LAKE TRAFFORD CRITICAL RESTORATION PROJECT – AQUASCAN RADAR SURVEY REPORT

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1.0 Introduction

In 1996, Lake Trafford suffered an extensive fish kill due to low dissolved oxygen levels in the lake. Studies were undertaken by the Florida Fish and Wildlife Commission to determine the cause of the low dissolved oxygen. The study results indicated that the accumulation of a thick layer of decomposing organic matter on the bottom of the shallow lake containing a high level of total phosphorous was the cause of the low dissolved oxygen levels and the incident fish kills.

A program was recommended by the Florida Fish and Wildlife Commission and supported by the Big Cypress Basin of the South Florida Water Management District for the restoration of Lake Trafford by removing the accumulated muck layer from the lake. Accurate information on the elevations of "Top of Muck" and "Top of Original Lake Bottom" is important to calculate the volume of sediment to be removed and to establish the reference elevations for the proposed dredging activities.

ART Engineering, LLC (ART) was contracted by Harrington Engineering & Construction (HEC), under contract to Jacobs MWH Joint Venture (JM JV), to determine the elevations of "Top of Muck" and "Top of Original Lake Bottom" at Lake Trafford using the AquaScan Radar Survey Technology. AquaScan Radar Survey was originally developed by MAP Surveying of the Netherlands, and is offered in the U.S. market by ART Engineering, LLC. AquaScan has been used successfully on many sediment characterization projects in Europe.

The AquaScan Radar Survey uses a radar signal to measure the difference in dielectric constant of various sediment layers. Based on the indicated shallow water depths for Lake Trafford, low water conductivity levels and difference in dielectric constants of muck and original lake bottom sediments (mainly consisting of "marl" and sand in some areas near shore), the conditions for use of AquaScan for Lake Trafford were expected to be very favorable for use of ground penetrating radar (GPR) technology. The use of GPR in conjunction with a Global Positioning System (GPS) enables quick and efficient coverage of large survey locations. The ground penetrating radar approach is not affected by the presence of gas bubbles as is reported for sonic methods. The information of the survey can be used to provide information regarding water depth, the thickness of the organic sediments and the top of the original lake bottom.

To determine if the AquaScan radar measurements could meet the survey objectives of determining "Top of Muck" and "Top of Original Lake Bottom" or "Top of Marl" with a reasonable accuracy at Lake Trafford, a series of measurements were carried out along two transect lines A and B, which were marked with buoys. Along the two transect lines, several sediment core samples were collected by HEC for detailed analysis of the sediments and determination of "Top of Marl". Water depth or "Top of Muck" measurements were also performed by independent contractor ARC Surveying (ARC) using radar and sonar. ARC's results correlated well with ART's results. After calibration of the radar data, the results obtained by ART were evaluated by HEC and a representative of JM JV. Based on the results, ART obtained approval from HEC to perform a survey of Lake Trafford.

2.0 Site Description

Lake Trafford is located 30 miles North East of Naples, Florida. The lake is encompassing an area of about 1,500 acres. The results of previous investigations done by Ardaman & Associates (in 1997, 2000, and 2001) and USACE (fall 2000) show that the present lake bottom is a relatively flat surface with a slope of approximately 0.05%. The muck around the edges of the lake slopes up at approximately 0.15%. The original lake bottom shows more variation in bottom elevation with bottom slopes up to 0.3%. The thickest muck is located in the east central part of the lake, where a depression in the original lake bottom goes down to elevation 9.0 feet NGVD (National Geodetic Vertical Datum of 1929). The figures also show some of the variation in lake size (aerial extent) that occurs between the wet and dry seasons. The United States Geologic Survey started recording the level of Lake Trafford in 1947 and reported an elevation range from 15.9 to 22.8 feet. In recent years, the water level has fluctuated between elevations 18.5 and 21.5 feet. The boundary of the lake, as shown on the figures, includes the outline from a January 6, 1999 aerial photograph, when the lake was at elevation 20.8 feet, and the outline as presented on the USGS topographic map survey in the year 1987 at 19.0 feet. The variation in lake aerial extent, with variation in water level, is as large as would be expected with a shallow lake the size of Lake Trafford.

The topography of the occupied part of the area is considered as rather flat. Based on the results of core samples, the lake bottom consists of mainly marl with sand in some local areas close to the shore.

A site overview of the survey area can be found in Figure 1. The survey lines are projected in this topographic map.

3.0 The Basic Principle of AquaScan GPR Measurements

AquaScan uses Ground Penetrating Radar (GPR) to determine water depth and perform sub-bottom sediment profiling. The measurements are non-intrusive and non-destructive, and are conducted along survey lines. Because the equipment can record up to 70 individual scans per second, a semi-continuous profile along the survey lines can be gathered while surveying at speeds in the range of 0.6-13 mph. Compared with other geophysical methods, GPR profiles have a very high resolution. The selection of the optimum radar frequency is essential to obtain a good resolution and sufficient depth penetration.

The GPR signal decays with increasing depth. Lower frequencies will decay slower, thus achieving a larger penetration of the signal. However, these lower frequencies provide less resolution. The choice of the most suitable antenna(s) to perform a survey is an important task, because penetration also depends on the electrical conductivity of the subsurface. In areas of a low conductivity (e.g., sand/fresh water), the GPR signal will penetrate deeper than in conductive areas (e.g., clay, saline groundwater). The GPR signal will not penetrate through layers of metal. When encountering subsurface rubble, or reinforced concrete, the penetration is limited.

For every individual measurement, an antenna transmits an electromagnetic pulse. This pulse is partly reflected by changes in dielectric constant of the subsurface layers. Unlike sound waves, which are reflected by transitions of density, the GPR electromagnetic wave reflects on transitions of the dielectric constant of the medium. The reflections of the source signal are received, enhanced, digitized and stored on a hard disk.

The GPR profile gives information on the geological or sediment layers of the subsurface and subsurface objects and structures. Because the measurements are time based, extra information (boring logs or soundings) are needed to convert the actual radar reflection time measurements to actual depth of the features seen in the profiles. Positioning of the GPR measurements is done by GPS satellite positioning. Figure 2 shows an example of a sediment GPR profile with interpretation. The radar profile shows travel time (time value) of the reflected radar waves. Through calibration of the measured time values to reference elevations obtained from cores, the radar data can be converted to actual depth values. This procedure was used for Lake Trafford, and is explained in detail in section 4.0 of this report.

For the AquaScan survey at Lake Trafford, a GSSI Sir 2000 georadar with a 200 MHz antenna was used. To obtain a good penetration, the antenna was placed directly on the water surface in an inflatable boat. Radar measurements were taken along survey lines as indicated in Figure 1. The survey lines were positioned in approximately 100 meter (110 yard) intervals, providing a good coverage for the entire lake. A Global Positioning Survey System was used to GPR data with real time Universal Trans Mercator (UTM) coordinates onto a portable computer.

4.0 Validation Test Transects and GPR Calibration

4.1 Validation Test Transects

To validate and calibrate the radar results before surveying the entire lake, measurements were taken along two transect lines established in Lake Trafford at the locations shown on Figure 3. Each transect line starts near the shore and is approximately 2,000 feet long, and is marked with buoys. Transect A was selected to cover an area where the muck thickness is shallow over both sand and marl original lake bottom. Transect B was selected to cover an area where the muck is thickest as determined from past work at Lake Trafford. Past work at the lake indicates that each transect will begin near the shore with a sandy bottom and will find progressively finer original bottom conditions as the transect progresses towards the center of the lake.

Eight sediment cores (one core approximately every 300 feet) were taken along each transect to determine the actual interface locations of the "Top of Marl" and "Top of

Muck". The radar data (measured time values) were calibrated to elevation of the "Top of Marl" based on actual interface location as determined from the cores.

In addition to radar measurements performed by ART, the top of muck elevation was also to be confirmed by the independent contractor ARC Surveying (ARC), using a 200 kHz transducer, as well as Ground Penetrating Radar.

4.2 Calibration of GPR and Comparison with Core Samples

Radar profiles (time measured values) of the two transect lines are shown in Figures 4 and 5. Time measured values for each of the sample locations along the transect lines are provided in Table 1. Time measured values are converted to distance (depth) using the average speed of radar waves in water and muck, as determined from calibration to core samples (Appendix 1).

Table 2 provides a comparison of results between core samples, ARC sonic depth profiling, ARC "Ground Penetrating Radar" and ART "Ground Penetrating Radar". The comparison between ARC and ART "Ground Penetrating Radar" results for "Top of Muck" and "Top of Marl" is good. Also, the result of the sonic profiling and Ground Penetrating Radar for "Top of Muck" compares well. When comparing the elevation of the Marl as determined by GPR and the core samples, there appears to be a good correlation between the results. The average error is 0.1 foot for Transect A and -0.3 foot for Transect B, based on the ART GPR. It should be noted that the interface between Marl and Muck is not a perfectly flat interface and shows variation even within cores. Overall, the results of the ART GPR for identification of "Top of Marl" match well with the core data.

When comparing the "Top of Muck" elevation determined by both Sonic and GPR methods and the "Top of Muck" determined from the core samples, it is noted that there is a significant difference between the elevation of "Top of Muck" and "Muck Thickness". HEC has developed a model for the Lake Trafford sediments which indicates existence of multiple zones of consolidated and non-consolidated muck ("fluff", "sticky muck", "consolidated muck"), which gradually turns into a more consolidated sludge with depth. It is assumed that the Sonic and GPR methods see the top of the loose fluff while based on the HEC developed model for sediments at Lake Trafford, the loose fluff would no longer exist after the cores are collected (fluff would settle out). This may explain the difference between radar measurements and the cores. A more detailed description of this theory is provided in the "Lake Trafford Critical Restoration Project – Report Site Investigation and Recommendations Dredging and Containment of Muck", prepared by HEC (March 2004).

5.0 Survey Results

5.1 Execution

Based on the results of the validation, ART obtained approval from HEC to perform a survey of Lake Trafford. The survey of the lake was carried out along pre-setup gridlines, spaced approximately 100 m (110 yards) apart. The positioning was carried out by GPS with Omnistar correction. The survey lines are indicated in Figure 6. Along the "shore" of the lake, a survey line has been conducted as close as possible to the edge of the lake. The survey was performed the week of January 19, 2004. The lake level during the survey was constant at 20.28 feet.

5.2 Results

A summary of the survey results is presented in Figures 7 through 11. A brief discussion of the survey results is provided in following sections.

5.2.1 Top Muck and Top of Marl

Results on distance from water surface to "Top of Muck" and "Top of Marl" are provided as a 3-dimensional representation in Figure 7 and as a contour map in Figure 8.

The results indicate that the lake is relatively flat with a slight depression in the "Top of Muck" in the north-eastern corner of the Lake. At this location the water depth is in the range of 7 to 7.5 feet.

5.2.2 Sludge Volume Estimate: Calculation Top of Muck to Top of Marl

Muck thickness is presented as a 3-dimensional representation in Figure 9 and as a contour map in Figure 10.

The results indicate that the muck thickness increases from the edges of the lake to maximum thickness of 5 feet in the centre of the lake. Just to the north east of the centre of the lake, the muck thickness is thin (less than 2 feet), as result of a sub-bottom anomaly in the original lake bottom (refer to discussion in section 5.2.3).

The muck volume has been calculated using positive and negative cut and fill volumes (Cut – Fill = Muck Volume) using "inversed distance griding method using 3D surface contouring and the mapping program *"Surfer*". The results indicate a total in-situ muck volume of 4,800,000 M3 (6,278,160 CY). Backup grid volume calculation is provided in Appendix 2.

5.2.3 Sub-Bottom Anomaly

During the survey, it was noted that a large sub-bottom anomaly (mound) appeared to be present in the subsurface. This anomaly is visible just off-centre (to East) in Figure 7. Figure 11 shows a detailed cross section over this area of interest. Figure 11 shows a deeper layer coming through the marl. This layer is covered by a thin (less than 2 feet) layer of muck. The radar reflections from the top of this layer suggest that the composition of this layer is clearly different from the surrounding marl. The reflections indicate layering of this other layer. Furthermore, parabolic reflections in the radar profiles over the area of interest indicate the presence of objects in the subsurface. ART has collected additional radar data along a dense grid of survey lines over the area of interest, which is available for further processing, if desired.

Tables

Table 1: Radar Calibration Table - Test Transects A & B

Transect and Core #	Time Difference (ns)			Elevation (ft)	Radar Speed (ns/ft)		Depth/Elevation (ft)		Thickness/Elevation (ft)	
	Top of Muck - Radar Reflection time	Top of Marl - Radar Reflection time	Muck Thickness - Time Difference	Top of Marl based on Core Samples	Average Radar Speed in Water [1]	Averag Radar Speed in Muck [1]	Top of Muck (Water Depth)	Top of Muck Elevation [2]	Muck Thickness (based on GPR)	Top of Marl Elevation based on GPR
TA-03	82.00	122.20	40.20	12.2	16.6	13.7	4.9	15.3	2.9	12.4
TA-04	86.90	131.10	44.20	12.4	16.6	13.7	5.2	15.0	3.2	11.8
TA-05	91.00	133.80	42.80	11.2	16.6	13.7	5.5	14.8	3.1	11.7
TA-06	95.80	140.10	44.30	11.3	16.6	13.7	5.8	14.5	3.2	11.3
TA-07	101.00	145.30	44.30	10.5	16.6	13.7	6.1	14.2	3.2	11.0
TB-03	82.20	126.40	44.20	11.4	16.6	13.7	5.0	15.3	3.2	12.1
TB-04	90.90	136.60	45.70	10.6	16.6	13.7	5.5	14.8	3.3	11.5
TB-05	93.80	148.90	55.10	10.3	16.6	13.7	5.7	14.6	4.0	10.6
TB-06	98.20	180.80	82.60	9.8	16.6	13.7	5.9	14.4	6.0	8.3
TB-07	101.80	186.60	84.80	9.2	16.6	13.7	6.1	14.1	6.2	8.0
TB-08	103.30	190.00	86.70	8.5	16.6	13.7	6.2	14.1	6.3	7.7

[1]: Refer to Radar Calibration Data Table in Appendix 1

[2]: Lake level at 20.28 ft during survey

Core = Results from Measuring Core Samples (January 8-9, 2004)

GPR = Ground Penetrating Radar

Table 2: Comparison of Survey Results - Test Transects A & B

Transect A

Core #	Top Muck Surface Elevation (ft)				Marl Elevation (ft)			Marl Elevation Error	
	Core Sample	ARC Sonic	ARC GPR	ART GPR	Core	ARC GPR	ART GPR	ARC GPR	ART GPR
1	16.9		17.3		16.6	17.3		0.7	
2	14.7	16.2	16.3		14.3	14.1		-0.2	
3	12.6	15.6	15.6	15.3	12.2	13.0	12.4	0.8	0.2
4	13.4	15.2	15.2	15.1	12.4	12.1	11.8	-0.3	-0.6
5	11.6	14.9	14.9	14.8	11.2	12.0	11.7	0.8	0.5
6	11.6	14.6	14.6	14.5	11.3	11.5	11.3	0.2	0.0
7	10.8	14.2	14.2	14.2	10.5	11.2	11.0	0.8	0.6
8	11.2	14.0	14.0		10.7	11.0		0.3	
Average Profundal		**14.8**	**14.8**	**14.8**		**Average Error**		***0.4***	***0.1***

Transect B

Core #	Top Muck Surface Elevation (ft)				Marl Elevation (ft)			Marl Elevation Error	
	Core Sample	ARC Sonic	ARC GPR	ART GPR	Core	ARC GPR	ART GPR	ARC GPR	ART GPR
1	16.4	16.5	16.5		16.3				
2	15.8	15.0	14.9		14.2	14.2		0.0	
3	12.5	15.3	15.4	15.3	11.4	12.2	12.1	0.8	0.7
4	11.6	14.7	14.7	14.8	10.6	11.6	11.5	1.0	0.9
5	11.1	14.7	14.7	14.6	10.3	10.8	10.6	0.5	0.3
6	10.7	14.3	14.3	14.2	9.8		8.3		-1.5
7	11.3	14.0		14.1	9.2		8.0		-1.2
8	9.8	13.8			8.5		7.7		-0.8
Average Profundal		**14.5**	**14.8**	**14.6**		**Average Error**		***0.6***	***-0.3***

ARC = ARC Surveying (1/9/04)
ART = ART Engineering (1/19/04)
GPR = Ground Penetrating Radar
Core = Results from Measuring Core Samples (January 8-9, 2004)

Figures

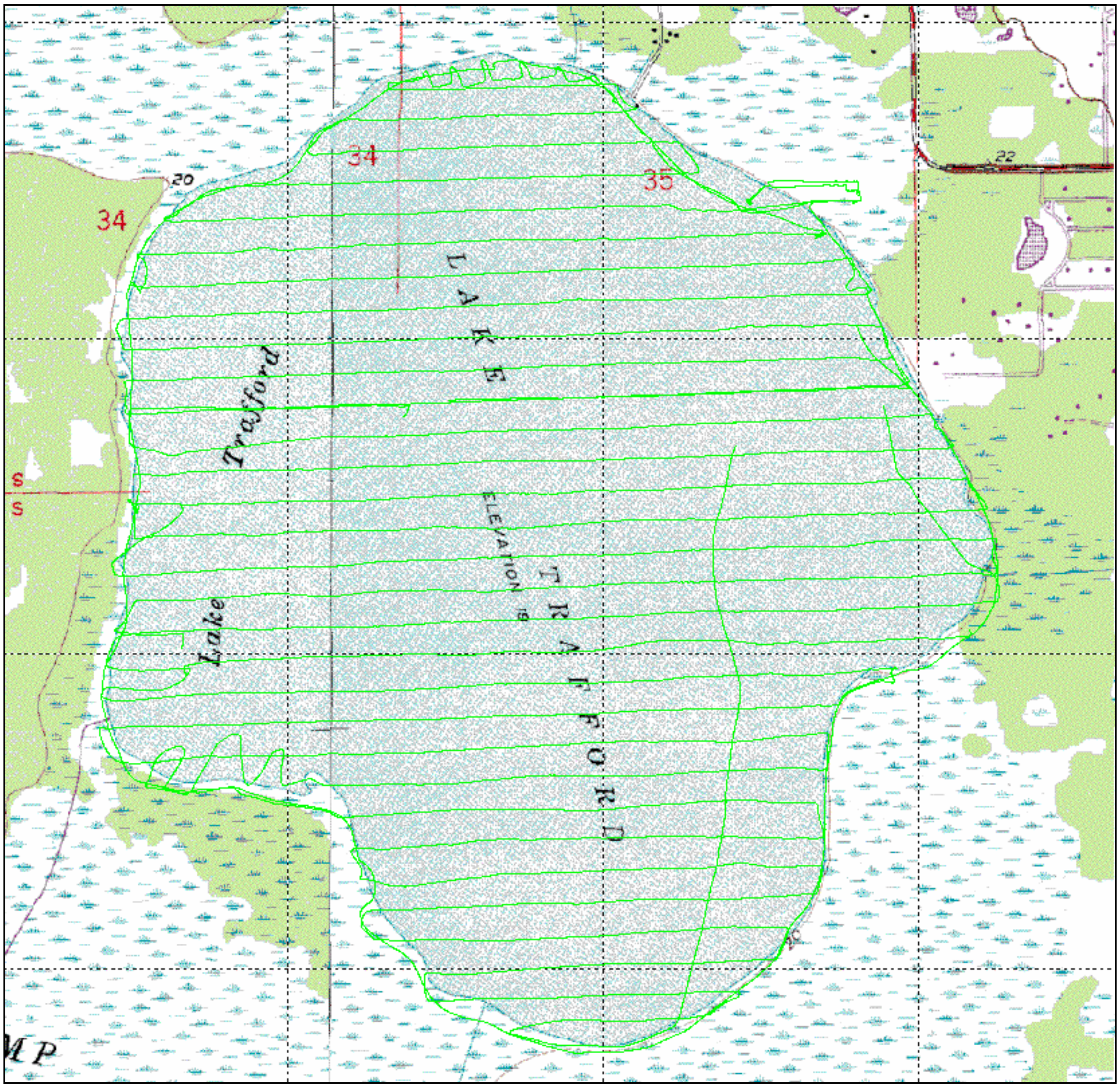

Figure 1: Map of Lake Trafford with Survey Lines

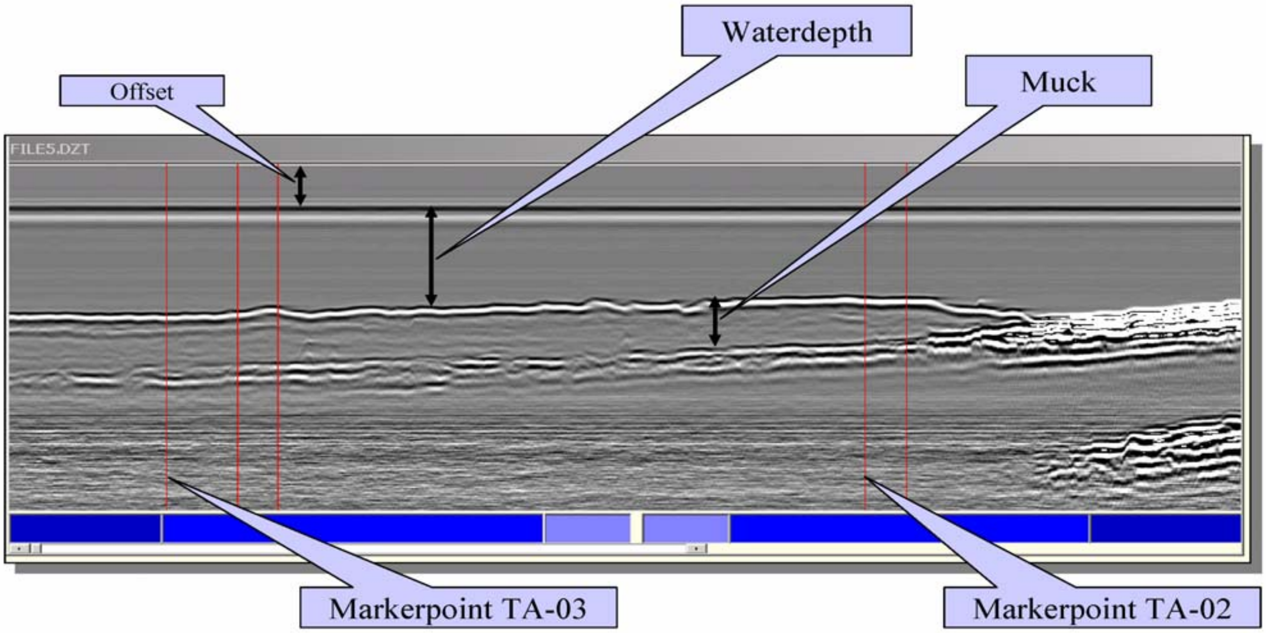

Figure 2: Example Radar Data Profile with Interpretation

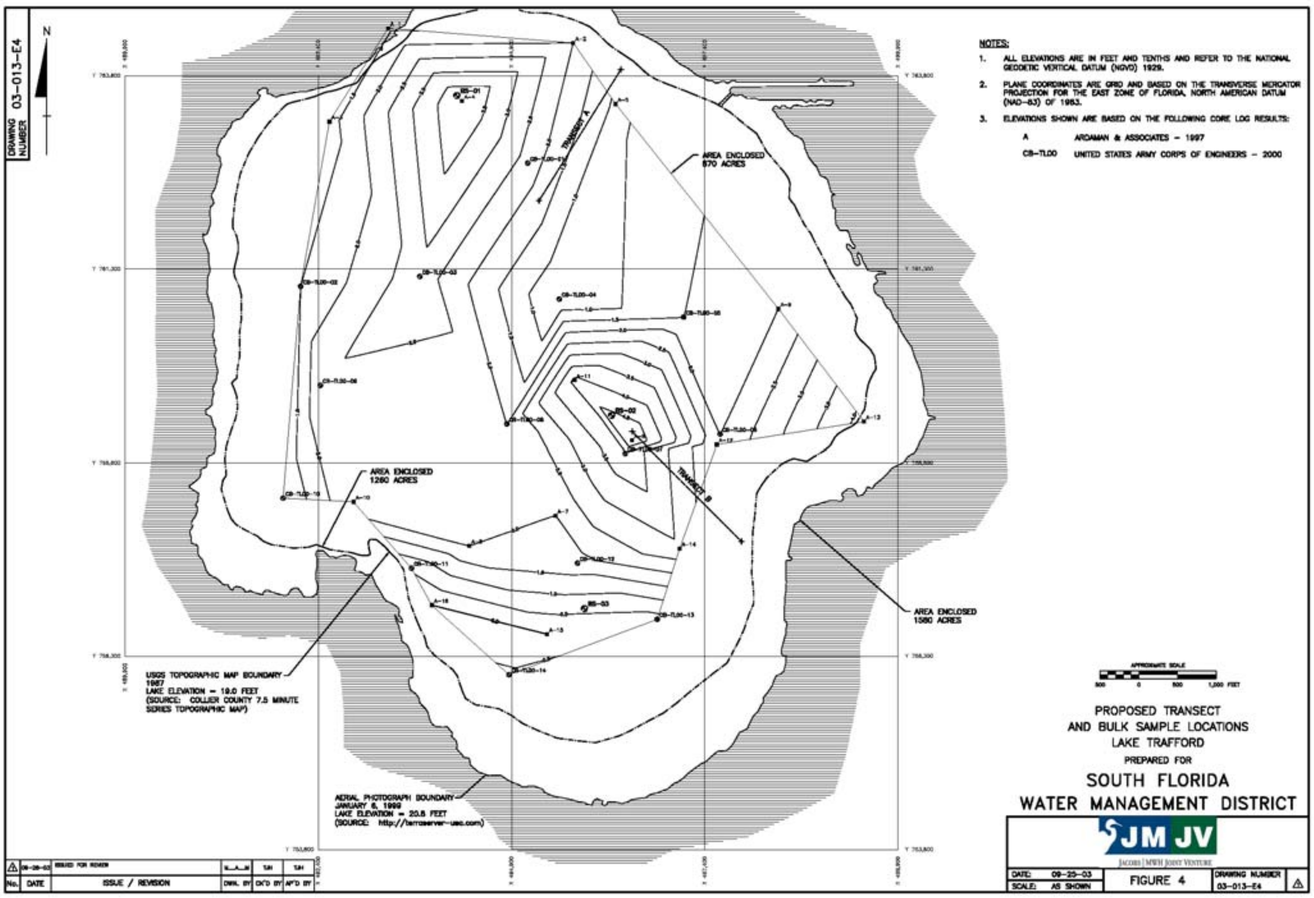

Figure 3: Location of Transect Lines A and B

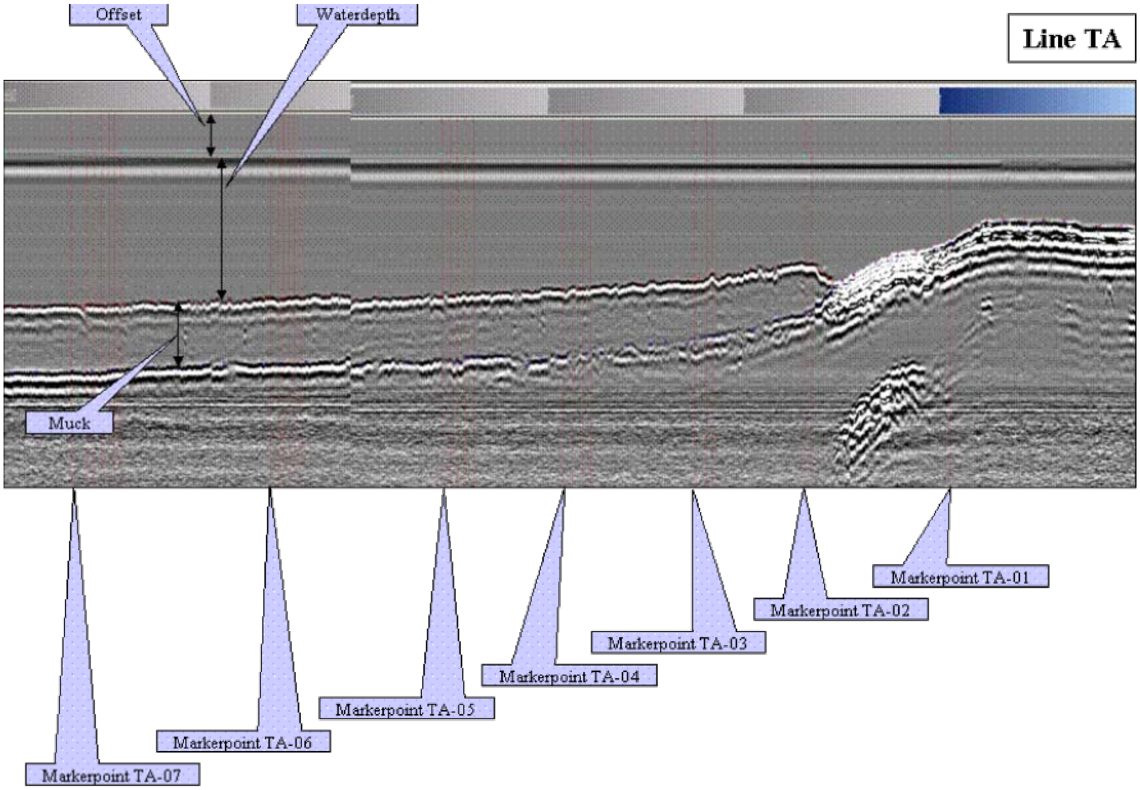

Figure 4: Radar Survey Profile - Transect Line A

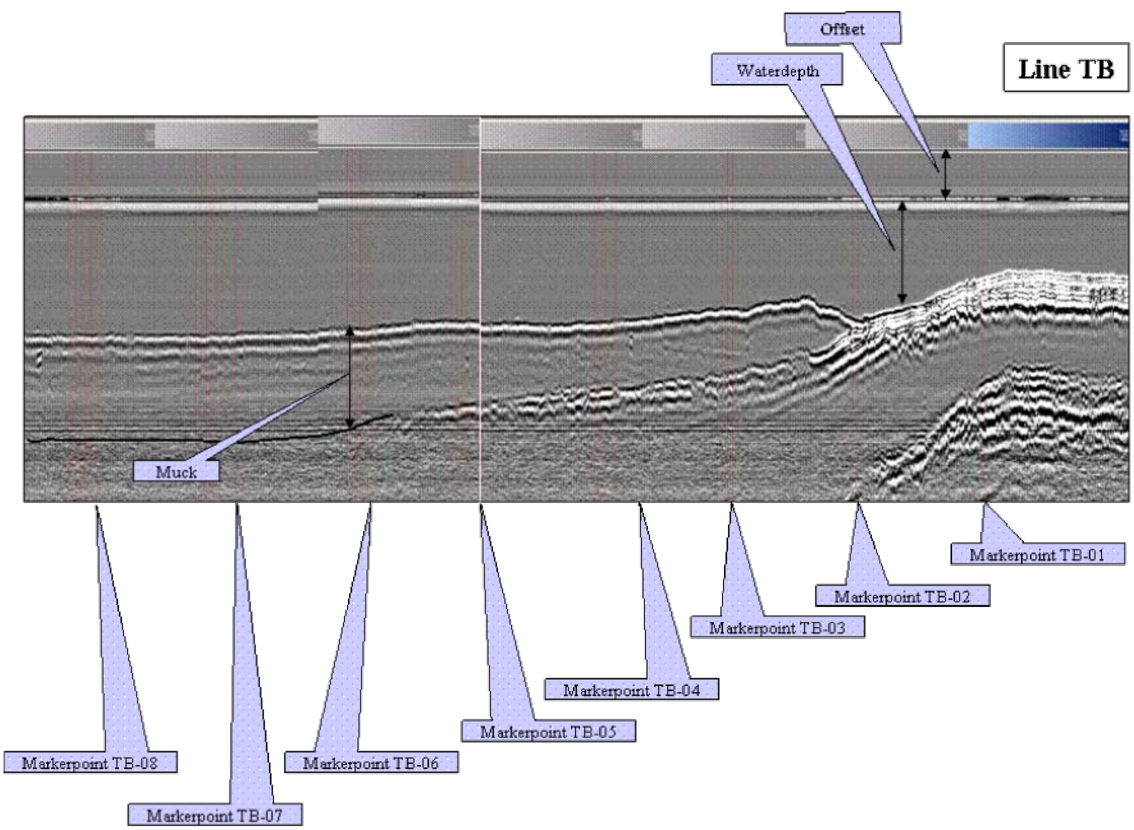

Figure 5: Radar Survey Profile - Transect Line B

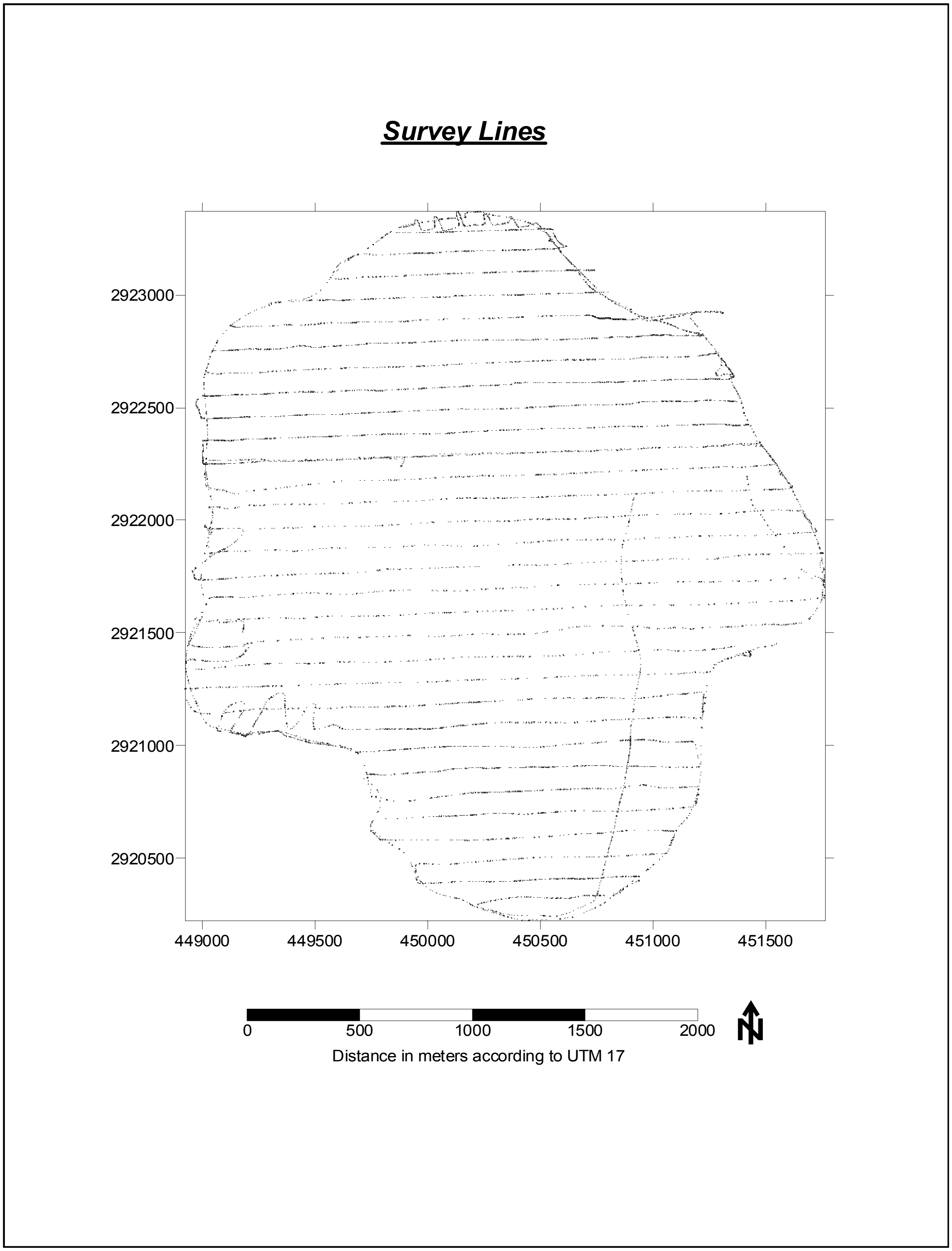

Figure 6: Lake Trafford Survey Lines

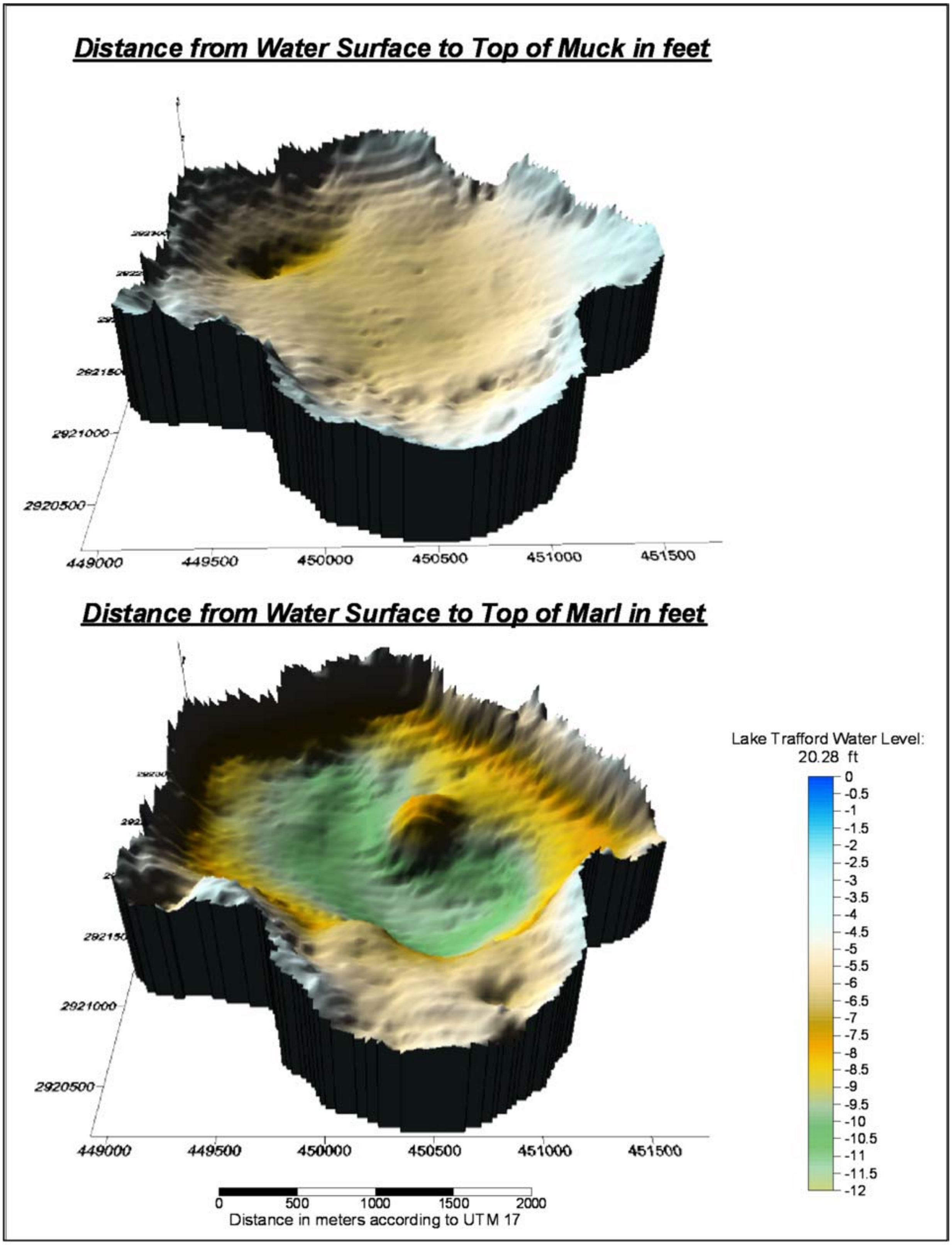

Figure 7: Top of Muck and Top of Marl – 3-Dimensional Representation

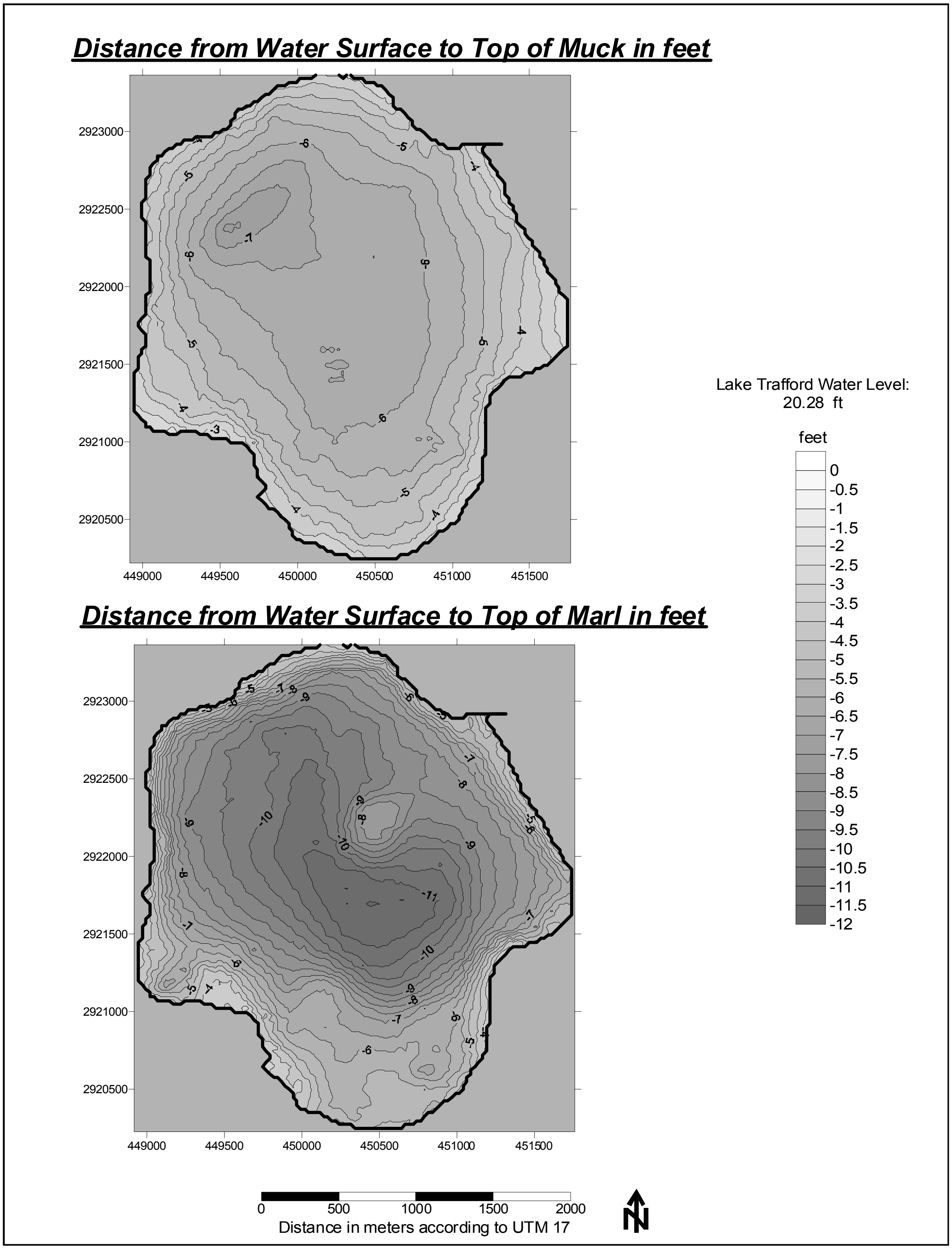

Figure 8: Top of Muck and Top of Marl - Contour Maps

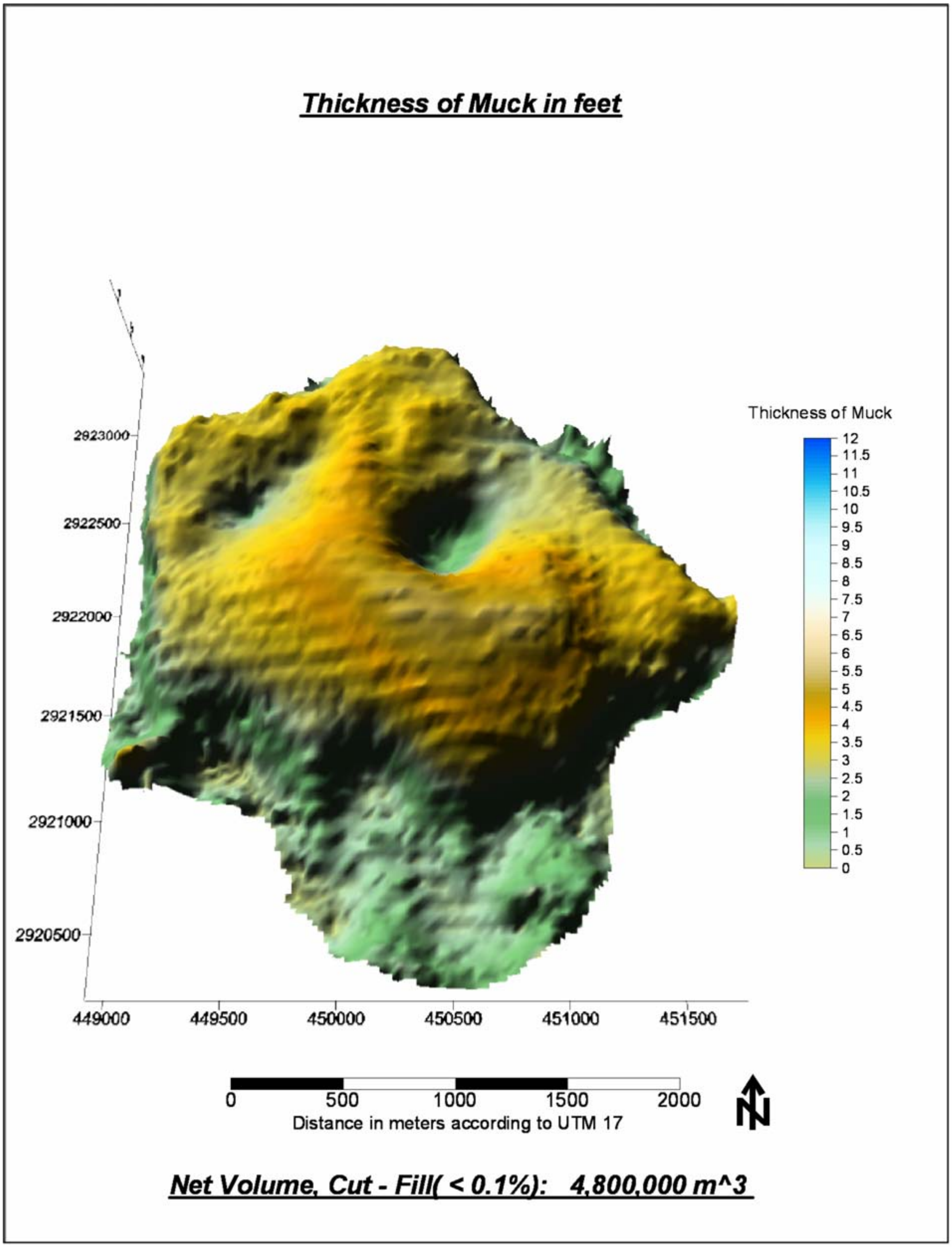

Figure 9: Muck Thickness – 3-Dimensional Representation

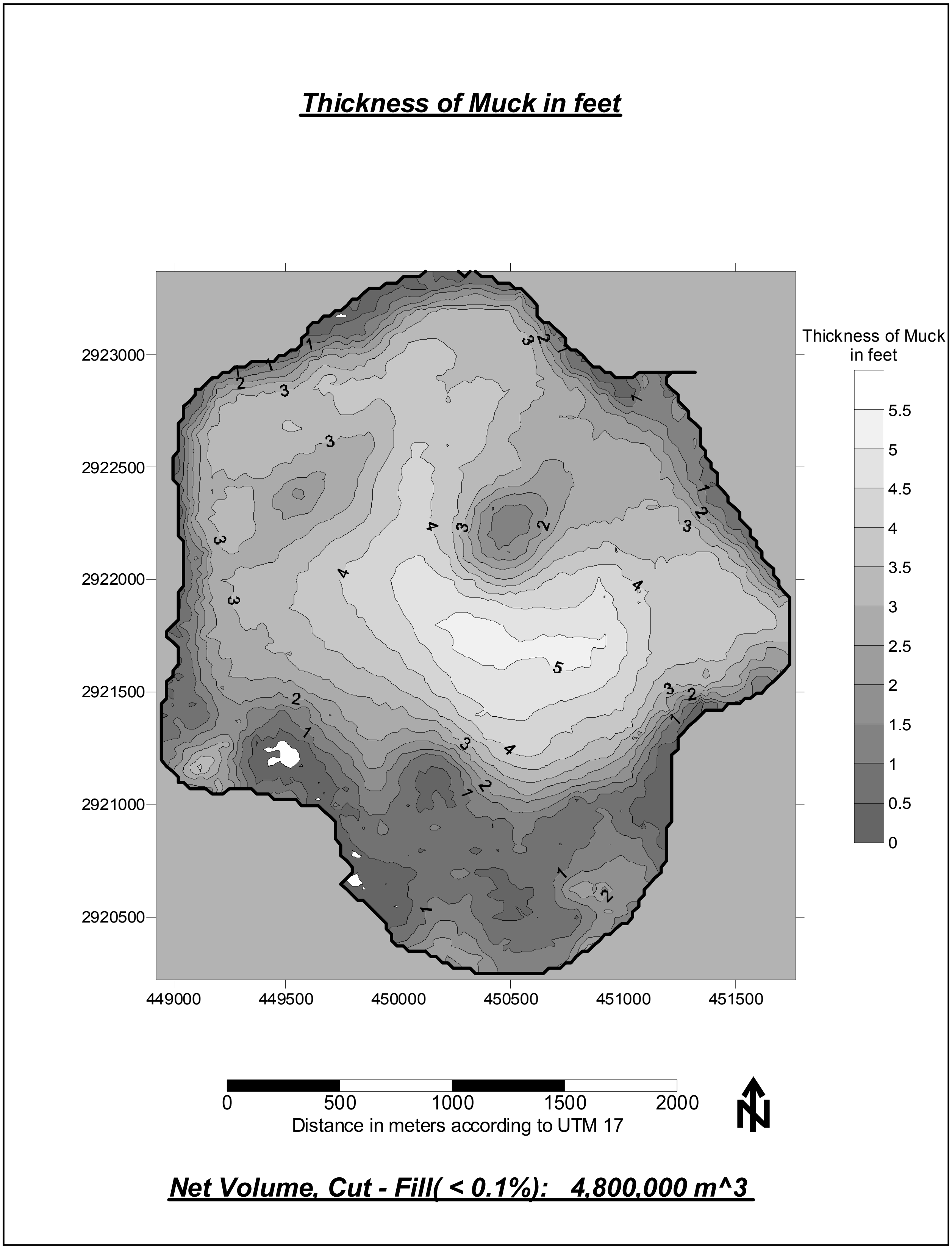

Figure 10: Muck Thickness – Contour Maps

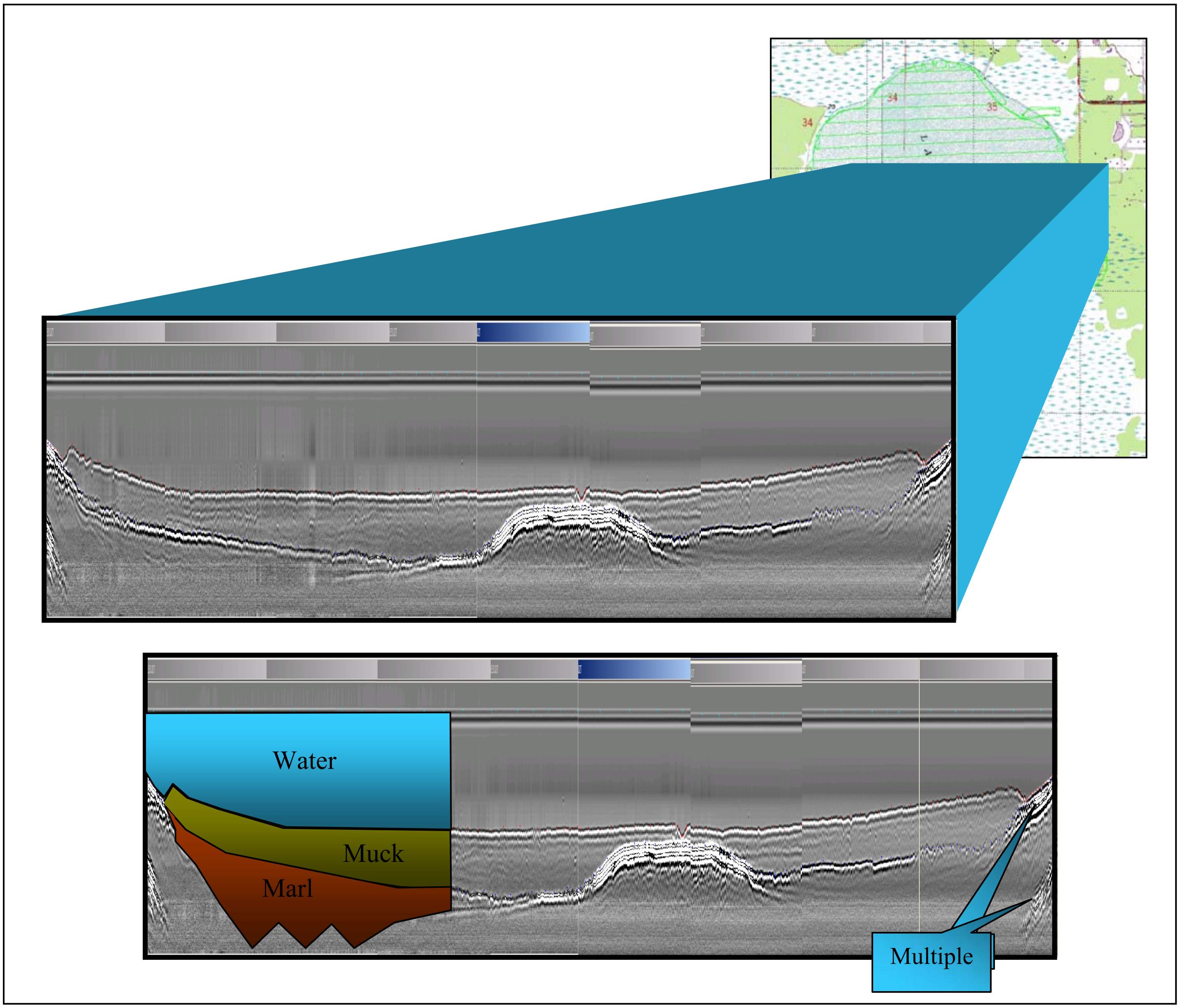

Figure 11: Cross Section Profile of Sub-Bottom Anomaly