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COMPLETION REPORT INTERIM/STABILIZATION MEASURE FOR AREA OF CONCERN 503 (AOC503) WITH TRANSMITTAL CNC CHARLESTON SC
10/10/1997
CNC CHARLESTON

COMPLETION REPORT

INTERIM/STABLIZATION MEASURE FOR AOC 503

CHARLESTON NAVAL COMPLEX

CHARLESTON, SC

Prepared By:

Supervisor of Shipbuilding Conversion and Repair
Portsmouth, Virginia, Environmental Detachment Charleston
1899 North Hobson Avenue
North Charleston, SC 29405-2106

10 October, 1997

DEPARTMENT OF THE NAVY
SUPERVISOR OF SHIPBUILDING, CONVERSION AND REPAIR, USN
PORTSMOUTH, VIRGINIA, DETACHMENT ENVIRONMENTAL CHARLESTON
1899 NORTH HOBSON AVENUE, BUILDING 30
NORTH CHARLESTON, SOUTH CAROLINA 29405-2106

IN REPLY REFER TO:

Ser: 1011
OCT 10 1997

Mr. G. Randall Thompson, Director
Division of Hazardous and Infectious Waste Management
Bureau of Solid and Hazardous Waste Management
South Carolina Department of Health and Environmental Control
2600 Bull Street
Columbia SC 29201

Dear Mr. Thompson:

The enclosed interim measure completion report for Area of Concern (AOC) 503 is submitted to fulfill the requirement of Permit Condition IV.D.6 for Permit Number SCO 170 022 560. If the Department of Health and Environmental Control should have any questions, please contact Reece Batten of Southern Division Naval Facilities Engineering Command (NAVFAC) at (803) 820-5578.

Sincerely,

for M/K Tunstall
E.R. Dearhart
Director

Encl:
(1) AOC 503 Completion Report

Copy to:
SCDHEC (Mr. Tapia, Mr. Bergstrand)
USEPA (Mr. Bassett)
CSO Naval Base Charleston (LCDR Rose)
NAVFAC (Mr. Batten)
EA&H (Ms. Maddux)
DDESB (Klinghoffer)

COMPLETION REPORT

INTERIM MEASURE FOR
AOC 503

NAVAL BASE CHARLESTON
CHARLESTON, SC

Prepared for:

DEPARTMENT OF THE NAVY
SOUTHERN DIVISION
NAVAL FACILITIES ENGINEERING COMMAND
CHARLESTON SC

Prepared by:

Supervisor of Shipbuilding, Conversion and Repair,
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October 9, 1997

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ACRONYM LIST

ACGIH	American Council of Governmental Industrial Hygienists
AFOL	Automated Ferrous Ordnance Locator
AOC	Area of Concern
AOE	Automated Ordnance Excavator
CEERD	Charleston Environmental Engineering and Remediation Detachment
CFR	Code of Federal Regulations
CHASP	Comprehensive Health and Safety Plan
CSAP	Comprehensive Sampling and Analysis Plan
CRZ	Contamination Reduction Zone
DDESB	Department of Defense Explosive Safety Board
DET	Environmental Detachment Charleston
DOT	Department of Transportation
EIS	Environmental Impact Statement
EOD	Explosive Ordnance Disposal
EPA	U.S. Environmental Protection Agency
ERT	Emergency Response Team
EZ	Exclusion Zone
HAZWOPER	Hazardous Waste Operations and Emergency Response
HW/HM	Hazardous Waste/Hazardous Material
IDLH	Immediately Dangerous to Life and Health
IM	Interim Measure
LEL	Lower Explosive Limit
MSDS	Material Safety Data Sheet
NIOSH	National Institute of Occupational Safety and Health
NPDES	National Pollution Discharge Elimination System
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limit
POTW	Charleston Publicly Owned Treatment Works
PPE	Personal Protective Equipment
PPM	Parts Per Million
RBC	Risk Based Concentration
RCRA	Resource Conservation and Recovery Act
RFI	Facility Investigation
SHSO	Site Health and Safety Officer
SOUTHDIV	Southern Division Naval Facilities Engineering Command
SSHSP	Site-Specific Health and Safety Plan
SZ	Support Zone
TLV	Threshold Limit Values
TNT	2,4,6-trinitrotoluene
UXO	Unexploded Ordnance

1. INTRODUCTION

1.1 INSTALLATION RESTORATION PROGRAM. The purpose of the Department of the Navy (DON) Installation Restoration Program (IRP) is to identify, assess, characterize and clean up or control contamination from past hazardous waste disposal operations and hazardous material spills at Navy and Marine Corps activities. The Defense Environmental Restoration Program (DERP) is codified in the Superfund Amendments and Reauthorization Act (SARA) Section 211 (10 USC 2701).

1.1.1 Naval Base Charleston IRP. At Charleston Naval Base Complex, a Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA) was prepared which divided the Naval Complex into zones and identified Solid Waste Management Unit (SWMUs) and Areas of Concern (AOCs) within each zone. The RFA evaluated each SWMU and AOC and determined which sites required further investigation. Based on the RFA, a RCRA Facility Investigation (RFI) work plan has been or is being prepared for each zone containing SWMUs and AOCs requiring further investigation. On completion of the RFI for each Zone, an RFI report will be prepared for that zone. The RFI reports will identify SWMUs and AOCs containing hazardous wastes requiring remediation. Eventually, Corrective Measures Studies (CMSs) will be prepared to determine the best means of remediating each site.

1.2 INTERIM MEASURES. Interim Measures (IM) performed as part of the IRP is intended to eliminate sources of environmental contamination or limit the spread of environmental contaminants and eliminate hazards prior to the completion of the RFI CMSs.

1.3 AREA OF CONCERN 503. AOC 503 consists of 9.85 acres located at the southern boundary of Zone H (see Appendix A Figure 2). This site is a wooded area bounded on the south by Shipyard Creek and on the north by Buildings 665 and 655. This site is identified as the area expected to contain unexploded ordnance (UXO). The ordnance at AOC 503 consists of two Mark 17 depth bombs which were jettisoned from a seaplane on October 8, 1943. This area was a marsh at the time the ordnance was dropped and has since been back filled with approximately six to eight feet of dredge material since 1943.

1.4 AREA OF CONCERN 503 INTERIM MEASURE. During the interval between the RFI and the completion of the CMS, it was decided by Southern Division Naval Facilities Engineering Command (SOUTHDIV) that an IM would be performed by Supervisor of Shipbuilding, Conversion and Repair, Portsmouth Va., Environmental Detachment Charleston (SPORTENVDETCHASN). The objective of this IM was to locate, excavate, and remove identified anomalies/ UXOs and any associated contaminated soil. If the UXO's were not found, the secondary objective was to perform a due diligent search and verify via a geophysical survey that the ordnance was either previously removed or is located at a safe distance below the ground surface to allow for unrestricted release of the property.

2. INTERIM MEASURE EXECUTION.

2.1 ACTIONS REQUIRED BY INTERIM MEASURE WORK PLAN. The actions performed at AOC 503 were spilt into five phases of work. The following brief description of the phases outlines the work performed.

Phase 1- Identifying and clearing affected area.

Phase 2- Performance of Quality Assurance / Quality Control (QA/QC.

Phase 3- Performance of Geophysical Survey and Interpretation of Data.

Phase 4- Excavation of identified anomalies.

Phase 5- Re-evaluation of data by an independent third party and re-survey of problem areas.

The following sections will give a brief synopsis of the actions taken during each of these phases.

2.1.1 Identifying and Clearing Affected Area. The initial indication of the location of the jettisoned UXO's was found on a Naval Base Map of the old seaplane runway by an "X" marked on the map (see Appendix A Figure 1). Based on this marking and the configuration of the old seaplane runway, a search area was calculated by the Naval Explosive Ordnance Tech Division (see Appendix A Figure 2). The 9.85 acre area that was identified was cleared of underbrush to allow for utilization of the survey equipment.

2.1.2 Performance of Quality Assurance/ Quality Control. To ensure that the Ultrasonic Ranging and Data System (USRAD) positioning system utilizing a G-822 L magnetometer could perform an accurate search, SPORTENVDETCHASN buried three clean fifty-five gallon drums at different intervals to test the system. The drums were utilized since they would resonate a similar magnetic signature as the Mark 17 depth bombs. A test run was performed on January 31, 1997, by Naval EOD Technology Division and the data interpreted to reveal the locations and depths of the drums. The locations and depths of the test run were then used to mark the surface. All the drums were located within one foot horizontally and vertically of the interpreted test data.

2.1.3 Performance of Geophysical Survey and Interpretation of Data. Naval EOD Technology Division, Indian Head, MD was utilized to perform the geophysics survey at AOC 503. The equipment used was the USRAD system with a G-822 L magnetometer attached as the input device. The technical specifications for this equipment is provided in Appendix F. Based on historical data, it was determined that portions of the survey area had been subjected to eight feet of back fill with dredged material. The potential depth and magnetic signature of the MK-17 depth bombs were calculated and determined to be eight to fifteen feet below ground surface depending on the trajectory of the bombs when dropped. The survey was commenced on January 28, 1997 in sixteen marked subsections. The initially survey identified eighteen anomalies. A re-survey of the eighteen areas was performed to eliminate surface objects and mark potential subsurface targets. Ten anomalies were eliminated due to being surface contacts which left eight potential subsurface anomalies. A ninth target was subsequently identified during re-evaluation of the data that was "masked" by another anomaly close by. The nine anomalies were marked for excavation (see Appendix A Figure 3).

2.1.4. Excavation of Identified Anomalies. Wright Laboratory (WL), Air Base Technology Branch, Tyndall Air Force Base was utilized to perform the excavations using an Automated Ordnance Excavator (AOE). The AOE is a Caterpillar 325L excavator with a WL developed teloperated remote control system. The technical specifications for the equipment is provided in Appendix B. The following sections provide a brief overview of each anomaly and the results of the excavation. Following each excavation, the holes were back filled and graded to match the surrounding area.

2.1.4.1 Anomaly #1 was estimated to be approximately eight feet below ground surface level at coordinates 2323634.6000 E and 368785.4700 N. WL excavated a piece of sheet metal located seven feet below ground surface that measured 6′ X 2.5′ X ¼″ thick. Following removal of the anomaly, the excavated hole was resurveyed with a hand held magnetometer and determined to be free of further targets by a Naval EOD Technology Division surveyor.

Sheet metal excavated at anomaly #1.

2.1.4.2 Anomaly #2 was estimated to be approximately five feet below ground surface level at coordinates 2323618.7900 E and 368791.9300 N. WL excavated a piece of sheet metal located five feet below ground surface that measured 4′ X 2.5′ X ¼″ thick. Following removal of the anomaly, the excavated hole was resurveyed with a hand held magnetometer and determined to be free of further targets by a Naval EOD Technology Division surveyor.

Sheet metal excavated at anomaly #2.

2.1.4.3 Anomaly #3 was estimated to be approximately one to two feet below ground surface level at coordinates 2323474.6300 E and 368654.2200 N. WL excavated a small piece of metal resembling a wash tub handle located two feet below ground surface. Following removal of the anomaly, the excavated hole was resurveyed with a hand held magnetometer and determined to be free of further targets by a Naval EOD Technology Division surveyor.

A metal handle excavated at anomaly #3.

2.1.4.3 Anomaly #4 was estimated to be approximately one to two feet below ground surface level at coordinates 2323520.2900 E and 368597.0200 N. WL excavated small pieces of metal fragments located two feet below ground surface. Following removal of the metal fragments, the excavated hole was resurveyed with a hand held magnetometer and determined to be free of further targets by a Naval EOD Technology surveyor.

Small pieces of metal fragments excavated at anomaly #4.

2.1.4.5 Anomaly #5 was estimated to be approximately seventeen feet below ground level at coordinates 2324057.0700 E and 368662.1000 N. WL excavated approximately ninety-four cubic yards of soil and reached a depth of seventeen feet. Due to the makeup of the soil in the area, water intrusion and cave in prevented excavation any deeper than seventeen feet. Post evaluation by UXB International of the data taken by Naval EOD Technology Division revealed that there may not have been an anomaly at this location. The initial interpretation may have been somewhat conservative due to the high density of targets in this area. However the on-site verification with the EM-61 metal detector discounted an anomaly at this location.

Excavated hole at anomaly #5.

2.1.4.6 Anomaly #6 was estimated to be approximately ten feet below ground surface level at coordinates 2324077.1300 E and 368680.8100 N. WL excavated two pieces of metal located seventeen feet below ground surface that both measured 3′ X 2′ X 1/8″ thick. Following removal of the metal pieces, the excavated hole was resurveyed with a hand held magnetometer and determined to be free of further targets by a Naval EOD Technology surveyor.

A piece of metal excavated at anomaly #6.

The other piece of metal excavated at anomaly #6.

2.1.4.7 Anomaly #7 was estimated to be approximately thirty feet below ground surface level at coordinates 2324130.9200 E and 368656.3400 N. Due to difficulty in excavating to depths greater than seventeen feet this anomaly was not excavated. This anomaly will be eliminated as a potential target due to the interpretation of the post excavation EM-61 metal detector survey data as outlined in Section 2.1.5.

2.1.4.8 Anomaly #8 was estimated to be approximately thirty feet below ground surface level at coordinates 2324090.8700 E and 368656.5200 N. Due to difficulty in excavating to depths greater than seventeen feet, this anomaly was not excavated. During the post excavation survey with the EM-61 metal detector, a 1.5" diameter pipe approximately eight feet long was found and determined to be anomaly #8. This is discussed in Section 2.1.5.

2.1.4.9 Anomaly #9 was estimated to be approximately four feet below ground surface level at coordinates 2324010.8000 E and 368670.9200 N. WL excavated eight cubic yards of soil to a depth of four feet without uncovering any metal objects. A survey of the excavated hole with a hand held magnetometer indicated the excavated hole to be free of any target by a Naval EOD Technology Division surveyor. The item was determined to be very small, close to the surface, and excavated during initial soil disturbance.

2.1.5 Re-evaluation of Data by a Independent Third Party and Re-survey of Problem Areas.

To ensure proper interpretation of the initial data taken by Naval EOD Technology Division, a separate company, UXB International Inc. (UXB), was contracted to evaluate the geophysical data and verify that all potential UXO targets were removed. UXB was contracted to perform the following: evaluate the existing magnetometer data, provide an independent estimate of mass and depth of remaining target anomalies not yet excavated and prepare a brief letter report describing their conclusions and recommendations. UXB initially had difficulty in distinguishing between potential UXO and other metallic bodies with similar characteristics especially where the objects were located within tight clusters. UXB recommended that another geophysical method, such as an EM-61 metal detector survey, be performed that would yield a better depth calculation than the magnetic data alone. The Detachment prepared the area for an EM-61 survey which consisted of gridding and clearing a seventy foot by one-hundred and fifteen foot area. This area included anomalies five through eight. The Detachment discovered a pipe while clearing the underbrush which was sticking out of the ground about two inches. This pipe was close to anomaly #8 and was not seen during the initial marking of the anomalies due to the underbrush and tight cluster of anomalies. The Detachment removed the pipe with a tractor prior to the EM61 survey. The pipe was eight feet long and one and a half inches in diameter. This pipe appeared to have been broken off during its removal which left a section below the ground. The Detachment performed a limited EM61 survey over this area of concern in Grid CHA-E-s1 and sent this information to UXB. After UXB reviewed both the magnetometer and EM61 data, their conclusion stated that the pipe found would have produced the anomaly seen on the data and that no other significant anomalies were noted (see Appendix D). This eliminates anomalies #7 and #8 as potential MK 17 depth bomb targets.

2.2 PROBLEMS ENCOUNTERED. The following problems were encountered during the execution of Interim/ Stabilization Measure for AOC 503:

- Magnetic Interference: A large drain pipe and a fence at the north end of grid CHA_1 caused magnetic signatures, as well as, the rocks and concrete which line the west road because many of them contained rebar. All of these materials made it difficult to analyze the data in those particular areas.

- Density of anomalies: Anomalies five through eight in grid CHA_E were close together which made it difficult to analyze the depths of each target.

- Difficulty in excavating: This area was a dredge spoil area during the nineteen-forties. Therefore, the porosity of the sandy soil made excavating past eight feet difficult.

3. INTERIM MEASURE OUTCOME.

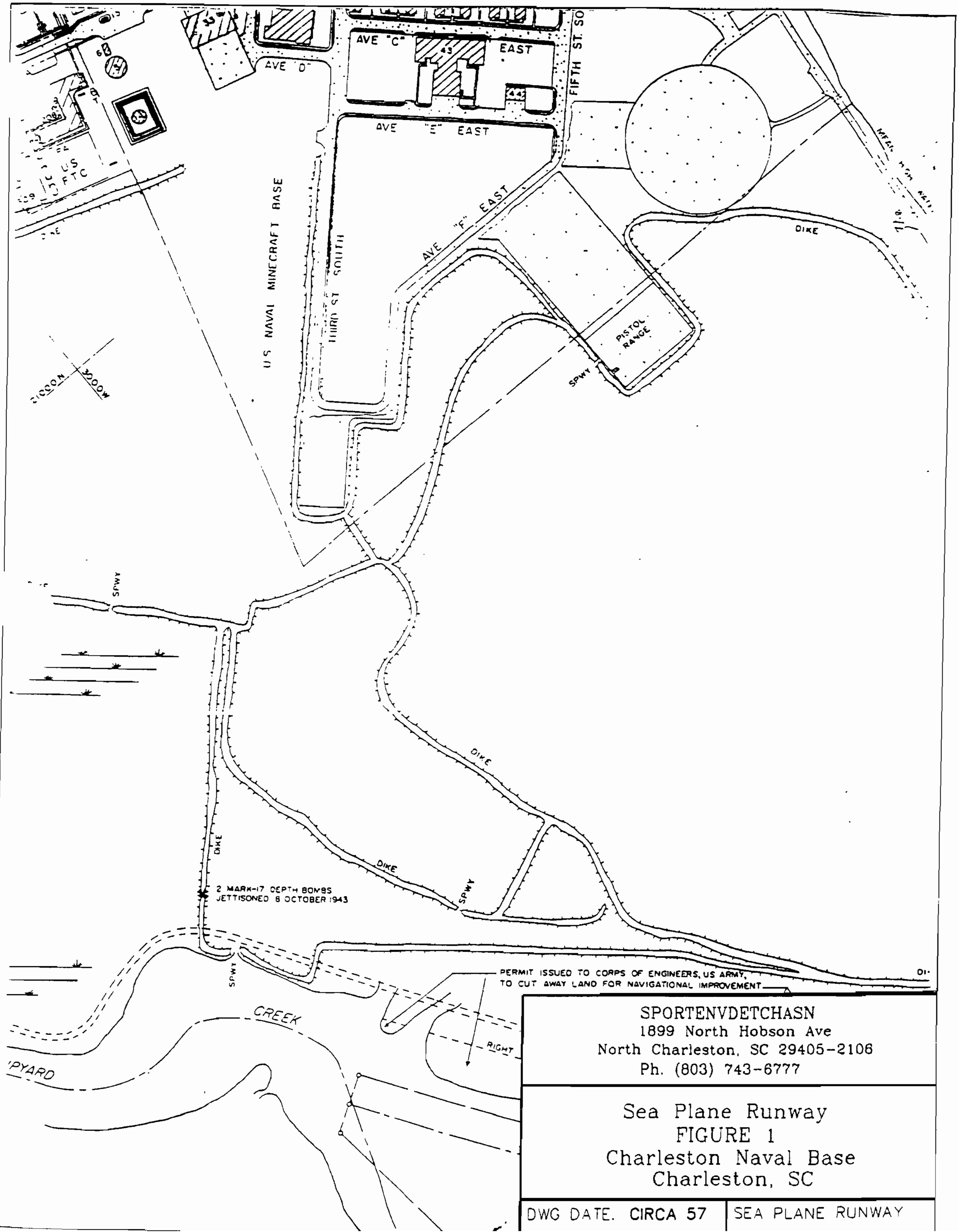
3.1 SITE CONDITIONS FOLLOWING COMPLETION OF WORK. Following the completion of all site work and data review on June 18, 1997, the Detachment had investigated all potential UXO targets and proved through geophysical surveys that no other potential UXOs exist within fifteen feet from the surface at AOC 503. Therefore, the Detachment has met the intent of performing a due diligent search and verifying via a geophysical survey that the ordnance was either previously removed or located at a safe distance below the ground surface of the property.

4. WASTE GENERATION.

4.1 NON-HAZARDOUS WASTE. Approximately 80 pounds of metal was recovered at AOC 503 and the metal was disposed of as scrap metal.

APPENDIX A

SITE MAPS



SPORTENVDETCHASN
1899 North Hobson Ave
North Charleston, SC 29405-2106
Ph. (803) 743-6777

Sea Plane Runway
FIGURE 1
Charleston Naval Base
Charleston, SC

DWG DATE. CIRCA 57	SEA PLANE RUNWAY

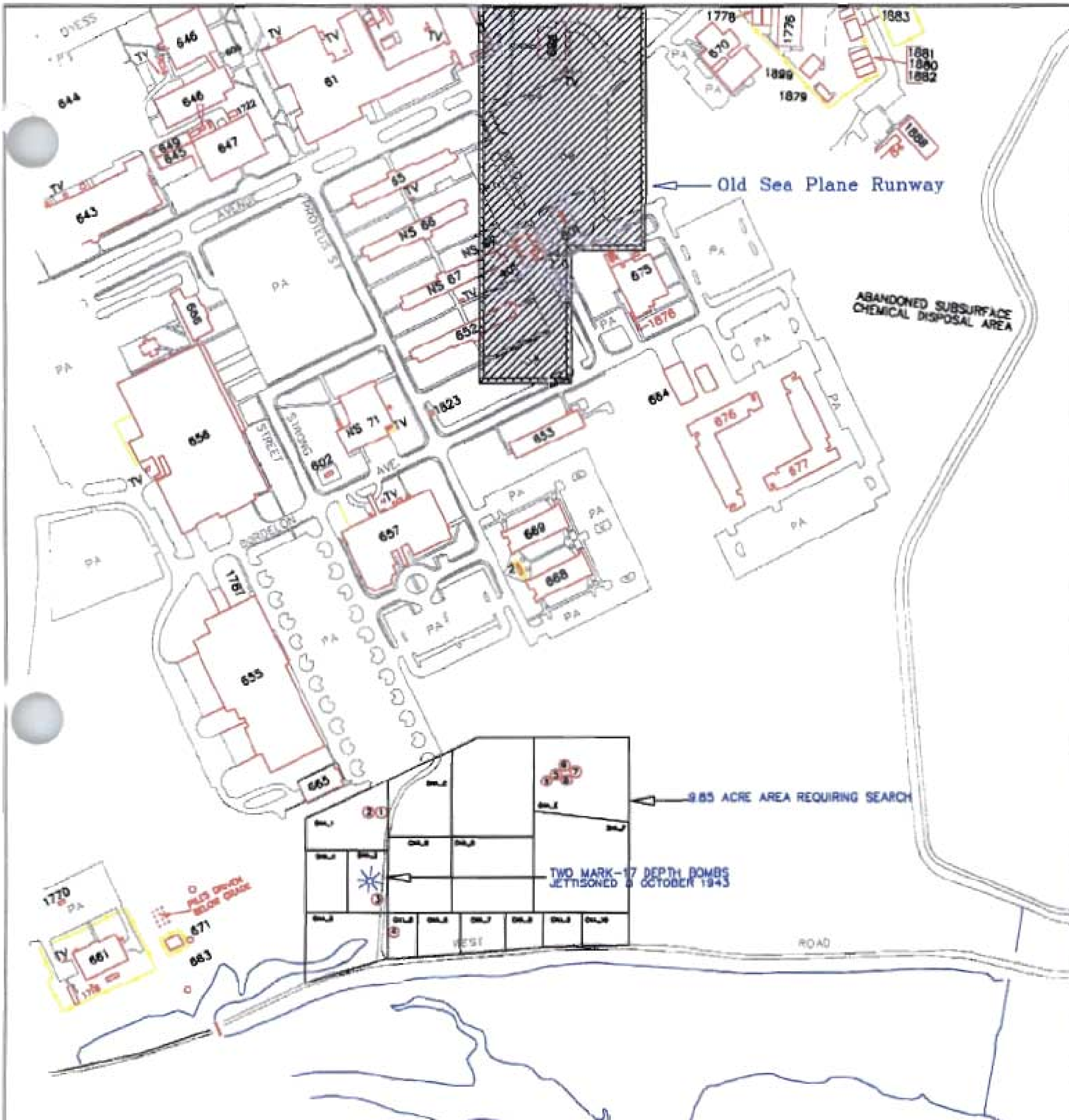
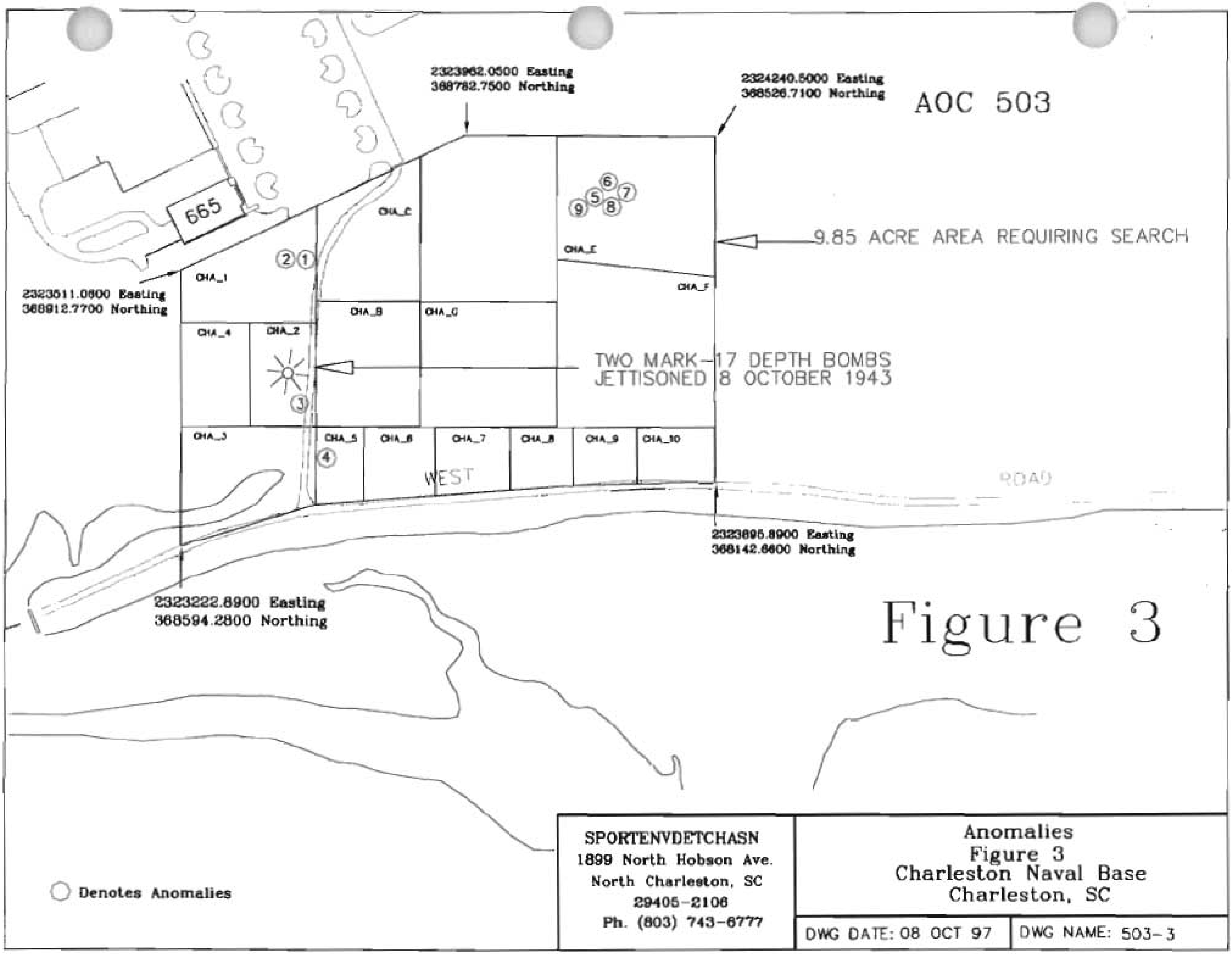


Figure 2

SPORTENVDETCHASN
1899 North Hobson Ave
North Charleston, SC 29405-2106
Ph. (803) 743-6777

Site Map
Figure 2
Charleston Naval Base
Charleston, SC

DWG DATE: 08 OCT 97 | DWG NAME: 503-2


AOC 503
2323962.0500 Easting
368782.7500 Northing
2324240.5000 Easting
368526.7100 Northing
665
CHA_C
CHA_E
CHA_F
CHA_1
CHA_2
CHA_3
CHA_4
CHA_5
CHA_6
CHA_7
CHA_8
CHA_9
CHA_10
CHA_B
CHA_G
9.85 ACRE AREA REQUIRING SEARCH
2323511.0600 Easting
368912.7700 Northing
TWO MARK-17 DEPTH BOMBS
JETTISONED 8 OCTOBER 1943
WEST
ROAD
2323695.8900 Easting
368142.6600 Northing
2323222.8900 Easting
368594.2800 Northing
Figure 3
Denotes Anomalies
SPORTENVDETCHASN
1899 North Hobson Ave.
North Charleston, SC
29405-2106
Ph. (803) 743-6777
Anomalies
Figure 3
Charleston Naval Base
Charleston, SC
DWG DATE: 08 OCT 97
DWG NAME: 503-3

APPENDIX B
Wrights Laboratory Automatic Ordnance Excavator Specifications

A SYSTEM FOR PERFORMING SITE REMEDIATION FOR TEST RANGES CONTAINING UNEXPLODED ORDNANCE

Capt Walter M. Waltz
Construction Automation Laboratory
Wright Laboratory, Air Base Technology Branch
139 Barnes Drive, Suite 2
Tyndall AFB, Florida 32403-5323
(904) 283-3725

ABSTRACT

The Government effort to rightsize the Department of Defense (DOD) forces and facilities has some far reaching implications including the turnover of DOD ordnance test ranges to the public. It will be DOD's responsibility to ensure that those ranges are free from the hazards of unexploded ordnance (UXO). The Naval Explosive Ordnance Technology Division (NAVEODTECHDIV) is the DOD designated research facility for Explosive Ordnance Disposal (EOD) and has accepted the mission to assess and develop the technologies to accomplish the Area Clearance/Range Remediation task. The Area Clearance mission is composed of two separate subtasks, characterization of the area of interest, and remediation of that area based on the findings of the characterization.

Because of the hazardous nature of the task, one of the program goals is to remove the human operator from the immediate area. This is accomplished through the use of robotic platforms. Wright Laboratory (WL) at Tyndall Air Force Base is the Office of Secretary of Defense (OSD) designated lead for construction automation. WL has been tasked by NAVEODTECHDIV to develop the robotic platforms that will perform the remediation tasks. One such system under development is the Automated Ordnance Excavator (Figure 1).

The goal of the remediation task is to render safe the ordnance targets determined in the task of site characterization. There will be three options during remediation which depend on the

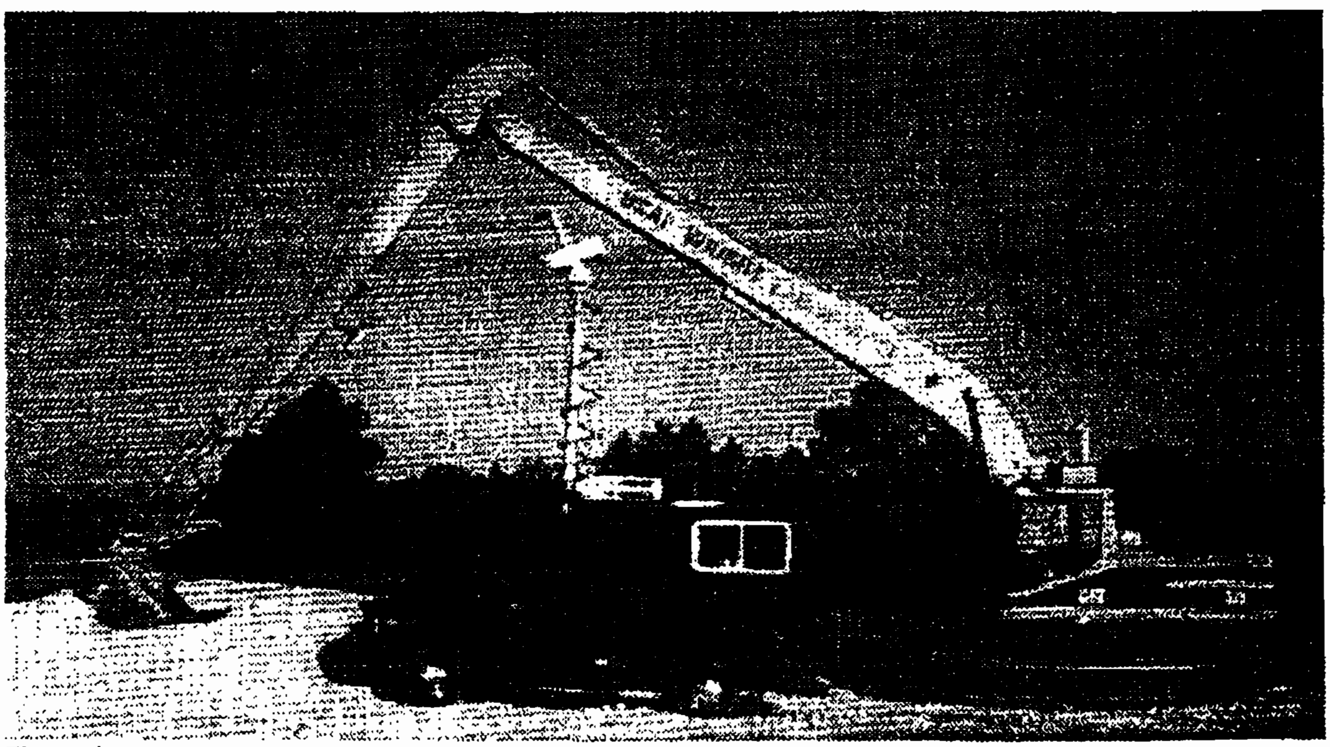


Figure 1
Automated Ordnance Excavator and
M bile Command Station

condition of the ordnance and the type of fusing: (1) a shape charge will be placed on the ordnance. (2) the material surrounding the ordnance will be removed to allow free access for the EOD technician (3) the ordnance will be removed from its resting place and placed on a pallet for later disposal. The remediation task can be accomplished by the Automated Ordnance Excavator (AOE) while minimizing risks to EOD personnel. It starts with a map containing target ordnance locations and proceeds to each target, in turn. It will remove the bulk of the material around the ordnance with a conventional bucket and then expose the ordnance for remediation. Once the ordnance has been identified, a method of disposal can be determined to safe and remove the UXO. The AOE uses the same advanced differential Global Positioning System (GPS) for navigation developed on the Autonomous Tow Vehicle to accomplish its site characterization task.

BASIC SYSTEM

The Automated Ordnance Excavator is a Caterpillar 325L "Long-Reach" excavator with an extended reach option. The "long-reach" option offers the longest configuration of the tracks which offer the most stable base for digging. The longest extended reach option makes the "bucket-to-machine" distance the maximum possible to offer some protection of the base machine in the event of detonation during remediation of a UXO. The length of reach of this excavator is 60.5 feet horizontally and 48.5 feet vertically. The AOE weighs approximately 65,000 lbs and is considered to be a large-scale remediation platform.

The AOE is powered by a Caterpillar turbocharged and aftercooled 3116 diesel engine with high-pressure, unit injection fuel system. Automatic engine control conserves fuel when manipulation and travel controls are not activated. A monitor panel located in the vehicles cab, provides status information for the operator through a high definition liquid crystal display (Figure 2). The travel and manipulation circuits are powered through two variable-displacement pumps.

OFF-THE-SHELF MODIFICATIONS

Prior to the delivery date for shipment of the excavator to WL, the AOE was sent off for additional factory modifications. This included the addition of a remote control system and manipulator thumb installation. Both available as off-the-shelf options.

Remote Control System

A Vectran remote-control system provides for full remote operation of the vehicle via two radio transmitters (one for data transfer and one for video transfer. Provisions are available for tethered cable control without the video feedback. The data transmitter/receiver uses a propriety Vectran radio operating at a frequency of 163.75 Mhz and less than 2 Watts power. The video transmitter/receiver uses a UHF associates FMCD radio operating at a frequency of 918.5 Mhz and less than 10 Watts power. RF control can be operated remotely up to 2 miles line-of-sight and tether operation up to approximately 2000 feet.

Remote operations include: left and right track operation for propulsion; boom, stick, bucket, swing, and thumb manipulation for digging; and iris, focus, zoom, pan, tilt and camera selection for video feedback. The camera system

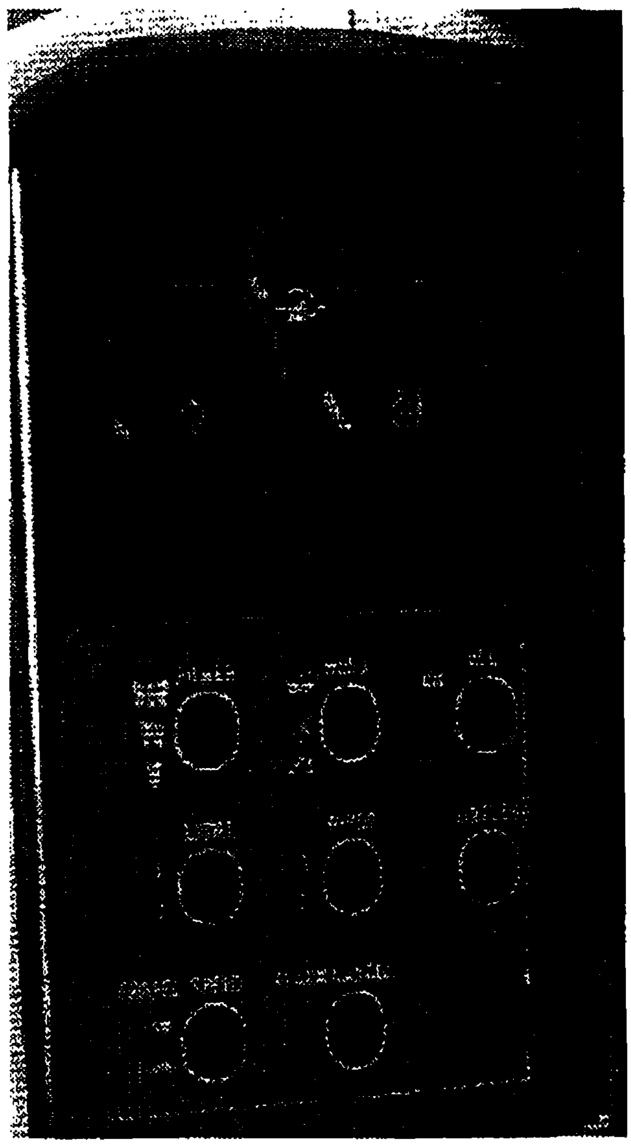


Figure 2
Operator's Liquid Crystal Display

implemented by Vectran provided for 3 remote views; however, only one view can be displayed at any given time. The cameras were located one above the vehicle cab for the driver's point-of-view perspective, one inside the cab to monitor the LCD display panel, and one mounted on the right side of the excavator looking forward for a right-side point-of-view perspective.

Manipulator Thumb

A Balderson Thumb has been installed that gives the AOE an ability to grasp objects. To grasp an object, the thumb is fully extended and the bucket is manipulated until contact with the object. The bucket is then closed and the thumb is back-driven allowing the bucket to fully rotate to bear the load of the object. The object can than be positioned for release.

WL MODIFICATIONS

After receipt of the AOE, WL further modified the vehicle with navigational aids such as GPS, map interface plus other minor improvements..

Navigation System

The primary navigation component for the AOE utilizes an Ashtech differential GPS. This GPS gives the AOE the ability to position itself within centimeters of a desired latitude/longitude. The GPS provides position updates at a rate of 1 hertz. Orientation of the AOE is determined by utilizing the previous latitude/longitude position with the current latitude/longitude. This method provides sufficient orientation information while the excavator is moving; however, inadvertent graphical rotations do occur while the excavator is motionless.

Bucket Teeth

The excavator bucket teeth have been extended by one foot and rounded to match the curvature of a 55 gallon drum or a 2000 lb munition simulating the largest UXO that may be found (Figure3). The bucket's four extended teeth are approximately one foot apart and gives the excavator the ability to rake through the soil to act a sifting mechanism to explore each lift of the soil.

Stick Camera

With the extended reach boom/stick, there was sufficient room to relocate the Vectran right side camera and mount it on the stick approximately 10 feet from the bucket to provide the operator an overhead view. The pan/tilt portion of the camera was removed; however, it still had zoom, focus, and iris control to allow the operator to zoom in and identify a suspected target.

Figure 3
Bucket Teeth

MOBILE COMMAND STATION

Remote operation of the AOE is conducted from a mobile command station. The Mobile Command Station (MCS) provides the operator a controlled atmosphere while operating at a safe distance from the hazards of uncovering a UXO. The MCS provides 110 AC power through a 5KW generator mounted over the passengers cab that is conditioned through a Universal Power Supply (UPS). The UPS unit provides for continuous conditioned power for the operator control unit, navigation computer, GPS units, and other auxiliary equipment and allows shutdown of these devices in the event of generator failure.

Camera System

A 30-foot telescoping mast/turret camera system provides the operator a "bird-eye" view of the remote operation from the MCS (Figure 4). The camera is mounted on a pan/tilt unit capable of 340° degrees horizontal rotation and 90° vertical rotation. The camera has zoom, focus and iris control and is manipulated from within the MCS.

Radios

Communications to the AOE is accomplished through the use of several radio transmitters/receivers depending upon the type of information being transferred.

An AACOM video transmitter/receiver establishes communication between the AOE and MCS for video transfer. The AACOM is a JF12-rated radio operating at a frequency of 1795.5 Mhz and requires frequency authorization

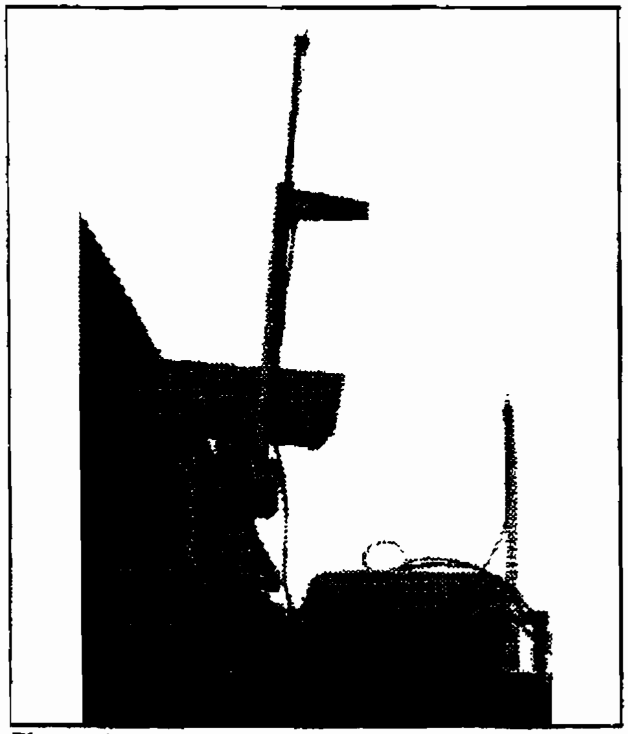


Figure 4
MCS Camera System

from the local frequency management authorities. A directional antenna mounted on the mast/turret pan/tilt mechanism is easily pointed at the AOE utilizing the video image feedback from the camera. There is only a manual tracking capability with this camera system.

A Freewave transmitter/receiver, utilizing a spread spectrum method operating with a tuning range of 902-928 Mhz, provides for the transfer of the GPS navigation information. This information is relayed to a WL-developed navigation map. The navigation map provides the remote operator a graphical representation that pictorially displays the AOE's at the current latitude/longitude position and excavator configuration.

Remote Control Interface

The Vectran operator control unit (OCU) is a stand-alone remote interface to the AOE (Figure 5). The OCU houses the joysticks, switches, and radio to remotely operate the AOE. Four joysticks located along the lower bottom of the OCU controls the primary movement of the excavator. The joystick layout mimics the vehicle controls in the cab and there is no difference (latency) from remote operation as manual operation. Both remote and manual operation of the vehicle

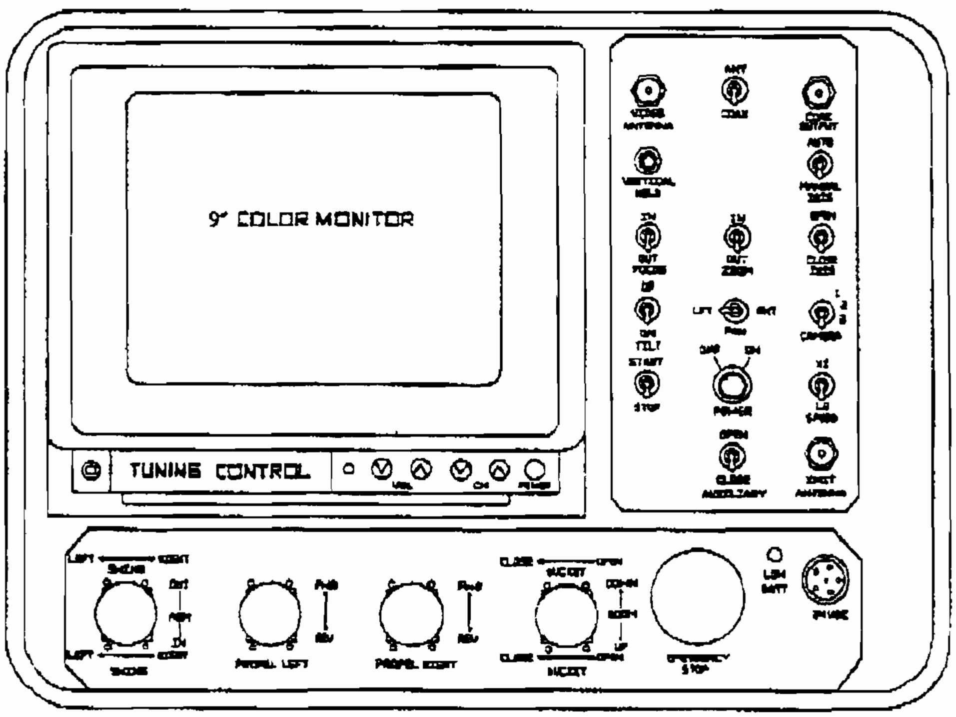


Figure 5
Vectran Operator C ntr l Unit

is accomplished through the CAT 325L pilot hydraulic system.

FIELD TESTING

As the designated OSD lead in construction automation, WL regularly participates in demonstrations to identify and improve each platform and subsystem under development. Some of these demonstration sites include Jefferson Proving Ground (JPG) Controlled Site, Jefferson Proving Ground Live-Site, and Fort Jackson Live-Site.

Jefferson Proving Ground

At the request Congress, the DOD established the JPG UXO Advanced Technology Demonstration Program. The objective of this program was to identify, demonstrate and evaluate the performance of technologies used to detect, characterize and remediate subsurface UXO. WL has developed several platforms/technologies that support these UXO and Area Clearance programs. This work is being accomplished under the sponsorship of the Army Environmental Center at the direction of the NAVEODTECHDIV.

In support of the Sep 1994 JPG demonstration, WL demonstrated the AOE as a large-scale remediation system. It is envisioned that the task of remediation will require a range of equipment to cover surface, shallow, medium, and deep buried UXO and the AOE covers the high end.

Prior to the demonstration, a local terrain map depicting trees, valleys and other obstacle was fed into the navigation map. Upon arrival at the JPG controlled site, a target list was given in local measurements of northing and easting and converted to a latitude/longitude for input to the navigation map. Target information also contained the location of implanted inert ordnance ranging from small, shallow buried 60mm mortars to a large, deep buried 500lb bomb and also unknown anomalies detected during previous detection demonstrations.

Based upon terrain conditions (i.e., approach to a target, distance from a target) a target was selected that offered the best approach (preferably line-of-sight for best communication with the vehicle) while maintaining a safe stand-off distance simulating an unexploded ordnance. End results showed the AOE was capable of remotely positioning over the target within centimeters. Results also showed the AOE was not well suited for remediating small UXO without the aid of detection system within the bucket. Visual recognition of UXO falling out of the bucket was difficult and targets were often missed. Another difficulty encountered was the ability to reposition the bucket over the target once the soil was disturbed. Methods for remotely uncovering ordnance and determining if the UXO would be removed, uncovered and detonated in place, or uncovered and rendered safe are not yet established for remote control operations.

Live-Site Program

At the conclusion of the first JPG controlled site demonstration, a Live-Site program was established that took the best detection systems and tried them on several, contaminated UXO sites. These sites included Jefferson Proving Ground, IN; Yuma Proving Ground, AZ; Eglin Air Force Base, FL; Fort Jackson, SC; and McChord Air Forc Base, WA. The AOE participated in two of these sites, JPG and Fort Jackson, to validate the locations that the demonstrators deemed the most probable location at which to find a UXO.

Prior to any remediation or survey, the records of each site are reviewed to determine the expected type of ordnance to be found. Often times records of these sites were vague and inaccurate because prior to the 1980's, record keeping was not mandatory for most installations. Initially areas are manually swept to clear the surface of any visible ordnance before demonstrators are allowed on the range. Inert UXO were also emplaced to provide the detection systems a means of truthing their data and remediation systems to proof their navigation ability against known and expected UXO types. These UXO was also used to validate the ability of the AOE's navigation system to precisely locate over the target.

Once a site was prepared, demonstrator's were allowed three weeks to cover the maximum area possible. After the surveying phase, demonstrators were given three weeks to identify and rank order their target list. The final phase of the live-site effort was the validation phase. This phase was given three weeks to validate as many targets as possible with a minimum of ten targets per demonstrator.

Validation consisted of excavating a hole a minimum of 9 feet wide by 9 feet long above the designated latitude/longitude down to the depth that the demonstrator estimate it to be. If no UXO was found, excavation continued an additional 3 feet below target depth. After each excavation, the dig site and spoil pile was scanned with metal detection devices to determine the presence of any metal signature.

In the event that objects other than UXO were located, the hole was still excavated to the required maximum dimensions. If an ordnance was found, the demonstrator was awarded a positive hit. If any other object was found that possessed a metallic signature, the demonstrator was awarded a false positive hit. When a non-metallic object or nothing was found, the demonstrator received a false negative. Targets that had multiple demonstrator hits, each demonstrator received the same scoring as the single targets.

Jefferson Proving Ground IN, Live-Site

Two sites located on JPG was selected for the demonstrators to survey. Both sites were approximately 1000 feet x 1000 feet. Each demonstrator identified hundreds of possible targets. Due to the saturation of contamination near the surface, any hits within 18 inches from the surface were not considered for validation. This still left hundreds of targets to select from. Further below the surface selection was accomplished by looking at multiple hits at one location from two or more demonstrators. From the remaining list, the top ten individual targets identified by each demonstrator was selected for validation. Targets that had multiple demonstrator hits were investigated separately after the initial 30 targets.

JPG validation efforts revealed several UXO. If a UXO was discovered, EOD technicians identified the type of UXO and directed the method to render the munition safe. Most of the ordnance found at JPG were practice rounds that possess an explosive spotting charge. All the UXO discovered was relocated to the furthest excavated hole for detonation at the end of each day. This prevented further saturation of the area with metal fragments. None of the UXO found possessed a high explosive capability.

Fort Jackson SC Live-Site

Two areas were also selected at Fort Jackson for this effort. The first area was a training area where the US Army practices air drop and battlefield maneuvers. The fields were plowed annually and planted with winter wheat. Records indicated that this area was once used as an impact area but had been cleared of all hazards. The second area selected was still an active impact range and possessed the possibility of producing live, hazardous UXOs. At both sites, the validation method followed the same approach as JPG. Several targets excavated in the maneuver area revealed various building materials, barbed wire, and telephone high tension wires. The only ordnance found and remediated was a high explosive 155mm round.

ISSUES

With each demonstration WL evaluates the effectiveness and limitations of the remediation system. We constantly explore new methods for remediating UXOs by remote means and establish operational guidelines for each system. After each demonstration, the team conducts a review of the methods and procedures for optimization or focusing of future technological improvements. For example, a minor problem encountered during the first demonstration was receiving the target list in northing/easting coordinates versus latitude/longitude coordinates. This lead to the establishment of how the target list would be conveyed between a detection system and a remediation system. The remediation system was enhanced to be able to handle a variety of inputs or the ability to convert coordinate systems to an acceptable input.

Other problems were discovered such as UXOs being missed during removal of the soil. Often smaller UXO was found in the spoil pile or were pushed under the front of the excavator. Sensor technology research is being conducted to help expose or locate the UXO before physically touching the UXO. This research ranges from inductance coil technology to ground penetrating radar technology. Other developments include tools to expose the ordnance with little physical contact such as rotating brushes and vacuum air-jet systems.

FUTURE MODIFICATIONS

As with any mechanical system, reliability and maintainability are serious concerns. Establishing long distance, line-of-sight RF communications between the AOE and MCS has been a significant factor in determining the requirements for the next generation/modification upgrade for the control of the AOE. The ability to diagnose malfunctions and isolate failed components are of concern as well.

The next generation of the AOE will incorporate a modular approach in the design of the control system. WL is exploring the application of the Controller Area Network (CAN) bus architecture for the control and monitoring of the vehicle. The CAN approach is a network of nodes distributed around the vehicle providing device power and network lines. The design of the network will follow a DeviceNet® specification. DeviceNet manufacturers provid off-the-shelf components (encoders, resolvers, etc.) and direct connectivity to the CAN bus by using CAN power and information feedback through the network. Other devices not DeviceNet compatible can be interfaced through Input/Output modules.

The CAN bus host uses the Lynx® real-time operating system. Drivers and diagnostic routines are being develop at WL for the real-time control of mobile vehicles. The CAN bus, coupled with the diagnostic routine, will provide a reliable, robust platform for field testing. In the event of a failure, the node at which the failure occurred can be easily diagnosed. It is the goal of this phase of development to design components for modularity and the ability to quickly remove and replace a failed part. The DeviceNet specification was selected due to the availability of products made compatible and designed for this specification.

OTHER ROBOTIC PLATFORMS

The AOE is designated as a "low-cost" platform and available off-the-shelf as a teleoperated excavator. The enhancements WL has made to the excavator will be distributed to industry through a technology transfer package. All developments at WL are unclassified and available as public information.

Remote Vehicle Excavation System

WL is sponsored by OSD to extend the state-of-the-art in construction automation. To evaluate and develop potential technologies geared toward vehicle automation and UXO remediation, WL has developed a state-of-the-art testbed excavator called the Remote Vehicle Excavation System (Figure 6).

technologies. Once a system or tool has been proven on the REVS, it is then implemented on the other platforms.

PRECISION EXCAVATION

Two precision excavation technologies currently under development on the REVS are an articulating clamshell and an air-jet vacuum system.

ARTICULATING CLAMSHELL

The articulating clamshell replaces the standard REVS bucket and incorporates a non-sparking rotating brush (Figure 7). The clamshell allows excavation of a hole to be controlled very precisely. As detection systems improve, the ability to precisely determine the type, depth, size and orientation of a UXO, the clamshell will offer the remote operator the ability to unearth and grasp the object with minimal impact. This system is expected to be delivered and installed for JPG III.

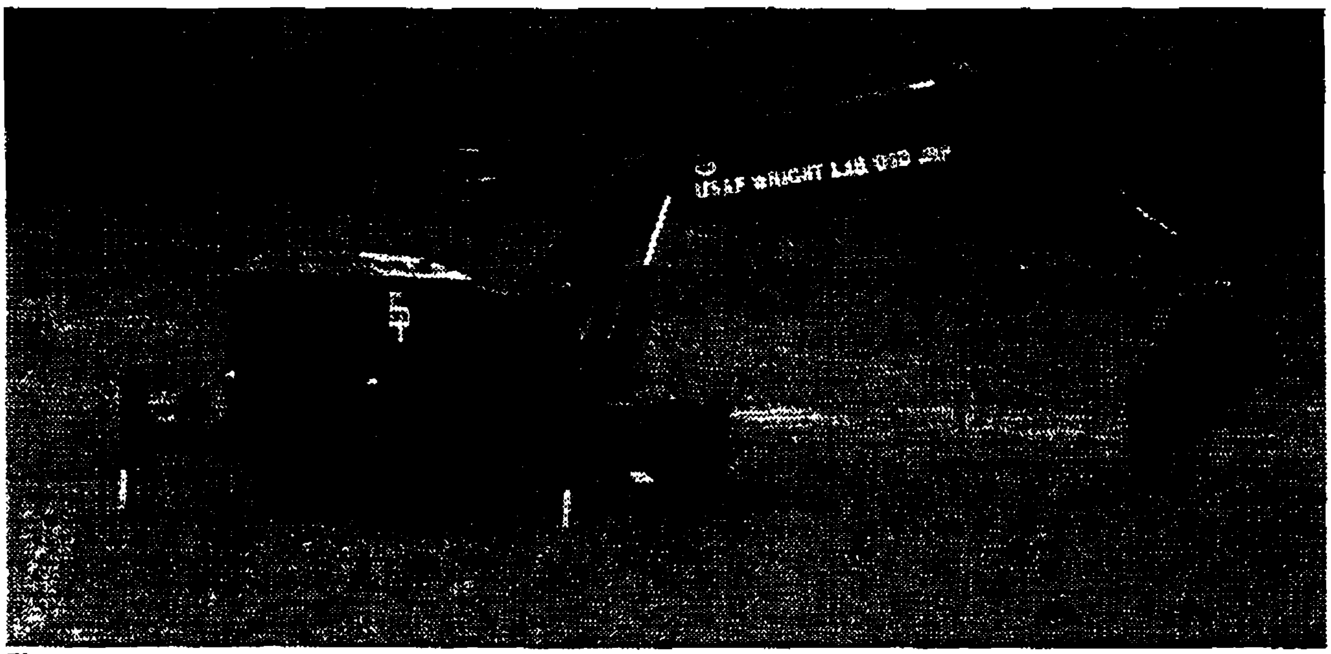


Figure 6
Remote Excavation Vehicle System

This system was designed as a state-of-the-art robotic testbed. Actuators and other devices are designed to be able to provide the most accurate monitoring and precise positioning capability. Future technologies such as different manipulators and tools will have sufficient hydraulic power and positioning ability available. Vehicle navigation is accomplished through on-board computers housed in an environmentally controlled enclosure at the rear of the vehicle and an RF interface with the mobile command station. The Remote Excavation Vehicle System (REVS) is focusing on autonomous/semi-autonomous

AIR-JET VACUUM SYSTEM

Similar in concept with the rotating brush gently uncovering the UXO, an air-jet vacuum system mounted at the end of the excavator stick will remove the soil surrounding the UXO without physically jarring it using a high velocity nozzle/vacuum system (Figure 8). A compressor/vacuum device will be towed by the host vehicle. This system is expected to be delivered at the beginning of FY 97.

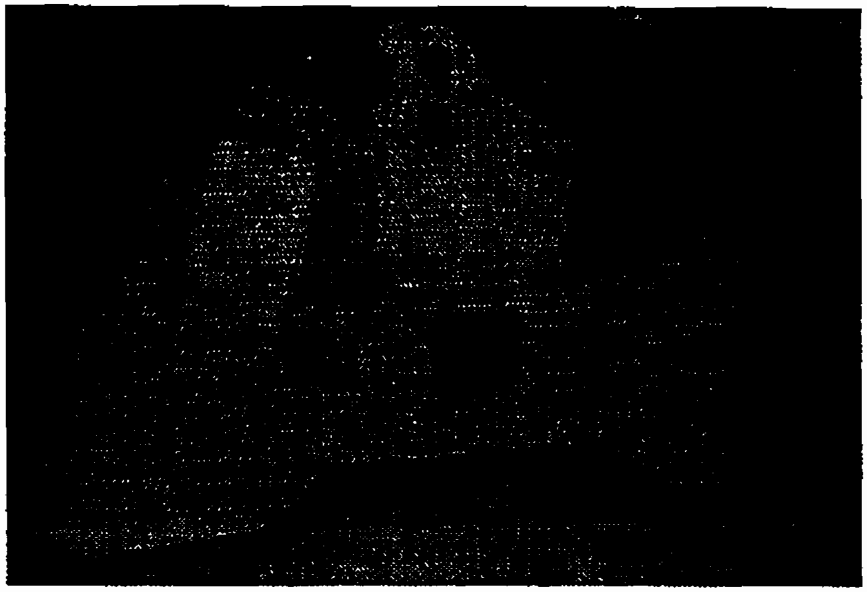


Figure 8
Articulating Clamshell

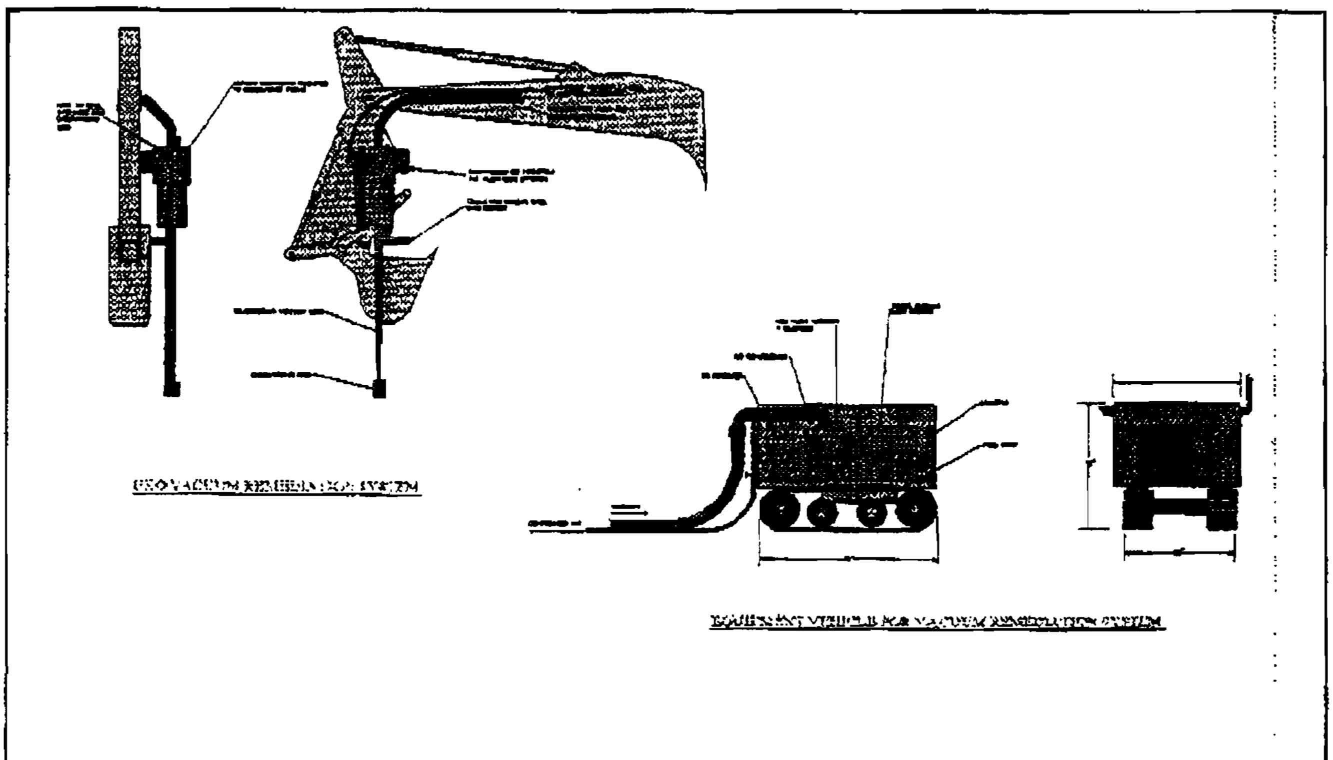


Figure 7
Air-Jet/Vacuum System

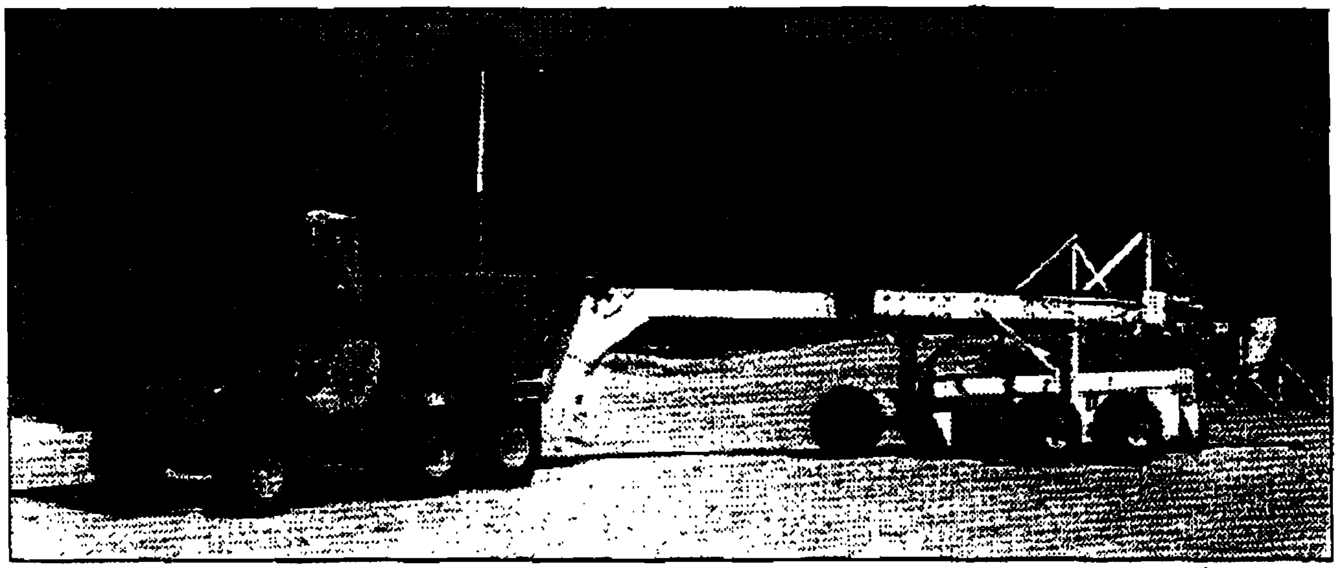


Figure 9
Subsurface Ordnance Characterization System

Subsurface Ordnance Characterization System

WL provides the NAVEODTECHDIV support for the development of an autonomous detection system known as the Subsurface Ordnance Characterization System (SOCS). Leveraging technology from the REVS program, SOCS is capable of autonomously surveying a plot of land while accurately characterizing subsurface UXO utilizing a ground penetrating radar and four Cesium vapor magnetometers. SOCS was designed as a test platform for exploring a new sensor technologies.

All-Terrain Remediation Vehicle System

The All-Terrain Remediation Vehicle Sytem (ATRVS) addresses the midsize UXO threat and a rough terrain excavatio system. A candidate platform known as the "spyder" meets these characteristics and will be the base platform. The "spyder" is a 20,000lb vehicle with a 7 degree-of-freedom manipulator and 3 degree-of-freedom leg (wheeled). The machine is capable of walking and rolling locomotion. The machine is utilized by the Department of Transportation for road-side ditch cleaning and maintaining runoff canals.

AUTOMATED ORDNANCE EXCAVATOR

1. Description: The Automated Ordnance Excavator (AOE) is a Caterpillar 325L excavator with an extended-reach option. The AOE can reach to extension of 60.5 feet and dig to a depth of 48.5 feet in order to retrieve buried ordnance while maintaining the furthest distance possible from the ordnance. The AOE has a WL developed teleoperated remote control system installed for RF operations up to distances of 2 miles. This system provides all the control functions that would be available to a cab operator. The AOE utilizes a global positioning system for locating the excavator within centimeters of a given target latitude/longitude. Other hardware is installed to provide real-time information concerning the configuration of the boom/stick to determine dig depth and motion of the bucket. An additional RF link is established for transfer of GPS and configuration information to a mobile command station (MCS) that displays the excavator's orientation and the implementation of Differential GPS.

2. Specifications:

Cat 325L:

Shipping Length:	44' 3"	Operating Weight:	63,590 lbs
Shipping Width:	11' 1"	Operating Reach:	60' 5"
Shipping Height:	10' 4"	Operating Depth:	48' 5"

Navigation System: GPS
Type: Ashtech
Model: Z12
Accuracy: +/- 2.2 cm

Command and Control Station:
Computer System: Sun Sparc 2

Camera/Mast Turret System: Maximum Height: 30'
Minimum Height: 8' 6"

Radios:

Brand: AACOM
Frequency: 1795.5 MHz Video
Bandwidth : 3.0 MHz
Power: 8 Watts

Brand: Freewave
Frequency: Spread Spectrum
No licensing requirements

For futher information, view our world wide web site @ www.robosun.tyndall.af.mil
See Conference papers, UXO Forum 96 by Capt Walter Waltz or contact Capt Walter Waltz at 904-283-3725 (DSN 523).

APPENDIX C

Photographs

WEST ROAD PRIOR TO CLEARING AT AOC 503.

THE CORNER OF DIKE ROAD AND WEST ROAD LOOKING NORTH PRIOR TO CLEARING.

STANDING ON THE DIKE ROAD LOOKING WEST PRIOR TO CLEARING.

THE DETACHMENT CLEARING UNDERBRUSH WITH TRACTOR AND BUSH-HOG.

NAVAL EOD TECHNOLOGY DIVISION BASE STATION ON THE WEST ROAD.

NAVAL EOD TECHNOLOGY PERFORMING GEOPHYSICAL SURVEY.

STATIONARY RECEIVERS LAYED OUT THROUGH GRID CHA_8.

WRIGHTS LABORATORY OPERATING THE AUTOMATIC ORDNANCE EXCAVATOR FROM INSIDE THE BASE STATION.

THE AUTOMATIC ORDNANCE EXCAVATOR REMOVING ANOMALY #6F ROM SEVENTEEN FEET BELOW GROUND SURFACE.

DEWATERING EXCAVATION #6.

LOOKING WEST WHERE ANOMALIES #5 THROUGH #9 WERE EXCAVATED (AFTER PHOTO).

APPENDIX D

Geophysical Survey Data Contour Maps

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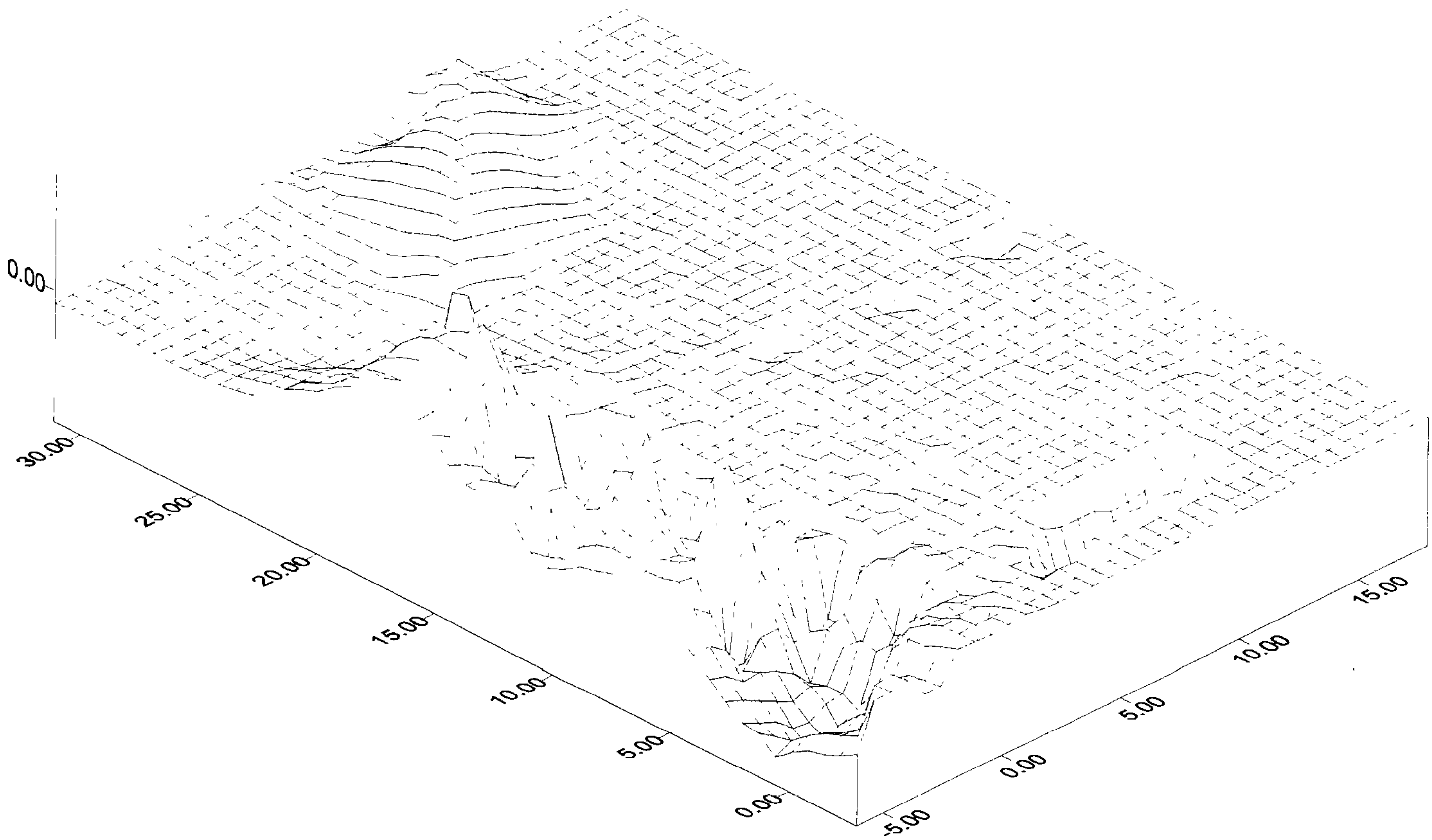

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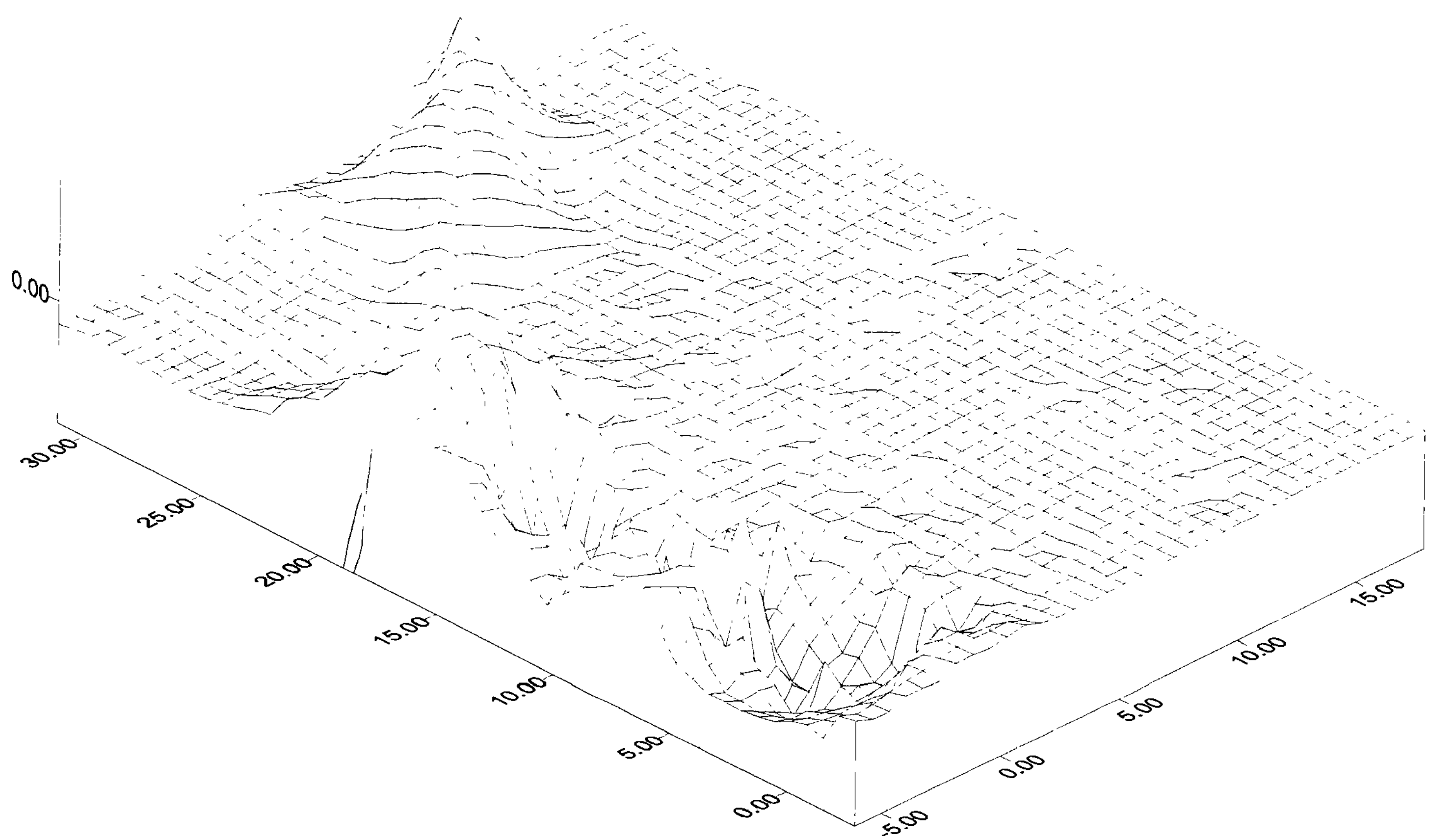

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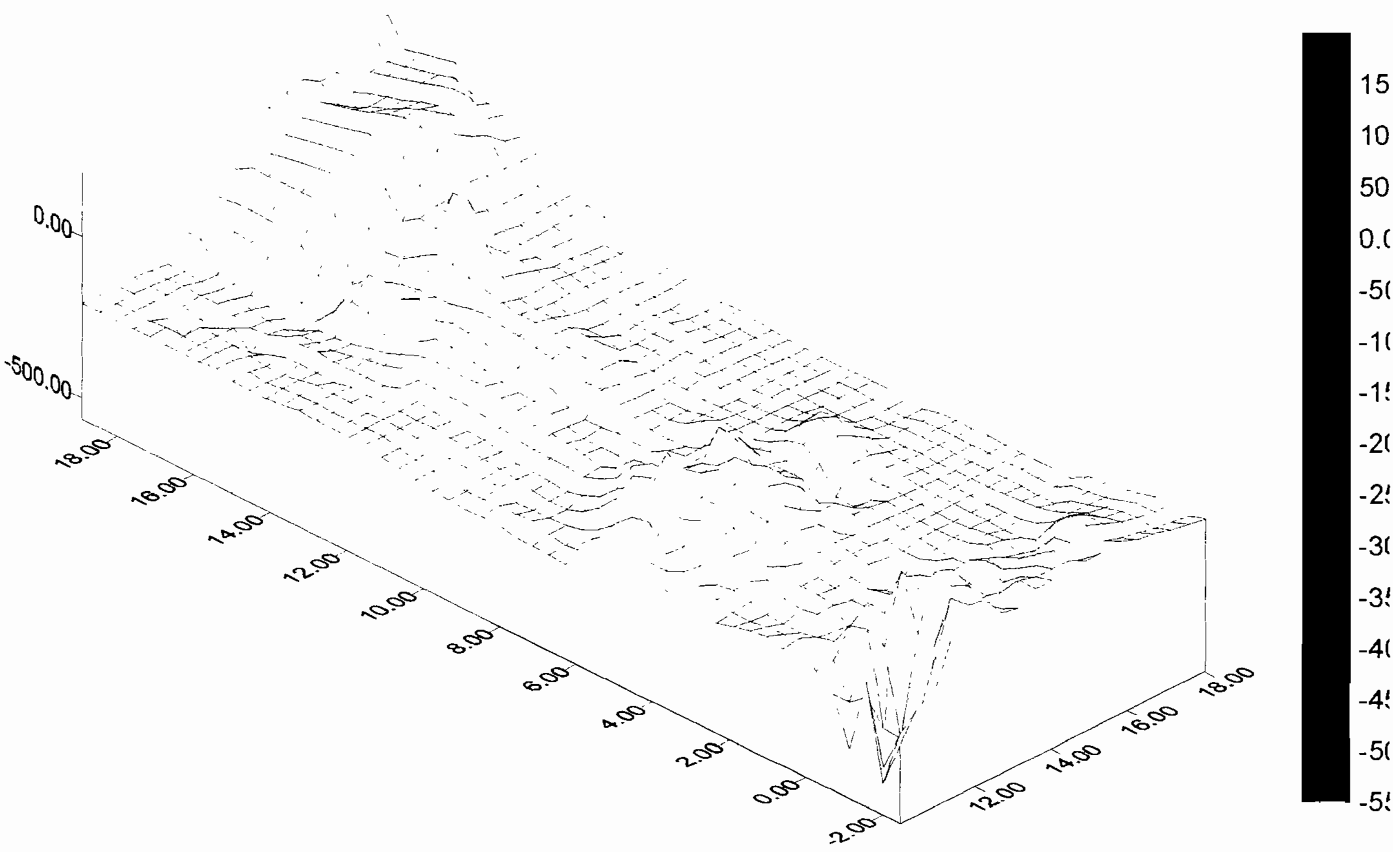

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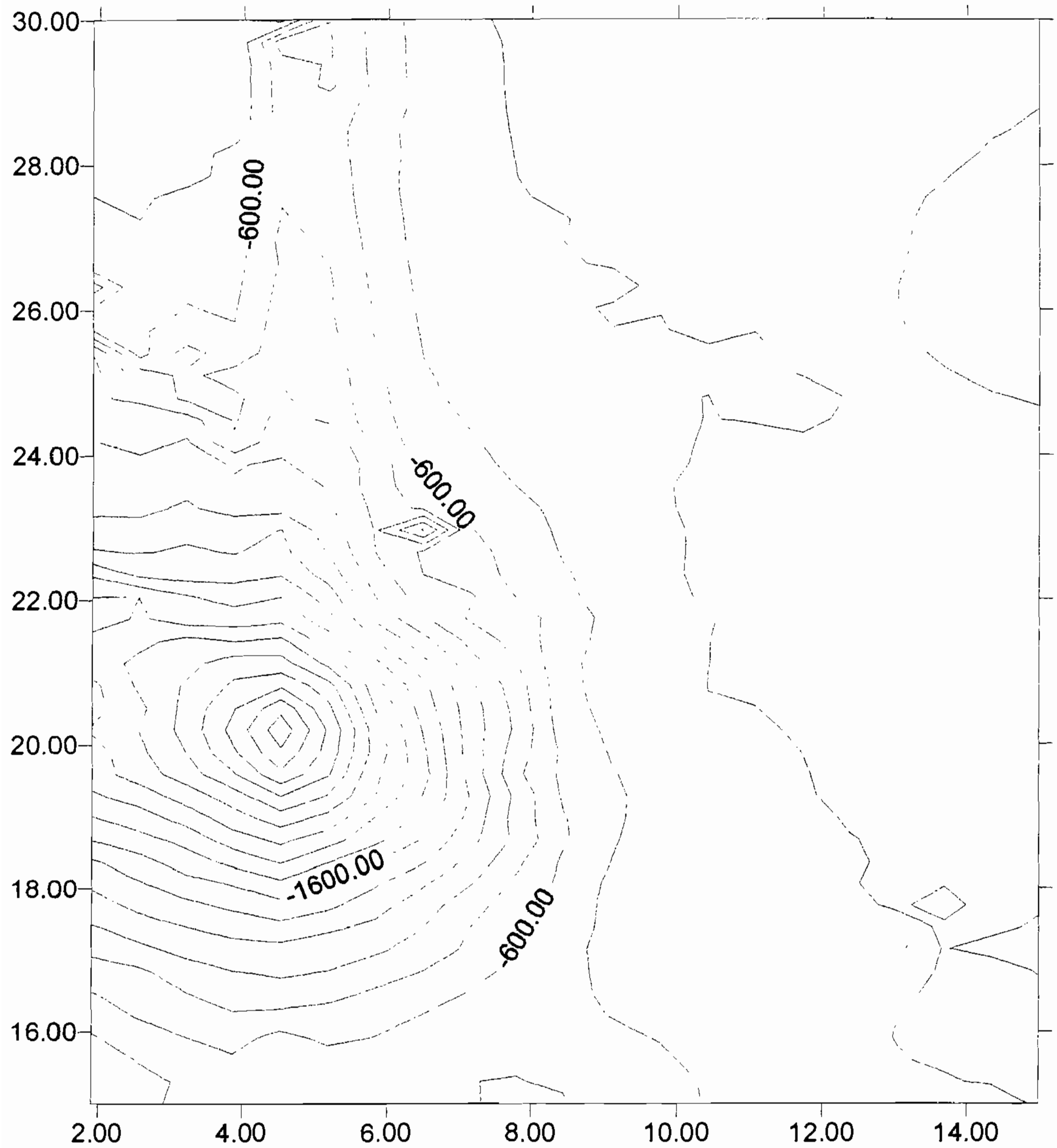

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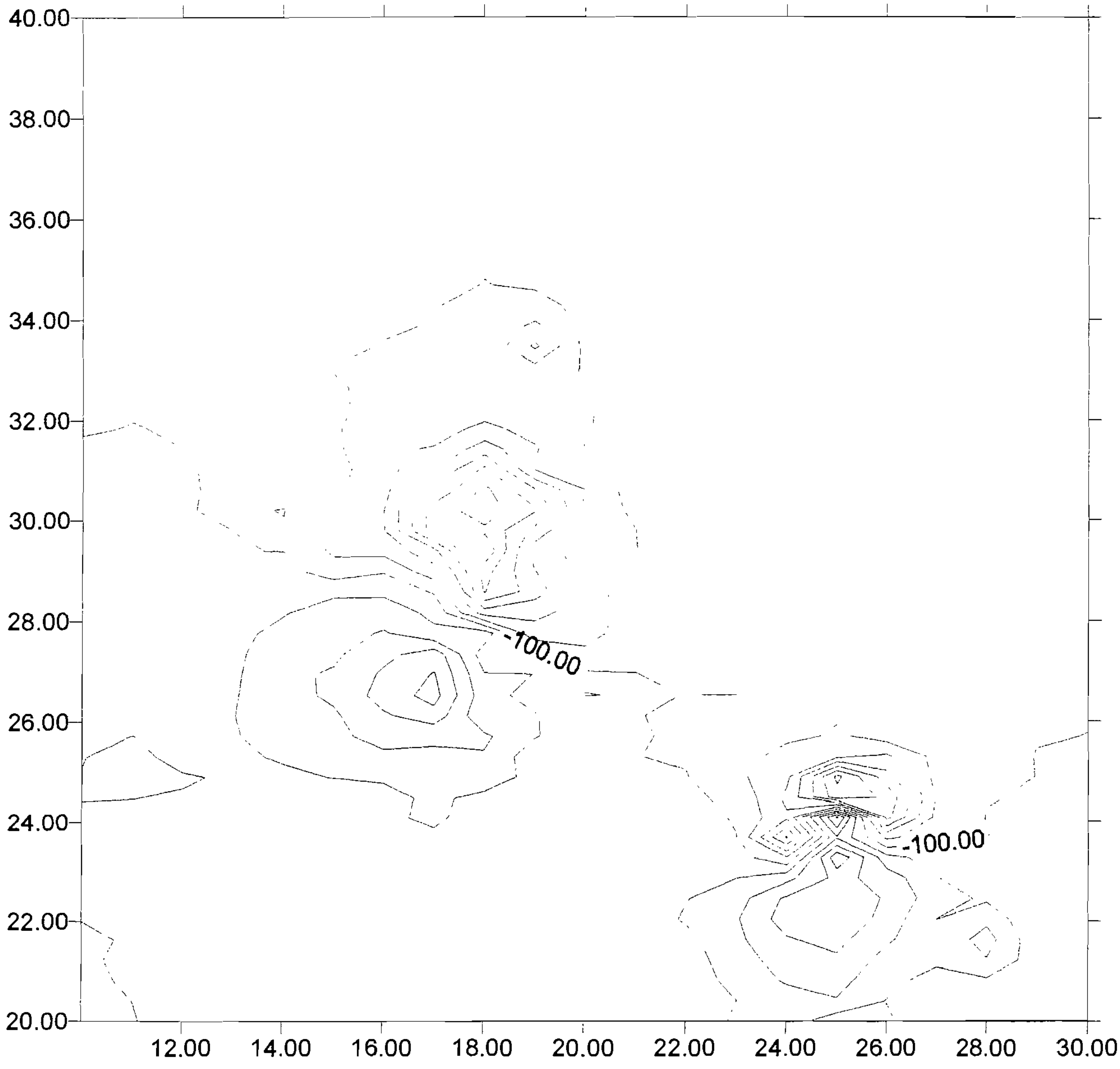

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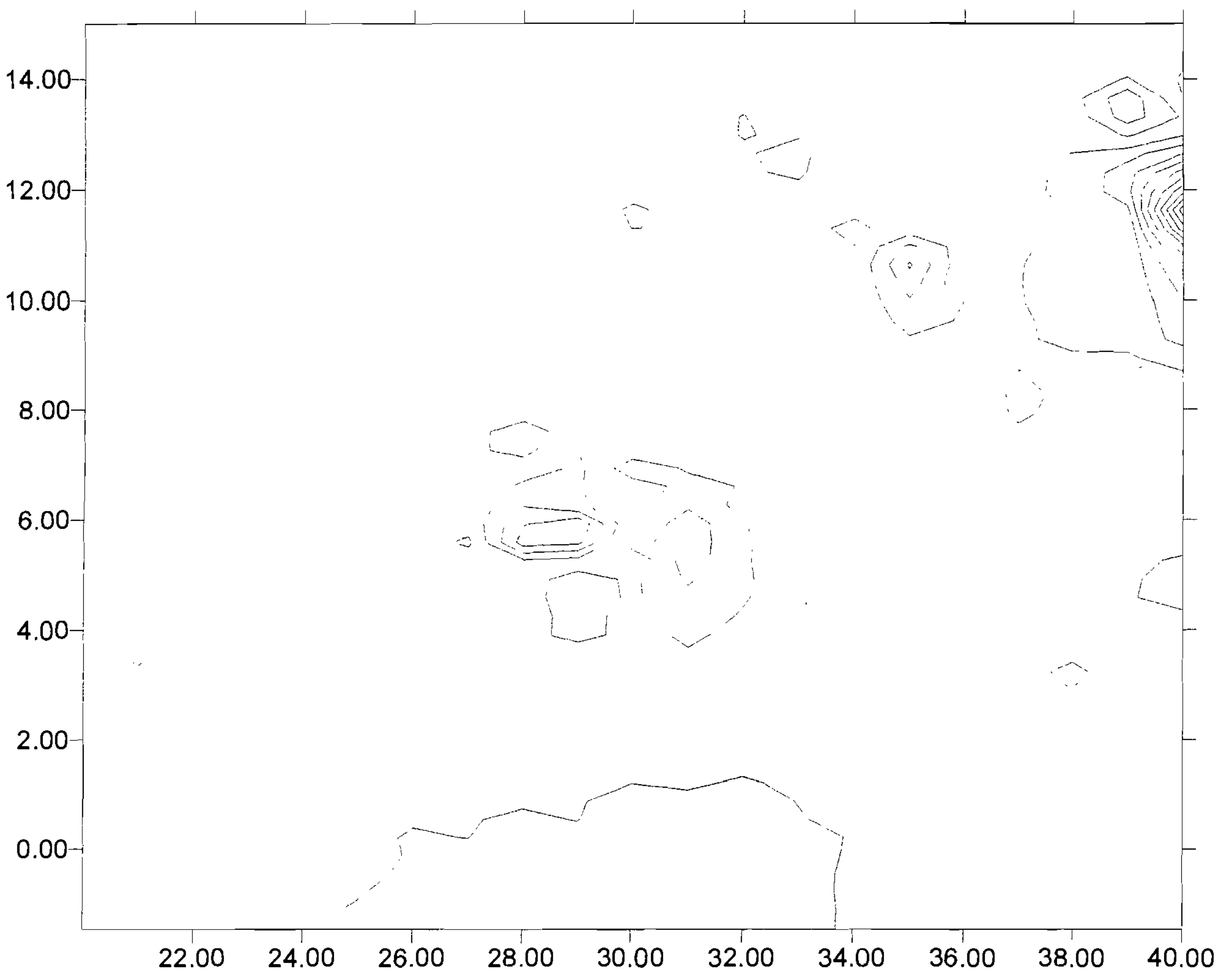
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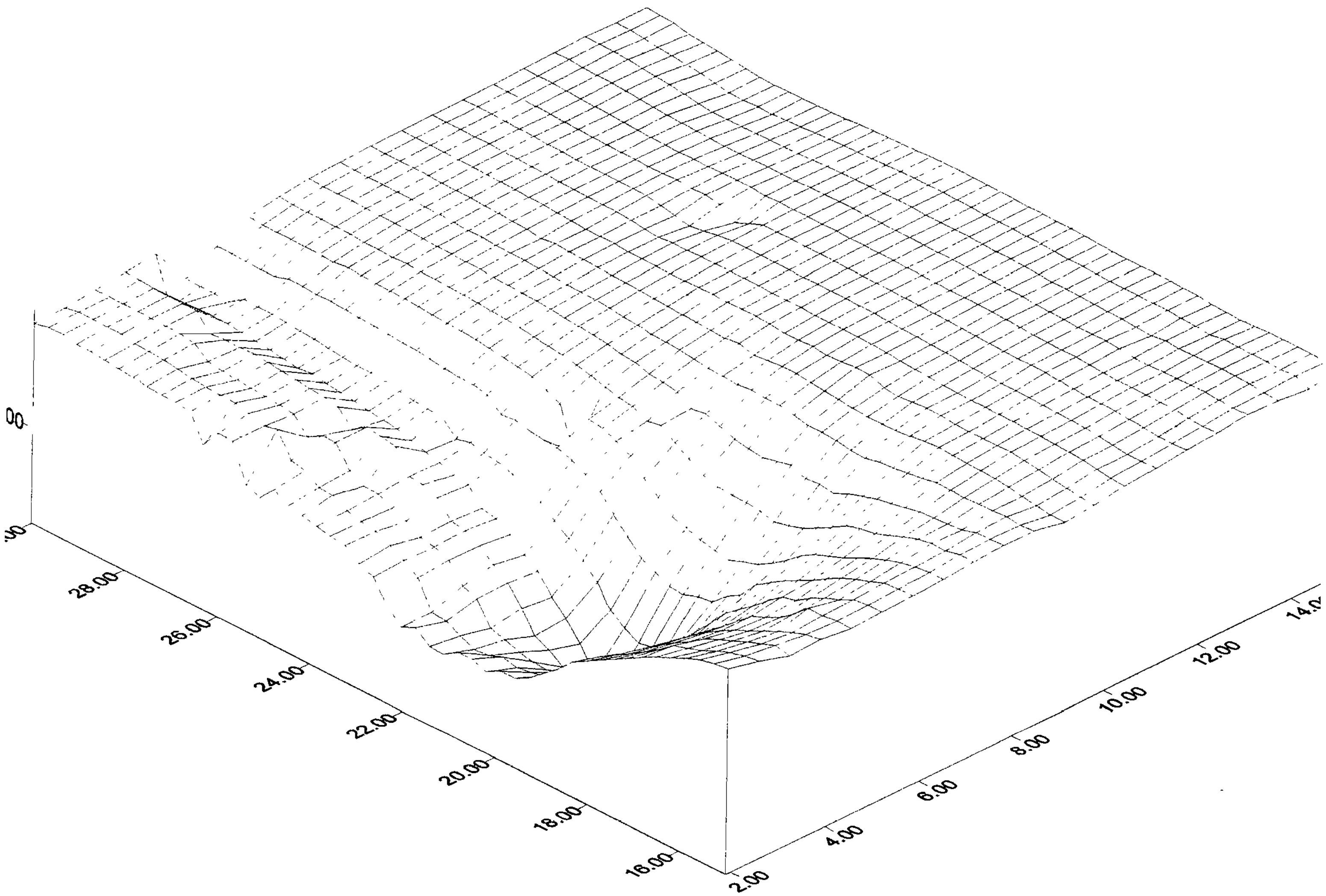

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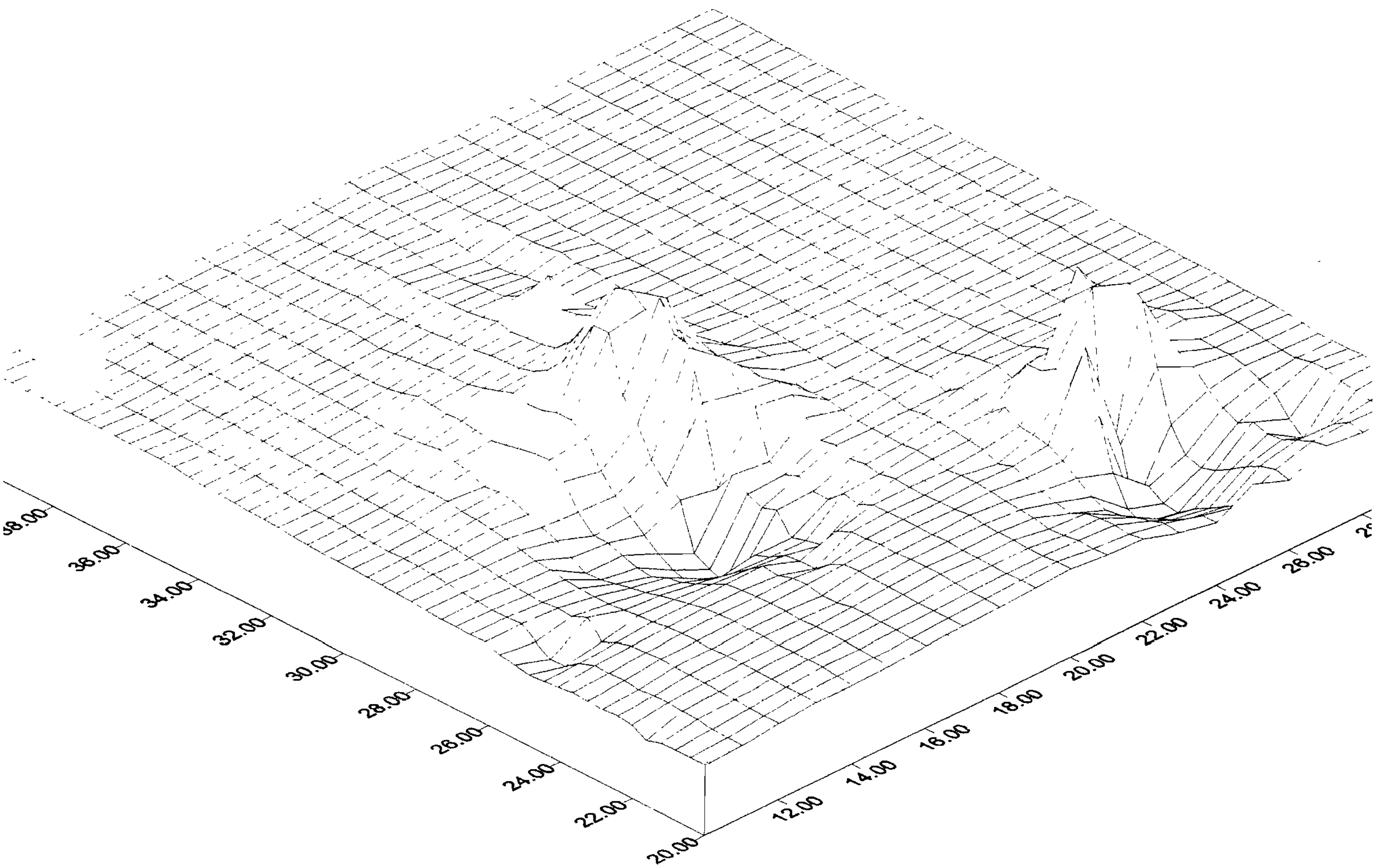

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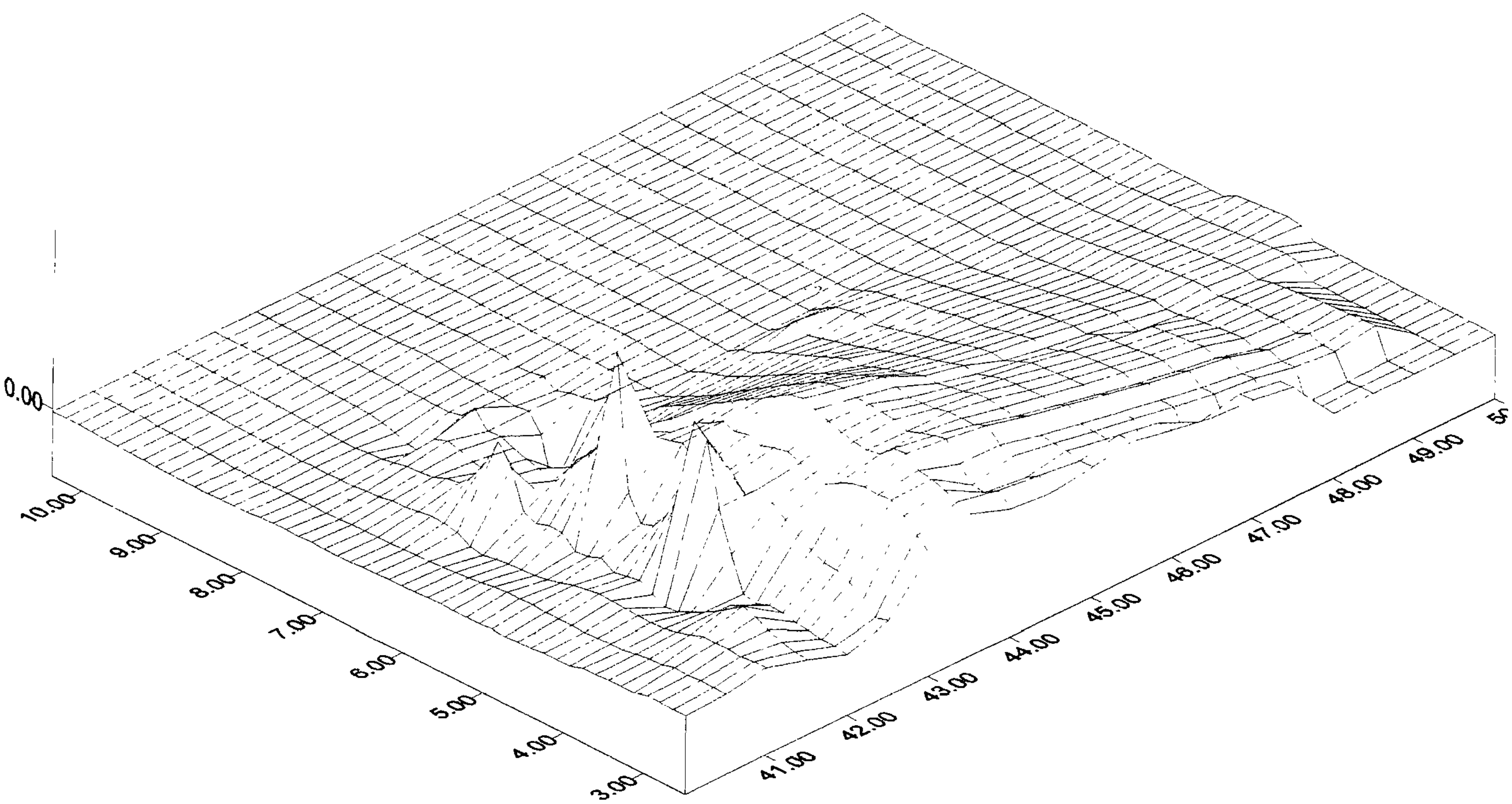

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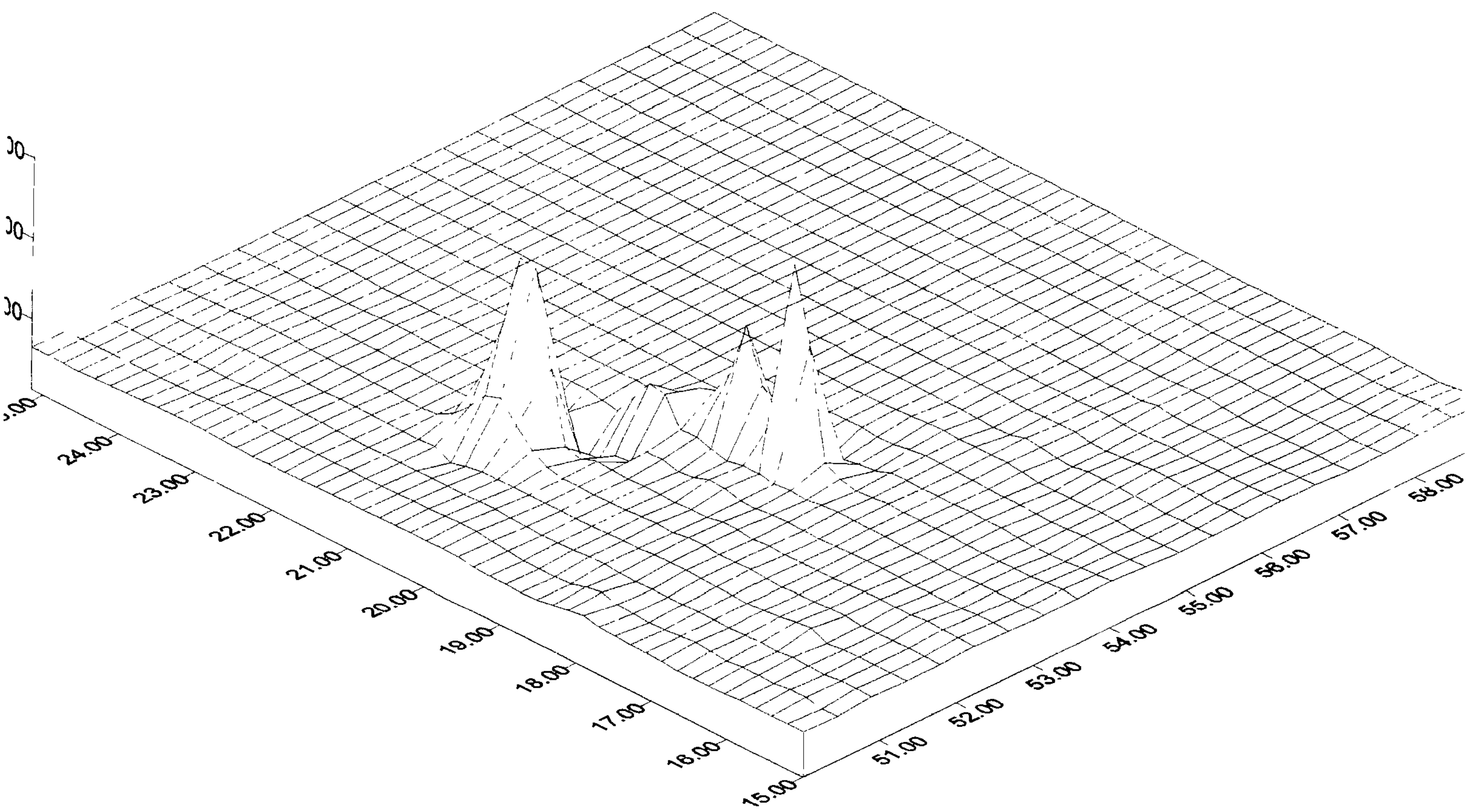
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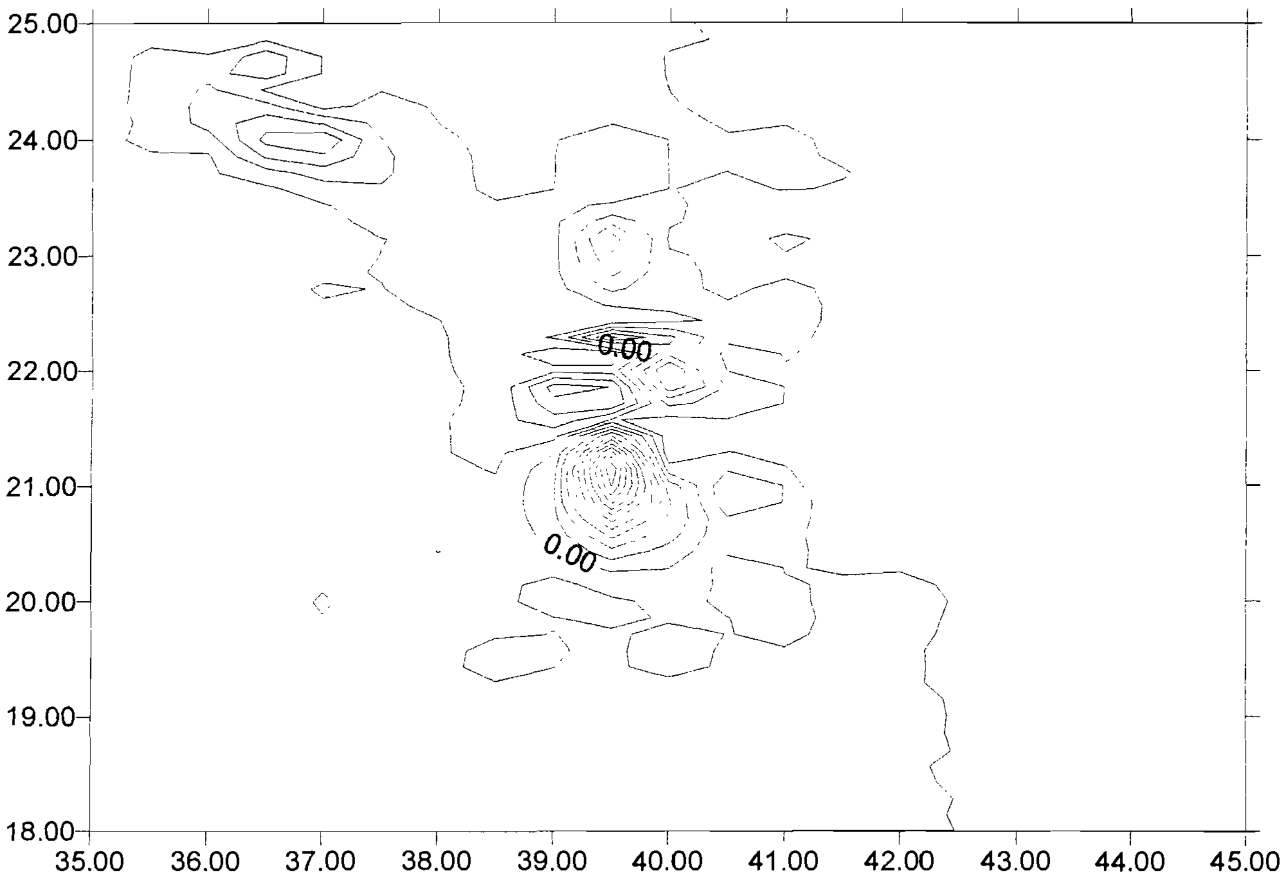

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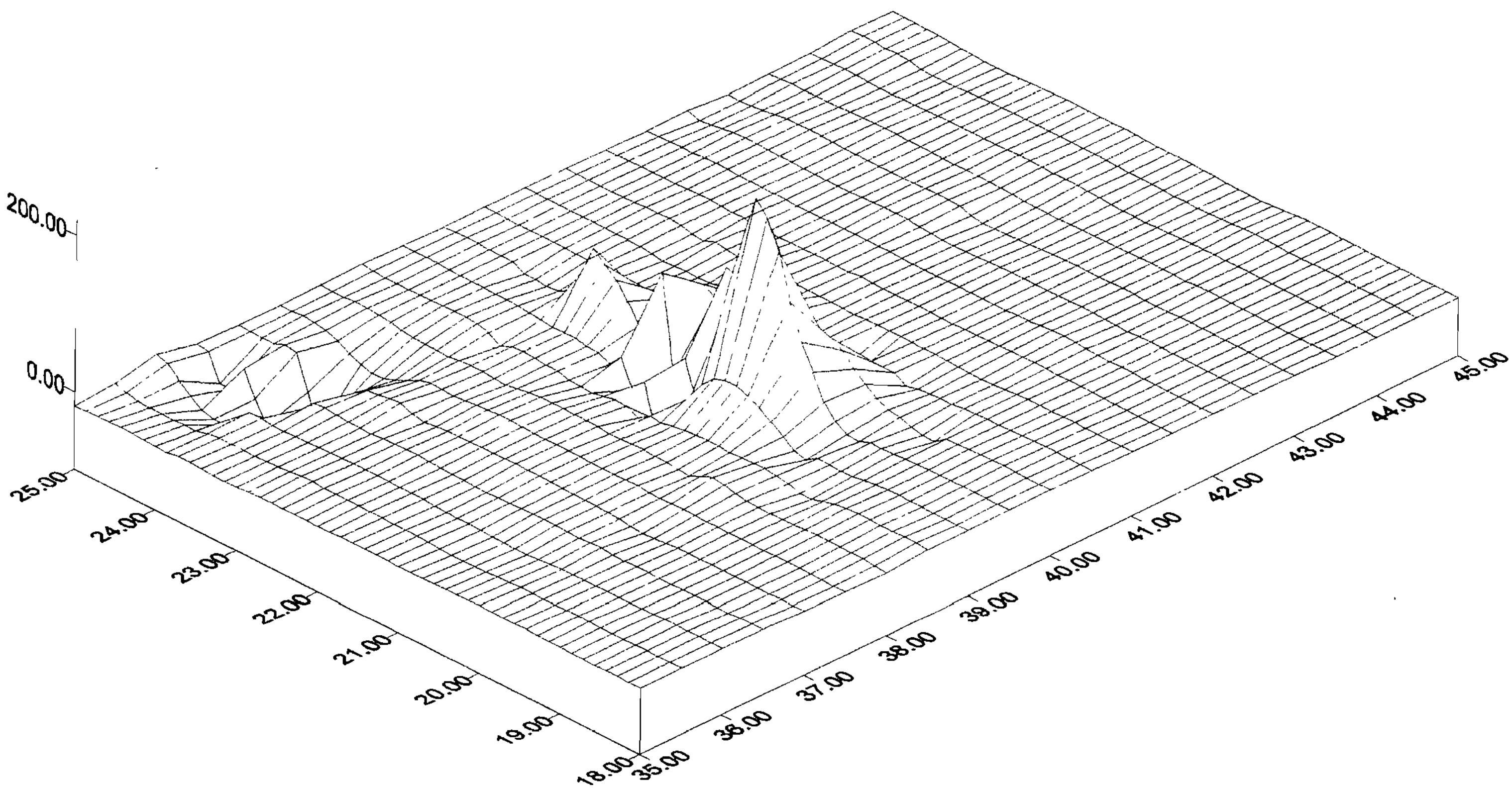
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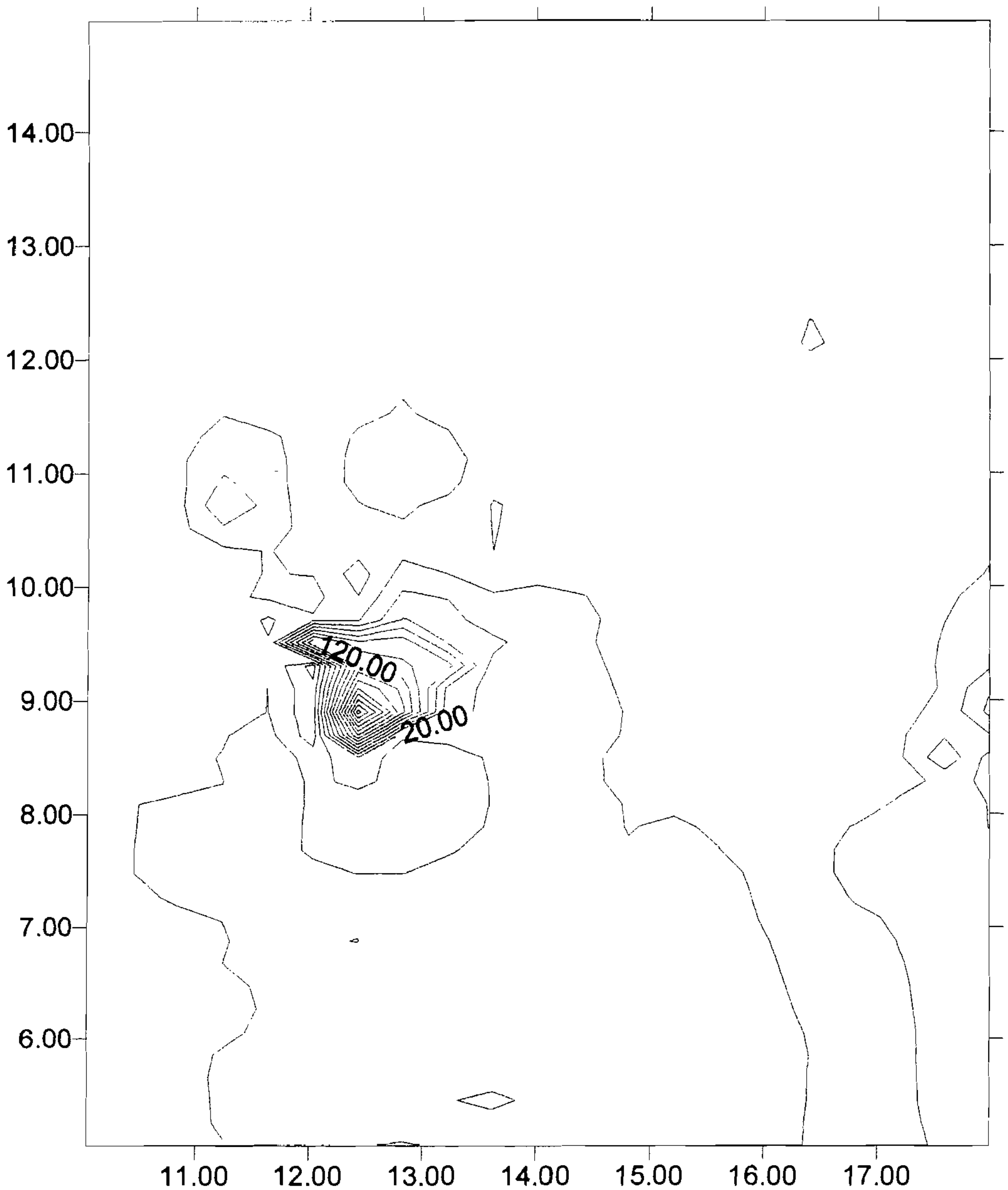

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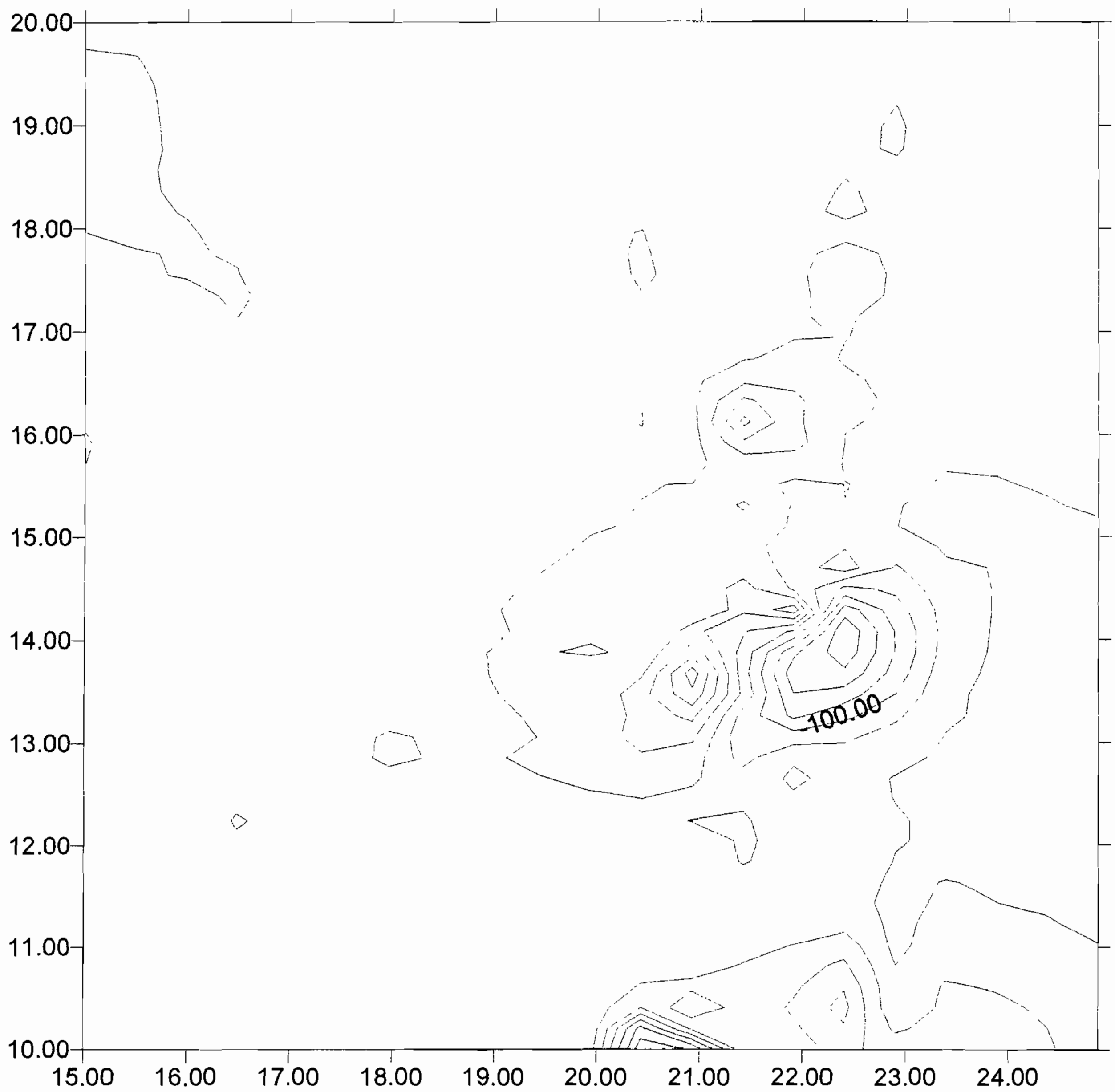

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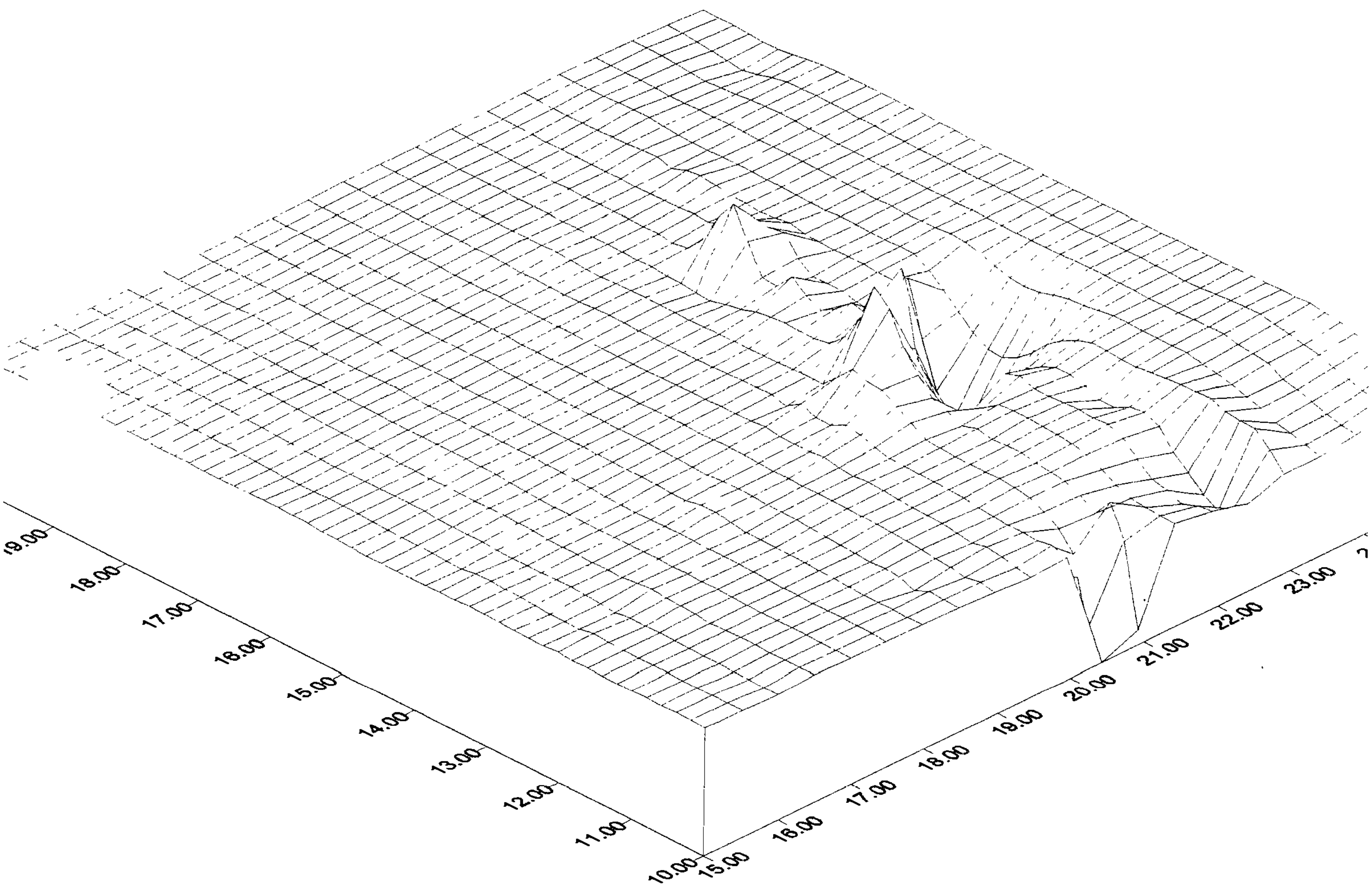

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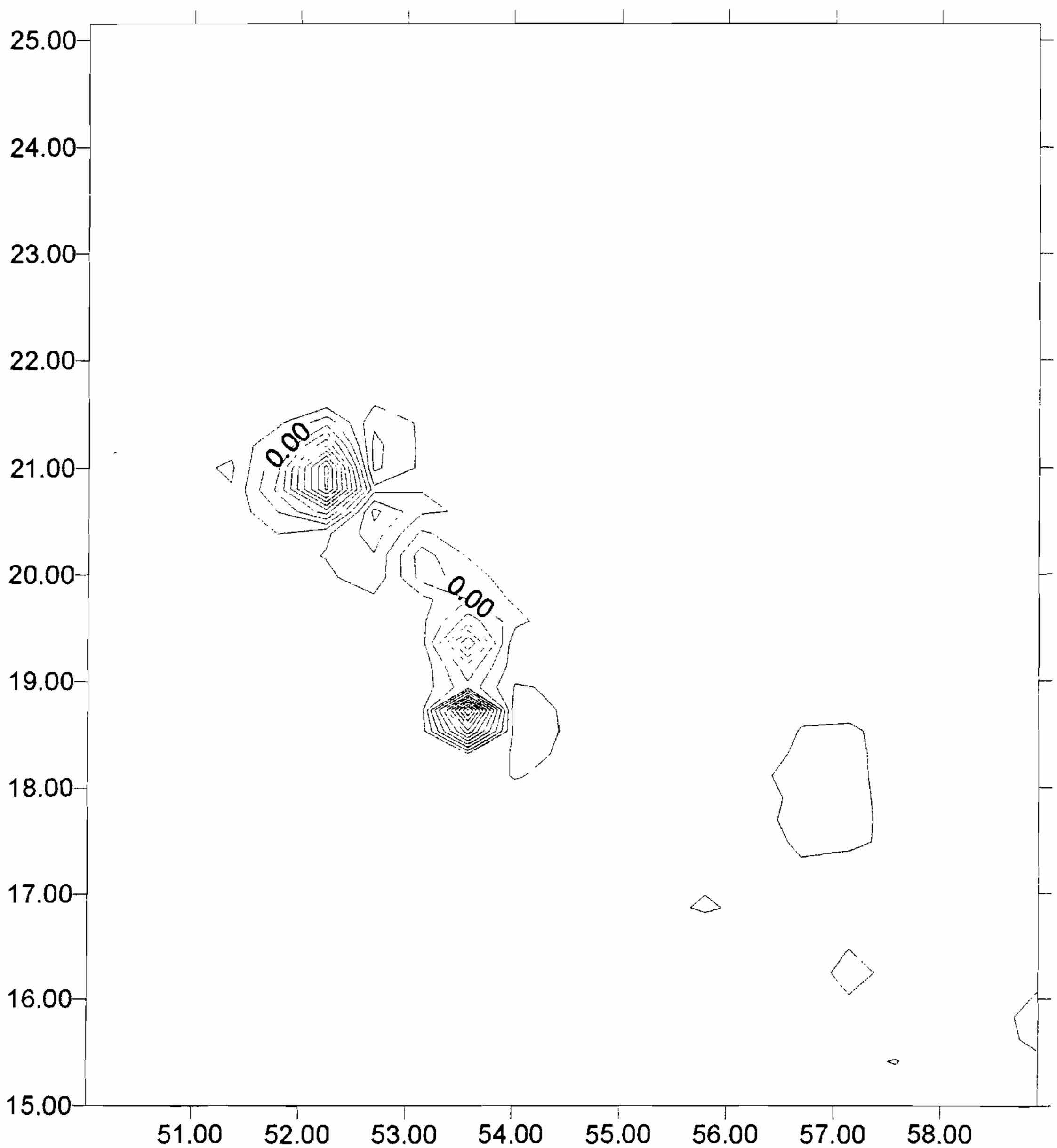

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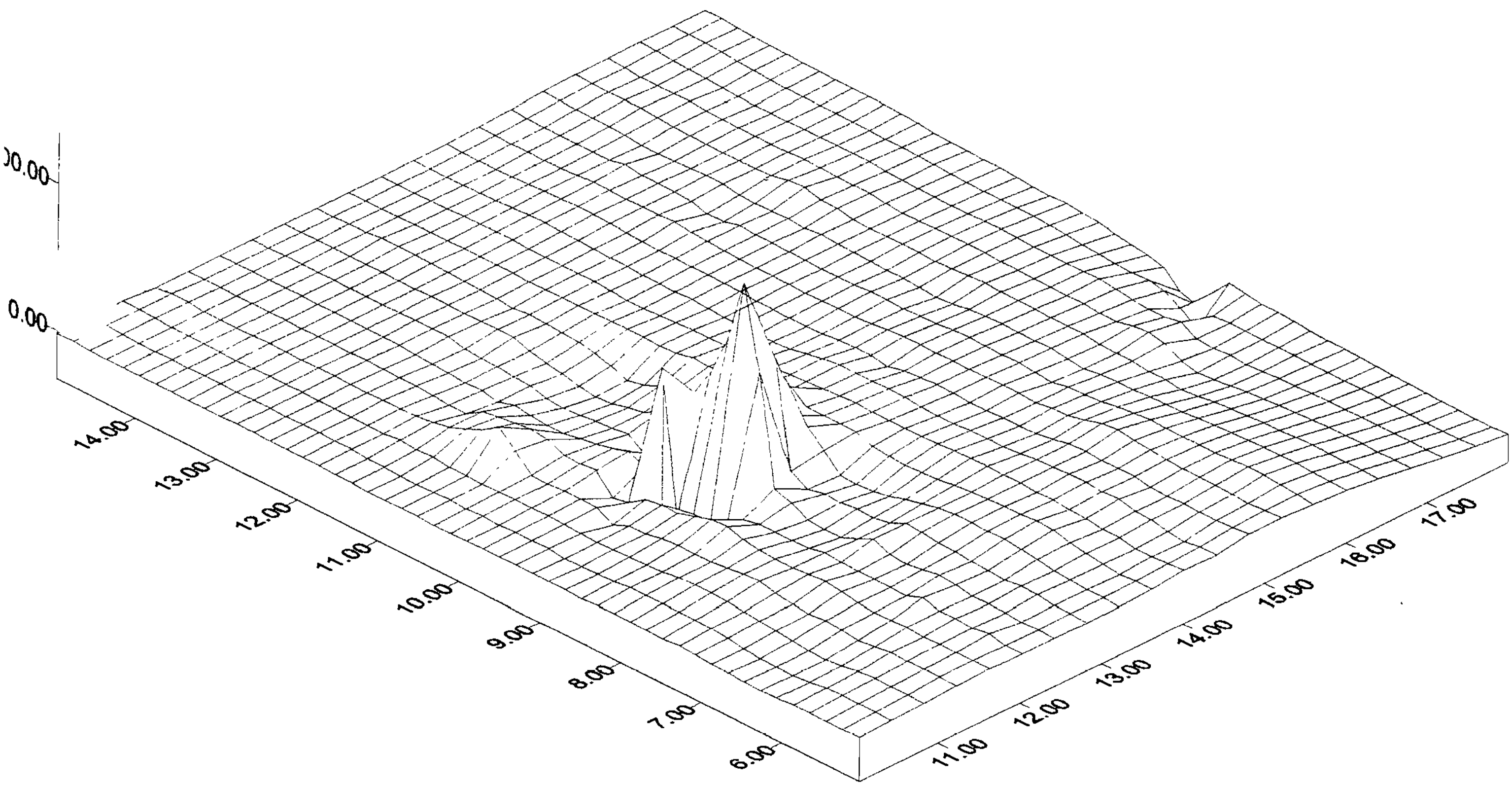

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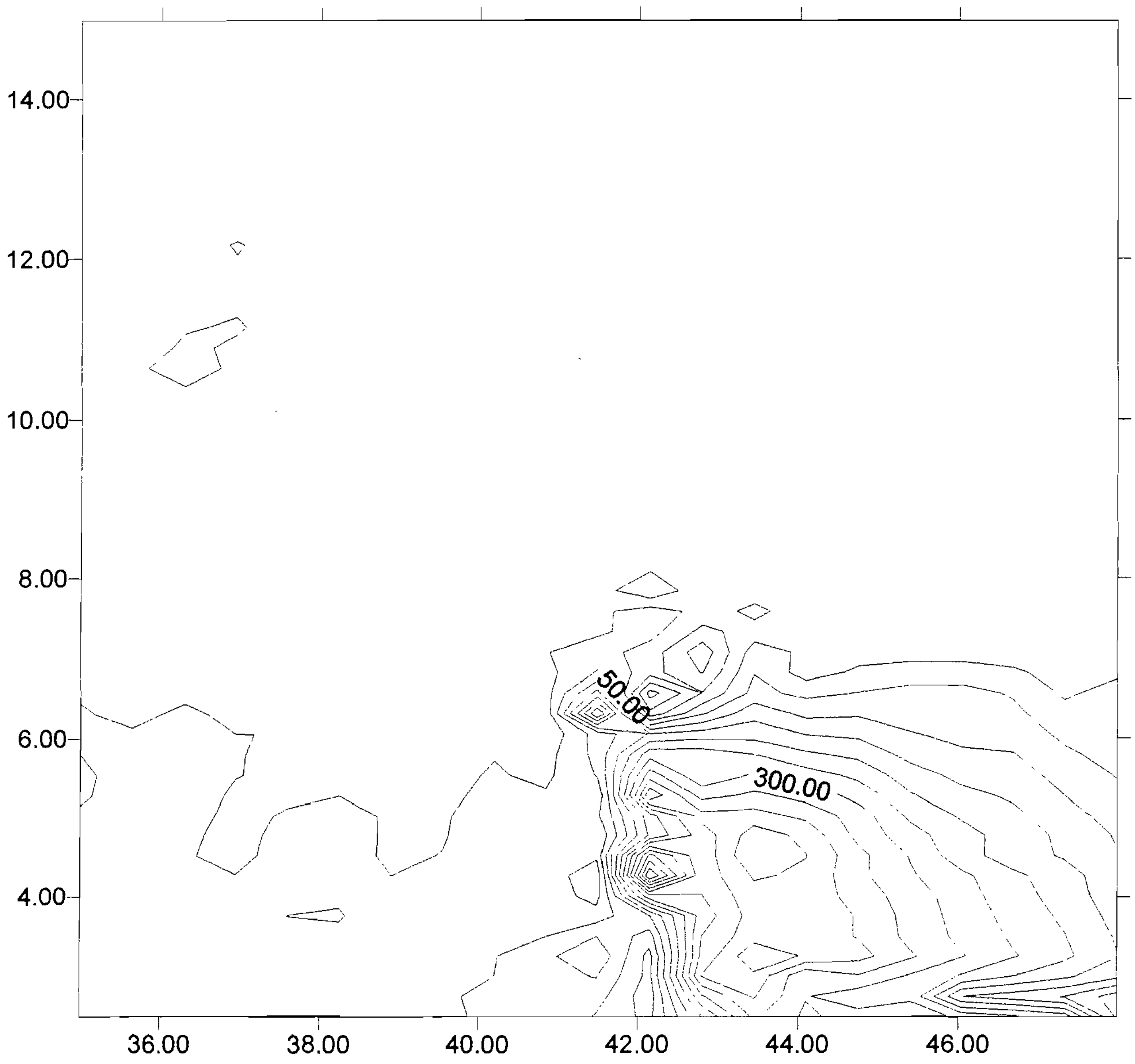

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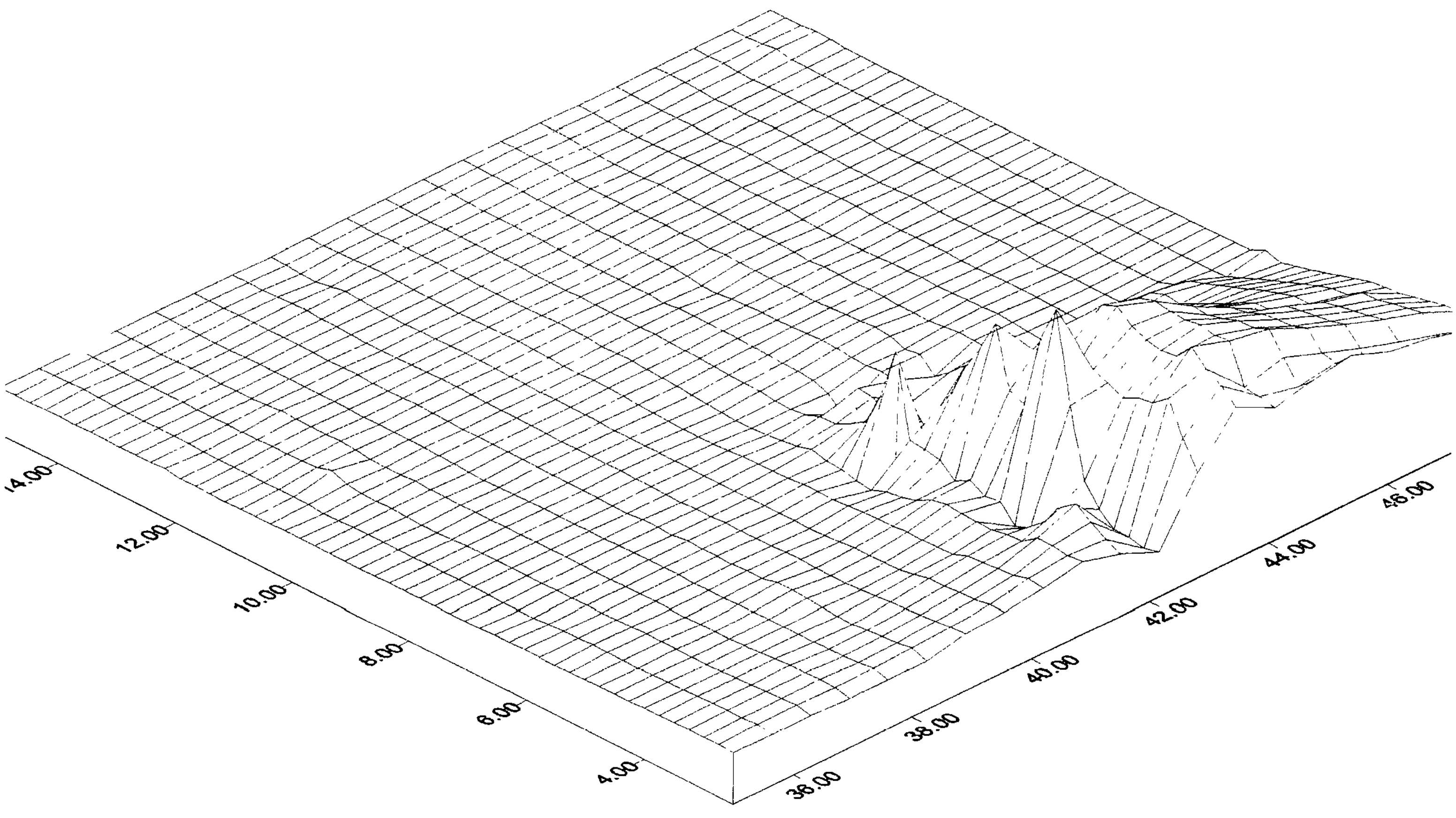

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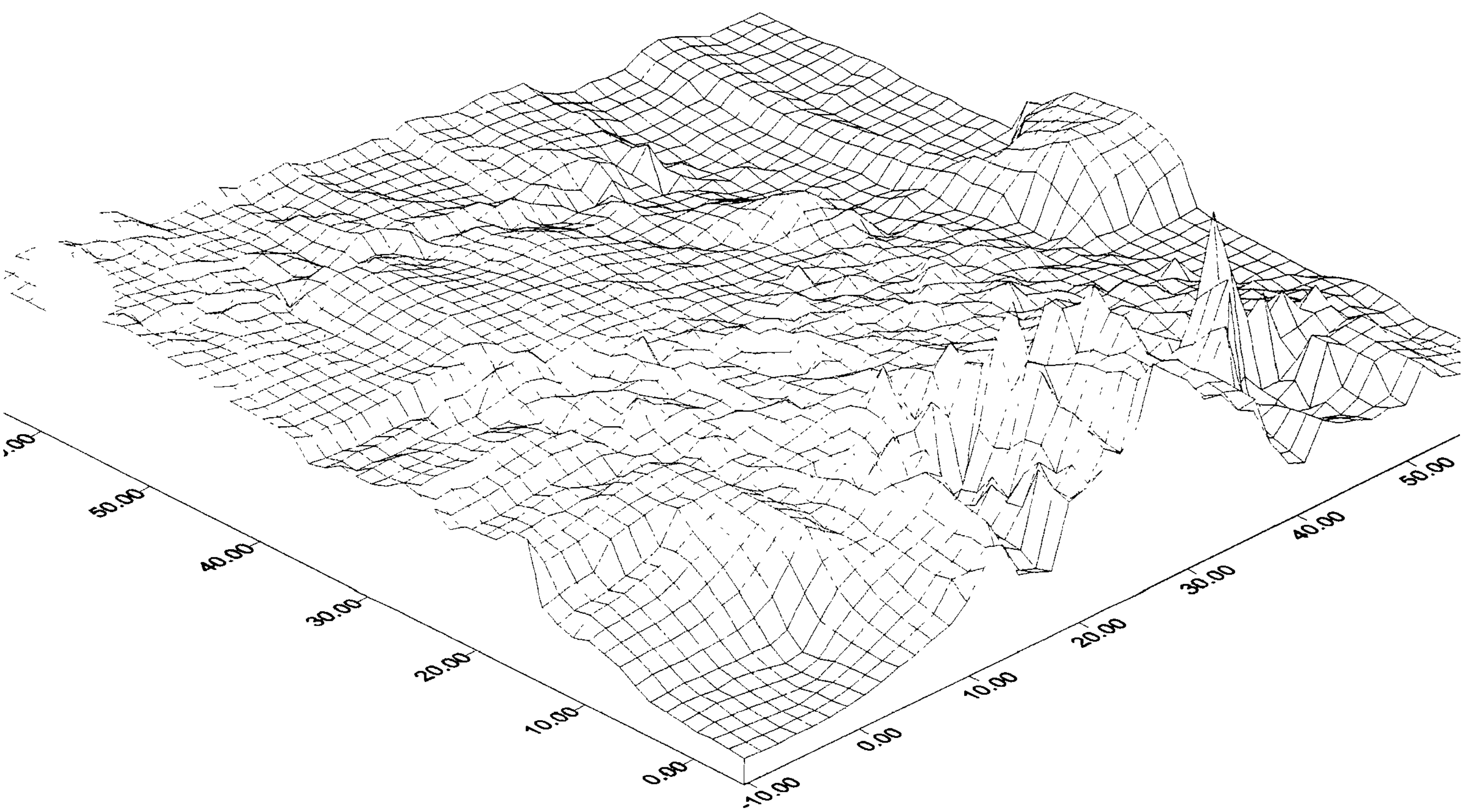
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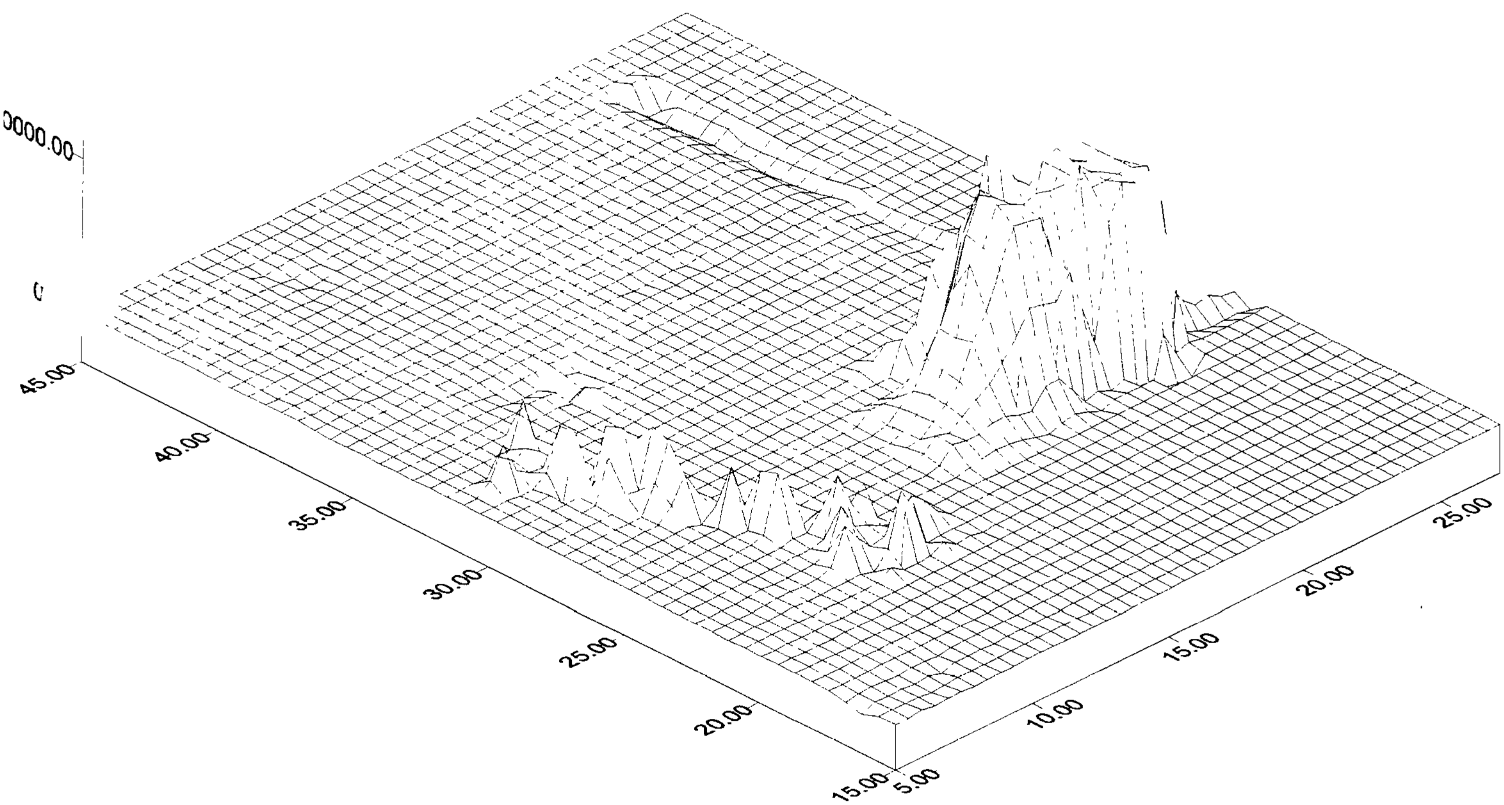

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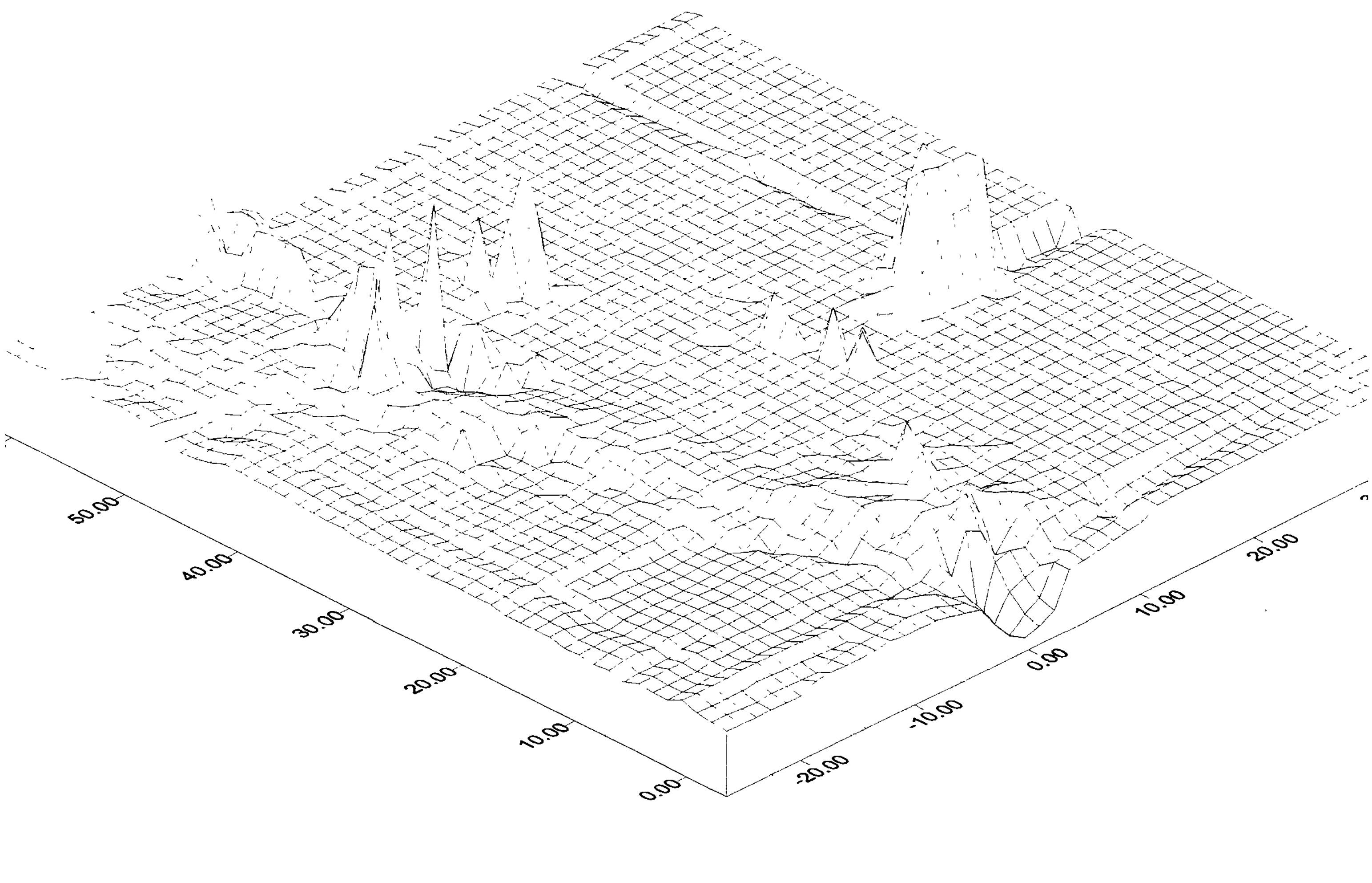

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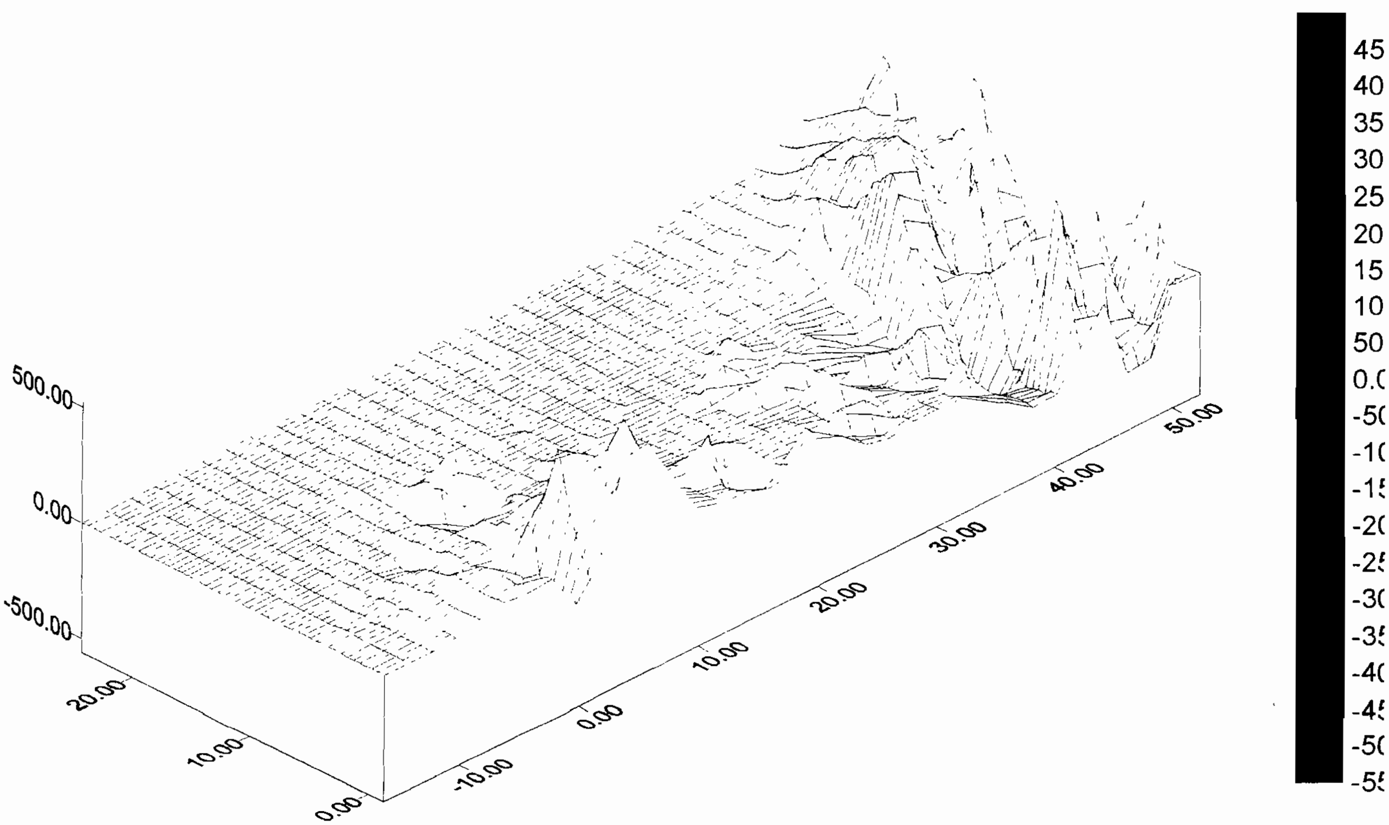
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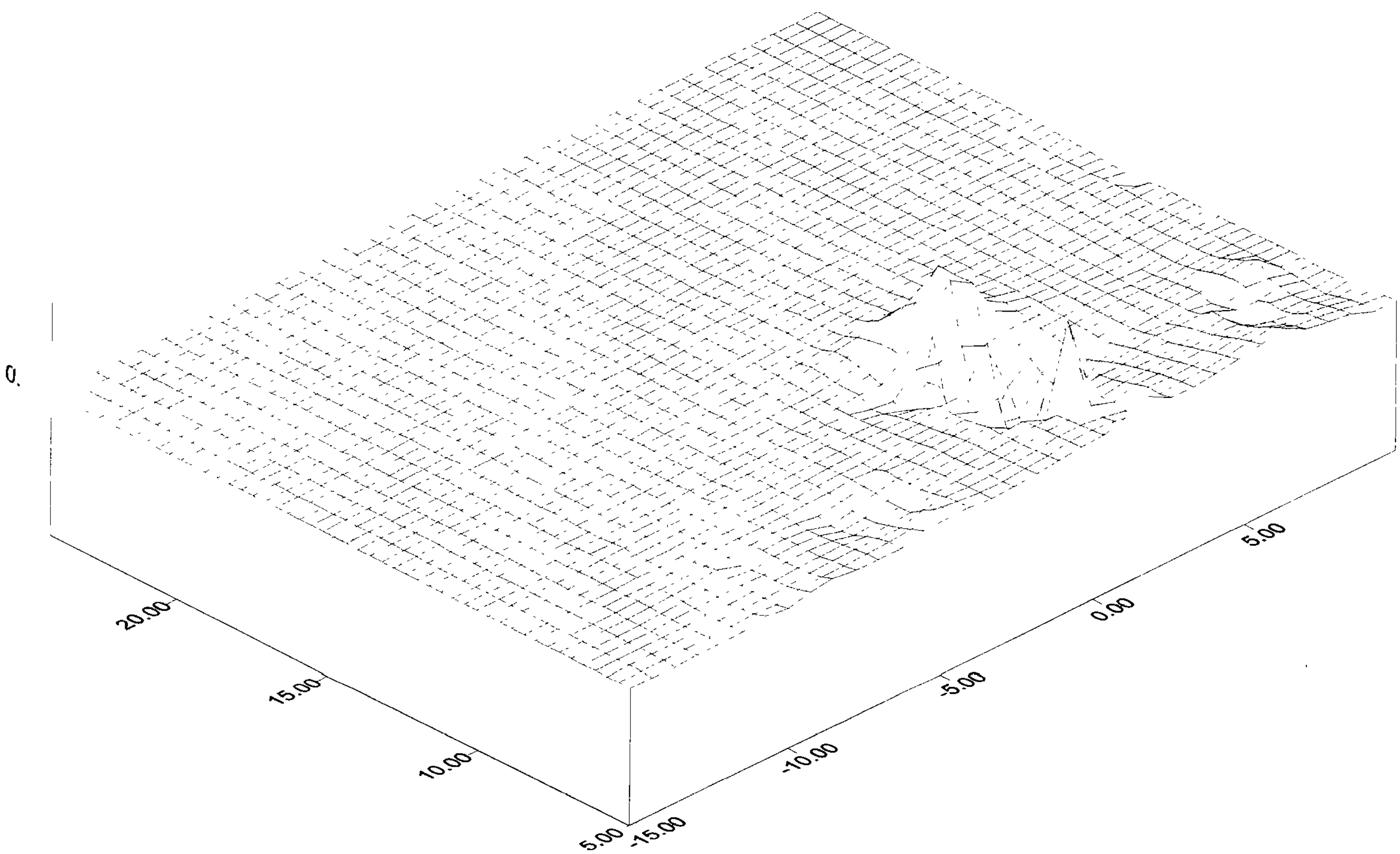

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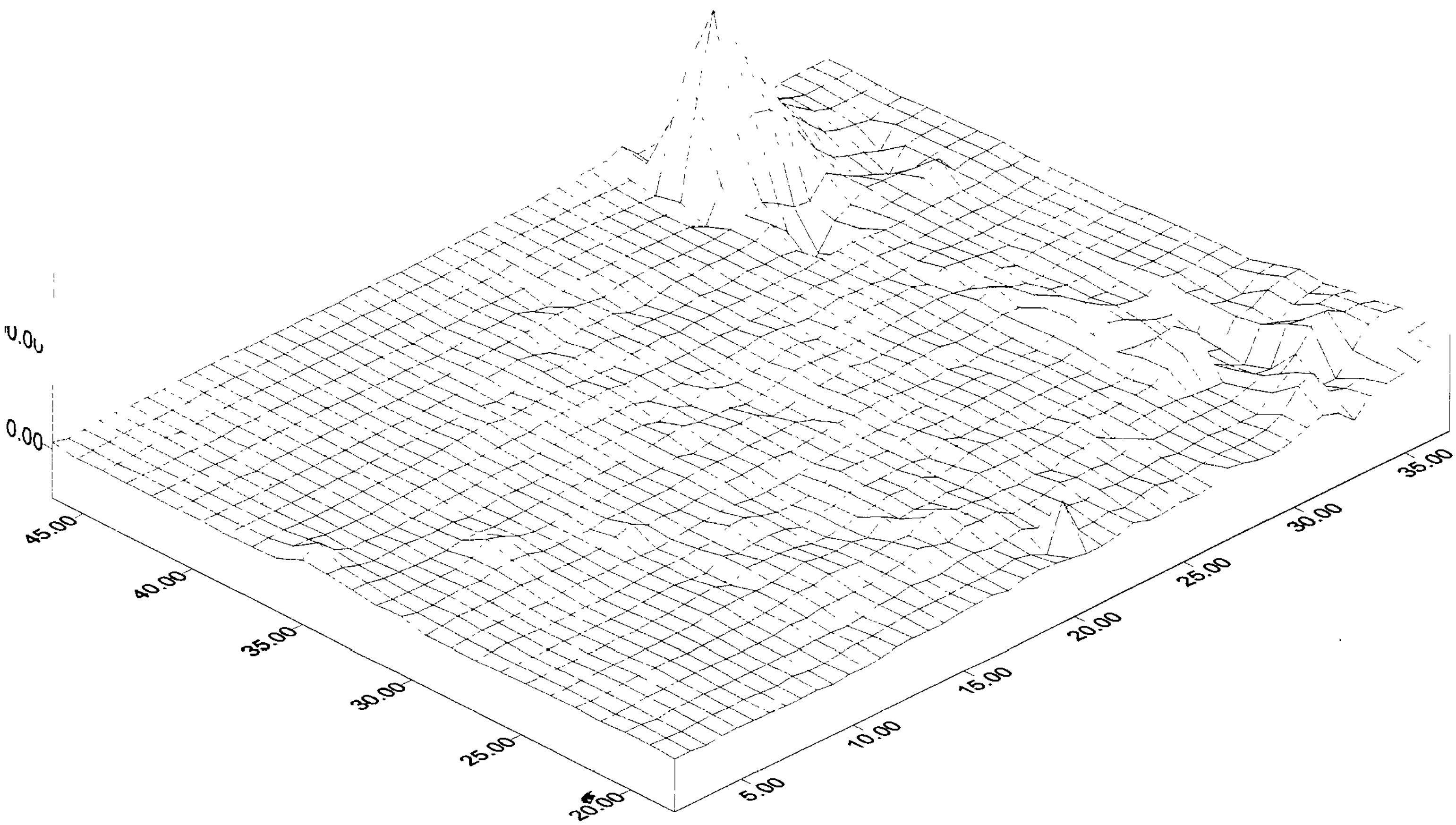

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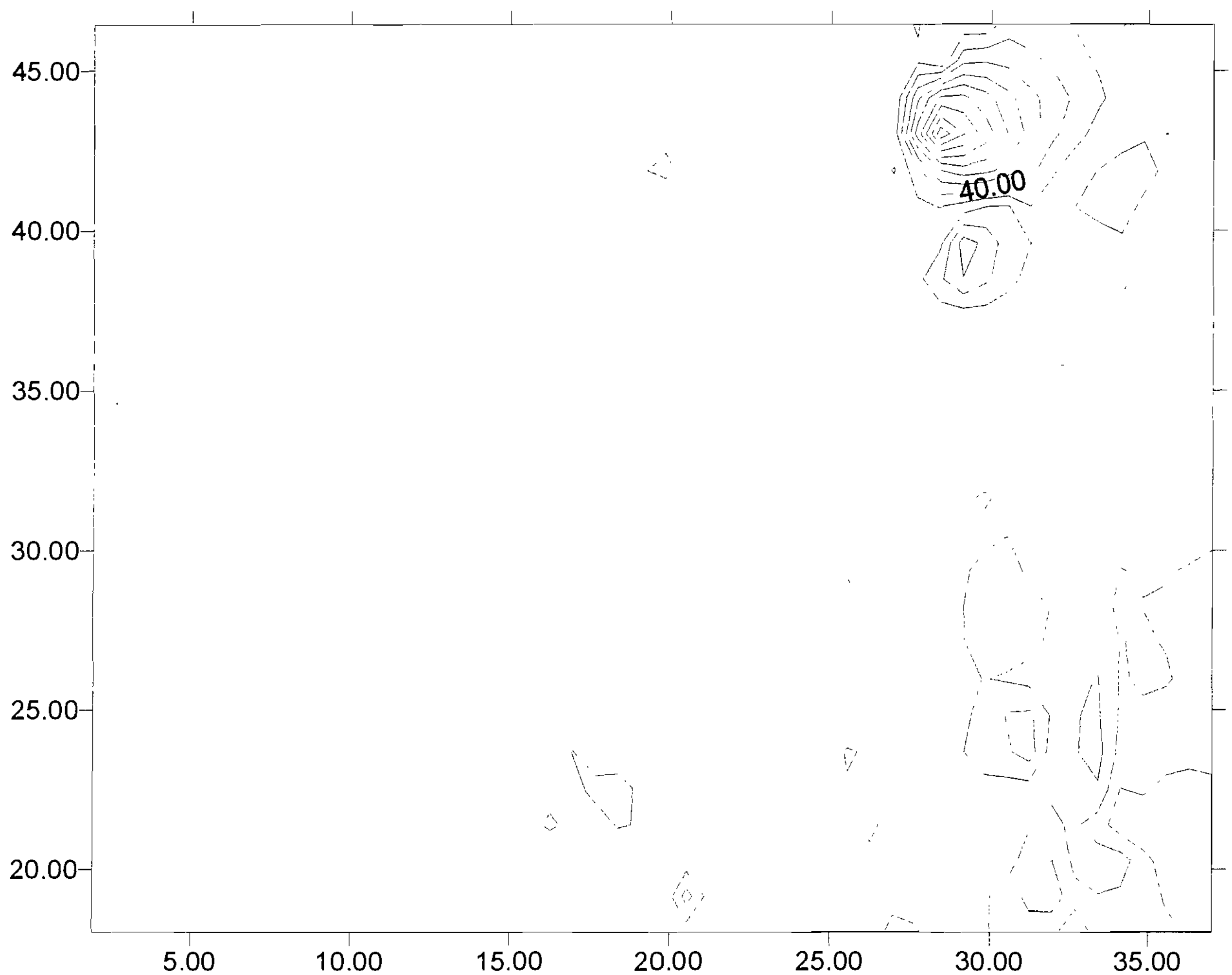

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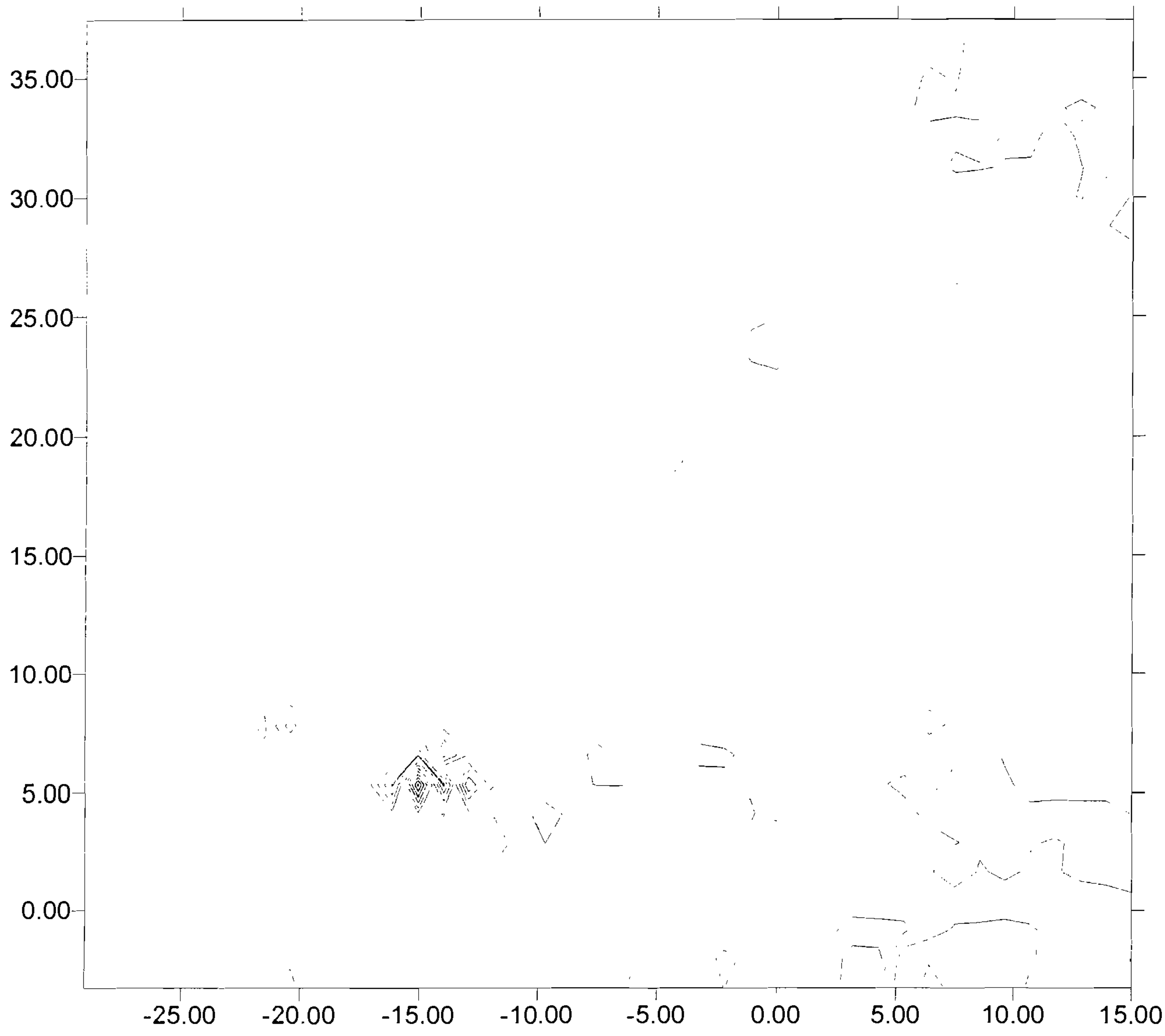
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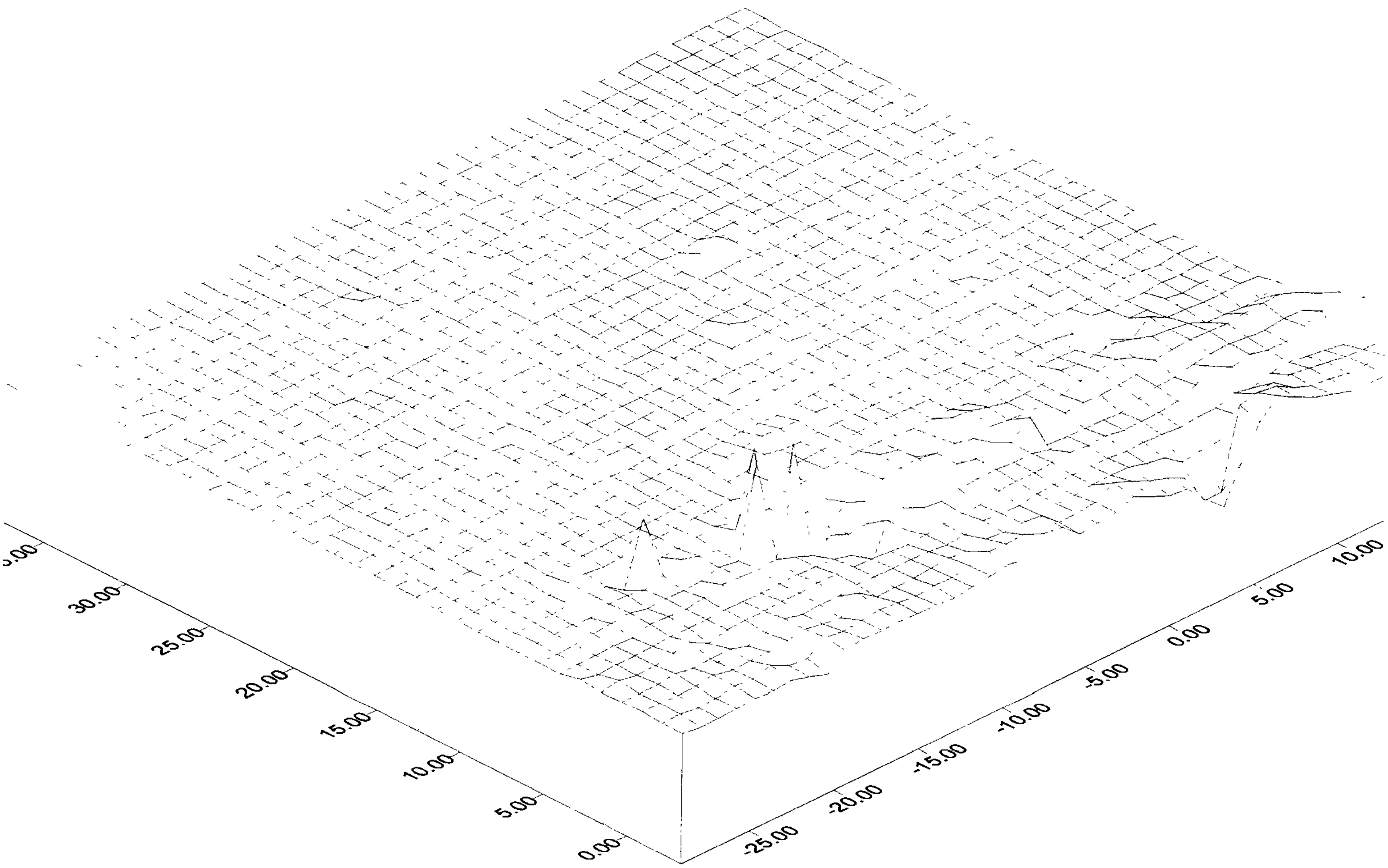

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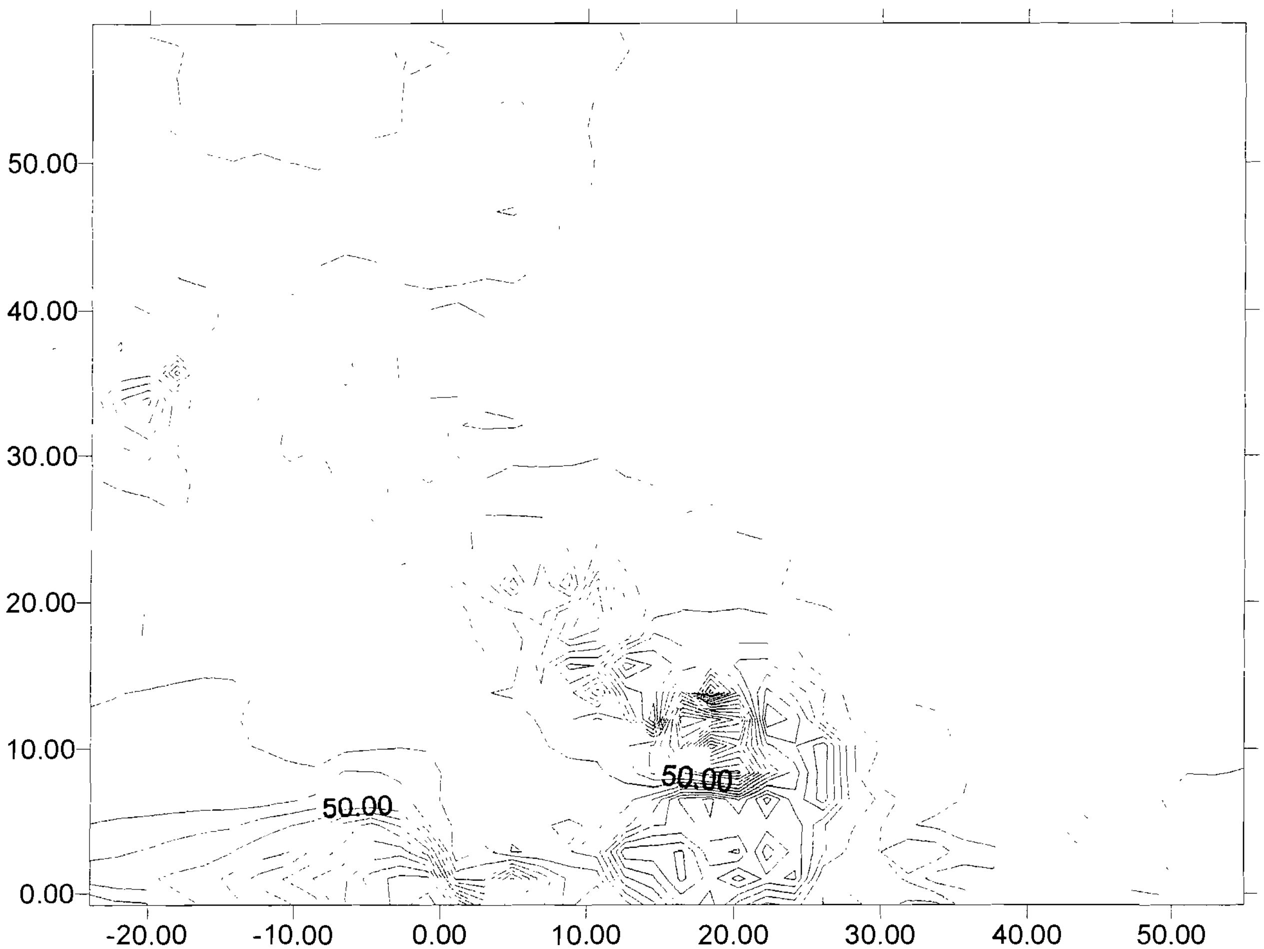

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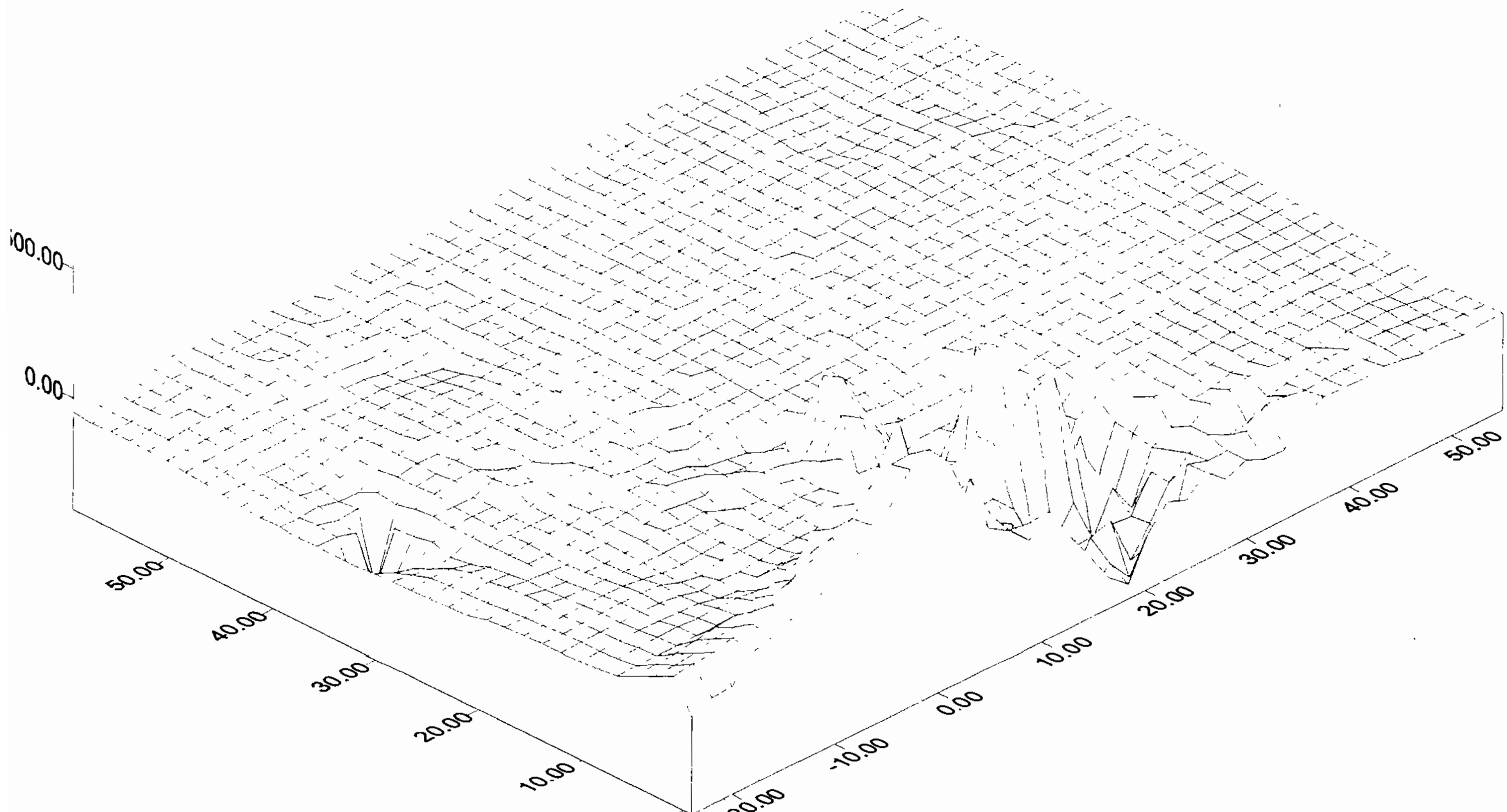

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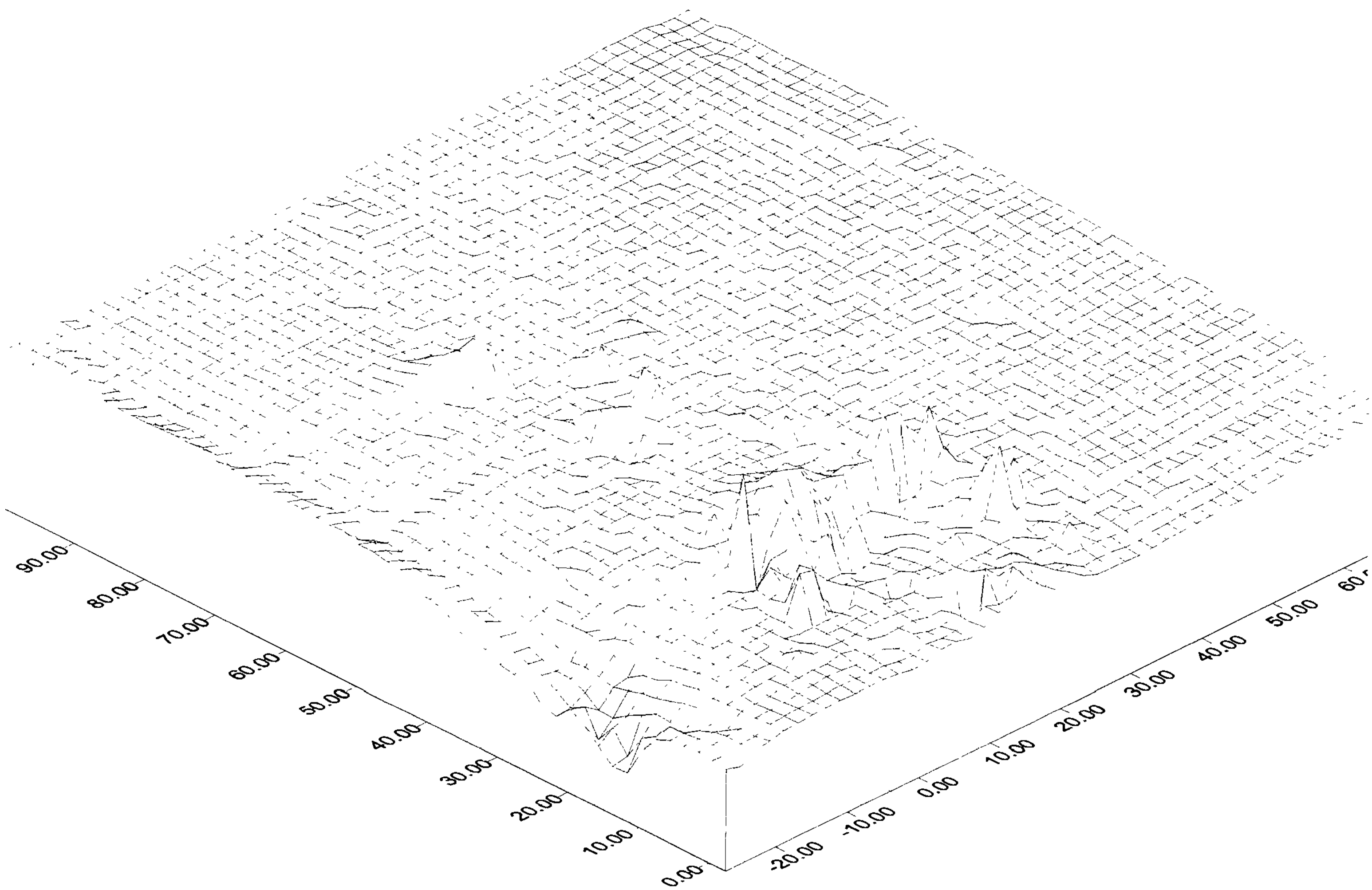
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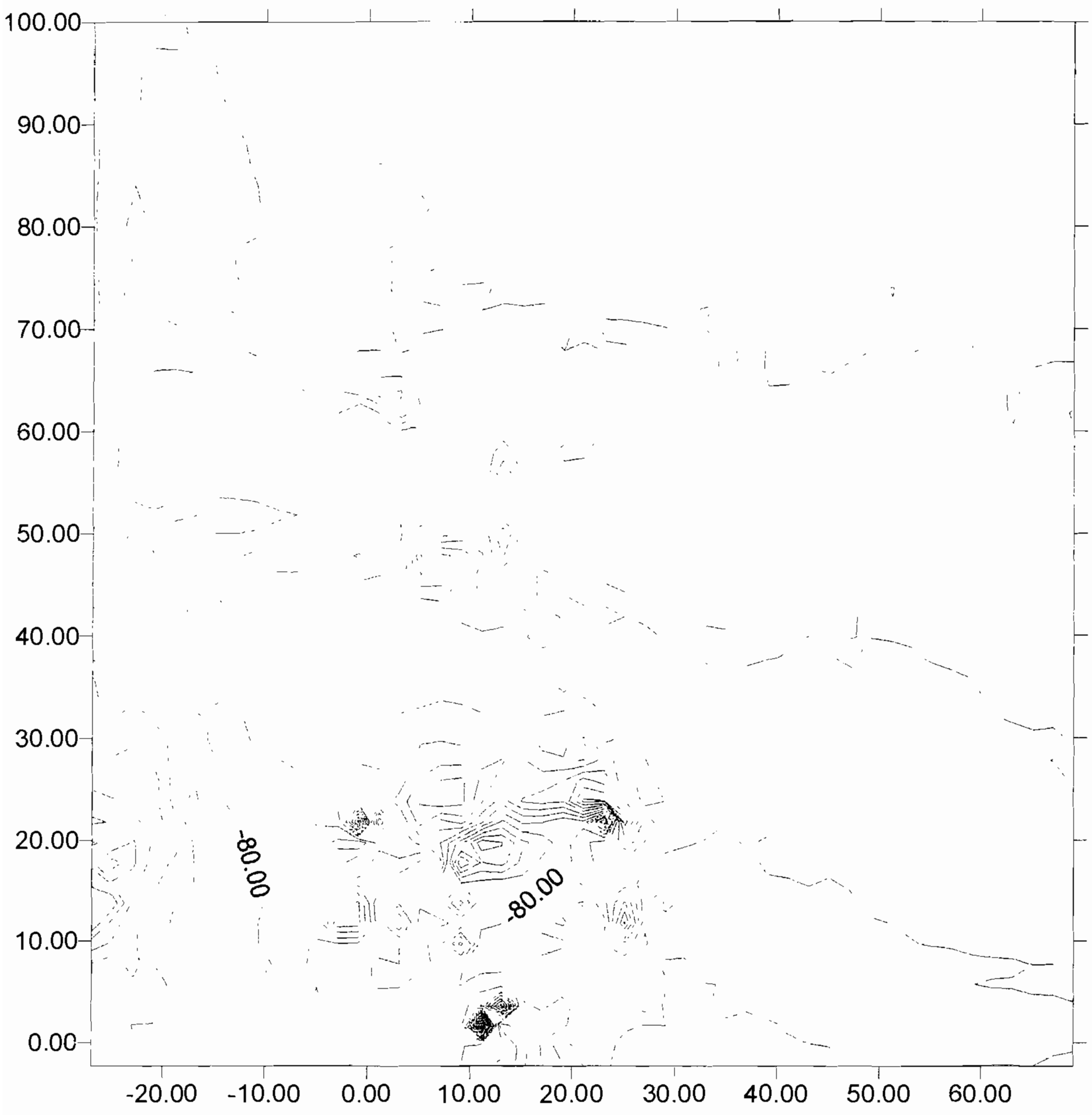

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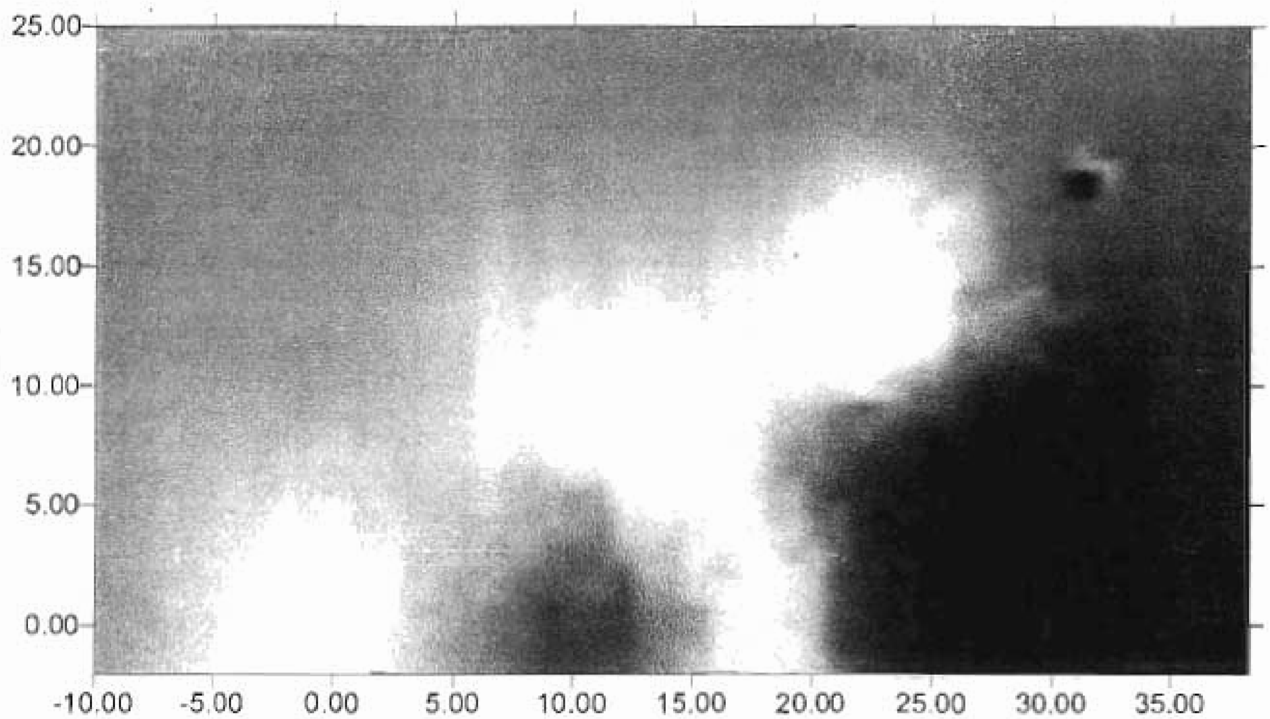
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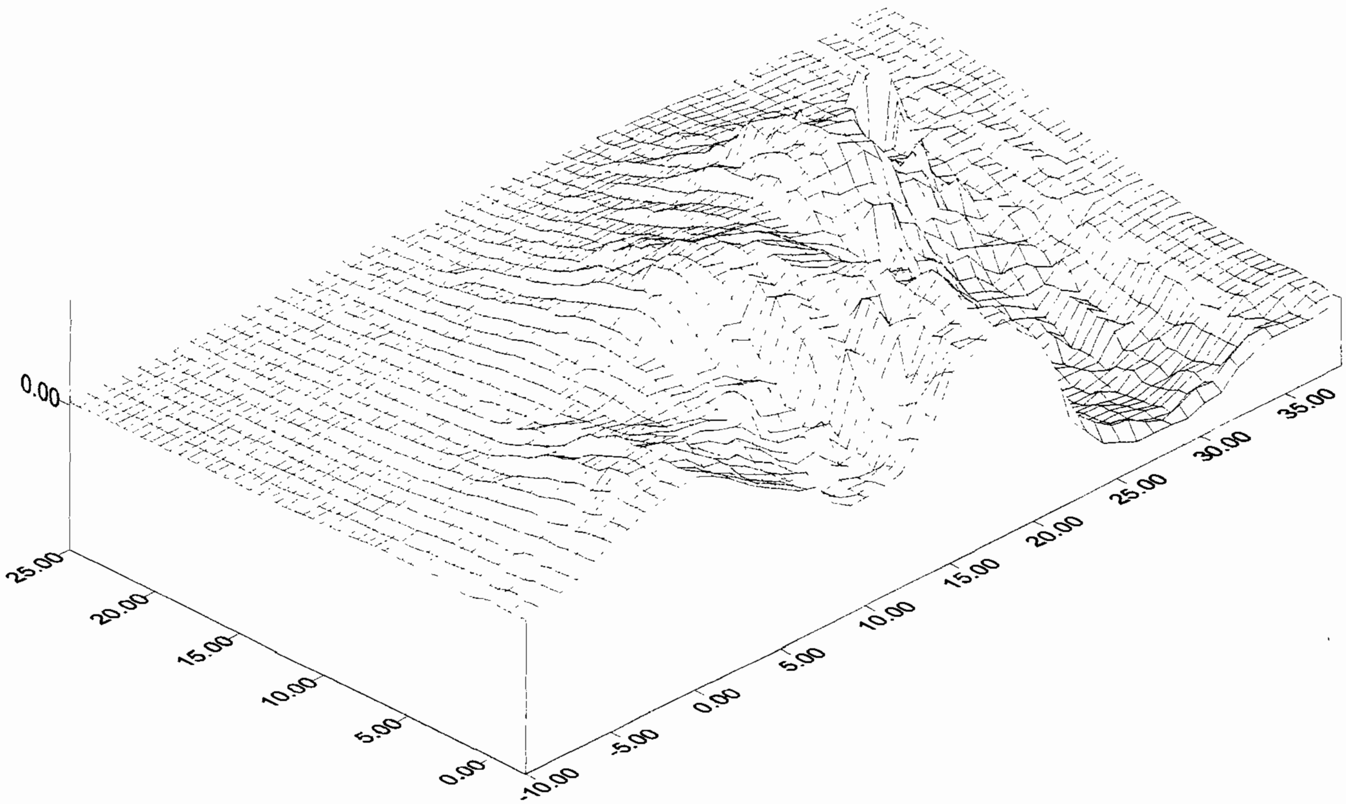

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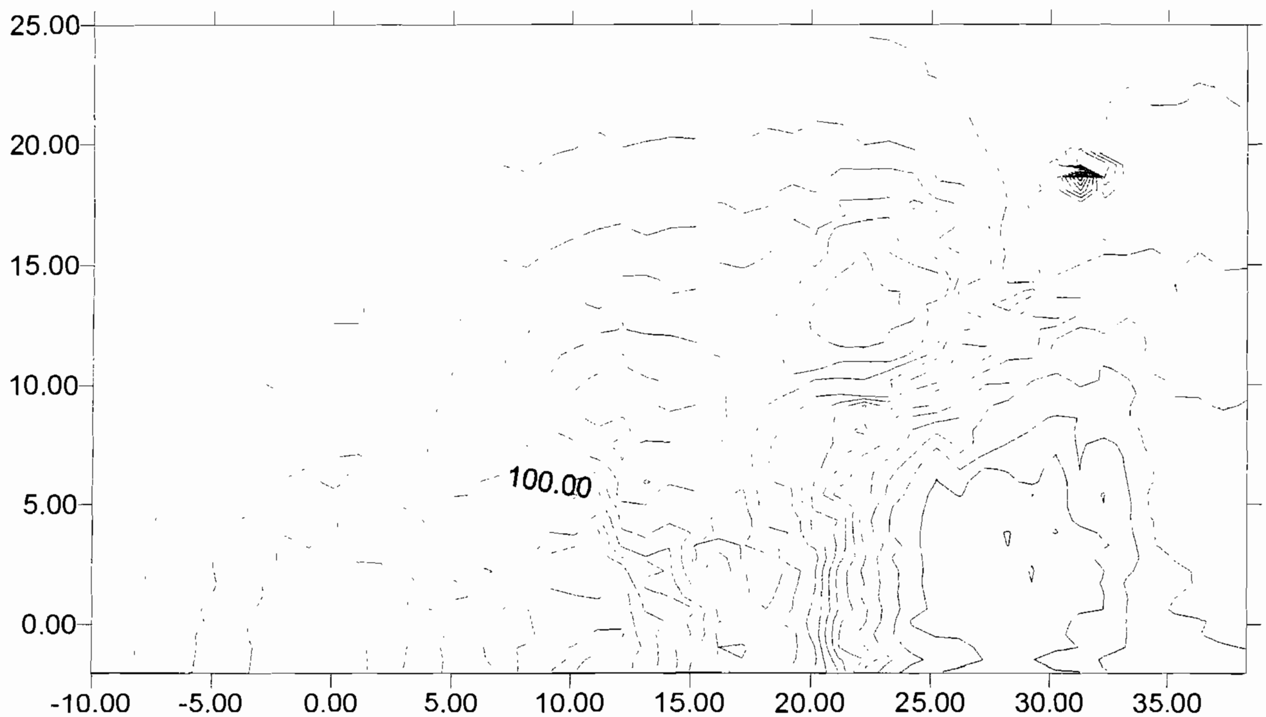
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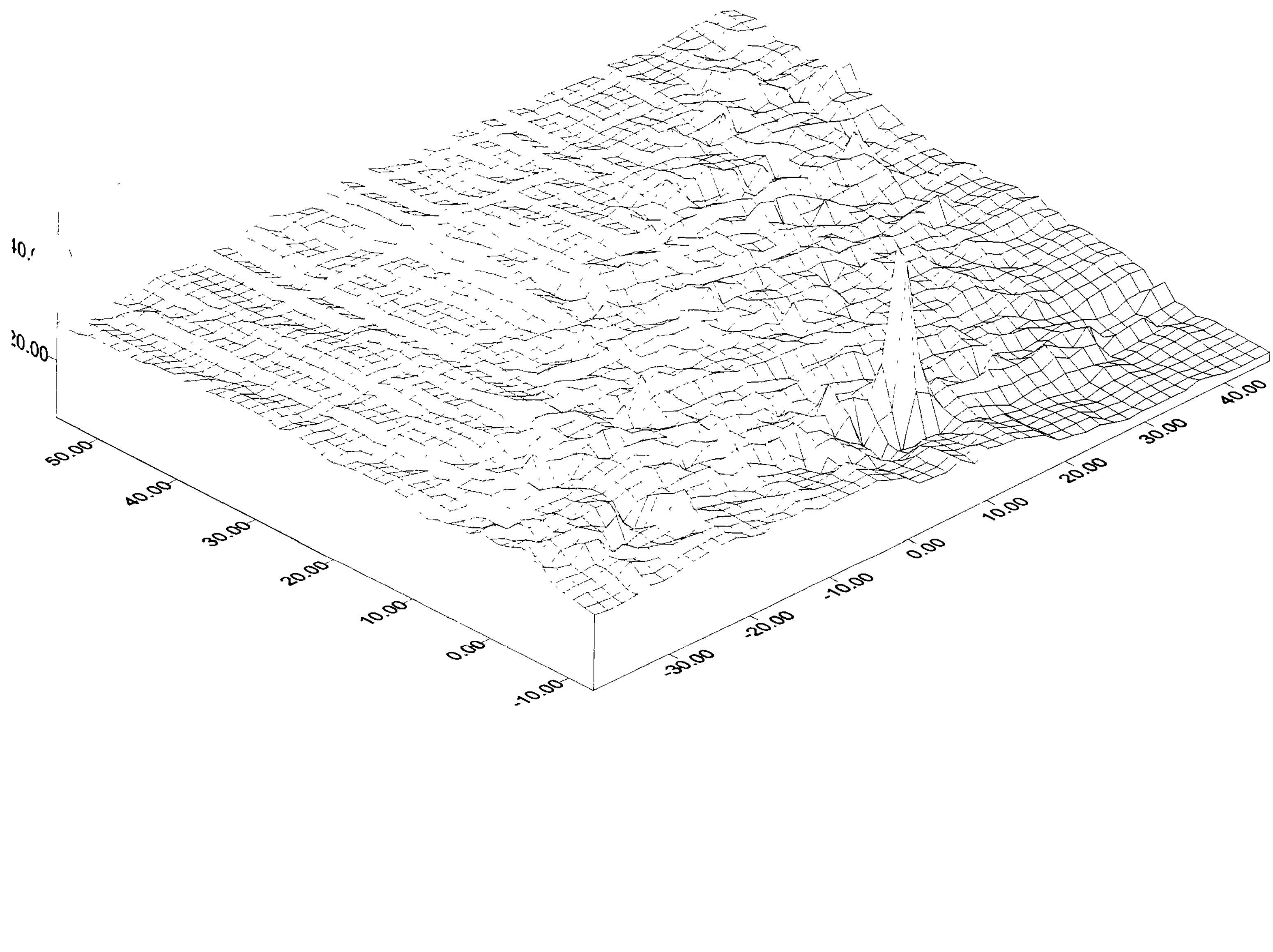

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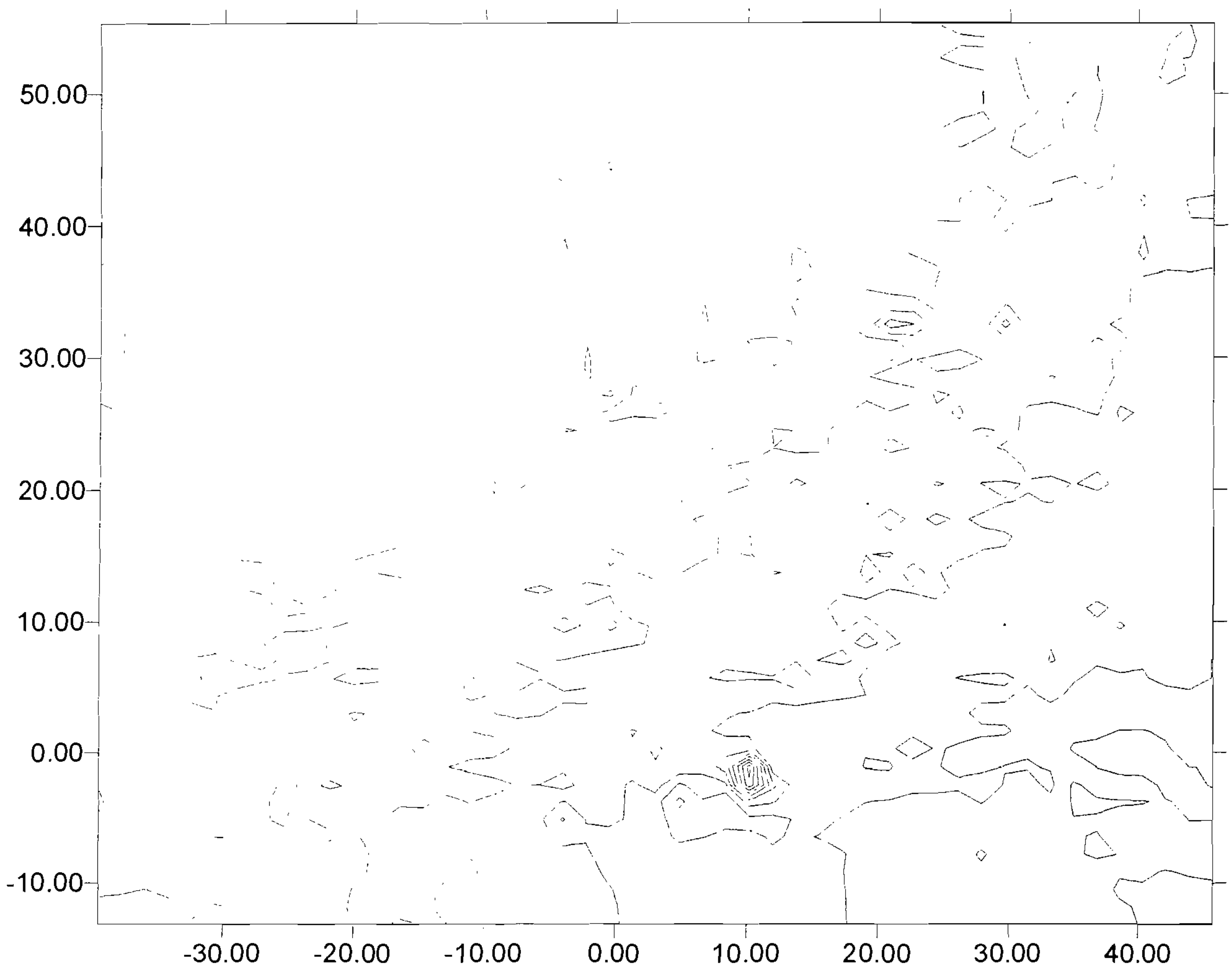

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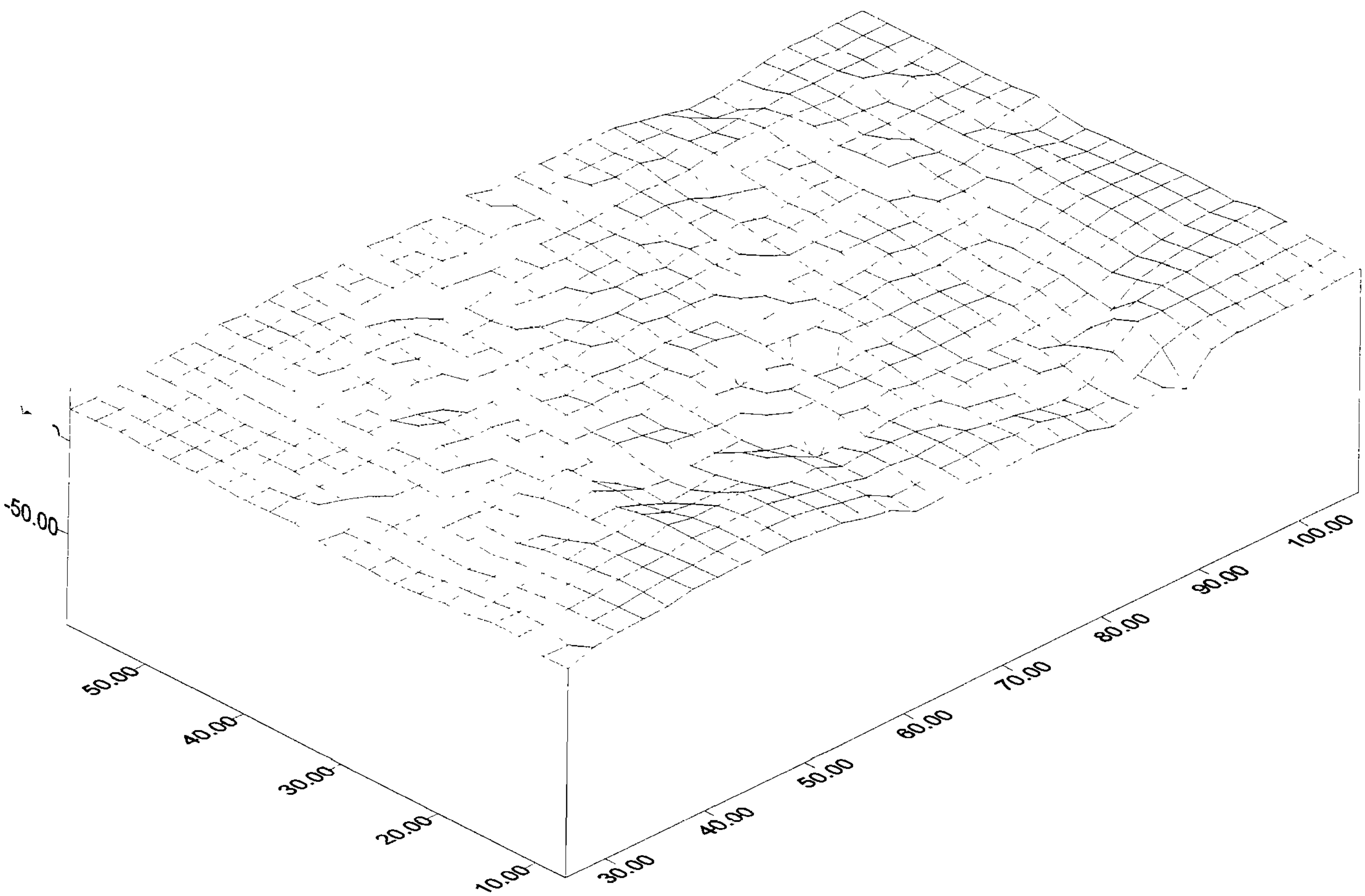

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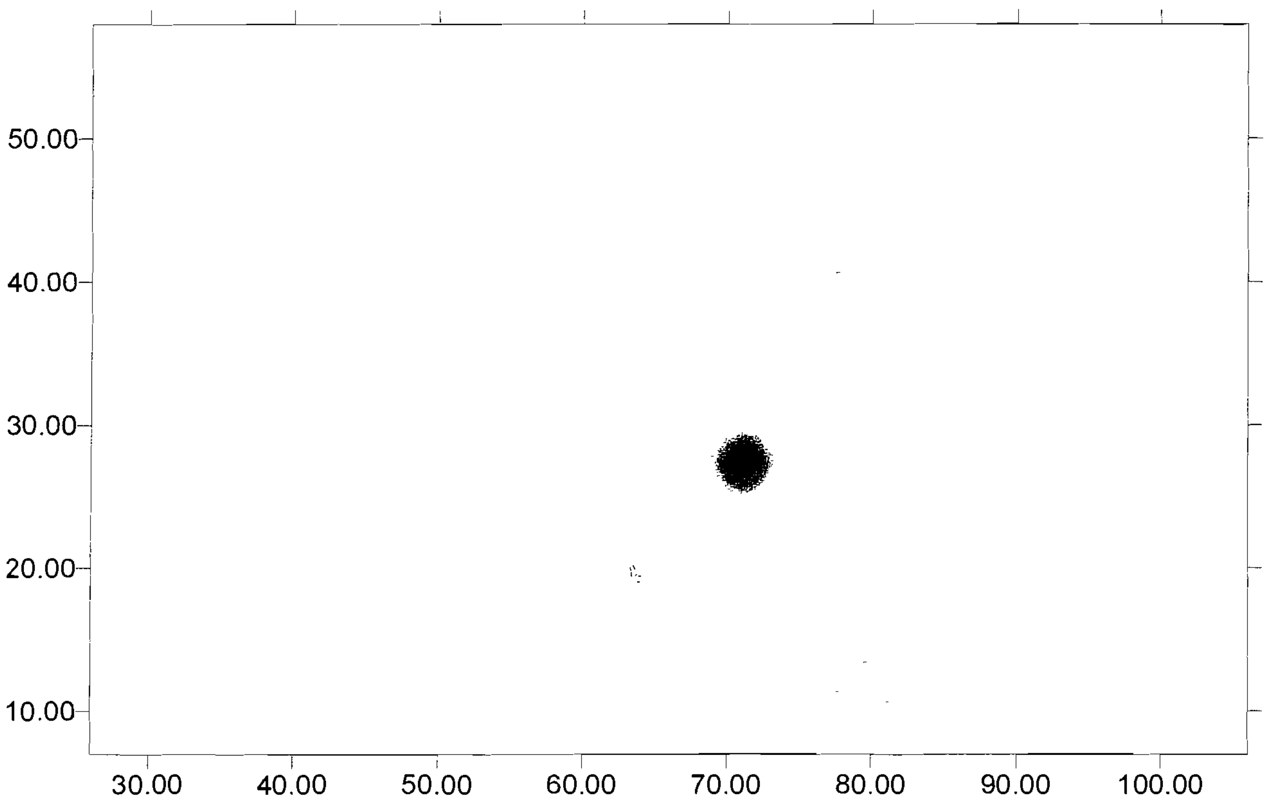
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APPENDIX E

UXB International Recommendations and Conclusions

processing. After the data quality was reviewed and corrected, the data was put into a grid format in preparation for analysis. This was accomplished using a minimum curvature algorithm. This algorithm can grid x-y position data which is "random" in it's positioning, as compared to an ordered grid.

After the data was put into a proper (for analysis) format, the data was transferred to a software program (UXO system) which allowed us to perform target analysis. It should be noted that any geophysical survey is sensitive to instrument accuracy, the survey methods employed, cultural and geological noise and the physical characteristics of the model which is being analyzed.

The UXO system is unable to distinguish between UXO and other metallic bodies with similar characteristics. It is unable to isolate individual UXO or other objects when they are located within a tight cluster of other objects. The application of another geophysical method, such as EM61 would yield a better depth calculation, than just the magnetic data alone.

The data was processed for interpretation, based on our assumption of the weight of the target for a 250-lb. (100-kg.) bomb was within a specified range (50-150 kg) for the target. The depth of the target was within a maximum depth of 5-8 meters (16–26 feet).

To assure us that the assumptions we were making were credible, we calibrated on the anomalies that your office detected and excavated. This assisted us greatly in our analysis of the data and validates our assumptions.

Data Analysis

The following is the our analysis of some of the known targets, which your office excavated and we interpreted for approximate weight:

Anomaly	Depth (feet)	Approximate Weight
1	8–given, 6.6-approx.	6.1 lb.
2	5-given, 3.3-approx.	4.4 lb.
3	Not determined*	
4	Not determined*	
5	Not indicated**	
6	17-given, 15.3-approx.	16 lb.

*These anomalies could not adequately analyzed to determine a location, depth and weight.

** No anomaly seen at this location.

The reader is reminded that numerous anomalies were noted in our analysis but these were filtered from the data analysis to focus on the pertinent anomalies.

To determine the possibility that ordnance, namely a 250-lb bomb exists in the areas of anomalies #7 and #8, we filtered the data based on weight. A weight range of 110-lb to 330-lb was set. Two (2) anomalies were located in grid CHA_E_S1 that may indicate that possible ordnance is present at the following location:

X	Y	Approximate Depth	Approximate Weight
31.83	0.30	9.8 feet	315-lb
16.82	9.28	10.8 feet	273-lb

Both locations are near the suspected anomalies of #5 and # 7 respectively. The #8 anomaly did not meet the assumptions as previously described and was eliminated in our analysis.

Conclusions

To illustrate our analysis of the data we have included some color figures of your magnetometer data. The following figures are included:

Figure (2) CHA_1
Figure (3) CHA_1S2
Figure (4) CHA_ES1
Figure (5) CHA _E2

These figures illustrate a few conclusions:

- Portions of the grid were not surveyed with the magnetometer.
- Numerous unaccounted anomalies exist, and may be due to surface interference or non-target materials.
- Magnetometer data **alone** is not sufficient for good depth calculations.
- Some correlation between known anomalies and the data analysis exist.

EM61 Data Review

After our initial review of the magnetometer data and subsequent conversations with your office, a limited EM61 survey was undertaken in the CHA_E area. That data was forwarded to us with the appropriate documentation. UXB analyzed that data utilizing software and our own experience in performing similar ordnance surveys.

A review of the data indicates three (3) lines 1055, 1060, and 1060 indicate a substantial anomaly. Figure 6 is a plot of the differential, top, and bottom channels of line 1060. Line 1060 was chosen since it had the most pronounced anomaly of the aforementioned lines. This anomaly is closely associated with the number 8 anomaly indicated in the magnetometer survey.

Inspection of the graphical representation of this anomaly, indicates that the anomaly is at or very near the surface, and the anomaly is relatively small, in comparison to the target of a 250-lb bomb. The peaks of the top and bottom channel are relatively narrow and the differential channel equals the bottom channel at the point of the anomaly. When analysis of the anomaly was done using the Geonics and Geosoft software, a maximum depth of the anomaly of 2.58 meters (8.46 feet) were obtained.

Your notes to us indicate that a pipe approximately 8 feet in length and 2 inches in diameter was located. This target would have produced the anomaly indicated by the magnetometer and the EM61. No other significant anomalies were noted in the EM61 data provided.

Conclusions – EM61 and Magnetometer

UXB believes that the combination of the magnetometer and EM61 data are powerful tools, when conducted by qualified personnel over formally established grids. Applying appropriate software, followed by data analysis by experienced geophysicists can yield high confidence in the detection of ordnance in areas where other metallic objects are present.

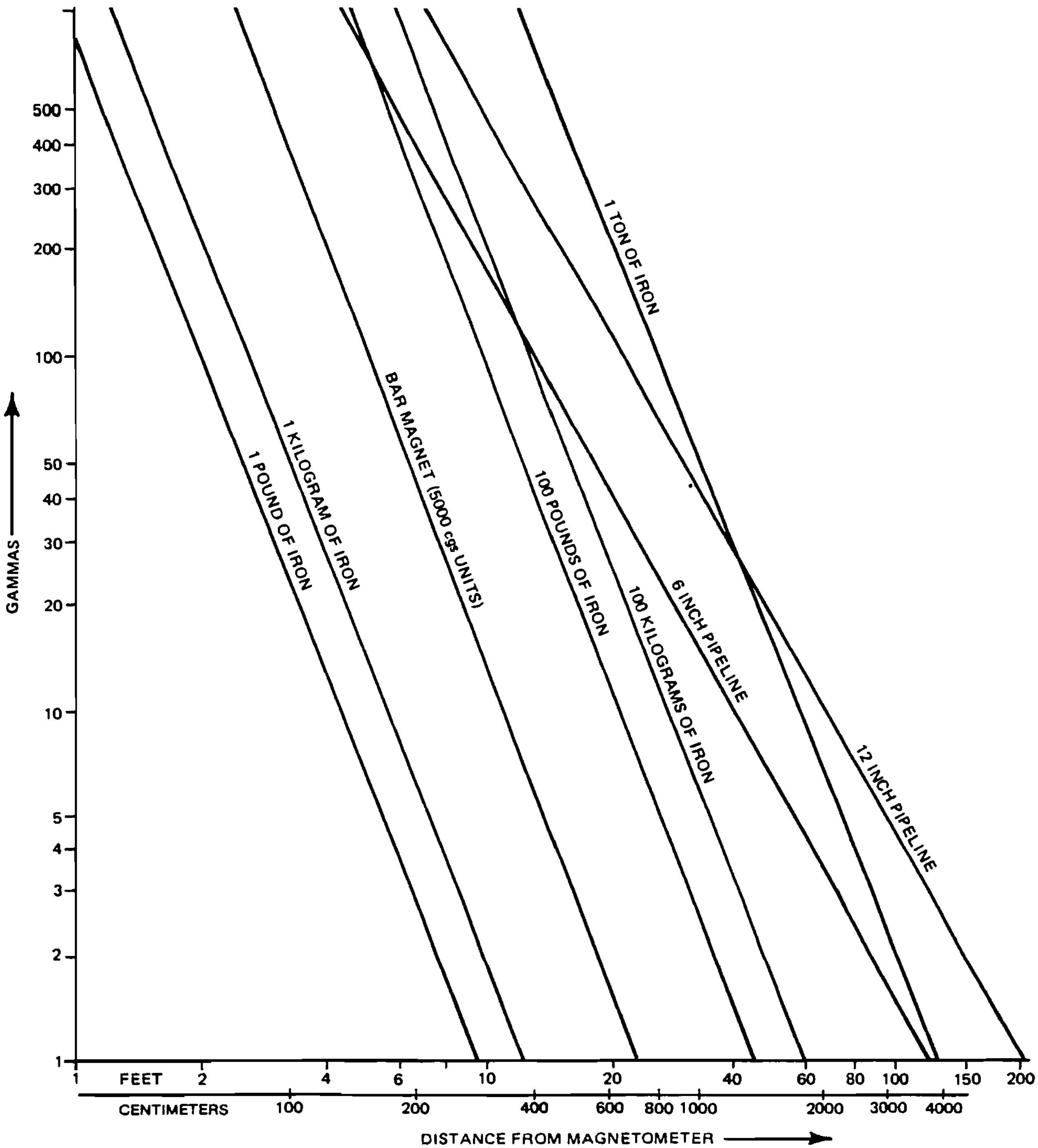
If you have any questions, please do not hesitate to contact us.

Sincerely,

Wayne Saunders, P.G.

Figure 1- Magnetometer Response

Nomogram for Estimating Anomalies from Typical Objects (assuming dipole moment M = 5 X 10^5 cgs/ton, i.e., k = 8 cgs. Estimates valid only within order of magnitude)

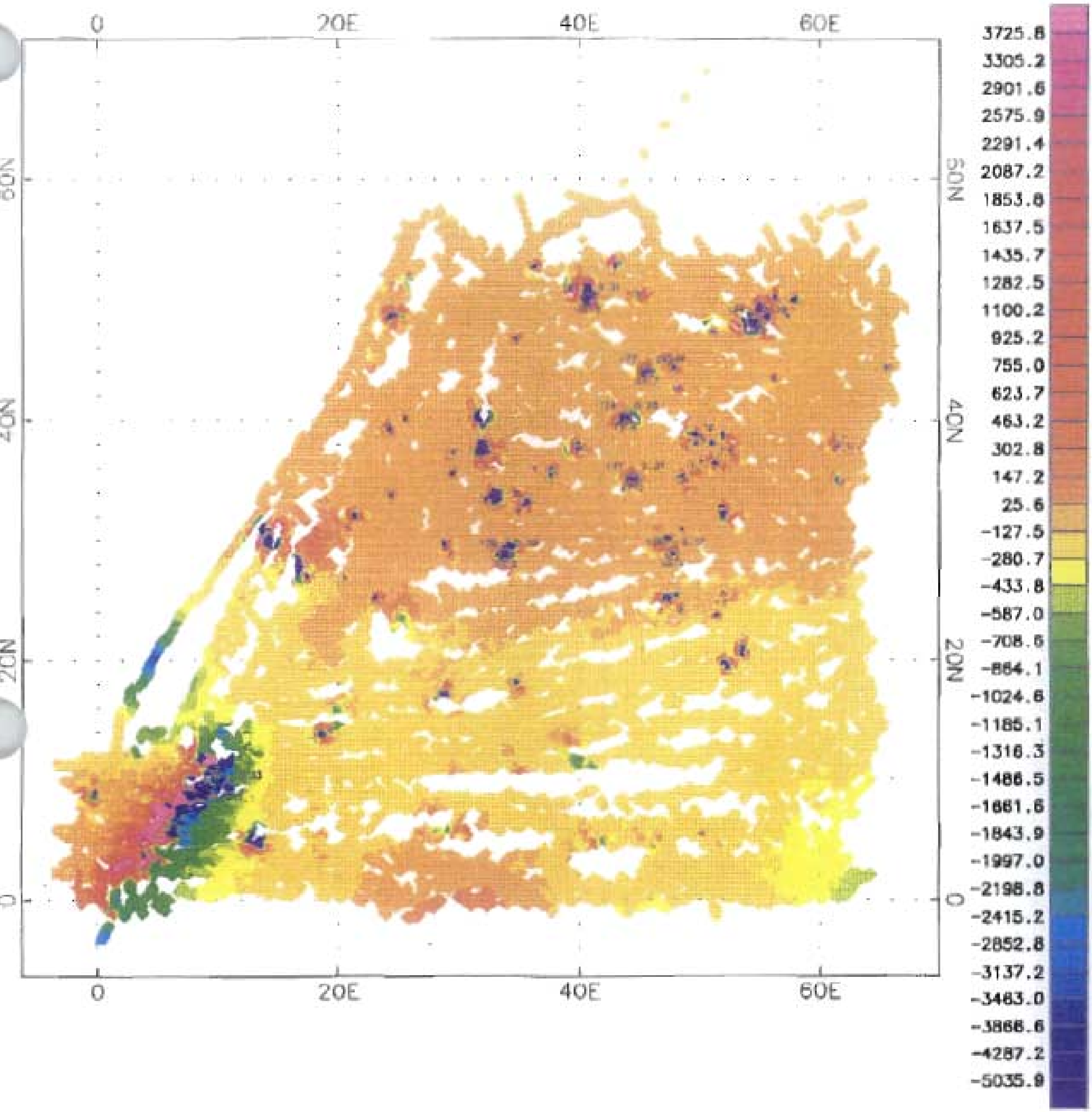


INSTRUCTIONS FOR USE:

To use the nomogram, select a given weight or type of object from among the diagonal labeled lines. Then choose a distance along the bottom line (abscissa) of the graph and follow a vertical line upwards from that distance until it intersects the diagonal line of the selected object. At that point, move horizontally to the left to a value on the vertical axis (ordinate) of the graph and read the intensity in gammas.

At a given distance, the intensity is proportional to the weight of the object. Therefore, for an object whose weight is not precisely that of the labeled lines, simply multiply the intensity in gammas by the ratio of the desired weight to the labeled weight on the graph. If the distance desired does not appear on the graph, remember that for a typical object the intensity is inversely proportional to the cube of the distance and for a long pipeline the intensity is inversely proportional to the square of the distance between magnetometer sensor and object. Due to the many uncertainties described herein, the estimates derived from this nomogram may be larger or smaller by a factor of 2 to 5 or perhaps more.

Figure 2 - Location of Anomalies CHA_1 Area



Environmental Detachment-Charleston

AOC 503

Targets Interpreted from Magnetic Data

UXB International

Mag Targets:

Figure 3 - Location of Potential UXO, CHA_1 Area

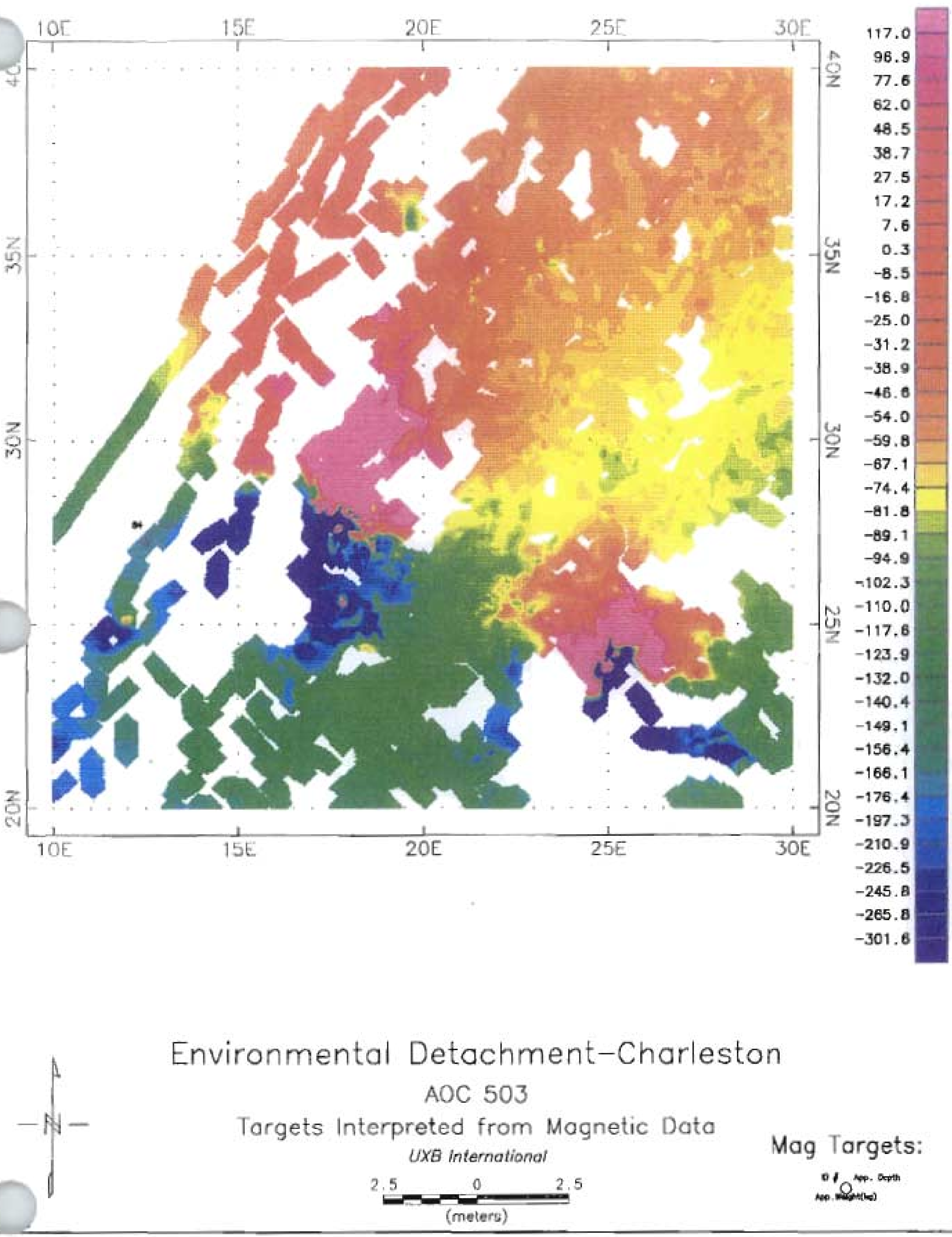


Figure 4 - Location of Potential UXO, CHA_E2 Area

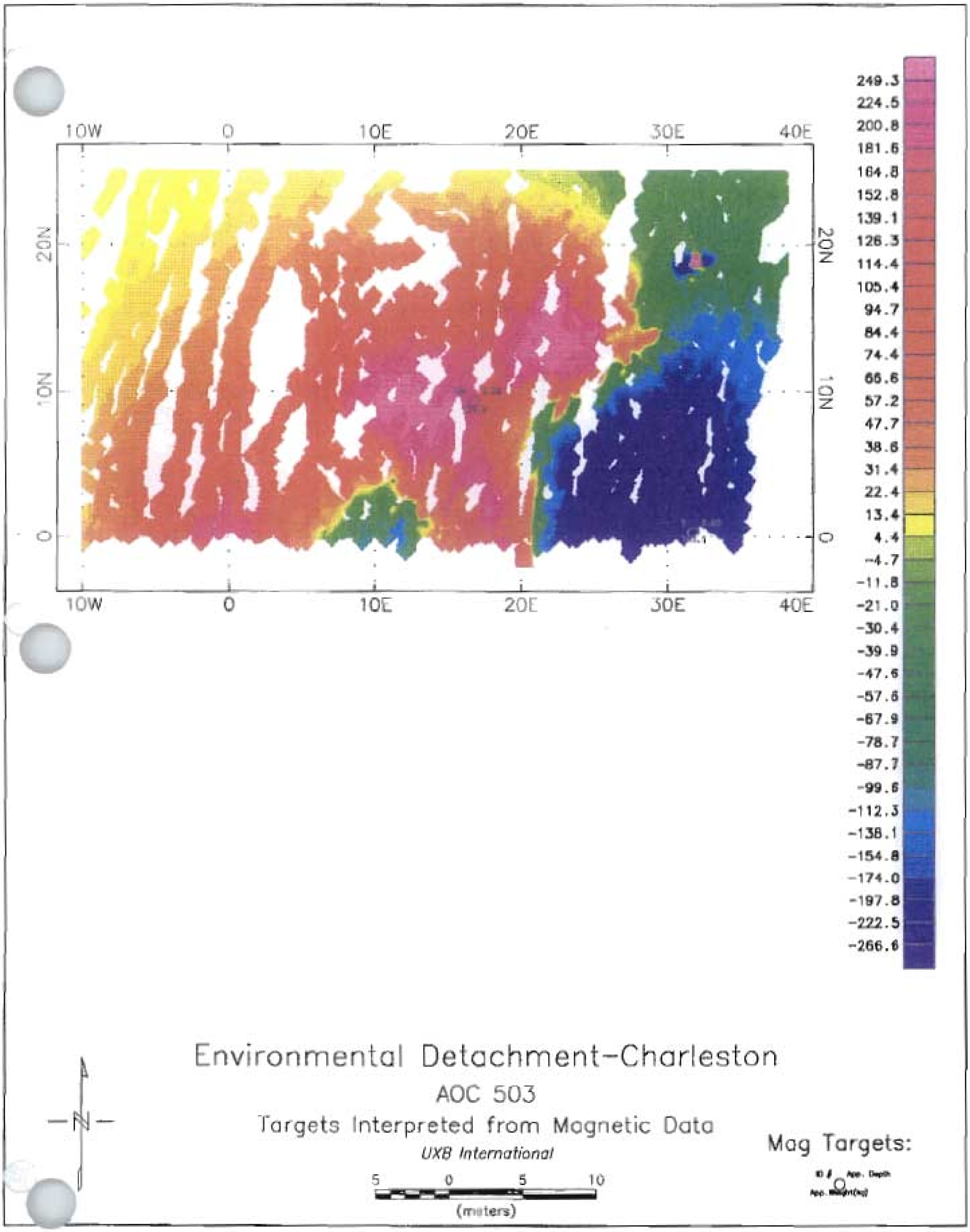


Figure 5 - Small Targets - Non-UXO, CHA_E2 Area

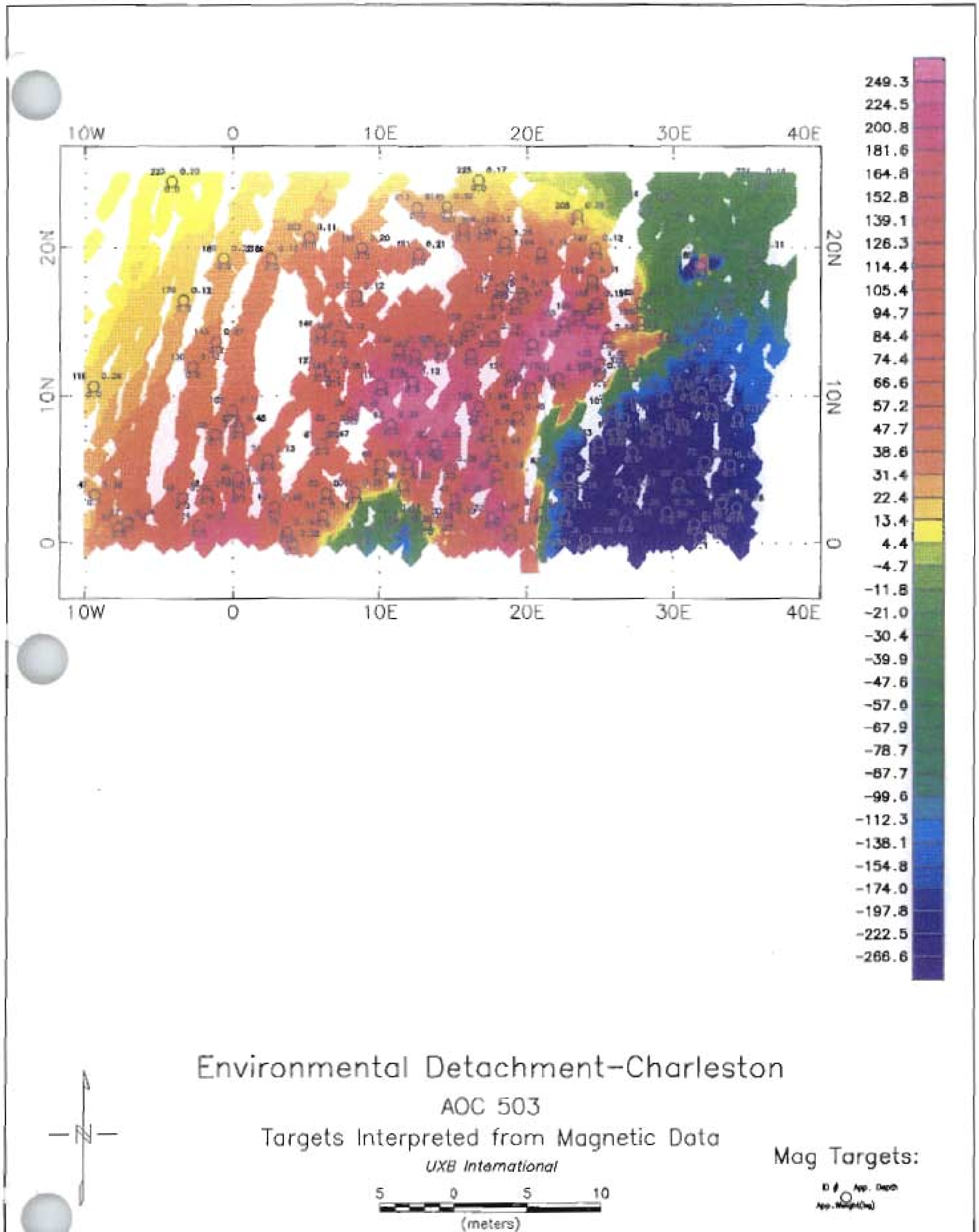
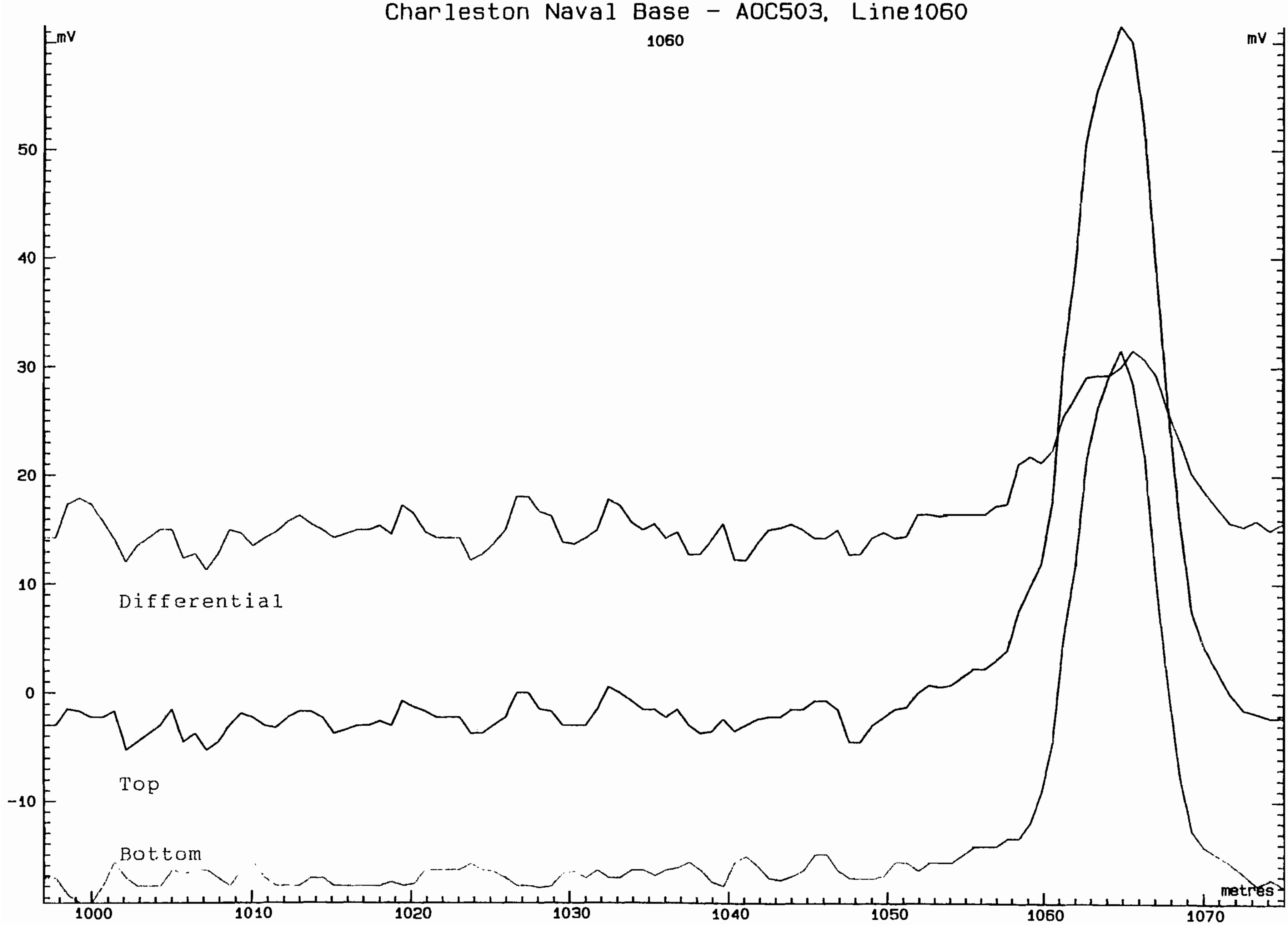


Figure 6 - EM61 Line Plot



APPENDIX F
Naval EOD Technology Division
Survey Equipment

OPERATING PROCEDURE

Mk 17 Depth Bomb Investigation at Naval Base Charleston Using the Automated Ferrous Ordnance Locator (AFOL)

12 December 96

Prepared by D. Gill
Naval Explosive Ordnance Technology Division
Indian Head, MD 20640
(301) 743-6850

Appendix F

1.0 Background

This document describes the Automated Ferrous Ordnance Locator (AFOL) operating procedure for a specific search for unexploded ordnance (UXO) at the Naval Base Charleston, Charleston, South Carolina.

1.1 Search Targets

The targets of this search are two AN Mk 17 depth bombs that were accidentally dropped from an airplane during take off more than 50 years ago. The impact location of the bombs was marked with an "X" on a map of the base. A portion of the prospective search area was subsequently back-filled with eight feet of soil. This additional soil decreases the probability of detection of the targets significantly, because magnetic dipole strength decreases with the cube of the distance. The area of concern is also in the vicinity of a commissary that was built after the accidental release of the bombs. Typically, the ground around buildings contains small and large parts of metal scrap left from the construction site. Small ferrous pieces of metal decrease detection probability, as they can mask deeply buried targets. Large ferrous pieces of metal may show up as false targets.

The physical description of the Mk 17, found in the identification guide for U.S. ordnance, is shown in Table 1.

Table 1. Mk 17 Depth Bomb Description

Total Weight	325 lb
Explosive Weight	221 lb
Case Weight	104 lb
Length	55.5 in
Diameter	16 in
Nose Factor	0.5 (spherical)

It is likely that these bombs have one or two fuzes installed. The possible fuzes are the AN-Mk 219, AN-M 103, AN-Mk 224, and Mk 234. These fuzes account for only a small percentage of the total amount of metallic content to the Mk 17 bombs, and will not significantly increase the probability of detection. These fuzes will not be touched or disturbed in any manner if they are encountered during the search.

Preliminary calculations were made to determine the potential depth and magnetic signature of the MK 17 bombs. These calculations assume that the depth bombs did not sink in the tidal marsh in the many years after impact. The Conventional Weapons Effects Program[1] was used to calculate the expected depth of these bombs. An impact velocity of 400 feet per second[2] (approximately 270 mph) was selected, and sand was chosen as the soil type[3]. The estimated depths for three different impact angles are shown below. The original depth and the depth with eight feet of additional soil are both shown. The software output is a range of values. These values have been averaged. For example, at 30° the output value range was 1.6 to 2.2 feet, which was averaged to 1.9 feet. Table 2 shows these depths and the depths associated with the potential eight feet of back-fill.

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[1] This software program was designed by D. W. Hyde, USAEWES/SS (20 Dec 1988). It calculates potential depth of dropped bombs, as well as many other characteristics.
[2] This value is the minimum selectable value in the Conventional Weapons Effects software. It was chosen because the bomb release occurred on take off, with World War II era aircraft that did not travel extremely fast. Also the height of the drop was not significant enough to increase the speed greatly.
[3] There are only four choices for soil type: sand, loamy sand, loam, and clay.

Table 2. Estimated Target Depths

Impact Angle	Original Depth (ft)	Original Depth Plus Back-fill
30°	1.9	9.9
45°	3.4	11.4
90°	5.9	13.9

To approximate the magnetic signature of the depth bombs at various distances, two methods were used. The first method was the use of figure 46, Nomogram for Estimating Anomalies from Typical Objects, in the "Applications Manual for Portable Magnetometers"[4]. These estimates are valid only to within an order of magnitude. The nomogram line for 100 pounds of iron was used, since we are considering weapons grade steel, which is assumed to be 98% to 99% iron, and the total steel content is assumed to be 104 pounds. The second method is illustrated in "Magnetometer Techniques in the Detection of Projectiles"[5]. The magnetic moment of an object is obtained (through a calculation or from tabulated data) and the total field at a specified distance is then calculated. Both methods use similar equations. Table 3 summarizes the results of both methods. The following assumptions were made to compile Table 3:

1. The casings of the Mk 17 depth bombs are intact and the weight of each is 104 pounds.
2. The casings are 99% iron.
3. The maximum original penetration depth of the bombs is 6 feet.
4. The axis of the ordnance lies in a north-south direction.

Table 3. Estimated Magnetic Signatures

	Estimated Magnetic Signature (gamma)	
Estimated Depth (feet)	Nomogram	Magnetic Moment Method[6]
9.9	180	15
11.4	105	10
13.9	65	5

The differences in the estimated magnetic signatures of the two methods are caused by the different assumptions used in the calculation of magnetic moments. The true magnetic signature should be somewhere between the two estimates for the particular depth of each Mk 17 bomb. Based on previous field experience, the true magnetic signature is expected to be very close to the lower values. If this is the case, the signature of the depth bombs at the 13.9 foot depth (5 gamma) would be very close to the noise floor (4 gamma), making it difficult to detect the bomb. Typically, detectable targets have signatures four or five times the noise floor (16 to 20 gamma).

1.2 Survey Site

As previously mentioned, the survey site is located near a building site (commissary). Along with the potential for ferrous clutter associated with building sites, there are other concerns that may make parts of the survey difficult. An original concern was that the area was covered with dense foliage that would make large parts of it inaccessible. The underbrush has been cleared, making the entire search area

[4] Breiner, S., "Applications Manual for Portable Magnetometers", 1973, pg 43.
[5] Pennella, J. J., "Magnetometer Techniques in the Detection of Projectiles", NAVEODTECHDIV Technical Report TR-239, March, 1982.
[6] The magnetic moments calculated for this method are based on estimates of induced moments only. Effects of remnant or permanent moments have been ignored.

accessible. A lesser concern is that the search area is mostly dirt and a heavy rain will result in a very muddy field. Mud will make it more difficult for the operator to maintain footing. This could result in a slip or fall, slow survey speed, or in not being able to maintain consistent ground separation and orientation of the magnetic sensor (creating the potential for corrupt data). There is also a steep-sided berm running through one portion of the area that may be difficult to traverse with the search equipment.

1.3 Survey Equipment

The main components of the AFOL system are the Ultrasonic Ranging and Data System (USRADS) positioning system, which includes a laptop computer, and the G-822L magnetometer. This is a prototype system, developed by the Naval EOD Technology Division for the Office of Special Technology. It has the advantage of operating without degradation of accuracy in wooded areas and areas of dense foliage, where global positioning systems (GPS) often fail to operate.

The USRADS positioning system consists of a base station, a backpack called the "datapack", and up to 15 stationary receivers. The stationary receivers are set up in the survey area. The operator carries the magnetometer and the datapack throughout the survey area. A second person coordinates the search from the base station. The operator can walk specific tracks or wander on a random path to conduct the survey. Specific search patterns or tracks provide the optimum survey data and accuracy. This positioning system has an accuracy of 6 inches (rms). Positioning information is obtained from time-of-flight data based on ultrasonic pulses. The base station is a laptop computer with capability to transmit and receive (wireless) data. The laptop also contains software to analyze the survey data and display near real-time survey tracking on its screen. The operator wears the datapack like a backpack. The datapack receives data from the magnetometer via the RS-232 port and sends it, along with timing data, to the base station laptop. The datapack emits the ultrasonic pulse that the time-of-flight data is based on. The stationary receivers detect the ultrasonic signal and transmit time-of-flight data to the base station laptop computer. The prototype system has 15 stationary receivers, with a capability of expanding up to 20. A minimum of four stationary receivers must be used. Additional stationary receivers increase the accuracy of the positioning system. All stationary receivers are mounted on tripods.

The G-822L magnetometer is a commercial version of the military MK 22 cesium vapor total field magnetometer. There are two differences between the G-822L and the MK 22. Although the G-822L has the same manufacturing specifications as the MK 22, it is not subjected to the military-type durability testing. The second difference is the addition of an RS-232 port to the G-822L for data transfer. The RS-232 port facilitates transfer of magnetometer data to the USRADS system, which allows the computer to tag the magnetometer data with time and locator position. A second G-822L magnetometer can used as a reference station to subtract the total field gamma reading from the roving magnetometer. This allows the operator to subtract diurnal and other fluctuations in the background magnetic field from the survey data. Typical noise values on past surveys have been in the 2 to 5 gamma range.

A gradiometer (Vallon 1302 A1) may be used for magnetic anomaly confirmation, while a Trimble DGPS unit will be used to establish absolute locations of the relative positions determined by the USRADS data. To determine the absolute (GPS) locations, a surveyed benchmark will need to be established within line of sight of the survey area. This should be accomplished before the survey team arrives.

2.0 Setup

2.1 Base Station

The base station consists of the master controller, a laptop computer, and a power supply. This equipment (without the power supply) is small, so that the base station can be set up practically anywhere. In the past, it has been set up in the back of a small truck and also on a small table. Both the master controller and computer run off 120 VAC, so a small generator or one 120V outlet is a sufficient power supply. The generator currently used with the system is a 1 kW, gasoline operated system.

The master controller coordinates the time gates for each stationary receiver and the datapack. It sends information to initialize the system, and ensures that each of the components in the system respond at the proper time. In order to communicate properly with the other system components, the master controller must be placed where RF signals won't be blocked by buildings or other large obstacles. The master controller has one power connection, one data connection, and an RF antenna.

The laptop computer contains the software to run a survey and analyze the survey data. It is connected to the master controller through an RS 232 port.

2.2 Reference Magnetometer

The reference magnetometer measures the background magnetic signature of an area and sends this information, with a time stamp, to the master controller. The master controller relays this information to the laptop computer, where it is stored on the hard drive. The reference magnetometer must be placed in an area that is clear of any magnetic clutter or targets, and where it will not be approached by people, cars, or other potential magnetic material carriers. It also operates on rechargeable batteries, with an operational time of approximately eight hours.

2.3 Stationary Receivers

The stationary receivers "listen" for the ultrasonic pulse transmitted by the datapack. They then send timing information to the master controller, so that the time-of-flight information can be calculated, resulting in a position measurement of the datapack/operator. They operate on internal rechargeable batteries, with an operational life of eight hours. The stationary receivers are placed on tripods and moved into the survey site. Two or three of the stationary receivers must be placed a measured distance apart. this distance is usually 100 feet. These receivers are then considered to be the baseline receivers. Typically, sites are surveyed one acre at a time. This can change depending on any obstacles or topography of the survey site. For a one acre site, 8 to 12 stationary receivers are placed in a pattern to obtain relatively equal coverage of the entire site. Before the survey begins, an autosetup program is run to ensure the laptop computer has a record of where all of the stationary receivers are located, and to account for wind, temperature, and humidity affects on the speed of sound. When the survey of a site is completed, the stationary receivers are moved to the next site.

2.4 Datapack/Operator

The operator carries the datapack, magnetometer, and battery pack. The datapack transmits an ultrasonic pulse received by the stationary receivers. It also sends an RF packet to the master controller, containing pulse timing information and measurements made by the magnetometer. Setup of the datapack/magnetometer subsystem consists of several electrical connections, initiation of the ultrasonic pulse, and initialization of the system to identify which type of sensor is in use (G-822L magnetometer, radiation sensor, or compass modes are available). The datapack is not involved in the autosetup of the stationary receivers.

2.5 Site preparation

The survey team will define the boundaries of the entire site, and then prepare a plan on how to obtain complete coverage of that site. They must take into account the topography and any man-made or natural obstacles, including dense foliage that cannot be penetrated. The maximum site size for an positioning system worsens. The solution is to run the autosetup program again to let the software account for the change in temperature and humidity. High temperatures can also affect the laptop computer. Although the AFOL system has been used successfully in 90° temperature environments, there is always the possibility that high temperature can cause malfunctions with the computer or even cause physical damage to its electronics. Also, extremely cold temperatures will decrease the operating life of the batteries, decreasing the length of the work day.

Rain is more of an operator safety problem than an equipment problem, although it can cause some problems for the equipment. The stationary receivers will function in the rain, as long as it is not a heavy rain. Light rain causes no impediment to a search operation for the equipment, but heavy rain may cause the stationary receivers to fill up with water (which has happened). Unfortunately, an operator's footing will become more treacherous as the rain continues. This will decrease the accuracy of the system, as the operator will concentrate more on foot placement than magnetometer control. Obviously, no searches will be conducted during a thunderstorm.

Search operations will only be performed when there is sufficient light to see the entire area clearly.

Wind does not typically cause problems during a survey, but certain situations involving wind may cause delays. If there is no wind at the beginning of a search, and then it becomes windy during the search, the autosetup program must be run to account for relative changes in the speed of sound. Wind has also been known to blow over the tripods that the stationary receivers are mounted on.

3.3 Survey Interruptions

If a survey is interrupted for any reason, the data taken up to that point is safely stored on the hard drive of the computer. Unintentional interruptions include circumstances such as, datapack battery failure, generator failure (or power outage affecting 120 VAC outlet), and operator mistake or injury. Intentional interruptions include operator breaks or changes in operators, end of day shut down to recharge batteries, and weather precautions.

4.0 Quality Assurance (QA)

To achieve at least a minimum level of QA, approximately five inert targets will be buried on the site in locations unknown to the surveyors. All but one of the targets will be buried at a depth such that their magnetic signatures are comparable to that of the expected Mk 17 depth bomb signatures. One target will have a larger magnetic signature.

5.0 Equipment Packout

The equipment will be packed into the same containers they were delivered in. There will be no equipment or other materials left behind on the site that were not there upon arrival.

6.0 Data Processing

There are three potential levels of processing available for each search. The first level will be completed at the survey site. The other two levels will be used on an as needed basis.

6.1 Software

The first level of processing is accomplished using the USRADS software. This method gives the operator a quick look at potential targets, but is not always capable of showing all of the anomalies present. It generally does indicate medium to large targets, similar in size to the Mk 17 depth bomb (medium size target). This processing can easily be done on site. The USRADS software generates a color map that shows the magnetometer readings and their relative positions. It can also list all of the anomalies and there associated positions.

The next level of processing is done with Surfer software. Rather than show just magnetometer readings and their associated positions, this software uses the Kriging method to grid and express trends in the data. This processing can also be done at the site; however, it can be time intensive for large amounts of data. Surfer is capable of generating color maps. These maps can show magnetic contours or 3-D maps showing peaks for each of the anomalies

The final type of processing available is done with PV Wave, a UNIX based software program. Since this is UNIX based, it is usually accomplished in an office environment. The output from PV Wave is similar to the maps of the Surfer software, but with higher resolution.

Suspected target positions will be identified from the processed magnetometer data. Twenty positions that are characteristic of the Mk 17 will be prioritized for excavation. These locations will be re-surveyed in WGS-84 datum by a Trimble DGPS navigation system. In the event that the DGPS is not functional, the target positions will be physically marked.