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PERFORMING PUMPING TEST DATA ANALYSIS APPLYING COOPER-JACOB'S METHOD FOR ESTIMATING OF THE AQUIFER PARAMETERS

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Abstract: Single well test is more common than aquifer test with having observation well, since the advantage of single well test is that the pumping test can be conducted on the production well with the absence of observation well. A kind of single well test,which is step-drawdown test used to determine the efficiency and specific capacity of the well, however in case of single well test it is possible to estimate Transmissivity, but the other parameter which is Storativity is overestimated, so the aim of this study is to analyze four pumping test data located in KAWRGOSK area by using cooper-Jacob's(1946) time drawdown approximation of Theis method to estimate the aquifer parameters, also in order to determine the reasons which are affecting the reliability of the Storativity value and obtain the important aspect behind that in practice.

Keywords: aquifer parameters, single well test, Cooper-Jacob's straight line method

1. Introduction

The most important method to estimate the aquifer parameters are testing with having observation well, but it's cost more than conducting pumping test without observation well which is called single well test, so that since the last decade there are many experiences that are tried to discover a method to estimate the aquifer parameters through analyze single well test data such as (choi,Byung-soo,2007)which tried to find out the Storativity by determining skin factor and effective wellbore storage, and the method of (P. N. Ballukraya, et al,1991) it derived an equation to estimate Storativity by recovery test, Also (M. Razack, et al, 1991) tried to determine Transmissivity through specific capacity data, then (Keith J. Halford, et al,2006) attempt to obtain Transmissivity from single test data, so the articles related to the study area locations are including (Imad Al-Din Omer Hassan,1998),(Mariwan Akram Hama Saeed Chnaray,2003), (Dara Faeq Hamamin,2004),(Salahaddin Saeed Ali,2007),(Diary Ali Mohammad Ameen Al-Manmi,2008),(Shwan Omer Ismail Shwani,2008), Also (Masoud Hussein Hamed,2013). There are many papers and references that ordered to the Storativity value in case of the absence of observation well is not accurate,because it depends mainly on the radial distances between pumping well to point of measuring drawdown from those(G.P. Kruseman, et al,1991),(Yaran M.Sternberg,1970),(J. Boonstra, et al, 2001),(Michael Kasenow,2006),and(Neven. Kresic,2006).

Single well aquifer testing can provide the value of Transmissivity,whereas preclude the cost and access of multi-well aquifer testing, so usually in this case the test data analyzed by Cooper-Jacob's (1946) straight line method due to it's simplicity. Transmissivity is estimated by fitting a straight line between time versus drawdown on semi-logarithmic paper. The test data of both confined and unconfined aquifers were analyzed by many practitioners that are used cooper-Jacob method to estimate the drawdown equation, regardless of the differences between theoretical and practical conditions. Whereas the Cooper-Jacob's(1946) method simplified the Theis(1935) equations, which was derived under the following assumptions: the pumped well should be fully penetrate, confined aquifer, homogeneous and isotropic[8].

Normally to analyze pumping test data it needed to obtain field data, that means drawdown and flow rate as a function of time, to simulate this data it should take the conditions that for constant pumping rate at the well and the other for the constant head at the well.

Theis(1935)assumed that the pumping rate is constant in a confined, homogeneous, isotropic, infinite areal extent and transient flow without recharge is:

$$\nabla^2 h = \frac{S}{Kb} . \frac{\partial h}{\partial t}$$

using boundary condition of the well:

Q=q. A

$$q = \frac{Q_{well}}{2\pi rb}$$

$h=h_{initial,}$ @ $r=r_w$,

@ $r=r\infty$

so Theis(1935) solution:

$$s = \frac{Q}{4\pi Kb}\int_u^\infty \frac{e^{-u}}{u} . du \quad , \int_u^\infty \frac{e^{-u}}{u} . du = W(u) = well\ function$$

$$W(u) = \left[\gamma - \ln u + u - \frac{u}{2.2!} + \frac{u}{3.3!} - \cdots\right], \gamma = Euler\ number = -0.5772$$

$$u = \frac{r^2 S}{4Tt}$$

or:

$s = \frac{Q}{4\pi T} W(u$, Theis equation for drawdown)

The above equation is known as Theis matching curve by plotting field data obtained during pumping test on type curve using the same scale on semi-logarithmic paper, then the two curves superimposed on each other the unknown values can be obtained to calculate the aquifer parameters. Later Cooper-Jacob suggested that Theis(1935) method can be simplified if Time is long and r is small,then u should be small or equal than 0.01, thus the only two first terms can be taken into account.

and also he supposed that the equation also can be used for water-table type aquifer if 2s<<b, which is the aquifer thickness, so that the presented study preferred to select this method for analyzing the test results, and recommend the reasons behind that carefully.

2. Cooper-Jacob's time drawdown method

Cooper and Jacob(1946) simplified Theis(1935) equation, who noted that for large values of time t, and small value of r, ($u \leq 0.01$), the series expansion of the Theis (1935) equation after the first two terms become negligible[17], so that:

Theis(1935) drawdown equation:

$$s = \frac{Q}{4\pi T}\left[-0.5772 - \ln u + u - \frac{u}{2.2!} + \frac{u}{3.3!} - \cdots\right] \quad (1)$$

where:

$$u = \frac{r^2 S}{4Tt} \quad (2)$$

According to Jacob's (1946) assumptions the drawdown equation simplified to:

$$s = \frac{Q}{4\pi T}\ [-0.5772 - \ln u] \quad (3)$$

Then rearranging the equation and changing -0.5772 to ln 1.78:

$$s = \frac{Q}{4\pi T}\left[-\ln 1.78 - \ln \frac{r^2 S}{4Tt}\right] \quad (4)$$

$$s = \frac{Q}{4\pi T}\left[-\left(ln1.78 + ln\frac{r^2 S}{4Tt}\right)\right] \quad (5)$$

$$s = \frac{Q}{4\pi T}\left[-ln\frac{1.78\, r^2 S}{4Tt}\right] \quad (6)$$

inverse the term using Ln rules to get:

$$s = \frac{Q}{4\pi T} ln\left[\frac{4Tt}{1.78\, r^2 S}\right] \quad (7)$$

For a small value of r, the eq.(7) is the equation of a straight line plotted between drawdown(s) and log of time(t) on semi-log paper, and rewriting the equation in the form of logarithmic,it become:

$$s = \frac{2.3Q}{4\pi T} \text{Log}\left[\frac{2.25Tt}{r^2 S}\right] \quad (8)$$

thus, the straight line equation is:

$$s = \frac{2.3Q}{4\pi T}\log\left[\frac{2.25T}{r^2 S}\right] + \frac{2.3Q}{4\pi T}\log\ t \quad (9)$$

$Y = B\ (intercept) \quad + A(slope)\ x$

The plot of s against Logt should be a straight line, the extend of the straight line at zero drawdwon, $t = t_o$, so that:

$$\frac{2.25Tt_o}{r^2 S} = 1 \quad (10)$$

or:

$$S = \frac{2.25Tt_o}{r^2} \quad (11)$$

and:

$$\Delta s = \frac{2.3Q}{4\pi T} \quad (12)$$

then Transmissivity is:

$$T = \frac{2.3Q}{4\pi \Delta s} \quad (13)$$

Where:

s - is drawdown [m]
Q - is constant rate pumping test [$m^3.min^{-1}$]
T - is Transmissivity [$m^2.min^{-1}$]
S - is Storativity [*unit less*]
r - is radial distance [m]
r_w - is well radius [m], see Figure1
u - is well constant
$W(u)$ - is well function
t - is time of pumping [min]
Δs - is slope of the line per one log cycle [m]
t_o - is the initial time of pumping test at zero drawdown [min]
γ - is Euler number = -0.5772
h - is aquifer thicknessin water-table aquifer [m]
b - is the aquifer thickness in case confined [m]

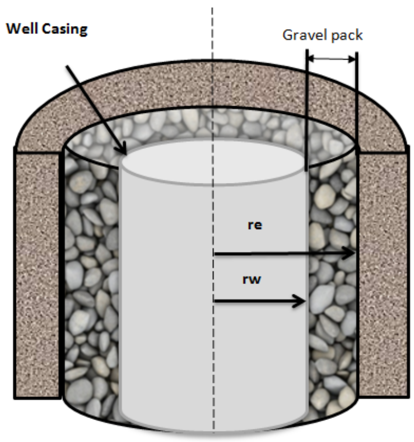

Fig. 1 - Section of the well

2.1. Study area location

The study area is KAWRGOSK, which is located at a distance of about 25km from center of Erbil city,Kurdistan Region of Iraq and the Area is about 108.379 km^2,the geological formation of the location is Bakhtiari formation,see Figure in Appendix. The map shown the position of the wells through GIS program (ArcMap10) with the following UTM coordinate system, see Figure2:

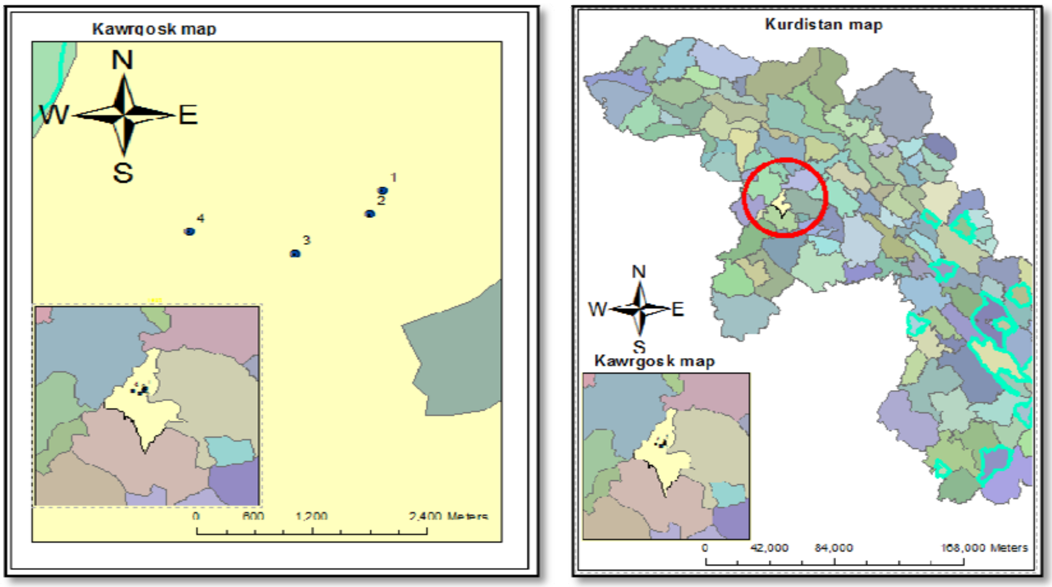

Fig. 2 - Wells location in KAWRGOSK.

and the coordinate of the well location is presented in the Table 1:

Table 1

Coordinate of well location in KAWRGOSK

Well Description	E (Longitude) 38 S	N(altitude)	Elevation
1	0393748	4023978	338
2	0393619	4023685	336
3	0392842	4023182	307
4	0391732	4023471	303

2.2. Application of Cooper-Jacob method

The pumping test results of the wells are plotted on semi-logarithmic paper, the slope of the line Δs with initial time of pumping test t_o were determined, as presented in Figure 3:

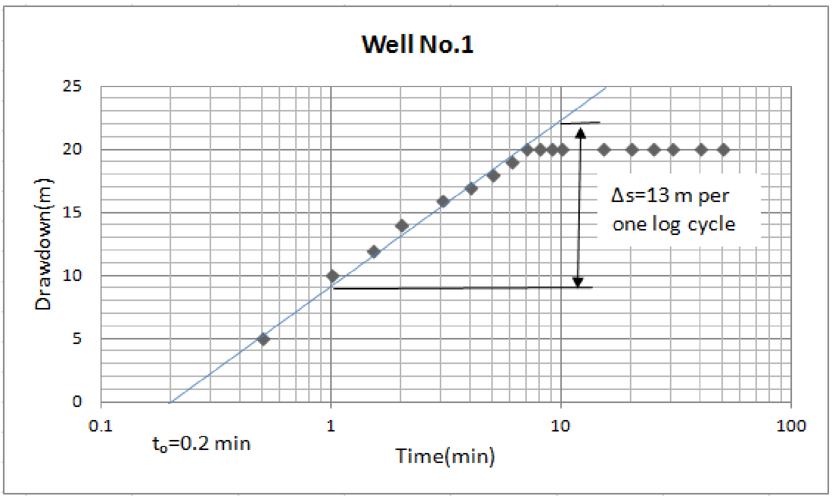

Fig. 3 - Well No.1 time-drawdown straightline plot

The test data of well No.1 have taken into account, see Table 2:

Table 2

Pumping test data of well No.1

Well 1		
Time(min)	sw(m)	Yield(m^3/min)
0	0	0
0.5	5	0.462
1	10	0.462
1.5	12	0.462
2	14	0.462
3	16	0.462
4	17	0.462
5	18	0.462
6	19	0.462
7	20	0.462
8	20	0.462
9	20	0.462
10	20	0.462
15	20	0.462
20	20	0.462
25	20	0.462
30	20	0.462
40	20	0.462
50	20	0.462

And the detail of the wells are shown in the Table 3:

Table 3

Well informations

Well	Yield (m^3/min)	well radius (m)	Casing radius (m)	well Depth(m)	Static water level(m)	Dynamic water level(m)
1	0.462	0.11	0.156	220	80	100
2	0.568	0.11	0.156	220	60	92
3	0.435	0.11	0.156	215	64	76
4	0.371	0.11	0.156	210	47	90

To estimate the Transmissivity and Storativity for well No. 1 is as follow:

Pumping rate, $Q=0.462\ m^3/min$ or ($0.0077\ m^3/sec$).

well radius $r_w=0.11m$

$\Delta s=13m$, and $t_o=0.2min$,see Figure 3;

$$T = \frac{2.3Q}{4\pi\Delta s} = \frac{2.3(0.462)}{4 * 3.14 * 13} = \frac{0.007m^2}{min}$$

$$T= 9.371 \frac{m^2}{day} \text{ or } 0.00012\ m^2/sec$$

and the Storativity:

$$S = \frac{2.25Tt_o}{{r_w}^2} = \frac{2.25 * 0.007 * 0.2}{0.11^2} = 0.242$$

The storage coefficient For unconfined aquifer type should be within 0.1 to 0.3 according to [11]. The pumping test results obtained for the other wells are shown in Tables 4,5,6 respectively.

Table 4

Pumping test data of well No. 2

Well 2		
Time(min)	sw(m)	Yield(m^3/min)
5	5	0.568
10	15	0.568
15	20	0.568
20	22	0.568
25	25	0.568
30	28	0.568
35	30	0.568
40	31	0.568
45	32	0.568
50	32	0.568
55	32	0.568
60	32	0.568
80	32	0.568
100	32	0.568
120	32	0.568
150	32	0.568
180	32	0.568
220	32	0.568
280	32	0.568
300	32	0.568
400	32	0.568

The time versus drawdown plot are illustrate in Figure 4:

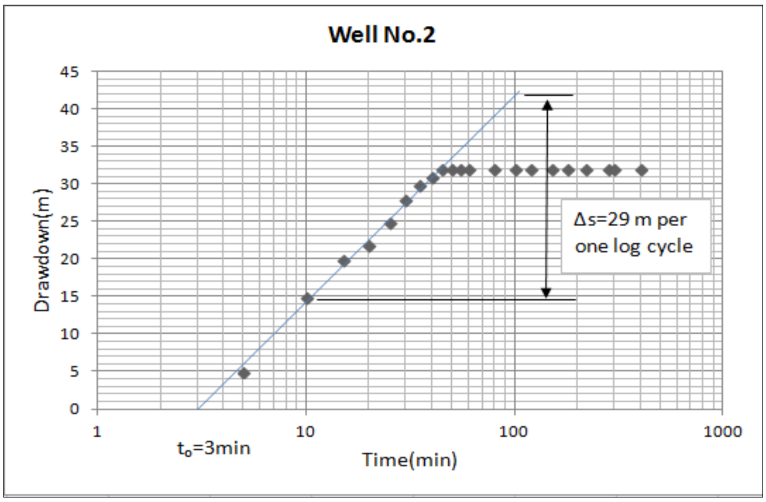

Fig.4 - Well No.2 time-drawdown straightline plot

The test data of well No.3 and the straightline of the time against drawdown in Table 5, and Figure 5 respectively.

Table 5

Pumping test data of well No. 3

Well 3		
Time(min)	sw(m)	Yield(m^3/min)
0	0	0.435
0.5	0.5	0.435
1	1	0.435
1.5	1.3	0.435
2	1.6	0.435
3	2.4	0.435
4	3.4	0.435
5	4.2	0.435
6	4.8	0.435
7	5.3	0.435
8	5.9	0.435
9	6.3	0.435
10	6.7	0.435
15	8.1	0.435
20	9.5	0.435
25	10.2	0.435
30	10.7	0.435
40	11.5	0.435
50	11.8	0.435
60	12	0.435
80	12	0.435
100	12	0.435
120	12	0.435
140	12	0.435
160	12	0.435
200	12	0.435

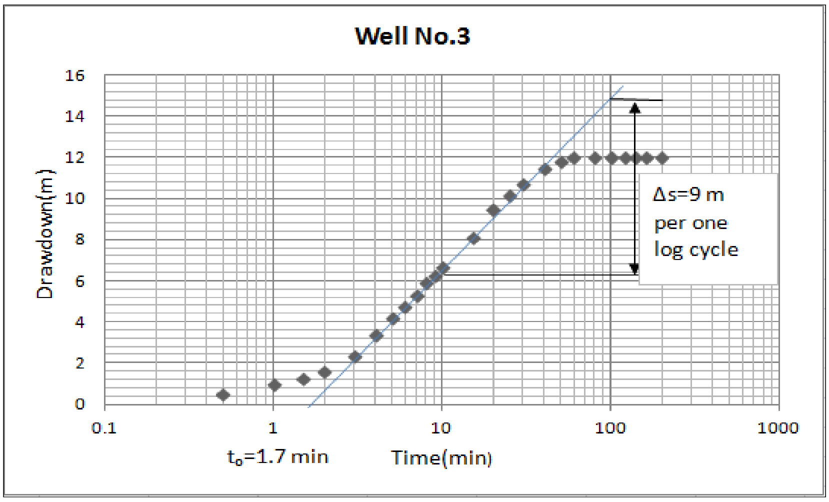

Fig.5 - Well No.3 time - drawdown straightline plot

The Test data of well No. 4 are presented in Table 6:

Table 6

Pumping test data of well No. 4

Well 4		
Time(min)	sw(m)	Yield(m^3/min)
0	0	0.371
0.5	0.3	0.371
1	0.8	0.371
1.5	1	0.371
2	2	0.371
3	4.5	0.371
4	7.2	0.371
5	9.6	0.371
6	11.9	0.371
7	13.7	0.371
8	15	0.371
9	16.8	0.371
10	18.1	0.371
15	22.4	0.371
20	26.4	0.371
25	29	0.371
30	30.5	0.371
40	34	0.371
50	36.6	0.371
60	38.2	0.371
80	41.5	0.371
100	43	0.371
120	43	0.371

The semilogarithmic plot of well No.4 are shown in Figure 6

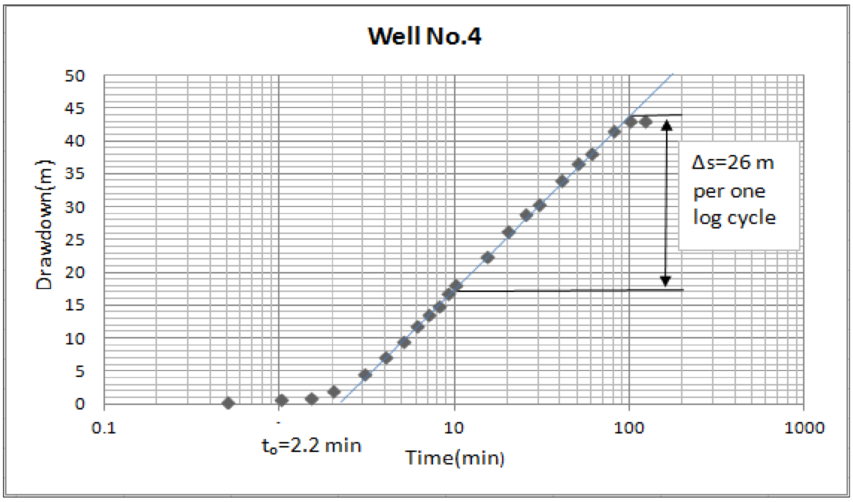

Fig.6 - Well No.4 time - drawdown straightline plot

Table 7

The calculation of well data.

Well	Q (m^3/min)	r_w (m)	Δs (m)	t_o (min)	T (m^2/day)	T (m^2/day)	class type	S	(S) range
1	0.462	0.11	13	0.2	9.371	1 to 10	Low	0.242	0.1-0.3
2	0.568	0.11	29	3	5.165	1 to 10	Low	2.001	0.1-0.4
3	0.435	0.11	9	1.7	12.745	10 to 100	Intermediate	2.798	0.1-0.5
4	0.371	0.11	26	2.2	3.763	1 to 10	Low	1.069	0.1-0.6

Classification of the Transmissivity according to [42],see Table 8:

Table 8

Classification of Transmissivity

Coefficient of Transmissivity (m^2/day)	class of Transmissivity magnitude	Designation of Transmissivity magnitude
>1000	I	very high
100 to1000	II	High
10 to 100	III	Intermediate
1 to10	V	Low
0.1 to 1	IV	Very low
<0.1	VI	Imperceptible

The lithology and well design profile of the each well are illustrated in Figures 8, 9, 10,11 respecitevely:

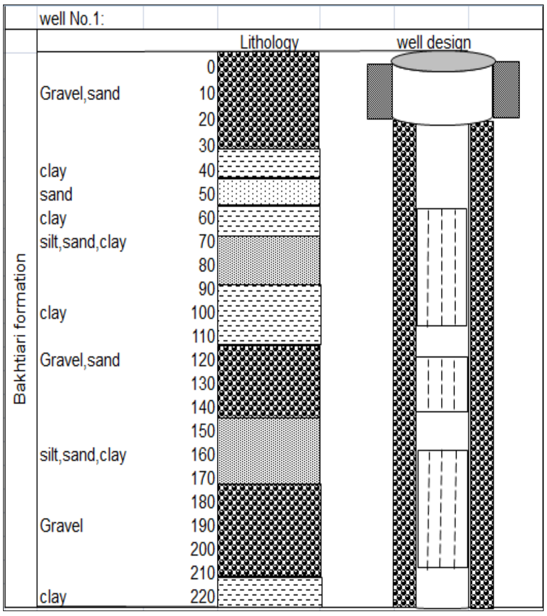

Fig.8 - Lithology of well No.1

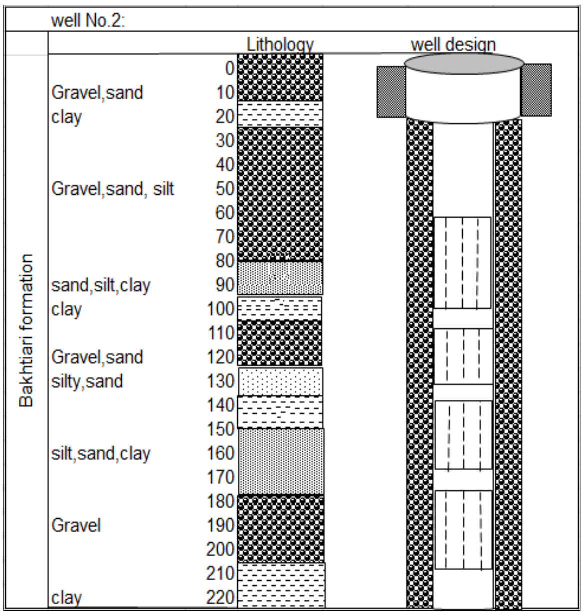

Fig.9 - Lithology of well No.2

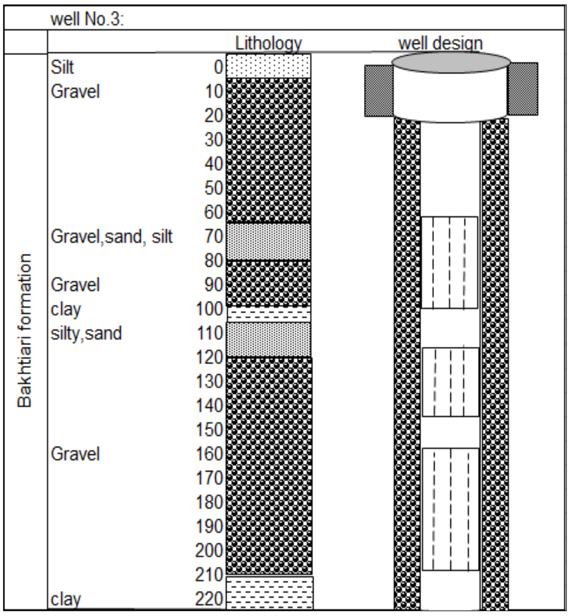

Fig.10 - Lithology of well No.3

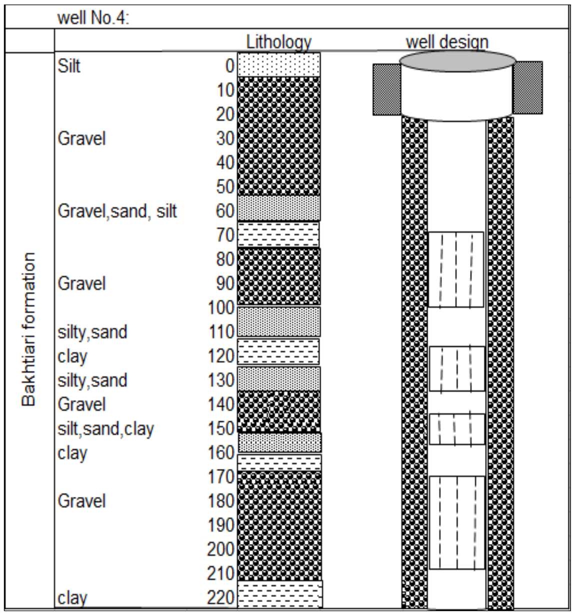

Fig.11 - Lithology of well No.4

3. Conclusion

According to the analysis of the test data, the results are satisfied that the value of storage coefficient is overestimate in case of single well test, due to well losses inside the production well,this leads to cause high drawdown on the plot of the straight line of time versus drawdown, see figures [3,6] in Appendix, and the radial distance in this case represented the radius of the well[r_w], which is the screened part of the well, and that's why the value of the specific yield is out of the standard range,because according to[11],the value of storage coefficient for water-table aquifer type should be within [0.1 to 0.3],and the degree of the accuracy the value of Storativity depends on the radial distance from pumping well observation well, so that in this study tried to determining the two main reasons behind that,which will cause to obtained unreality value of Storativity or specific yield, however the Transmissivity is regardless the above two reasons of the Storativity, it can be estimated with or without observation well and that is all the aim of the research to present the main factors that affecting on estimating the value of the aquifer parameters, so it is recommended that in case of single well test it is better to first obtain the radial distance,the effective wellbore store radius should be introduced as a radius to imaginary monitoring well i time-drawdown analysis, it can be estimated through step-drawdown test or skin factor equation. A method should be developed to estimate the real effective well radius to obtain the reliable value of Storativity. The following are the explaination of the pumping well and radial distances during the pumping test, see Figure 12, appyling continuity equation.

$Q_1=Q_2$

$A_1V_1=A_2V_2$

$2\pi R_1h_1V_1= 2\pi R_2h_2V_2$

$R_1V_1=R_2V_2$

$R_2>R_1$

$V_1>V_2$

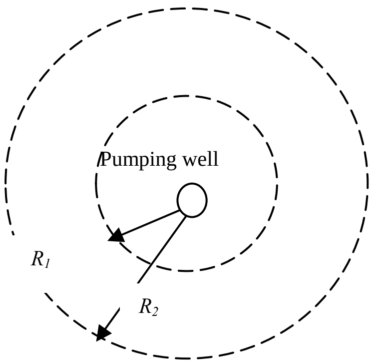

Fig 12 - Plan view of the imaginary well

Notation:

s - is drawdown[*m*].

Q - is constant rate pumping test [$m^3.sec^{-1}$]

T - is Transmissivity [$m^2.sec^{-1}$].

S - is Storativity[*unit less*].

r - is radial distance [*m*].

u - is well constant.

W(u) - is well function.

t - is time of pumping [*sec or min*].

Δs - is slope of the line per one log cycle [*m*]

t_o -is the initial time of pumping test at zero drawdown [*sec or min*].

γ -is Euler number = *-0.5772*.

h - is aquifer thickness [*m*] in water-table aquifer.

b - is the aquifer thickness for confined aquifer type [*m*]

r_w - is radius of the well [*m*].

r_e - is the effective radius of the well [*m]*

s_w - is the drawdown at the well [*m*]

Sc - is the specific capacity of the well [$m^3.s^{-1}$*per m drawdown*]

Y - is linear equation

B - is intercept of the line.

C - is the slope of the line.

x - is x-axis.

swl - static water level [*m*]

dwl - dynamic water level [*m*]

R_1,R_2 - the radial distances from pumping well to observation well 1 and 2.[*m*]

V_1,V_2 - the velocity of the water of section 1 and 2.[*m/s*]

h_1 and h_2- the thickness of the aquifer @R_1 and R_2 respectively [*m*]

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