WSRC-MS-96-0319
CONF-9607132--1

Application of UAVs at the Savannah River Site

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A document prepared for ASSOCIATION FOR UNMANNED VEHICLE SYSTEMS at Orlando from 07/15/96 - 07/19/96.

DOE Contract No. DE-AC09-89SR18035

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Abstract

Small, unmanned aerial vehicles (UAV's) equipped with sensors for physical, chemical and radiochemical measurements of remote environments have been tested at the Savannah River Site (SRS). A miniature helicopter was used as an aerial platform for testing a variety of sensors with outputs integrated with the flight control system for real-time data acquisition and evaluation. The sensors included a precision magnetometer, two broad band infra-red radiometers, a 1-inch by 1-inch NaI(Tl) scintillation detector and an on-board color video camera. Included in the avionics package was an ultrasonic altimeter, a precision barometer, and a portable Global Positioning System. Two separate demonstration locations at SRS were flown that had been previously characterized by careful sampling and analyses and by aerial surveys at high altitudes. The Steed Pond demonstration site contains elevated levels of uranium in the soil and pond silt due to runoff from one of the site's uranium fuel and target production areas. The soil at the other site is contaminated with oil bearing materials and contains some buried objects. The results and limitations of the UAV surveys are presented and improvements for future measurements are discussed.

Introduction

Unmanned aerial vehicles (UAV) provide an efficient means of surveying remote, and possibly hostile, environments. Remote surveys are useful for waste site characterizations, emergency response, facilities decommissioning, and environmental restoration activities. Sites which are contaminated with chemicals or radioactive material require characterization prior to and during remediation activities. Remote monitoring supplements historical records and compliments manual sampling methods for site characterization. Area surveys provide general contamination levels which are not affected by local sampling inhomogenieties. If the site is highly contaminated, personnel may be excluded from these areas due to the hazardous conditions. UAVs provide the opportunity for confirmatory measurements in those areas. Remote monitoring techniques and technologies are being developed for direct measurement of specific chemical agents or radionuclides in the environment. Hand-held sensors, transportable (mobile) systems, and fixed site monitoring stations have expanded the technologies of fieldable systems for real-time analysis. Direct and indirect methods for assessing site conditions from an aerial platform are under continual development.

UAVs have many advantages over conventional aircraft, in that capital and operational costs are substantially lower and the UAV can survey small areas at low airspeeds (< 2 meters/sec) and low altitudes (< 5 meters). A suitable UAV platform for remote monitoring must also have adequate payload, stability in flight, and have reasonable flight time between refueling.

The sensors described in this study are commercially available but have been modified where necessary for real-time readout which is telemetered from the UAV to the ground control station. These data are recorded in computer compatible form for off-line detailed evaluation. For meaningful measurements, accurate position coordinates are obtained from an on-board Global Positioning System (GPS) and correlated with sensor output. Several sensor suites were tested at both SRS sites and are discussed in the remainder of this paper.

Description

UAV Platform

Scientists and engineers at the Savannah River Site (SRS) have investigated one type of UAV as an aerial survey platform. The flight vehicle used in this study is a miniature helicopter with a rotor diameter of 150 cm and an empty weight of approximately 5.5 kg. This UAV was supplied by Guided Systems Technologies, Inc. of Atlanta, Georgia and has been described elsewhere. (1) The small helicopter is equipped with a miniature avionics package which integrates the state-of-the-art in solid-state inertial sensor technologies, microprocessors, GPS solutions, and digital communications equipment. A small payload bay is provided on the helicopter for sensor installation. Detachable stubwings are available for mounting of sensor elements external to the fuselage. The sensor data is collected by the flight control computer either in analog or digital form, and transmitted to a ground computer via a radio link. Real-time display of the sensor data is possible via custom software in the ground control station. The sensor data is stored in computer compatible form along with all vehicle status parameters.

Sensor Packages

Several simple sensors have been tested on the UAV platform. A radiation survey instrument containing a 3.8 cm by 3.8 cm NaI(Tl) scintillation detector was interfaced to the UAV analog to digital converter and telemetered from the helicopter to the ground flight computer at the Steed Pond flight-test site. Only minor modifications to the commercial GM-1 radiation detector system (mfg. geoMetrics, Inc.) were required to record the integrated count rates with the UAV data acquisition system. Simultaneous position coordinates were received from the on-board GPS along the same data link. The GPS coordinates, altitude, and total integrated detector count rate were recorded in the data file. The survey instrument will detect a 37 kBq source of Cs-137 at ≈30 cm (approximately 0.03 μSv/hour integrated dose rate).

Another sensor tested on the UAV platform is a broad-band OS-600 infrared radiometer for making radiative temperature measurements. The analog signals, proportional to the surface temperatures, are converted to digital readings by the on-board analog to digital converter and telemetered to the flight control system computer. As with the radiation detector, simultaneous position and altitude readings are recorded with radiometer readings in the output file. The sensitivity of the radiometer is ±1 deg-F at ambient conditions with ≈ 0.1 steradian field of view. Only slight modifications to this commercial instrument (mfg. Omega Engineering, Inc.) are required to interface with the UAV data communication system. The third system employed for the UAV was a 3-axis magnetometer from the HMR Series "Smart Digital Magnetometer" produced by the Honeywell Solid State Electronics Center.

Experimental

γ-ray Radiation Scanning

Many traditional aerial surveys have been conducted at SRS to determine the quantity and spatial distribution of natural and man-made radionuclides near site facilities and in the surrounding areas; see reference 1 for details. These surveys were conducted by EG&G Energy Measurements, Inc. using a large NaI(Tl) scintillation detector array mounted in a MBB BO-105 helicopter. The surveys were conducted at altitudes of ≈ 46 meters, with 76 meter flight line spacings at ≈ 40 m/second ground speed. During the flight missions, spectral and position data were collected on-board the helicopter and stored on magnetic media. The large detector array and extensive data acquisition system permits the spectroscopic analysis of the data into man-made and natural components and the identification of some specific radionuclides. Uranium has a characteristic γ-ray signature and can be mapped by this technique. Far-field measurements of the average uranium concentrations in the Steed Pond area were determined by this aerial survey technique. The results indicated a maximum uranium content in the vicinity of Steed Pond of ≈ 500 ppm which is about 25 times the natural uranium background. These results have been confirmed by extensive surface and core sampling followed by laboratory analyses. Experience has shown that the uranium is localized to the Steed Pond area and is not affected by normal rainfall and surface runoff.

Steed Pond is a small 11-acre pond, fed by a natural spring, which discharges to an on-site stream via a small earthen spillway. The pond often dries up to a small stream during the summer months and is totally covered with natural vegetation. Under these dry conditions, the pond turns into a swamp with sinkholes and quicksand. Snakes and other biological species in the area make sampling an undesirable task.

As a test of the UAV technology, a portable ground station was set up near the Steed Pond shoreline which included a small trailer and a portable motor generator for power. A GPS Recorder, developed by scientists at SRTC, was set up on the shoreline as a base station for the measurements. The UAV equipped with a second GPS unit, the radiation detector, and the on-board video camera was flown over the area under the manual control of the pilot. The latitude, longitude, altitude, count rates, were stored as a function of satellite time during these surveys. The geographic positions were also recorded by the base station as a reference. This technique permitted the calculation of relative location and improved the precision of the GPS positions. The video image was also synchronized with satellite time and served to confirm the surface features and resolve data fluctuations. The results of the scan of the Pond during one of the flights is shown in Figure 1. It was demonstrated that careful repetitions of these scans could be used to map out the distribution of radionuclides in the area.

In order to quantify the data, accurate distances from the ground to the UAV helicopter is required. It was found that an ultrasonic altimeter was seriously affected by the reeds and other high vegetation in the area. A precision barometer was installed in the UAV but the turbulence created by the rotor blades created too much dispersion in the data. Even if the turbulence could be minimized, the barometric pressure would yield an altitude value and not the distance above the ground. The GPS can yield altitude information but is only accurate to several hundred meters. It is planned to explore the improvements to the altitude parameter using differentially corrected GPS coordinates. This involves the storage of all parameters from all satellites in view and complex calculations. This still does not provide accurate source-to-detector distances to correct the radiation data. More accurate methods involving active techniques (e.g., radar) will be explored.

Thermal Mapping

Campbell Scientific OS-600 broad-band IR thermometers were modified and mounted on the left and right side of the helicopter stub wings. These sensors proved to be ideal for this demonstration in that they were lightweight, rugged, low cost with little power requirements. The field of view of 15 degrees provided a ground sample size about one half of the sensor altitude.

A study of the surface temperature in vicinity of the D-Area Oil and Seepage Basin was recently completed. The preliminary results indicate that buried waste in trenches affect soil moisture content and soil temperature of the overlying soils by as much as 1.5 deg-C when compared to background temperatures. The thermal signature is most prominent at night and in most cases the soil over the trench is cooler and more moist than background. Figure 2 shows a sketch of the DOSB obtained from a thermal image collected in October 1995. The sketch shows areas of coldest soil temperature in black which are located over the buried trenches. The location of the trenches are shown in Figure 3 from a photograph of the DOSB in 1973 before the trenches had been filled in. Figure 4 shows surface temperature measurements from the two IR sensors during a June 1995 UAV transect across the DOSB. Although there appears to be a bias between the left and right sensor, the surface temperature appears significantly cooler over flag position 20 to 30 corresponding to the location of the buried trenches. Another parallel transect shown in Figure 5 does not show a reduction in temperature over the trenches.

Magnetometer Measurements

A detailed magnetometer was conducted of the DOSB during July 1993 (2). The grid established for the magnetic survey was defined by 1-meter station intervals along lines spaced 3 meters apart. Magnetic data were collected with and EG&G Geometrics G-856 gradiometer with the top sensor at 1.22 m from ground level and the bottom sensor 0.6 m from ground level. Figure 6 shows a color coded map of the magnetic field over the DOSB. The large positive values shown in violet and the large negative values shown as dark blue appear to indicate buried objects in the trenches. The two white lines at x=63 and x=81 are locations of UAV magnetometer transects. Figure 7 shows a plot of total field strength of the two sensors along the eastern transect. Note the trenches are located between positions 40 and 55.

The magnetometer employed for the UAV was an HMR Series "Smart Digital Magnetometer" produced by the Honeywell Solid State Electronics Center. Honeywell magnetoresistive (HMR) series of magnetometers is based on Permalloy (NiFe) thin films deposited onto a silicon substrate patterned as a Wheatstone resistor bridge. Three independent bridges are oriented to provide an X, Y and Z axis output. In the presence of an external magnetic field, the magnetoresistive characteristic of the Permalloy causes a change in the bridge resistance. The corresponding change in bridge voltage is then converted to a 12-bit (11-bit plus sign) digital value using an internal delta-sigma A/D converter. The field measurement range of the unit is plus and minus 1 Gauss. Accuracy is plus and minus 1% of full scale, resolution is 0.5 mG/LSB, and noise is plus and minus 1 mG. GST recorded the x, y and z readings of the magnetometer at two second intervals (all other sensor data was recorded at one second intervals), and also stored the total field strength computed as the square root of the sum of the squares of the x, y and z components. This data was imported to a spread sheet program immediately after it was collected, and total field strength was computed and plotted in the sequential order of collection to verify proper sensor function, and to verify that the flying survey would register significant enough variation in the field strength to make the runs of interest.

The first test conducted was on 6/19/95 using the magnetometer interfaced only to a laptop computer. The unit was held at the top of a 3 foot aluminum rod and a walking survey conducted along the eastern transect. The second and third tests were conducted by flying the UAV along the same transect at altitudes of 1 m and 2 m, respectively. Figure 8 shows the total field strength for the three tests plotted on a scale comparable to the scale used for the 1993 survey. Note the UAV data lack the detail of the 1993 survey but do show similarities, particularly the low values at position 25 and the elevated values between 40 and 50. The elevated values between 40 and 50 appear to coincide with the location of the trenches.

Conclusions

The objectives of the UAV demonstration were met. Temperature and magnetometer data were collected over a waste site which could be used to infer location of buried waste. Gamma radiation intensities were obtained over a waste site having hazards to a walking survey such as thick vegetation, mud, snakes and contamination. Problems encountered in all aspects of the demonstration could be solved by improvements in georeferencing of the data in three dimensions.

Recommendations for Further Work

This status report does not include utilization of the color video images collected by the UAV camera. The authors would have liked to have the tapes reviewed by a botanists to develop a species diversity index along the various UAV transects. In addition the monochrome camera utilizing different narrow band pass filters was not tested due to funding and equipment problems. The authors would like to collect multispectral images in order to calculate vegetation stress on a leaf-by-leaf basis.

References

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2. R. J. Cumbest, D. Marcy, J. Hango, S. Bently, B. Hunter, B. Cain, "Magnetic Survey of the D-Area Oil Basin Waste Unit", Report WSRC-TR-94-0378, September 1994.

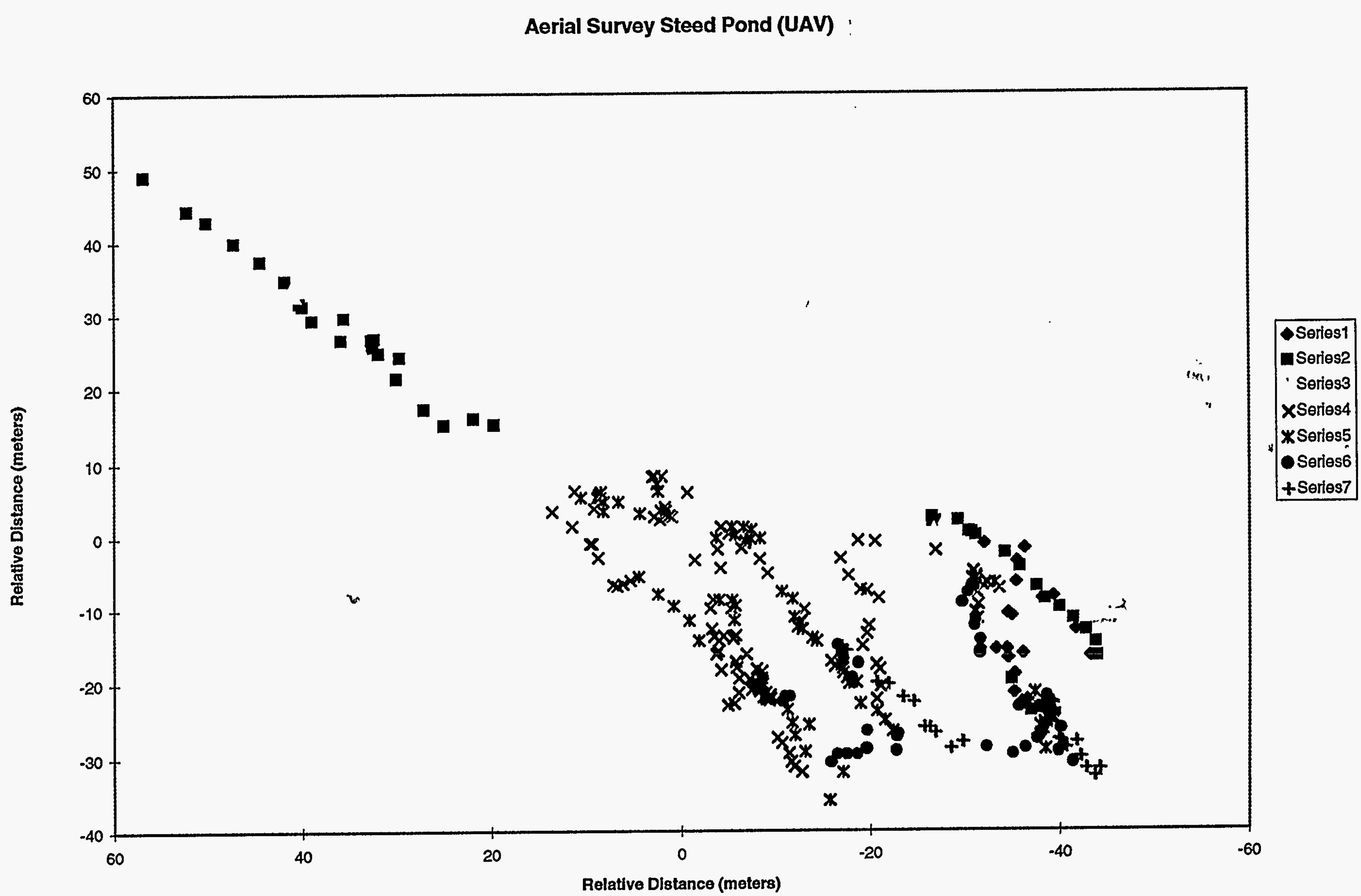
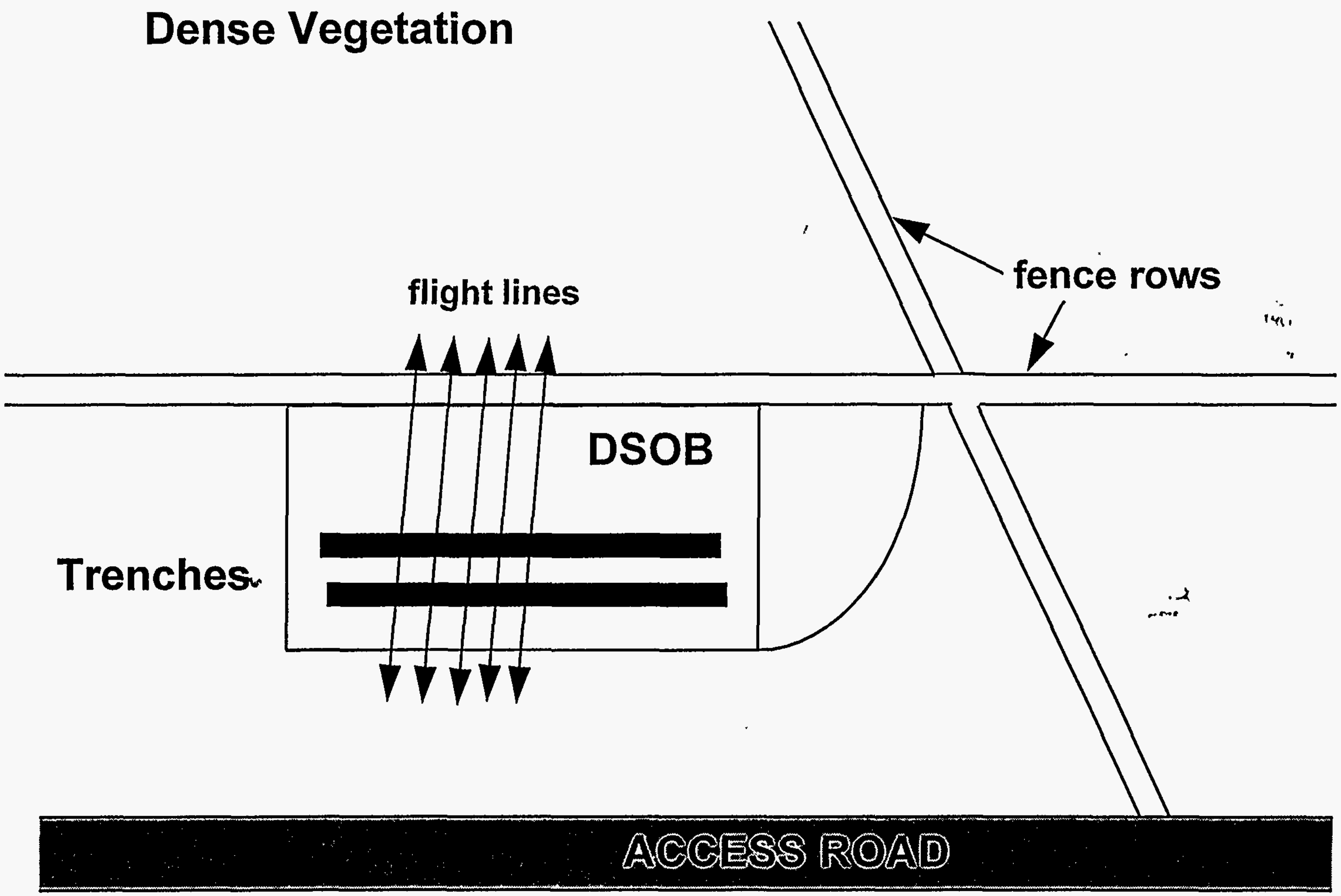

Aerial Survey Steed Pond (UAV)
60
50
40
30
20
10
0
-10
-20
-30
-40
Relative Distance (meters)
60
40
20
0
-20
-40
-60
Relative Distance (meters)
Series1
Series2
Series3
Series4
Series5
Series6
Series7

Figure 2



Dense Vegetation
flight lines
fence rows
DSOB
Trenches
ACCESS ROAD

D-31873.JPG

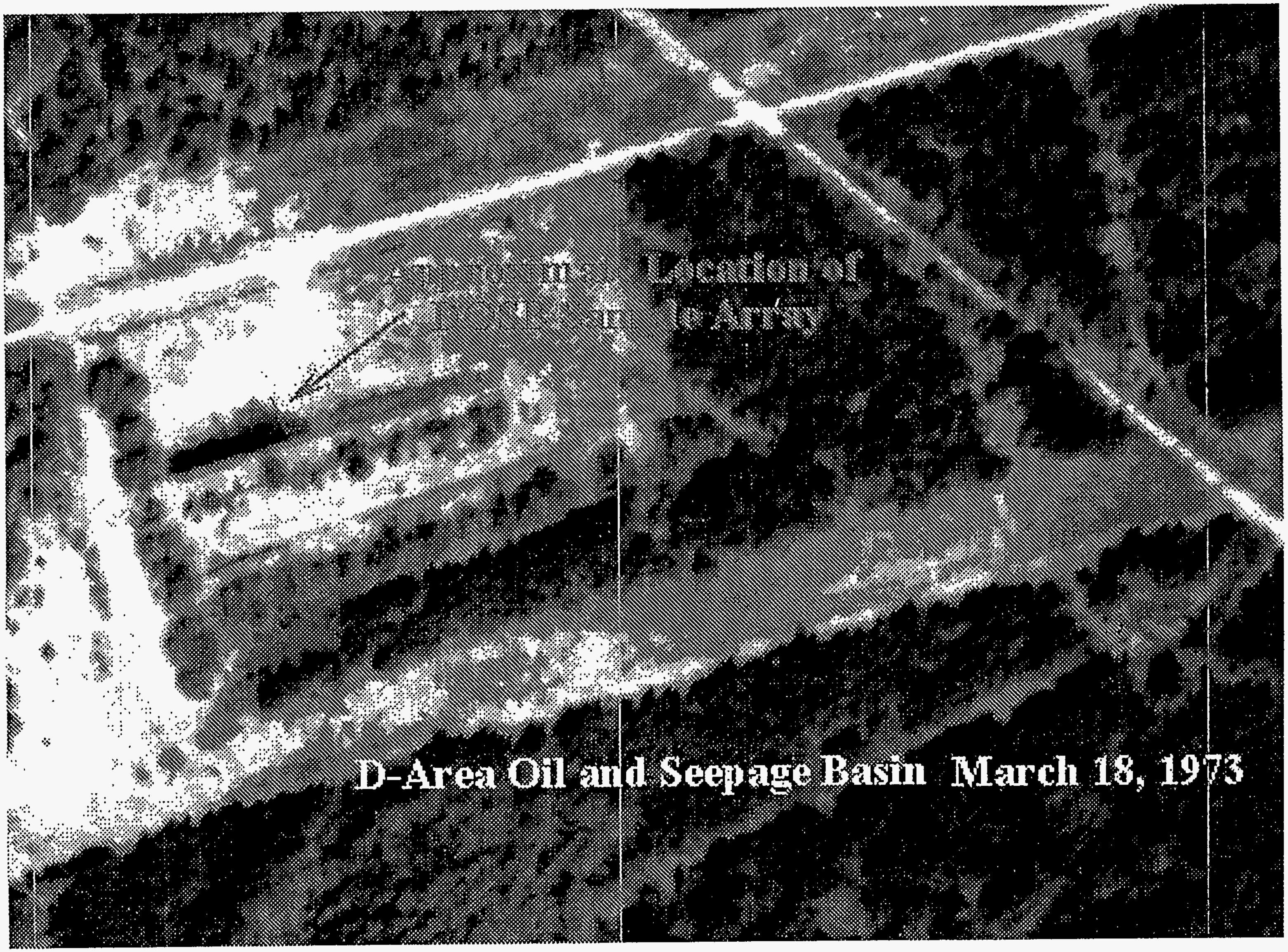


Figure #4

Surface IR Temp DOSB June, 1995

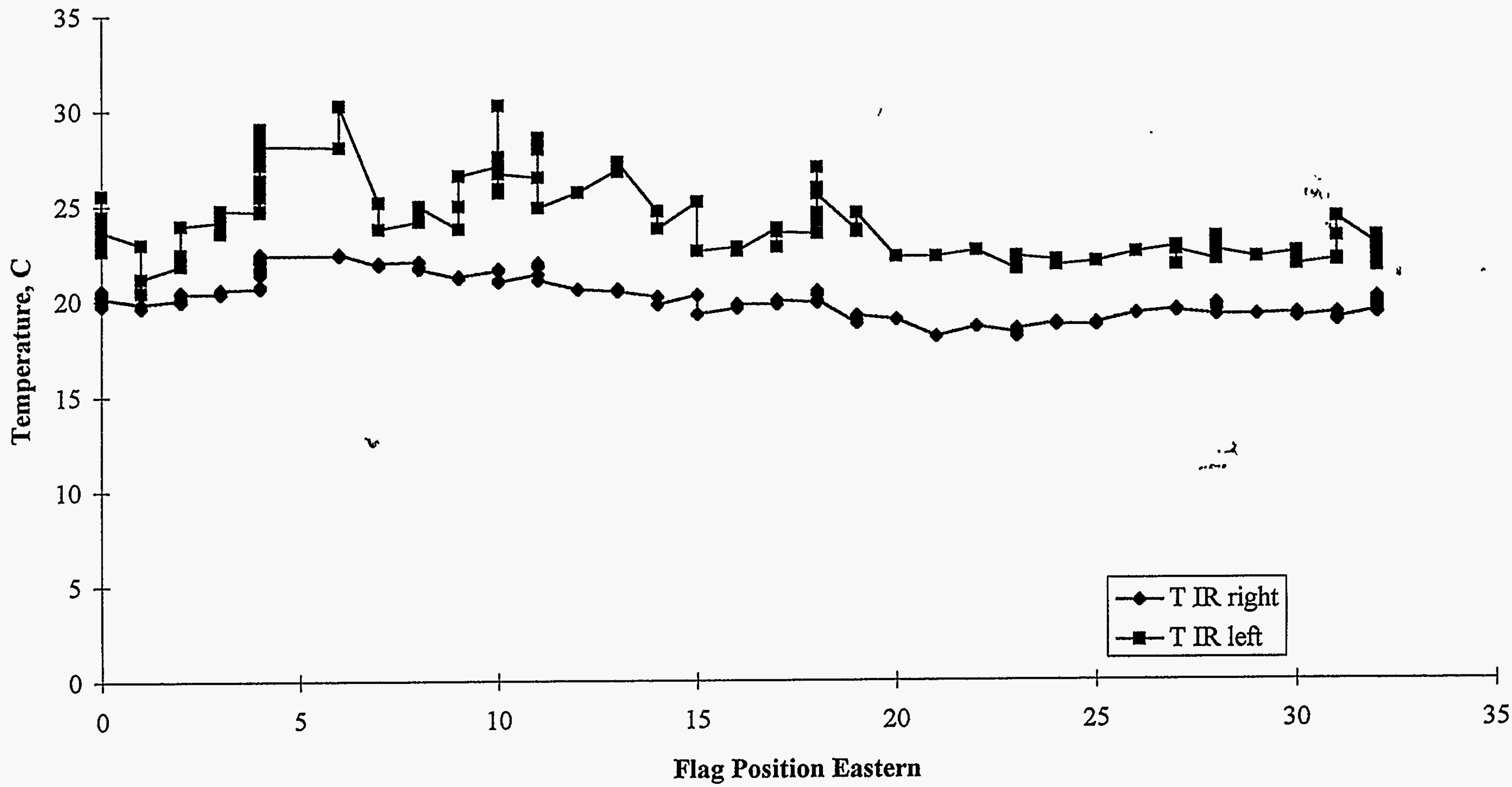
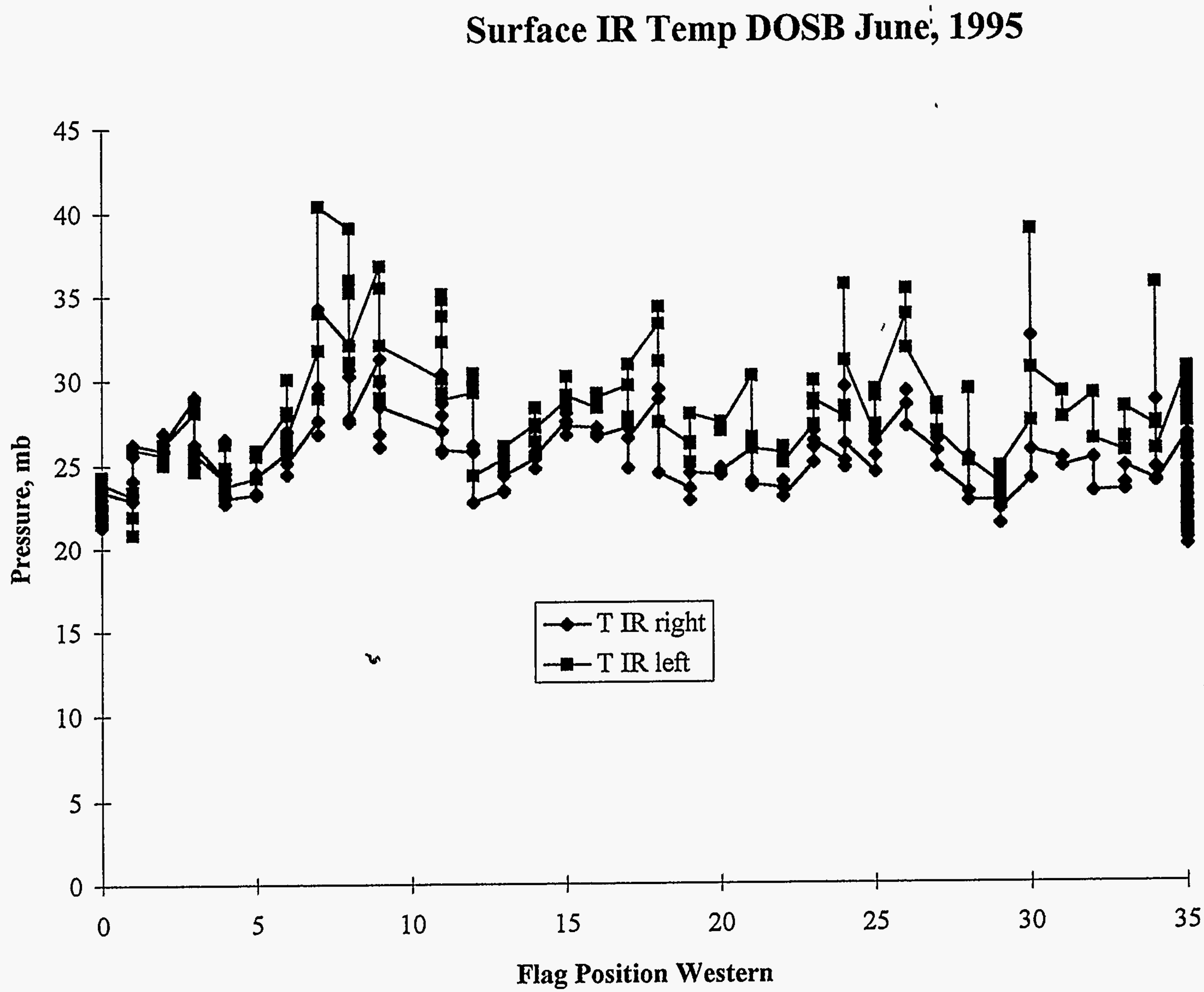
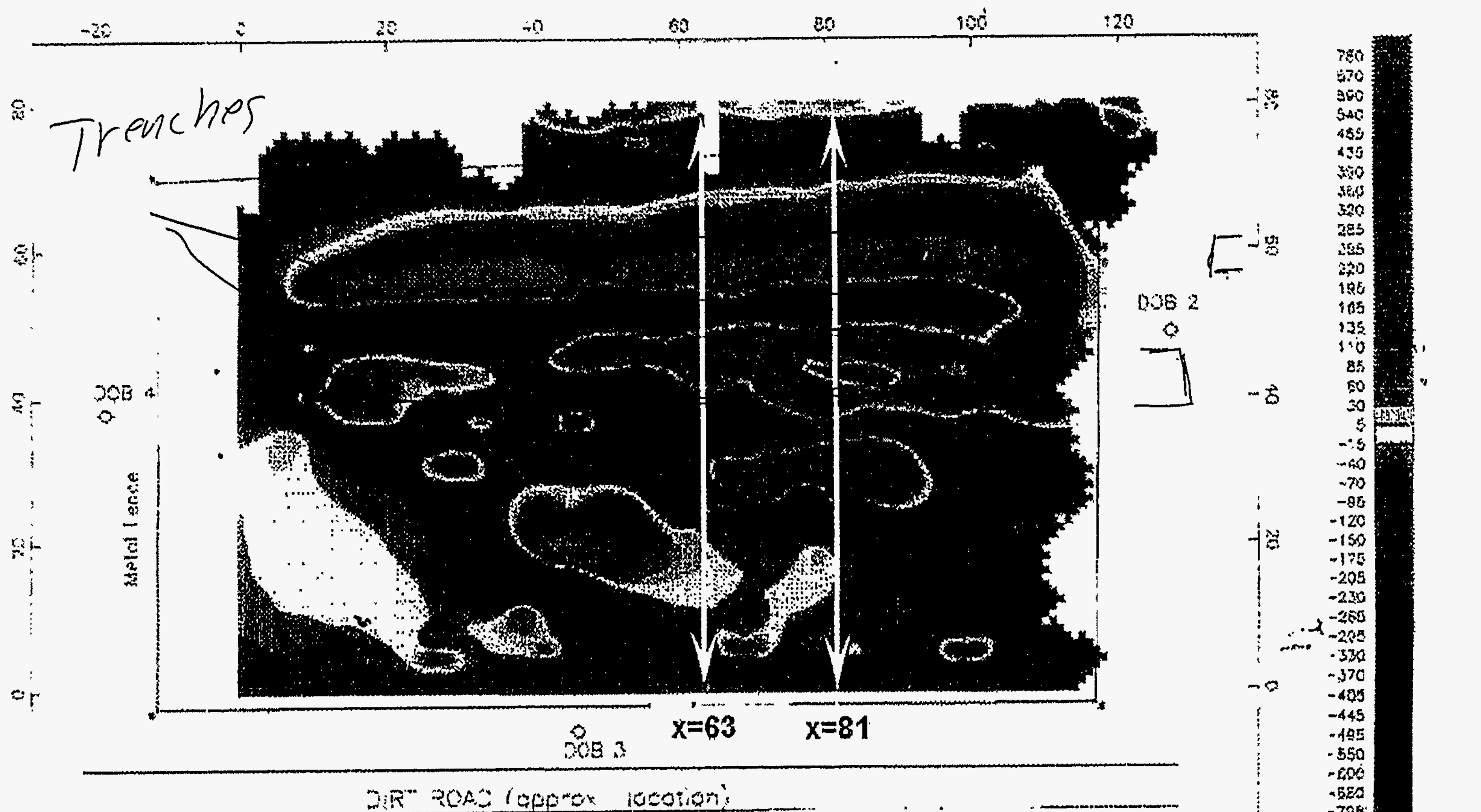


Figure No. 5



Test1dIR.xls

Figure 6.



Approximate Path of Model Helicopter Magnetometer Survey
(x=63 m and x=81 m)

Figure 7.

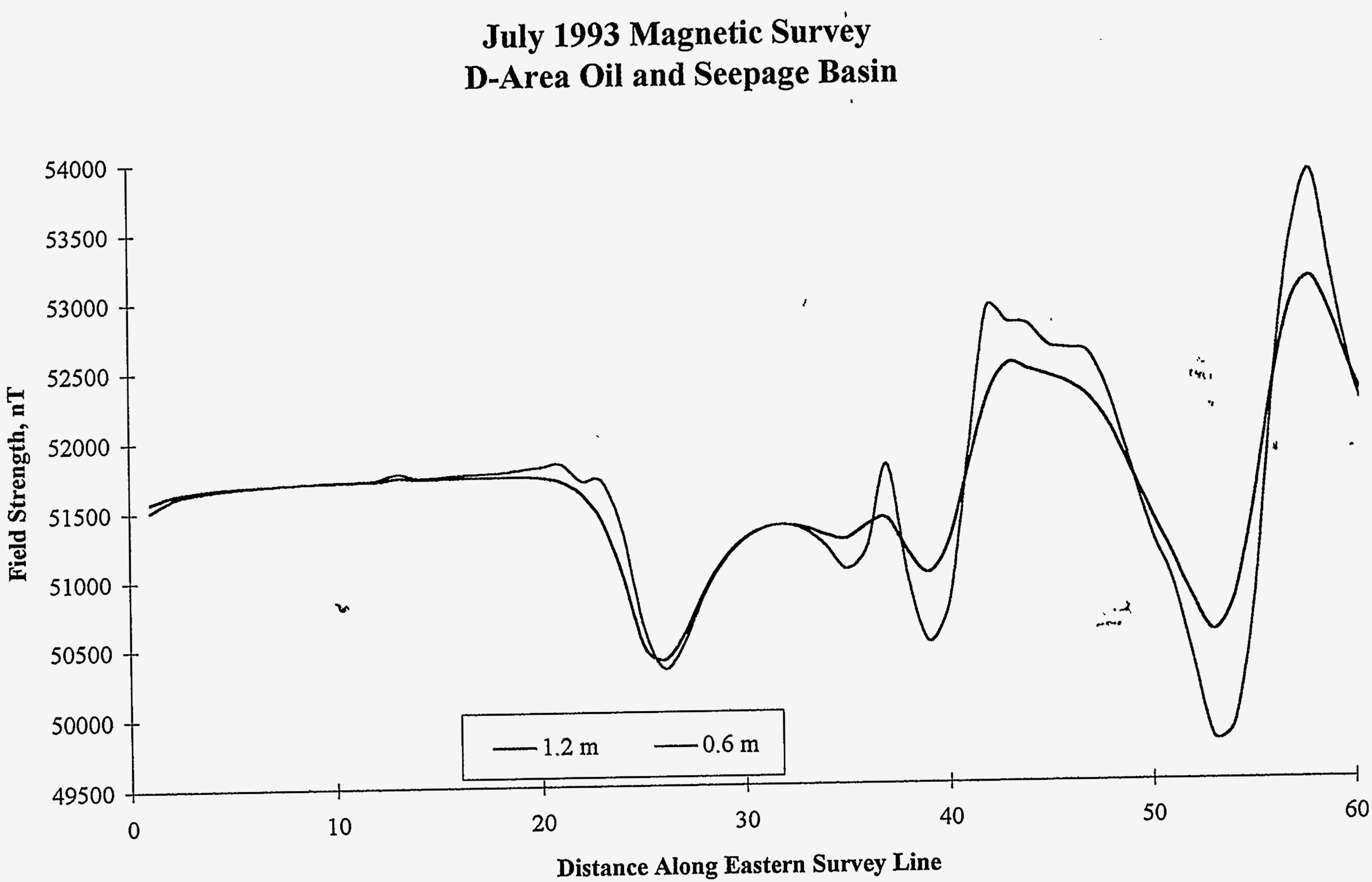
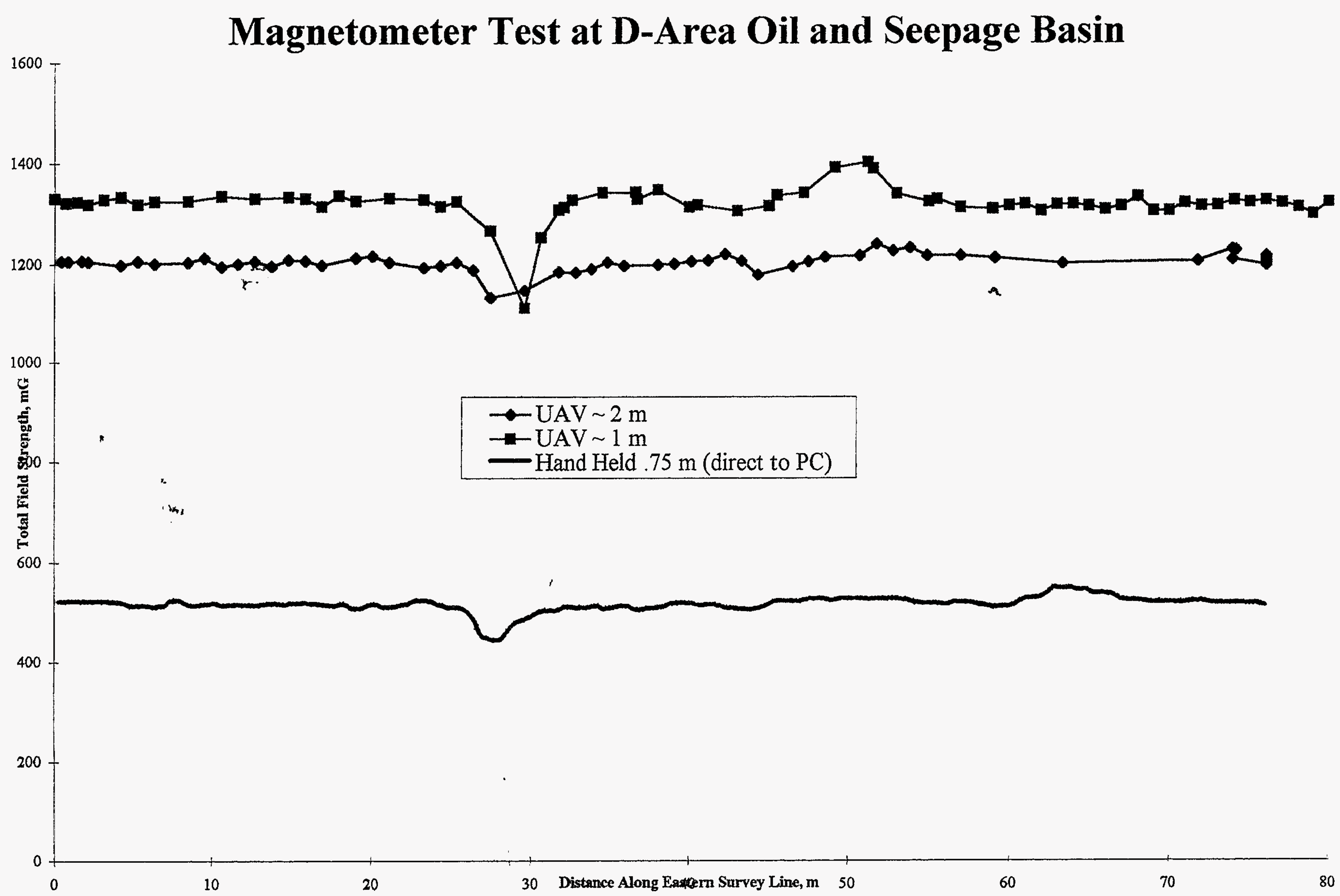

July 1993 Magnetic Survey
D-Area Oil and Seepage Basin
Field Strength, nT
54000
53500
53000
52500
52000
51500
51000
50500
50000
49500
0
10
20
30
40
50
60
Distance Along Eastern Survey Line
1.2 m
0.6 m

Figure 8.



uavall.xls