Application of Vertical Electrical Sounding to Delineate and Evaluate the Hydrological Conditions in Baiji –Tikrit Basin

Muhanna Mitaab Ahmed
Zaidoon Taha Abdulrazzaq
Sabbar Abdullah Salih
Department of Applied Geology, College of Science, University of Tikrit, Tikrit, Iraq

Abstract
The current study includes applying the vertical electric sounding by using the symmetrical Schlumberger configuration in the area which located between Baiji and Tikrit to the West of Tigris river, between longitudes (43° 40’ 12.3”) and (43° 56’ 22.6”) and latitudes (34° 35’ 13.3”) and (34° 54’ 41.7”), with total area of approximately (700 km²), in order to identify the thickness and the expansion of the aquifers, then to delineate and evaluate their hydraulic characters.

This study adopted the measurements of apparent resistivity measured in 40 VES points in the area. VES points were distributed along 6 geoelectric traverses in order to obtain a possible coverage of the studied area. The spreading of current electrodes (AB/2) reached a distance up to (400 m), and a distance of (40 m) was reached for the spreading of voltage electrodes (MN/2); thus, a depth penetration of (151 m) was obtained.

Apparent resistivity measurements were drawn, and their deformations, which resulted from smoothing, were treated. Field curves of VES points were interpreted qualitatively by three procedures to obtain a primary idea about the number of the electrical zones and the depths of the separating surfaces between them, and to map the vertical and horizontal change locations in the apparent resistivity values. Then the curves were interpreted quantitatively manually by Auxiliary point method and Ebret method to find out the values of quantitative resistivity and thickness of the electrical zones. After that, the sounding curves were interpreted automatically by the computer program (IPI2win) applying the Inverse manual interpretation method to scrutinize the manual interpretation results and enhance their accuracy if it might be few of their parts by manual interpretation.

The program (IPI2win) results of interpretation were used to draw (6) Geoelectrical sections along the survey traverses, then they were transferred to geological sections by achieving the proper smoothing, after the matching of the electric zones limits gained from the interpretation process results with the limits of the layers which were penetrated by the drilled wells in the area of study with regard to the effect of the two principle of equivalence and suppression. Likewise, the results of the interpretation showed that the thickness of the main aquifer of the area is from (50-128 m) and consists of sediments (sand, clay sand and clay) which belongs to the Injana formation, whose conditions are apt to change in the area, from the confined type to the semi confined, depending on the confining clay layer thickness which bound the aquifer from the top part, and the extent of being affected by folding. A gravel layer belong to Quaternary sediments mounts the aquifer in middle and south of the study area; a part of this layer is within the water saturated zone in the southern part of the study area, which made in this area a sub-aquifer of the unconfined type with a thickness of about (5-25 m). Moreover, the geoelectrical sections showed the existence of a high-conductivity layer bounds the aquifer from beneath and was considered as a layer of claystone saturated with salt-water.

Many empirical relations have been put between the geoelectrical parameters, and the Hydraulic parameters by which a Geophysical model was suggested for the aquifer which is supposed to have a constant thickness and varying resistivity and hydraulic conductivity. These relationships have given several mathematical equations, some of them were used to calculate the hydraulic parameters represented by (Hydraulic conductivity and Transmissivity) at the electric VES points where no experimental pumping wells were available. These values were used to draw the two maps of the hydraulic conductivity and the transmissivity for the aquifer. These two maps displayed sites where hydraulic parameters for the aquifer and the areas of low hydraulic parameters rise, so it became possible to new wells locations with high discharge.

Keywords: VES, Apparent resistivity, Groundwater, Hydrogeologic characters, Geoelectrical sections

Introduction
The groundwater is considered one of the main national treasure, it is also considered an important parameter facing the shortage of surface water. To invest the groundwater in a proper way and to lay down a model plan for wells distribution and to control the pumping operation, a hydrogeological evaluation system and hydraulic parameters of this aquifer will be needed. The geophysical studies were considered, one of important method to do so. Then, these studies were considered as the fastest method in groundwater exploration, and cheap in correlation with drilling wells (Kosinski and Kelly, 1981).
In contrast, the random drilling can lead to drill unproduced or little producing wells, and/or could be a weak hydraulic properties. Therefore, it should be start with a geophysical surveys in such studies, prior to drilling, in order to detect the depth and thickness of underground (subsurface) aquifers of their water quality and hydraulic parameters. There were a lot of geophysical methods to be used in such studies, but the famous and often one is the electrical resistivity (keller, 1967). Due to its low cost, easy to apply, and fast to get a result, in correlated with the other methods.

The area of study is located between Tikrit and Baiji towns, on the western side of Tigris river, between longitudes (43° 56' 22.6"- 43° 40' 12.3'') and latitude (34° 35' 13.3"- 34° 54' 41.7''). It bordered by Tigris river from the east and subsurface Tikrit anticline from the west, while Wadi Shishen from the south, and fields of sand dunes from the north and north west of the area (figure 1). The area was semi rectangular shape of 45 km length, and 700 km$^2$ total area.

![Figure 1. Location map of the studied area](image)

The age of the exposed rocks was ranged from middle Miocene to the quaternary, Injana formation was the oldest one was exposed in the northern part of the region (figure 2), also exposed in Wadi shishen (southern part), which is composed of alternation of fractured claystone, siltstone and sandstone. (Hamza, et al., 1990). The quaternary deposits were divided into two part, firstly, the Pleistocene deposits, which composed of gravel (river terraces), besides the Gypserous soil (Gypcrite). The size of these deposits were range from boulder to pebble, and has a weak cemented one, that led to be a good strata to penetrate the water to underground aquifers (Al-Ani, 1997). The deposits were divided into four facies, like (clayey gravel, clayey sandy gravel, sandy gravel and sandy clayey gravel) (Basi and Karim, 1990). While the gypsons soil cover a large part of the area and contain of gravel, sand, silt, and clay, which were rich by secondary gypsum, that classified as gypcrite facies (gypsious soil).

The Holocene deposits, which consist of soft detroital deposits, like flood plain of Tigris river between Baiji and Tikrit in a zigzag belt of 3 km width, and more than 3 meters thickness sediments alternation of sand, silt and clay silt (Aljanabi, 2008), and valley deposits of gravel, sand, silt, clay and gypsum, which came from the surrounding high areas, with about one meter thick (Aljanabi, 2008). Sand dunes deposits were also existed in NW part of Baiji, making a recent cover over sediments (Jassim and Goff, 2006).

Geomorphologically, the area was plain shape in general, with small valleys directed to east and southeast towards Tigris rivers, the river terraces were covered 2/3 of the region with, gypsious soil and gravel. The area elevated between 160 m above sea level on the western part near Tikrit anticline, and 100 m. towards Tigris river on the east. The seasonal valleys were the most observed geomorphologic features, which are characterize by two systems, denidritic and parallel valleys, and were in fife orders. These valleys were concentrated to the western part, near the subsurface Tikrit anticline, (figure 2), to form the surface discharge system, which diverted to the southeast to be ended at Tigris river via wadi shishen valley. The general, the valleys were gently slope, fill by loose fine grains sediments.

The north–northwest part of the region were characterized by less dominant valleys ended with depressions inside the studied area to capture the rain water in order to recharge the underground aquifers (Al-jubouri, 2011). While, the eastern part of the studied area, which run parallel to the Tigris river consists of a group of short valleys started from the edge of river terraces, and finished east toward the river. Another geomorphological feature were existed, like the scarps, falling mass accompany in the Tigris river and the existing of dunes and sand sheets. (Al-ani, 1997).
Tectonically, the area lies within the Mesopotamian zone, Ammara – Tikrit secondary subzone (GEOSURV, 1996), belong to the unstable shelf according to (Budy and Jassim, 1981). There is no surface features, that can indicate the structural phenomena, except the existence of NW-SE Tikrit subsurface anticline, along the western side of area. This subsurface structure effected the topography, there is also a fault intersect the Tikrit structure. This deep-seated fault has extended from Jurassic till Miocene rock, (GEOSURV, 1996), (Hamza, et al., 1990), (Al-ani, 1997). It is believed that, there are many subsurface faults in the region, which had a great effect on the aquifer properties, because, changing from confine to semi and unconfined type, due to the hydraulic connection resulted from the fracturing of faults.

Parsons, 1955, evaluated the hydrogeological conditions from the large diameter wells in the area, and (Alfurat Center, 1989), classified the subsurface aquifers, according to lithological and hydraulic properties, and evaluate the hydrochemistry of aquifers. Al-Ani, 1997, and Al-Daffai, 2002, both evaluated the quality of groundwater of the aquifer in the area, and they described the aquifers in the region as a complex hydrogeological system, due to the lateral and vertical heterogeneity of aquifers, which caused to change the conditions of the aquifers, from the unconfined type to semi- and confined.

Al-joubori, 2011, studied the hydrogeological conditions of Tikrit-Baiji basin west Tigris river, to assess the groundwater through the water balance and evaluated the hydrogeological basin from the in-situ measurements, scene of large diameter wells, drilled boreholes, pumping test to evaluate the hydraulic conductivity, transmissivity, storage coefficient.

**The aim of the study**

Depending on VES measurements, pumping test of the previous studies on some existing wells in the region, and, on the chemical analysis of wells water, the aim of the study can be concluded as the following:

1- Delineate the thickness and extension of the water bearing beds. Then delineate the groundwater system, and movements direction and levels in the area.

2- Create the relation between the geoelectrical coefficients and hydraulic one, and study the geological-hydrogeological water bearing beds according to these empirical relations.

3- Suggest geophysical model for the aquifer of the studied area.

4- Delineate the promising area, and the candidate area of expansion plan to drill borehole for groundwater investment.

**Instrumentations and field work**

French Syscal R2 resistivity meter, IRIS, were used to measure the electric resistivity in the groundwater exploration. Syscal R2 consist of a complete system of measure and calibration, with 1200 W converter to transform the current from AC to DC, output voltage up to 800V, besides the (220V, 50 Hz) generator to supply the current. The instrument can compute and illustrate the apparent resistivity automatically, for famous electrode arrangement like (Schlumberger, Dipole-dipole and Wenner) as well as can be used for self potential (SP) and induced polarization (IP) survey (Syscal R2, 2007).

Field work were implemented with the geophysical team of the general directory of groundwater, for the period between 11/17-4/8/2010, and measure (40) VES points in symmetrical Schlumberger arrangement.

GPS was used to detect the elevation and attitude of the VES points, which distributed along six traverses, of 6-14km. length (figure 3), five traverses oriented NE-SW, perpendicular to the subsurface anticline axis that existed in the area of NW-SE direction, depending on, Iraqi structural map, (GEOSURV, 1996), (Hamza et al., 1990) and (Al-ani, 1997). These studies were indicated that a large effect of these structures on the groundwater aquifer and controlling the hydraulic parameters. Also noticed that the direction of electrode layout for the VES point was oriented parallel to beds strike (i.e NW-SE) in order to illuminate the strata-dip effect. The sixth geoelectric traverse (H’-H) was directed perpendicular to the other traverses (C-C, D-D, F-F) and parallel to the subsurface strike, in order to illustrate the aquifers expansion in this direction, the distant was 4.6 km between the traverses, with 2 km offset between the VES points, and AB/2= 350m except in traverse A-A, which AB/2= 400m MN/2= 40 m for the most traverses in the studied area, except for the military zone between traverses B-B and C-C.

**Interpretation of the electrical sounding curves**

The aim of sounding curves interpretation were to delineate the resistivity values and thickness of the subsurface geoelectrical zones, and to convolve these interpreted results with the available geological-hydrogeological information of the studied area, in order to study the vertical and horizontal variations of the zones and to map the water bearing strata, their extension and subsurface situation of the region, (Flathe, 1963; Bhattacharya and Patra, 1968; Keller and Frischknect, 1970; Zohdy, 1974).

The quantitative interpretation methods used in this study, the field curves prepared by smoothing process, these curves extracted to get the resistivity and thicknesses of geoelectrical zones. These results can be used to elicit a geological image for the area. The interpretation process can be executed either manual or by computer software.
Manual interpretation

There were two essential methods used for quantitative interpretation of the manual field curves, first, called complete curve matching, which needs standard curves for two, three, and four layers, in order to interpreted quantitatively, (Orellana and Mooney, 1966; Rijkswaterstaat, 1969). This method had a limited use because it needs an ideal complete field curve matching with the standard theoretical curves, and also needs a lot of standard curves, and then a lot of efforts and time to match the field curves furthermore, there was no standard curve for five and six layers, so it was preferred to use the second method, which called the partial curve matching or auxiliary point method that considered the most used one (Zohdy, 1965), it can be match a part of the field curve with the curves of two, and three layers and use the auxiliary graphs A, H, K and Q. It did not need a lot of standard curves, and it can interpret the multilayer field curves. The precision of this method can be decreased with the increase of number of layers, besides there was parts of the field curves, could not be interpreted in this method, because of highly gradient parts of these curves did not matched with the standard one, as we noticed in VES no. 7F (figure 4A), 2F (figure 4B). Therefore, it is preferred to carry auto interpretation by special computer software, after the interpretation by this manual method, in order to get high precision. The idea of auxiliary point method was to decrease the number of layer, by mixing two layer or more in one layer of fictitious resistivity and thickness, therefore, it called fictitious layer, (Orellana and Mooney, 1966; Keller and Frischkncht, 1970).

The auxiliary point method of interpretation can be carried by two methods, the first called Orellana method, which can use two type of field curves, such A and H type, which were not used in this study, because of field curves were of K and Q type. Therefore, the second method of Ebert method was used, due to capability to interpret all kind of two layer field curves with their auxiliary graphs for all VES point in this survey. Theoretical background and procedure of auxiliary point method were explained in references, (Zohdy, 1965; Orellana and Mooney, 1966; Bhattacharya and Parta, 1968; Keller and Frischkncht, 1970; Koefoed, 1979; Al-ani, 1983).

In the case of quantitative interpretation, it is preferred to interpret sounding point located close to drilling wells, (figure 5A, VES point 3A), for correlation process, in order to delineate the resistivity of each strata unit, then to correlate this with that of VES point located in the areas without drilling wells.
Software interpretation

After quantitative interpretation were carried manually using auxiliary point method, it is preferred to carry auto-interpretation using computer software, many programs were designed by researcher's and institutes for quantitative interpretation of electrical sounding and induced polarized (IP), for different electrode configurations. The most famous program were Resist, VES, IPI2win and IX1D.

In this study, program IPI2win was used to interpret all the electric sounding, in order to check the results of manual interpretation, and increase the accuracy of interpretation, besides of the capability of the program to interpret some parts of the field curve that can difficult to interpret it manually. Also, IPI2win can draw apparent resistivity sections for qualitative interpretation, and draw geoelectrical section instead of manual drawn, which can offered effort and time.

This program was designed to interpret the VES data of one dimension (1D), and induced polarization (IP) data. IPI2win includes two methods of quantitative interpretation, the first called forward calculation method, which include to input the apparent resistivity values (ρa), and AB/2 values in to the program, as well as to input the geoelectrical model (resistivity and thickness), that computed from the manual interpretation. Then the program can plot the field curve, as well as the theoretical curve for the given geoelectric model, and later on the program can compute the thickness and resistivity of electric zone. The second method called the inverse modeling one which include to input values of resistivity and thickness from the manual interpreted field curve to the IPI2win program (Bobachev, 2002), and then this program can carry correction to the manual interpretation results, to reduce the percentage of root mean square error (RMS%), which represent the function of matching between the field and theoretical curves, i.e low RMS% means better matching (Zohdy, 1989).

It is preferred to use the manual inverse modeling in order to check and improve some of manual interpretation of field curves (figure 5B, VES point 3A), to be coincite with the bed boundary in drilling wells, and within the equivalent limit of capability to change the resistivity and thickness values for each bed with certain limits without changing the shape of field curves (Keller and Frischknecht, 1970).

Figure 4. A: part of the field curve cannot matching with the standard curve because of high gradient.
B: small partition at the end of field curve which cannot matching with the theoretical curve.

Figure 5. A Ebert method of interpretation of VES point 3A correlated with geoelectrical model and drilled well near the point 3A.
B Geoelectric model for VES point 3A, interpreted by inverse modeling, correlated with manual interpretation results.
**Geoelectrical and geological sections**

The geoelectrical section were considered as the most important means of displaying the results of the quantity interpretation of VES data, which explain the vertical and lateral changing of resistivity and thicknesses of different electrical zones. Depending on the resistivity contrast, the geoelectrical sections between different beds were constricted, in assistance with geological and borehole information. Therefore, the connection between the nearby values were combined. The separation process between the electric zones depended on the high differences of the resistivity values, in spite of the difficulty of that within the same VES point. The connection process ended in mapping the boundary of resistivity changing with thickness, however, it is not necessary to coincidence between the electric zone boundaries with the bedding planes, except in the high differences in resistivity values between the beds. The difference in resistivity values were due to the variation of cementing materials or differences in moisture, dryness, or water table within the bed, or salinity. The geological beds were distinguished by the existing of clay in some of the traverses, causing the decreased value of resistivity, which can cause difficulty in drawing the geoelectrical section, therefore, these sections were executed with the help of drill wells information and final results interpretation, (figure 6) for all the traverses.

![Image of geological and geoelectrical sections](image)

**Figure 6. The lithological description of the dried wells in the area**

It had been noticed that the existence of rock bed, which was equivalent to two geoelectric units or more, like that in top soil bed of the studied area, which showed that two geoelectric units in some VES points, likewise three units in other point, due to moisture content ratio differences and discrepancies of physical, chemical, and mineralogical properties.

In other cases, like in this research, one geoelectric unit was equivalence to two or more units of rocks, as an alternation between the gravel, sand, silt and clay beds were dominant. The geological section can be extracted from the geoelectrical section, through the help of geological and drilled wells information as well as the smoothing process. Six geological and geoelectrical section were plotted, also the process of suppression principle problem was carried, by using the available drilled wells, but equivalence principle problem couldn't for the saturated zone, because of the result of division the resistivity and thickness of this zone by the resistivity and thickness of the overlying were out of range of Pylaeves sketches, which were used to resolve this principle. Description of the traverses were as follows:

1. **The geoelectrical and geological section along A-A' traverse:**

   This traverse is passing through four VES points (figure 7), and the sounding point (3A), was located near of observation well 4, from correlation of the interpreted sounding points with the Ob. well 4, the ranges of resistivity had been detected, as well as that of the thickness equivalent for different zones. The geoelectrical section was smoothed, then the geological section was assessed from it, with the use of the Ob. well 4 as in figure 8. From the sections, the following zones can be observed:
   a. The first zone:

   This zone was represented by top soil, which can be divided in two sub zones : the first was soil subzone, which had a high resistivity ranged between (292-882.3 Ω.m), and that due to the soil moister differences, and of properties discrepancy, while the thickness was ranged between (1.356-1.94m). The second secondary zone of top soil had a
low resistivity value was ranged between (68.7-98.5 $\Omega$.m), and the thickness ranged between (4.9-8.4 m), while the total thickness of the zone ranged between (6.33-9.76 m).

Figure 7. The geoelectrical section along A-A' traverse

Figure 8. The geological section along A-A' traverse

b. The second zone:
This zone was consisted coarse gravel deposits, represented by river terraces belong to the quaternary, which was varied in resistivity values due to vary of dryness, resistivity values was ranged in this zone between (140-346 $\Omega$.m), while it’s thickness between (7.41-14.74 m).

c. The third zone:
This zone represents the unconfined aquifer, and that was due to unseen of existing confined layer bounded the aquifer from the top, therefore, lowered resistivity values were noticed, and ranged between (19.3-52.9 $\Omega$.m). Also, this zone was distanced by high thickness relative to other electric zones, thickness ranged between (89.8-97.7 m).
this zone was consisted of coarse gravel at the top, which represents the river terraces of 26 m thickness, this was detected depending on the observation well 4. The middle and lower part of this zone was consisted of sand, clay, and clay sandy deposits of Injana formation.

The values of resistivity was increased at points (4A, 1A), that was caused by the decreasing of porosity water salinity, because of the location of point 1A from Tigris river. While VES point 4A the increase of resistivity value was resulted from the percolation of rain water through the valleys located near the point 4A, while this point was approached from the recharge area of the aquifer (represented) by subsurface anticline located west of the traverse.

d- The fourth zone:

This zone was the last one represents the lower boundary of the aquifer, resistivity values were largely decreased to reach mean value of 6.6 Ω.m, this zone was consisted of claystone saturated with saline water (AL-Minshid, 2001). Claystone layer was not well recognized in the drilled well section in the area, because of limited depth. While this zone was observed at the same depth in the Al-Minshid study.

2- Geoelectrical and geological section along B-B’ traverse

This traverse is passing through six sounding points, figure 9. A large similarity between this traverse with that of traverse A-A’. in terms of number of zones and the resistivity values, therefore the geological section of this traverse was constructed, depending on the geoelectrical, geological sections of A-A’ traverse, (figure 10). The assistance of drilled well no. 94 information shown by figure 6, which was away north-east of point 1B by 1km. was used in this process.

The following zone. Were observed from this traverse:

a- The first zone:-

- Divided into two secondary zones, the first was top soil of high resistivity, the second was top soil of low resistivity, due to the difference of dryness and property discrepancy.
- There was a noticed decreasing in resistivity of points (2B, 3B, 4B), due to the area depression and crossed by valley of seasonal rain water. The resistivity values ranged between (52.2-1203 Ω.m), and thickness between (4.61-11.2m).

b- The second zone:-

- This zone was consisted of quaternary river terraces gravel deposits. The resistivity values ranged between (123.2-338 Ω.m), this fluctuation was due to vary of cementing material of secondary gypsum and clay. The thickness of this zone was ranged between (17.7-30.2 m).

c- The third zone:-

- It represents the unconfined aquifer, where the resistivity was noticeably decreased, in the range of (14.7-65.2 Ω.m). This zone was consisted of gravel, sand and clay deposits. The upper part of this zone was the river terraces gravel of about 15-20 m thick, while, the middle and lower part of it were consisted of Injana formation of sand, clay and clay sandy deposits. It was noticed in this zone, that increasing in resistivity values on both sides of the geoelectrical section, and decreasing in the middle part of it, in points (3B, 4B), due to the changing in salinity of groundwater.
The resistivity was increased in points (5B, 6B), due to the location of these points near the recharge area, presented by the boundary of the subsurface fold, where the rain water were penetration through the valleys existed on the eastern flank of the fold. Again the resistivity values were decreased in points (3B, 4B) with the direction of groundwater, due to the increase of salinity resulted from reaction of groundwater with the surrounding deposits, and then the resistivity values increased in points (1B, 2B), because of it's location from Tigris river, and therefore the mixing of the aquifer water with that of aquifer on both sides of river the thickness of this zone was ranged between (91.4-100 m).

d- The fourth zone:
This zone was the last one, which represents the lower boundary of the aquifer, and was considered of claystone saturated with saline water, where the resistivity was largely decrease and reached mean value of (6.18 Ω.m).

3- The geoelectrical and geological section along C-C’ traverse:
This traverse is passing through seven sounding points (figure 11). A correlation process of interpretation VES point was made with the stratigraphic section of observed well no.3, and then detection of resistivity ranges with the different equivalent electric zones. After that, the geological section was drawn out form the geoelectric one, after smoothing (figure12). Study the two sections; the following zones can be noticed:

Figure 10. The geological section along B-B’ traverse

Figure 11. The geoelectrical section along C-C’ traverse.
10

Figure 12. The geological section along C-C’ traverse.

a- The first zone:-
As mentioned in the previous sections, there were two subzones of the top soil zone, the first was represented by high resistivity values of (113-982 Ω.m), while the second subzone of low resistivity values of (45.8-181 Ω.m), due to the degree of moisture in the two subzone and soil properties discrepancy. The total thickness of the zone ranged between (2.6-8.82 Ω.m).

b- The second zone:-
The gravel deposits of river terraces, which belong to the quaternary age, had resistivity values ranged by (39.8-300 Ω.m). That differences were due to the degree of moisture and vary of cementing material quality (mostly of clay or secondary gypsum). The thickness of this zone was ranged of (8.34-18.3m).

c- The third zone:-
This zone was considered as the aquifer of the area with the conditions of unconfined, this was due to thin clay bed existence in upper part of the aquifer, resistivity values were decreased noticeably of (8.5-20.5 Ω.m). This decreasing in resistivity values were not related as due to salinity increased in that zone, but can caused also by the electric conductivity of the existing clay deposits. This zone was consisted of sand and clay deposits as well as the small ratio of gravel mixed with the dominant deposits of Injana formation. This zone had a big thickness correlated with the above zones, thickness was ranged of (85.7-90.2 Ω.m), and this thickness did not represent the total saturated zone thickness, a problem of suppression principle was faced, due to the existing of clay bed at the top of the aquifer, which had a thin thickness and moderate value of resistivity. That can be missed the field curve. This situation caused the difficulty in detection the groundwater level in exact from, but water level was detected in this zone by the help of some drilling wells in the region,(figure11), (Al-joburi, 2011).

d- The fourth zone:-
This was represented by the saturated claystone bed with saline water, which called the lower boundary of the aquifer, and had a mean resistivity of (4.12 Ω.m).

4- The geoelectrical and geological section along D-D’ traverse:
Figure13 shows the location of seven VES points on the traverse. The correlation was made between the interpreted VES point 7D and the stratigraphic section of observed well no.3, than the detection of the resistivity values and the equivalent thickness of different electrical zone were resulted. After that the deduction of geological section form the geoelectrical one was made after smoothing (figure4). The following zones can be concluded as follows:

a- The first zone:-
As in the previous traverses, this zone was presented by two subzones, the first one was reflected by points 1D, 2D, 3D, which had a high resistivity ranged by (137-436 Ω.m). The section top soil subzone was represented by a low resistivity values of (46.4-92.6 Ω.m). The VES points (4D, 5D, 6D and 7D) were belonged to the first subzone of low resistivity zone of values range between (82.3-392 Ω.m), which the second subzone had a high resistivity values of (111-462 Ω.m). The fluctuation of resistivity values in top soil zone, was resulted from the difference of moisture, dryness, and discrepancy of physical, chemical and mineralogical properties of the weathered soil, as well as, to the existence of plant cover and agriculture use of the soil. The total thickness of this zone was (1.63-6.24 m).
b- The second zone:
VES points (1D, 2D, 3D and 4D), represents the quaternary deposits of river terraces gravel. Resistivity values ranged from (106-201 Ω.m), which, the thickness of this zone was of (17.7-22.3 Ω.m). On the other side the VES point (5D, 6D and 7D) were reflected the Injana formation of sand deposits, which outcropped in these point, and the resistivity values were ranged between (14.6-15.3 Ω.m), and the thickness (10-17.4m).

c- The third zone:-
Resistivity values were decreased in this zone, ranged by (6.37-13.8 Ω.m), due to the existing of groundwater. It is also noticed the close values of resistivity, could be reflect the similarity of lithology and groundwater quality along the geoelectrical section. This zone was consisted of clay, sand and sand clay of Injana formation, which considered as semi-confined aquifer of the region, due to the existing of confining layer of clay at the upper of the aquifer. The thickness of this zone was (74-96.3 m), this thickness didn't represent the total saturated thickness, due to electric suppressed clay layer, which bounded the top of zone, because this layer had a thin thickness moderate resistivity, relative to layers of upper and lower of the aquifer, and was not noticed in the field curves. That cause the difficulty in precise detection of groundwater. So, it was detected by the help of well no.25 which was located near the VES point (5D), near the well no.28 away of 1.5km northeast of VES point 1D, which was measured by (Al-joburi, 2011).

d- The fourth zone:-
This was the last zone of saturated claystone layer with saline water, and this zone was detected in all the geoelectrical section along the traverses, which had a value of 3.6 Ω.m, which considered as the lower boundary of the aquifer.

![Figure 13](image13.png) The geoelectrical section along D-D' traverse.

![Figure 14](image14.png) The geological section along D-D’ traverse.
5- The geoelectrical and geological section along F-F' traverse:

This traverse is passing through eight VES point (fiure15). The correlation of interpreted VES point (5F) with the stratigraphic section of the observed well no.1, located about 1 km. north-west of this well, were carried out, and detected the resistivity, and equivalent thickness to different electric zones. Later on, the geological section was drawn out from the geoelectrical section after smoothing (figure16) when study the two sections, the following can be resulted.

- The first zone:
  This zone represent the top soil of relatively small thickness of (1.5-3.13m) and resistivity varies of (30.9-320 Ω.m), and dryness in the zone discrepancy of soil property and differences of moisture and dryness in the zone. This zone was divided in two secondary zones at VES points (7F, 8F), while, the rest of VES points, were shown as one zone.
- The second zone:
  This zone was noticed in all the VES point of the traverse, except at point (1F). The lithology was determined as sand deposits belongs to the outcropped Injana formation, of resistivity value range of (17.1-86.1 Ω.m), due to differences of moisture and dryness degree near surface. The thickness in these VES point vary from (2.93-11 m).
- The third zone:
  This zone was represented by the confined clay bed which, bound the aquifer from the top, and belongs to Injana formation. The resistivity were decreased between (12.9-20.5 Ω.m). The thickness was ranged between (5-23.3 m).
d- The fourth zone:
This zone was consisted of alternation beds of sand, clay, and sandy clay, which represents the Injana formation. Because of the existing of clay layer, which bound the aquifer from the top, with a large thickness. This zone was represented by confined aquifer, due to the existing of groundwater and decrease the resistivity values to the range of (5.14Ω.m). The electrical conductivity of clay deposits can play the important factor of reducing the values of resistivity in this zone. Otherwise, values of resistivity were increased in VES points (3F, 4F, 5F and 6F) to reach the mean value of (35Ω.m), due to the existing of sand lens of average thickness up to (30m). The total thickness of this zone was ranged between (79.2-147m). There was noticed that the large displacement in the thickness of this zone reached to about (6m), where, the thickness was increased in the middle part of the traverse, while reduced at the end at points (1F, 8F), these displacement might because by the local faults located at the subsurface fold flank. But, due to the lack of geological information, and the similarity values of the resistivity along the geoelectrical section, could make it difficult to detect these faults.

e- The fifth zone:
This zone was equivalent to the fourth zone of all the previous traverse.

6- The geoelectrical and geological section along H-H' traverse:
This traverse is crossing the three previous C-C', D-D' and F-F' traverse, and passing through eight VES point (figure 17). The correlation of interpreted VES point (1H, 7H), with the stratigraphic section of observed wells no.(1&3) were carried out, and then the ranges of the resistivity and equivalent thickness to the different electrical zones were detected. After that, the geological section was deduction from the smoothed geoelectrical section (figure 18). Also the regional fault plane, whose, passing through the area and crossing the traverse between the VES points (3H, 4H), was fixed. This fault plays the main control factors of the aquifer parameter in the area. Quick look at the two section, five zones can be concluded as follows:

a- The first zone:-
This zone was represented in VES points (1H, 2H, 3H), as the top soil of thickness not more than (3.30m), and resistivity value up to (118Ω.m), while at VES points (4H, 5H, 6H, 7H and 8H), two secondary zones were recognized, the first, with top soil of low resistivity ranged between (27.8-127Ω.m), The cause of the differences was due to the discrepancy of soil character and moisture. The total thickness in these VES points were ranged by (6.38-8.98Ω.m).

b- The second zone:-
VES points (1H, 2H, 3H) was considered as sand deposits belongs to outcrop Injana formation of resistivity value ranged between (25.9-58.9Ω.m). The cause of this variation in resistivity values was due the difference of Moisture and dryness near the surface. The thickness of this zone at these VES point was ranged by (2.34-6.14m). while at VES points (4H, 5H, 6H, 7H and 8H), were represented by gravel deposits of quaternary river terraces, of resistivity values ranged by (67.03-236Ω.m), the variation in values were due to the quality of cementing materials which were accounted as clay or secondary gypsum. The thickness of this zone was ranged between (6.7-27.65Ω.m).

c- The third zone:-
VES points (1H, 2H, 3H) was considered as the zone of low resistivity clay layer belongs to Injana formation of resistivity value means (14.58Ω.m), which represents the confined upper limit larger of the aquifer. While, the VES points (4H, 5H, 7H and 8H) considered as the zone of aquifer with low resistivity values means of (8.9Ω.m), which, consisted of clay, sand and sandy clay with little of Injana formation gravel deposits. The existing of little thickness clay layer at the upper part of the aquifer zone, to become confining to semi- confining aquifer. The thickness of this zones at these VES points were ranged between (50.8-73m). Because of the existing of the electrical suppressed clay layer, that caused of the difficulty to detect the groundwater level, and that required the assistance of well no.39, whose measured by (Al-joburi, 2011). Besides, that the traverses (C-C') and (D-D') were crossed by (H-H') traverse at VES point (3C and 4D), which can easy to deduce the groundwater table of the area.

d- The fourth zone:-
This zone was consisted of clay, sand and sandy clay of Injana formation deposits at VES points (1H, 2H, 3H), which represents the confined aquifer in the area, due to the existing of clay layer at the top, as well as, the existing of sand lens at the bottom with (15-28m) thickness, and average resistivity of (31.5Ω.m). The resistivity values were decreased in this zone to reach the average of (8.6Ω.m). The thickness, were due to the vertical displacement which, caused by the existing fault in the area. The other VES points (4H, 5H, 6H, 7H and 8H) were considered as claystone layer of low resistivity value reached an average of (3.34Ω.m), due to saline water saturation.

e- The fifth zone:-
VES points (1H, 2H, 3H) were represented the zone of claystone layer of low resistivity reach to average of (2.3Ω.m). This layer was considered as the end of the Injana formation aquifer, which bounded by claystone bed. It was
also noticed formation that, there was incredible decreasing in resistivity values at VES point (3H), near the fault plane, and that might be resulted from the seepage of saline groundwater through this fault from the lower geologic formations which most likely from Fatha formation.

![Figure 17. The geoelectrical section along H-H' traverse.](image1)

![Figure 18. The geological section along H-H' traverse.](image2)

**Calculation of thickness and resistivity of aquifer in the studied area**

The thickness and resistivity values were calculated for the groundwater saturated at all (VES) points, depending on final interpretation of vertical electrical sounding (VES), and on the drilling wells in the area. Then the values of thickness and resistivity, were used in drawing the saturated isopach thickness and resistivity maps of the aquifer (figure19 and figure 20). It was noticed from figure 19, that the saturated layer thickness was relatively constant at most of studied area, except in the north-west part, where is an increased thickness towards the north-west of the area, up to (138 m). This increment was coincided with the position of displacement caused by the subsurface fault, which was clearly noticed in geoelectrical of geological section along (H-H')traverse. The rest of the studied area was characterized by gradually gently increase in saturated zone thickness, staring from the area of subsurface fault, towards south-east of the area, about (50-95m) thickness of the zone. The reason of that increase, was due to the increased of gravel layer thickness, of quaternary deposits in this direction, near Tigris river, to reach of about (40 m) layer thick, which was considered in some areas, as a part of the aquifer.
in the region. While, the Iso-resistivity map of the saturated layer, shows the increased in values of the resistivity with that of increased the thickness of the saturated zone. This increase was started from the position of fault and towards south-east. Also this increase in Iso-resistivity values, near the subsurface fold, which was considered as recharge area for the basin, due to the rain water in put through the streams located on west of the region, and as approaching from the Tigris river. The reason for that increase was to the mixing between groundwater with water of beach aquifers location on both sides of the Tigris river. Variation of aquifer lithology was also another caused for this increase, besides the existing of river terraces gravel deposits layer, which had high resistivity values, relative to the resistivity of Injana formation deposits. The gravel resistivity could affect that of saturated zone resistivity, but this depends on the saturated thickness of this layer, which combined with that of total saturated zone thickness. The existing of gravel layer above the aquifer in the area was considered as a good filtration layer through the aquifer. It was noticed the decrease values of resistivity in north and north-western part of the area, could be due to the absence of gravel bed, as well as to the increase of clay in aquifer deposits, which caused the resistivity decreasing. A resistivity value decreasing also, clearly noticed on both sides of subsurface fault position, might be resulted from groundwater salinity increasing, due to the seepage of saline groundwater from the existing formation at the bottom of the main aquifer of the area through the fault plane, and mixing with Injana deposits of the main aquifer of the area.

Groundwater levels and it's movement in the studied area

The level of groundwater bearing strata values, relative to the sea-level were calculated, at each VES point, with the use of geoelectrical and geological section. Then these values were used in drawing the counter map to explain the position of level variation (figure 21), which can conclude the direction of groundwater movement in the region. It was noticed in the north-western part of the area, that the groundwater levels map did not detect the direction of water movement, but, was explained in a random directions, and that was due to the changing of the aquifer characteristic from the confine to the semi-confine one, in the region. The reason of that was the existing of confined clay layer, which bound the aquifer from the top, and clearly exposed in the geoelectrical section along F-F' traverse (figure 15). The water level was taken the topographic shape of confined layer as in figure 16 and figure 18. Then the direction of water movement will take
a certain direction after the subsurface fault area, due to the changing of aquifer characteristics from the semi-confined, to the unconfined type in that area.

The direction of water movement was to the south, after the fault area, then changed gradually at the middle of the studied area, towards the south-east (i.e the Tigris river) which represents the general direction of the groundwater of the area. Later on the direction of movement at the southern part of the studied area, to become east and north east towards the valley crossed that area. It was found that the derivation of water movement directions from the (figure 21), was completely coincide with the values of water levels above sea level (figure 22), which computed in some drilled wells of the studied area, except that of north and north-western part of the area. It was noticed from the (figure 22), that the water movement was towards the south east and that due to the process of water levels measurement in the drilled wells existing in the area, did not represent the real level of the aquifer, because it’s of the confined type, which in that the well can be considered as local situation, so that to let the pressure of the aquifer will rise the water level in the drilled well only to the level that, equalized the atmospheric pressure with the confined water which called potentiometric surface. This can give the wrong estimation of water level, but the direction in that area shown at the map, was towards the general trend of the groundwater in the area, due to topographic reason.

A closed contour was noticed in the south-eastern part of (figure 22), which can be considered as a severe pumping discharge area of groundwater, that let the part recharged from all direction in a radiation pattern. This large coincidence in groundwater movement direction, shown in the drawn map, was depended on the results of VES survey, and the direction from well information, will improve the success of the VES method to detect the groundwater level in the studied area. The accuracy of the interpreted results with the procedure of data interpretation was also improve that.

![Figure 21. groundwater levels and movement direction map from the VES survey.](image1)

![Figure 22. groundwater levels and movement direction map from the wells information.](image2)

The geoelectrical and hydraulic parameters relations

The geoelectrical and hydraulic parameters of the studied area aquifer were used, which were extracted from the result of four VES points curves interpretation, location about one km. away from four observed wells, in order to get more precise imperial relation later on.
The relation in (Zohdy, 1974), were used. While the transmissivity values have been obtained from the experiment pumping test results, carried by (Al-joburi, 2011), for four wells, which were computed by Jackob's method in analysis of the results of pumping test, and that gave high confident factor R².

The hydraulic conductivity values were calculated from the relation between the transmissivity and the thickness of aquifer, (Table 1).

Table (1) values of geoelectrical and hydraulic parameters for the aquifer in some of VES point and wells in the studied area

<table>
<thead>
<tr>
<th>VES No.</th>
<th>Well No.</th>
<th>Transmissivity T (m²/day)</th>
<th>Hydraulic Conductivity K (m/day)</th>
<th>Transverse resistivity ρt (ohm.m²)</th>
<th>Longitudinal conductance S (ohm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A</td>
<td>Ob.4</td>
<td>881.9</td>
<td>16.64</td>
<td>2426.83</td>
<td>3.64</td>
</tr>
<tr>
<td>7D</td>
<td>Ob.2</td>
<td>162.1</td>
<td>2.15</td>
<td>585.9</td>
<td>8.36</td>
</tr>
<tr>
<td>1H</td>
<td>Ob.1</td>
<td>1092</td>
<td>13.24</td>
<td>1818.9</td>
<td>9.14</td>
</tr>
<tr>
<td>7H</td>
<td>Ob.3</td>
<td>152.2</td>
<td>2.34</td>
<td>435.25</td>
<td>7.53</td>
</tr>
</tbody>
</table>

The resistivity values for porosity water (pw) were calculated from the water (EC) readings of some the wells measured by (Al-joburi, 2011), by using the relations mentioned in (Todd, 1980). Then these results were used to calculate the formation factor (F) with the resistivity values, which was calculated from some (VES) point located near of the used wells by 1 km. (Table 2).

Table (2) porosity water resistivity and formation factor of the aquifer in some (VES) point and wells of the studied area.

<table>
<thead>
<tr>
<th>VES No.</th>
<th>Well No.</th>
<th>Hydraulic Conductivity K (m/day)</th>
<th>Aquifer resistivity ρ (ohm.m)</th>
<th>Electrical conductivity of water Ec (μmhos.cm)</th>
<th>Water resistivity ρw (ohm.m)</th>
<th>Formation factor F</th>
</tr>
</thead>
<tbody>
<tr>
<td>3A</td>
<td>Ob.4</td>
<td>15.82</td>
<td>25.9</td>
<td>3400</td>
<td>2.94</td>
<td>8.8</td>
</tr>
<tr>
<td>7D</td>
<td>Ob.2</td>
<td>2.63</td>
<td>8.37</td>
<td>3500</td>
<td>2.85</td>
<td>2.92</td>
</tr>
<tr>
<td>1H</td>
<td>Ob.1</td>
<td>9.14</td>
<td>14.1</td>
<td>4100</td>
<td>2.43</td>
<td>5.1</td>
</tr>
<tr>
<td>7H</td>
<td>Ob.3</td>
<td>3.58</td>
<td>7.6</td>
<td>4900</td>
<td>2.04</td>
<td>3.72</td>
</tr>
</tbody>
</table>

Figure 23 show the normal linear relationship between the hydraulic conductivity and formation factor of the studied area aquifer, and used the relation pointed in figure 23, with confidence factor R²= 0.98.

From the above relations, some conclusion can be made:

1- There was an inverse relation between the porosity and hydraulic conductivity in the aquifer, due to un homogeneity distribution of porosity in aquifer deposit, where, it was noticed that the changing in grain size in gravel, sand and clay, from coarse grains without cementing material or with cementing materials of clay or sandy clay. It was also noticed that the sand grain size changing from fine to coarse grain, because the clay that exist in after or mixed with sand or silt or gypsum. The packing process have the large effect on porosity to change in grain size (Lohman, 1972).

2- Reverse proportional relationship between the resistivity with porosity according to Archie’s law. Due to the normal proportional relationship between the hydraulic conductivity and formation factor, and reverse relation with porosity, it was concluded that, the normal relation between resistivity and hydraulic conductivity was existed in the aquifer of the studied area.

The relationship between resistivity and hydraulic conductivity

This relation was considered as one of the complex relations that connected many geological and hydrogeological factors, to control the type of either normal or reverse relation and it's linear or curved shape. But often was normal in the clastic not consolidated aquifers. The relation was normal if exist more than one type of rocks or different grain size deposits. It was often a curve relation for the clastic aquifer, because of an isotropy. It was also noticed that, the relation was larger depended on the ration of clay (Kelly, 1977).

In this study, It was preferred to use the transverse resistivity (ρt) in drawing the relation with hydraulic conductivity for getting the best possible relation, due to the following reasons:

1- The conditions of the aquifer were very convenience, where the aquifer was relatively thicker than the unproduced layer and placed or postured directly above the impermeable claystone layer of high electrical conductivity. That was clearly appeared in all geoelectrical section.

2- The studied area aquifer was considered as stratified type. It consist of alternate layers of gravels, sand, clayey sand and clay. So, the flow direction of water in the aquifer, was considered, parallel to the strata plane. Therefore, the
best possible relation will be existed between the transverse resistivity and hydraulic conductivity of the parallel strata plane.

3- The flow direction of the electric current in the aquifer was perpendicular to the strata plane, due to impermeable claystone layer existence, that bounded the aquifer from the bottom, which have higher conductivity that the aquifer. So that's why? The transverse resistivity was controlling in the aquifer.

![Figure 23](image1.png)  ![Figure 24](image2.png)

*Figure 23.* shown the relation of formation factor with hydraulic conductivity in the aquifer of the studied area.  
*Figure 24.* shown the relation of transverse resistivity with hydraulic conductivity in the aquifer of the studied area.

The values of transverse resistivity (ρt) and hydraulic conductivity (Table 1), was used in plot the normal linear relation as shown in figure 24. It was found that the confidence factor of the relation in figure 24 was R² = 0.96.

Again from the normal relation between transverse resistivity and hydraulic conductivity, the following can be concluded:

1- There was a normal relation between the resistivity (ρ) and hydraulic conductivity, because of the normal relation of the transverse resistivity with the resistivity. But at the same time, that means the reverse relation between the porosity and hydraulic conductivity was existed, that relation was courage by the relation of formation factor with the hydraulic conductivity.

2- The underground aquifer was considered as heterogeneous medium in lithology and grain size, so that alternate of many layers in the aquifer of the area, was affected the porosity and hydraulic conductivity.

3- The normal relation in the unconsolidated clastic aquifer depends on the ratio of existed clay in the aquifer, where, the clay is acting on decreasing the resistivity and hydraulic conductivity, which will affect the porosity, as was the case of studied area. Where, it was shown the existed of high personage of clay deposits in the most of the drilling wells that was existed in the area.

4- The normal relation means, there was no large effect of fracture on the hydraulic parameters in the area in spite of the existing some local and regional faults in the studied area. That was because of the existing of clay in these cracks and fractures, which acting on the decreasing both of resistivity and hydraulic conductivity for the studied area aquifer, besides, the existing of saline water, which also decrease the resistivity.

5- From figure 24, it was noticed from the normal relation, that the calculation of resistivity of the porous water in the four wells values listed in (Table 2) was nearly closed and ranged between 2.04-2.94 Ωm.

Therefore, the variation in resistivity values was depended here on the aquifer lithology, where was noticed the increasing of clay ratio in the wells will lead to decrease the resistivity values as in (ob.1, ob.2).

Increasing of the clay ratio on both wells will decrease the value of resistivity in VES point located near them, as in VES point (1H) near ob.1 (figure17) and VES point (7D) near ob.2 (figure13). On contrary, noticed that rising in resistivity values in VES point located near the wells that contains on low ratio of clay deposits, as in VES point (3A) near (ob.4) and VES point (7H) near (ob.3), (figures. 7, 17).

The relation of transverse resistivity with hydraulic conductivity was used to calculate hydraulic conductivity values at any point within the studied area, just finding the transverse resistivity values of any point, and use the equation in (figure24), however, transverse resistivity values of the aquifer were calculated from the quantitative interpretation result, and then used the equation in figure24, to calculate the hydraulic conductivity at each VES point. Then, the calculated hydraulic conductivity values were used to plot the hydraulic conductivity map of the aquifer (figure 25). This map can be used to
delineate the locations of high and low hydraulic conductivity, and then can be used to detect the location of new good production drilling wells, and avoid the locations of low production. The equation of figure 25 can be used to calculate the hydraulic conductivity in the new area of the similar geological and hydrogeological conditions to the area of study. From the above discussion, a problem of groundwater hydrogeological division, can be noticed. Two aquifers were classified in VES points along A-A’ and B-B’ traverses, the first one was located within the quaternary deposits, and the second aquifer was represented by Injana formation. But these aquifers were shown as one aquifer electrically, due to the similarity of their resistivity, and there is no clear change in water quality of both aquifers, or existing of clear contact between them. In this case hydraulic conductivity values were needed for both of the aquifers, which were unavailable here, and therefore, can be calculated for both aquifers, through the computed transmissivity values of the aquifer from the pumping test results achieved by (Al-Joburi, 2011). The calculated values of resistivity were represented for both of aquifers, so, the hydraulic conductivity has been computed for both aquifers, which can be represented the average hydraulic conductivity in the area of the traverses mentioned above, which represent the southern part of the studied area. The rest parts of the area, one aquifer was noticed which represented by Injana formation, and finally the computed hydraulic conductivity in the rest of the studied area was reflected the total hydraulic conductivity of the aquifer. The hydraulic conductivity map shown the gradually increase in the values from the southern part of the regional fault towards the south and southern east, and that because of the increased gravel ratio belongs to the quaternary within the aquifer in this direction. This was indicated by the good conductivity of the gravel layer and the decrease of clay ratio and increase porosity in the aquifer in the same direction also. It was also noticed the relative increase in hydraulic conductivity values as approaching the subsurface fold feeding area, due to the active porosity increase, which was resulted from the increased secondary porosity represented from fractures and creaks in clay layers results from the folding process and from the local faults along the fold flanks. If that was the case, the hydraulic connection will occurred in the aquifer parts with the other formations. The hydraulic conductivity was also increased as approaching the drainage area (i.e Tigris river), due to the existing of highly porosity and permeability flood plain deposits on Tigris river shoulder. It was also noticed the big decrease in hydraulic conductivity in the area located on both sides of the regional fault and the area located north and north east of the fault, that was due to the increased clay ratio, and decrease the active porosity, which was mainly the conductivity depended on. The Injana formation as the main aquifer of the area, was outcropped in this part of the region. The clay was acting on decreasing the transverse resistivity values proportionally with the hydraulic conductivity in equation on figure 25. Also noticed that the gradually increased in hydraulic conductivity values at the north part of the basin as approached from the sand dunes (feeding area), and because of the increased thickness of the aquifer in the same direction due to displacement caused by the fault. The thickness increased up to (138m) in this area did not affect the conductivity value, due to the increased clay ratio at the area as explained in ob.1 section (figure 6 and 17).

The relation of geoelectrical parameters with transmissivity

Two geophysical models can be suggested for the aquifer by evaluate the sharp of relation between the geoelectrical and hydraulic parameters of the studied area. A comparison with the models suggested by Frohlich was made in order to choose the suitable one for the studied area aquifer. This can be accomplished through studied the following relations:

1- Relation of transverse resistivity ($\rho_t$) with longitudinal electric conductivity ($S$).
2- Relation of transmissivity ($T$) with transverse resistivity ($\rho_t$).
3- Relation of transmissivity ($T$) with longitudinal electric conductivity ($S$).

The final aim of these relations was to derive transmissivity values for the studied area's aquifer, that which calculated from the geoelectrical properties, as in the case of hydraulic conductivity and at the end, the map of transmissivity variation was constructed for the area (figure 26).

The normal relation between the resistivity and hydraulic conductivity was obtained with confidence factor of $R^2=0.94$ and by using equation in figure 27. from the three relation that were used in plotting for the suggested model (i.e values of transverse resistivity, longitudinal electric conductivity, and transmissivity as listed in table 1). It was noticed the conformation with second model of Frohlich, 1994, which resistivity and hydraulic conductivity were varied with the fixed thickness as in figure 28, the following items in this figure can be noticed:

1- Reverse relation between the longitudinal electric conductivity and transverse resistivity (figure 28a), and normal relation between the transverse resistivity and transmissivity (figure 28b), while the relation of longitudinal electric conductivity with transmissivity gave the reverse relation (figure 28c).

2- From the relations 28b and 28c in (figure 28 b, c), it was noticed that the transverse resistivity relation with transmissivity was better than longitudinal electric conductivity with transmissivity due to its controlling effect in
the aquifer, and gave higher confidence factor with transmissivity than that of longitudinal electric conductivity with transmissivity. So where the relation of transverse resistivity with transmissivity was preferred than the longitudinal electric conductivity relation, when the normal relation of resistivity and conductivity was obtained, on opposite, when the relation of longitudinal electric conductivity with transmissivity was preferred from the relation of transverse resistivity with transmissivity, when the relation of resistivity and hydraulic conductivity was reversed. But in the case of the studied aquifer, the relation was normal, and that means the transverse resistivity was controlled in the studied aquifer.

Figure 26. Transmissivity map of the area, according to geoelectrical properties.

Figure 25. Hydraulic conductivity map of the area, according to geoelectrical properties.

3- The weak connection between points in figures 28a and 28c, and scattering the points was due to vary of the studied aquifer thickness at all VES points, or the existing clay ratio in aquifer caused the distortion in the longitudinal electric conductivity relation with both of transverse resistivity and transmissivity. The major part of conductivity caused by the existing clay in the aquifer.

4- It was concluded from the above relations that the studied aquifer was anisotropic medium, because of the two variable resistivity ($\rho_v$) and hydraulic conductivity ($k_v$). While the thickness was relatively constant ($h_v$), as noticed in Isopach map of figure 22, the thickness was changing in small limit, except the affected area by displacement around the regional fault. The hydraulic conductivity was varied from part to part in the aquifer which consists of alternation of gravel sand, and clay. The resistivity was affected by three factors in the aquifer. There are the porosity, lithological structure and saline porous water, (figure 20).

5- The equation (26-5) was used to compute the transmissivity value at any location within the studied area by getting transverse resistivity at that location. The transverse resistivity calculated at each VES point, and then these values were used to calculate. The transmissivity values at each VES point by using this equation, and later on the transmissivity map for the aquifer could be plotted (figure 26). This map was used to delineate the high values that represents the location of new suggested wells of good production. While the equation in (figure 28c) cannot be used to calculate the transmissivity values in the studied area, because of very weak confidence factor $R^2 = 0.21$.

6- The equation 28b in figure28b was used to calculate the transmissivity values for aquifers in other area with similar geological and hydrogeological condition to the studied area. It was noticed from (figures 26, 25) the complete matching between the two maps, due to the normal relation of hydraulic conductivity with transmissivity as in
There was an increase transmissivity value towards the south and south east (figure 26), and that was coincided with the increased active porosity and thickness of quaternary gravel within the aquifer. This layer have good active porosity (i.e increased hydraulic conductivity which proportional to the transmissivity), that was led to increase the aquifer thickness and transverse resistivity which also proportional to the transmissivity (equ. 28b). Relations of transmissivity values with that of conductivity values as approach the feeding area of subsurface fold, was noticed in the studied area.

Conclusions
Depending on: result of the interpreted VES points, and the geological –hydrogeological information, and the suggested geophysical model, we can conclude follows:

1- Two aquifer were detected in the region, these area:
   a- Primary main aquifer represented by Injana formation (U-Miocene)(sand, clay sand, and clay), which had a changing type of aquifer from the confining aquifer one, in northern part of the region, to the semi-confine aquifer in the mid-and south of the region. This aquifer has a thickness ranging of 50-128m, increasing in the northern part due to the discilacement of the regional fault. In the other hand, thickness of the aquifer was relatively constant the middle and southern the region.
   b- Secondary unconfined aquifer consist of gravels of river terraces of Quaternary. This aquifer appears in the southern part of the region at the Traverses A-A’, B-B’ only, and existed at the top of the main aquifer with 5-25m. thickness. The resistivity has changed from 39.8- 346 Ωm due to the existent lateral and vertical changes of clay –secondary gypsum ration.
2- The clay layer as lower boundary of the main aquifer, has a very low resistivity ranged between 1.28-8.3 Ωm, which can helped to delineate the depth penetration of the survey. These low resistivity could be salted groundwater saturation (due to concentration of the current this layer and could not penetrated).

3- Groundwater table were ranged between 87.97 to 130.87 m, above S.L., which increased in the northern part of region as approached from the subsurface fold, while decreasing in the middle and southern part of the region, i.e towards the discharge area (River).

4- Agreement of general trend of groundwater movement with the topographic of the area, i.e towards the south-east (towards the river).

5- Increasing, the salinity and conductivity of the groundwater in the contrary with it is motion. That means towards the north and north west, which is due to non homogeneity in porosity distribution of the aquifer sediments. Noticed that the porosity decrease with the direction of increased salinity and conductivity (mid-north region), due to the absent of gravel layer there. Also due to the effect of the regional fault on the increasing salinity in mid-north area, due to the mixing of water in the main aquifer along the fault plane, with the water of the formation under line (like Fatha Fm. or Injana Fm. from secondary aquifer).

6- Harmonized between the suggest geophysical model of the studied area, with the second model of Frohlich, whose was supposed to have a constant thickness and varying resistivity and hydraulic conductivity of the aquifer, which is indicate that:
   a- The main aquifer was considered as non-identical media in terms of resistivity and hydraulic conductivity, while a constant thickness was relatively in most area, with minor exception, in the north and south of the regional fault part of the studied area.
   b- The variability of the resistivity and hydraulic conductivity, were resulted from the lithology changing in the aquifer (gravel, sand, clay) which can affect the active porosity, changing the salinity and increasing clay ration in the aquifer.

7- Transmissivity for the aquifer were computed and ranged between 200/2200 m²/day, while the value of hydraulic conductivity ranged between 2-36 m/day. These variation were due to:
   a- Increasing and decreasing of saturated thickness: transverse resistivity was normal proportional with thickness, hydraulic conductivity, and Transmissivity.
   b- Lithologcal variety: Aquifer resistivity was proportional to the transverse resistivity and changing active porosity, which effect on hydraulic conductivity.
   c- Clay ratio: increasing clay ratio leads to decrease the transverse resistivity value and active porosity, which they are both proportional with Transmissivity and hydraulic conductivity.

8- In spite of the shortage in pumping test wells in the area, but it shows the superb distribution of the studied area.

9- VES point along traverses A-A' and B-B', could be considered as a new location for a very high production wells, due to high value of Transmissivity, range between 552.9-2180 m²/day and high thickness of the aquifer range between 89.9-100m. As well as the VES points (3C, 2D, 3F, 4F, 1H), which a Transmissivity value (403, 547, 700, 612, 445, 477) respectively.

10- Many quarries can be located to exploit the quaternary gravel in the southern of the area, as approaching the river.

**Recommendations**

The urgent needs of water in region because of its importance in the Agriculture, which invited us to establish a plan for water source management. Therefore, a recommendation can be made through this study as follows:

1- No utilization in the region located near the regional fault, unless drill a new wells away 2km at least from the position of the fault, because of the decreasing the saturated thickness and increasing the salinity of groundwater there.

2- Carrying out horizontal or 2D electrical survey for the region, or carrying another geophysical methods especially in the northern part of the region and on the subsurface fold flank, in order to delineate the local faults and their defect on the aquifer conditions.

3- Execute a new VES point near the military area on inside it and to connect the results with that of this study in order to complete the geological and hydrogeological profile in the region.

4- Carry on the recent study on the neighbor basins, because, it is one of the distinctive economic study, easy to excite and fast in getting the results.

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