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The Use of DC-Resistivity to Outline the Subsurface Hydrogeological and Structural Setting Beneath a Proposed Site for Subsurface Dam Building, Makkah Al-Mukarramah, Saudi Arabia

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Abstract. The present study is conducted in the down stream area of Wadi No'man, Makkah Al Mukarramah, Saudi Arabia. Wadi No'man is bounded by Gabal Kabkab from the north and Gabal No'man from the south; it discharges its water to the Red Sea. The area under investigation forms a part of the Arabian shield of the western Saudi Arabia. Accordingly, igneous and metamorphic rocks cover the study area. In the upstream of Wadi No'man, the escarpment is a conspicuous structural feature, besides; major and minor faults are dominant in Wadi No'man and adjacent areas.

Historically, Ain Zubida used to be the main groundwater source in the area. Intensive and uncontrolled discharge led to lowering the groundwater level. The aim of this study is to determine the main hydrological and structural setting beneath a proposed site of subsurface dam. The purpose of building the subsurface dam is to control the groundwater flow in this area to rise the water table in the area surrounding Ain Zubida galleries.

DC resistivity using profiling and vertical electrical sounding surveys was conducted for horizontal and vertical investigation of the hydrological and structural parameters beneath the study area. This method lead to the classification of alluvium, which covers the basement rocks but, according to the DC resistivity values, it is divided into two distinctive alluvial layers. The upper layer has relatively high resistivity values (dry alluvium) and the lower alluvial layer has relatively low values since it consists of moist alluvium. The middle layer

corresponds to the expected water saturated layer with the lowest resistivity values. Finally, at the bottom of the Wadi, the resistivity values increase due to the occurrence of the basement rocks which forms the Wadi basin.

Introduction

Along the past centuries, in many parts of the world, groundwater was transferred from its resources sites (up reaches of valleys) to the populated areas using rock lined surface and subsurface tunnels (galleries) known as Ains. Ain Zubida, east of Makkah Al-Mukarramah city is a famous example of these Ains. Wadi No'man, represents the main source of groundwater recharge to Ain Zubida galleries. High demand of water and uncontrolled and unregulated discharge of groundwater at different sites along the Wadi prevent the water to circulate through the galleries due to the decrease of the groundwater level. Therefore, there is a need to build a subsurface dam, in order to control the groundwater flow, which will raise the water level around Ain Zubida galleries. Accordingly, a proposed site for building a subsurface dam is suggested west of the main shaft of Ain Zubida (Fig. 1 and 2).

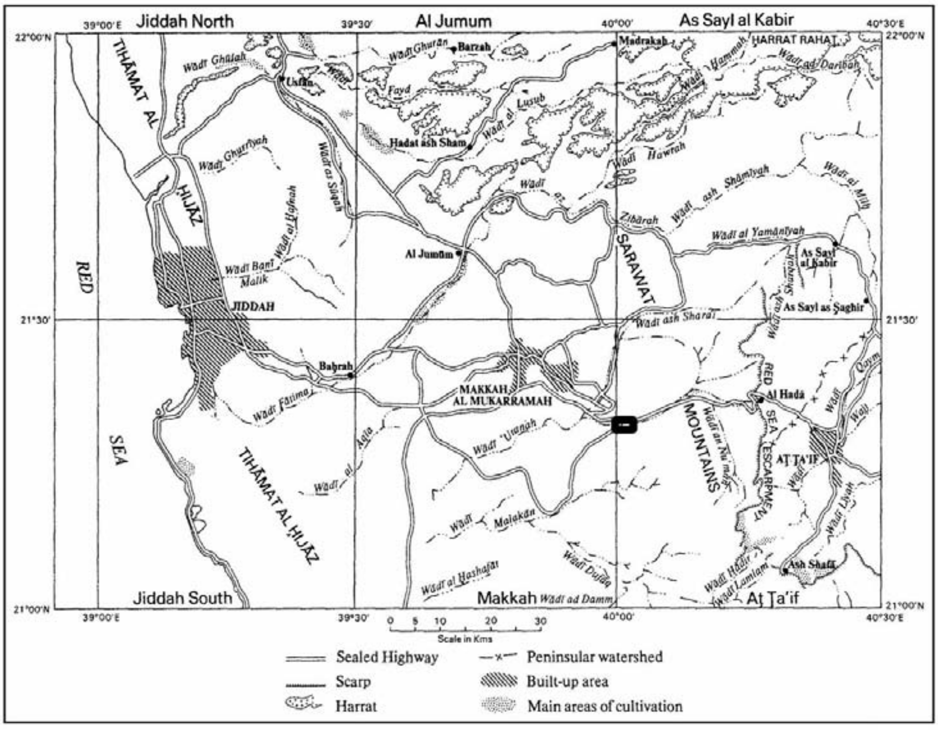

Fig. 1. Location of the study area.

Previously, many geological and geophysical studies were carried out along Wadi No'man (Jamaan, 1978, Mokhtar *et al*., 2003 and 2006). These studies delineate the subsurface structural setting of the area, between Wadi Rahjan and west of Arafat, allowing the storage of reasonable amounts of ground water. Accordingly, a subsurface dam is suggested at the west of this area to limit the groundwater flow and increase the water level in Ain Zubida.

This present study aims to determine the main hydrological and structural setting beneath the proposed site of the subsurface dam to provide necessary information for geotechnical engineers to build the subsurface dam. Geoelectrical method is suggested to be a successful technique in such targets.

Electrical prospecting methods are increasingly used for characterizing shallow geological targets, environmental and engineering applications as fluid migration (Park, 1998), detection of contaminants (Gofio and Naldi, 2003), mapping of internal landfill structures (Bernstone *et al*., 2000), imaging faults (Demanent *et al*., 2001) landslide investigations (Havinith *et al*., 2000) and imagining of engineered hydraulic barriers (Daily and Ramirez, 2000). One of the major reasons for using electrical resistivity is the broad range of resistivity values (Reynolds, 1997), allowing the potential discrimination between various geological materials or their conditions, including water content, fracturing, or contamination (Rey and Jongmans, 2006).

Accordingly, this present study used DC resistivity profiling and vertical electrical sounding surveys for horizontal and vertical investigation of the hydrological and structural parameters beneath the study area. This method lead to the classification of alluvium, which covers the basement rocks, according to the DC resistivity values.

DC resistivity profiling survey, using Wenner array, was conducted along 6 profiles and vertical electric sounding (VES) was conducted at 24 VES locations using Schlumberger array in order to cover the proposed area for the subsurface dam building. Data were processed and interpreted using the appropriate modern software and plotted in curves as well as geoelectric sections.

Geology of the Area

The geology of the area around the suggested dam site in Wadi No'man is shown in Fig. 2. The basement rocks encountered in the area are mainly granites and metagabbros which were mapped by Moore and Al-Rehaili (1989). Metagabbros are recorded mainly along the southern flank of Wadi No'man while granites occur along the northern flank; they extend further north and northeast, forming the huge mountainous block of Gabal Kabkab. The syn-tectonic granitic narrow zone lying in the vicinity of the main Wadi No'man is intensively sheared being deformed, foliated and lineated with remarkable preferred orientation of quartz, feldspars and mafic minerals. They show intrusive contact against the two mountainous blocks of syn-tectonic metagabbros encountered near the mouth of the wadi, and are themselves invaded by unmappable basic dyke swarms oriented in N-S to NNW-SSE and NE-SW to ENE-WSW directions.

Fig. 2. Geological setting around the study area (Mokhtar *et al*., 2006).

Along Wadi No'man, the area is covered by alluvial deposits, the main part of the flooded water is percolated through this alluvium.

The most important structural fabric elements observed in the study area (Fig. 2) are faults which show two main trends; ENE-WSW to E-W and NNW-SSE to N-S. These faults exhibit strike-slip sense of shear and are observed in the field and traced on the Landsat Thematic Mapper (TM). It is worth to mention here that horizontal displacements along most faults are too small to be detected in the field, except when faults cross dykes.

Faults could be classified in the area of study into two sets; ENE-WSW and E-W. The first set is represented by the inferred master fault crossing Wadi No'man. Basic dykes intruding the syn-tectonic metagabbros and possessing the same trend of Wadi No'man are dextrally displaced by the NNW-SSE faults. The second set is manifested by three conspicuous E-W faults encountered in the central and northern part of the mapped area.

The NNW-SSE to N-S faults are dominant if compared to the previously mentioned faulting trend, and are remarkably displacing the inferred Wadi No'man fault in a dextral-slip manner.

Geopysical Field Survey and Data Processing

In order to reach the goals of this study, DC resistivity using profiling and vertical electrical sounding surveys was conducted during horizontal and vertical investigations of the hydrological and structural parameters beneath the study area. This method lead to the classification of alluvium, which covers the basement rocks, according to the DC resistivity values. The survey equipment used is a modern 1200 Watts D.C. resistivity meter model ELREC-T (IRIS Instruments).

Resistivity surveys provide a picture of the subsurface resistivity distribution which corresponds to the subsurface geological picture, some knowledge of typical resistivity values for different types of subsurface materials and the geology of the area under investigation which still require information.

Electrical resistivity surveying is a procedure that introduces direct current into the ground through surface electrodes, it provides and measures the potential difference which can then determine the subsurface resistivity distribution.

Profiling Electric Survey

Profiling resistivity surveys can be employed to detect lateral variations in resistivity. This type of survey, provides estimates of the spatial variation in resistivity at some fixed electrode spacing (Zohdy *et al*., 1974).

For a Wenner survey, the two current electrodes and the two potential electrodes are placed in line equidistant from one another and centered on certain location. After making a measurement, we would have to move all four electrodes to new positions. When the resistivity methods are employed to find vertical structures, one would typically use resistivity profiling.

Accordingly, the geologic structures which involve a vertical boundary between two different resistivity materials would be observed using a Wenner array as the array is moved from one side to other. If the electrode array is far away from the vertical fault, the measured apparent resistivity corresponds to the resistivity of the underground rocks. As the array approaches the fault, the resistivity varies in a discontinuous fashion. That is, the change in resistivity with electrode position does not vary smoothly but abruptly. The discontinuities in the resistivity profile correspond to array locations where electrodes move across the fault.

If the vertical feature does not extend to the surface, the electrode spacing must be large enough to induce sufficient electrical current to depths below which the vertical contrast exists. Usually, electrical soundings is conducted on both sides of the vertical structure that you wish to map.

This type of electric survey aims to investigate the lateral variation in electrical properties which are mainly related to the other physical and structural parameters of the soil for limited depth along the profile extension. Profiling electrical sounding survey was conducted using Wenner array which is used for its advantages in such type of surveys. This array is characterized by its sensitivity for vertical variation in the subsurface reisistivity below the center of the array. However, it is less sensitive to horizontal changes in the subsurface resistivity. The median depth of investigation of this array is approximately 0.5 times the "a" spacing used (Loke, 2000). Also, the Wenner array has the strongest signal strength; therefore, it is the most appropriate array for DC-resistivity survey in the area under investigation.

In this study, six profiles were conducted, one of these profiles is conducted across the wadi strike at the narrowest distance between the two wadi flanks overall the area under investigation Fig. (3). Many trials are performed along this profile using different electrode spacing (a) of 10,30 and 50m, to define the structural variations across the wadi strike and the effective depth in the area under investigation. The other 5 profiles extend from east to west along the surface of the area under investigation using relatively wide electrode separation (100 m) to investigate the deeper structural variations all over the area to a certain depth that includes most of the lateral and vertical structural variations. The data were presented as resistivity curves (Fig. 4 and 5) and compiled on one sheet to obtain the resistivity contour map (Fig. 6).

Vertical Electrical Sounding Method

Resistivity sounding is the method of survey which is designed to determine resistivity variations with depth beneath some fixed surface location. In this survey, electrode spacing varies for each measurement, however, the center of the electrode array, where the electrical potential is measured remains fixed.

When doing resistivity sounding surveys, Schlumberger array is most commonly used. Shlumberger array is the most time effective in terms of field work. In this array, electrodes are distributed along a line, centered at a midpoint that is considered the location of the sounding. Therefore, the two current electrodes and the two potential electrodes are placed in line with one another and centered on some observed location. The current electrodes are at equal distances from the center of the sounding (AB/2). The potential electrodes are

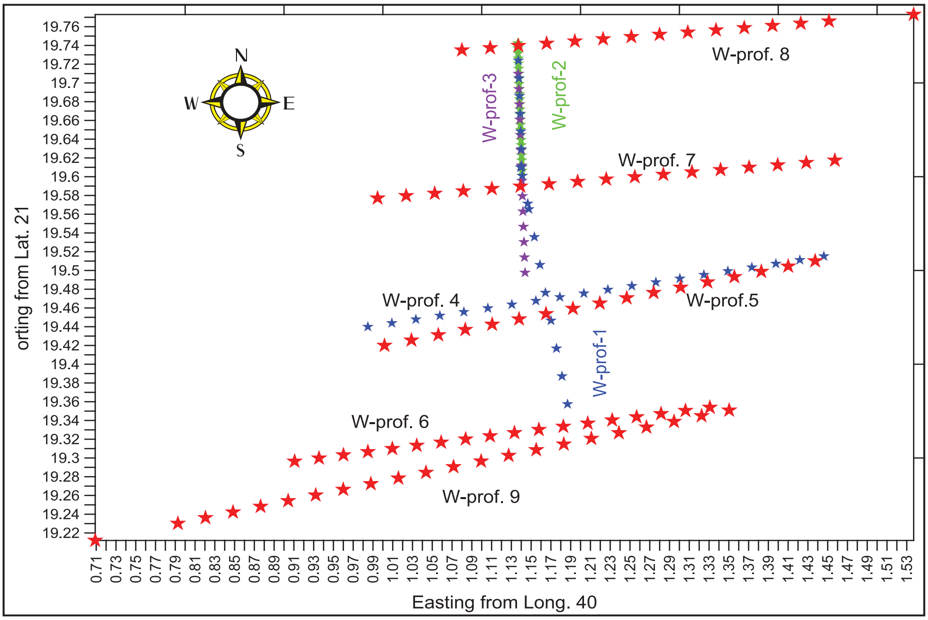

Fig. 3. Profile locations using Wenner array.

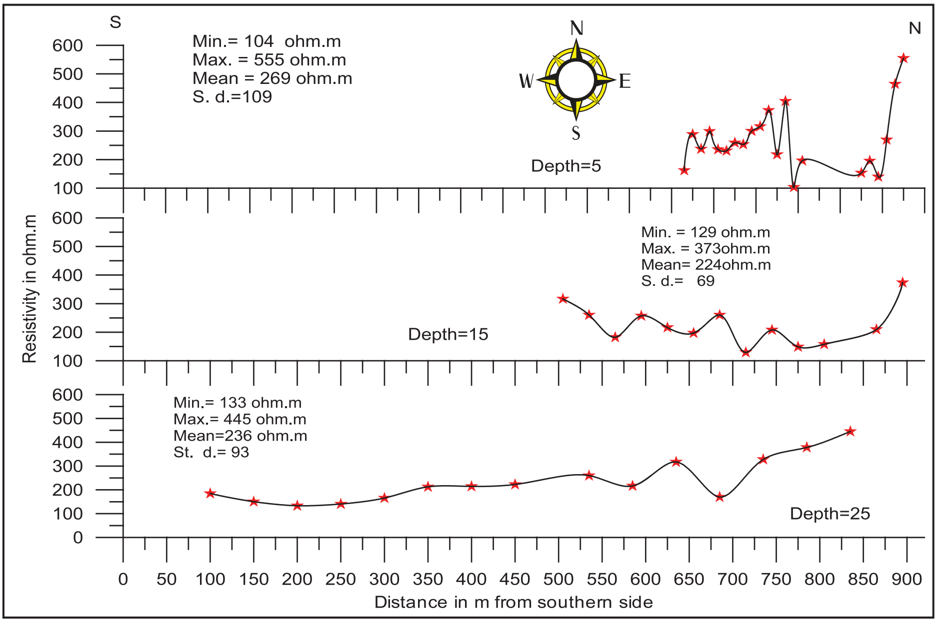

Fig. 4. Resistivity curves along profile no. 1 using different electrode spacing (a 10, b 30, and c 50m respectively, from surface to bottom).

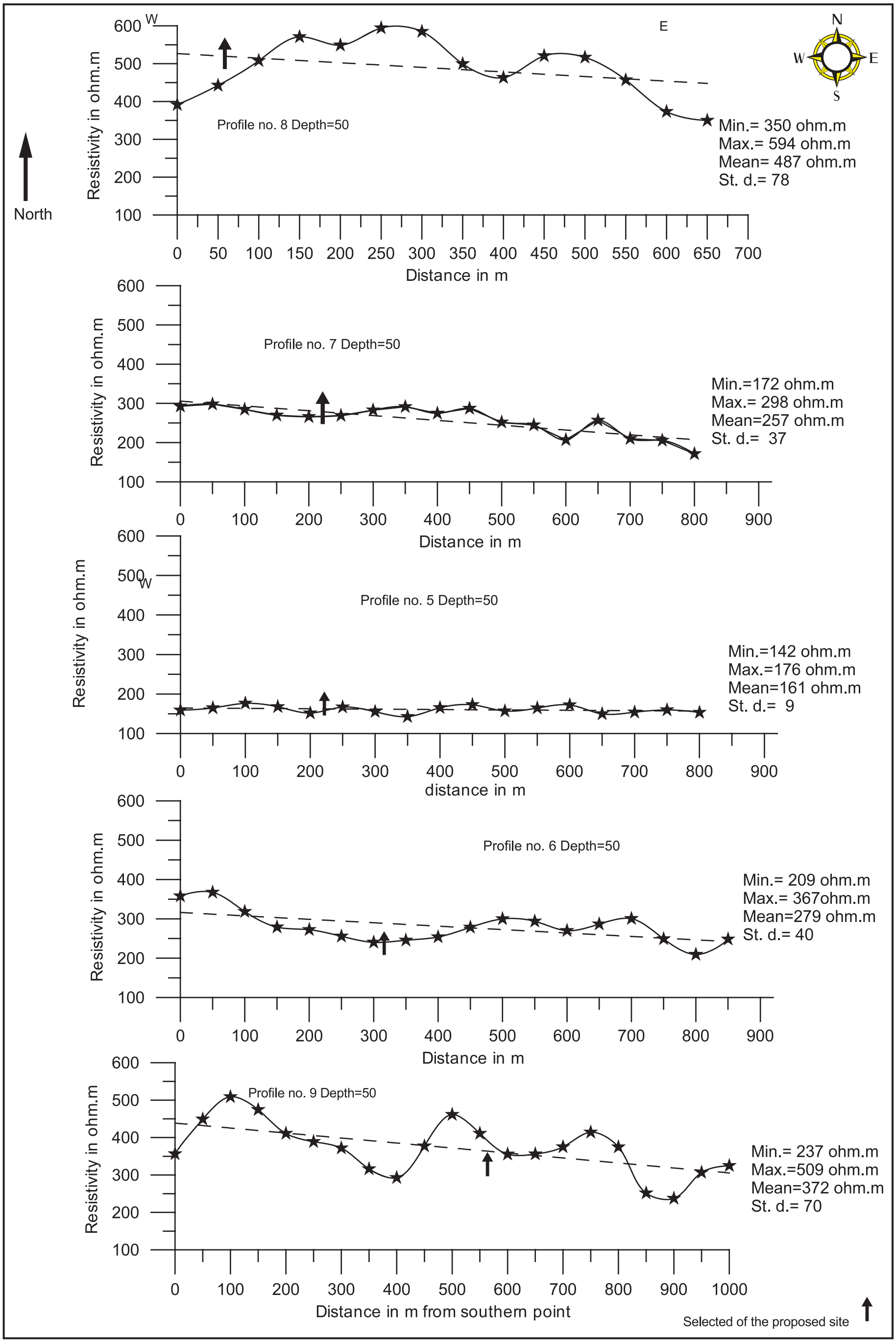

Fig. 5. Resistivity curve along profiles no. 8, 7, 5, 6 and 9 using electrode spacing (100).

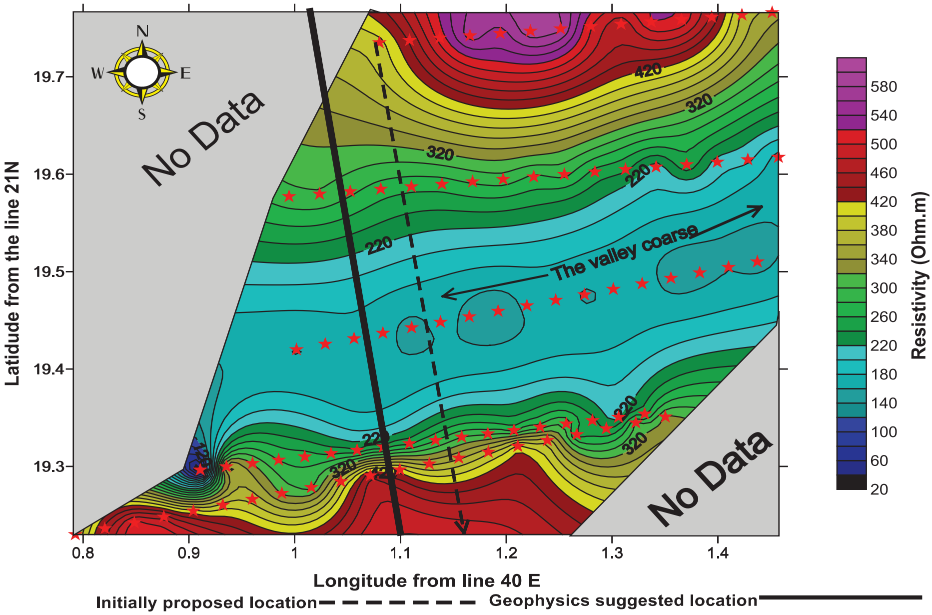

Fig. 6. Resistivity contour map of the study area.

also at equal distances from the center of the sounding; however, this distance (MN/2) is much less than the distance AB/2. Most of the available interpretation software assumes that the potential electrode spacing is negligible compared to the current electrode spacing. Vertical electrical sounding survey (VES) was conducted using Shlumberger array at 24 VES sites, 8 of them are conducted along the S-N profile at the proposed site. The other 16 VES sites are selected along three profiles, extending from West to East. These VES profiles are coded as 1000 W-E, 600 W-E and 500 W-E (Fig. 7).

The VES specifications were selected as seven measurements per decade to obtain reasonable data continuity, while half current electrode spacing (AB/2) ranges from 1 m to 300 m. These specifications allow considerable depth penetration beneath each sounding site. The survey equipment used is a modern 1200 Watts D.C. resistivity meter model ELREC-T (IRIS-Instruments). For each site, the field data, AB/2 and the corresponding measured apparent resistivity are represented as log ñlog curves, (*e.g.* Fig. 8a).

The data were reduced and analyzed for each vertical electrical sounding curve. It was first compiled to describe the apparent resistivity (ρ_a) from the different segments on the discontinuous curve, obtained during field measurements. The continuous sounding curve was then smoothed and digitized to produce six apparent resistivity (ρ_a) readings per decade of half the electrode

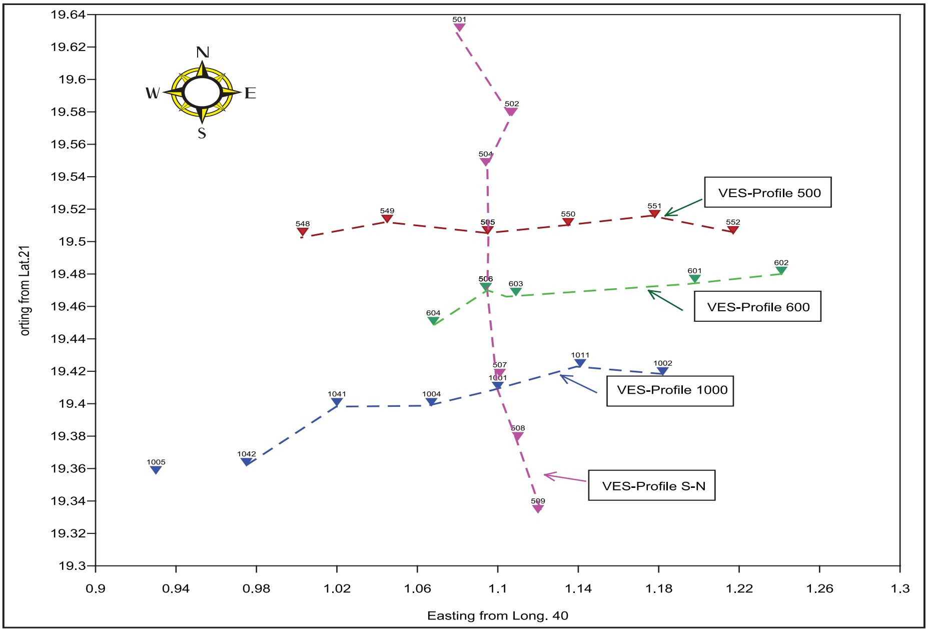

Fig. 7. Locations of vertical electrical soundings (VES).

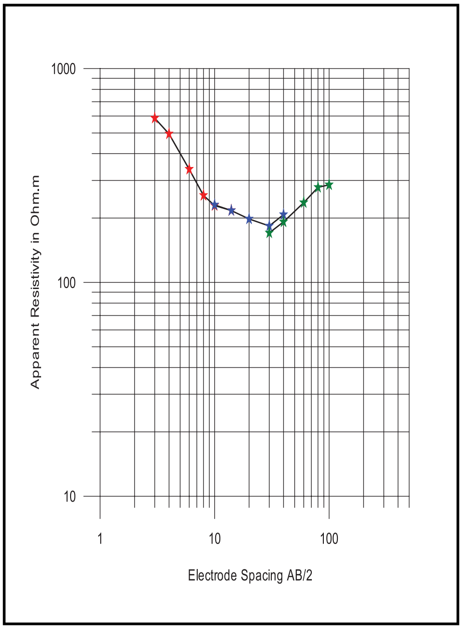

Fig. 8(a). Apparent resistivity field curve.

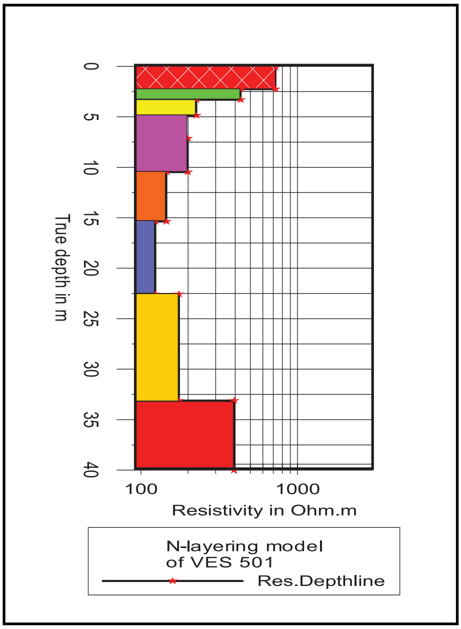

Fig. 8(b). The interpreted n-layer model.

spacing to avoid or minimize the effect of natural and artificial lateral inhomogeneties of the overburded structures under the array extensions (Al-Garni, 1996). The digitized resistivity data of the reduced field curve were inverted and interpreted using the inversion technique developed by (Zohdy, 1975 and Zohdy and Bisdorf, 1989) to obtain the equivalent layer models (n-layered model, Fig. 8b). The n-layers models of the different soundings were used to construct the subsurface true resistivity contour sections along each profile using vertical sounding along this profile (Fig. 10-13). The contour values represent the logarithmic values of the resistivity.

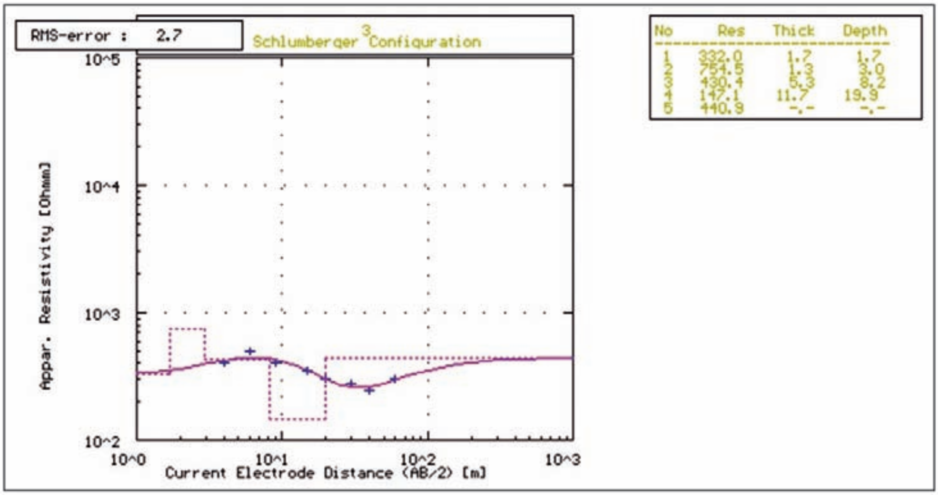

Fig. 9. Forward modelling interpretation technique using Resist program table includes number, thickness, depth and resistivity of the interpreted layers of the model.

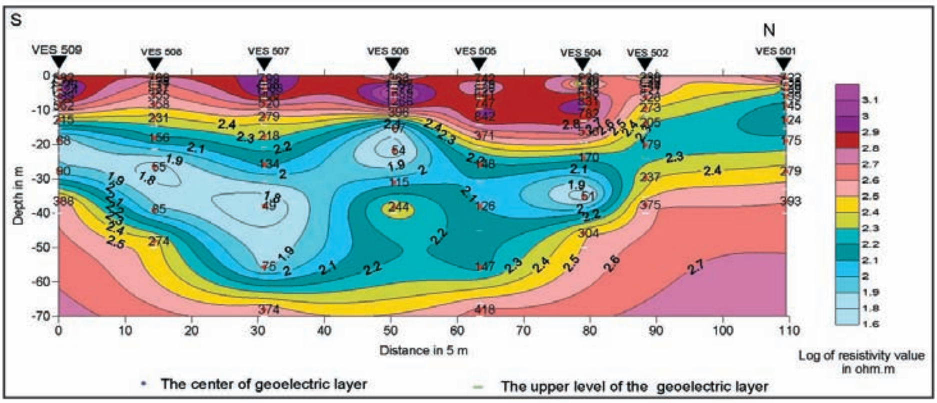

Fig. 10. Resistivity contour section along profile S-N.

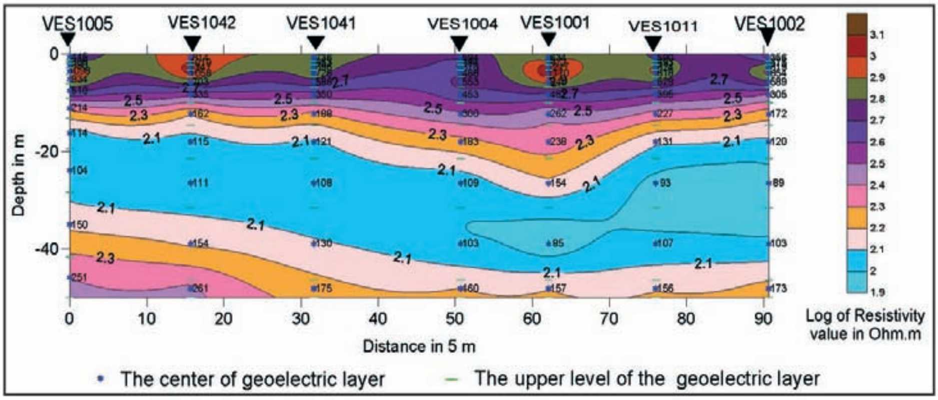

Fig. 11. Resistivity contour section along profile 1000 W-E.

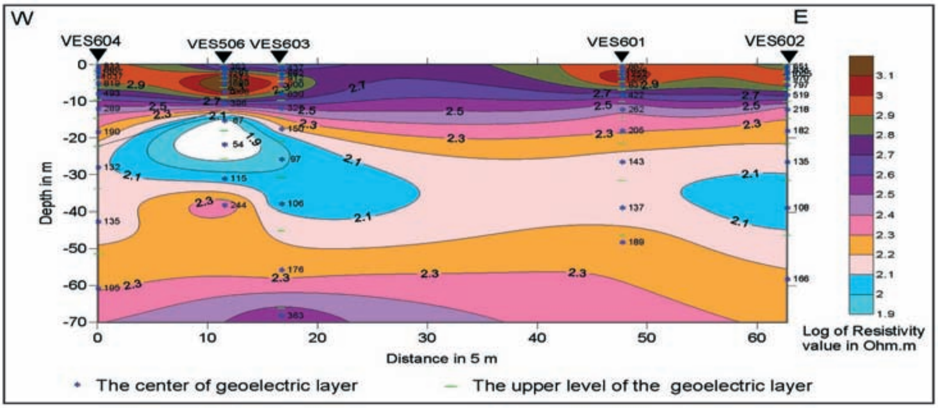

Fig. 12. Resistivity contour section along profile 600 W-E.

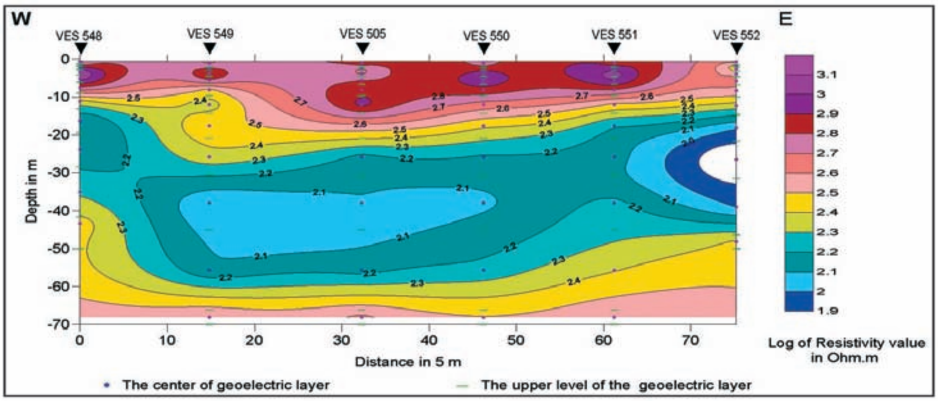

Fig. 13. Resistivity contour section along profile 500 W-E.

The n-layers model of each VES was used to suggest the initial model for the forward modeling process using Resist program (Ghosh, 1971 and Davis, 1979) to obtain the corresponding subsurface layers model at each VES site (Fig. 9). The results of forward molding of each group of VES's along each profile were used to construct the subsurface layering model of this profile. Figures 14-17 represent the interpreted subsurface layered models along profiles S-N, 1000 W-E, 600 W-E & 500 W-E, respectively.

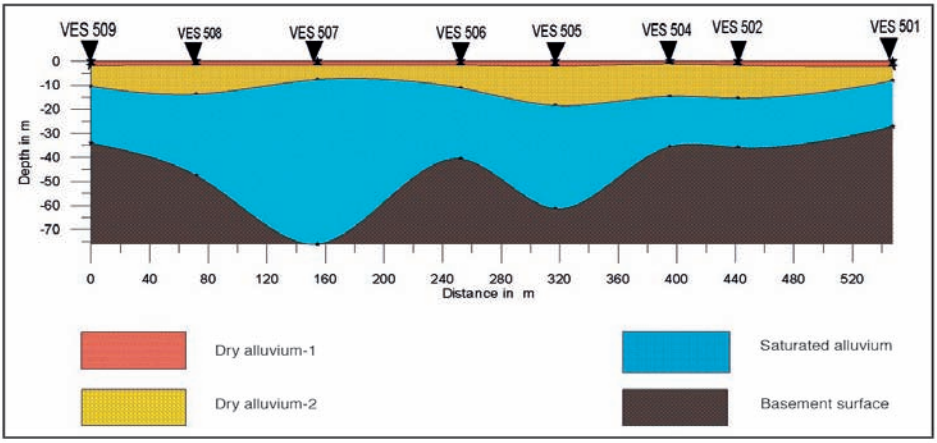

Fig. 14. Subsurface interpreted layering geoelectric model along profile S-N.

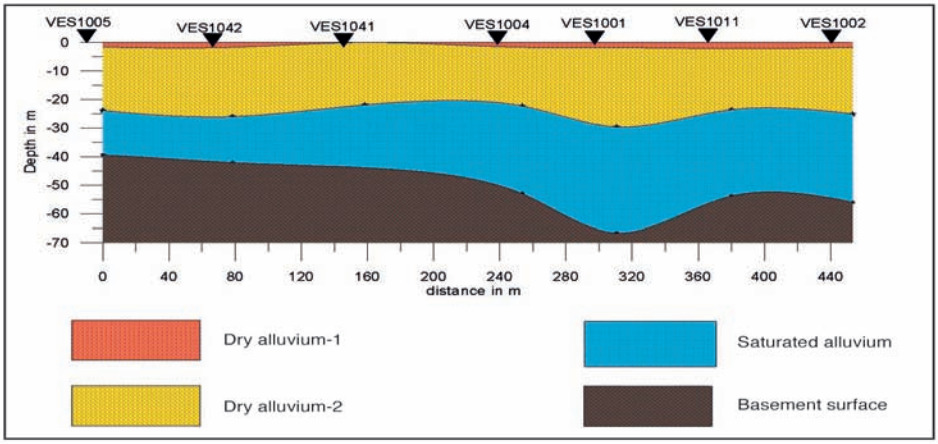

Fig. 15. Subsurface interpreted layering geoelectric model along profile 1000WE.

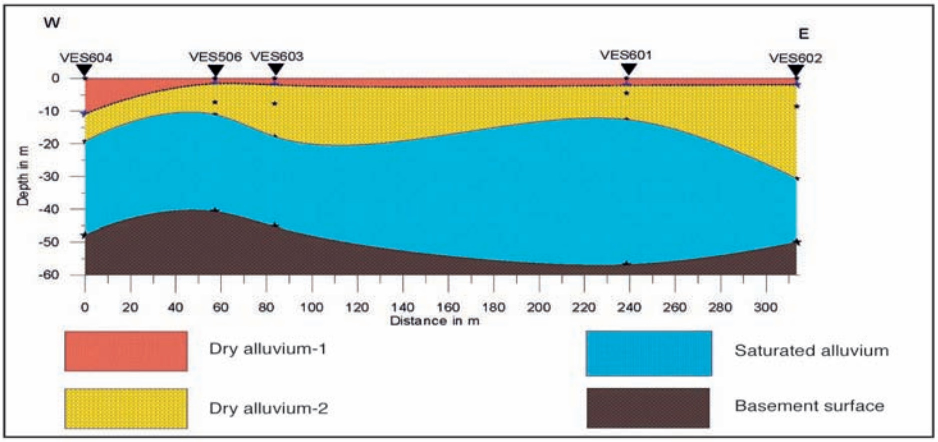

Fig. 16. Subsurface interpreted layering geoelectric model along profile 600WE.

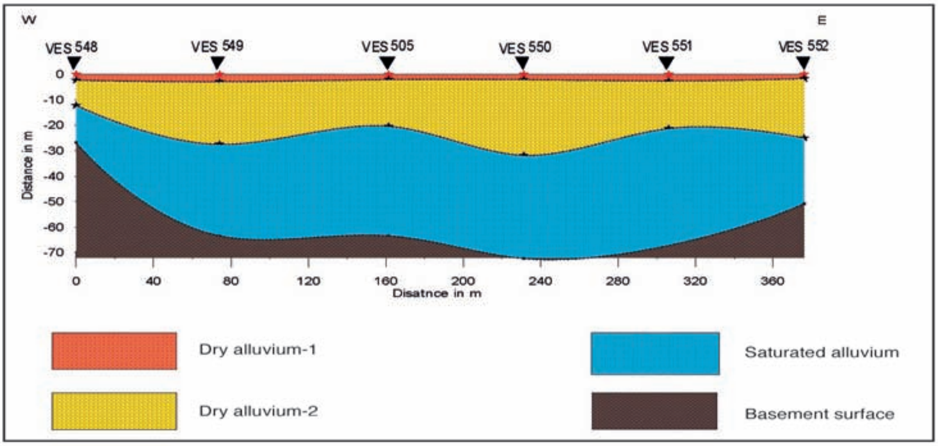

Fig. 17. Subsurface interpreted layering geoelectric model along profile 500WE.

Data Analysis and Interpretation

The subsurface geological section of the study area consists of the alluvium which covers the basement rocks. The alluvial thickness varies according to the variation in depth of the basement surface. The distribution of groundwater beneath the wadi level is mainly affected by the depth of basement and the thickness of alluvium. The thickness of alluvium increases with increasing depth of basement. The depth of basement is mainly controlled by the structure elements affecting the area during and after the wadi formation. On the other hand, the increase of resistivity in the alluvium is attributed to the decrease of the moisture especially near surface alluvium which is subjected to evaporation. Shallow basement rocks usually lead to increase in resistivity measurements. Accordingly, the present study used profiling and sounding techniques to define the relation between the subsurface structural setting and groundwater distribution.

Interpretation of Electrical Profiling Survey

Careful examination of the resistivity curves (Fig. 4) was employed to set the appropriate resistivity ranges that correspond to the lithological variations beneath this profile. Along the base Wenner profile array (S-N profile) the different electrode spacing (10m, 30m and 50m), show different resistivity ranges. The apparent resistivity at shallow depth (5 m) ranges between 104 Ohm.m and 555. Ohm.m; with increasing depth to 15m, this range changes to lie between 129 Ohm.m to 373 Ohm.m. When the depth is increased to 25m, the resistivity range becomes between 133 Ohm.m to 445 Ohm.m. The average value shows distinctive subsurface variation (270 Ohm.m, 224 Ohm.m and 236 Ohm.m, respectively) with increasing depth.

The area is covered mainly by high resistivity materials. Figure 4(a) represents the profiling survey along a segment of profile using electrode spacing 10 m at the northern side of the wadi. The observed decrease in resistivity values along the north of this part of this profile indicates that, a shallow structure filled with low resistivity materials may occur. This may be attributed to the effect of E-W fault which bounds the wadi from north direction. Figure 4(b) indicates that the resistivity still continues to decrease with depth which may reveal the continuing of this structure to depths more than 15 m. Figure 4(c) indicates the disappearing of the northern structural zone at depth between 15 and 25m. Also, the curve shows distinguishable low resistivity zone, that extends to about 200 m. width with resistivity values decreasing to about 133 Ohm.m at the southern part of profile. This indicates that a degree of water saturation in the southern part of the wadi may be corresponding to the course of water under the wadi surface with depths more than 25 m.

The average resistivity values along E-W profiles nos. 9, 6, 5, 7 and 8, which are arranged from southern side of wadi to the northern side, are 372 Ohm.m, 280 Ohm.m, 161 Ohm.m, 257 Ohm.m and 487 Ohm.m, respectively. These results indicate that the electric resistivity increases from the wadi center toward the southern and northern sides of wadi. The resistivity contour map (Fig. 6), constructed from the resistivity survey shows the distribution of resistivity at depth of 50m. The density of contour lines demonstrates a low resistivity zone in the wadi center between the extension of profiles nos. 6 & 7. This zone represents the subsurface course of underground water from east to west.

Interpretation of Vertical Electrical Soundings (VES) Data

The 24 VES resistivity data are analyzed and investigated in order to distinguish the interesting vertical variations in geoelectric characters of soil beneath each VES site. The depth and resistivity results of the vertical electrical soundings along each sounding profile are correlated to delineate the different subsurface variation along this profile. Therefore, the interpretation of vertical electrical sounding in the present work depends on the depth and resistivity results beneath each VES site, the description of the subsurface true resistivity contour section and the subsurface geoelectric layering section along each profile. This interpretation aims mainly to delineate the structural subsurface relation betweens VES sites as described by the different geoelectric variation, which appears from the different types of subsurface sections (Fig. 10-17).

According to the geology of the study area and the interpreted results of vertical electrical sounding, the subsurface lithology consist of two different units. These two units are the alluvial cover overlying an infinite depth of basement rocks. The alluvium can be classified into saturated (fully or partially) and dry parts. The interpretation of vertical electric sounding delineates the different lithological units and also determines the level of water saturation beneath each VES site. These subsurface lithological and structural features are recognized from the different resistivity contour sections (Fig. 10-13) and the geoelectric layering models (Fig. 14-17).

Interpretation of VES's along Profile S-N

This profile includes 9 VES's, 501-509 (Fig. 7) from south to north. VES data of these sites reveal that the depth of the upper alluvium ranges between 7 and 30 m with resistivity up to 1600 Ohm.m. The depth of lower alluvium part varies from 22 and 66m with resistivity ranges between 70 and 192 Ohm.m in average, respectively. The maximum depth of basement surface is shown in the VES no. 505 (66m) and VES 508 (46m). The resistivity values which correspond to basement rocks are relatively low, this delineates that the depth of penetration for the present D.C. did not reach the proper basement but is still in the level of altered and fractured basement. Also, the low resistivity values of the lower alluvium part 50 Ohm.m indicates that this part of alluvium is fully or partially saturated with ground water.

Interpretation of 1000W-E VES Profile

This profile includes 7 VES's, 1005, 1042, 1041, 1004, 1001, 1011 & 1002 (Fig. 11) from west to east. VES data of these sites reveal that the depth of the upper alluvium ranges between 9 and 21 m with resistivity up to 1217Ohm.m.

The thickness of lower alluvium part ranges between 31m and 36m with an average resistivity ranges between 104 and 146 Ohm.m, respectively. The depth of basement surface is 46 m at the eastern 5 VES's the depth decreases to 41 m at VES no.2005.

Interpretation of 600W-E VES Profile

This profile includes 5 VES's, 604, 506, 603, 601 and 602 (Fig. 12) from west to east. VES data of these sites reveal that the depth of the upper alluvium ranges between 14 and 22 m with resistivity up to 1252 Ohm.m. The thickness of lower alluvium part ranges between 24m and 30 m (beneath the VES's no. 604, 506, 601 & 602) and 50 m (beneath the VES's no. 603) with an average resistivity ranges between 79 and 141 Ohm.m respectively. The depth of basement surface reaches 51m and 66 m beneath the VES's no. 604 & 603. The depth decreases to 36 m beneath VES no. 506 which lies between VES's 604 and 603.

Interpretation of 500W-E VES Profile

This profile includes 6 VES's, 548, 549, 505, 550, 551 and 552 (Fig. 13) from west to east. VES data of these sites reveal that the depth of the upper alluvium ranges between 13 and 30 m with resistivity up to 1228 Ohm.m. The thickness of lower alluvium part ranges between 30 m (beneath the VES's no. 548, 549, 551 & 552) and 45 m (beneath the VES's no. 505 & 550) with an average resistivity ranges between 88 and 150 Ohm.m, respectively. The depth of basement surface reaches 66 m beneath the VES's no. 505, 550 & 551.

Conclusions

In the present study, DC electric survey was conducted by using profiling and vertical electrical sounding (VES) techniques to outline the main structural, and lithological configuration as well as the ground water distribution beneath the proposed area in support of the subsurface dam siting.

The apparent resistivity measurements along several profiles was selected and conducted, using Wenner array, across the wadi strike in order to delineate the variations in resistivity values along these profiles. The resistivity ranges between 104 Ohm.m and 555 Ohm.m with the highest resistivity values recorded at shallow depths and near both sides of the wadi. This indicates that variations in resistivity values are controlled by the incorporated thickness of the basement rocks which represent the floor of the ground water in the area. Accordingly, the extreme range of variation of resistivity values beneath the wadi surface reflects the irregularity of basement floor. Also, the stream of ground water flow is delineated by the low resistivity zone at the resistivity contour map. The width of this zone reaches up to 300 m. In addition, the results show some limited extension of relatively low resistivity zones along the profiles. These zones may be related to the expected subsurface structural features (faults or fractures) which may be filled with clay accumulations or wet alluvium.

The results of profiling resistivity survey, using Wenner array, was utilized in selecting the appropriate sites for recording the variation in resistivity with depth using vertical electrical sounding (VES) technique.

The interpretation of the 24 VES's, which are conducted along four profiles, demonstrated that the layering section beneath the ground surface of the area can be classified according to the resistivity measurement variations. Accordingly, the layering can be classified into three distinct formations: unsaturated alluvium, saturated sedimentary and the basement rocks. The depths and resistivity of these three formations were determined to delineate the saturated water zones. The depth of the upper surface of the saturated alluvium layer ranges from 9 to 31 m, while the depth of basement rock surface reaches to 66 m.

The contour of the resistivity sections which were constructed along the VES profiles delineated the depth of the abasement rocks and the overlying alluvium formations. The variation in these depths indicates that the area was subjected to different phases of structural events. The trends of these structures are E-W, NE-SW and N-S trends.

The interpreted subsurface geoelectrical section which is constructed along a line of VES data, delineated that the dry alluvium formation can be classified into two distinctive subdivisions, the upper one is affected by the meteorological environments of the area which are mainly dry with rarely rains falling and some times floods were taken place from the surrounding high mountains. This environment leads to form accumulations of clays and terraces which cover the surface of the wadi into a limited depth. Therefore, the resistivity of this part is extremely variable but high. The second subdivision is considered the transition zone (vadose zone) for water percolation to the saturated formation. Therefore, the resistivity of this part of alluvium is mainly affected by level of the groundwater table which is changed seasonally. In addition, these geoelectric subsurface sections reveal the structural setting of the saturated formation and its relation with underlying basement rock.

These results are considered highly important for selecting the suitable site of the dam body and also as valuable information for the design and the construction of the dam.

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استخدام تقنيات المقاومية الكهربائية باستخدام التيار المستمر للوقوف على الوضع التركيبي والهيدروجيولوجي تحت موقع مقترح لبناء سد تحت سطحي، منطقة مكة المكرمة ، المملكة العربية السعودية

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المستخلص. نفذت الدراسة الحالية على منطقة تقع على مجرى وادي نعمان بمنطقة مكة المكرمة بالمملكة العربية السعودية. يحد وادي نعمان من الشمال جبل كبكب ومن الجنوب جبال نعمان، ويصرف ماؤه في البحر الأحمر. تعتبر منطقة الدراسة جزء من الدرع العربي بغرب المملكة العربية السعودية، وهو يتكون من الصخور النارية والمتحولة. يوجد عند أعالي وادي نعمان منحدر تركيبي واضح إلى جانب الصدوع الكبيرة والصغيرة السائدة في وادي نعمان والمناطق المحيطة.

على مدى تاريخ طويل ، كانت عين زبيدة المصدر الرئيسي للمياه الجوفية في المنطقة. ولقد أدى السحب الجائر وغير المنظّم لانخفاض مستوى المياه الجوفية. تهدف الدراسة الحالية إليالتعرف على الوضع الهيدرولوجي والتركيبي تحت موقع مقترح لبناء سد تحت سطحي للتحكم في سريان المياه الجوفية في المنطقة، لرفع مستوى الماء الجوفي في المنطقة المحيطة بروافد عين زبيدة.

في هذه الدراسة، استخدم التيار الكهربائي المستمر لإجراء المسوح الجانبية، والسبر الرأسي لقياس المقاومية الكهربائية لدراسة المعاملات التركيبية والهيدروجيولوجية تحت سطح المنطقة. أدى استخدام هذه

الطريقـة إلى تقسيم الرواسب الـوادية التي تغطي صخـور الأسـاس على حسب مقـاوميتهـا الكهربـائية إلى طبـقتين محددتين. تتميز الطبـقة العليـا بارتفاع قيم مقاومتهـا الكهربائية نسبيًا والسفلى بانخفاض قيم مقاوميّتها الكهربائية. من المتوقع أن الطبقة السفلى تقابل الطبقة المشبعة بالماء.