



NRL/MR/6110--02-8640

MTADS Geophysical Survey of Potential Burial Pits Along the C&O Canal in Washington, DC

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September 30, 2002

20021015 014

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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1. REPORT DATE (DD-MM-YYYY) September 30, 2002		2. REPORT TYPE Final Report		3. DATES COVERED (From - To) February 2000-June 2002	
4. TITLE AND SUBTITLE MTADS Geophysical Survey of Potential Burial Pits Along the C&O Canal in Washington, DC				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Herbert H. Nelson, Daniel A. Steinhurst,* and Nagi Khadr†				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER 61-5802-02	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, Code 6110 4555 Overlook Avenue, SW Washington, DC 20375-5320				8. PERFORMING ORGANIZATION REPORT NUMBER NRL/MR/6110--02-8640	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Center for Urban Ecology National Park Service 4598 MacArthur Blvd., NW Washington, DC 20007				10. SPONSOR / MONITOR'S ACRONYM(S) National Park Service	
				11. SPONSOR / MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES *Nova Research, Inc., Alexandria, VA 22308 †AETC, Inc., Arlington, VA 22202					
14. ABSTRACT The Chemistry Division of the Naval Research Laboratory has performed geophysical surveys on three areas adjacent to the C&O Canal towpath near the Chain Bridge in Northwest Washington, DC to characterize the extent and source of a series of magnetic anomalies discovered by personnel from the DC Department of Health. The magnetometer survey results lend themselves to two observations. First, there is no evidence of a series of 14 regularly spaced burial pits as suggested by the anecdotal reports. We have identified, however, 30 magnetic anomalies in and adjacent to the survey site. Many of the anomalies have been identified with ferrous metal objects visible on the surface or arise from shallow trash and scrap. There are eight anomalies that appear to arise from relatively large ferrous metal objects buried at depths greater than 6 to 8 feet. These remaining anomalies may require further investigation.					
15. SUBJECT TERMS Multi-sensor Towed Array Detection System (MTADS); Magnetic Anomaly; Unexploded ordnance (USO)					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Herbert H. Nelson
Unclassified	Unclassified	Unclassified	UL	21	19b. TELEPHONE NUMBER (include area code) (202) 767-3686

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MTADS GEOPHYSICAL SURVEY OF POTENTIAL BURIAL PITS ALONG THE C&O CANAL IN WASHINGTON, DC

INTRODUCTION

During World War I, the American University Experiment Station, located in what is now the Spring Valley neighborhood of Washington, DC, was used by the U.S. Government for research and testing of chemical agents, equipment, and munitions. Several caches of weapons and residual chemicals have been discovered in the Spring Valley area over the last ten years.¹ At war's end, as the Experiment Station was closing down operations, there were considerable quantities of chemical munitions remaining in the inventory. The details of the disposal or destruction of these munitions have never been determined.

In 1993, at the time of the first US Army response to a discovery of buried munitions at Spring Valley, the District of Columbia's Mayor's Office received a call from an individual reporting that, while he was in the Civilian Conservation Corps in the mid 1930's, he was involved in the disposal of chemical munitions, including French 75-mm mustard rounds, in a series of pits dug by steam shovel in the Spring Valley area. It has been speculated that these pits may have been the fate of the Experiment Station chemical munitions. Acting on this anecdotal evidence, personnel from the DC Department of Health initiated a search for likely locations of these pits. Attention quickly centered on the C&O Canal towpath area for several reasons. There are aerial photographs from 1937 that show a cleared strip near the Canal and the Park Service has a contemporaneous photograph showing a rail-borne steam shovel on a railroad bridge over the Canal. The Canal itself was dormant from 1924 to 1937 before being transferred to the National Park Service in 1938.¹

Guided by the evidence discussed above, DC Department of Health personnel searched the towpath area for evidence of buried ferrous metal using a hand-held magnetometer system. They identified a number of possible targets just off the towpath within 1500 feet of the Chain Bridge both north and south of the bridge. Based on the proximity of these targets to the Spring Valley area and the railroad bridge mentioned above, they designated this area as a possible location of the series of burial pits. With the equipment at their disposal, however, they were not able to classify these targets as arising from deeply buried ferrous metal as opposed to a collection of near-surface trash and scrap. This information was communicated to the US Environmental Protection Agency and the National Park Service.

The Chemistry Division of the Naval Research Laboratory (NRL) has developed the Multi-sensor Towed Array Detection System (*MTADS*) for the underground imaging of metallic objects with particular emphasis on Unexploded Ordnance (UXO). The system has been demonstrated at a number of prepared and live ordnance ranges to assess its cost and performance relative to the existing, manual methods of UXO detection and location.^{3,4} We have also demonstrated the system on the Jamaica Island and Topeka Pier Landfills at the Portsmouth Naval Shipyard in Kittery, Maine.⁵ For environments that are not conducive to vehicular surveys, we have developed a man-portable adjunct to the *MTADS*.⁶

Because of the unique capabilities of the *MTADS*, the EPA recommended and the National Park Service requested that NRL perform a geophysical survey of land adjacent to the towpath just above and below the Chain Bridge to map the extent of these anomalies and estimate their depth and positions. This report conveys the results of that survey.

MTADS TECHNOLOGY DESCRIPTION

Field Hardware

The vehicular *MTADS* technology has been described in detail previously.^{5,6} Briefly, the system consists of a low-magnetic-signature vehicle that is used to tow linear arrays of magnetometers and pulsed-induction sensors to conduct surveys of large areas to detect buried UXO. The *MTADS* tow vehicle, manufactured by Chenoweth Racing Vehicles, is a custom-built off-road vehicle, specifically modified to have an extremely low magnetic signature. Most ferrous components have been removed from the body, drive train and engine and replaced with non-ferrous alloys.

In order to collect high-quality field data in areas not amenable to vehicular surveys, NRL has also developed a pair of man-portable adjuncts to the *MTADS*. The man-portable magnetometer system, Figure 1, is designed to collect data equivalent to that collected by the vehicular system. As in the original *MTADS*, the sensors, Cesium-vapor full-field magnetometers (Geometrics Model 858), are spaced 25 cm apart and are held 25 cm off the ground. The magnetometer cart is constructed of a combination of fiberglass and plastic components with the two wheels placed side-by-side between the sensors. This design is effective on rugged and uneven terrain. Not shown in Figure 1 is an optional hood that can be placed over the magnetometers and GPS antenna for situations where grass or low brush can snag the sensors. The magnetometer cart weighs 38 lbs. without the hood and 52 lbs. with it. The operator's backpack, which contains the GPS receiver, radio, and system batteries, weighs 18 lbs.

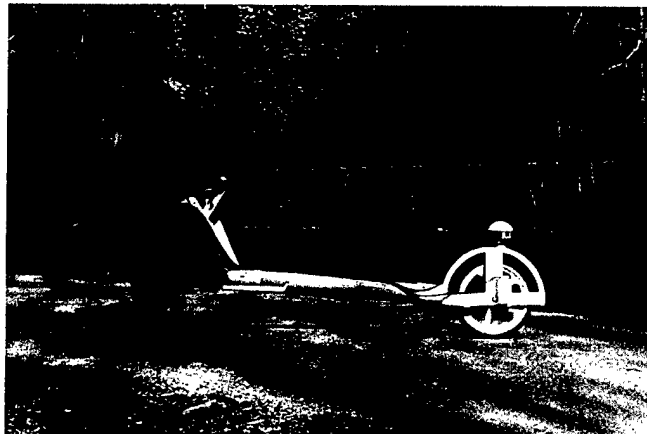


Fig. 1 – *MTADS* man-portable magnetometer system deployed on the C&O Canal towpath

Sensor and location data are logged in a modified Geometrics G858 data recorder. We have had this unit modified by the manufacturer to better suit our survey requirements. These modifications include an increase in system timing precision of more than a factor of 10, incorporation of two additional serial ports for logging of additional location strings and the 1 PPS sync pulse from the GPS receiver, and display of the GPS fix quality on the logger screen in real time. With these modifications, the data collected by the man-portable system is indistinguishable from vehicular data.

In the baseline *MTADS* the sensor positions are measured in real-time (5 Hz) using the latest Real Time Kinematic (RTK) Global Positioning System (GPS) technology which results in position accuracies

of ~5 cm. We have available several other navigation and location systems for use when the sky view is limited and cm-level GPS is not possible. These include meter-level Differential GPS (DGPS) and an acoustic system manufactured by ChemRad. In this survey, there was sufficient sky view for DGPS. In preparation for the survey, the location accuracy of the DGPS system was tested in an open field and at the C&O Canal site. Measured system accuracy ranged from ~1/3 m in the open field to ~3/4 m under the tree cover at the canal. All navigation and sensor data are time-stamped with Universal Coordinated Time (UTC) derived from the satellite clocks and recorded by the data logger. The sensor, position, and timing files are downloaded periodically throughout a survey into a notebook computer and transferred to the Data Analysis System (DAS) for analysis.

Data Analysis System

The *MTADS* Data Analysis System converts the sensor and position data files into an anomaly map by interpolating the individual sensor readings using the GPS-derived positions. The DAS software was developed specifically for the *MTADS* program as a stand-alone suite of programs. PC-based code is now available and was used for this operation. The DAS is written for use by both sophisticated and novice users. Even the novice can perform a complete anomaly analysis using menu-driven tools and default settings. For the advanced user, there is an extensive range of options available including navigation data cleanup, sensor nulling and leveling, noise filtering, etc. The working screen of the DAS is shown in Figure 2.

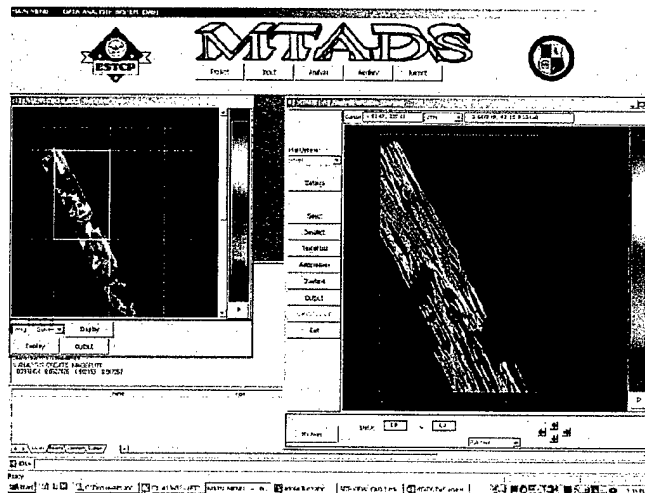


Fig. 2 – Working screen of the *MTADS* Data Analysis System showing analysis of magnetometer data from this survey

In the case of isolated ordnance targets in the far field (i.e. farther from the sensors than their characteristic dimension) the DAS employs physics-based models to determine target size, position, and depth.⁷ Extensive data sets have been acquired and processed to calibrate these models. These analysis capabilities are not applicable however to large, shallow targets such as underground storage tanks or extended collections of overlapping small targets that might be found in a landfill. In these cases, anomaly maps are simply used to estimate the position and extent of the anomaly and no attempt is made to completely characterize the underlying target, which gives rise to the anomaly in the geomagnetic field.

MTADS FIELD OPERATIONS

Survey Navigation Control

The *MTADS* sensor location system relies on differential corrections radioed from a GPS receiver at a known (first order, if possible) base station to the survey system for its accuracy. Generally, these reference positions are established by a commercial surveyor prior to the *MTADS* survey. For this survey, GeoMetrics GPS, Inc., a survey firm in Fredericksburg, VA visited the C&O Canal near Chain Bridge on December 7th, 2001 to establish control for the *MTADS* surveys. Two semi-permanent survey markers were installed by GeoMetrics GPS, Inc. The coordinates of these control points are listed in Table 1.

Table 1 – Control Points Used For the *MTADS* Geophysical Surveys

Station	Latitude	Longitude	Ellipsoidal Height
GPS 1	38° 55' 44.02510" N	77° 06' 41.64864" W	-20.218 m
GPS 2	38° 55' 52.33232" N	77° 06' 46.58378" W	-20.266 m

Mobilization and Survey Set-Up

The *MTADS* man-portable magnetometer system, reference magnetometer, field equipment, GPS base station, and data analysis computers were mobilized to the C&O Canal near the Chain Bridge on Monday morning, February 25th, 2002 in a rented van. This van was used to store the equipment overnight, charge the batteries for the next day's survey, and as office space for the data analyst.

Several tasks had to be accomplished before survey activity could begin. Two of these tasks were system related and one was site related. As mentioned above, the *MTADS* sensors were located using DGPS, using corrections radioed from a base station, during this survey. All surveys in this report were conducted using point GPS 2 for the reference point. The GPS base station and radio are shown located on this point in Figure 3. Magnetometer survey data are corrected for the diurnal variation in the earth's

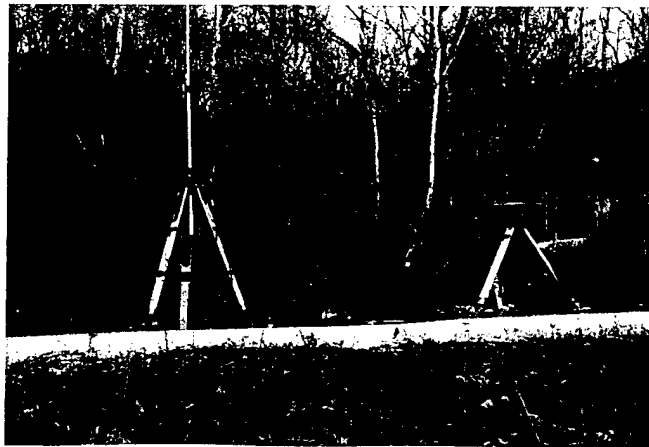


Fig. 3 – GPS base station and radio on point GPS 2

field through the use of a reference magnetometer. This magnetometer is located in a remote site, far from interferences and monitors variations over time in the earth's magnetic field. The reference magnetometer is shown in use during this survey in Figure 4.



Fig. 4 – Diurnal reference magnetometer positioned near the Potomac River just upstream of the Chain Bridge

The boundaries of the area to be surveyed by the *MTADS* system were agreed upon by Park Service, US EPA, and District of Columbia Department of Health personnel. Based on this agreement, the Park Service marked the survey area with plastic flagging and contracted to have all brush smaller than 1-in diameter cut to facilitate the conduct of the survey. The clearance contractor did not remove the cut brush from the marked survey area. Prior to surveying each portion of the site, Park Service maintenance workers and Project Manager, *MTADS* team members, and other observers of the survey operations cleared the survey area of brush, Figure 5.

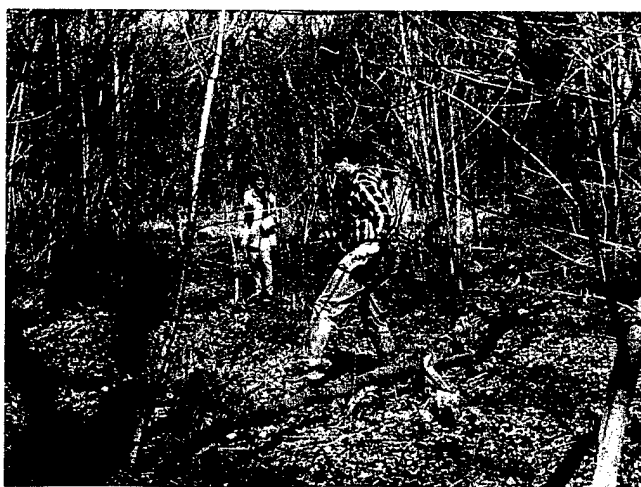


Fig. 5 - Brush being cleared from the survey area prior to the survey

Survey Operations

The initial, total coverage of the site was accomplished by a series of parallel survey traverses over the site. Wooden stakes were used to define 2-m lanes across the 60-foot dimension of the site and string was used to define the lane for its length. The two-sensor array was pushed over each lane boundary and in the middle of each lane. Survey speed is approximately 1 to 1.5 m/s giving a down-track sampling interval of 10 to 15 cm. Survey coverage using this method is illustrated in Figure 6. The line spacing

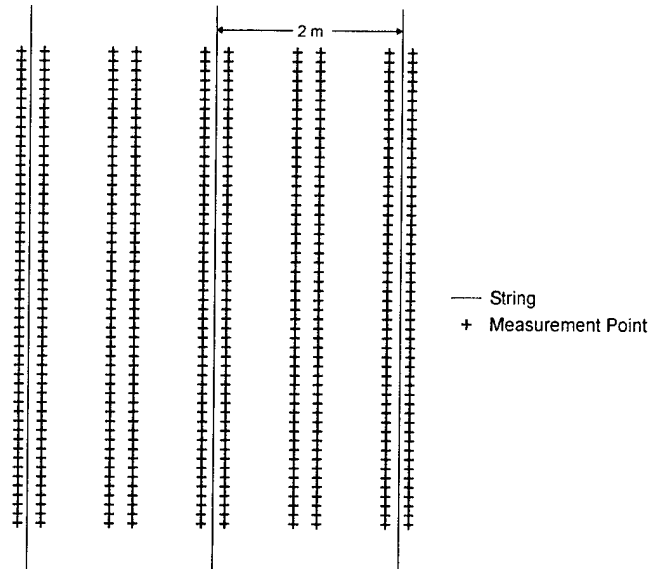


Fig. 6 – Schematic of measurement positions during the initial survey of the towpath area

employed here is somewhat larger than would be used in a standard UXO survey in an open field. The spacing used is justified, however, by the reduced precision of the GPS locations under the trees and the size of the anticipated targets. The actual lane spacing achieved was limited by the density of trees, Figure 7, but coverage was sufficient for our purposes throughout the site.



Fig. 7 – Initial survey at the C&O Canal

After analyzing the data from the initial survey, we determined that several candidate targets were not covered in sufficient detail to accurately characterize them. The choice of these anomalies was guided by simple modeling efforts, as outlined in the following section. We returned to the site on Thursday, March 28, 2002 to conduct a more finely-sampled, gridded survey of those areas. The procedure for these measurements involved laying out a 5- by 5-m or 6- by 8-m grid using wooden stakes and strings.

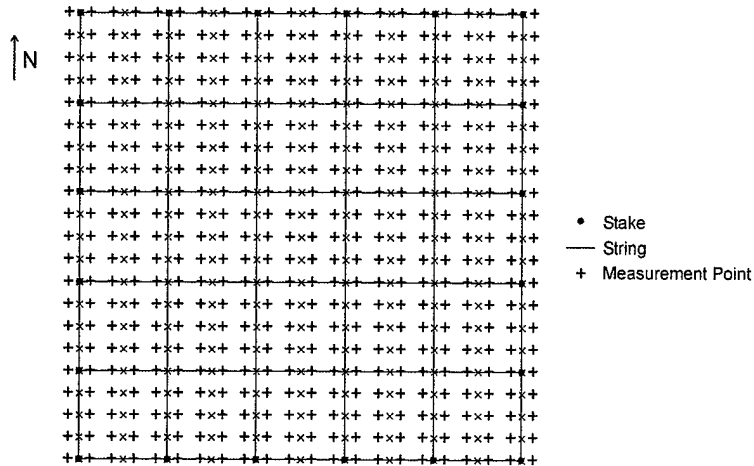


Fig. 8 – Schematic diagram of the gridded surveys conducted at the C&O Canal

Measurements were then collected with a sensor spacing of 0.25 m in both directions as shown schematically in Figure 8. At each grid point, ten individual field measurements from each sensor were averaged to increase the reliability of the results. For these measurements, the man-portable cart was replaced by a jig for the sensors held by a team member with minimum ferrous metal on his body, Figure 9. To minimize interference, the data logger was held by another team member at a distance from the sensors.



Fig. 9 – Conduct of the gridded survey at the C&O Canal. Note the analyst in the upper right processing the survey data in real time.

Anomaly Modeling

During the investigations at Spring Valley, burial pits have been found with items located between 8 and 12 feet below the surface. Since the items in question are possibly French 75-mm mustard rounds, we aimed to get a rough estimate of the magnetic anomaly signals that may actually arise by considering various assemblages of 75-mm projectile-sized ferrous metal objects.

The peak signal prediction for one isolated such object, as a function of depth, is shown in Figure 10. It is clear from the figure that a dependence on the orientation of the object exists, with much greater signals stemming from the object when its long axis is aligned with the geomagnetic field (i.e. when it is nearly vertical) than when its long axis is transverse to the geomagnetic field (i.e. when it is nearly horizontal).

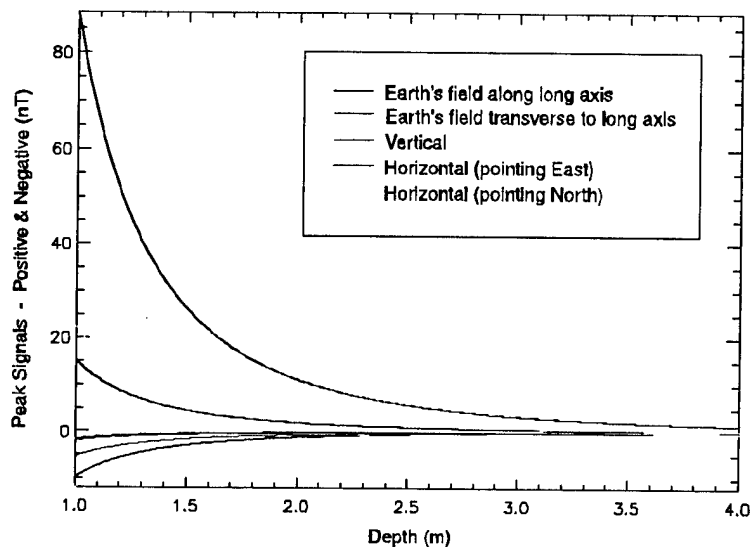


Fig. 10 – Dependence of peak magnetic anomaly on object orientation and depth

Since we expect at least a couple dozen items in a typical burial pit, Figure 11 shows peak signal predictions for various arrays of vertical objects, as well as various arrays of horizontal objects. An $M \times N$ array of vertical objects thus denotes N side-by-side east-west rows, with each row containing M vertical objects, whereas an $M \times N$ array of horizontal objects denotes N rows piled on top of one another, with each row containing M horizontal objects all pointing in the stated direction.

Note from Figure 11 that at a depth of 2.5 m (approximately 8 ft), peak signals are in the several hundred nT range. If we analyze, as an example, the composite signal from the 20×5 array of vertical objects at that depth, we find that by using the magnetic dipole model⁷ for an equivalent sphere of radius 0.48 m, the data is very well fit. Similarly, for the 20×5 array of horizontal objects pointing north, the data is well represented by the dipole field from a sphere of radius 0.33 m, while for the 20×5 array of horizontal objects pointing east, the data is well fit by the dipole field from a sphere of radius 0.26 m. This large variability in equivalent sphere sizes indicates that the best discriminant we have in identifying potential burial pits are the purported depths.

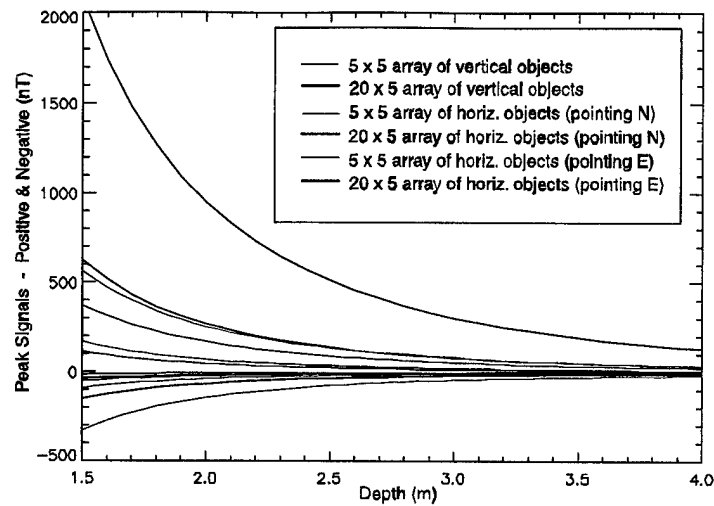


Fig. 11 – Peak signal expected from a number of arrays of simulant objects as a function of depth

SURVEY RESULTS

The survey was conducted in three distinct areas. For the remainder of this section, we will discuss the results from each area separately.

Area North of Chain Bridge

The first portion of the site surveyed was the large area north of the Chain Bridge. This decision was driven by our assumption that the up-stream side of the bridge would have fewer scrap targets associated with river flooding, particularly broken components of the original bridge. A magnetic anomaly map of this portion of the survey is shown in Figure 12. This map depicts deviations in the measured magnetic field in units of nanoTesla (the absolute value of the earth's field is approximately 52,000 nT).

Inspection of Figure 12 shows a number of significant anomalies that have been identified. For each numbered anomaly, the underlying equivalent sphere target parameters that best represent the data are determined. The location in local coordinates (relative to the GPS2 reference point), depth, size (given as an equivalent radius), and an indication of the fit quality are all listed in Table 2. Isolated ordnance items typically have a Fit Quality of greater than 0.9. Note, however, that most of the anomalies in Table 2 do not fit the model nearly as well. This is due in part to the lower quality sensor positioning achieved in this survey and, in part, to the extended nature of some of the targets and the possible presence of surface clutter.

Table 2 – Abbreviated Target Report for the Area North of Chain Bridge

ID	Local X (m)	Local Y (m)	Depth (ft)	Size (m)	Fit Quality
N1	-125.30	215.84	20	1.03	0.812
N2	-124.24	216.71	2	0.17	0.641
N3	-118.55	220.40	10	0.45	0.646
N4	-118.01	213.27	12	0.68	0.507
N5	-78.11	129.04			
N6	-73.75	133.44	2	0.25	0.866
N7	-75.03	131.74	5	0.36	0.713
N8	-68.10	120.89	4	0.32	0.869
N9	-70.18	119.21	4	0.21	0.912
N10	-77.99	112.85	10	0.40	0.591
N11	-73.57	97.81	11	0.42	0.676
N12	-60.47	82.95	2	0.15	0.974
N13	-50.96	74.12	9	0.46	0.672
N14	-27.63	19.90			

Several of the targets identified in the area North of the bridge are shallower than would be expected for items in a burial pit. As mentioned above, we focused on the depth range 8 to 12 feet here since that is the range of burial pits found elsewhere in Spring Valley. Obviously, anomalies at other depths could result from burial pits. All significant anomalies are carried through to the final section of this report. Five of the anomalies in Table 2 are in the depth range of interest and have been highlighted in the Table. These targets were reinvestigated using the gridded survey method described above.

An example of the data obtained from one of the reinvestigated targets, Target N4, is shown in Figure 13. In this case, there was little change in the appearance of the anomaly upon denser sampling. The fitted model parameters indicate a smaller and shallower source than the initial survey. The contours shown in the figure are relatively smooth and broad. These are all characteristics of an anomaly caused by a large deep target with little trash and clutter above. An example of a different result will be shown in the next section.

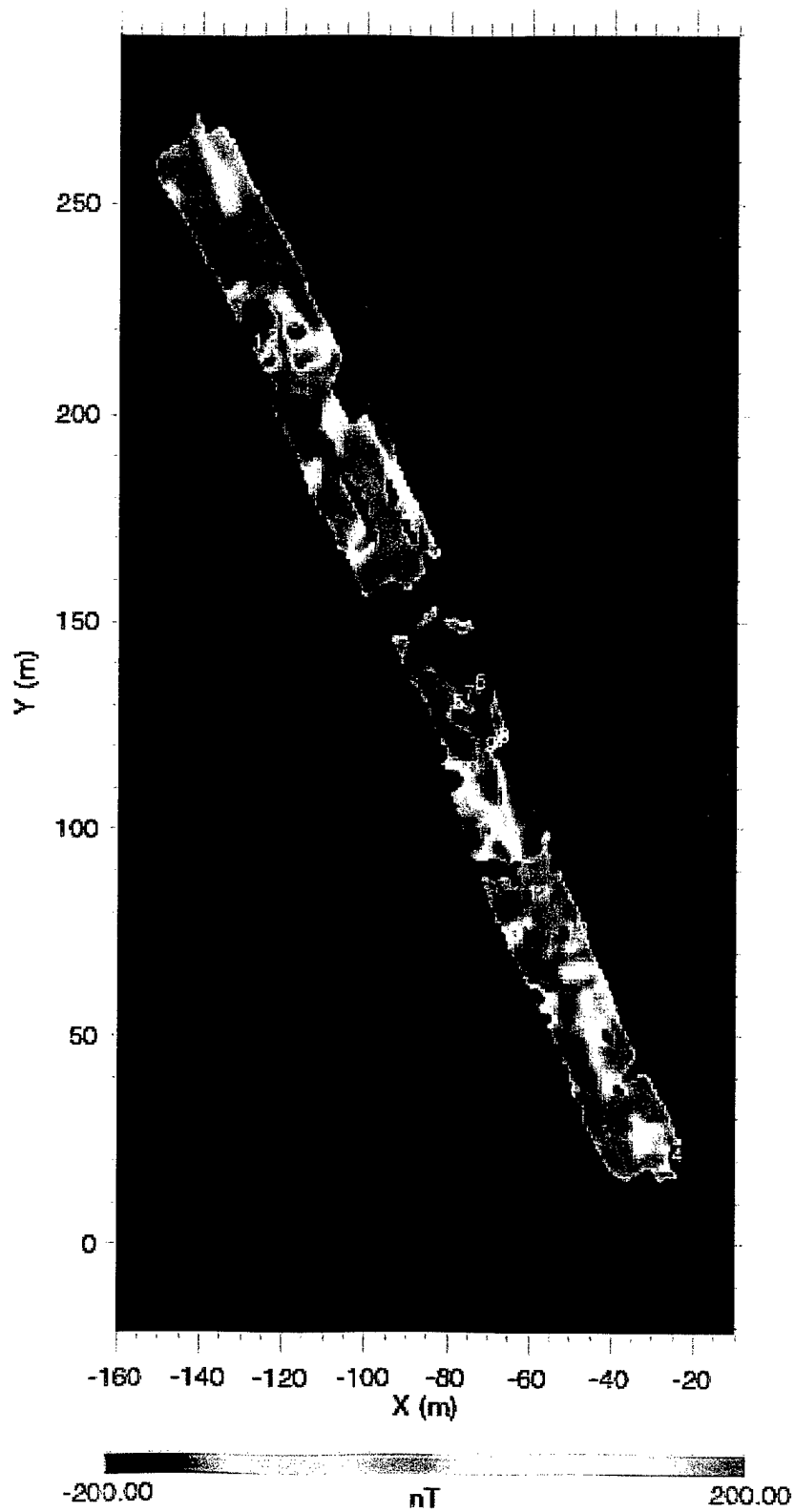


Fig. 12 – Magnetic anomaly image map of the area north of the chain bridge

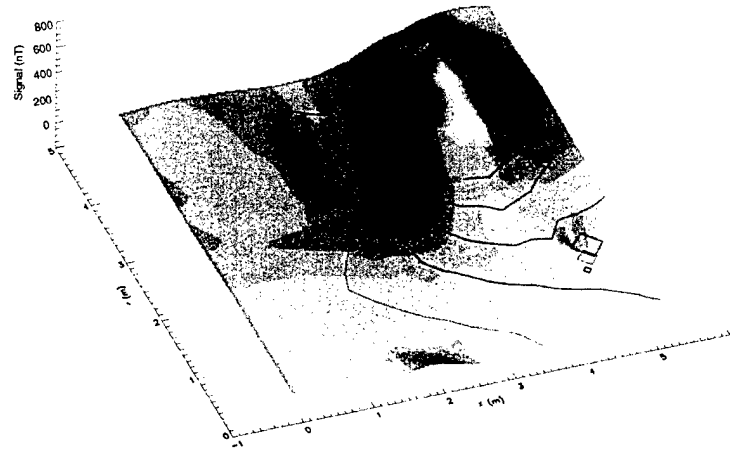


Fig. 13 – Contour plot of magnetic anomaly from the gridded survey of target N4

Area South of Chain Bridge

The magnetic anomaly image map of the survey area south of the Chain Bridge is shown in Figure 14. Just as in the case of first section studied, several anomalies were identified south of the bridge. Table 3 contains an abbreviated target report for this section. Contrary to our expectation, there was not significantly more surface trash observed in this, downstream, area. Two of the observed anomalies can be correlated with metal objects observed on the surface. Target S1 is a steel pipe that sticks out of the ground at the very South end of the survey. Target S6 correlates to a portion of metal rod that extends out of the ground and is presumably associated with the original bridge. The fitted depth suggests that the rod extends a distance into the ground.

One of the anomalies in the South section, target S9, was chosen for reinvestigation. A contour plot of those data is shown in Figure 15. Upon finer sampling, this anomaly breaks up into a number of small, near-surface targets and one larger, deep target.

Table 3 – Abbreviated Target Report for the Area South of the Chain Bridge

ID	Local X (m)	Local Y (m)	Depth (ft)	Size (m)	Fit Quality
S1	175.85	-429.75	0.3	0.17	0.707
S2	150.28	-387.29	1.0	0.13	0.623
S3	149.95	-389.56	1.7	0.17	0.571
S4	160.49	-379.62	1.5	0.12	0.922
S5	147.17	-362.09	2.1	0.27	0.500
S6	134.95	-348.86	5.0	0.60	0.430
S7	133.68	-339.55	2.6	0.20	0.922
S8	120.25	-326.75	0.3	0.10	0.827
S9	124.16	-324.16	8.0	0.40	0.579
S10	102.55	-274.50	1.4	0.12	0.815

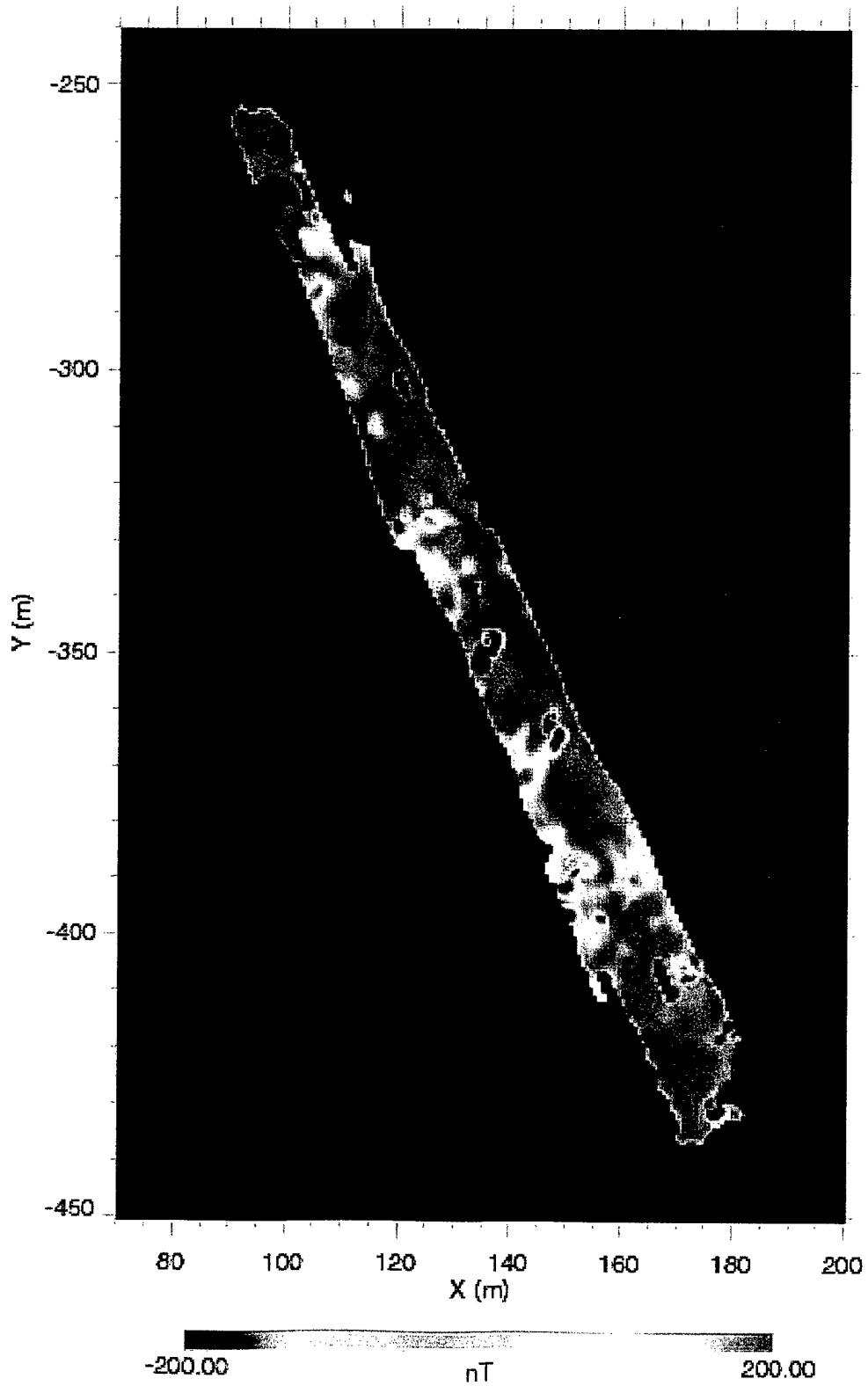


Fig. 14 – Magnetic anomaly image map of the area South of the Chain Bridge

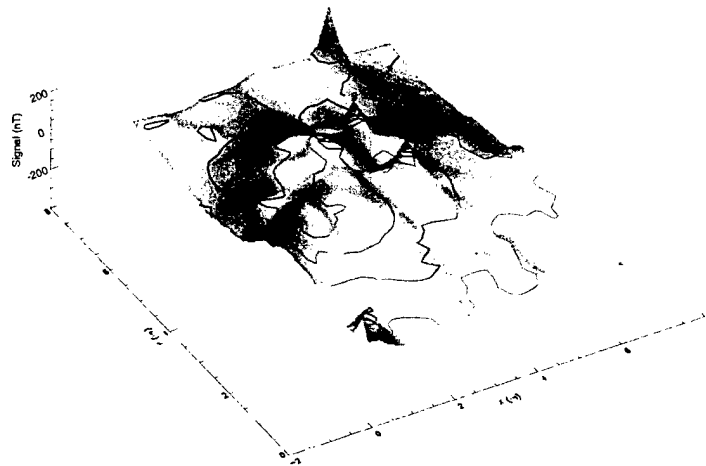


Fig. 15 – Contour plot of magnetic anomaly from the gridded survey of target S9

North-most Area

During the initial site investigation by the DC Department of Health, a small area approximately 1500 feet north of the main survey was identified as a possible target location. We surveyed that area with the man-portable magnetometer system on the third day of the initial deployment. A magnetic anomaly image of this area is shown in Figure 16. This image shows, most notably, two very large anomalies, with one extending outside the boundaries to the south.

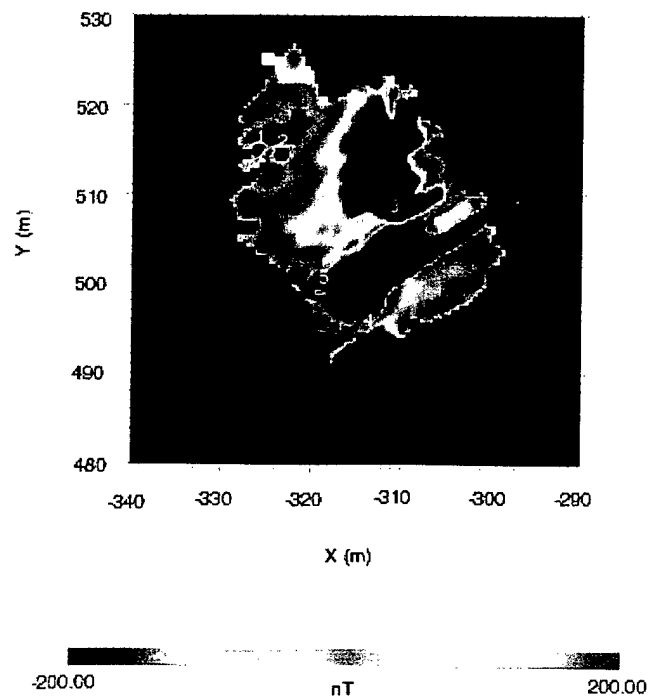


Fig. 16– Magnetic anomaly image map of the north-most area surveyed

Remaining Anomalies

As discussed in the previous sections, we identified several anomalies in each of the sections surveyed for reinvestigation. For some of these, there was no change from the initial results. For others, the apparent anomaly broke into a mix of small and large targets upon denser sampling. There are eight anomalies remaining that could be due to large, deep objects. The details of these anomalies are listed in Table 4.

Table 4 – Details of Remaining Anomalies After Reinvestigation

ID	Depth (ft)	Size (m)	Comment
N1	19	1.00	too deep?
N3	9	0.44	no change
N4	5	0.38	smaller and deeper than initial estimate
N5-N9			small items on large gradient (landfill?)
N11	2.8	0.18	larger dipole possibly off western edge of survey area
N13	7	0.45	mix of large and small dipoles
North-most			relatively poor fit, something large
S9	10	0.48	mix of large and small dipoles

The location of these anomalies has been provided to the Park Service for correlation against both historical and current utility and construction maps. Many of these remaining anomalies may be explained by known structures within the Park.

SUMMARY

The Chemistry Division of the Naval Research Laboratory has performed geophysical surveys on three areas adjacent to the C&O Canal towpath near the Chain Bridge in Northwest DC to characterize the extent and source of a series of magnetic anomalies discovered by personnel from the DC Department of Health. The magnetometer survey results lend themselves to two observations. First, there is no evidence of a series of fourteen regularly-spaced burial pits as suggested by the anecdotal reports. We have identified, however, thirty magnetic anomalies in and adjacent to the survey site. Many of these anomalies have been identified with ferrous metal objects visible on the surface or arise from shallow trash and scrap. There are eight anomalies that appear to arise from relatively large ferrous metal objects buried at depths greater than 6 to 8 feet. These remaining anomalies may require further investigation. Their locations have been provided to the National Park Service and are being matched against historical and current utility and construction maps.

ACKNOWLEDGMENTS

We thank Mr. Glenn Harbaugh for his assistance with the measurements reported here and Ms. Susan Alberts for her support and assistance with numerous logistical details.

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