J KAU: Earth Sci., vol. 6, pp 35-45 (1413 A.H. / 1993 A.D.)

An Application of True Resistivity Contour Sections in Groundwater Exploration (A Case History)

HAMDY S. SADEK, HASSAN M. ABDELHADI and SALAHELDIN A. SOLIMAN
Nuclear Materials Authority, Egypt

ABSTRACT. A resistivity survey was conducted in the vicinity of El Sadat City in the Western Desert of Egypt as a part of an exploration program for groundwater resources in this district. The survey consisted of 12 vertical electrical soundings (VES) distributed along three profiles. The Schlumberger probe configuration was used with a maximum electrode spacing of about 2 km and density of measurements of 7 per decade. The resistivity measurements of each sounding were subjected to automatic reduction and analysis using modern software of two methods which allow the calculation of a layering model as well as an n-layers model. Three subsurface true resistivity contour sections were constructed along the profiles using the n-layers models of the soundings located on each profile. Meanwhile, subsurface resistivity bar sections were also constructed along the same profiles using the layering models of the respective soundings.

The subsurface true resistivity contour sections were successfully employed to obtain more precise interpretation of the corresponding subsurface geological layers and the water-bearing formation compared with that provided by the traditional bar sections. In addition, the contour sections provided valuable information about the lithological variations within the subsurface geological and hydrological units. In this respect, it was possible to map a number of clay lenses as well as gravel rich zones in the discovered water bearing formations. The conclusions reached from this interpretation, were confirmed by the subsequent drilling, based on the present study. A heavy duty water well field was constructed in the investigated area to supply El Sadat City with most of the present water needs for domestic uses (about 40,000 m/day).

Introduction

In the last two decades, an extensive effort has been paid to improve the precision of interpretation of resistivity data using the automatic inversion methods. In this respect, many styles of data analysis and geoelectrical modeling techniques have been tested, accepted or discarded. The algorithm, and sometimes the computer software of most of these methods are discussed in several publications (e.g. Koefoed 1979). Most of these methods provide an equivalent geoelectrical model for each sounding curve and a subsurface true resistivity bar section along a profile which includes a number of soundings. In the present time, this style of resistivity analysis is the most simple and widespread specially when dealing with the interpretation of an individual sounding. However, it still lacks the mode of continuity necessary for the precise interpretation of a multi sounding profile. Such mode of continuity can be only reached through a subsurface resistivity contour section or map built from continuous or semicontinuous true resistivity data located at appropriate depths beneath each sounding. In the past, many investigators used the subsurface pseudo-resistivity contour sections and maps constructed from the apparent resistivity measurements of soundings located at appropriate spacing. However, their interpretation is rather complex since the depths and resistivity values are not true and do not allow reliable quantitative interpretation.

One of the most interesting automatic methods of sounding analysis is the Zohdy method (Koefoed 1979) which is based on the modified Dar Zarrouk function (Zohdy 1975). The geoelectric layering model (n-layers model) offered by this method for a sounding curve presents a semicontinuous sequence of true resistivities in depth. Therefore, the models of a number of soundings, located at appropriate spacing on a profile, can be successfully employed to produce a subsurface true resistivity contour section beneath the profile. Moreover, this method offers a reliable base for constructing subsurface true resistivity maps at selected depths for a group of soundings distributed along several profiles when the sounding spacing is convenient. Another advantage of this method is that it does not require a suggested input model to start the automatic iteration for calculating the final model as the other methods do. Instead the number of current electrode spacings in a sounding is considered as the number of layers while the apparent resistivity values are considered as the equivalent input resistances for each layer. The only reason that this method is not of wide use is that the preparation of true resistivity contour sections from the sounding models requires a certain experience, while the interpretation of these sections requires a considerable skill.

This paper presents an example on the application of this method during a groundwater exploration program executed in the district of El Sadat City in the Western Desert of Egypt (Fig. 1). The project was contracted by the Nuclear Materials Authority (NMA) from the Egyptian Authority of New Urban Communities. The first phase of exploration included the conduction of 12 vertical electrical soundings (VES) using Schlumberger array. The sounding sites were distributed at suitable spacing along three parallel profiles in the northeastern part of the district. The sounding data were analysed using a computer software which provides the equivalent n-layers model as well as the conventional layering model for each sounding, based on the methods suggested by Zohdy (1975) and Parasnis (1979) respectively. The two sets of models were used to produce the corresponding subsurface true resistivity sections and the resistivity bar sections for each surveyed profile. The interpretation of both sets of sections lead to the discovery of a considerable groundwater aquifer in a thick Pleistocene section of sand and gravel facies. In addition the contour sections were successfully employed to reveal more information about the subsurface lateral variations such as gravel channels and clay lenses. They better revealed the aquifer configuration in terms of precise depth to water table, thickness of the water bearing formation and outlines of the base formation. The subsequent drilling, based on the present study, confirmed most of the previous conclusions and resulted in the implementation of groundwater field of heavy duty wells with total capacity of about 40,000 m^3/day which covers most of the water needs in El Sadat City.

Geology

The West Delta Region is covered by a succession of sedimentary rocks (Fig. 1) ranging from Quaternary to Tertiary (Said 1962) and can be divided into three main lithological units.

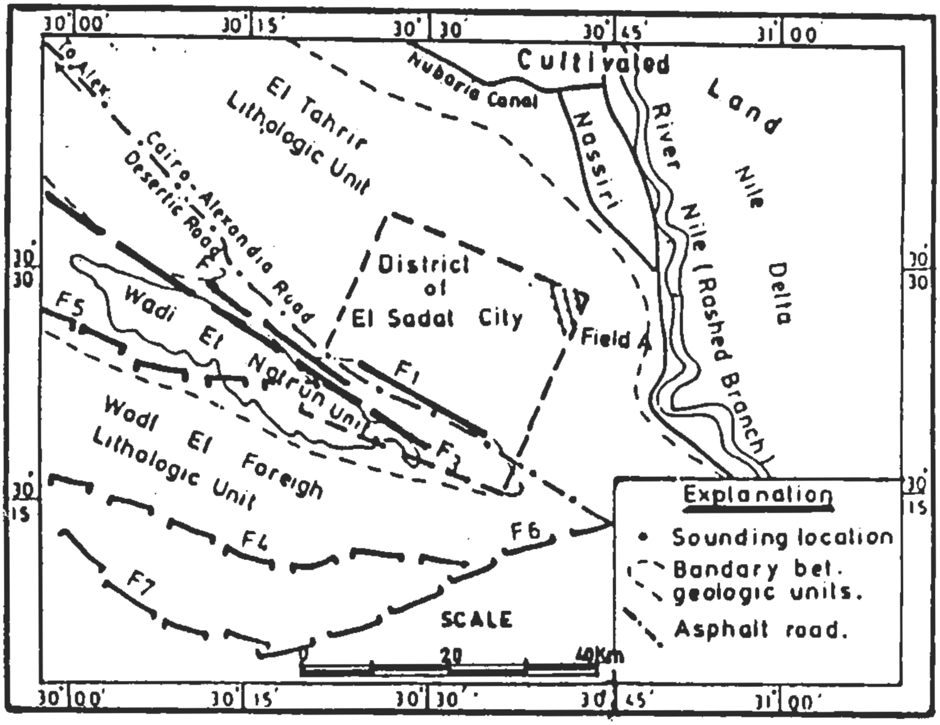

FIG. 1. Index map showing location, geology and hydrology of the West Delta Region as well as the surveyed part.

The Tahrir lithological unit, in the north, is covered by thick Pliestocene deposits which are essentially developed into sand and gravel facies frequently intercalated with clay lenses and gravel terraces. The whole section is based by a thick plastic

Pliocene clay layer (Cairo University 1985). The thickness of the Pleistocene section ranges between 300 m, near the Delta, to about 80 m, near Wadi El Natrun. Wadi El Natrun lithological unit, in the middle of the region, is covered by the Miocene deposits which are essentially sandstones of the Moghra formation intercalated with clays, sands and gravel. Wadi El Fareigh lithological unit, in the south, is covered by Oligo-Miocene deposits which ranges from the Miocene Moghra formation to the Oligocene coloured clays, sands, silt and sandstones with basalt sheets and fossilliferous wood. The main structural features are two sets of northwest and northeast trending faults in the south of the area.

Hydrology

The climate of the West Delta Region is almost arid however, limited rainfalls rarely occur in the winter. The topography of the district of El Sadat City is not rugged but relatively elevated over the plains in the Nile Delta by few tens of meters. The groundwater in the district is originated from two main sources; the fresh aquifers in the Nile Delta and the limited rainfalls which frequently occur. The groundwater reservoires in the Nile Delta are continuously charged with fresh water which sinks from the irrigation and drainage systems in the Delta are expected to circulate a considerable amount of this water through the porous Pleistocene section since the two units are believed to be in a hydraulic connection (Cairo University 1985). It is believed that a groundwater circulation from the Nile Valley along the fault planes f_1, f_2, f_3, f_4, f_5, f_6 allows the water charged of the porous formations in Wadi El Natrun and Wadi El Fareigh units (Fig. 1). It is also believed that the limited rainfalls (estimated as few millimeter/year) have insignificant contributions to the groundwater potentiality in the West Delta Region.

Geophysical Survey

Twelve sites were selected along three profiles to conduct Schlumberger vertical electrical sounding (VES) survey in the northeastern part of the district of El Sadat City (Fig. 1). The VES specifications were selected as 7 measurements/decade and half the current electrode spacing (AB/2) ranges from 1 m to 1 km in order to obtain reasonable data continuity and considerable depth penetration. The instrument used in the survey is a 750 watts modern resistivity meter model Syscal-R2 (a B.R.G.M. made) with a microprocessor and RS-232C interface to link the survey equipment with a field computer model HP-85 where the field data are analysed.

Sounding Analysis

The automatic analysis of the sounding curves was achieved using the software of two methods operated by the field computer. The first method is the Zohdy method (Koefoed 1979) which is based on the modified Dar Zarrouk function, suggested by Zohdy (1975) to analyse the sounding curve in an equivalent n-layers model. This model consists of a number of horizontal geoelectric layers comparable with the number of measurements which describe the sounding curve. The method does not require a suggested input model since the sample values on the apparent resistivity curve are taken as the first approximation of the layering model and the final model is reached after applying successive modifications on the resistivities and thicknesses of the model layers through a number of iterations. A Basic computer software was modified from a previous program, written by Zohdy (1974), to allow the user to carry out the sounding analysis using a field computer with a limited core memory. The program uses the coefficients of the linear filter suggested by O'Neill (1975) to calculate the resistivity curve. An example of the sounding analysis, using the modified computer software operated on a field computer model HP-85, is illustrated in Fig. 2. The resulted model for each sounding was plotted beneath the sounding site where each geoelectric layer is represented by a resistivity value located at a point at the mid-depth between the upper and lower surfaces of this layer. Finally, the subsurface resistivity values were contoured in the vertical plane beneath three profiles along which a number of soundings are arranged at reasonable spacings (Fig. 3). In addition, horizontal subsurface resistivity contour sections, at depths of 20, 40, ... 120 m below the surface were prepared from the resistivity models of all the soundings (Fig. 4).

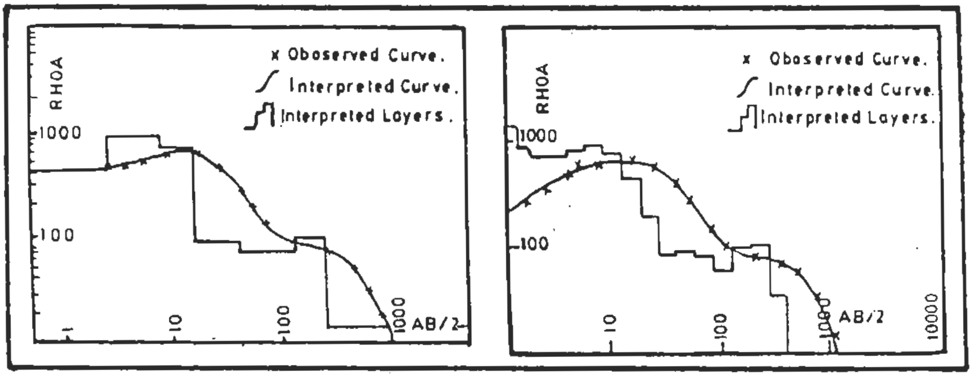

FIG. 2. Example on the sounding analysis of VES-7 using; (a) layering model, (b) n-layers model.

The second method is based on the solution suggested by Parasnis (1975) for the following equation which describes the apparent resistivity curve.

$$\rho_r = r^2 \int_0^\infty \tau(\lambda)\, J_1(\lambda)\, \lambda\, d\lambda$$

where AB is the current electrode spacing, r = AB/2, $J_1(\lambda)$ is the first order Bessel function and $\tau(\lambda)$ is the resistivity transform. The solution was programmed in Basic by the ABEM (a Swedish Corp.) using the linear filter suggested by Ghosh (1971). The computer program, which can be operated on a field computer, requires a suggested input layering model. This initial model is modified in, resistivities and thicknesses through a number of iterations until the best fit between the calculated resistivity of the model and the sounding curve is obtained. An example, applied to a field sounding curve, is illustrated in Fig. 2. The final layring models of the soundings

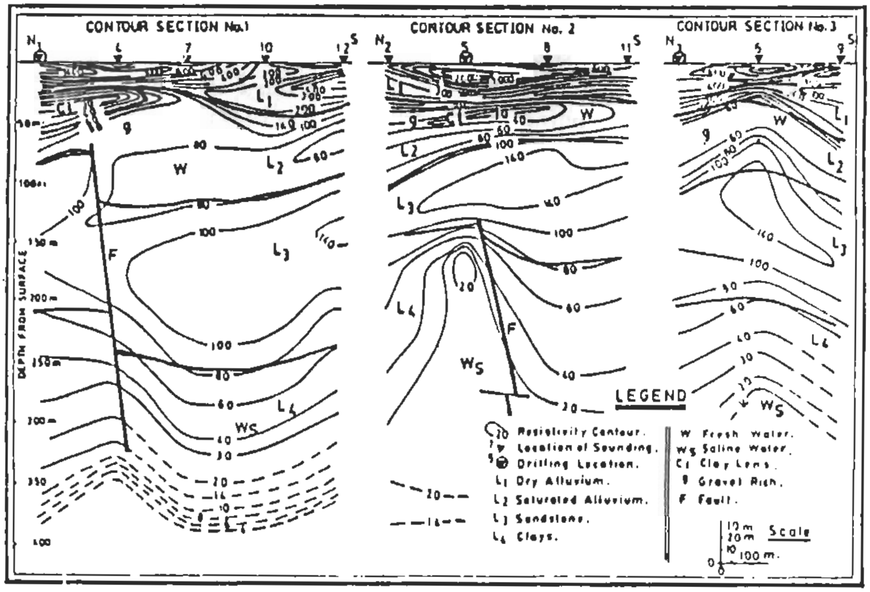

FIG. 3. Subsurface true resistivity contour sections along 3 profiles with the interpreted geology superimposed.

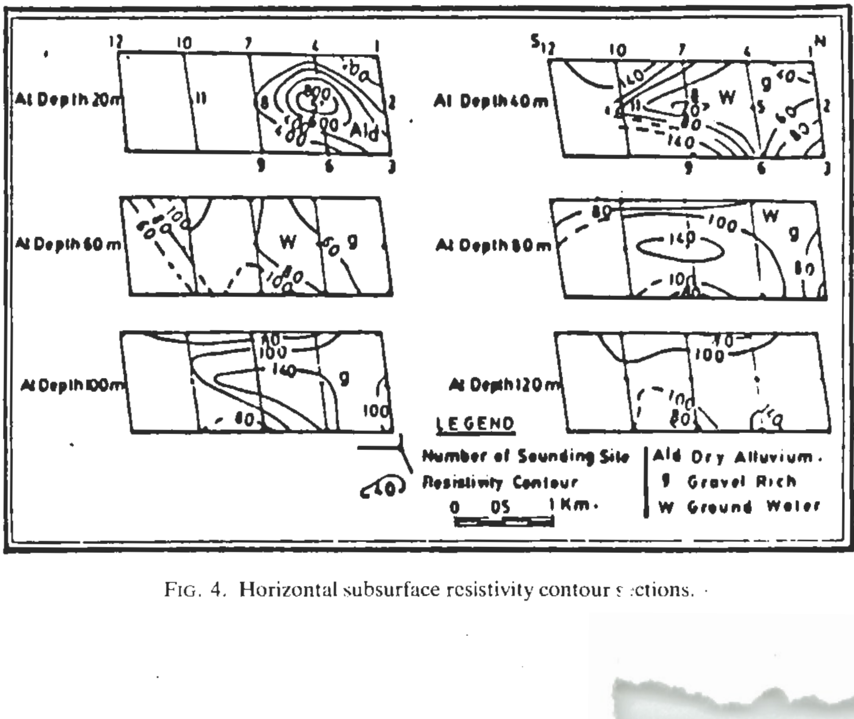

FIG. 4. Horizontal subsurface resistivity contour sections.

were used to prepare the resistivity bar sections along the subsurface of the same profiles (Fig. 3).

Interpretation

The interpretation of the VES data was achieved using the subsurface resistivity contour sections which reveal the vertical and lateral variations in the resistivity of the investigated area. Such interpretation can better distinguish the subsurface configuration of the different formations and the groundwater occurrences that may exist in the surveyed part.

Subsurface Resistivity Contour Sections

The interpretation of the vertical subsurface resistivity contour section (Fig. 3) was carried out after the careful examination of the resistivity contour behaviour. The contour gradient was used to locate the boundary between two geoelectric layers, while the closed contour was used to described the thickness of any interpreted layer. Using this criteria, it was posible to obtain an equivalent subsurface geoelectric configuration which can be expressed by the lithologic model superimposed on the contour sections (Fig. 3). It is clear from the model that the groundwater occurs in two separate aquifers separated by an impervious layer. The shallow aquifer lies in the porous Pleistocene formations at a depth ranging from 20 to 30 meters having an average thickness of about 70 meters. The resistivity values within this aquifer ranges from 35 to 60 ohm m which may suggest that the groundwater in this formation is almost fresh. The deep aquifer occurs at depths of about 200 m where it exists within the plastic Pliocene clay layers and the formations beneath it. The relatively low resistivity values in this zone suggest that the groundwater in this aquifer aquired high salinity which confirms with the previous investigations which pointed out that a huge saline old marine fossil water occurs at depths greater than 200 m in many parts of the Western Desert of Egypt. The sections also demonstrated the lateral lithologic variations, such as gravel rich channels and clay lenses, within the Pleistocene formations.

Horizontal subsurface contour sections which cover the investigated area were constructed at different levels to recognize the gravel rich portions in the saturated part at different depths. The sections (Fig. 4) reveal that the northwestern part of the area (beneath the soundings 2, 3, 4 and 5) may represent the gravel rich section in the investigated area. Drill hole sites were recommended in this part to investigate the best groundwater potentiality within the water saturated formations.

Subsurface Resistivity Bar Sections

The subsurface layering of the different sections was obtained by the lateral interpolation between the sounding layers which have comparable resistivity. The sections reveal the occurrence of the two aquifers, however, the resolution of the configuration of the shallower one is poor compared with that inferred from the contour section. Besides, the lateral variations within the saturated formation, can not be distinguished from these sections (Fig. 5).

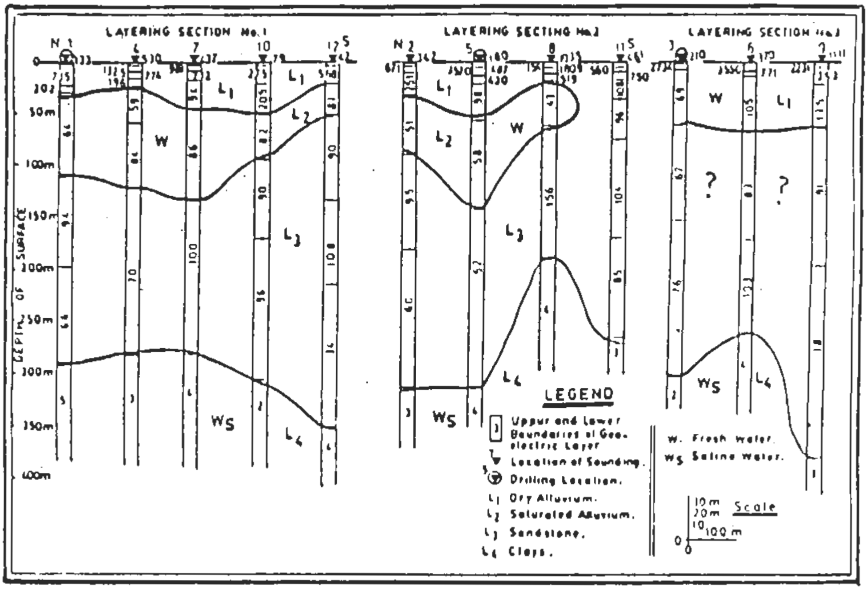

FIG. 5. Subsurface resistivity bar sections with the interpreted geology.

The subsequent exploration drilling based on this study in the sounding sites 1, 3 and 5 resulted in the discovery of a fresh groundwater aquifer with a thickness ranging between 60-90 m of Pleistocene formations. The discovered groundwater is believed to represent a part of a huge aquifer in the Pleistocene section which originates from the Nile Delta. Water wells of heavy duty production are currently constructed in the surveyed area to supply El Sadat City with about 40,000 m^3/day.

The geological and geophysical logs of water well A3 (Fig. 6) were correlated with the previous geophysical interpretation of the sounding data in this location. The depth to water table (about 20 m) and the thickness of the saturated section (about 100 m) show excellent correlations with the corresponding values obtained from the previous interpretation. The most conspicuous feature is the presence of gravel rich part (sandy gravel in Fig. 6) in the saturated section with about 35 m thickness at depth of about 100 m which was also expected from the interpretation of the sounding data. It should be pointed out that most of the water discharge in water well A3 is supplied by the gravel rich part of the saturated section where the well can produce about 250 m^3/hour. The drilling data of the rest of the water wells constructed in the study area provided geological and hydrological information which confirm well with the previous interpretation of the sounding data.

Conclusion

The previous discussion demonstrated that the subsurface resistivity contour sec-

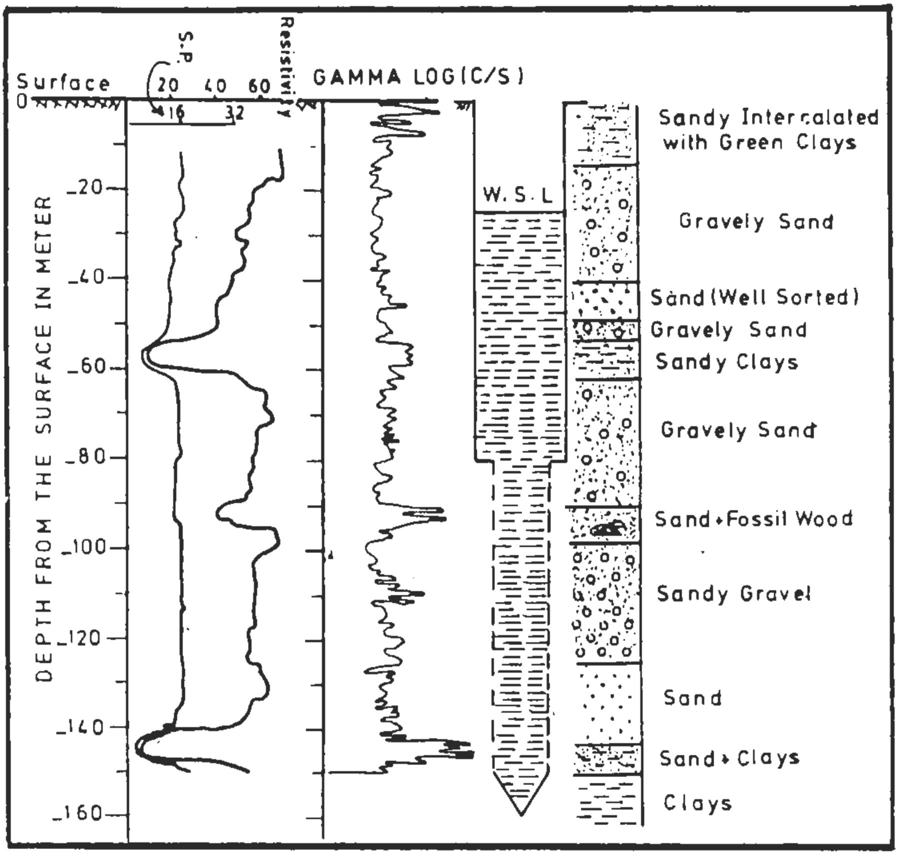

FIG. 6. Geological and geophysical logs of the water well A3, in the site of VES-3, in Field A, El Sadat City.

tions have several advantages over the other equivalent sections constructed from the traditional layering methods of sounding analysis. Among other advantages, they better reveal the aquifer configuration, the lateral variations within the different subsurface layers and the local subsurface structures.

References

Cairo University (1985) *A hydrogeological study of El Sadat City district*, Development Research and Technical Planning Center, Internal Report, 86 p.

Ghosh, D.P. (1971) Inverse filter coefficients for the computation of apparent resistivity standard curves for a horizontally stratified earth, *Geophys. Prosp.* **19:** 769-775.

Koefoed, O. (1979) *Geosounding principles*, Amsterdam, Elsevier Publishing Company, 276 p.

O'Neill, D.J. (1975) Improved linear filter coefficients for application in apparent resistivity computation, *Bull. Aust. Soc. Exp. Geophys.* **6:** 104-109.

Parasnis, D.S. (1979) *Principles of Applied Geophysics,* London, Chapman and Hall.
Said, R. (1962) *The Geology of Egypt,* Amsterdam, Elsevier Publishing Co. 377 p.
Zohdy, A.A. (1974) A computer program for automatic interpretation of Schlumberger sounding curves over horizontal stratified media, *U.S. Geological Survey Report, USGS,* **GD-74-017,** PB 232703, 116 p.
Zohdy, A.A. (1975) Automatic interpretation of Schlumberger sounding curves, using modified Dar Zarrouk functions, *US Geological Survey Bull. 1313-E,* 39 p.

تطبيـــيق لقـــطاعات المقاومـة الكهربائيـة الحقيقيـة في استكشاف المـــياه الجوفيـــة (حالة تاريخيـــة)

حمدي س. صادق ، حسن م. عبد الهادي و صلاح الدين أ. سليمان
هيئة المواد النووية ، جمهورية مصر العربية

المستخلص . لقد تم إجراء مسح المقاومة الكهربائية بجوار مدينة السادات في صحراء مصر الغربية كجزء من برنامج استكشافي لموارد المياه الجوفية في هذه المنطقة . ولقد شمل المسح إجراء ١٢ جسة كهربائية عمودية موزعة على ثلاثة قطاعات . وتم استخدام توزيع شلمبرجير حيث بلغ أقصى بعد لقطبي التيار ٢ كم ، وبلغت كثافة القياسات ٧ في الدورة العشرية الواحدة . ولقد تم تصحيح وتحليل القراءات لكل جسة آليًا باستخدام حزم برامج كمبيوتر حديثة بطريقتين تسمحان بحساب نموذج الطبقات وكذلك نموذج آخر للطبقات المتعـددة . وكـذلـك تم إعـداد ثلاثة قطاعات كُنتورية تحت سطحية للمقاومة الحقيقية باستخدام نماذج الطبقات المتعددة للجسات الواقعة على كل قطاع .

ولقـد استخـدمت القـطاعات الكُنتورية تحت السطحية للمقاومة الحقيقية بنجاح في التفسـير الأكثر دقة للطبقات الجيولوجية المكافئة والتكاوين الحاملة للمياه وذلك بالمقارنة لتلك التفسـيرات التقليدية التي يتم الحصـول عليهـا من قطاعـات أعمـدة المقـاومـة . وبـالإضـافة إلى ذلك فلقد أوضحت القطاعات الكُنتورية معلومات قيمة عن التغيرات الصخرية في الوحدات الجيولوجية والهيدرولوجية تحت السطحية . وفي هذا الخصوص فلقد كان من الممكن تحديد عدد من عدسـات الـطفلة وقطاعات غنية بالحصى في المكونات الحاملة للمياه . ولقد تأكدت النتائج التي تم الحصول عليها من هذه التفسيرات من الحفر الذي تم اقتراحه من هذه الدراسة . وبالتالي أُنشيء حقل آبار ذات انتاجية عالية في منطقة الـدراسـة لإمـداد مدينـة السـادات بكـل احتياجاتها من المياه للأغراض المدنية (حوالي ٤٠,٠٠٠ متر مكعب يوميًا) .