A RESISTIVITY SURVEY FOR GROUNDWATER IN PERLIS USING OFFSET WENNER TECHNIQUE

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Abstract

Vertical electrical soundings using the Offset Wenner array were carried out throughout Perlis, Peninsula Malaysia to investigate the hydrogeology of the state. The survey has been successful in locating proper sites for drilling and in determining depths to bedrock. In some cases VES curves show quite clearly the presence of karstic limestone which is the potential source of groundwater in Perlis. Hydraulic transmissivities obtained from pumping tests of 15 boreholes have been correlated with the electrical transverse resistance corrected for porewater resistivity. It shows that an inverse non-linear relation, contrary to the direct relation reported elsewhere for sand and gravel aquifers, exists for karstic limestone aquifers in Perlis. This nonlinear inverse relationship may be useful for predicting aquifer transmissivity in the area surveyed provided the electrolytic resistivity is known accurately.

Introduction

Inadequate supply of potable water in Perlis, Malaysia, has been a chronic problem for many years. Besides rapidly increasing demand for water due to urbanization, water is also necessary for agriculture as sugarcane and paddy are the main sources of income of the state.

The aim of the present study is to investigate the hydrogeology of Perlis state by geophysical methods. Such investigation is important to the development of water supply and to construction engineering as well. The Irrigation Department has planned to construct two small dams - one north of Beseri and the other near Arau. This study also hopes to supply the Irrigation Department and Public Works Department with additional information regarding the subsurface and hydrogeologic parameters.

Previous geophysical surveys (mostly resistivity) were confined to the areas south of Beseri and in selected areas of Chuping. Lithologic data from 50 boreholes and pumping test data from some boreholes are available from the area. Most of the boreholes are concentrated in the Chuping and Arau areas. The Public Works Department has developed a few wells in Arau to supplement the existing water supply for Kangar and other small towns nearby. However, the total supply of water still falls short of the requirement by about 1 million gallons per day.

D.C. resistivity using the Offset Wenner technique, gravity and induced polarization methods were used in the present study. However we shall discuss only the results obtained from the D.C. resistivity method in this paper.
Based on the interpretation of VES data, we recommended drilling on a few sites. Correlation between these two sets of results has also been discussed. An attempt has been made to establish a relationship between hydraulic transmissivities from 15 boreholes and the transverse resistance of the aquifers. Several authors including Ponzini et al (1984), Singhal and Niwas (1983), Schimschal (1981), Uris (1981), Worthington (1977a, b, c), Henriet (1976) and Bendini (1976) have studied the correlation between hydrogeological parameters and surface geophysical measurements. A good reference on the subject is available in the paper by Ponzini et al (1984). Most of the authors have found a direct relationship, whether linear or non-linear, between apparent formation factors and hydraulic parameters such as transmissivity and conductivity of alluvial (sand) aquifers. However, Hegold et al (1979) and Schimschal (1981) have reported an inverse relationship between electrical resistivity, measured by surface geophysical method, and hydraulic conductivity for a glacial outwash and limestone aquifers respectively.

Climate

The region experiences an equatorial maritime climate. Rainfall occurs mostly during April to November with peak periods in April - May and August - October. The period from December to March is often virtually dry. Average rainfall ranges from about 1750 mm in north Perlis to 3250 mm in the extreme south of Kedah (Fig. 2). Variations in daily temperatures are very small. The average daily temperature is 27 °C with maximum at 32 °C and minimum at 21 °C throughout the year. Relative humidity is high with mean monthly values of 78 % in the dry period and 85 % in the peak rainy season. Annual mean open water evaporation ranges from 1700 to 2000 mm with high and low mean daily rates of 6 mm and 3.7 mm.

Geology and Hydrogeology

The geology of Perlis and three roughly east - west geological crosssections are shown in Figures 1 and 3 respectively. The Setul, Kubang Pasu and Chuping Formations make up most of the surface and subsurface geology of Perlis. The Setul limestones are continental shelf deposits consisting of hard brittle dark grey crystalline limestones with minor detrital rocks in the upper part. The formation has undergone major folding and faulting and forms typically steep - sided topography. Karst development as observed at outcrops in the west is usually large scale with a few small solution cavities. The eastward dipping Kubang Pasu sediments overlie the Setul Limestone unconformably. Above the Kubang Pasu Formation lie the eroded residues of the Chuping Limestone, which occupies two narrow parallel synclines. The Kubang Pasu Formation is the result of further deep basin sedimentation. The rocks are pale grey mudstones and shales interbedded with minor sandstone beds. The sandstones form typical north - south strike ridges as a result of folding.

The Chuping Formation passes upwards from calcareous sandstones and shales into pale grey to white finely crystalline limestones with dolomitic limestones and limestone breccias. The formation occurs in an anticline striking north - south. Subsequent faulting and erosion have resulted in spectacular limestone hills.
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Fig. 1 – Perlis Geology and Water - Short Areas.

Fig. 2 – VES and Borehole Locations.
Two types of karst zones have been encountered both in the Setul and Chuping limestones. A highly broken zone with limestone gravel and rubble beds is usually found at shallow depths and more isolated karst features of more random occurrence are found at greater depths. The yield in these types of aquifers in more than 50 l/s. (PWD Report, 1982). The yield in the Kubang Pasu Formation is generally low irrespective of whether it is fractured or not. However yields of 0.4 to 17.8 l/s. have been obtained from the relatively thin sandstone bands where they are fractured. Average annual depth to the water levels in wells is between 2 and 4 m below ground level. It rarely exceeds 10 m. Groundwater flow occurs downslope through the lower weathered and fractured zones to produce confined artesian groundwater conditions (PWD Report, 1982).

Drilling in Setul and Chuping limestones show intervals of increased transmissivity associated with cavities, mainly along bedding planes.

Field Technique

There are numerous electrode configurations available in the geophysical literature. Their advantages and disadvantages have been discussed by several authors including Kunetz (1966) and Whiteley (1973). Barker (1982) has proposed the Offset Wenner Array for resistivity sounding in searching for groundwater. For easy and fast field operations with this technique we have made a control switch box as suggested in Barker’s paper. Because of inavailability of suitable multicore cable, we have bundled eight single core cables of selected lengths together. Two such "multicore cables" (bundles) were used, on the right and left sides of the sounding point where the control switch box and ABEM SAS 300 Terrameter were placed. We followed the electrode spacings of 1, 2, 4, 8, 16, 32, 64 and 128 m because our depth of investigation was confined to about 50 m. In some cases (VES 18, Fig. 4) the electrode spacing was increased to 341 m where either the bedrock is presumably very deep (> 50 m) or cavities/potholes are suspected at greater depths. One of the advantages of offset Wenner is that the apparent resistivity value at twice the last electrode spacing in a resistivity sounding spread can be calculated without actually measuring it. We fully exploited this with success in situations where the spread of the sounding line is restricted due to marshy land, paddy fields, hills, thick bushes or jungle which are very common in equatorial contries like Malaysia. Moreover, performance of some resistivity measuring equipment like YEW resistivity meter is limited to a depth of 50 m. During the first part of this survey we had to use YEW resistivity meter to measure apparent resistivities at 35 electrical sounding points (Fig. 2) and we found that this particular advantage of the Offset Wenner technique can extend the depth of investigation beyond the manufacturer’s recommended depth.

A D C resistivity survey using the Offset Wenner technique was carried out for the first time in Malaysia in May and August 1984 and also in April 1985 together with induced polarization and gravity surveys. The purpose of the survey was to locate potential aquifers in limestone areas, areas of Quaternary and Tertiary deposits and in some cases, in areas of Kubang Pasu (mostly mudstone, sandstone and siltstone) rocks. The survey involved measurements at a network of 156 vertical electrical sounding points (Figure 2).

The Offset Wenner sounding data were processed in the field using a TI–59 programmable calculator.
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Geophysical Interpretation

The processed data were first interpreted by matching standard and auxiliary curves. The parameters so obtained were then fed into the computer of the University Sains Malaysia for inverse interpretation. Interpretation of some of the representative curves is discussed later. Resistivity sounding curves show the existence of three main types of bedrock in Perlis. The first kind is massive limestone or mudstone. Interpretation of these curves mostly shows non-existence of any aquifer. The second type representing karstic limestone indicates presence of water. The third type of curves acquired from the Tertiary beds (sandstone) in the Chuping sugarcane plantation area and Felda Rimba Mas-Mas are of the K-type whereas most of the rest of the curves showing limestone, mudstone or shales as bedrock are of the Q-type. However, we shall confine our discussion here to the second type of curves only. The observation errors calculated in the field while taking readings are less than ±5% which indicates that the data are of high quality.

Interpretation of VES 18, 19, 20 and 22

These sounding curves (Fig. 4) were measured near and south of the intersection of the roads to Kaki Bukit and Padang Baser (Fig. 2). The sounding points were taken at 300 m intervals on the average, using the Offset Wanner Array. VES 19 was restricted to an electrode spacing of 64 m only due to limited space available in the paddy field. However, we exploited the advantage offered by the Offset Wanner Array to calculate the apparent resistivity value at a spacing of 128 m. This particular data point is important in deciding the trend of the curve (Fig. 4). Quite convincingly, it shows that the curve begins to descend confidence as the HAK type (Keller & Frishknecht, 1966). All these sounding curves show the presence of karstic limestone at varying depths. Bangka drilling at a location 5 m away from that of VES 18 confirms the depth to bedrock as determined from sounding data (3.0 m) and that the bedrock is weathered limestone (resistivity 290 Ω m). The fourth layer having a resistivity of 141 Ω m represents karstic limestone and a possible aquifer at a depth of 49 m from the ground surface. VES 19 which is 100 m away from VES 18 and located in the paddy field shows almost similar subsurface geology except for a larger depth (69 m) to the suspected karstic aquifer.

The sounding curves 20 and 22 have shapes of the types KHK and QHK respectively. The depths to bedrock determined from VES 20 and 22 are 11 m and 18 m respectively. It is very likely that both the third layers are lateritic clays. The fourth layer represent massive limestone and below them is karstic limestone. The depths to the karstic limestone beds are respectively 24 m and 32 m. In the next and final phase of our survey we are planning to do diamond drilling at either of the locations of VES 20 and 22.

The sounding point VES 18 was repeated with an induced polarization equipment (max. current 4 Amp.) Capable of measuring apparent resistivity values. A maximum Wenner spacing of 341 m. was used to confirm the shape of the curve as obtained with the Offset-Wenner Array by calculating the last data point. The repeated sounding curve does confirm that the curve begins to descent, after the last measured data point. This trend is considered to be the same VES 19, 20, and 22.
Fig. 3 — Perlis Geological Section.

Fig. 4 — Interpretation of VES curves from karstic limestone bed.
Interpretation of VES 130, 131 and 98

VES 130 and 131 (Fig. 5) were measured inside the campus of a recently constructed vocational training centre for 800 students. The two sounding points are about 300 m apart and were measured in response to a request by the Public Works Department. VES 131 shows the presence of fractured bedrock at a depth of about 5 m and subsequent hand drilling showed that the bedrock is in fact fractured sandstone. This may not be a good aquifer, but even then the Public Works Department is very soon going to drill a borehole with a diamond drilling machine because 5–6 l/s of discharge will be enough to fulfill the water requirements of 800 students. Except for the Tertiary bed in the Chuping Sugarcane Plantation, this is the only water-bearing layer composed of sandstone. It is very likely that this is a thin sandstone lens associated with the Kubang Pasu Formation (mudstone, siltstone and sandstone). VES 130 was taken in the middle of the playground. Our analysis shows that the bedrock is massive, deep (34 m) and very likely mudstone. Drilling was not recommended at this sounding point.

VES 98 is located inside the village Kampong Melayu. The sounding curve (Fig. 5) has a flat shape for the minimum which apparently narrows down the possible range for the value of the true resistivity of the conductive layer, above bedrock, to about 75 m. Inverse interpretation based on the 4-layer model \( \rho_1 < \rho_2 < \rho_3 < \rho_4 \) i.e. KH type) gives the depth to the bedrock as about 28 m. This however varies considerably from the depths-to-bedrock determined from nearby sounding points. We have interpreted this with a 6-layer model having progressively increasing resistivities to account for the flat minimum. Based on this interpretation, a subsequent drilling (hand drilling) confirmed the depth to the bedrock as 14 m. It showed that the bedrock is weathered shale and water was found at a depth of 8 m from the ground surface.

Relationship Between Surface Geophysical Measurements and Hydrogeological Parameters

Out of 156 vertical electrical sounding points (Fig. 2) we have chosen fifteen for establishing a relationship between corrected transverse resistance, obtained from surface geophysical measurements, and the transmissivity of the aquifer. These selected VES points are located at or near the locations of the existing boreholes of the Geological Survey of Malaysia. Interpretation was carried out by first using auxiliary curves and two-layer standard graphs and then using these information as input to inverse interpretation with the computer (Model IBM 4381) of the University Sains Malaysia. However care was taken to utilize the lithological logs of the nearby wells as control while interpreting these VES data. This is important for determining accurately the hydrogeological parameters such as the thickness and resistivity of an aquifer. We shall consider VES 137 and 138 for discussion here (Figs. 6 and 7).

All these sounding points are within 25 m of the nearby boreholes. VES 137 near borehole GS 780 gives a false impression of a three layer curve \( \rho_1 < \rho_2 > \rho_3 \). However we have modelled it with six layers based on borehole data. The effect of the fifth layer, which corresponds to the main water producing fracture zone is not shown in the sounding curve because its thickness is quite small. This kind of situation is fairly common in Perlis.
Fig. 5 – Interpretation of VES 98, 130 and 131.

Fig. 6 – Interpretation of VES 137 with the aid of GS 780.
VES 138 is 25 m away from borehole GS 797. The shape of the curve is of the AKH type. However we have interpreted it by a seven-layer model \((\rho_1 < \rho_2 < \rho_3 > \rho_4 < \rho_5 > \rho_6 < \rho_7)\). In this case the main water producing zone is the limestone rubble zone, which is immediately below a high resistive zone composed of gravel and residual limestones. Unless extreme care is taken, aquifers of the type considered in VES 137 may go unnoticed while interpreting them in the absence of borehole data.

Table 1 shows the resistivities and thicknesses of aquifers determined from surface geophysical measurement and the transmissivities and thicknesses of the aquifers as determined from pumping test. The resistivity of the aquifers in Perlis (except the Tertiary bed) varies between 20 and 90 \(\Omega\) m and the porewater resistivity varies between 19.6 and 28.2 \(\Omega\) m. Corrected transverse resistance \((pt/p_\omega)\) is plotted against transmissivity in a bilogarithmic graph paper (Fig. 8). The relationship between these two parameters is non-linear and inverse. Higher hydraulic transmissivity indicates lower transverse resistance, corrected for electrolytic resistivities, which in turn means lower resistivity or thickness or a combination of both. The transverse resistance corrected for porewater resistivity has been shown to be related to the hydraulic transmissivity by an empirical function: \(R_c = \rho \cdot t/p_\omega\) where \(R_c \) is the corrected transverse resistance, \(T\) is the transmissivity, \(\rho\) and \(p_\omega\) are the resistivities of the aquifer and the electrolyte respectively, \(t\) is the thickness of the aquifer and \(A, B\) are the constants determined from power regression analysis as 1.020 and \(-0.368\) respectively. Corrected transverse resistance is in fact formation factor \(F\) multiplied by the thickness \(t\). The term \(\rho \cdot t\) is the transverse resistance.

<table>
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<tr>
<th>VES No.</th>
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<th>From boreholes and pumping tests</th>
<th>Corrected transverse resistance</th>
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<td>Aquifer resistivity (p) ((\Omega) m)</td>
<td>Aquifer thickness (t) (m)</td>
<td>Transmissivity, (T) m(^2)/sec (x 10^{-4})</td>
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**TABLE 1.** Aquifer parameters from VES and pumping test, and corrected T.R.
Fig. 7 – Interpretation of VES 138 with corresponding borehole data.

Fig. 8 – Empirical relationship between transverse resistance and transmissivity.
Most of the sounding curves measured at or near the location of existing boreholes show karstic limestone as the main source of water. These aquifers occur either at the interface of laterite and fractured limestone or at depths inside the limestone itself. The type of VES curves are therefore of the type $\rho_1 > \rho_2 > \rho_3 < \rho_4 < \rho_5$. In most cases the fourth layer represents a karstic aquifer and in a few cases the third layer is the aquifer. VES sounding curves will not show the effect of the fourth layer if it is not thick enough. Therefore care must be taken in interpreting VES curves from karstic limestone areas. If either the thickness or the resistivity of a karstic aquifer is known a priori then the product of the resistivity and the thickness can be determined accurately from VES interpretation and therefore can be used to predict transmissivity of an aquifer at the location of the VES point.

The relationship between transverse resistance and hydraulic transmissivity is simple and straightforward. On the other hand the computation of the hydraulic conductivity from the transmissivity requires extra data and also is a source of other possible errors (Ponzini et al, 1984). However the karstic limestone aquifers, such as in Perlis, are mostly semi-confined aquifers and determination of the saturated thickness of the aquifer is not difficult as the phreatic level is fairly accurately known. Furthermore the pumping test data categorically indicate the zone of maximum discharge of water.

Conclusion

D.C. resistivity surveys using the Offset Wenner array show quite clearly the presence of karstic limestone aquifers in the areas from Beseri to Kaki Bukit. Karstic limestone aquifers seem to be the only source of groundwater in some areas of Perlis. Deep diamond drilling (depth $> 50$ m) should be able to strike water in the potential karstic limestone aquifers.

The empirical relationship between corrected transverse resistance and transmissivity is valid only for limestone aquifers in the area considered. We find that this relationship depends, besides other factors already mentioned by Ponzini et al (1984), on the degree (or amount) of karstification of limestone beds. We believe a separate relationship might hold for aquifers in and around the Arau area where porewater resistivity is considerably lower.

Acknowledgement

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REFERENCES


