United States Department of Agriculture

Soil Conservation Service

Northeast NTC
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Subject: Geophysical surveys of animal waste lagoons in South Carolina, 25 June - 2 July & 10 - 15 July 1988

Date: September 19, 1988

To: Burton Wells
State Conservation Engineer
Columbia, South Carolina

File code: 210-26-5

Purpose:

To evaluate the applicability of ground-penetrating radar (GPR) and electromagnetic (EM) techniques for determining the presence and extent of contaminant and leachate plumes emanating from animal waste lagoons.

Principal Participants:

Billy Beard, Soil Conservation Technician, SCS, Chester, SC
Dr. Dave Brune, Assoc. Professor, Clemson University, Clemson, SC
Jim Doolittle, Soil Specialist (GPR), SCS, Chester, PA
Kim Kroeger, Geologist, SCS, Raleigh, NC

Activities:

During the weeks of June 27 and July 11, 1988, the following lagoon sites were grid and geophysical surveys completed using both GPR and EM techniques:

Site 1 - Ralph O'Neil's lagoon (hog), Marion County
Site 2 - George Peebles' lagoon (hog), Clarendon County
Site 3 - Wilbur Fogle's lagoon (dairy), Orangeburg County
Site 4 - Al Bates' lagoon (dairy), Orangeburg County
Site 5 - Gary Hegne's lagoon (dairy), Bamberg County
Site 6 - Ray Bryant's lagoon (hog), Bamberg County
A Site 7 - Roy Frick's lagoon (poultry), Lexington County
C Site 8 - Jimmy Haltiwanger,s lagoon (dairy), Newberry County
B Site 9 - James Long's lagoon (poultry), Newberry County

Geophysical Equipment:

GPR -

The ground-penetrating radar is the SIR System-8 manufactured by Geophysical Survey Systems, Inc. 1. The System-8 consists of a model 4800 control unit with microprocessor, an ADTEK SR 8004H graphic

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1. Use of trade names in this report is for identification purposes only and does not constitute endorsements.

recorder, an ADTEK DT 6000 tape recorder, and a power distribution unit. The microprocessor, which has programs to enhance or amplify weak signals and remove background noise, was not used in this study. The system was powered by a 12-volt vehicular battery.

Five antennas (80, 120, 250, 300, and 500 MHz) were available for this study. The lower frequency antennas (80 and 120 MHz) have longer pulse widths, greater radiation powers, and emit pulses that are less rapidly attenuated by earthen materials. The higher frequency antennas (300 and 500 Mhz) have shorter pulse widths and greater powers of resolution, but are more rapidly attenuated by earthen materials and limited to shallow depths. For most field work, the 120 MHz antenna provided the best balance of probing depth and resolution.

The GPR recording and control units were mounted on a shelf within a four-wheel drive vehicle. The antennas were towed behind the vehicle along the flagged grid lines at speed of 3 to 5 km/h. The GPR unit operated well with the exception of the newly acquired 250 MHz antenna. This recently designed antenna malfunctioned and provided no meaningful subsurface information. The antenna has been returned to the manufacturer for repairs and modifications.

EM -

The ground conductivity meter is the model EM 34-3 manufactured by Geonics Limited 1. The EM 34-3 consists of three reference cables (10, 20, and 40 meters), receiver and transmitter consoles, and receiver and transmitter coils. The EM 34-3 can be used with three fixed intercoil spacings of 10, 20, and 40 meters. The coils can be positioned in both horizontal (coils in the upright position) and vertical (coils laying flat on the ground) dipole modes. With the coils upright (vertical coil orientation and horizontal dipole mode), the instrument senses approximately 0.75 times the intercoil spacing. With the coils laying flat on the ground (horizontal coil orientation and vertical dipole mode), the instrument senses approximately 1.5 times the intercoil spacing. Table 1 summarizes the sounding depths of the EM 34-3. The transmitter and receiver are powered by 8, disposable 'D' and 'C' batteries respectively.

The EM 34-3 was used with only the 10 meter intercoil spacing. This spacing was believed to be adequate for the detection and delineation of contaminant plumes from the lagoons. The coils were positioned in the horizontal (coils in the upright position) dipole modes at all sites and in the vertical (coils laying flat on the ground) dipole modes at sites 7, 8, and 9.

The EM 34-3 malfunctioned and became inoperable during the second week of the field study. The system was troubleshooted over the phone with technicians from Geonics Limited in Canada. The system could not be repaired in the field. Geonics Limited had a replacement to us in the field at Newberry, South Carolina, within 24 hours and at no cost. A most remarkable and noteworthy feat of responsiveness.

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Table 1.

PROFILING DEPTHS FOR THE EM 34-3 AT VARIOUS INTERCOIL SPACING2.

| Intercoil Spacing (meters) | Exploration Depth (meters) Horizontal Dipoles | Vertical Dipoles |
|---|---|---|
| 10 | 7.5 | 15 |
| 20 | 15 | 30 |
| 40 | 30 | 60 |

Survey Procedures:

At each site systematic sampling was conducted with the GPR and EM on irregularly shaped, rectangular grids. Sampling grids varied in size and were dependent upon considerations of lagoon size, accessibility, and available time and manpower. With the exception of Site 9, surveying flags were set out at grid intervals of 30 by 50 feet. At site 9, the grid interval was 50 by 50 feet. A transit was used to determine the surface elevation at each grid intersect.

The GPR antenna was towed behind the four-wheel drive vehicle along parallel grid lines. Even though the radar provides a continuous profile of subsurface features and conditions, discrete observation points (the flagged grid intersections) were used to locate the radar image and to evaluate contaminant plumes within the sites. Coincidence of grid points with the radar images was established by electronically impressing reference marks on the graphic profile as the radar antenna passed each flagged grid intersect.

The EM 34-3 was operated at an intercoil spacing of 10 meters. The transmitter coil was positioned over the referenced grid intersect. The receiving coil was located at the prescribed 10 meter spacing from the transmitting coil, aligned, and and used to measure the conductivity at the site of the transmitter. The EM measurements represent the weighted average of the actual (and often differing) conductivities of the layers scanned. As explained by Benson and others (1984), the absolute values are not necessarily diagnostic in themselves, but lateral and vertical

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2.Geonic Limited. 1980. Electromagnetic terrain conductivity measurement at low induction numbers. TN-6. Mississauga, Ontario. pp 15.

variations in conductivity are significant.3. Interpretations of the EM data are based on identification of spatial patterns in the data set.

Discussion:

Site 1 - Ralph O'Neil's lagoon (hog), Marion County

The lagoon is located in an area of Eunola loamy sand, 0 to 2 % slopes and is adjacent to an area of Blanton sand, 0 to 6 % slopes. Eunola series is a fine-loamy, siliceous, thermic Aquic Hapludults and Blanton series is a loamy, siliceous, thermic Grossarenic Paleudults. Soils observed in the field were mostly Blanton.

Buildings and cultivated crops restricted the survey to the east and north sides of the lagoon.

The GPR provided excellent resolution of many subsurface features including the wetting front, the E/Bt horizon interface, and a distinct strata which occurred at a depth of about 6 meters (19.7 feet). In Figure 1, images from many closely spaced interfaces are evident within the upper 2 to 2.5 meters of the soil profile. Only the wetting front and the sand/sandy loam or sandy clay loam interface separating the E from the Bt horizon were clearly identified and depths confirmed by ground-truth observations. The image of the water table, which is closely subadjacent to the upper surface of the Bt horizon and occurs between depths of 1.2 to 1.8 meters (4 to 6 feet), has been masked by the strong signals reflected from E/Bt horizon interface.

Figure 1 is from transect line 10 at site 1. At grid intersect 10D, the radar signal has been severely attenuated between depths of 4 to 7 meters. The strata, which is so distinct and continuous across the the profile at a depth of about 6 meters, is hardly discernible around this site. The presence of a contaminant plume having a high electrical conductivity is inferred from signal attenuation. Earthen materials having high conductivities rapidly dissipate the radar's energy and restrict its probing depth. The principal factors influencing the conductivity of earthen materials to electromagnetic radiation are: (i) degree of water saturation, (ii) amount and type of salts in solution, and (iii) the amount and type of clay. It is believed that contaminates emanating from the lagoon have increased the electrical conductivity of the soil and are responsible for the noticeable attenuation of the radar signal.

In Figure 2, an area within Site 1 having attenuated radar imagery has been plotted (for each grid intersect, elevation to nearest hundredth of a foot and EM to nearest tenth of mS/m is given). This area conforms with an area of higher conductivities as measured with the EM (see Table 2). Apparent terrain conductivities measured with EM are lowest (12-14 mS/m) in the "background areas" immediately north of the lagoon.

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3. Benson, Richard C., Robert A. Glaccum and Michael R. Noel. 1984. Geophysical techniques for sensing buried wastes and waste migration: an application review. In David M. Nielsen and Mary Curl (ed.) Surface and Borehole Geophysical Methods in Ground Water Investigations. NWWA/EPA Conference, San Antonio, Texas. February 7-9,1984. p. 533-566.

Highest apparent conductivities can be observed to form a broad lobe which extends eastward and downslope from the lagoon. Within this lobe, conductivity values range from 14 to 26 mS/m with the highest values adjacent to the lagoon.

At Site 1, both GPR and EM worked well and provided comparable data. The concurrent use of these two geophysical techniques improved data interpretation. In areas of Blanton soils, the GPR appears to be sensitive to areas having conductivities greater than 16 mS/m. While the GPR defined the boundaries of an area having generally higher subsurface conductivities, the radar provided no measure of the conductivity.

The reliability of EM data is based on the premise that no lithologic variation exists within the grid. Variations in the depth to or thickness of various layers or the unsaturated zone will degrade the quality of the EM interpretations. GPR defined the uniform underlying stratigraphic conditions and provided confidence in the interpretation of the EM data.

Site 2 - George Peebles' lagoon (hog), Clarendon County

The lagoon is located in areas of Foreston fine sand and Rutledge loamy fine sand. Foreston series is a coarse-loamy, siliceous, thermic Aquic Paleudults and Rutledge series is a sandy, siliceous, thermic Typic Humaquepts. Included areas of Leon soils (sandy, siliceous, thermic Aeric Haplaquods) were observed in the field.

Buildings obstructed the survey on the east side of the lagoon. Areas of cultivated crop restricted the breadth of the surveyed area on the north and south sides of the lagoon.

Both EM and GPR techniques worked well at this site. The radar signal was severely attenuated and higher conductivities were measured with the EM along the east, southeast, and northeast sides of the lagoon.

Figure 3 is a representative radar profile from Site 2. It is from grid line 13 (see Fig 4 and Table 3). The image of the water table consists of three subparallel lines and is most apparent between grid intersects 13h and 13j at depths of 0.6 to 1.3 meters. The radar climbed the lagoon embankment to the right of grid intersect 13m. This explains the apparent 1.2 meter drop in the strata and the water table. Along grid line 13, the radar signal appears to be severely attenuated at a depth of about 1.3 meters between grid intersects 13m and 13k. As seen in Table 3, the east side of the lagoon has higher conductivities as measured by EM. This substantiates the inferences drawn from the radar imagery.

Knowledge of the lagoon history helps to clarify the distribution and significance of areas having high radar signal attenuation and higher apparent conductivities. The lagoon was recently enlarged. Fill material from the original lagoon was redistributed about the areas having the higher conductivities in Figure 4. This material was dredged from the original lagoon bottom and undoubtedly contained a large fraction of waste residues. Its placement along the embankment conforms with the areas of higher conductivities apparent in Figure 4 and Table 3. The redistribution of fill material rather than seepage from the lagoon is believed to be responsible for the higher conductivities in this area.

## Site 3 - Wilbur Fogle's lagoon (dairy), Orangeburg County

The lagoon is located in an area of Lynchburg and Coxville soils. Lynchburg series is a fine-loamy, siliceous, thermic Aeric Paleaquults and Coxville series is a clayey, kaolinitic, thermic Typic Paleaquults. Soils observed have sandy clay loam subsoils which grade to sandy clay or clay (>40 percent clay) within depths of 1 meter.

Buildings precluded a survey on the south side of the lagoon (see Figure 6). Also, multiple rows of wire fence lines prohibited a geophysical survey (time limitations) of the lagoon's east side. The lagoon was enclosed by a wire fence.

EM techniques worked well at this site (Table 4). Background readings averaged 5 to 6 mS/m. As defined by Duran (1984), "background" consists of conductivity values expected in areas of uniform geology and hydrology which are also unaffected by contaminants.4. Higher EM readings were measured adjacent to the lagoon (15 to 24 mS/m) and in a lower portion of the landscape to the north of the lagoon (7 to 14 mS/m). This lower-lying area is wetter and had been partially disturbed by the installation of a buried outlet pipe (see "^" in Figure 6). These artifacts and natural conditions have undoubtedly interfered with and affected the EM data. The EM is susceptible to "cultural noise" induced by such objects as buried pipes, overhead power lines and metallic fences and "topographic noise" induced into the data by variations in strata thickness or depth to the zone of saturation.

The penetration and general performance of the GPR was poor in these conductive and fine textured soils. The high clay content of the subsoil restricted the probing depth of the GPR to the upper 60 cm of the soil profile (Figure 5). Figure 5 is from grid line 6 (see Figure 6). Other than from surface sources, contaminants would be expected to occur below the subsoil and at depths in excess of the radars profiling.

All of the systems antennas (80, 120, 250, 300, 500) were employed at Site 3 in a futile attempt to attain greater depths of penetration. The 120 MHz antenna provided the best balance of probing depth and resolution of subsurface features. However, its profiling depth was too restricted to detect zones of subsurface contamination.

## Site 4 - Al Bates' lagoon (dairy), Orangeburg County

The lagoon is located in an area of Uchee soils. Uchee series is a loamy, siliceous, thermic Arenic Hapludults. The subsoil is variable in texture and includes layers of sandy clay loam and sandy loam.

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4. Duran, Philip B. 1984. The effects of cultural and natural interference on electromagnetic conductivity data. In David M. Nielsen and Mary Curl (ed.) Surface and Borehole Geophysical Methods in Ground Water Investigations. NWWA/EPA Conference, San Antonio, Texas. February 7-9,1984. p. 509-530.

The survey of Site 4 was restricted by a cultivated field of corn on the west and a property boundary on the north. No survey was conducted along the south side of the lagoon where a feedlot and farm buildings would obstruct survey lines and prohibit rapid access. The lagoon is enclosed by a wire fence along the base of its embankment.

Both GPR and EM techniques worked well at this site and defined an area having higher conductivities (Figure 7 and 8, and Table 5). The GPR provide clear and interpretable data to depths of 1.8 meters in areas of lower conductivities (<10 mS/m). Higher conductivities (14 to 20 mS/m) were measured with the EM and the radar signals were severely attenuated in an area along the north and east sides of the lagoon. Background EM measurements ranged from 6 to 13 mS/m.

Figure 7 is the radar profile from grid line 3 (see Figure 8). The strongly expressed subsurface interface which appears at a depth of about 30 cm is the upper boundary of the Bt horizon. Along this grid line, the radar signal appears to be severely attenuated at a depth of about 40 centimeters between grid intersects C and E and at a depth of about 1 meter between grid intersects A and B, and at F. As seen in Table 5, the zone of shallow attenuation (3C to 3E) corresponds with EM measurements greater than 14 mS/m. Areas having radar signal attenuation at depths of about 1 meters have values of 13 to 14 mS/m.

It is believed that the profiling depth of the GPR and conductivity values measured by the EM were significantly affected by surface runoff and contamination emanating from the higher-lying animal feedlot. Rills and colluvial deposits are clearly evident in areas having the higher conductivity values. On the basis of these observation, it is believed that geophysical methods provide information concerning a surficial source of contamination but little insight into whether or not contaminants were seeping from the lagoon. To determine the existence of any subsurface sources of contamination, the EM survey should be expanded at this site through additional and deeper measurements.

Site 5 - Gary Hegne's lagoon (dairy), Bamberg County

The lagoon is located in an area of Emporia and Rains soils. Emporia series is a fine-loamy, siliceous, thermic Typic Hapludults; Rains series is a fine-loamy, siliceous, thermic Typic Paleaquults. The subsoil occurs at depths of 25 to 50 centimeters and includes sandy loam, sandy clay loam, and sandy clay textures.

This site was poorly accessible. Wandering cattle, electric fences, and highly contaminant surface (feedlot) conditions minimized the probing depth of the GPR and caused low and highly erratic EM readings. The GPR probe to the argillic horizon (25 to 50 centimeters). Further penetration was impossible as a result of excessive signal attenuation and background noise. It is believed that high concentration of salts in the animal wastes within the surface layers restricted radar penetration.

EM results at Site 5 were inconsistent and erratic. Table 6 and Figure 9 are included in this report for reference, but EM values are suspected of error. The EM equipment was susceptible to interference from the electric fence. At each site, EM values were higher when the horizontally orientated dipoles were positioned perpendicular to rather than parallel with the electric fence.

Site 6 - Ray Bryant's lagoon (hog), Bamberg County

Though the area had been mapped as Lakeland (thermic, coated Typic Quartzipsamments) sand, 0 to 6 % slopes, the soils within the surveyed area are members of fine-loamy, siliceous, thermic Arenic and Grossarenic Hapludults. The soils have a sandy clay loam Bt horizon which ranges in depth from 65 cm to 2 meters across the study area.

The lagoon was enclosed by a wire fence and buildings precluded the survey on one side of the lagoon. Wooded areas and property boundaries restricted the breadth of the surveyed area.

Both EM and GPR techniques worked well at this site. No discernible pattern was observed in the data (see Figures 10, 11, and Table 7). Variations in EM values do not appear to be related to the lagoon and are probably related to variations in the particle size, degree of saturation, and thickness of underlying strata. The Bt horizon forms a limiting layer (to the through flow of water and radar penetration) which, though variable in depth, is continuous across the the survey areas. In Figure 10, the radar image of this horizon is apparent between depths of 1 and 1.8 meters. Figure 10 is from grid line 6. At this site, the GPR provided interpretable imagery to depths of about 3 meters.

Site 7 - Roy Frick's lagoon (poultry), Lexington County

The lagoon is located in an area of Blaney sands, 2 to 10 % slopes and Lakeland soils, undulating. Blaney series is a loamy, siliceous, thermic Arenic Hapludults and Lakeland series is a thermic, coated Typic Quartzipsamments.

Buildings precluded an extensive survey on the north side of the lagoon. Areas of cultivated crop restricted the breadth of the surveyed area on the east side of the lagoon.

Both EM and GPR techniques worked well at this site. The radar signal was severely attenuated along the south and west sides of the lagoon. Higher conductivities were measured with the EM along the south side of the lagoon.

The lagoon was constructed seven years ago. The large area of contamination along the south side of the lagoon is a result of direct overflow and possibly seepage. Where contaminants are evident on the surface, "x"s have been placed on Figure 13. This area corresponds with the zone of highest EM values (Table 8) and greatest radar signal attenuation (Figure 12). This large, triangular zone extends outward from a rather broad base adjacent to the lagoon to a well-defined drainageway at its apex. A weaker zone of high conductivities appears to be spreading westward along a low towards the road which forms the field and survey boundary.

Varying the orientation of the EM dipoles helps to confirm that the general depth of contamination (7.5 or 15 meters with EM-34-3 and a 10 meter intercoil spacing).

Figure 12 is the GPR profile from grid line B (see Figure 13). The radar signal is severely attenuated within depths of 50 cm of the surface and the image of the argillic horizon (dark bands at depths of about 0.5 to 1.0 m) is broken between grid intersects B11 and B17. This zone represents a zone of higher near surface conductivities. The zone has an averaged EM value of 7.8. The other portion of this grid line (see Table 8) has an averaged EM value of 1.14. The deep profiling of the radar in the uncontaminated areas provides geologic meaning to EM data and improves interpretations.

Site 8 - Jimmy Haltiwanger,s lagoon (dairy), Newberry County

The lagoon is located in the Piedmont in an area of Appling sandy loam, gently sloping and Durham sandy loam, gently sloping. Appling series is a clayey, kaolinitic, thermic Typic Hapludults and Durham series is a fine-loamy, siliceous, thermic Typic Hapludults.

The high embankment to the lagoon and field boundaries limited the area which was readily accessible to EM and radar.

The texture of the Bt horizon is sandy clay loam in the upper part and clay in the lower part. The high clay content of the Bt (argillic) horizon restricted radar penetration to depths of less than 1 meter (see Figure 14). With the exception of monitoring near surface soil conditions or surface contamination, the utility of GPR is too restricted at this site.

The EM worked exceptional well at this site. In Table 9 and Figure 15, a distinct zone of higher conductivities can be observed along grid line 8, 9, and 10. Compared with the lower background values of about 4 to 9 mS/m, a distinct plume having conductivities of 11 to 22 mS/m can be seen emanating from the lagoon.

Site 9 - James Long's lagoon (poultry), Newberry County

The lagoon is located in areas of Cecil sandy loam, strongly eroded, sloping and Mixed Alluvial Land, well drained, along Kinards Creek. Cecil series is a clayey, kaolinitic, thermic Typic Hapludults.

The survey was conducted downslope from the base of the lagoon in the most probably direction of contaminant flow.

The soils at this site were extremely variable over short distances. Textures varied from loamy sands to clays. The profiling depths of the GPR ranged from 0.7 to 2.5 meters depending on the clay contents of the underlying strata.

Though both EM and GPR techniques worked well at this site, no discernible pattern of higher conductivities (Figure 16) or signal attenuation were apparent.

Results:

1. Geophysical techniques are capable of detecting areas of higher electrical conductivities surrounding animal waste lagoons. Areas of higher electrical conductivities can be associated with contaminants emanating from lagoons. Inferences are based on the location, shape, and relative conductivities within the plume. However, physical and chemical analysis is needed to confirm inferences and to determine whether the levels of contamination detected by geophysical techniques pose a problem. Results of the geophysical surveys are dependent upon physical and chemical analysis to be made by Dr. Brune, Clemson University.

2. EM techniques provided the most useful data concerning the location of zones of higher conductivities at all sites. However, at sites having high levels of "cultural noise" (electric fences, metallic buildings and objects, buried artifacts), EM data were suspected of error. EM is the preferred geophysical technique for detecting and locating contaminant plumes.

3. GPR techniques provided useful data at all sites underlain by predominantly coarse-textured earthen materials. In areas of moderately-fine or fine textured earthen materials, the profiling depth of the GPR was too depth restricted to detect subsurface sources of contamination.

4. A comprehensive approach is the most effective approach. Both EM and GPR techniques are compatible and their combined use is encouraged where ever possible to insure more complete information and accurate interpretations. Geophysical surveys must be supported by adequate ground-truth information (soil sampling, drill logs, etc.).

5. Present methods for locating monitoring wells can miss potentially hazardous contaminant plumes. Installation of monitoring wells should be based upon the results of geophysical surveys. Geophysical surveys provide greater knowledge of site conditions and facilitate the accurate and most meaningful placement of monitoring wells.

Recommendations:

Compared with conventional methods, geophysical techniques are many times faster, provide greater areal coverage, less likely to miss subsurface features, and are non-destructive. If laboratory and statistical analysis supports inferences made from this geophysical survey, the use of these tools should be encouraged and expanded. The development of a team of specialists trained in the use of geophysical techniques should be explored as SCS becomes increasingly involved in monitoring of ground water quality.

EM methods have demonstrated a wider range of application for the detection and monitoring of zones of higher electrical conductivities (and probably contamination). This equipment is more portable and affordable than GPR. Although the model EM 34-3 Terrain Conductivity Meter was used (borrowed) in this study, the model EM 31 Terrain Conductivity Meter is more portable, requires only one person to operate, and may provided sufficient probing depths to investigate lagoons.

It is recommended that this study be continued and expanded to other areas of the country. In Florida and Massachusetts, where SCS actively uses GPR, the application of this technique for monitoring groundwater flow and contamination in areas of coarse-textured soils should be encouraged and explored.

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TABLE 2

EM Measurements at Site 1

| | a | b | c | d | e | f | g | h |
|---|---|---|---|---|---|---|---|---|
| 10 | | | 12 | 14 | 15 | 14 | 15 | 15 |
| 9 | 13 | 13 | 14 | 15 | 17 | 18 | 19 | 19 |
| 8 | 12 | 12 | 13 | 14 | 17 | 19 | 20 | 20 |
| 7 | 13 | 13 | 16 | 18 | 21 | 23 | 22 | 20 |
| 6 | 13 | 13 | 14 | 17 | 21 | 25 | 25 | 24 |
| 5 | 13 | 13 | 15 | | | 26 | 26 | 25 |
| 4 | 13 | 14 | 16 | ////// | ////// | ////// | ////// | ////// |
| 3 | 13 | 14 | 17 | / | | | | |
| 2 | 13 | 14 | 17 | / | LAGOON | | | |
| 1 | 14 | 14 | 16 | / | | | | |

-50 ft-

<--North

TABLE 3

EM Measurements at Site 2

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a | | 5 | 5 | 5.2 | 5 | 5.2 | 5 | 5.2 | 5.4 | | | | |
| b | | 5.4 | 5.2 | 5.2 | 5 | 5.4 | 5.4 | 5.6 | 5.6 | 5.8 | | | |
| c | | 5 | 5.8 | 5.4 | 5.2 | 6 | 5.8 | 6 | 5.6 | 6 | 6 | 6 | |
| d | | 5 | 6 | 5.6 | 5.8 | 5.6 | 6 | 6 | 6 | 6.6 | 6.6 | 6.4 | 6.8 |
| e | | 5.6 | 5.4 | 5.2 | ////// | ////// | ////// | ////// | | 5.8 | 6.4 | 6.8 | 7 |
| f | | 5.6 | 5.6 | 5.4 | / | | | / | | 6.6 | 6.4 | 6.8 | 7 |
| g | 6.8 | 6.8 | 6 | 5.6 | / | | | / | | 6 | 7.2 | 7 | 7.4 |
| h | 7.4 | 7.4 | 8 | 6.4 | / | | | / | | 6.2 | 7.2 | 7.4 | 7.9 |
| i | 8.8 | 8.4 | 9.2 | 6.8 | / | LAGOON | | / | | 6.5 | 9 | 7.8 | 8.4 |
| j | 9.4 | 10 | 11 | 9.2 | / | | | / | | 7 | 9.2 | 8.4 | 8.6 |
| k | 12 | 10 | 12 | 11 /// | | | | /// | | | 7.4 | 9.2 | 10 |
| l | | 14 | 14 | 12 | ////// | ////// | ////// | ////// | | | | | 11 |
| m | | 16 | 13 | 13 | 10 | 11 | 10 | 10 | 9.4 | 10 | 11 | | 9.6 |
| n | | 12 | 10 | 12 | 10 | 8.4 | | | | | | | |
| o | | | 8 | 9.4 | 9 | 8.2 | | | | | | | |

Site 2 (continued)

| | 14 | 15 |
|---|---|---|
| h | 6.6 | |
| i | 7 | 7 |
| j | 8.4 | 8.6 |
| k | 9.6 | 10 |
| l | 11 | 11 |
| m | 10 | 11 |

<- 30 feet->

## TABLE 4

### EM Measurements at Site 3

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| aa | 5.6 | 6.4 | 6.8 | 6.5 | 7.6 | 7.7 | 8.6 | 9.4 | 11 | 13 | |
| a | 5.6 | 6.4 | 6.2 | 7.2 | 6.5 | 10 | 9.4 | 10 | 9.6 | 11 | |
| b | 6 | 6.8 | 7.2 | 10 | 11 | 14 | 11 | 13 | 10 | 14.5 | |
| c | 5.6 | 8.6 | 8.6 | 13 | 13 | 20 | 15 | 19 | 14 | 18 | |
| d | 6 | 9.6 | 11 | 15 | 17 | 22 | 23 | 22 | 18.5 | 23 | |
| e | 6 | 12 | 16 | 17 | ///////////////////// | | | | 22 | | <-30 ft-> |
| f | 7 | 12 | 17 | 17 | / | | | / | 24 | | |
| g | 7.4 | 9.2 | 15 | 15 | / | Lagoon | | / | | | |

## TABLE 5

### EM Measurements at Site 4

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| aa | | | | 6.8 | 6.8 | 6.4 | 10 | 8 | | |
| a | | | 13 | 11 | 12 | 13.5 | 12 | 14.5 | | |
| b | | | 13 | 13 | 13 | 17 | 14 | 18 | | |
| c | | 15 | 14 | 16 | 16 | 19 | 18 | 20 | | <-30 ft-> |
| d | | 15 | 16.5 | 18 | ////////////////// | | | | | |
| e | 15 | 15 | 17.5 | 18.5 | / | | | / | | |
| f | 12.5 | 9.8 | 13.5 | 15 | / | LAGOON | | / | | |
| g | 9.6 | 7.8 | 9.6 | 14 | ////////////////// | | | | | |
| h | | | | 10 | 10 | 8.8 | 9.4 | 9.2 | 9.6 | |

## TABLE 6

### EM Measurements at Site 5

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|---|---|---|---|---|---|---|---|---|---|---|
| a | 2.3 | 1.3 | 1.6 | 2.7 | 7 | 9.4 | 9 | 8.2 | 8.2 | |
| b | 1.9 | 2.1 | 0.6 | 2.1 | 2.4 | 7.8 | 6.4 | 8 | 8.2 | |
| c | 2.2 | 2.3 | 2.1 | 2.0 | 2.2 | 7.4 | 5.8 | 6 | 5 | |
| d | | | | | | 5.8 | 4.8 | 4.2 | | |
| e | | //////////////// | | | | 4.8 | 5.4 | 3 | 1.8 | |
| f | | | | | // | 5.4 | 6.8 | 2.9 | 1.8 | <-30 ft-> |
| g | | LAGOON | | | // | 6 | 7 | 2.2 | 0.8 | |
| h | | | | // | 11 | 6.6 | 6.8 | | | |
| i | | | // | | 14 | 7.4 | | | | |

TABLE 7

EM Measurements at Site 6

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
|---|---|---|---|---|---|---|---|---|---|
| a | | 12.5 | 14.5 | 16 | 17 | 18 | 20 | 24 | |
| b | | 15 | 16 | 17.5 | 19 | 21 | 24 | 24.5 | |
| c | | 15 | 17.5 | 16.5 | 18.5 | 19 | 20 | 22 | |
| d | ////// | ////// | ////// | ////// | 19.5 | 20 | 21 | 22 | |
| e | | | | / | 20 | 22 | 19.5 | 20 | |
| f | LAGOON | | | / | 19.5 | 20 | 20.5 | 21 | <-30 ft-> |
| g | | | | / | 21 | 20 | 19 | 20 | |
| h | | | | / | 19 | 19 | 19.5 | 19 | |
| i | ////// | ////// | ////// | ////// | 17 | 17.5 | | | |
| j | 10 | 12 | 13 | 14 | 15 | | | | |
| k | 10 | 9.6 | 11 | 11 | 12 | | | | |

TABLE 8

EM Measurements at Site 7

| | a | b | c | d | e | f | g |
|---|---|---|---|---|---|---|---|
| 1 | 8.0/0.0 | 0.7/8.0 | 1.0/0.0 | 1.4/6.3 | | | |
| 2 | 0.0/5.2 | 0.8/2.6 | 1.0/3.4 | 1.4/3.4 | 1.5/3.0 | 1.5/3.1 | 1.6/3.0 |
| 3 | 0.0/1.8 | 0.7/2.1 | 1.0/2.4 | 1.5/3.2 | 1.4/2.6 | 1.4/2.7 | 1.4/2.5 |
| 4 | 0.0/1.2 | 0.8/2.2 | 1.1/2.1 | 1.7/2.8 | 1.6/2.5 | 1.5/2.6 | 1.5/2.7 |
| 5 | 0.0/1.2 | 0.7/2.0 | 1.4/2.3 | 2.5/4.0 | 1.7/3.0 | 1.4/3.0 | 1.3/2.4 |
| 6 | 0.0/1.2 | 0.9/2.3 | 1.5/2.5 | 3.8/3.5 | 1.6/3.4 | 2.1/2.9 | 1.2/3.6 |
| 7 | 0.3/1.2 | 1.3/2.6 | 2.3/3.2 | 6.4/3.5 | 3.5/4.1 | 1.8/4.3 | 2.2/4.6 |
| 8 | 0.5/1.4 | 1.4/2.7 | 2.4/4.4 | 7.7/4.4 | 3.6/7.4 | 6.0/10 | 6.4/11 |
| 9 | 0.7/1.3 | 1.9/3.5 | 3.2/5.0 | 8.4/2.5 | ////////// | ////////// | ////////// |
| 10 | 0.9/2.1 | 2.9/6.0 | 6.0/4.4 | 14.0/5.1 | / | | |
| 11 | 1.4/2.8 | 7.0/4.0 | 7.4/5.0 | 19.5/2.0 | / | | |
| 12 | 1.4/3.4 | 12.0/3.2 | 9.8/11.5 | 25.0/2.7 | / | LAGOON | |
| 13 | 3.0/7.4 | 12.0/6.2 | 15.0/4.8 | 25.0/7.9 | / | | |
| 14 | 6.8/1.6 | 9.8/5.8 | 17.0/11.0 | 19.0/7.5 | / | | |
| 15 | 11.0/4.2 | 6.8/7.7 | 14.5/8.1 | 14.0/7.8 | / | Dipole orientation: | |
| 16 | 6.8/0.5 | 4.6/4.9 | 12.5/4.4 | 9.0/6.1 | / | Hort./Vert. | |
| 17 | 2.7/6.7 | 2.6/5.4 | 9.1/6.8 | 5.7/9.5 | / | | |
| 18 | 1.3/4.0 | 1.6/3.4 | 7.1/8.2 | 4.1/8.6 | / | | |
| 19 | 0.8/2.8 | 1.3/3.2 | 6.7/2.8 | 3.6/7.7 | / | | |
| 20 | 0.7/2.2 | 0.9/2.6 | 5.6/3.5 | 3.4/8.2 | / | | |
| 21 | 0.5/2.2 | 0.8/2.3 | 3.2/5.0 | 3.4/6.3 | / | | |
| 22 | 0.5/1.9 | 0.6/2.0 | 2.5/4.2 | 4.0/5.6 | / | | |
| 23 | 0.7/1.7 | 0.5/1.8 | 2.2/3.8 | 3.4/3.2 | ////////// | ////////// | ////////// |
| 24 | 0.7/1.6 | 1.7/3.2 | 2.1/4.8 | 4.3/11.5 | 0.4/14 | 10.0/14.0 | 14.0/12 |

Site 7 (continued)

| | h | i | j | k | l | m |
|---|---|---|---|---|---|---|
| 2 | 1.7/3.1 | 1.6/2.9 | 1.6/3.2 | | | |
| 3 | 1.5/2.8 | 1.6/2.8 | 1.8/2.7 | 2.3/3.1 | 1.6/2.0 | |
| 4 | 2.2/2.6 | 2.4/2.6 | 2.6/3.4 | 2.5/3.8 | 0.0/8.4 | |
| 5 | 1.2/2.7 | 1.2/3.0 | 2.8/4.8 | 0.0/2.0 | 1.8/4.6 | |
| 6 | 1.0/3.2 | 1.6/3.2 | 0.0/2.3 | 1.9/7.6 | 3.1/6.6^ | |
| 7 | 2.1/4.6 | 2.3/4.3 | 2.2/5.2 | 0.7/11.0 | 1.8/3.8 | |
| 8 | 5.8/11.5 | 4.4/11.0 | 4.2/10.0 | 3.4/6.4 | 3.8/9.4 | |
| | ////////// | ////////// | ////////// | ////////// | ////////// | |
| | | | LAGOON | | | |
| | ////////// | ////////// | ////////// | ////////// | ////////// | |
| 24 | 14.0/12 | 17.0/5.7 | 11.0/6.7 | 6.9/8.0 | 4.0/6.8 | 3.0/4.8 |

TABLE 9

EM Measurements at Site 8

| | a | b | c | d | e | f | g |
|---|---|---|---|---|---|---|---|
| 1 | 7.2/6.4 | 4.1/5.5 | 4.8/6.7 | 5.7/4.9 | 7.0/8.1/ | | |
| 2 | 6.0/7.6 | 4.6/7.4 | 4.6/6.3 | 5.0/6.1 | 6.5/8.6/ | | |
| 3 | 6.0/7.0 | 6.0/6.0 | 5.0/6.9 | 5.1/7.0 | 6.9/7.7/ | | |
| 4 | 6.4/7.4 | 5.4/7.2 | 4.6/7.4 | 5.7/5.9 | 6.9/8.0/ | Dipole Orientation | |
| 5 | 7.5/6.5 | 5.3/7.0 | 4.6/7.0 | 5.7/6.9 | 5.7/8.8/ | Hort./Vert. | |
| 6 | 7.4/8.0 | 5.1/7.7 | 4.1/7.0 | 5.4/7.7 | 6.5/8.5/ | | |
| 7 | 7.0/8.5 | 6.0/8.0 | 4.2/7.6 | 5.1/7.8 | 5.9/10.5/ | ////////// | ////////// |
| 8 | 6.5/8.2 | 6.1/7.4 | 5.0/7.8 | 5.0/7.8 | 4.7/8.8 | 7.0/11.0 | 9.0/15 |
| 9 | 5.9/8.6 | 6.7/6.1 | 5.6/8.4 | 5.1/8.1 | 5.5/9.2 | 4.8/8.6 | 6.2/11 |
| 10 | 5.6/8.0 | 6.6/8.0 | 5.0/6.7 | 5.0/8.0 | 5.5/8.9 | 6.1/7.3 | 5.2/10 |
| 11 | 5.7/8.0 | 5.1/8.0 | 6.0/7.4 | 4.5/9.0 | 5.4/7.7 | 4.0/8.3 | 4.2/9.6 |

Site 8 (continued):

| | h | i | j | k | l | m | n |
|---|---|---|---|---|---|---|---|
| | | | | LAGOON | | | |
| | ////////// | ////////// | ////////// | ////////// | ////////// | ////////// | ////////// |
| 8 | 13.0/16 | 15/18.5 | 15.0/22 | 16.5/20 | 17.0/18 | 14.5/16 | 12.5/17 |
| 9 | 6.0/12.5 | 9.4/11.5 | 11.5/14 | 12.0/13 | 12.0/14 | 10.0/14 | 9.0/14 |
| 10 | 5.8/12.0 | 6.6/8.1 | 6.4/12.0 | 6.6/10.0 | 6.6/11.5 | 7.1/11.5 | 7.9/12 |
| 11 | 4.4/8.1 | 5.1/9.7 | 4.5/8.9 | 5.5/9.5 | 5.1/9.0 | 5.1/10.0 | 5.8/9.4 |

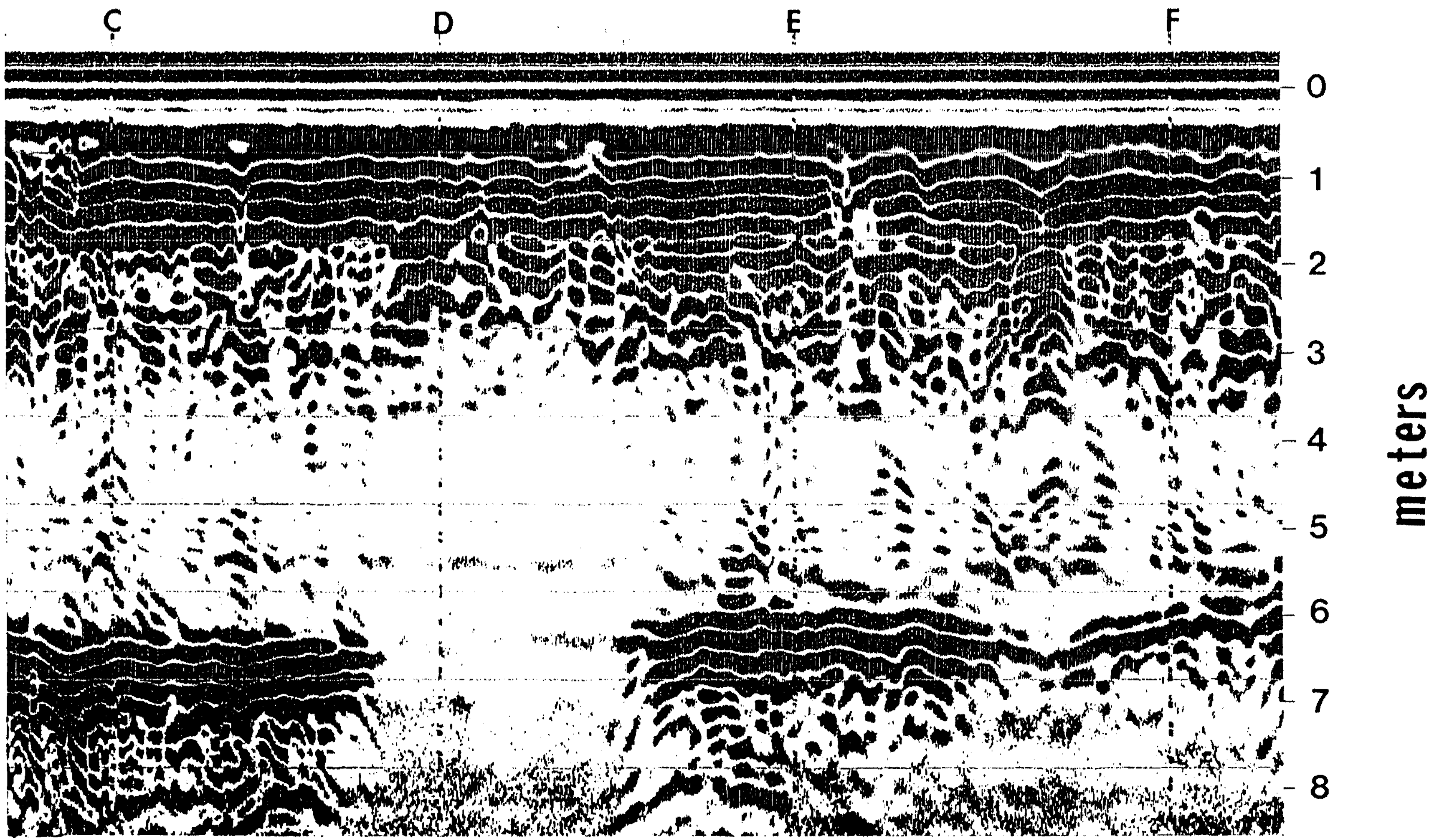
Site 8 (continued):

| | o | p |
|---|---|---|
| | LAGOON | |
| | ////////// | ////////// |
| 8 | 11.0/18 | 10.5/16 |
| 9 | 9.0/14.0 | 9.0/10.5 |
| 10 | 8.7/11.0 | 7.2/9.8 |
| 11 | 6.8/8.9 | |

TABLE 10

EM Measurements at Site 9

| | | | a | b | c | d | e |
|---|---|---|---|---|---|---|---|
| 1 | | / | 4.4/3.8 | 7.2/4.6 | 6.3/7.2 | 8.6/8.8 | 8.2/8.8 |
| 2 | | / | 5.8/6.0 | 7.5/8.2 | 11.0/6.0 | 9.5/6.2 | 9.8/11.0 |
| 3 | | / | 6.8/6.0 | 7.6/7.2 | 12.5/7.2 | 9.9/8.9 | 10.5/8.2 |
| 4 | | / | 8.0/6.8 | 6.0/8.4 | 7.2/9.9 | 7.1/7.5 | 9.6/7.7 |
| 5 | | / | 8.4/8.0 | 6.6/7.3 | 5.9/5.8 | 6.4/5.3 | 6.9/8.1 |
| 6 | | / | 8.0/9.8 | 8.2/7.6 | 7.2/4.8 | 8.3/14.0 | 6.0/8.0 |
| 7 | L | / | 11.0/6.0 | 8.1/8.2 | 6.2/8.4 | 6.5/16.0 | 7.5/6.0 |
| 8 | A | / | 9.8/9.0 | 9.3/8.6 | 7.9/6.2 | 6.5/7.2 | 7.2/6.8 |
| 9 | G | / | 10.0/10 | 11.0/5.6 | 8.4/4.7 | 8.5/7.0 | 5.6/6.8 |
| 10 | O | / | 10.8/7.0 | 11.5/7.3 | 10.0/8.2 | 9.6/7.3 | 6.1/6.2 |
| 11 | O | / | 10.0/1.8 | 11.0/3.9 | 9.4/9.5 | 10.5/4.0 | |
| 12 | N | / | | 9.0/2.3 | 11.0/2.5 | 8.6/4.1 | |
| 13 | | / | | 6.5/0.4 | 5.8/5.9 | 4.7/8.8 | |
| 14 | | / | | 4.8/1.4 | 7.1/1.9 | 4.8/4.2 | |
| 15 | | / | | 5.6/4.2 | 6.3/1.2 | 4.0/2.5 | |
| 16 | | / | | 7.4/3.8 | 5.8/2.7 | 5.4/3.3 | |




# SITE 1, MARION COUNTY, SC

Fig 1

KGK
JD
6-27-88

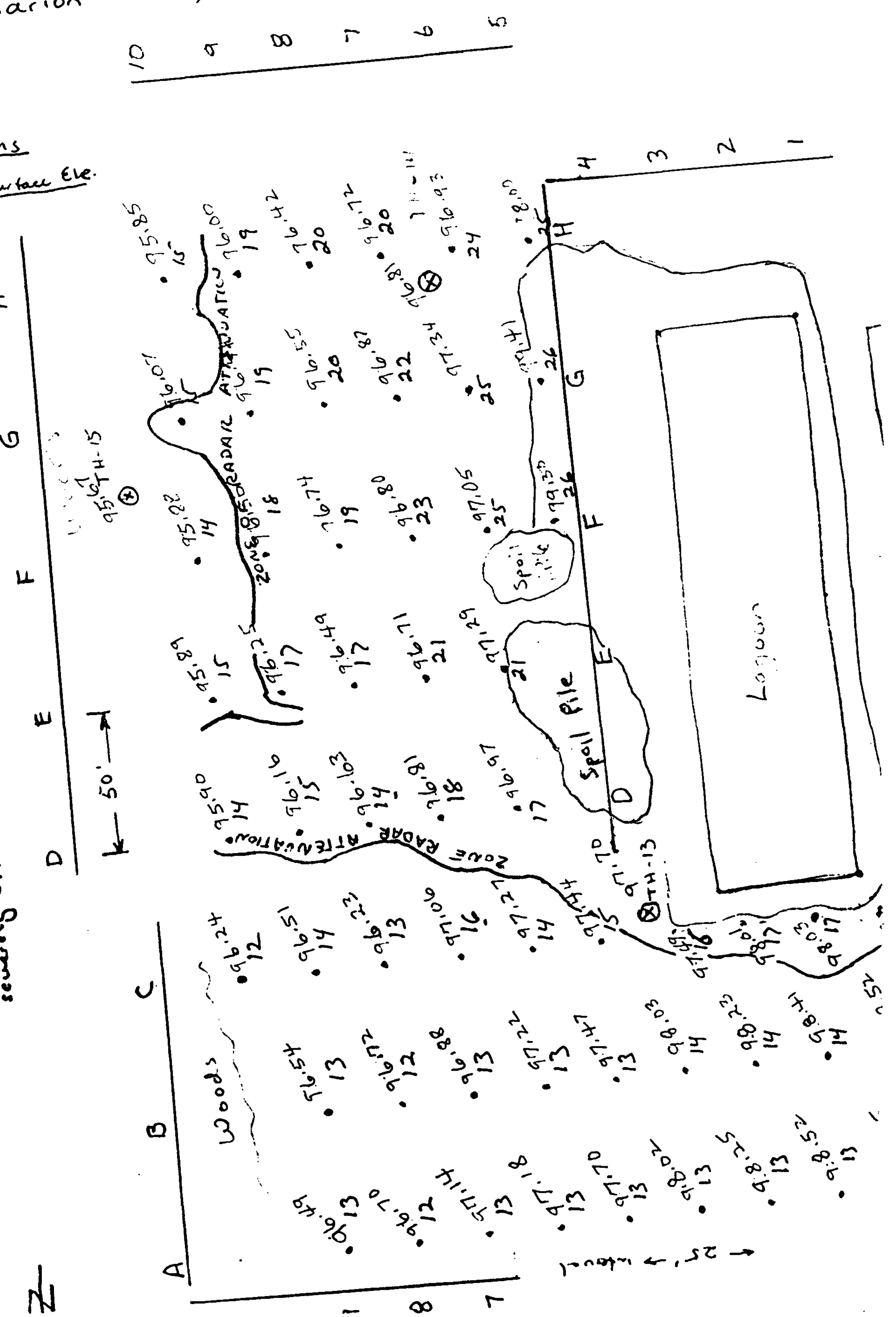
Ralph O'Neal Site, Hog Lagoon
Marion Co., South Carolina

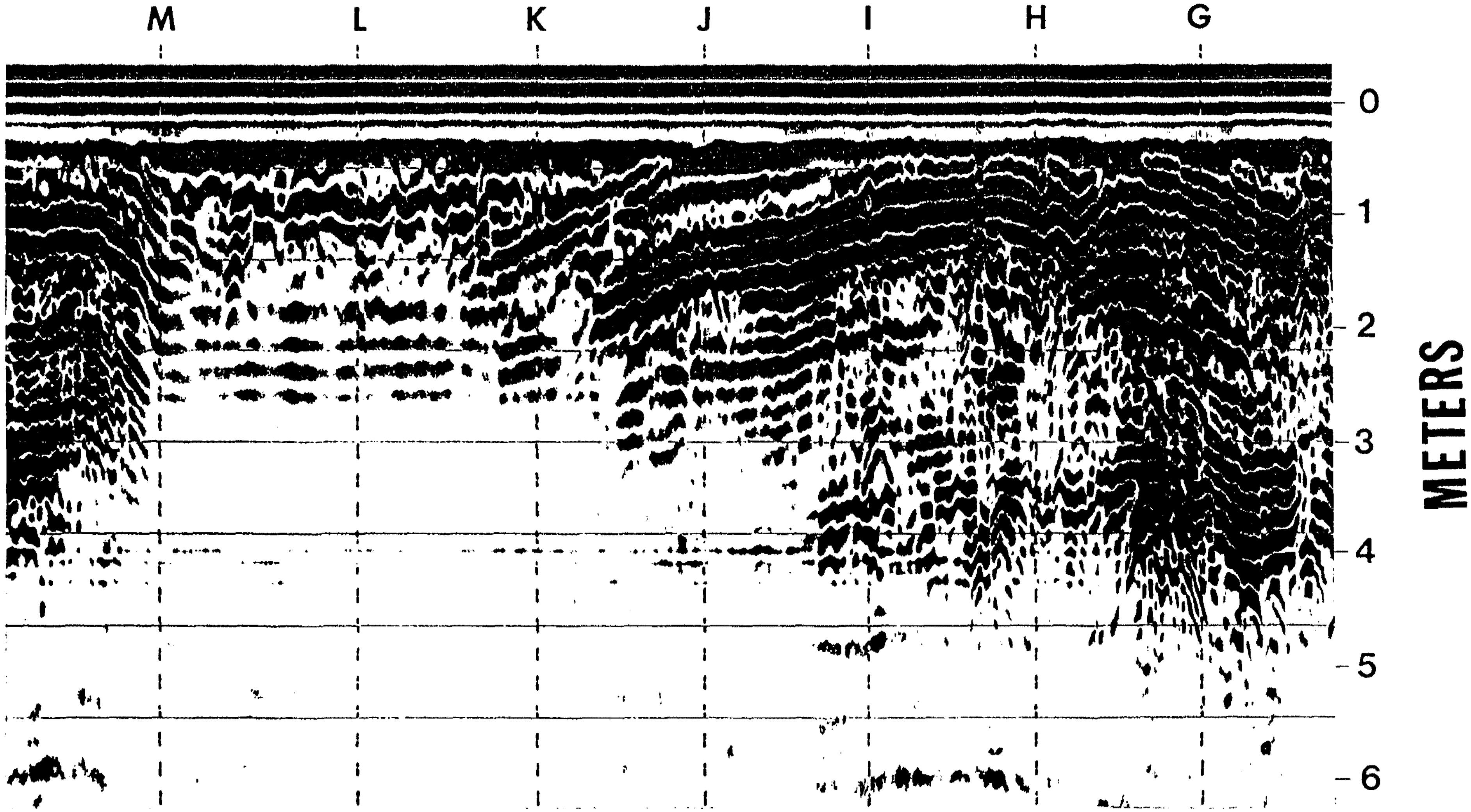
Water Table Depths
(6-27-88)

| | WT |
|---|---|
| TH-13 | 5.5' |
| TH-14 | 4.7' |
| TH-15 | 4.3 |
| TH-16 | 6.4' |

Surface Ele.

EM readings noted at each site in mS/m
area enclosed by green line denotes radar signals
severely attenuated






SITE 2, CLARENDON COUNTY, SC

George Peebles, Clarendon County
Hog Lagoon near Turbeville

28 June 88

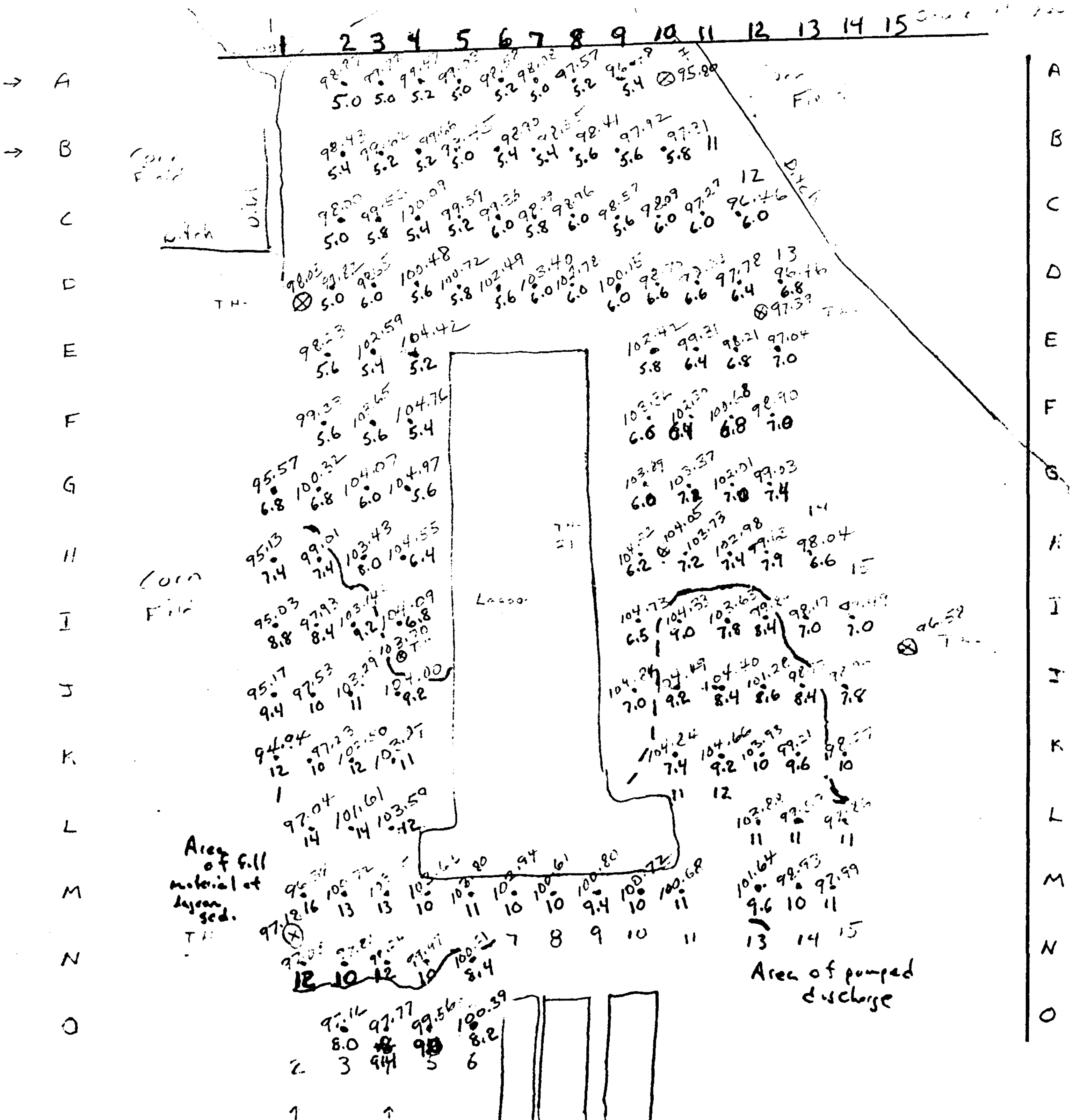
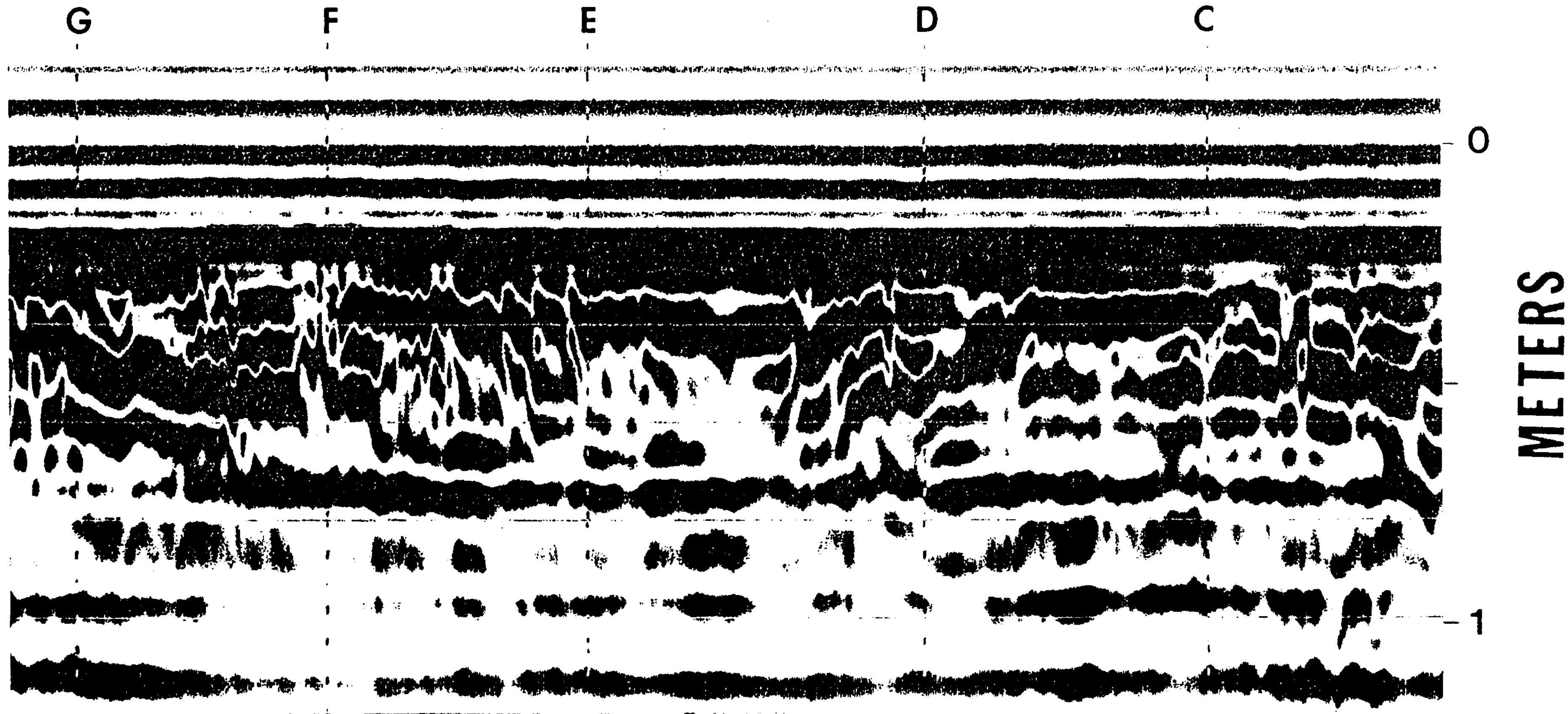



Fig 4

Conductivity by EM given in m
Green indicates areas of hog
according to GPR




SITE 3, ORANGEBURG COUNTY, SC

Wilbur Fogle Farm (Dairy)
Orangeburg County, South Carolina

6-29-88

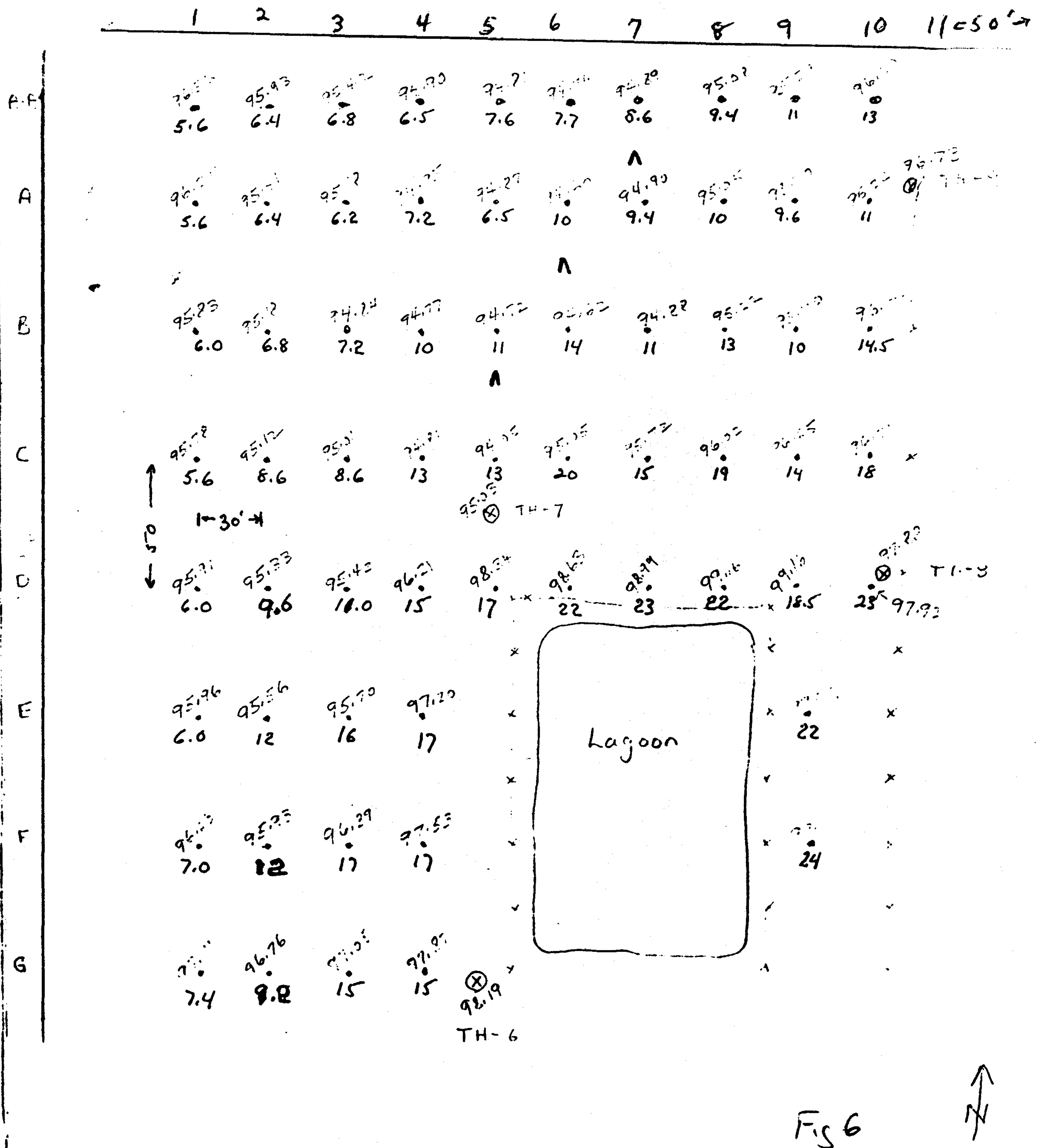
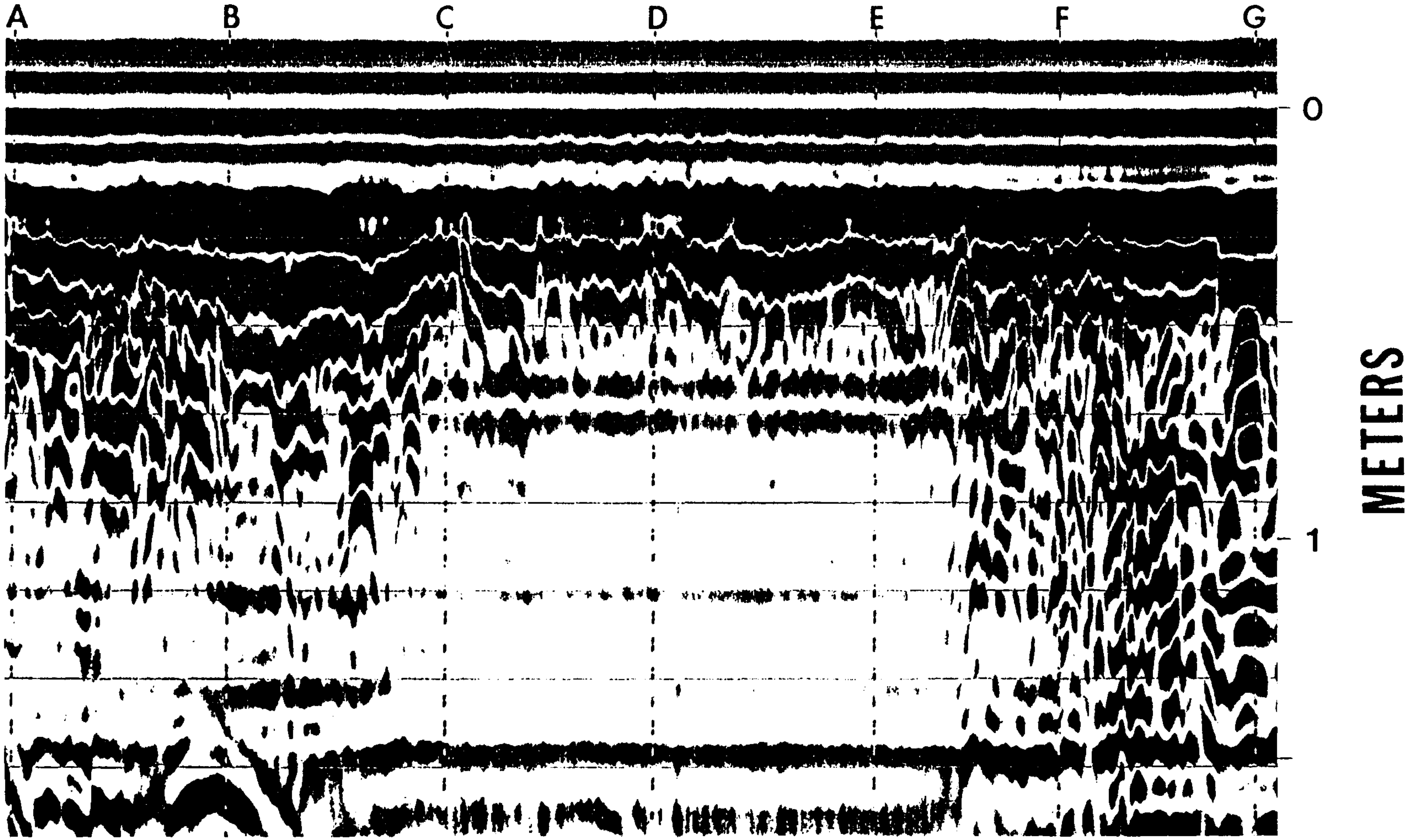



Fig 6




SITE 4, ORANGEBURG COUNTY, SC

Al Bates Farm
Orangeburg County, South Carolina

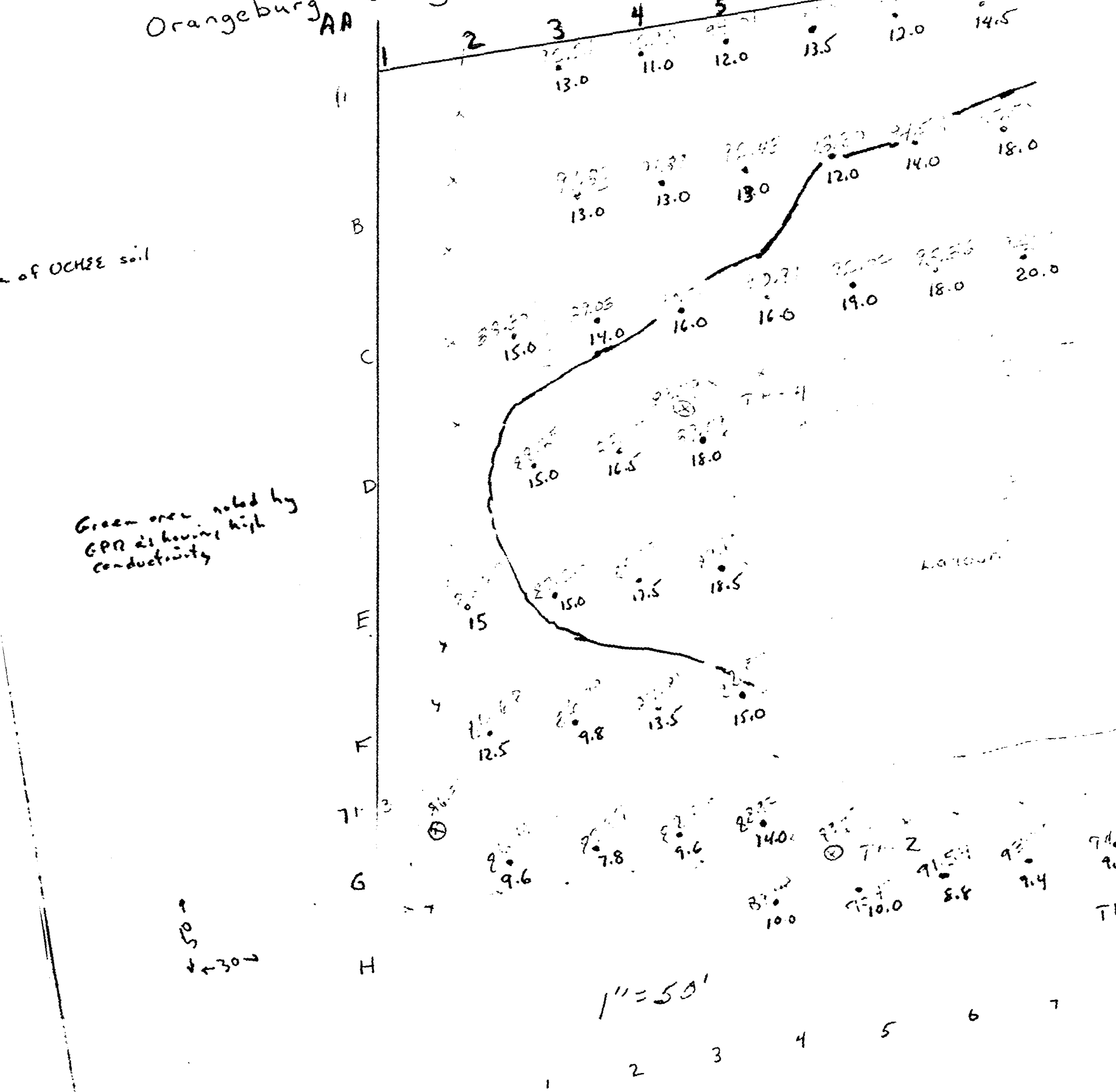



Fig 8

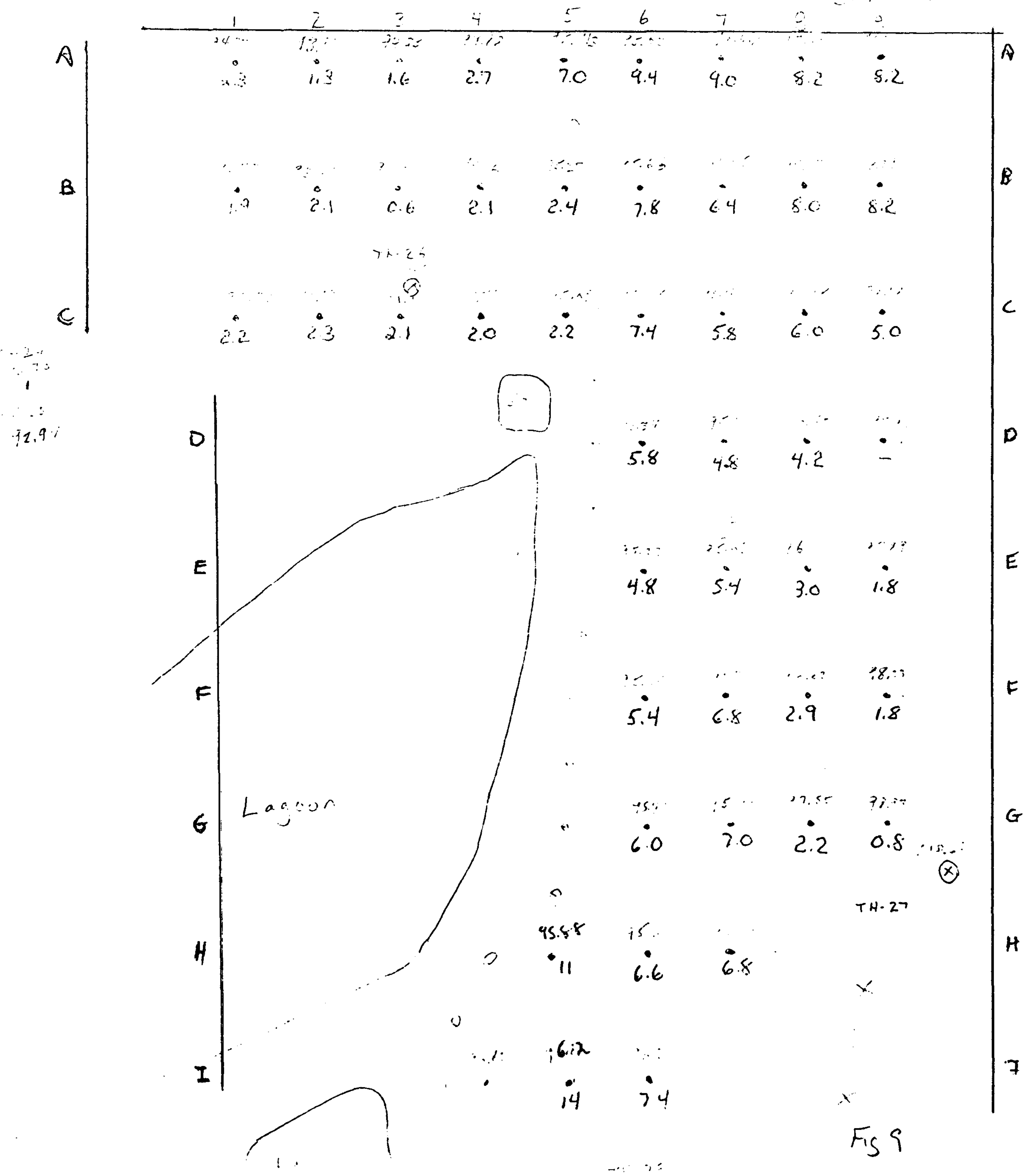
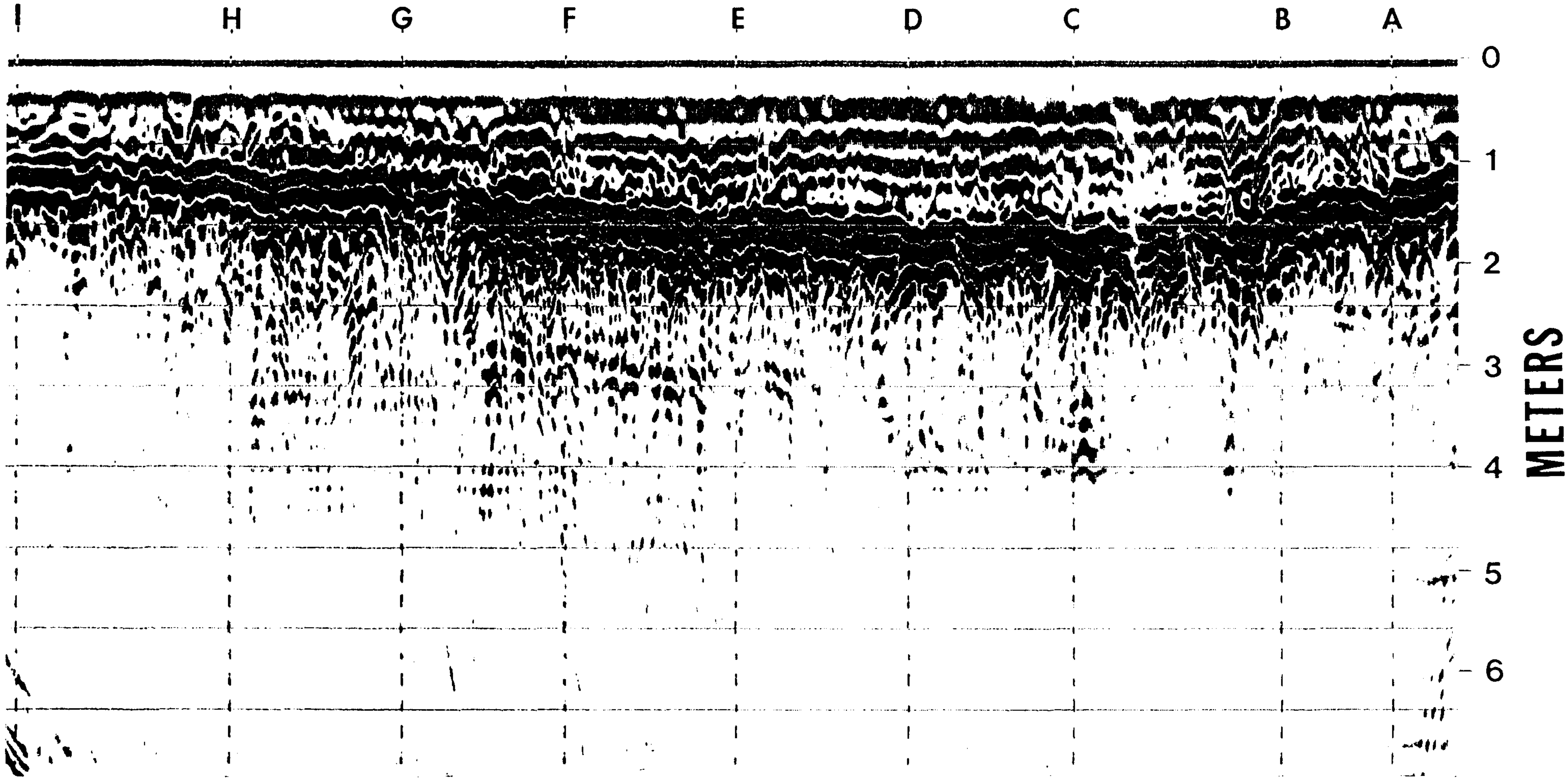

1 2 3 4 5 6 7 8 9
A
1.3 1.6 2.7 7.0 9.4 9.0 8.2 8.2
B
2.1 0.6 2.1 2.4 7.8 6.4 8.0 8.2
TH-26
C
2.2 2.3 2.1 2.0 2.2 7.4 5.8 6.0 5.0
D
5.8 4.8 4.2
E
4.8 5.4 3.0 1.8
F
5.4 6.8 2.9 1.8
G
Lagoon
6.0 7.0 2.2 0.8
TH-27
H
95.88
11 6.6 6.8
I
16.12
14 74

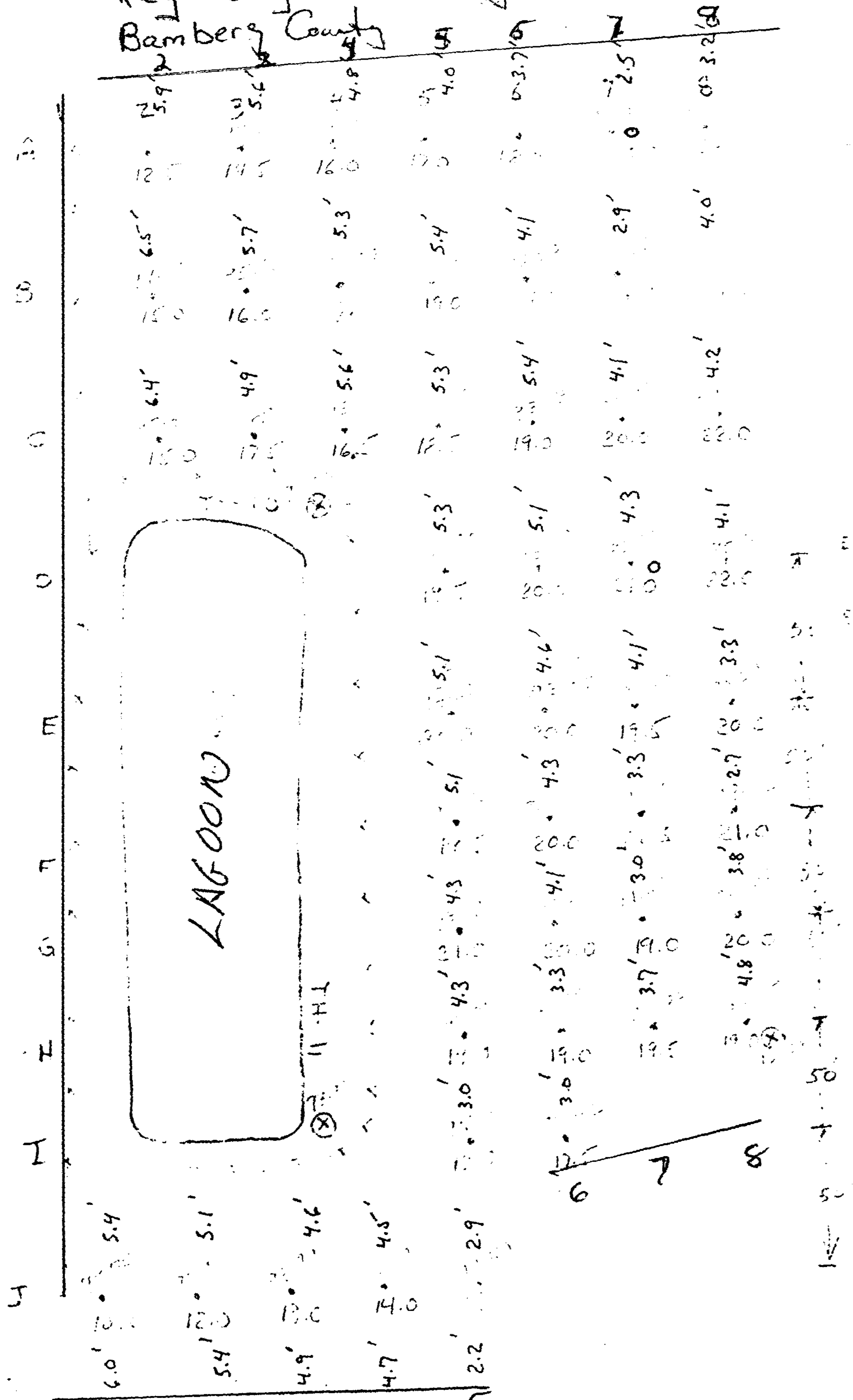
Fig 9




SITE 6, BAMBERG COUNTY, SC

Fig 10

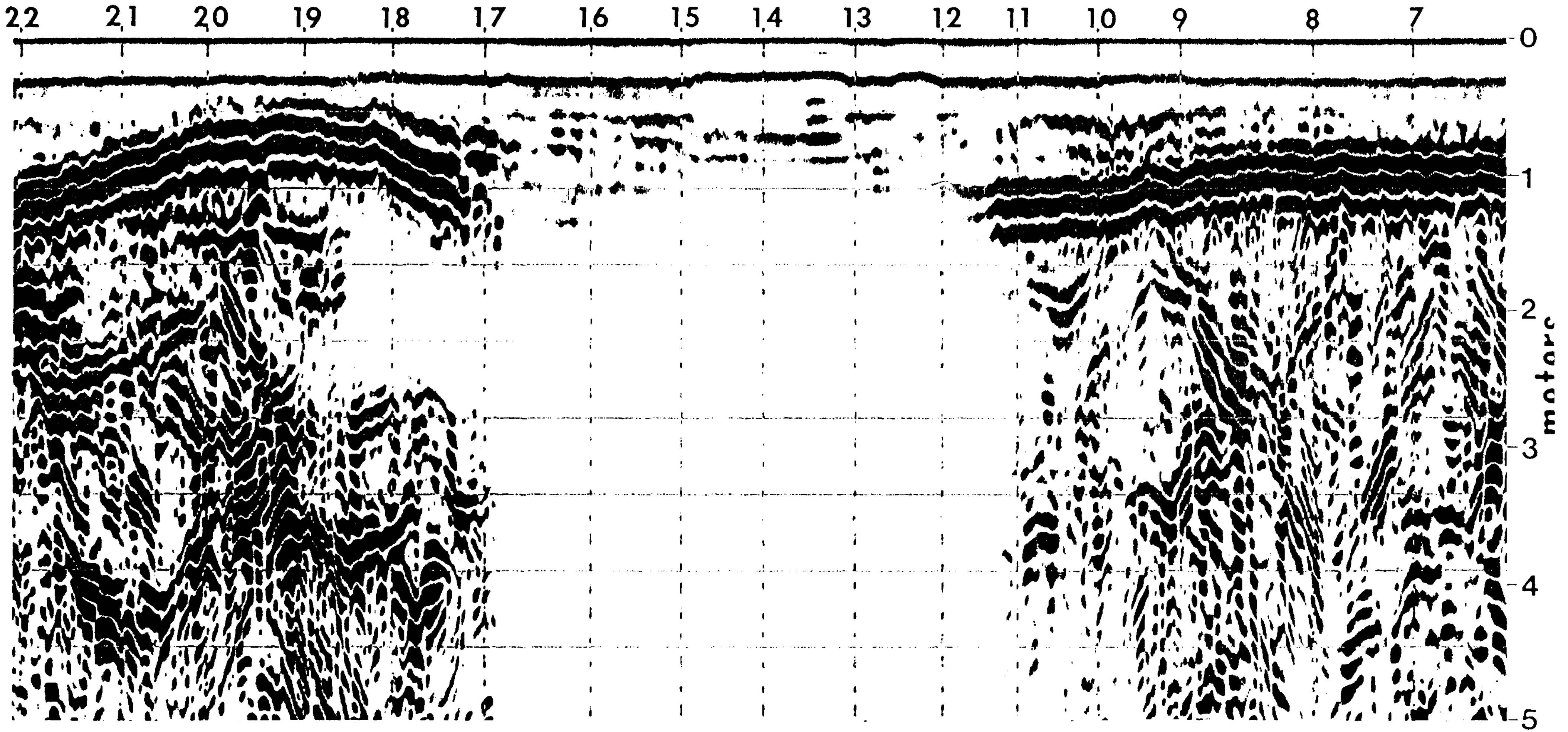
Ray Bryant's Hog Farm
Bamberg County




Ap 0-6 S 10YR 3/2
B 6-21 S 10YR 6/
E 21-34 gs 10YR 6/4 f.d 10YR
E 34-44 7.5YR
10YR 7/2
BE 44-50 scl 7.5YR 7/6

Fig 11

Depth to BE horizon




SITE 7, LEXINGTON COUNTY, SC

Fig 12

Roy Frick Poultry Farm
Lexington Co South Carolina

7-11-88

-50'-

| | A | B | C | D | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 95.82 | 96.10 | 95.34 | 94.54 | 94.17 | 94.01 | 98.39 | 94.10 | 94.32 | 94.90 | | | |
| 2 | 96.50 | 95.65 | 94.60 | 93.85 | 93.49 | 93.62 | 95.62 | 93.80 | 94.27 | 95.22 | | | |
| 3 | 96.66 | 95.47 | 94.34 | 93.59 | 93.41 | 93.55 | 94.42 | 94.22 | 94.65 | 95.55 | 96.13 | 96.82 | |
| 4 | 96.99 | 95.62 | 94.19 | 93.47 | 93.22 | 93.58 | 94.45 | 94.58 | 94.99 | 95.62 | 96.28 | 97.16 | |
| 5 | 97.14 | 95.46 | 93.93 | 93.34 | 93.25 | 93.67 | 94.18 | 94.97 | 95.44 | 96.46 | 96.23 | 97.68 | |
| 6 | 96.94 | 95.11 | 93.65 | 92.98 | 93.16 | 93.84 | 93.18 | 95.03 | 95.67 | 96.27 | 97.05 | 98.06 | 100.35 |
| 7 | 96.59 | 94.85 | 93.42 | 92.92 | 93.19 | 94.69 | 93.62 | 96.35 | 96.85 | 97.24 | 96.69 | 98.33 | 100.25 |
| 8 | 96.02 | 94.42 | 93.18 | 92.80 | 97.39 | 98.38 | 94.10 | 98.00 | 97.85 | 98.09 | 98.32 | 98.85 | 99.88 |
| 9 | 94.99 | 93.67 | 92.99 | 92.98 | | | | | | | | 98.67 | 99.84 |
| 10 | 94.40 | 93.58 | 92.88 | 92.98 | | | | | | | | 98.75 | 99.74 |
| 11 | 93.98 | 93.22 | 92.98 | 93.28 | | | | | | | | 98.88 | 99.74 |
| 12 | 93.41 | 92.78 | 93.08 | 93.23 | | | | | | | | 98.85 | 99.53 |
| 13 | 93.14 | 92.80 | 92.91 | 92.96 | | | | | | | | 98.71 | 99.33 |
| 14 | 92.79 | 92.89 | 92.92 | 92.76 | | | | | | | | 98.70 | 99.40 |
| 15 | 92.67 | 92.95 | 92.81 | 92.92 | | | | | | | | 98.59 | 99.43 |
| 16 | 92.90 | 93.11 | 92.92 | 92.99 | | | | | | | | 98.63 | 99.44 |
| 17 | 93.28 | 93.16 | 93.00 | 93.26 | | | | | | | | 98.70 | 99.45 |
| 18 | 93.64 | 93.50 | 92.90 | 93.37 | | | | | | | | 98.69 | 99.62 |
| 19 | 94.65 | 93.86 | 93.04 | 93.60 | | | | | | | | 98.57 | 99.61 |
| 20 | 95.86 | 94.79 | 93.63 | 93.99 | | | | | | | | 98.63 | 99.18 |
| 21 | 97.18 | 96.09 | 94.35 | 94.37 | | | | | | | | 98.49 | 99.25 |
| 22 | 98.27 | 97.05 | 95.51 | 94.53 | | | | | | | | 98.35 | 98.88 |
| 23 | 99.34 | 98.03 | 96.62 | 94.07 | 98.87 | 95.88 | 95.43 | 95.62 | | | | 97.54 | 96.75 |
| 24 | 99.95 | 99.02 | 97.41 | 95.25 | 94.06 | 94.17 | 94.60 | | 95.[illegible] | 95.98 | 97.39 | 98.00 | 98.26 |

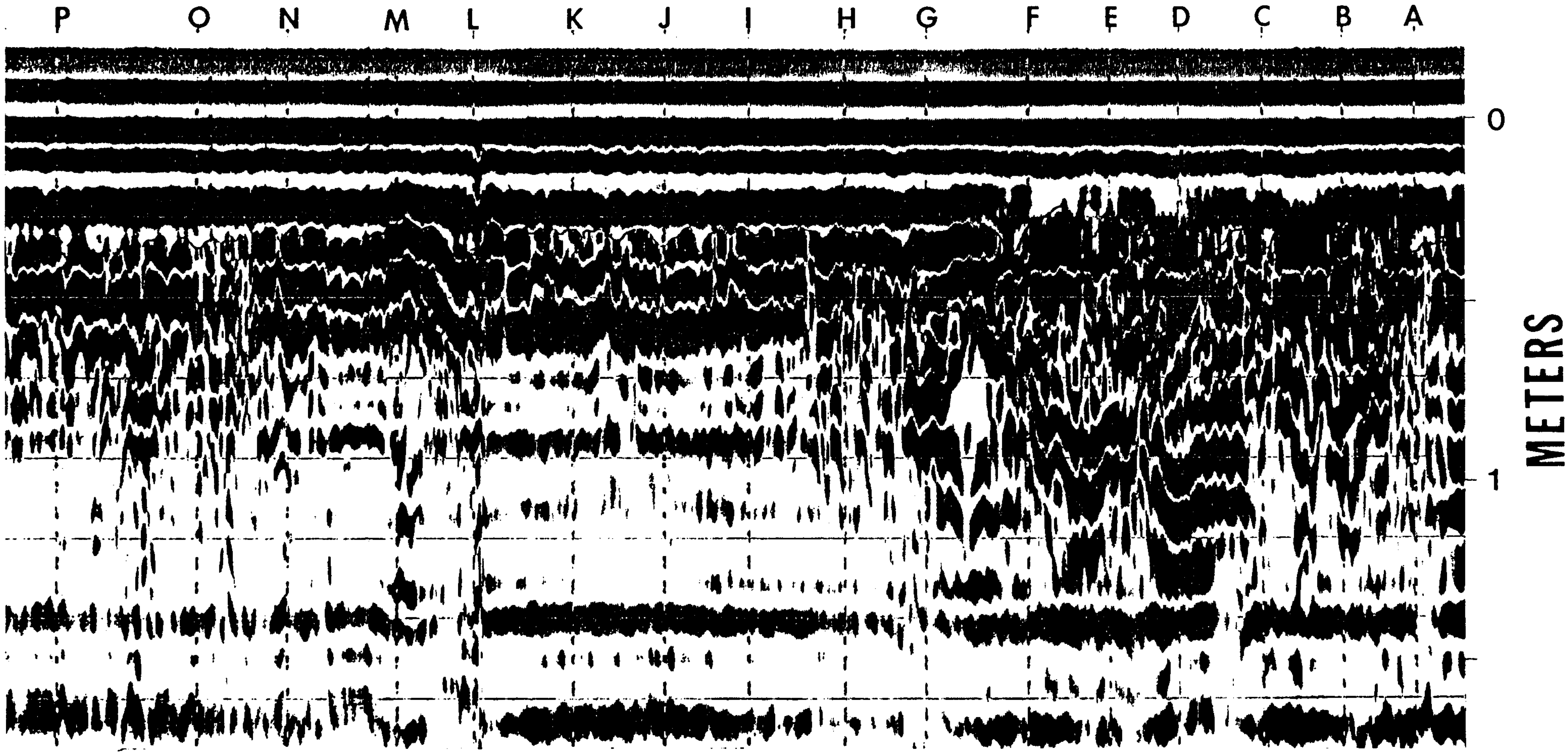
LAGOON

CHICKEN COOP

-30'-

ditch

Fig 13

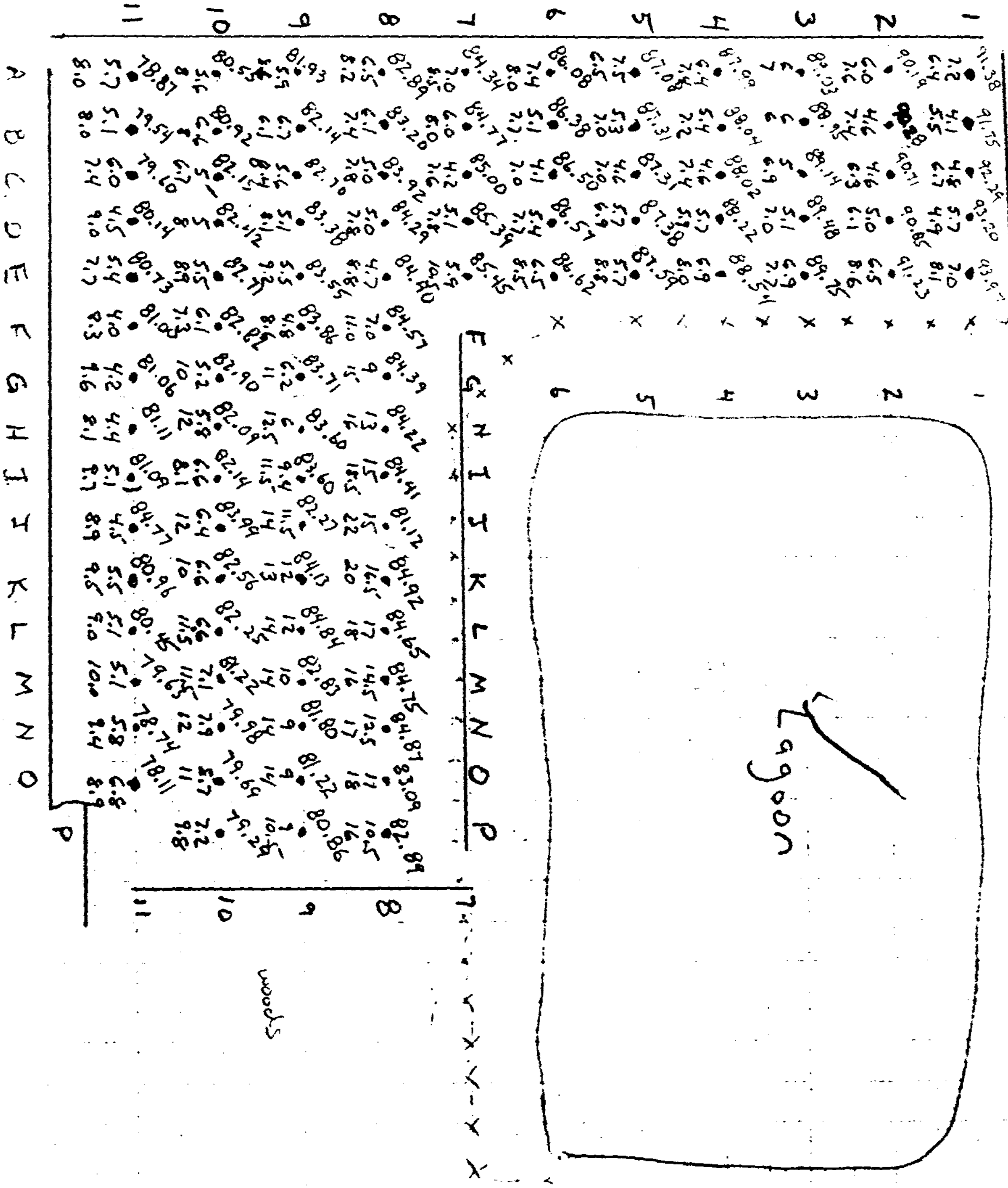



SITE 8, NEWBERRY COUNTY, SC

Fig 14

Jimmy Halliwanger Farm
Newberry County, South Carolina

7-12-8




Jim Doolittle -
David Brune -
Billy Beard -
Harold WAE
Kim Krueger

Fig 15

James Long Farm (Poultry)
Newberry County, South Carolina

7-13-88

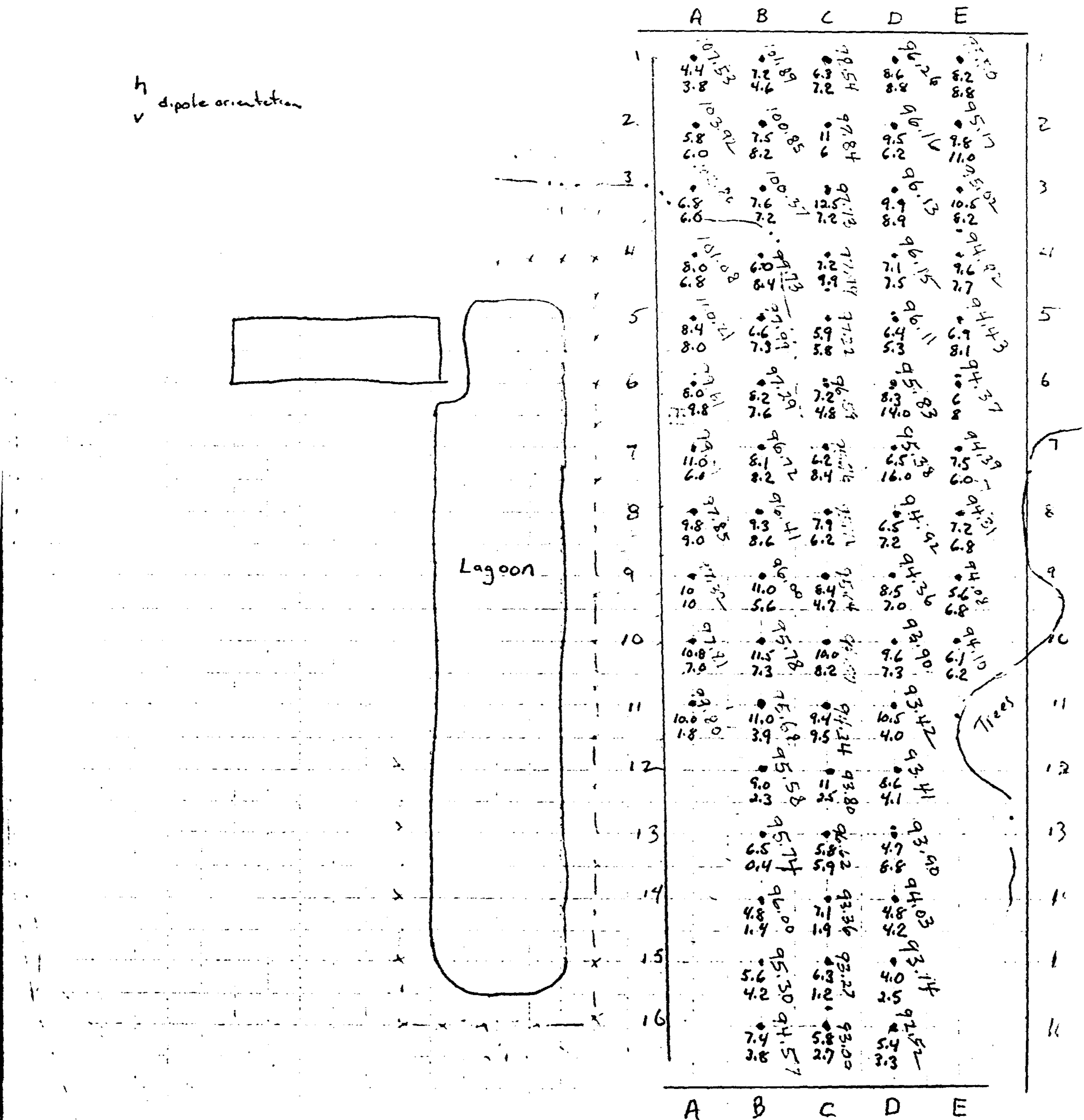



Fig 16

Ralph O'Neal Site, Hog Lagoon
Marion Co., South Carolina

KGK
JD
6-27-88

**Water Table Depths**
(6-27-88)

| | WT |
|---|---|
| TH-13 | 5.5' |
| TH-14 | 4.7' |
| TH-15 | 4.3 |
| TH-16 | 6.4' |

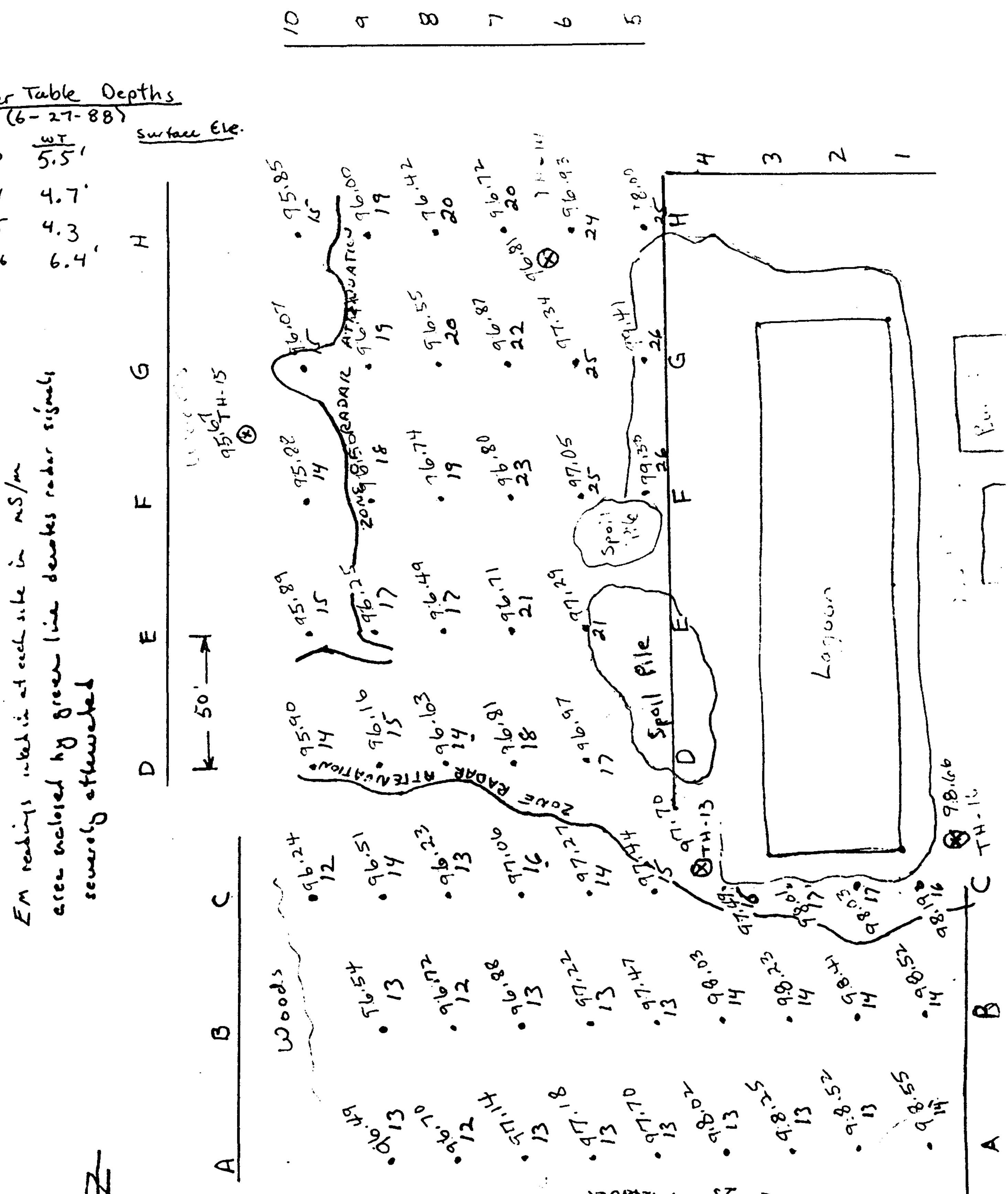



Fig 2