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TIME VARIATIONS OF THE RESISTIVITY IN A LAYERED STRUCTURE WITH UNCONFINED AQUIFER*

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ABSTRACT

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During a ten months period a series of 10 Schlumberger V.E.S. have been executed in a spot of the Palermo coastal plane upon a layered structure with unconfined aquifer in order to study the time variations of the shapes of the curves and their interpretations obtained by means of a computerized indirect method. Meanwhile the stratigraphy and the different hydrological conditions have been examined by means of a water well, and also the rainfall has been measured in the same period. The interpretation of the V.E.S., carried out with the help of many geological and hydrological data, has shown a six-layer electrostratigraphy, while the time behaviour of the interpreted resistivities presents large variation coefficients for some layers. These variations have been connected with the different conditions of the water contents of the rocks, showing a good correlation, except for the water-bearing layer, the resistivity variations of which have been ascribed both to small errors due to different locations of the electrodes and to instrumental ones. Finally, the reliability of the V.E.S. for a systematic control of the hydrological behaviour of the water-bearing aquifer is discussed.

INTRODUCTION

This work has been carried out in order to study the possible variations in the shapes of the V.E.S. curves — and, consequently, in their interpretations — due to different sources of errors and/or to the variations of the physical conditions of the involved geological formations.

For this purpose a geologically known area in the Palermo plane has been chosen, where a layered structure with unconfined shallow aquifer is present and observable by means of a large water well.

In a spot of this area, a series of periodically executed V.E.S., during a

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one-year period, has been planned, and the hydrological conditions have been regularly checked in order to study their connections with the resistivity of the various formations.

Unfortunately, the increasing urbanization of the Palermo coastal plane has touched the area of investigation so as to prevent the possibility of carrying out the last two V.E.S. Therefore, a ten-months period, from August 1976 up to May 1977, has been considered for the study of the hydrological conditions.

However, the results obtained seem to show useful indications for the planning of a systematic control of the hydrological behaviour of the water-bearing aquifer.

FIELD WORK

The spot of the Palermo coastal area which has been chosen for the investigation is located 13°19′57″E and 38°05′38″N. Here there is an old hand-sinked water well, 19 m deep, square shaped, with 2 m side.

In the well, unused in the last two years, it is possible to observe the stratigraphy (Fig. 1), which generally is regular in the Palermo coastal area, as well as the phreatic level of the water in the shallow aquifer represented by the calcarenites.

In fact the thin limestone layer is not very permeable and the clayey formation is the impermeable bed of the water-bearing stratum.

At a distance of about 20 m from the well, 10 V.E.S. have been carried out, from August 3, 1976 up to May 5, 1977, with a periodicity of about one month.

The V.E.S. have been executed using the Schlumberger array, 60°E oriented, with AB_{max} = 280 m, 13 measured apparent resistivity values for every logarithmic decade, and three-point matchings. The topographic situation is flat enough (± 1m), while the errors in the location of the electrodes have been kept within 0.5% for the distances and within ± 0°30′ for the central angles, so that the possible topographic errors on the apparent resistivity would be less than 1%.

During the period of investigation the phreatic level has been checked in the well, the rainfall in the surrounding area has been recorded, and the water resistivity has been measured in connection with the execution of the V.E.S. This last seems to be relatively constant in time, with an average value of 11.58 Ohm.m and a variation coefficient of 12.24%. The variations of the water resistivity do not seem to be easily correlable with hydrological and geological phenomena, so that they have been ascribed to random artificial or natural perturbing factors and/or to measurement errors.

The graphs of the V.E.S., after the matching operation, are presented in Fig. 2. It is possible to observe that the differences are mostly concentrated in the first part of the curves.

The variation of the rainfall is plotted in Fig. 3: as a rule, in regions with

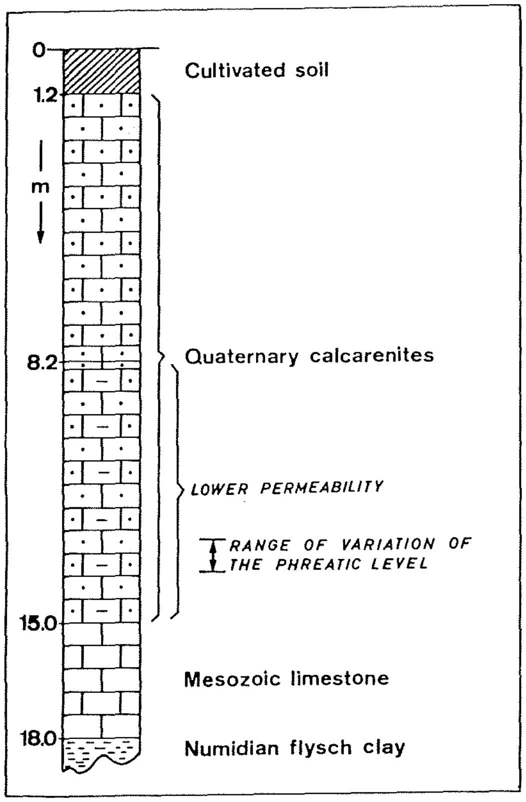

Fig. 1. Stratigraphy observable in the water well located in the area of investigation. The limestone layer is not very fractured so that it is practically impermeable.

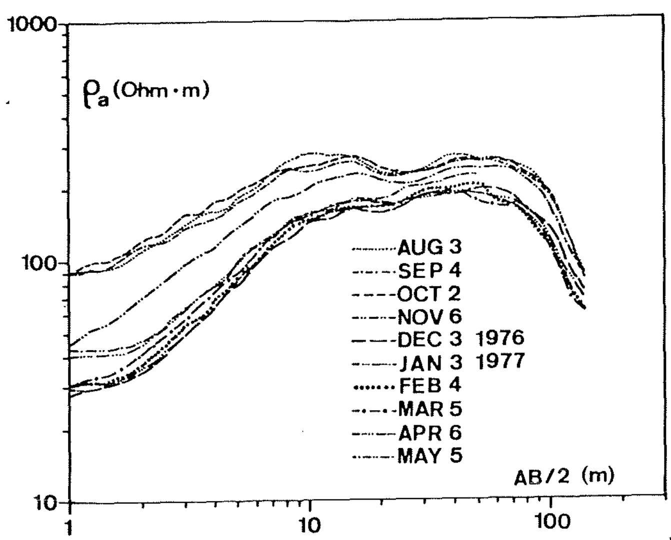

Fig. 2. Curves of the V.E.S. carried out in the same spot and in the same direction during a ten-month period. The stretch of the curves have been shifted according to the best matching.

warm temperature climate characterized by summer drought the rainfall is concentrated in the October—March period, while a scarcity of rainfall is evident in the January—March period in Fig. 3.

In Fig. 4 the behaviour of the phreatic level of the shallow aquifer during the period of investigation is presented. It is possible to notice large exploitations in August and October.

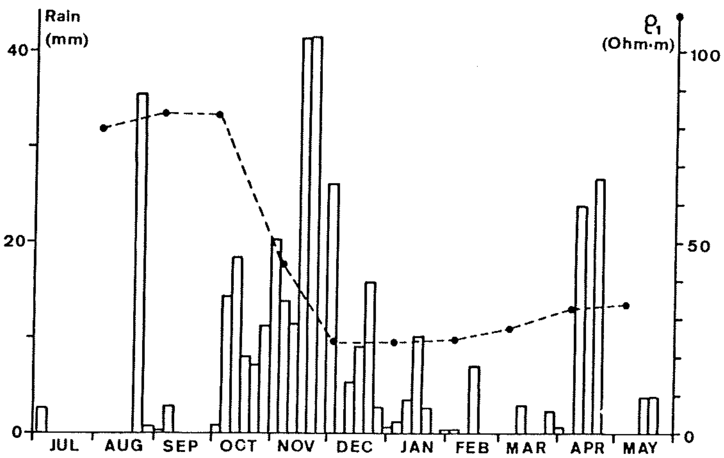

Fig. 3. Time behaviour of the rainfall in the area of investigation during the considered time period (left) and ρ_1 resistivity estimated values (right).

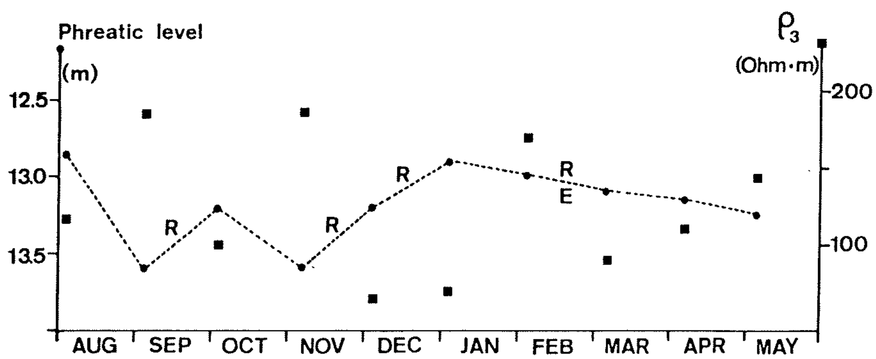

Fig. 4. Time behaviour of the phreatic level of the shallow aquifer (left) and ρ_3 resistivity estimated values (right). R = recharge; E = exploitation.

INTERPRETATION

The interpretations of the V.E.S. have been executed by means of an IBM 370/145 computer (I.E.I. and Pisa University) using an indirect interpretation method (Cecchi et al., 1977).

The well known geological situation and the inspection of the well have allowed to emphasize the importance of the "geological concept" (Flathe, 1976).

As a matter of fact, the known parameters, i.e. the thickness of the layers observable in the well, have been constrained during the interpretations, as well as the resistivity of the clayey formation, which has been considered steady in the time.

The results obtained are shown in Table I, where the sum of the error squares and the standard deviation of the measured apparent resistivities are also indicated. Of course these quantities would be lower without any constraining procedure, but this would be to misinterpret some lateral heterogeneities and/or some measurement errors.

Probably minor variations of the thickness of the hydrologically active layers could be assumed in a second-order interpretation, with the help of other more sophisticated procedures.

In Table I the average values of the resistivities ρ_i and their variation coefficients σ/ρ_i are also indicated. It can be noticed the relatively high stability ($V = 6.8\%$) of ρ_2 (high permeability calcarenite formation) and ρ_5 (limestone formation), while large variations are observable for ρ_1 ($V = 53.7\%$, cultivated soil), ρ_3 ($V = 34.9\%$, lower permeability calcarenites) and ρ_4 ($V = 28.6\%$, water-bearing calcarenites).

In order to interpret these variations some correlations have been attempted.

So, in Fig. 3 the behaviour of ρ_1 has been correlated with the rainfall during the same period: the dependence of ρ_1 on the rainfall is evident, as it would be natural to expect. In fact the high resistivity in August, September and October was due to the drought of the cultivated soil overburden, while the large amount of rain in October and November has produced a lowering of ρ_1. The moderate rainfall of December and January has caused the steady low values of ρ_1, while the very poor rainfall of February and March has given rise to an increase in the resistivity in spite of the irrigations which have been indispensable for the agriculture, unusual for this period of the year.

Finally, the trend of ρ_1 to increase towards the summer values has been temporarily reduced because of the unusually large amount of rainfall in April.

In Fig. 4 the behaviour of the resistivity ρ_3 during the period of investigation is plotted with the phreatic level of the water-bearing formation. It is possible to observe three periods of total recharge in September, November and December, respectively caused by the rainfall of August—September, October—November and November—December, while the recharge in February, caused by the December—January rainfall, is masked by the unusual exploitation in this period due to the exceptional drought and to the necessity of artificial irrigations. The lowering of the resistivity ρ_3 after the recharge periods should be noted.

TABLE I

Resistivity and thickness interpreted values and mean values

V.E.S.	ρ_1 (Ohm.m)	h_1 *1 (m)	ρ_2 (Ohm.m)	h_2 *1 (m)	ρ_3 (Ohm.m)	h_3 *1 (m)	ρ_4 (Ohm.m)	h_4 *1 (m)	ρ_5 (Ohm.m)	h_5 *1 (m)	ρ_6 *1 (Ohm.m)	E.S.S.	S.D.
Aug. 3, 1976	79.61	1.2	351	8.0	120	4.7	50.7	2.1	3800	3.0	0.7	0.1572	0.1195
Sep. 4, 1976	83.60	1.2	323	8.0	187	5.4	25.0	1.4	3814	3.0	0.7	0.1423	0.1140
Oct. 2, 1976	83.24	1.2	343	8.0	100	5.0	66.0	1.8	3800	3.0	0.7	0.1598	0.1205
Nov. 6, 1976	44.30	1.2	350	8.0	187	5.4	25.0	1.4	3800	3.0	0.7	0.1210	0.1048
Dec. 3, 1976	23.96	1.2	344	8.0	66	5.0	59.0	1.8	3800	3.0	0.7	0.2080	0.1375
Jan. 3, 1977	23.84	1.2	350	8.0	69	4.7	50.0	2.1	3800	3.0	0.7	0.3068	0.1670
Feb. 4, 1977	24.41	1.2	374	8.0	170	4.8	50.0	2.0	3330	3.0	0.7	0.4099	0.1930
Mar. 5, 1977	27.60	1.2	342	8.0	90	4.9	35.8	1.9	3600	3.0	0.7	0.4727	0.2073
Apr. 6, 1977	32.64	1.2	322	8.0	109	5.0	57.9	1.8	3086	3.0	0.7	0.1829	0.1289
May 5, 1977	33.97	1.2	288	8.0	143	5.1	57.5	1.7	3419	3.0	0.7	0.0742	0.1029
$\bar{\rho}$(Ohm.m)	45.72		340		124		47.7		3625				
V(%)	53.7		6.8		34.9		28.6		6.8				

*1 Imposed values. E.S.S. = error squares sum; S.D. = standard deviation; $V = \sigma/\bar{\rho}$ = variation coefficient.

This can be interpreted as follows: the high permeability calcarenites, characterized by relatively steady ρ_2 values, rather rapidly transmit the water to the layer below, which is characterized by a lower permeability so that it roughly acts as a "flywheel" for the recharge, and it keeps low resistivity values for a longer period because of the retained moisture.

The large variation coefficient of the resistivity ρ_4 (water-bearing calcarenites) is not easily interpretable. In fact the variations of the water resistivity, even if real, have certainly been much lower, so that the behaviour of ρ_4 would be rather considered as due to random errors. Actually, it can be observed that the intrepretation in the portion of the curves related to ρ_4 is very critical, so that both small measurement errors and small lateral heterogeneities can highly bias the estimates of the ρ_4 values.

CONCLUSIONS

The investigations carried out in this work emphasize the interesting role that resistivity prospecting can play in hydrological studies.

As a matter of fact, by means of a careful and suitable periodical resistivity prospecting surveys much direct information about the recharge of groundwater can be obtained, provided that a good knowledge of the geological, hydrological and geophysical situation is available.

So, this role, which would be included, at least in particular stituations, among the possibilities of the resistivity prospecting (Van Dam, 1976), can be extended and the time behaviour of the V.E.S. can be inserted in the planning of the study and the control of the groundwater regimes.

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