PERFORMANCE EVALUATION OF WATER WELLS IN HAIBAT SULTAN MOUNTAIN, KURDISTAN, IRAQ

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ABSTRACT

Some of the cities in Kurdistan Region of Iraq depend completely on the groundwater, as a main source of water in their water supply systems, where the cities are too far from surface water resources, and because the mountainous topography of the land makes the transformation of surface water for long distances, too difficult. One of those towns, which depends on the groundwater, as one of the main sources in water supply is Koi Sanjak, located in Erbil Governorate, north of Iraq.

In this study, the groundwater is carefully investigated by evaluating the performance of water wells, which are located within Haibat Sultan Mountain; to the east of the city. From the previous geological investigations, the study area includes four geological formations, which are from oldest to the youngest, Kolosh, Gercus, Pila Spi and Fatha formations. The deep wells are drilled within Pila Spi Formation, the lithology consists of fissured marly limestone, thickness of the aquifer ranges between (149 – 188) m, this type of formation is considered as a good aquifer for the groundwater accumulation. For the study of the hydraulic characteristics of the aquifer, five deep wells were selected. The single well test method was used for analyzing the well characteristics; since observation wells are not available in the studied area. Pumping test data are analyzed to obtain the hydraulic properties of the aquifer, such as transmissivity, coefficient of permeability, specific capacity and specific yield. The pumping test also gives information about hydro-geological properties of the aquifer, such as the type and thickness of the aquifer.

The previous geological investigation in Haibat Sultan Mountain exhibits, that Haibat Sultan aquifer is of unconfined type; while the results of the current study exhibit that the aquifer varies from unconfined, at some location to leaky aquifer in others. This may give an expectation that the slope sediments on the overlying layer may act as aquitard and causing the aquifer to behave as a leaky aquifer. The current total yield of Haibat Sultan aquifer is 1194 m^3/day.

تقييم أداء الآبار المائية في جبل هيبة سلطان، كوردستان، العراق

محمد عويد، گلاويز بكر باپير و هاوكار باپير بكر

المستخلص

تعتمد بعض المدن في إقليم كردستان العراق كليا على المياه الجوفية كمصدر أساسي في نظام تجهيز المياه وذلك بسبب بعد تلك المدن عن مصادر المياه السطحية وبسبب طبوغرافية المنطقة مما يجعل من الصعب نقل المياه السطحية لمسافات طويلة لتجهيز المدن. ومن تلك المدن التي تعتمد على المياه الجوفية في تجهيز المياه هي مدينة كويسنجق التي تقع في محافظة أربيل، شمال العراق.

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في هذه الدراسة سوف يتم التحري بعناية عن المياه الجوفية من خلال تقييم أداء منظومة الآبار المائية الواقعة على جبل هيبة سلطان إلى الشرق من هذه المدينة. وجد من التحريات الجيولوجية السابقة بأن المنطقة قيد الدراسة تتألف من أربع تكوينات جيولوجية من الأقدم إلى الأحدث وهي كولوش، جيركس، بيلاسپي وفتحة. تم حفر الآبار في تكوين بيلاسپي والمقطع الجيولوجي يتألف من الصخور الجيرية الطفلية المتشققة، سمك الطبقة الحاملة للمياه يتراوح بين (149 – 188) م وهذا النوع يعتبر من الطبقات الجيدة لتجمع المياه الجوفية.

لدراسة الخصائص الهيدروليكية للطبقة الحاملة للماء تم اختيار خمسة آبار للفحص، حيث إن بقية الآبار غير مهيأة لهذا الغرض. تم استعمال طريقة فحص البئر المنفرد في دراسة خصائص البئر، في حين لم تتوفر آبار مراقبة في منطقة الدراسة. تم استعمال فحص الضخ للبئر المنفرد في تحديد الخصائص الهيدروليكية للطبقة الحاملة وهي الناقلية الهيدروليكية، معامل النفاذية، السعة النوعية والإنتاج النوعي.

إن فحص الضخ يمكن أن يعطي تصورا عن الخصائص الهيدروجيولوجية للمنطقة، مثل نوع الطبقة الحاملة وسمكها. إن خصائص الآبار التي تم فحصها تشير إلى أن الإنتاج النوعي والسعة النوعية للآبار تزداد بالاتجاه الشرقي للمنطقة قيد الدراسة.

أظهرت الدراسات الجيولوجية السابقة لجبل هيبة سلطان بأن الطبقة الحاملة للماء هي من النوع غير المحصور، لكن نتائج الدراسة الحالية أظهرت بأن هذه الطبقة الحاملة للماء تتباين من النوع غير المحصور، في بعض الأماكن إلى طبقة ناضحة في أماكن أخرى، وهذا يمكن أن يعطي تصورا بأن ترسبات المنحدرات في الطبقة العليا من الطبقة الحاملة يمكن أن تعمل كطبقة شبه نفاذة مما يجعل الطبقة الحاملة تتصرف وكأنها طبقة ناضحة، يبلغ الإنتاج الحالي لطبقة هيبة سلطان الحاملة للماء 1194 م^3/ يوم.

INTRODUCTION

The study area is located in Haibat Sultan Mountain, 2.5 Km north of Koi Sanjak town and 70 Km east of Erbil city, central northern part of Iraq. It is bounded by UTM 3991000 and 3998300 in the north and 467000 and 476000 in the east, as shown in Figs. (1 and 2). Haibat Sultan Mountain represents a limb of Safeen anticline, the bedding planes are steeply dipping with an amount of $(40 – 50)^o$ to the southwest direction, it extends in NW – SE direction and has an elevation of about 1200 m, above sea level.

The southwestern flank of Haibat Sultan Mountain is suitable for drilling deep water wells; therefore, many deep wells are drilled in the study area with different depths, depending on the thickness of the aquifer. For determining the hydraulic characteristics of the aquifer, five water wells were selected to be tested by pumping, the pumping test is also known as aquifer test. The test was performed by pumping the well for a sufficient period of time and the change in water level in the well was observed.

Many studies have been carried out in the study area by several authors, most of the studies are focused on the geological exploration of the area, among them are:

- Sissakian and Youkhanna (1979) dealt with the stratigraphy, structure and geomorphology of the study area.
- Al-Qayim and Nisan (1989) dealt with the sedimentary facies analysis in the area.
- Al-Saadi and Al-Jassar (1993) studied the instability of rock slopes controlling part of the main road cut slopes at the southwestern side of Haibat Sultan Mountain.
- Sissakian (1997) dealt with the geology of the study area.
- Saber (2006) studied the role of the natural geographical factors on the slope surface of Haibat Sultan Mountain.

This study aims to evaluate the performance of Haibat Sultan's wells and finding the aquifer characteristics.

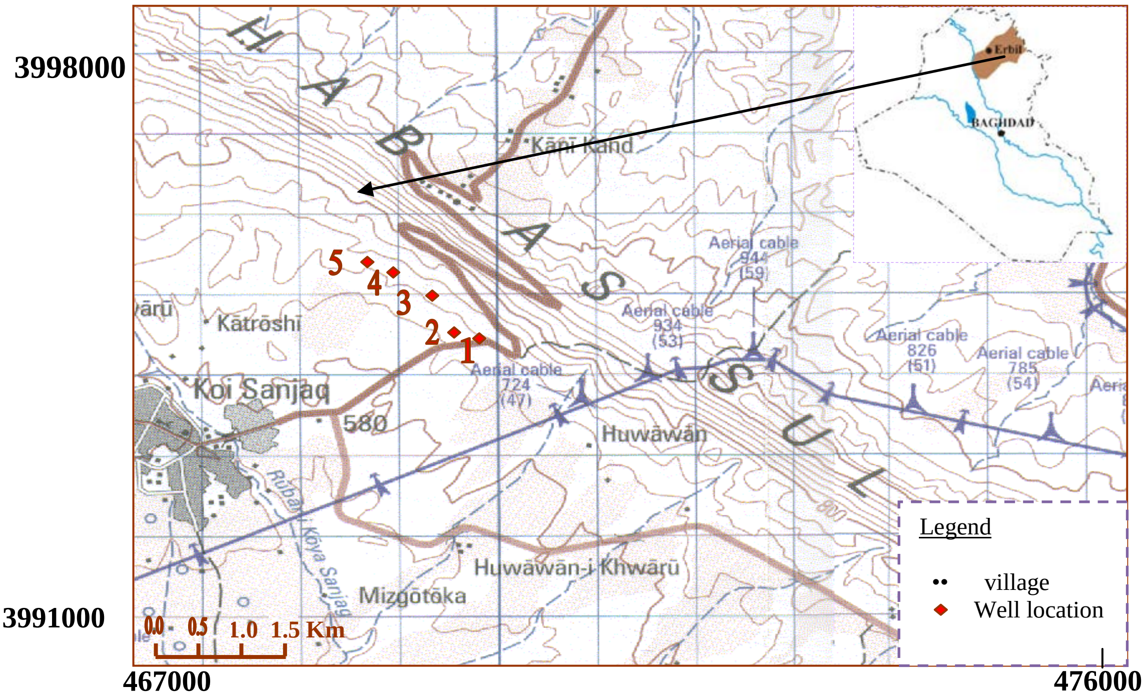

Fig.1: Topographic map of Haibat Sultan Mountain
shows the locations of the wells

Fig.2: Satellite image of Haibat Sultan Mountain

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

According to the classification of Buday and Jassim (1987), the study area is located within the boundary of the High Folded Zone and Foot Hill Zone, Chamchamal – Butma Subzone. This zone occupies the central part of the Unstable Shelf. The Haibat Sultan Mountain represents a limb of Safeen anticline; the bedding planes are steeply dipping with (40 – 50)º to the southwest direction. In the study area, four formations are exposed, these are from the oldest to the youngest:

─ **Kolosh Formation:** The age of this formation is Paleocene – Lower Eocene (Bellen *et al*., 1959) it is exposed in the northeastern part of Haibat Sultan Mountain, it consists of green, dark grey shale and thin lenses of sandstone, and the overlying formation is Gercus.

─ **Gercus Formation:** The age of this formation is Middle Eocene (Bellen *et al*., 1959), it is exposed in the northeastern side of Haibat Sultan Mountain. This formation consists of alternation of red claystone, siltstone and sandstone; tongues of limestone also may exist.

─ **Pila Spi Formation:** This formation is of Middle – Upper Eocene age (Bellen *et al*., 1959 and Buday, 1980). It forms continuous steep ridges at the crest and southwestern sides of Haibat Sultan Mountain. The formation, in the study area consists mainly of light gray and yellowish white color, well bedded fissured limestone and marly limestone.

─ **Fatha Formation:** This formation is of Middle Miocene age (Bellen *et al*., 1959). It forms a continuous belt at the southwestern side of Haibat Sultan Mountain. The formation consists of cyclic sediments of mudstone and thin layers of limestone and gypsum. The mudstone is reddish brown in color, soft and represents the main constituent of the formation. The limestone is light grey and brown in color, well bedded and hard, some limestones are fossiliferous with chert nodules, also gradual changes of marl and marly limestone occur at the middle part of this formation.

The lithological section for each deep well is illustrated in Fig. (3). From the section of the wells, the thickness of the aquifer was determined. A brief description of the wells is mentioned hereinafter.

Well No.1, from the ground surface to the depth of 28 m, consists of slope sediments, and from the depth of 28 m to 216 m the well lithology consists of fissured marly limestone, which is characterized by high fissures and joints and is considered as a good aquifer. The thickness of the aquifer is 188 m.

Well No.2, from the ground surface to the depth of 16 m, consists of slope sediments, and the thickness of the aquifer is 149 m. The lithology consists mostly of fissured marly limestone.

Well No.3, from the ground surface to the depth of 24 m, consists of slope sediments and the thickness of the aquifer is 186 m. The lithology consists of fissured marly limestone.

Well No.4, from the ground surface to the depth of 16 m, consists of slope sediments, and the thickness of the aquifer is 186 m. The lithology consists mostly of marly fissured limestone.

Well No.5, the aquifer thickness is 184 m and has the same characteristic of well No.4.

In a vertically layered structure, with some of layers are being aquifers and others being aquitards or perhaps aquicludes. Pila Spi Formation, which consists of bedded fissured marly limestone, is considered as a good unconfined aquifer in the study area.

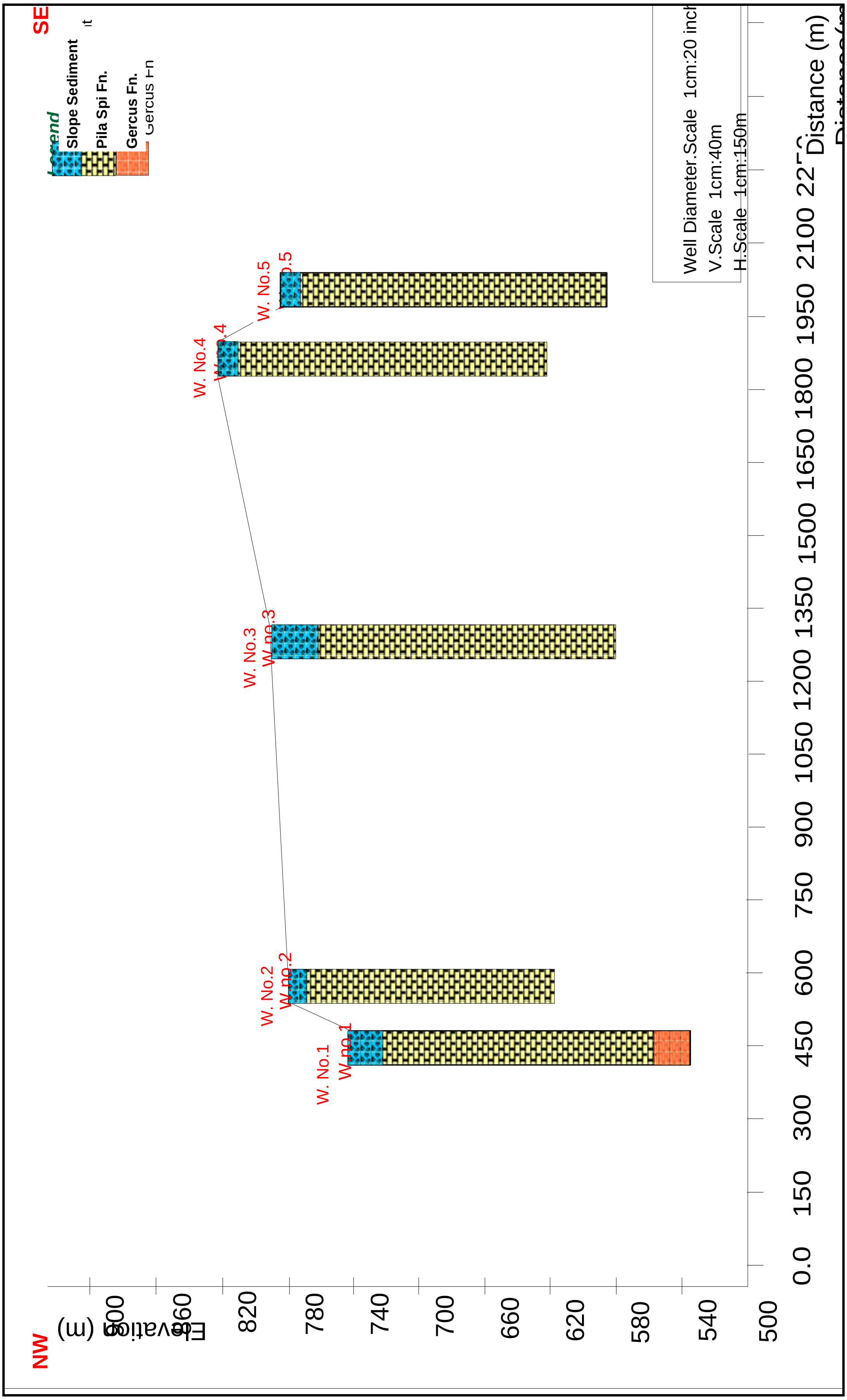

Fig.3: Stratigraphic Section of deep water wells in Haibat Sultan Mountain

AQUIFER TEST

Haibat Sultan aquifer is considered as unconfined, according to the previous studies. The aquifer characteristics that may be obtained by pumping test are; transmissivity (T), coefficient of permeability (K), Specific capacity (Sc), and specific yield (Sy), which characterize the capacity of the aquifer to release groundwater from the storage in response to decline in hydraulic head.

Before pumping test starts, the static water level (S.W.L) was measured, this is the depth from the ground surface to the water level in the well. After the beginning of pumping, the water level drops, the rate of draw down is rapid at the beginning, then it becomes slower as the time progresses, therefore the readings should be taken more frequently at the beginning of the test and more rarely as the time increases; as it is recommended in Table (1). For measuring the depth to the water level, electric measuring tape (electric sounder) was used.

In the test area, there is no any observation well (piezometers), also when pumping was performed in any particular well; it was observed that there is no any influence on the water levels in the adjacent wells. Therefore, these wells cannot be employed as observation wells, thus a method of a single well test; given by Jacob (1946) in Kruseman and Ridder (1994) should be used in determining the unconfined aquifer characteristics.

Five deep wells were selected for pumping to determine the aquifer characteristics in Haibat Sultan Mountain; the locations are shown in Fig. (1). The observed draw down; as a function of time for 12 hours pumping of the five wells, are shown in Table (2).

Table 1: Recommended schedule of dynamic water level measurement according to time from the beginning of the pumping test (Lurkiewics, 2002)

Time	Interval
1 – 5 minutes	every 30 seconds
5 – 10 minutes	every minute
10 – 30 minutes	every 2 minutes
30 – 60 minutes	every 5 minutes
60 – 120 minutes	every 10 minutes
120 – 180 minutes	every 15 minutes
180 – 360 minutes	every 30 minutes
360 minute – end of test (24 hours)	every 60 minutes

RESULTS AND DISCUSSION

The coordinates of the wells and data of pumping test are shown in Table (3), the discharge of each well was determined by measuring a certain volume of water in a definite period of time where a flow meter or any measuring devices are not available on the outlet of the wells, i.e. the test is of a constant discharge.

The observed drawdown (s) versus time (t) is plotted for each well on semi-log paper; it is on a logarithmic-scale.

Table 2: Time-drawdown values of the pumped wells

Time (min.)	Drawdown (m) Well No.1	Drawdown (m) Well No.2	Drawdown (m) Well No.3	Drawdown (m) Well No.4	Drawdown (m) Well No.5
1	67.5	120.03	154.96	112.22	121.50
2	67.6	120.03	154.96	112.22	121.98
3	67.65	120.15	155.04	112.45	121.98
4	68.2	120.25	155.25	112.46	122.09
5	68.2	121.09	155.39	112.48	122.67
6	68.2	124.76	155.42	112.65	122.86
7	68.2	124.35	155.49	112.66	123.01
8	68.2	125.02	155.52	112.97	123.19
9	68.2	125.04	155.58	112.97	123.22
10	68.2	125.15	155.63	112.98	123.22
`12	68.2	125.95	156.98	113.28	123.23
14	68.2	126.12	157.25	113.28	123.25
16	68.2	126.50	157.46	113.37	123.32
18	68.2	127.86	158.23	113.37	123.35
20	68.2	127.91	158.45	113.42	123.36
22	68.35	129.89	159.09	113.51	123.37
24	68.35	129.95	159.24	113.54	123.39
26	68.35	130.02	159.44	113.60	123.42
28	68.35	130.15	159.65	113.88	123.42
30	68.42	130.22	163.21	113.95	123.47
35	68.53	130.54	163.64	115.62	123.47
40	68.53	130.57	163.84	115.62	123.56
45	68.59	130.92	164.91	116.81	123.56
50	68.59	130.93	166.95	116.84	123.63
55	68.59	130.98	167.03	116.87	123.65
60	68.59	138.45	167.35	116.92	123.67
70	68.62	138.75	169.24	117.75	123.67
80	68.62	142.30	169.92	117.77	123.69
90	68.62	142.31	170.31	117.98	123.67
100	68.62	142.38	171.63	117.99	123.69
110	68.67	144.34	172.32	117.99	123.74
120	68.62	146.51	174.51	118.02	123.77
135	68.67	150.23	175.74	118.14	123.89
150	68.67	150.45	176.02	118.15	123.99
165	68.67	152.22	176.54	118.23	124.00
180	68.67	152.92	177.12	118.23	124.11
210	68.72	153.83	179.45	118.23	124.15
240	68.72	154.92	180.24	118.23	124.16
270	68.72	155.32	180.47	118.23	124.16
300	69.01	155.32	180.56	118.23	124.17
330	69.01	155.32	180.62	118.23	124.17
360	69.02	155.59	180.62	118.29	124.18
420	69.02	155.90	180.80	118.29	124.11
480	69.02	156.06	181.01	118.30	124.16
540	69.05	157.02	181.72	118.33	124.17
600	69.05	157.03	182.00	118.33	124.17
660	69.05	157.03	182.00	118.33	124.17
720	69.05	157.03	182.00	118.33	124.17

Time-drawdown curves for most of the wells show a typical **S** shape, a relatively steep early time segment, a flat intermediate segment and a relatively steep again a let time, as they are depicted through Figs. (4a to 4e) for the five wells. Through the points of these figures, a best-fitting straight line was drawn by visual inspection, for each plot a straight line was extended until it intersects the time axis (S = 0) and the value of time (t_0) was recorded. The time of zero drawdown and the slope of the line, i.e. Δs per log cycle of time also are given in Table (3).

By using Jacob method, the aquifer characteristics from a single well test can be found using the mentioned equations below (Delleur, 1999).

As a sample for calculation, the data of the well No.1 is applied:

$$T = \frac{2.3Q}{4\pi\Delta s} = \frac{2.3 \times 281.6}{4 \times \pi \times 0.44} = 117.14 \ m^2/day$$

$$K = \frac{T}{D} = \frac{117.14}{118} = 0.623 \ m/day$$

$$S_y = \frac{2.25Tt_0}{r^2} \times 0.025 = \frac{2.25 \times 117.14 \times 2 \times 10^{-4}}{(0.1)^2} \times 0.025 = 0.1318$$

$$S_c = \frac{Q}{S_w} = \frac{281.6}{1.55} = 181.67 \quad m^2/day$$

The Aquifer characteristics transmissivity (T), coefficient of permeability (K), specific yield (Sy) and Specific capacity (Sc) that are calculated from applying of pumping tests in the five wells are presented in Table (4).

The other parameters are: **Q**, which is the well discharge (m^3/day), **D** is the aquifer thickness (m), **r** is the well radius (m), and $\mathbf{S_w}$ is the total drawdown (m).

The Haibat Sultan aquifer exhibits a high transmissivity at the locations of wells No.1 and No.5, and also with an associated high permeability, specific yield and specific capacity, as they are compared with those of the other wells, which exhibit low transmissivity and other parameters.

The typical value of specific yield (Sy) for unconfined aquifer ranges from (0.01 – 0.3) as given by Kruseman and Ridder (1994). While the values given by Todd (1959) range from (0.05 – 0.3), which are much higher than the storativities for confined aquifers, which range from ($5 \times 10^{-5} - 5 \times 10^{-3}$) (Kruseman and Ridder, 1994). Thus, all the values of specific yield of the wells in Haibat Sultan aquifer reveal unconfined aquifer according to the range of $\mathbf{S_y}$ given by Kruseman and Ridder (1994), while according to the range given by Todd (1959), the wells exhibit unconfined aquifer, except in the location of wells No.1 and No.5, whereas the other wells may exhibit semi confined or leaky aquifer. When the range of $\mathbf{S_y}$ given by Todd (1959) is considered, then the aquifer characteristics at wells No.2, No.3, and No.4 should be re-calculated for semi confined or leaky aquifer.

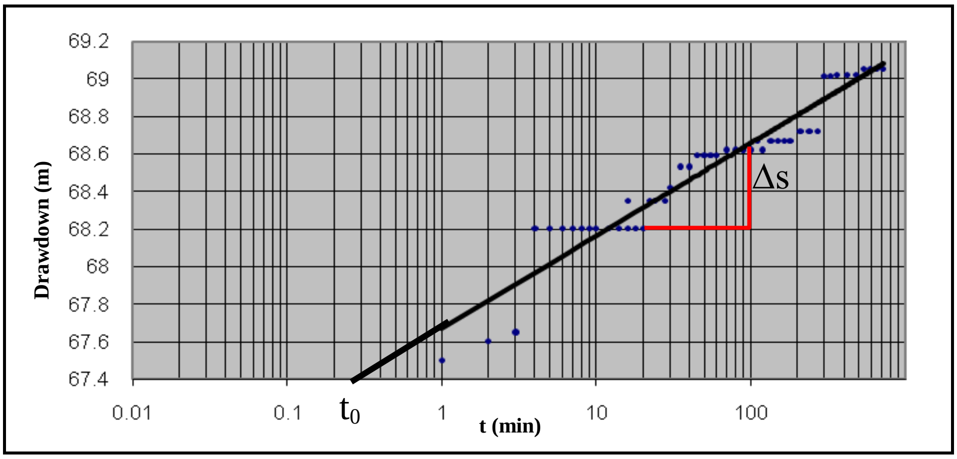

Fig.4a: Time-drawdown plot of field data of an aquifer test for well No. (1)

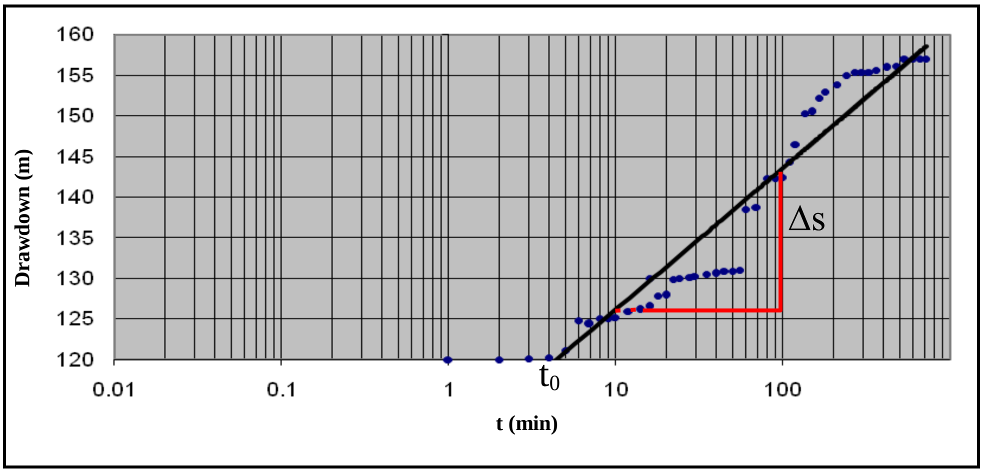

Fig.4b: Time-drawdown plot of field data of an aquifer test for well No. (2)

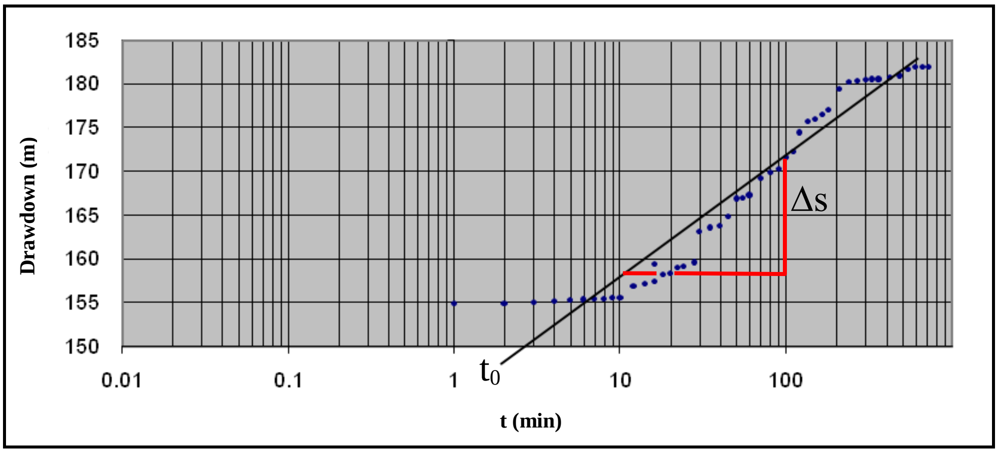

Fig.4c: Time-drawdown plot of field data of an aquifer test for well No. (3)

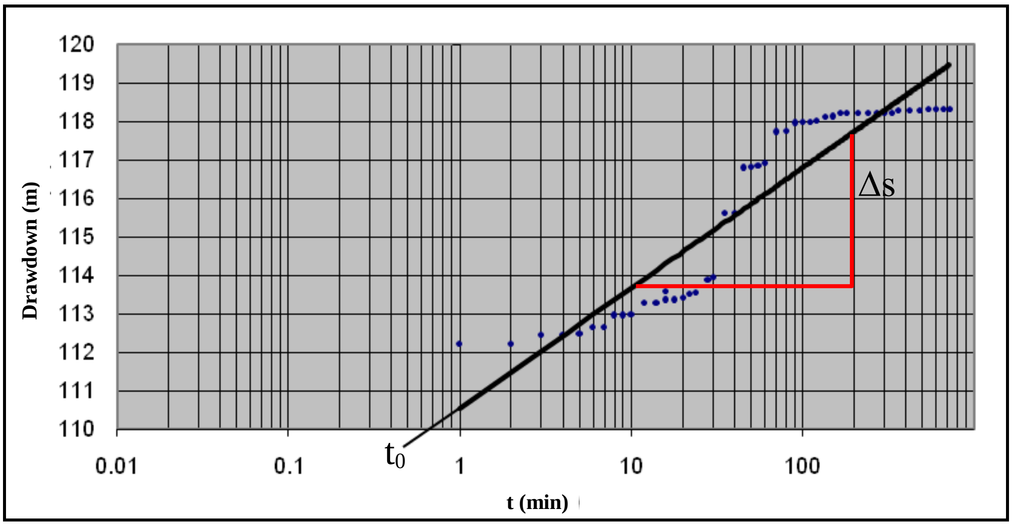

Fig.4d: Time-drawdown plot of field data of an aquifer test for well No. (4)

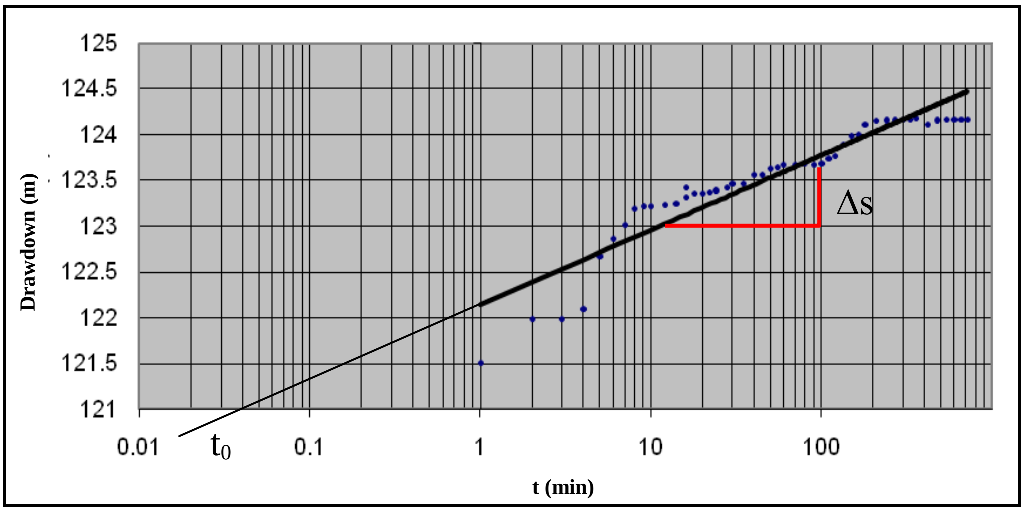

Fig.4e: Time-drawdown plot of field data of an aquifer test for well No. (5)

Table 3: Data of the pumped wells

Well No.	X (UTM)	Y (UTM)	Z (m)	Static Water level (m)	Dynamic water level (m)	Discharge (m^3/day)	t_0 (day)	Slope (Δs/ log cycle)	Well depth (m)
1	469910	3994845	755	67.5	69.05	281.6	2.0×10^{-4}	0.44	216
2	469892	3995047	796.5	120.03	157.03	180.2	3.0×10^{-3}	18.4	165
3	469393	3995553	804.7	154.96	182	144.86	1.0×10^{-3}	14.5	210
4	468954	3995968	822	112.22	118.33	227.20	4.0×10^{-4}	3.1	200
5	468856	3995997	797	121.50	124.17	359.91	2.0×0^{-4}	0.8	200

Table 4: Aquifer characteristics of the pumped wells by Jacob's method

Well No.	T (m^2/day)	K (m/day)	Sy	Sc (m^2/day)	Total drawdown S_w (m)
1	117.14	0.623	0.1318	181.67	1.55
2	1.795	0.012	0.0303	4.87	37
3	1.829	0.00983	0.0103	5.35	27.04
4	6.986	0.0376	0.0157	37.185	6.11
5	82.84	0.447	0.0926	134.8	2.67

- **Leaky Aquifer Test, Hurr – Worthington's Method**

Hurr (1966) outlined a procedure for estimating the transmissivity of a confined aquifer from a single drawdown observation in pumped well. Worthington (1981) incorporated with Hurr (1966) procedure in a method for estimating the transmissivity of leaky aquifer from a single well drawdown data (Kruseman and Ridder, 1994), by modifying this equation, the equation is written as:

$$S_w = \frac{Q}{4\pi kD} W(U_w)$$

$$U_w = \frac{r^2 \, cw \, S}{4kDt}$$

$$W(U_w) = \frac{4\pi kDS_w}{Q}$$

$$U_w W(U_w) = \frac{4\pi kDS_w}{Q} \times \frac{r^2 \, cw \, S}{4kDt} \times \frac{\pi \, r^2 \, cw \, S}{t} \times \frac{S_w}{Q}$$

Hurr – Worthington's method involves calculating the pseudo-transmissivity (pseudo-T) values by applying the following procedure to a sequence of observed drawdown data:

– For a single well drawdown observation, $\mathbf{U_w\ W(U_w)}$ is calculated from equation (4), for known or estimated value of storativity **(S)** (**S** = 1×10^{-4}) (Kruseman and Ridder, 1994).
– Knowing $\mathbf{U_w\ W(U_w)}$, the corresponding value of $\mathbf{U_w}$ is determined from appendix (1).
– The values of $\mathbf{U_w}$**,** $\mathbf{r_w}$**, t and S** were substituted into equation (2) and pseudo-T was calculated.
– On semi-log paper, the pseudo-T values were plotted versus corresponding **t** (**t** on the logarithmic-scale). The minimum value of pseudo-T was determined from the plot. This is the best estimation of aquifer's transmissivity.

After applying the aforementioned procedure on the drawdown data of the wells No.2, No.3 and No.4, the calculated values of pseudo-T for the three wells are given in appendix (2) and the plots of pseudo-T versus **t** for the three wells are depicted in Figs. (5a to 5c).

From well No.2 (Fig.5a) a best estimation of aquifer transmissivity was found to be 8 m^2/day. From well No.3 (Fig.5b), the estimated aquifer transmissivity was 42 m^2/day. From well No.4 (Fig.5c), the estimated aquifer transmissivity was 8 m^2/day.

The aquifer transmissivity calculated by Hurr – Worthington's method in well No.3 is much higher than the value obtained by Jacob's method, shown in Table (4) (1.829 m^2/day). This may give a direct indication that the aquifer of these three wells seems to be leaky aquifer and return to be unconfined at the other wells (No.1 and No.5).

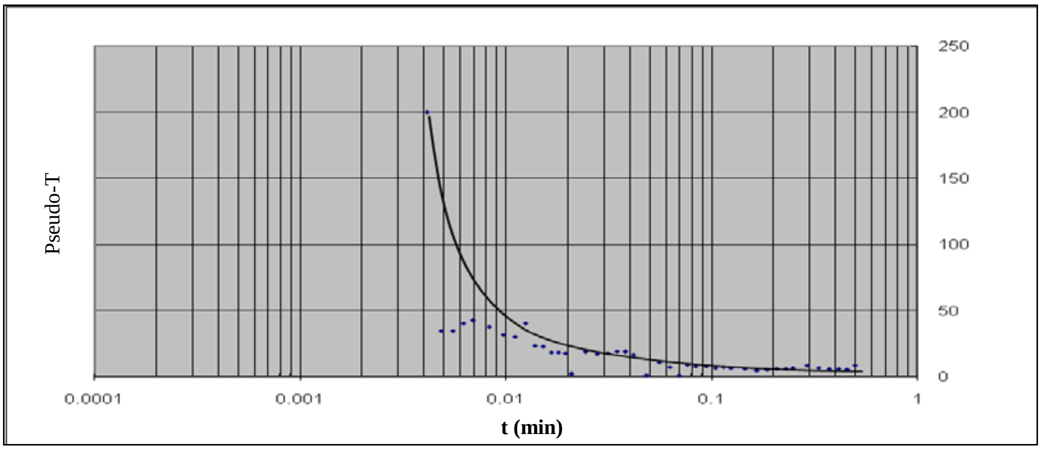

Fig.5a: Determination of the aquifers transmissivity in well No.2

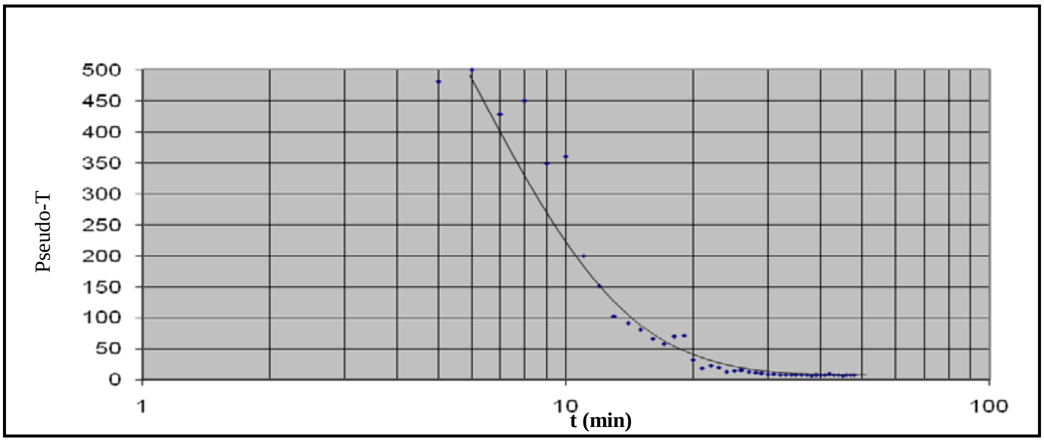

Fig.5b: Determination of the aquifers transmissivity in well No.3

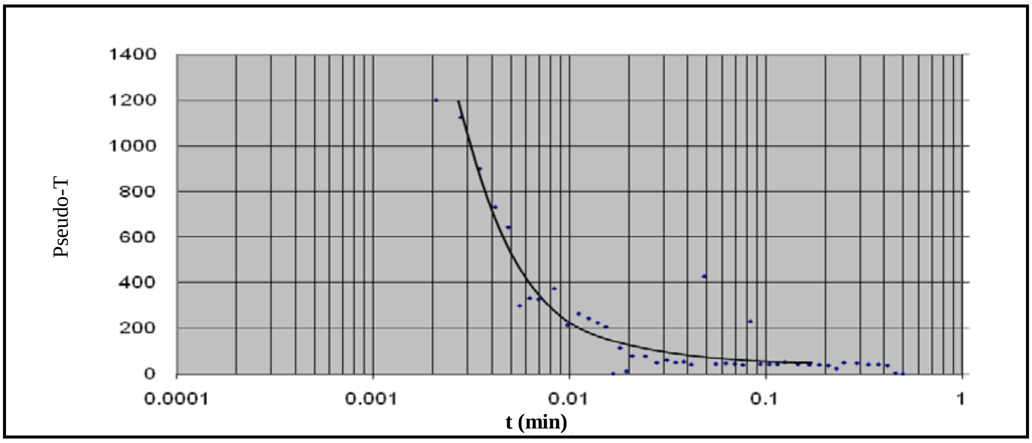

Fig.5c: Determination of the aquifers transmissivity in well No.4

CONCLUSIONS

Based on the results of this study, the following conclusions can be obtained:

- Haibat Sultan aquifer is classified as unconfined aquifer according to the geological setting of the area and lithological sections of water wells, while the results of pumping test revealed that some parts of the aquifer tend to be leaky aquifer; from well location No.2 to well No.4, where the specific yield of this region at these wells is too low. This result may give an expectation that the slope sediments on the upper layer of the aquifer may act as aquitard, which make the aquifer to behave as a leaky or semi-confined, at some locations. The current total yield of the aquifer was 1194 m^3/day.
- Well No.1 has the greatest capacity and yield, this is due to the higher permeability and transmissivity at the aquifer at the well location, also the depth of this well is the largest one (216 m).
- The specific yield and specific capacity of Haibat Sultan aquifer increase in the direction of well No.1 and well No.5, i.e. in northwest and southeast directions, the future development for extracting ground water may be in these directions.

APPENDICES

Appendix 1: Values of $\mathbf{U_w\ W(U_w)}$
for single-well constant-discharge tests

U_w	$U_w\ W(U_w)$	U_w	$U_w\ W(U_w)$
8	3.014 (–4)	8 (–6)	8.928 (–5)
6	2.161 (–3)	6 (–6)	6.870 (–5)
4	1.512 (–2)	4 (–6)	4.740 (–5)
2	9.780 (–1)	2 (–6)	2.510 (–5)
1	2.194 (–1)	1 (–6)	1.324 (–5)
8 (–1)	2.485 (–1)	8 (–7)	1.077 (–5)
6 (–1)	2.726 (–1)	6 (–7)	8.250 (–6)
4 (–1)	2.810 (–1)	4 (–7)	5.660 (–6)
2 (–1)	2.446 (–1)	2 (–7)	2.970 (–6)
1 (–1)	1.823 (–1)	1 (–7)	1.554 (–6)
8 (–2)	1.622 (–1)	8 (–8)	1.261 (–6)
6 (–2)	1.377 (–1)	6 (–8)	9.630 (–7)
4 (–2)	1.072 (–1)	4 (–8)	6.584 (–7)
2 (–2)	6.710 (–2)	2 (–8)	3.430 (–7)
1 (–2)	4.038 (–2)	1 (–8)	1.784 (–7)
8 (–3)	3.407 (–2)	8 (–9)	1.446 (–7)
6 (–3)	2.727 (–2)	6 (–9)	1.101 (–7)
4 (–3)	1.979 (–2)	4 (–9)	7.504 (–8)
2 (–3)	1.128 (–2)	2 (–9)	3.890 (–8)
1 (–3)	6.332 (–3)	1 (–9)	2.015 (–8)
8 (–4)	5.244 (–3)	8 (–10)	1.630 (–8)
6 (–4)	4.105 (–3)	6 (–10)	1.240 (–8)
4 (–4)	2.899 (–3)	4 (–10)	8.424 (–9)
2 (–4)	1.588 (–3)	2 (–10)	4.352 (–9)
1 (–4)	8.633 (–4)	1 (–10)	2.245 (–9)
8 (–5)	7.085 (–4)	8 (–11)	1.824 (–9)
6 (–5)	5.486 (–4)	6 (–11)	1.378 (–9)
4 (–5)	3.820 (–4)	4 (–11)	9.344 (–10)
2 (–5)	2.048 (–4)	2 (–11)	4.812 (–10)
1 (–5)	1.094 (–4)	1 (–11)	2.475 (–10)

Appendix 2a: Determination of aquifers transmissivity in well No.2

t (min)	t/day	S_w (m)	U_w $W(U_w)$	U_w	KD (m²/day)
1	0.000694	0	0	0	–
2	0.001389	0	0	0	–
3	0.002083	0.12	1.004E–06	7.00E–08	1.71E+03
4	0.002778	0.22	1.38E–06	9.00E–08	1.00E+03
5	0.003472	0.22	1.104E–06	7.20E–08	1.00E+03
6	0.004167	1.06	4.433E–06	3.00E–07	2.00E+02
7	0.004861	4.73	1.696E–05	1.50E–06	3.43E+01
8	0.005556	4.32	1.355E–05	1.30E–06	3.46E+01
9	0.00625	4.99	1.391E–05	1.00E–06	4.00E+01
10	0.006944	5.01	1.257E–05	8.50E–07	4.24E+01
12	0.008333	5.12	1.071E–05	8.00E–07	3.75E+01
14	0.009722	5.92	1.061E–05	8.20E–07	3.14E+01
16	0.011111	6.09	9.551E–06	7.50E–07	3.00E+01
18	0.0125	5.47	7.625E–06	5.00E–07	4.00E+01
20	0.013889	7.83	9.824E–06	7.80E–07	2.31E+01
22	0.015278	7.89	8.999E–06	7.20E–07	2.27E+01
24	0.016667	9.86	1.031E–05	8.20E–07	1.83E+01
26	0.018056	9.92	9.574E–06	7.50E–07	1.85E+01
28	0.019444	9.99	8.953E–06	7.20E–07	1.79E+01
30	0.020833	10.12	8.464E–06	6.50E–06	1.85E+00
35	0.024306	10.19	7.305E–06	5.50E–07	1.87E+01
40	0.027778	10.51	6.593E–06	5.20E–07	1.73E+01
45	0.03125	10.54	5.877E–06	4.50E–07	1.78E+01
50	0.034722	10.89	5.465E–06	3.80E–07	1.89E+01
55	0.038194	10.9	4.973E–06	3.50E–07	1.87E+01
60	0.041667	10.95	4.579E–06	3.70E–07	1.62E+01
70	0.048611	18.42	6.603E–06	4.50E–06	1.14E+00
80	0.055556	18.72	5.872E–06	4.20E–07	1.07E+01
90	0.0625	22.27	6.209E–06	5.60E–07	7.14E+00
100	0.069444	22.28	5.591E–06	4.30E–06	8.37E–01
110	0.076389	22.35	5.098E–06	3.70E–07	8.85E+00
120	0.083333	24.31	5.083E–06	3.80E–07	7.89E+00
135	0.09375	26.48	4.922E–06	3.50E–07	7.62E+00
150	0.104167	30.2	5.052E–06	3.70E–07	6.49E+00
165	0.114583	30.42	4.626E–06	3.10E–07	7.04E+00
180	0.125	32.19	4.487E–06	3.00E–07	6.67E+00
210	0.145833	32.89	3.93E–06	2.80E–07	6.12E+00
240	0.166667	33.8	3.534E–06	3.20E–07	4.69E+00
270	0.1875	34.89	3.242E–06	2.50E–07	5.33E+00
300	0.208333	35.29	2.952E–06	2.00E–07	6.00E+00
330	0.229167	35.29	2.683E–06	1.80E–07	6.06E+00
360	0.25	35.29	2.46E–06	1.60E–07	6.25E+00
420	0.291667	25.56	1.527E–06	1.00E–07	8.57E+00
480	0.333333	35.87	1.875E–06	1.20E–07	6.25E+00
540	0.375	36.03	1.674E–06	1.15E–07	5.80E+00
600	0.416667	37	1.547E–06	1.00E–07	6.00E+00
660	0.458333	37	1.407E–06	1.00E–07	5.45E+00
720	0.5	27	9.41E–07	5.80E–08	8.62E+00

Appendix 2b: Determination of aquifers transmissivity in well No.3

t (min)	t/day	S_w (m)	U_w $W(U_w)$	U_w	KD (m^2/day)
1	0.00069	0	0	5.00E–04	–
2	0.00139	0	0	2.10E–04	–
3	0.00208	0.23	1.53E–06	1.00E–07	1.20E+03
4	0.00278	0.24	1.19E–06	8.00E–08	1.13E+03
5	0.00347	0.26	1.03E–06	8.00E–08	9.00E+02
6	0.00417	0.41	1.36E–06	8.20E–08	7.32E+02
7	0.00486	0.42	1.19E–06	8.00E–08	6.43E+02
8	0.00556	0.73	1.82E–06	1.50E–07	3.00E+02
9	0.00625	0.74	1.64E–06	1.20E–07	3.33E+02
10	0.00694	0.74	1.47E–06	1.10E–07	3.27E+02
12	0.00833	0.74	1.23E–06	8.00E–08	3.75E+02
14	0.00972	1.13	1.61E–06	1.20E–07	2.14E+02
16	0.01111	1.13	1.41E–06	8.50E–08	2.65E+02
18	0.0125	1.18	1.3E–06	8.20E–08	2.44E+02
20	0.01389	1.27	1.26E–06	8.00E–08	2.25E+02
22	0.01528	1.3	1.18E–06	7.90E–08	2.07E+02
24	0.01667	1.36	9.41E–05	8.50E–06	1.76E+00
26	0.01806	2.18	1.67E–06	1.20E–07	1.15E+02
28	0.01944	2.25	1.6E–06	1.00E–06	1.29E+01
30	0.02083	3.92	2.6E–06	1.50E–07	8.00E+01
35	0.02431	3.92	2.23E–06	1.30E–07	7.91E+01
40	0.02778	5.11	2.54E–06	1.80E–07	5.00E+01
45	0.03125	5.14	2.27E–06	1.30E–07	6.15E+01
50	0.03472	5.17	2.06E–06	1.40E–07	5.14E+01
55	0.03819	5.22	1.89E–06	1.20E–07	5.45E+01
60	0.04167	6.04	2E–06	1.40E–07	4.29E+01
70	0.04861	6.06	1.72E–06	1.20E–08	4.29E+02
80	0.05556	6.27	1.56E–06	1.00E–07	4.50E+01
90	0.0625	6.28	1.39E–06	8.50E–08	4.71E+01
100	0.06944	6.28	1.25E–06	8.00E–08	4.50E+01
110	0.07639	6.31	1.14E–06	8.00E–08	4.09E+01
120	0.08333	6.43	1.50E–06	1.30E–08	2.31E+02
135	0.09375	6.44	9.49E–07	6.00E–08	4.44E+01
150	0.10417	6.52	8.65E–07	5.50E–08	4.36E+01
165	0.11458	6.52	7.86E–07	5.00E–08	4.36E+01
180	0.125	6.52	7.21E–07	3.80E–08	5.26E+01
210	0.14583	6.52	6.18E–07	3.90E–08	4.40E+01
240	0.16667	6.52	5.41E–07	3.60E–08	4.17E+01
270	0.1875	6.52	4.81E–07	3.20E–08	4.17E+01
300	0.20833	6.56	4.35E–07	3.20E–08	3.75E+01
330	0.22917	6.57	3.96E–07	4.50E–08	2.42E+01
360	0.25	5.57	3.08E–07	2.00E–08	5.00E+01
420	0.29167	6.57	3.11E–07	1.80E–08	4.76E+01
480	0.33333	6.59	2.73E–07	1.75E–08	4.29E+01
540	0.375	6.59	2.43E–07	1.55E–08	4.30E+01
600	0.41667	6.59	2.19E–07	1.60E–08	3.75E+01
660	0.45833	6.59	1.99E–07	1.40E–07	3.90E+00
720	0.5	6.59	1.82E–07	3.80E–07	1.32E+00

Appendix 2c: Determination of aquifers transmissivity in well No.4

t (min)	t/day	S_w	U_w $W(U_w)$	U_w	KD (m²/day)
1	0.000694	0	0	0.00E+00	–
2	0.001389	0	0	0.00E+00	
3	0.002083	0.08	8.32E–07	5.50E–08	2.18E+03
4	0.002778	0.29	2.26E–06	1.10E–07	8.18E+02
5	0.003472	0.43	2.68E–06	1.50E–07	4.80E+02
6	0.004167	0.46	2.39E–06	1.20E–07	5.00E+02
7	0.004861	0.53	2.36E–06	1.20E–07	4.29E+02
8	0.005556	0.56	2.18E–06	1.00E–07	4.50E+02
9	0.00625	0.62	2.15E–06	1.15E–07	3.48E+02
10	0.006944	0.67	2.09E–06	1.00E–07	3.60E+02
12	0.008333	1.02	2.65E–06	1.50E–07	2.00E+02
14	0.009722	1.29	2.88E–06	1.70E–07	1.51E+02
16	0.011111	1.56	3.04E–06	2.20E–07	1.02E+02
18	0.0125	1.77	3.07E–06	2.20E–07	9.09E+01
20	0.013889	1.98	3.09E–06	2.22E–07	8.11E+01
22	0.015278	2.62	3.72E–06	2.50E–07	6.55E+01
24	0.016667	2.77	3.6E–06	2.60E–07	5.77E+01
26	0.018056	2.97	3.57E–06	2.00E–07	6.92E+01
28	0.019444	3.13	3.49E–06	1.80E–07	7.14E+01
30	0.020833	4.69	4.88E–06	3.80E–07	3.16E+01
35	0.024306	7.03	6.27E–06	5.50E–07	1.87E+01
40	0.027778	7.23	5.64E–06	4.00E–07	2.25E+01
45	0.03125	8.3	5.76E–06	4.10E–07	1.95E+01
50	0.034722	10.34	6.45E–06	5.70E–07	1.26E+01
55	0.038194	10.4	5.9E-06	4.50E–07	1.45E+01
60	0.041667	10.72	5.58E–06	4.00E–07	1.50E+01
70	0.048611	12.61	5.62E–06	4.00E–07	1.29E+01
80	0.055556	13.29	5.19E–06	3.80E–07	1.18E+01
90	0.0625	13.68	4.74E–06	3.90E–07	1.03E+01
100	0.069444	15	4.68E–06	3.80E–07	9.47E+00
110	0.076389	15.69	4.45E–06	3.50E–07	9.35E+00
120	0.083333	17.87	4.65E–06	3.80E–07	7.89E+00
135	0.09375	1.91	4.42E–07	3.50E–07	7.62E+00
150	0.104167	19.38	4.03E–06	3.00E–07	8.00E+00
165	0.114583	1.99	3.76E–07	2.80E–07	7.79E+00
180	0.125	20.48	3.55E–06	2.60E–07	7.69E+00
210	0.145833	22.51	3.35E–06	2.40E–07	7.14E+00
240	0.166667	2.33	3.03E–07	2.30E–07	6.52E+00
270	0.1875	23.39	2.7E–06	1.90E–07	7.02E+00
300	0.208333	23.45	2.44E–06	1.50E–07	8.00E+00
330	0.229167	23.52	2.22E–06	1.40E–07	7.79E+00
360	0.25	23.7	2.05E–06	1.20E–07	8.33E+00
420	0.291667	23.89	1.78E–06	1.10E–07	7.79E+00
480	0.333333	24	1.56E–06	1.00E–07	7.50E+00
540	0.375	24.28	1.4E–06	1.00E–07	6.67E+00
600	0.416667	24.28	1.26E–06	8.00E–08	7.50E+00
660	0.458333	24.28	1.15E–06	7.20E–08	7.58E+00
720	0.5	24.28	1.05E–06	7.00E–08	7.14E+00

REFERENCES

Al-Qayim, B. and Nisan, B., 1989. Sedimentary facies analysis of a Paleogene mixed carbonate – clastic sequence, Haibat Sultan ridge, NE Iraq. Jour. Iraqi Geol. Soci., Vol.32, No.4, p. 225 – 257.

Al-Saadi, S.N. and Al-Jassar, S.H., 1993. Rock slides along Haibat Sultan area, N Iraq. 3rd International Conference on case histories in Geotechnical Engineering, St. Louis, Missouri, p. 443 – 450.

Bellen, R.C., van Dunnington, H.V., Wetzel, R. and Morton, D., 1959. Lexique Stratigraphic International. Asie, Fasc. 10a, Iraq, Paris, 333pp.

Buday, T., 1980. The Regional Geology of Iraq. Vol.1, Stratigraphy and Paleogeography. In: I.I., Kassab and S.Z., Jassim (Eds.). GEOSURV, Baghdad, Iraq, 445pp.

Buday, T. and Jassim, S.Z., 1987. The Regional Geology of Iraq, Vol.2, Tectonism, Magmatism and Metamorphism, In: I.I., Kassab and M.J., Abbas (Eds.). GEOSURV, Baghdad, Iraq, 352pp.

Delleur, J.W., 1999. The Hand Book of Ground Water Engineering. Published by CRC Press LLC, 940pp.

Hurr, R.T., 1966. A new approach for estimating transmissivity from specific capacity, Water Resources, Res., 2 (4), p. 657 – 664.

Kruseman, G.P. and Ridder, N.A., 1994. Analysis and Evaluation of Pumping Test Data. International Institute for Land Reclamation and Improvement, 200pp.

Lurkiewics, A., 2002. Drilling and testing water wells. FAO representation in Iraq, FAO Sulaimaniya Sub-office.

Saber, S.S., 2006. Slope characteristics of Haibat Sultan Mountain and it's basin's Morphometry. Unpub. M.Sc. Thesis, University of Koya, College of Education, Iraq, 143pp. (In Kurdish).

Sissakian, V.K., 1997. The Geology of Erbil and Mahabad Quadrangles, scale 1: 250 000, sheets NJ-38-14 and NJ-38-15 (G.M. 5 and 6). GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Youkhanna, R.Y., 1979. Report on Regional geological mapping of Erbil – Shaqlawa – Koisanjak – Raidar Area. GEOSURV, int. rep. no. 975.

Todd, D.K., 1959. Ground Water Hydrology. Jon Wiley and Sons, Inc., New York and London, 336pp.

Worthington, P.F., 1981. Estimation of Transmissivity of Thin Leaky-Confined Aquifers from Single-Well Pumping Test. Jour. Hydrology, Vol.49, p. 19 – 30.

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