Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Aquifer Pumping Test Data Analysis for the Well (B7-3) at Ain–Tamer Area West of Iraq

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Article information

Received: 5-Dec-2022

Revised: 14-Jan-2023

Accepted: 29-Jan-2023

Available online: 30- June- 2023

Keywords:
Storativity
Transmissivity
Hydraulic Conductivity
AQTESOLV

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ABSTRACT

Pumping test analysis is one of the most hydrogeological urgent issues encountered by hydrogeologists to discover reliable values for hydrological formation. The current study included the use of pumping test data wells (B7-3) done by a Yugoslavian company (Consortium), where this well penetrated each of the Dammam Formation and Umm Er Radhuma Formation in Ain –Tamer area west of Iraq. The type aquifer of the study area has been considered a confined aquifer regarding the geological situation. The AQTESOLV v4.5 program has been used to simulate the pumping test data of this well, Barker, Cooper-Jacob, Hantush, Murdoch, Papadopulos -Cooper, and Theis-Hantush methods which are used to calculate the hydraulic properties of this aquifer. The results show that each of the Papa-Cooper and Theis-Hantush methods present the same value for transmissivity and storativity of the aquifer, (0.016-0.2) m^2/sec respectively. While the Cooper-Jacob method gave values for aquiver properties higher relatively. Also, each of Barker and Murdoch's Methods offered different values for specific storage (0.006-0.06) m^{-1} respectively. Both methods had different values for Kx as well. The results prove that the pumping test methods have to apply carefully when identifying the hydrogeological parameters of aquifers.

DOI: 10.33899/earth.2023.137784.1037,

تحليل نتائج الضخ التجريبي لبئر (B7-3) في منطقة عين التمر غرب العراق

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معلومات الارشفة

تاريخ الاستلام: 5-ديسمبر-2022

تاريخ المراجعة: 14-يناير-2023

تاريخ القبول: 29-يناير-2023

تاريخ النشر الالكتروني: 30-يونيو-2023

الكلمات المفتاحية:
الخازنية
النفاذية
التوصيل الهيدروليكي
AQTESOLV

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الملخص

يعدّ تحليل اختبار الضخ من أكثر المشكلات الهيدروجيولوجية إلحاحًا التي تواجه علماء الجيولوجيا المائية وذلك لاكتشاف قيم موثوقة للتكوين الهيدرولوجي. تضمنت الدراسة الحالية استخدام آبار بيانات اختبار الضخ (B7-3) والمعدّة من قبل الشركة اليوغوسلافية (كونسورتيوم)، حيث اخترق هذا البئر كل من تشكيل الدمام وتكوين أم الرضومة في منطقة عين التامر غرب العراق. تم اعتبار طبقة المياه الجوفية في منطقة الدراسة على أنها طبقة مياه جوفية محصورة من حيث الوضع الجيولوجي. تم استخدام برنامج AQTESOLV v4.5 لمحاكاة بيانات اختبار الضخ لهذا البئر، وكذلك طرق Barker و Cooper-Jacob و Hantush و Murdoch و Papadopulos -Cooper و Theis-Hantush التي تُستخدم لحساب الخصائص الهيدروليكية لطبقة المياه الجوفية. أظهرت النتائج أن كل من طريقتي Papa-Cooper و Theis-Hantush تعطيان نفس القيمة الخاصة بالناقلية المائية والتخزين لطبقة المياه الجوفية، (0.2–0.016) متر مربع/ثانية على التوالي. بينما أعطت طريقة Cooper-Jacob قيماً لخصائص المياه الجوفية أعلى نسبياً. بينما أعطت كل من طريقتي باركر ومردوخ قيماً مختلفة للتخزين المحدد (0.06–0.006) م$^{-1}$ على التوالي. وكذلك كان لكلتا الطريقتين قيماً مختلفة لـ Kx. اثبتت النتائج أن طرق اختبار الضخ يجب أن تطبّق بعناية عند تحديد المعاملات الهيدروجيولوجية لخزانات المياه الجوفية.

DOI: 10.33899/earth.2023.137784.1037, ©Authors, 2023, College of Science, University of Mosul.

Introduction

In the hydrogeological investigation of groundwater flow cases, hydrogeologists or engineers must look out for true values for the hydraulic properties of the water-bearing layers that the groundwater is flowing through. (Al-Muqdadi et al., 2020). The only significant technique for finding these properties is to do and analyze in-situ hydraulic checks. Pumping tests have proved that it is the most certified way to determine the hydraulic properties of aquifers on a large scale over the world (Dewandel et al., 2008). The response of pumping rate and direction of flow style of groundwater due to groundwater aquifers' development and sustainable control of groundwater aquifers (Singh and Tripura, 2022). This test is concluded by discharging out from a well at an almost continuous or in certain cases different rate, and meanwhile observing the water level response at the observing well or the same pumping well (Mawlood and Ismail, 2019). The result of the analysis of this test is the evaluation of the water-bearing geological units to manage this water resource now and in the future. Where the graphical solutions are employed to obtain the aquifer parameters which include hydraulic conductivity (K), transmissivity, T; specific storage, Ss; and storativity, S (Anomohanran, 2015; Oladunjoye, et al., 2020). This study compared the pumping test analysis methods prepared by Barker, Cooper-Jacob, Hantush, Murdoch, Papadopulos-Cooper, and Theis-Hantush methods to calculate the hydraulic properties of this aquifer. The study used pumping data from the well (B7 -3), in the Ain-Tamer area west of Iraq that was conducted by the Yugoslavian Company (Consortium), (Consortium-Yugoslavia, 1977). The results of this study may help to determine the suitable values of hydraulic properties of the Umm Er Radhuma Aquifer which is considered an aquiclude aquifer type in this interesting part of Iraq (Al-Muqdadi et al., 2020).

Materials and Methods

Case of Study

The pumping test data of the well (B7-3) have been used in the current study. The well (B7-3) was drilled by the Yugoslavian company (Consortium) in 1976. The depth of the well is (196) meters, this well penetrates the recent sediment to a depth of (3) meters and then the Dammam Formation to a depth of (84) meters, as well as penetrates the Umm Er Radhuma Formation which extends from a depth of (84)meters to a depth of (196) meters. Figure 1 and 2 shows the calcite fiches that have fossils and marl at the boundary in the Dammam formation.

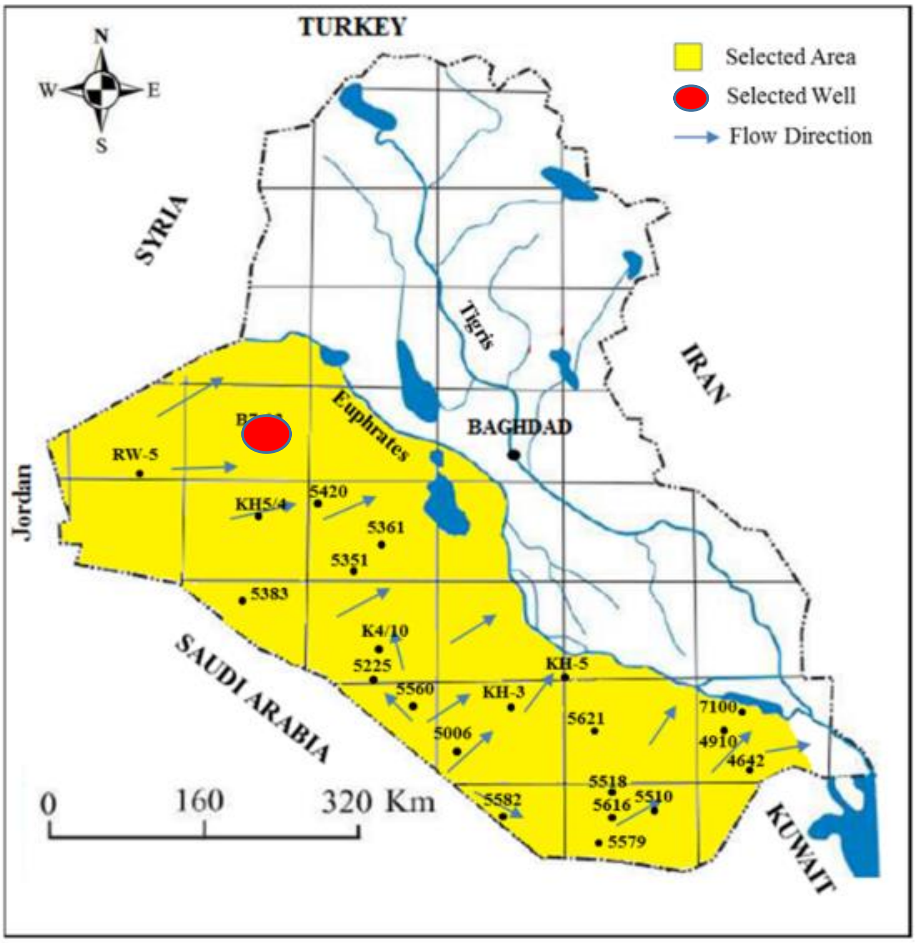

Fig. 1. The Location of the selected well study (Sachit and Azawi, 2018).

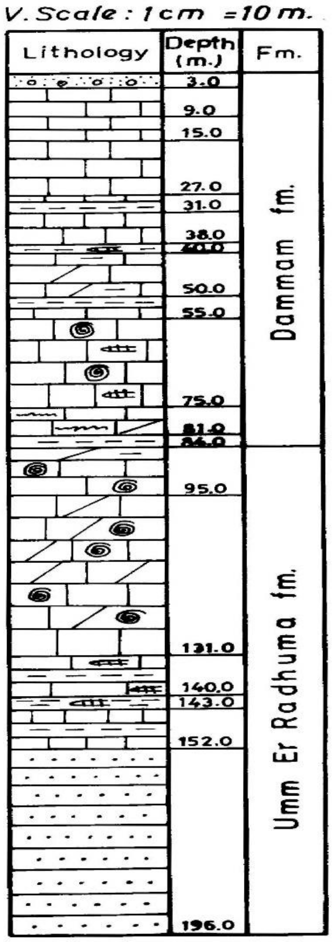

Fig. 2. Vertical section for the well (B7-3), after (Consortium, 1977)

While the sandstone layers in the Umm Er Radhuma Formation are visible. The aquifer of this well represents the formation of Umm Er Radhuma and the lower part of the Dammam Formation with a depth of (84) meters. The water rises to a depth of (22) meters. The description of pumping test information has been shown in Table 1.

Table 1. Pumping test data for well (B7-3), (Consortium,1977).

Drawdown during pumping time			Recovery after stopping pumping	
Time min	Depth of water m	Drawdown m	Recovery time min	Recovery m
0.0	23.49	0.0	0.0	1.31
1.0	24.05	0.56	1.0	0.85
2.0	24.09	0.60	2.0	0.80
3.0	24.15	0.66	3.0	0.77
4.0	24.18	0.69	4.0	0.75
5.0	24.20	0.71	5.0	0.73
7.0	24.24	0.75	7.0	0.70
10.0	24.29	0.80	9.0	0.68
15.0	24.31	0.81	15.0	0.63
20.0	24.33	0.83	25.0	0.60
30.0	24.37	0.88	35.0	0.55
40.0	24.39	0.90	50.0	0.50
50.0	24.42	0.93	60.0	0.48
180.0	24.51	1.02	180.0	0.32
480.0	24.67	1.18	300.0	0.24
720.0	24.71	1.22	420.0	0.17
960.0	24.73	1.24	480.0	0.16
1320.0	24.74	1.25	600.0	0.14
1560.0	24.75	1.26	720.0	0.11
1800.0	24.75	1.26	960.0	0.10
2040.0	24.77	1.28	1080.0	0.09
2280.0	24.79	1.29	1200.0	0.08
2520.0	24.81	1.31	1260.0	0.07
2880.0	24.81	1.31	1440.0	0.07

Pumping Test Analysis methods

The pumping test utilized in this study included each of Barker, Cooper-Jacob, Hantush, Murdoch, Papa-Cooper, and Theis-Hantush by using the AQTESOLV v4.5 program.

1: Barker Method

Usually, this method is applied for analysis of the pumping test data under non-integer flow dimensions (Barker, 1988). Where this conventional model is more suitable for the explanation of simple hydraulic responses of aquifers (Méité et al., 2022). Where the Laplace equation of groundwater flow drawdown at the pumping well can be represented as

$$hw = Q[1+Sw\Phi\nu(x)] / p[p\beta[1+Sw\Phi\nu(x)]+Kb^{3-}n\alpha_n r_n^{-2w}\Phi\nu(x)] \text{--------(1)}$$

$$\nu = 1-n/2 \quad \text{-------------- (2)}$$

$$\lambda^2 = pSs/K \quad \text{-------------(3)}$$

$$\mu = \lambda rw \quad \text{-------------(4)}$$

$$\Phi(z) = zK_{\nu-1}(z)/K\nu(z) \quad \text{--------------(5)}$$

$$\alpha_n = 2\pi n^{/2} / \Gamma(n/2) \quad \text{----------------(6)}$$

$$\beta = \pi r^2_c \quad \text{-----------------(7)}$$

$$x = \mu \quad \text{---------------(8)}$$

In this equation "b is the extent of flow region [L], h is the hydraulic head at time t [L], K is hydraulic conductivity [L/T], K_ν is the modified Bessel function of the second kind, order ν, n is flow dimension [unit less], p is the Laplace transform variable, Q is pumping rate [L^3/T], rw is well radius [L], Ss is specific storage [unit less]. Sw is wellbore skin factor [unit less]"(AQTESOLV, 2022).

2: Cooper-Jacob

The Cooper-Jacob method has been applied in many cases over the world successfully. This technique represents a simplification of Theis's solution (Pongmanda and Suprapti, 2020). The aquifer parameters according to this method are as follows

$s = 2{,}3Q4\pi T\ Log_{10}\ (\ 2.25Tt/r_w^2S)$ ------------------(9)

$s = 2{,}3Q4\pi T\ log_{10}\ (2.25T/r_w^2\ S) + (2.3Q/4\pi T)\ log_{10}\ t$ ------ (10)

The scheme of drawdown versus log time is the shortest route, the elongation of this route in the drawdown is zero, $t = t_o$ so

$$T = \frac{2.3Q}{4\pi\Delta(h_0 - h)} \quad \text{------ (11)}$$

$$S = \frac{2.25Tt_0}{r^2} \quad \text{---------- (12)}$$

Where

S: "aquifer storativity", r: radial distance from pumping well, T: "aquifer transmissivity", Q: "steady pumping amount", $\Delta(h_o\text{-}h)$: drawdown to each logarithmic round of time, t_o= time where the shortest route intersects the zero drawdown axis.

3: Hantush

Hantush, 1960 discovered a method for analyzing the pumping test data of a confined aquifer (Atangana, 2018). The following equation can be used for the calculation of the aquifer properties at the pumped well with-short time pumping.

$$S = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-y}}{y}\, erfc\, \frac{\beta\sqrt{u}}{y(y-u)}\, dy \text{-------------- (13)}$$

$$u = \frac{r^2 S}{4Tt} \text{ ---------------------------------- (14)}$$

$$\beta = \frac{r}{4}\sqrt{\frac{K^{'}S^{'}}{b^{'}TS}} \text{ ------------------------------ (15)}$$

Where "b′" is the thickness of the first confining unit (L), "K′" is the vertical hydraulic conductivity of the confining unit (L/T)," discharge "(L^3/T)", r is the radial distance between the observation well and pumping well (L),s is drawdown (L), S is storativity (unitless), S′ is "storativity" of first confining unit (unitless),t is elapsed time since the start of pumping (T), T is transmissivity (L^2/T).

4: Murdoch

Murdoch, 1994 discovered an analytical explanation for unsteady flow for any complicated geometries of the confined aquifer (Murdoch and Franco, 1994; Murdoch et al., 2021). The hydrogeological parameters of the aquifer can be calculated by the following,

$$s = \frac{Q}{4\pi\sqrt{T_x T_y}}\frac{\sqrt{\pi}}{2}\int_0^{tD}\left[erf\,\frac{1-XD}{\frac{2}{\sqrt{\pi}}} + erf\,\frac{1+XD}{\frac{2}{\sqrt{\pi}}}\right] e^{\frac{-y_z^2 T_z}{4\pi T y}}\, d\tau/\sqrt{T} \text{ -----------(16)}$$

$t_D = T_x t / S X_t^2$ -- (17)

$X_D = X / X_t$ -- (18)

$y_D = y / X_t$ -- (19)

where "Q is discharged (L^3/T)", s is "drawdown" (L), "S is storativity" (unitless), t is passed time as the discharge begins (T), "Tx is transmissivity in x direction" (L^2/T), "Ty is transmissivity in the y direction" (L^2/T), τ is variable of integration, x, and y are coordinate directions (L)," xt is the half-length of the trench in the x direction" (L).

5: Papadopoulos – Cooper

Papadopulos-Cooper finds the storativity for the confined aquifer for the pumping well large-diameter (Waterloo, 2022). The confined aquifer run out in the discharge well given as

$$S_w(t) = \frac{Q}{4\pi T} F\left[\frac{Tt}{r_w^2}, \alpha\right] \text{------------------------ (20)}$$

$$\alpha = \frac{r_w^2 S}{r_c^2} = 1/\ 2C_D \text{ ------------------------------------ (21)}$$

"s_W: run out in the discharge well", "r_{ew}": effective radius of the filter well, "r_c": radius of the full pipe, in which the water level changes, C_D: unitless storativity

6: Theis-Hantush

This technique has been created to further improve the Thesi method by adding a condition of limited breakthrough for discharge well in a vast anisotropic un-leaky confined aquifer (Anwar, 2018). This model can be written as follow

$$s_W = \frac{Q}{4\pi T}\left[w\,(u) + \frac{2b^2}{\pi^2(1-d)^2}\sum_{n=1}^{\omega}\frac{1}{n^2}\left(\sin\left(\frac{n\pi l}{b}\right) - \sin\left(\frac{n\pi d}{b}\right)\right)^2 . w(u,\beta) + \frac{2b}{(1-d)}s_w\right] + CQ^p \text{ ------------------------------------ (22)}$$

$$u = \frac{r_w^2 S}{4Tt} \text{ --(23)}$$

$$\beta = \sqrt{\frac{K_z}{K_r}}\frac{n\pi r_w}{b} \text{ --(24)}$$

Where,

"b is aquifer thickness" (L), "C is nonlinear well loss coefficient" (TP/L^{3P-1}), "d is the depth to the top of the pumping well screen (L), "Kr is the radial (horizontal) hydraulic conductivity" (L/T), "Kz is the vertical hydraulic conductivity" (L/T), l is the depth to the bottom of pumping well screen (L), "Q is discharge amount" (L^3/T),"rw is well radius" (L),"sw is drawdown in the pumped well" (L), "S is storativity" (unitless), Sw is wellbore skin factor (unitless),t is passed time as the discharge begins (T), "T is transmissivity" (L^2/T), w(u) is the Theis well function for nonleaky confined aquifers (unitless), w(u,β) is the Hantush and Jacob well function for leaky confined aquifers (unitless)(AQTESOLV, 2022).

Results and Discussion

There are multi-software programs that deal with or solve hydrological problems, one of the best of these programs is AQtesolv software. This software is the most developed over the years and easily managed to cover most of the pumping test problems with less training effort compare with the others (Ficaj et al., 2021). The results of using this program to simulate the pumping test data of the well (B7-3) at Ain –the Tamer region can be seen in Table (2) and Figure (3).

Table 2. Aquifer properties of pumping test solution techniques.

Pumping Test solution method	*Aquifer properties model*
Barker	Ss = 0.0064 K= 0.000416 m/sec
Cooper-Jacob	T = 0.021 m2/sec S = 0.0366
Hantush	T = 0.016 m2/sec S = 0.256
Murdoch	Kx = 0.00067 m/sec Ss = 0.069 m-1
Papadopulos–Cooper	T = 0.016 m2/sec S = 0.256
Theis-Hantush	T = 0.016 m2/sec S = 0.22

The minimum value of hydraulic conductivity was recorded for the Barker method with (0.00041 m/sec). Where the confined aquifer flow system is supposed to be at simple hydraulic responses of aquifers (Méité et al., 2022). Transmissivity of the aquifer was calculated by Cooper-Jacob, Papadopulos–Cooper, and Theis-Hantush. The maximum value was for the Cooper-Jacob straight-line method (0.021 m2/sec). The matching log-log methods have the same value for transmissivity. Although, the similarity in analytical matching techniques for pumping test data but the storativity of the aquifer was 0.22 less estimation for the Theis-Hantush method. The straight line of (The Cooper-Jacob) Method has a very low value for storativity compared with the other techniques.

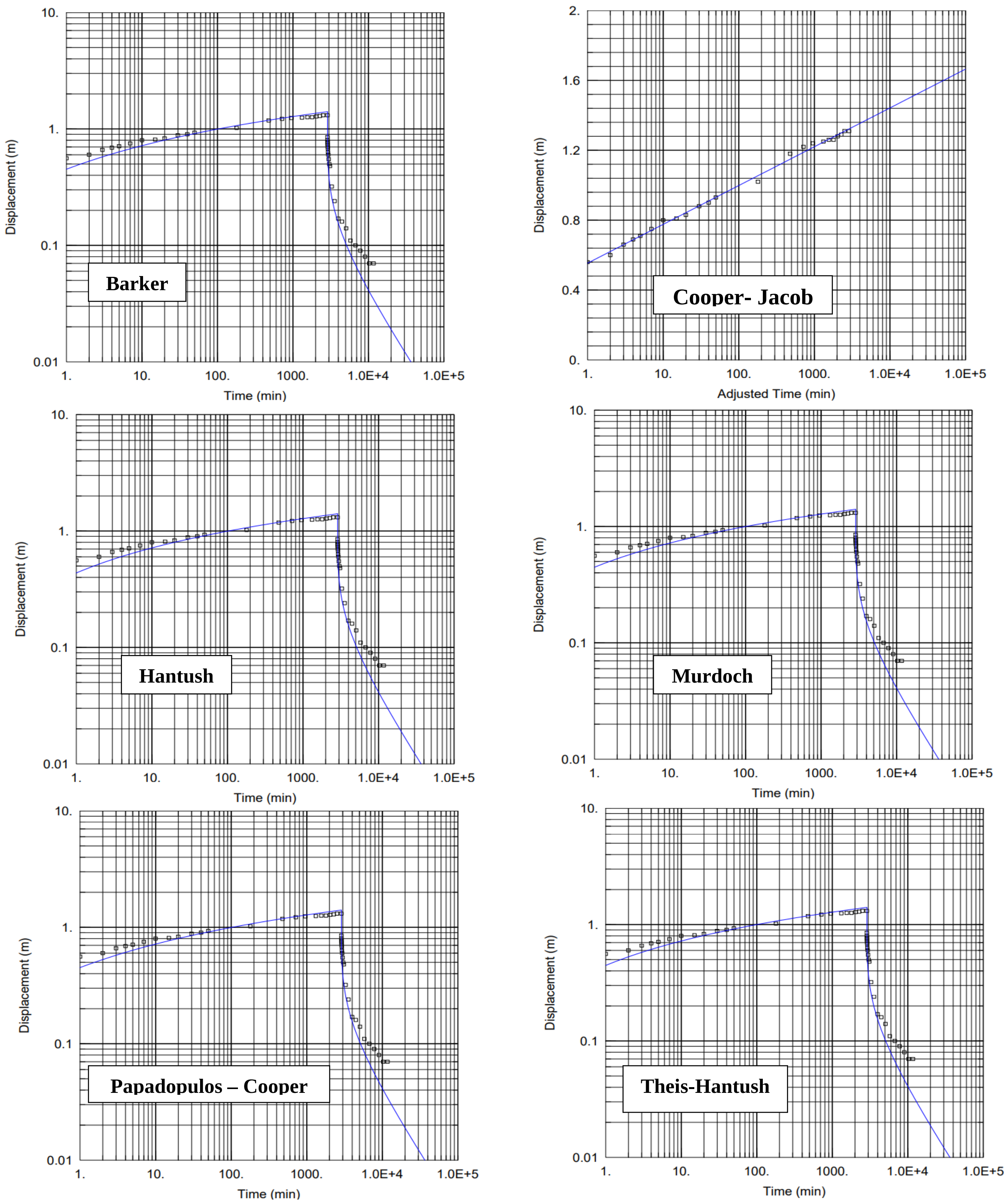

Fig. 3. The results of the pumping test graphic presentation for the methods used

Conclusion

The application of analytical modeling for the analysis of pumping test data for the well (B7-3) which is drilled by the Yugoslavian company (Consortium) in the west of Iraq, shows that there is a wide range of aquifer properties. Although the aquifer type is considered a confined aquifer, the hydraulic transmissivity ranged between 0.016 to 0.021 m2/sec. The range was more for storativity which ranged between 0.0064 to 0.256. This lead to conclude that the analytical solution for pumping test data fit is not quite enough to estimate aquifer properties without additional field and log well data information. The result of this research can allow information about the possible solution of the aquifer Umm Er Radhuma Formation for future planning.

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