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LEICHHARDT DOWNS ELECTROMAGNETIC SURVEY

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1. INTRODUCTION

A small electromagnetic survey was carried out over part of Leichhardt Downs between 5th and 8th December, 1988. A team of three comprising one person from James Cook University (this report's author) and two QWRC personnel completed a total of 10510m of EM traversing in a time of approximately 20 working hours. Of this total distance, 4600m (4 lines) were surveyed with a 25m measurement interval with readings taken at three frequencies, 4700m (1 line) were surveyed with a 25m measurement interval with readings taken at 1 frequency, while 1270m (4 lines) were surveyed at a measurement interval of 5m and with readings taken at 1 frequency.

2. SURVEY AIMS

The aim of the survey was to test the use of the EM method in defining drilling sites for highly productive bores.

As has been explained in Doherty (1988), it will be necessary to carry out a small number of pump tests as part of the physical-property-estimation effort upon which the success or otherwise of a numerical groundwater model of the Leichhardt Downs Stage 2 Development area rests. As was also explained, because of the heterogeneous nature of the aquifer, those holes pump-tested need to be the best water producers in any sub-area if the interpreted aquifer characteristics are to be usable in the numerical model. As well, some understanding of the nature of fracture control of permeability in the immediate vicinity of any such hole is necessary for correct positioning of monitoring bores and pump-test data interpretation.

The permeability of the unconfined aquifer which exists within the moderately to slightly weathered country rock of the Leichhardt Downs area is thought to be controlled mainly by an approximately N-S trending fracture system. This fracturing is associated with the emplacement of a series of andesite dykes and, to date, good producing bores have often intersected andesite, prompting the theory that fracturing is most intense, and less likely to be clay-filled, within and next to these dykes. However, the picture is somewhat complicated by the fact that some andesite dykes are thought to be groundwater barriers either because they are unfractured or because fracturing with an E-W component (the direction of groundwater flow) is non-existent.

Both dykes and fractures are thought to be vertical. Because of the optimum coupling that exists between vertical electrical conductors and the transmitting-receiving coil geometry of the EM "slingram" method when used in the horizontal loop configuration, it was decided to test the ability of the EM method to locate zones of enhanced permeability due to increased fracturing intensity. As EM surveys can be conducted rapidly, and as target resolution can be increased by varying measurement parameters such as coil orientation, spacing and transmission frequency, the method, if successful, would be useful in locating drilling sites both within the Stage 2 area, as well as over the broader BRIA yet to be developed and under which the geology is often similar.

3. INSTRUMENTATION

A MAXMIN system manufactured by APEX of Canada was used for the survey. This sytem can operate in the horizontal loop, vertical loop, and perpendicular loop configurations at frquencies of 222Hz, 444Hz, 888Hz, 1777Hz and 3555Hz. Coil separation can be set at 25m, 50m, 100m, 150m, 200m or 250m. In-phase and out-of-phase field components are both displayed, up to a maximum level of ±100% of the primary field. The makers also boast a design that minimizes electrostatic coupling and interference from electrical transmission lines.

In use the transmitting coil, together with power oscillator and batteries, is carried by one or two men. A cable connects the transmitting and receiving coils, the latter being mounted on the case which houses the receiving electronics. This receiver is carried by one man, who takes the readings at each station and records them.

4. SURVEY TECHNIQUE

The survey was carried out in 3 parts; the locations of all lines traversed during the survey are shown in Figure 1. On all lines, the coils were used in the horizontal coplanar configuration with coil separation maintained at 100m.

The first part of the survey comprised lines over known highly-producing bores (Lines 2,3 and 4), as well as a line (Line 1) along the road through the middle of the Leichhardt experimental farm where the geology is well known. For these lines a 25 m sampling interval was employed (a quarter of the coil separation), while measurements at three frequencies (222Hz, 888Hz and 3555Hz) were made. On the basis of these measurements, it was decided to use only 888Hz for the remainder of the survey, allowing for a greater speed of coverage. In the second part of the survey, Line 5 was traversed; this line passes close to the existing bores 892, 893, 894 and 895. It is intended that, through the drilling of a number of extra bores along this line in the forthcoming QWRC 1989 drilling program, a "borehole traverse" for geological and hydrological monitoring will be constructed. This line was traversed at a measurement interval of 25m, but using only 888Hz. For the third phase of the survey, significant anomalies detected in the second phase were re-surveyed at a 5m sampling interval for accurate drilling site definition; again, measurements were taken only at 888Hz.

At all measurement points both the in-phase (IP) and out-of-phase (OP) secondary magnetic field (that due to electrical conductivity within the earth) were measured as a percent of the primary field (that (in phase) field which would exist at the receiver if measurements were made a great distance away from anything that conducts electricity). For Lines 1, 2, 3 and 4 distance measurements were made in the course of surveying; the lines were tied to known points as they were passed, these being indicated on Plate 1 where the results are presented. Line 5 was pegged prior to EM surveying, at roughly 100m intervals, the distances being measured with a vehicle odometer; this was done so that any anomalies in the results could be located later using the pegs. It should be noted that the distances between these pegs show a ±20% variation about 100m, as can be seen from Plate 2 where the results are plotted. Distances along the traverse were also measured in the course of conducting the actual EM survey so that the coil spacing was maintained at 100m, and the distance between readings was held at 25m, except where adjustments were made for peg location. The positions of these adjustments are noted on the survey raw data sheets, and should be referred to if the results of the 25m survey are to be used to locate drilling sites other than those indicated in the next section. For the 5m measurements, a string and belt odometer were used to maintain an accurate 5m measurement interval, and the positions of survey pegs were noted as they were passed in the course of traversing the line; see Figs. 2 to 5. Drilling sites can be taken directly from these figures.

5. SURVEY RESULTS

In a complex geological environment such as that of Leichhardt Downs, the response of any (especially electrical) geophysical technique will also be complex. However the following points can be used as a guide for understanding the EM profile results plotted on Plates 1 and 2 and Figs. 2 to 5.

For a horizontal loop survey taken over a thin steeply-dipping conductor, both the IP and OP secondary fields will go low, with their lowest values directly over the causative body. Readings will be lower than normal as long as the target is between the coils i.e. for three or four consecutive readings in the case of a measurement interval equal to a quarter of the coil separation. An indication of the electrical conductivity of the target is provided by the magnitude of its effect on the profile curve, with bigger conductivities being responsible for bigger effects, and with the effect increasing with frequency. As the conductivity of a target increases, the OP component responds first with a good accompanying IP response indicating, in general, a conductive target. For an extremely conductive target, the OP response diminishes, this effect being noticed first at high frequencies.

A thin vertical resistor can also cause a series of consecutive low readings; however readings will be low over seven or eight consecutive readings instead of the four expected from a thin conductor. If the target is wider than "thin", there will be a hump in the centre of this low, with the size of this hump increasing until it dominates the response, as the resistor becomes wider. However, as little has been published on the response of resistors, this description of their anomaly shapes may not be valid over a wide range of host conditions.

Obviously, in a situation where resistors and conductors are in juxtaposition, the profile shapes will be distorted from the ideal shapes discussed above. However intuition, based on experience with the EM method, and a knowledge of the environment, can lead to an understanding of the response of the method in the Leichhardt Downs area. The results of the present survey are discussed below.

<u>Line 1</u>

Profile anomalies indicating the presence of subsurface conductors are lettered on the plate; the arrow above each letter marks the probable location of the conductor. The 3555Hz results for anomaly D, indicate that a resistor may also be present in juxtaposition to the conductor, making this site a very likely one for drilling a hole in the hope of obtaining a good producer, if the inference is drawn that an andesite dyke is accompanied by fracturing at this location.

Anomaly F is mainly due to the fence on the western boundary of the farm. However as the anomalous response is felt even when the coils do not subtend the fence, it appears likely that a subsurface conductor exists about 25 m east of the fence where this line crosses it. However the anomaly size and shape is indeterminate because of the fence's response.

To the west of 1700W on this line, the average response levels change, rising for the 222Hz IP and OP components and the 888Hz IP component, and falling for the others. This is an effect of the electrically conductive clayey soils underlying this part of the traverse. Profile anomalies due to conductors below the clayey soils, are superimposed on this background response (e.g. anomaly G).

Only one of the anomalies on this line has a hole drilled near it, viz. bore 1058 near anomaly E. This bore is described as having a "good airlift" on the borelog. The EM results indicate a conductor centred 30m to the west of 1058, so it is possible that this bore would have been a better producer had it been shifted appropriately.

The traverse does pass through one highly-producing bore viz. 1073; see Plate 1. While this location corresponds with a small amplitude low on the profile, it would not have been selected as a good site on the basis of the EM results.

Line 2

On Plate 1, Line 2 is plotted such that it is aligned with Line 1 in a N-S direction, this being the strike direction of dyking and associated fracturing within the area. Anomalies A, B, C and D are marked on these results, these appearing to correspond with anomalies A, B, C and D respectively of Line 1. Again, anomaly D appears to represent the strongest electrical conductor and, like on Line 1, appears to have a resistive band associated with the conductor. Borehole 1072, a very high yielding bore, has been drilled on the anomaly, as shown on Plate 1; water was extracted from fractured andesite.

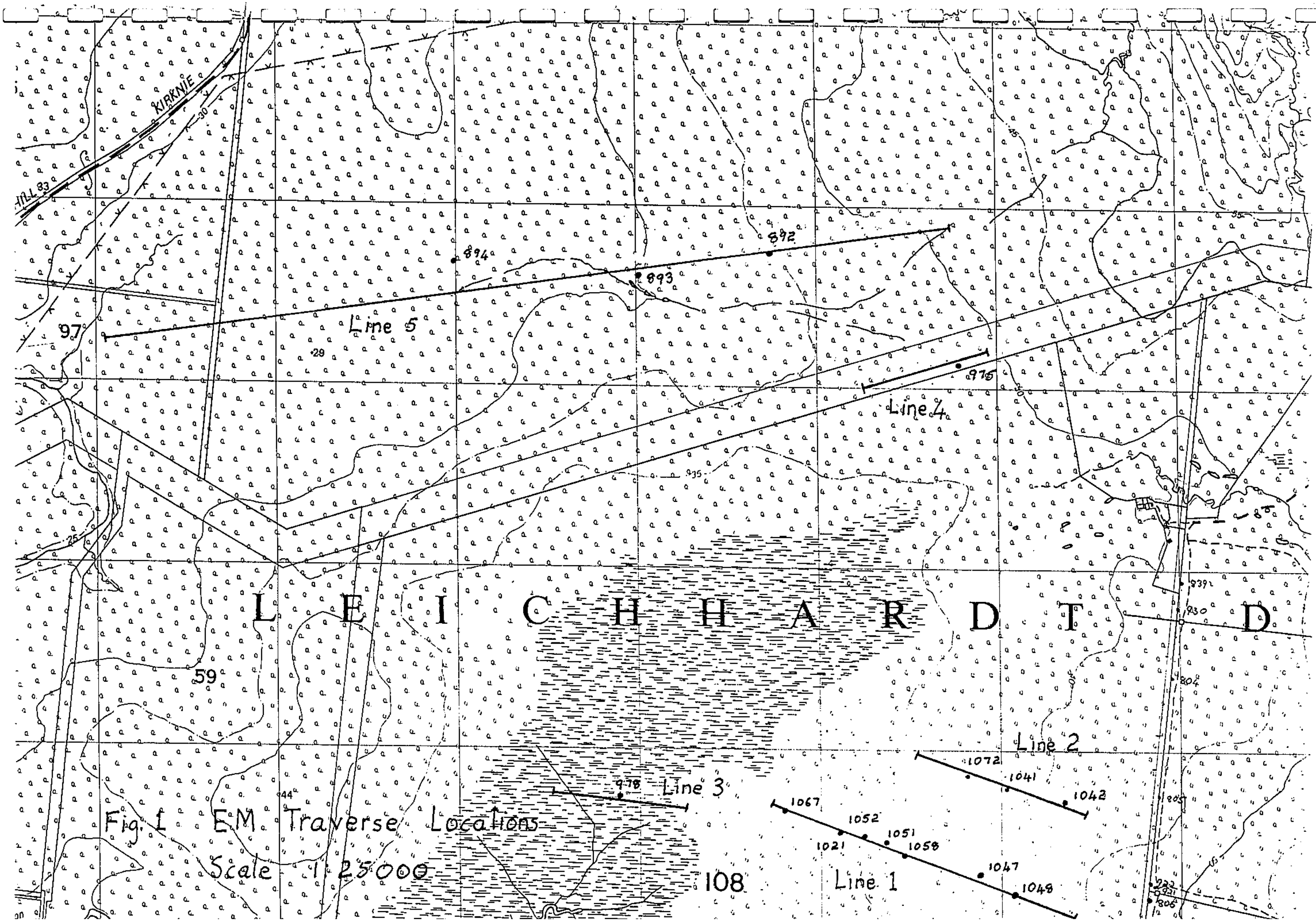


Fig. 1 EM Traverse Locations
Scale 1:25000

Line 3

Line 3 was run in order to test whether there was a response at Borehole 978, a highly productive bore drilled into fractured andesite. It lies within the alluvial plain to the west of the Leichhardt experimental farm in a region of no outcrop.

The profile shows a marked anomaly at the bore. The anomaly would appear to result from a wide steeply-dipping resistive body. The anomaly shape is not that of a classical thin resistor in a half-space but, as has been mentioned, next to nothing has been published on the anomalies caused by resistors, and little or nothing is known of the effect of their width or of conductive overburden on the anomaly shape, a phenomenon which influences considerably the shape of anomalies caused by conductors.

The causative resistive body is centred between 10 and 30m west of 978; the latter appears to have been drilled at the edge of the body. This is in harmony with the current hydrogeological model for the area which suggests that water can best be extracted from fissuring associated with andesite dykes; this fissuring is likely to be strongest at the edges of a dyke.

Line 4

Line 4 was run through another highly productive bore, 975; the latter taps water in what is probably a coarse porphyry andesite (Peter Evans, pers. comm). The EM results are somewhat affected by the presence of a nearby fence to which the line runs parallel at a distance of about 40m, though at the eastern end of the line the fence is only 10m away. However an anomaly to the east of 975 is clearly visible; rocks are strewn over the ground surface at the location of the anomaly. The anomaly appears due to a resistive body, this being apparent from its width. However the expected hump in the middle of the response is superimposed on a trough, indicating the likelihood of an associated conductor. It is possible that a hole drilled at 300W on this line would be highly productive.

Bore 975 itself is not asociated with any distinctive features of the profile.

Line 5

Line 5 passes through Borehole 892; it also passes close to holes 893, 894 and 895. As already mentioned, it is intended that a number of other holes will be drilled along this line as well, so that a hydrogeological section can be drawn through it. From the existing holes it has been recognized that the hydrologic gradient is locally very steep between bores 892 and 893. It is inferred that one or a number of andesite dykes are responsible for this.

The EM profile is presented in Plate 2; note that measurements were made only at 888Hz. The major anomalies are labelled A to I on this profile. Parts of the line were re-surveyed at a 5m measurement interval so that anomaly shapes could be better defined for accuracy in drill hole location. These results are presented in Figs. 2-5. Each of the anomalies is now discussed in turn, and drilling sites are suggested.

Anomaly A

This appears to be caused either by a wide conductive feature, or three thin ones, the latter alternative being the preferred one. On the assumption that this latter interpretation is correct, the best place to drill is at 81m west of the 1000E peg while the next best site is 37.5m west of the 1000E peg. These locations are marked on Figure 2.

Anomaly B

The width of this anomaly indicates that its source is resistive, though the absence of a central peak suggests a conductive source; hence it is likely that it is due to a composite body, possibly a dyke with accompanying fracturing. It is suggested that the best place to drill is at the lowest reading, viz. 56m west of the 600E peg. See Figure 3.

Anomaly C

Neither the IP nor OP components of this anomaly are as strong as for anomaly B. Again, the causative body appears to be composite and, selecting the site of the lowest readings, the best drilling site is 21m west of the 300E peg. See Figure 3.

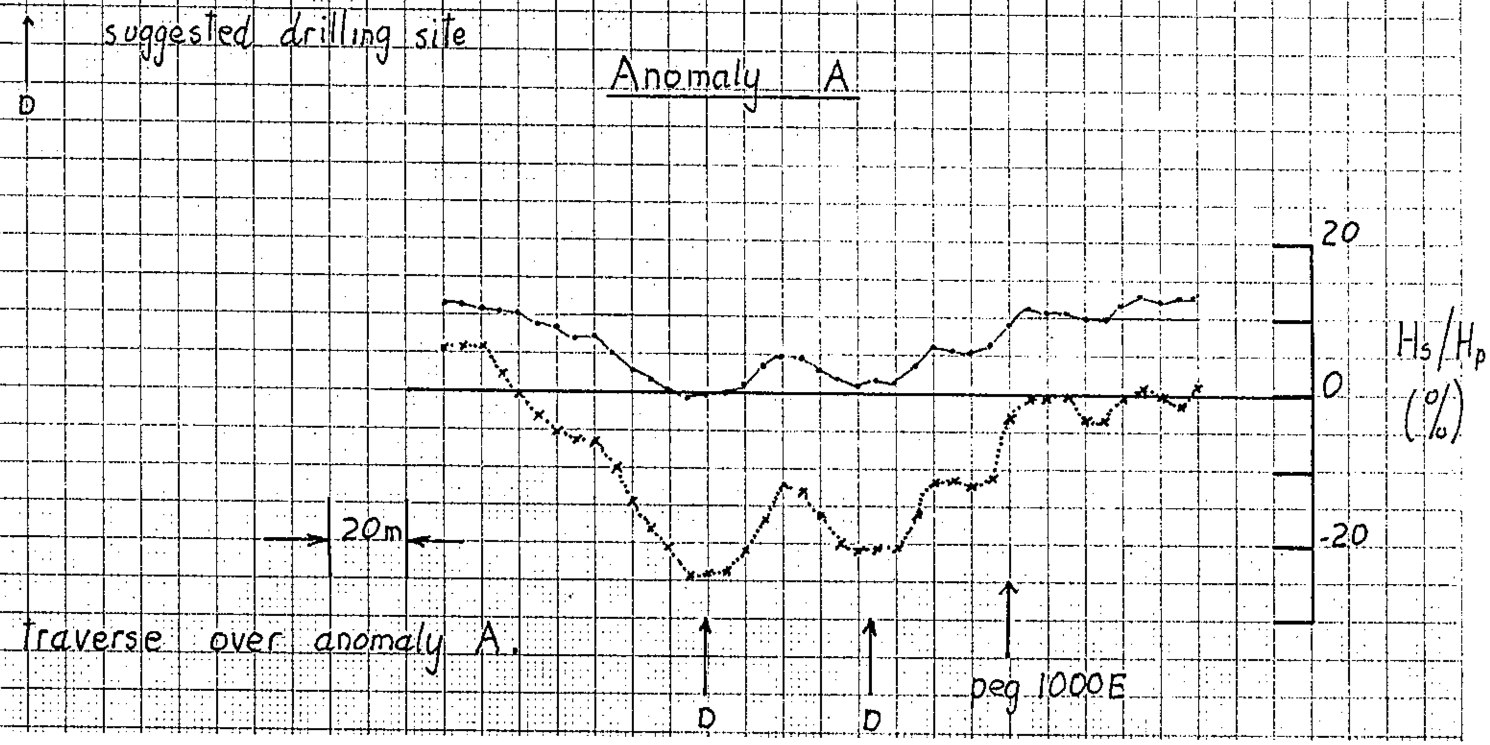
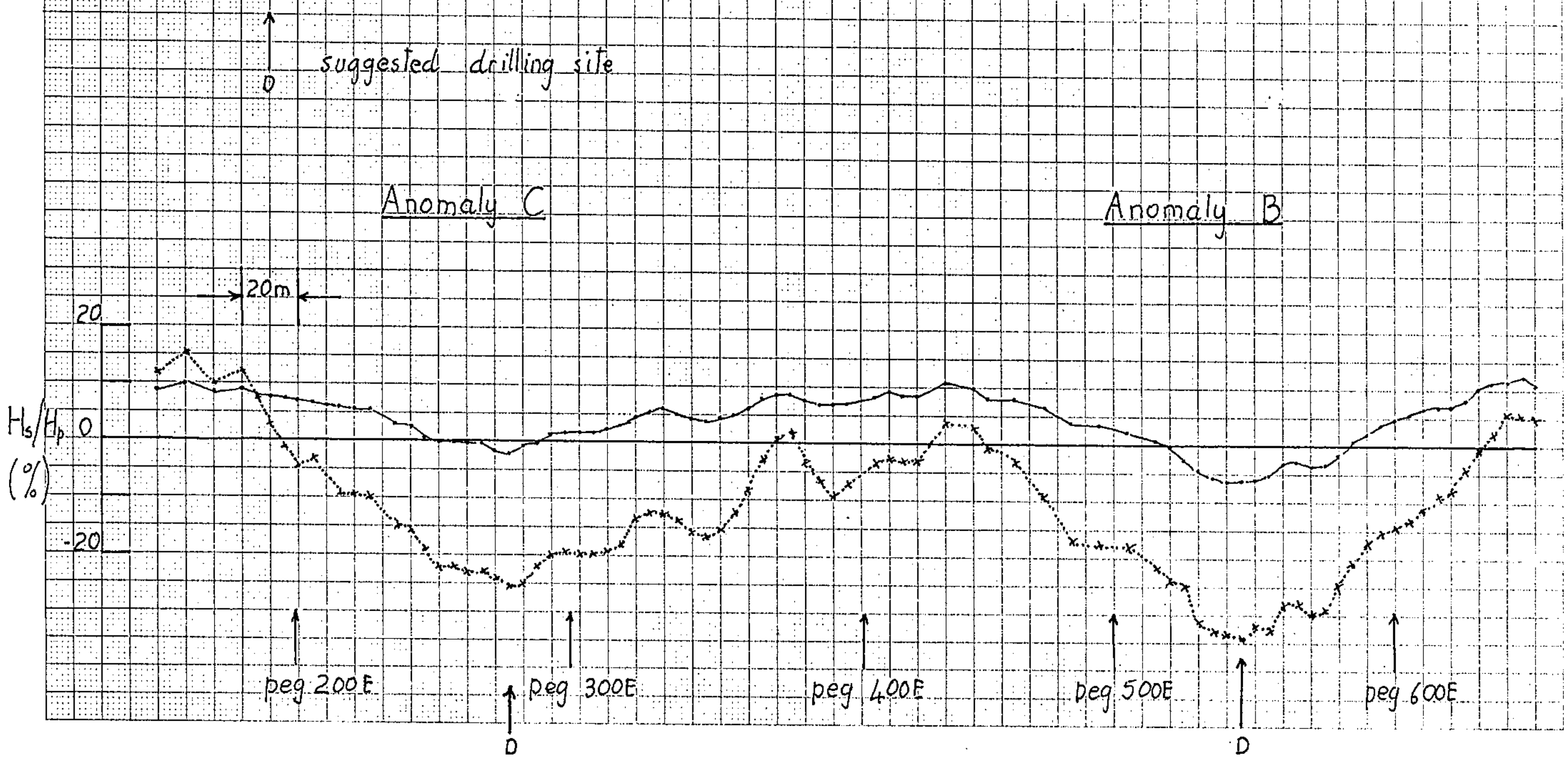


Fig 2. Detailed traverse over anomaly A.

Fig 3. Detailed Traverse over anomalies B and C.



Anomaly D

No detailed follow-up work was done over this anomaly. However it is a strong anomaly, with the IP component responding well, in harmony with the OP component. Like anomalies B and C, it is wide enough to be the response of a resistor, but lacks the central peak, indicating perhaps accompanying conductivity. Without any other information it is suggested that the best place to drill is at the anomaly centre, viz. 37m east of the 400W peg.

Anomaly E

This also appears to be a composite feature, with a resistor probably responsible for the spike at 700W. The deepest part of the anomaly probably results from a conductive feature and would be the best place to drill. This is situated 110m west of the 500W peg.

It is highly likely that the groundwater barrier responsible for the sharp water level drop between holes 892 and 893 is associated with either (or both) of anomalies D or E. As mentioned, both indicate the presence of a subsurface resistive feature, probably an andesite dyke in each case. Associated conductive bodies would be accompanying fracturing either within the dykes themselves or the neighbouring country rock.

Anomaly F

This results from a conductive subsurface body. A drill hole placed 19.5m west of the 2000W peg should intersect it. See Figure 4.

Anomaly G

Anomaly G is composed of a trough together with a broad peak. The peak is reminiscent of the response in the vicinity of bore 978; it is possible that the trough is a geometric effect of the horizontal loop system's response to the thick vertical resistor which gives rise to the peak. It is suggested that the best drilling site is next to the "notch" seen on Fig. 5, this figure showing the results of the detailed follow-up survey. This site is just uphill from the centre of the causative feature and is, again, reminiscent of where bore 978 is situated on its anomaly. This site lies 61m west of peg 2400W.

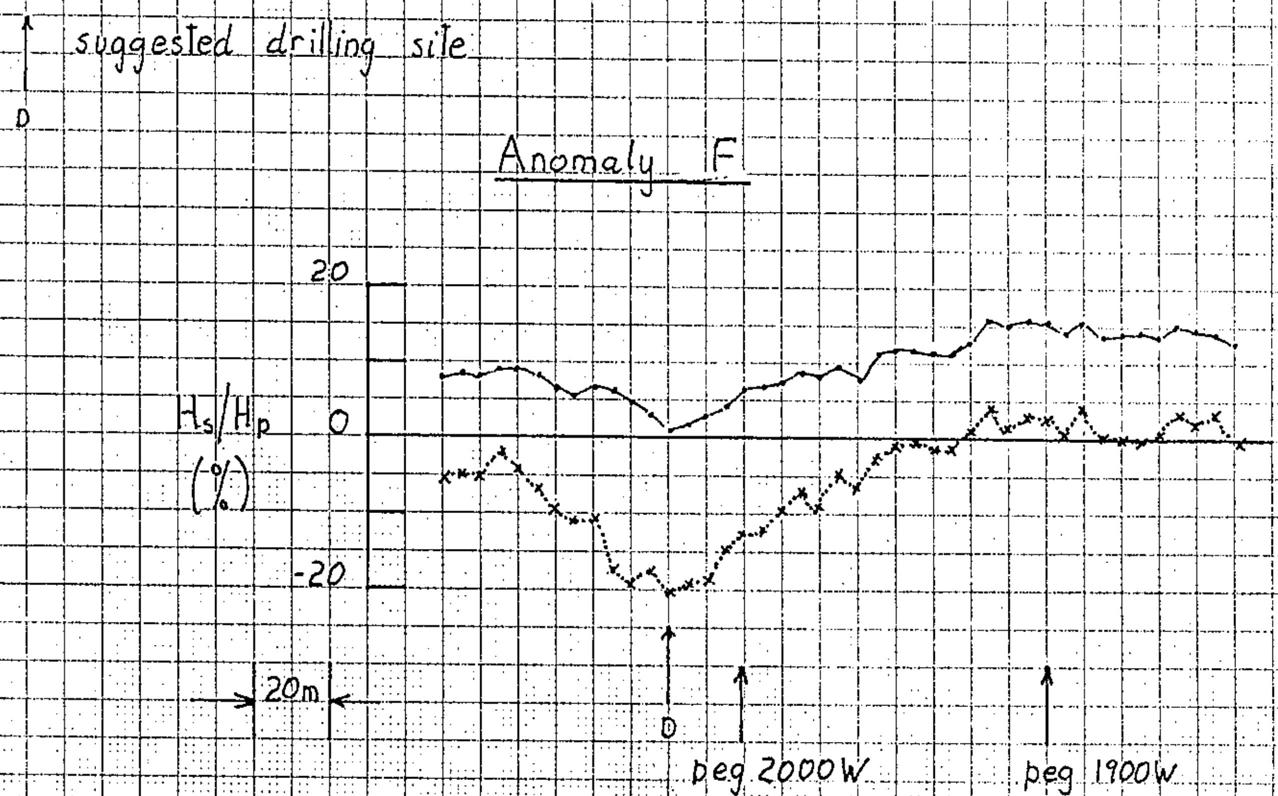
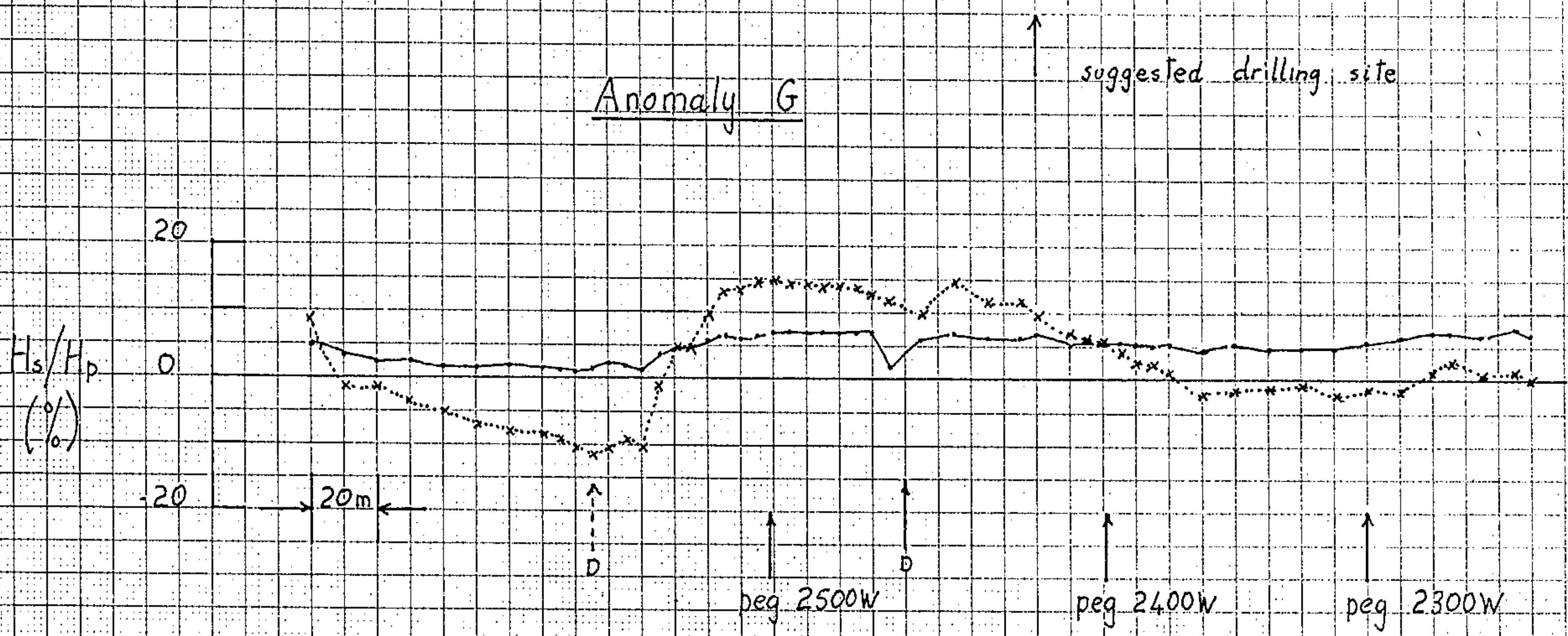


Fig. 4. Detailed Traverse over anomaly F.

Fig. 5. Detailed traverse over anomaly G.



If a hole drilled at the above site is not a good producer, it would be worthwhile drilling 54m west of peg 2500W at the deepest part of the anomaly's trough in case the above explanation of its cause is incorrect.

Anomaly H

There is some confusion here. If the peak to the immediate west of this anomaly is due to the fence, then the shape of anomaly H has been artificially distorted and little can be said about it. If not, then it represents a conductive feature, the best drilling site being 38m west of peg 2900W.

Anomaly I

Like anomalies B, C, D and E, the anomaly's source appears to possess a resistive and conductive component. There are signs of a central peak, this contributing to the inference of a resistive source. The anomaly's greatest amplitude occurs 80m west of peg 3100W.

It should be noted in the above discussion that drilling sites based on follow-up measurements at 5m interval are liable to be more accurate than those based on the original survey with a measurement interval of 25m. This is especially the case if causative conductors are narrow.

6. CONCLUSIONS

Lines 1 to 4 carried out through the farm and through known highly-producing bores give cause for optimism that the EM method will be of use in selecting drilling sites within the Leichhardt Downs area and further afield. The results suggest that while the EM method may not be able to locate every site at which a highly-producing bore may be drilled, it does yield anomalous responses which, if interpreted with the hydrogeological model for the area in mind, may yield more than enough producing bores for pump-testing. It thus is hoped that the probability of drilling a poorly producing hole on a site chosen on the basis of EM results will be small, or at least greatly reduced from that if no geophysics had been used.

Lines 1 and 2 demonstrate the reproducible nature of the EM results along the strike of the dominant structural features of the area. The fact that bore 1072, a high producer, was drilled at a point that would have been selected on the basis of the EM measurements, and that bore 1058, a good producer, was drilled near such a point, demonstrate that the fracturing that locally enhances hydraulic conductivity may also increase electrical conductivity. Line 3 demonstrates that major andesite dykes are detectable beneath an alluvial cover, a pleasing result in view of their significance both as groundwater barriers and as being associated with fracturing. The series of anomalies detected on Line 5 indicate that subsurface features, probably mostly dykes or the fracturing related to the dykes, are detectable and hence mapable; this may prove useful when farms and/or drainage systems are designed within the area.

The complete assessment of the EM method's usefulness must now await the drilling results from Line 5.

7. REFERENCES

Doherty, J. Salt and water movement on hillslope soil toposequences in the Burdekin River Irrigation Area: Progress Report, October 1988.