improvement would be to redesign the tow strategy with a portable winch/tow system that can be utilized on a variety of watercraft or take special care to confirm that the acquisition boat is sufficiently equipped to lift and tow heavy equipment. Also, the combination of the underwater camera angle and the speed of the boat need to be adjusted in order to increase the amount of usable footage. Time-syncing the video record with the geophysical data would also be a useful improvement. Furthermore, time should be taken prior to field work to test all systems. In this study highly accurate positioning was not a priority. However, if future projects have an objective to match specific side-scan targets to geophysical anomalies, higher positional accuracy will be needed.

Another recommendation to aid in the characterization of the nearshore Plum Tree Island area would be to further investigate the areas circled in red in Figure 19. These areas are above the background density, but they are not clearly defined target regions. To better resolve the nature of these features it is recommended that the area is either covered by tighter transects to determine if a smaller target might be present or otherwise investigated (e.g. via ROV, diver or dredging) to determine if the elevated anomaly count is due to MEC/MD.

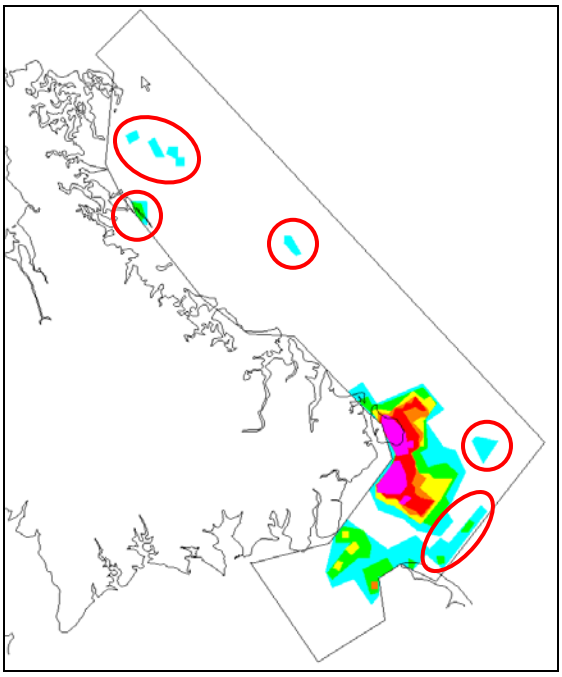

Figure 19 Areas recommended for further investigation