RESEARCH PAPER

Comparing pumping test between Boulton and Neuman in unconfined aquifer

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A B S T R A C T:
Groundwater is known as a crucial source of water in the history of human, as it less contaminated, it has more preferable than surface water. Analyzing data of pumping test for evaluating aquifer parameters specific yield (Sy), transmissivity (T) and storativity (S) are usually using standard procedures like Theis or Jacob method. Boulton was the first to present the delayed response concept of unconfined aquifers under pumping conditions. Then Neuman used a different method than Boulton to develop an analytical model for a fully penetrating well in unconfined aquifers. The Neuman's model is depended on physical parameters which are well defined in aquifer system that is the main difference comparing to Boulton model. The main objective of this research on understanding water table aquifers in the Xabat area is to analyze the two main Boulton and Neuman methods by using aquifer test pro 2016 software and to see which of them are most appropriate for this area, which is the main reason for applying and comparing the two methods. The results of the layer property (specific yield, transmissivity, and storativity) are similar depending on the user and the availability of the methods, as well as the future development of the program analysis.

1.INTRODUCTION :

Groundwater hydrologists for their quantitative studies usually conduct pumping test and analyze data to get aquifer parameters. Analyzing data of pumping test for an unconfined aquifer is known to be a marginally complex due to the curve of transient drawdown, which displays three segments in the response to the pumping. At the beginning of the pumping time and during the first segment, the storage water is released immediately.

The vertical gradient close to water table produces porous matrix drainage throughout second segment, as a result, rate of hydraulic head would drop and then slowing down and it might lead to stop after an amount of time. Lastly, when the flow is fundamentally horizontal, nearly all of pumping is provided by the specific yield, Sy, in the last segment. Parameters of aquifer could be estimated at a specific site through a pumping test, after collecting data different method could be used to analyze these data for example Jacob or Theis. The simple graphical method to estimate storativity and transmissivity of the aquifer which is based on Theis's formula is proposed by Chenini *et al*., (2008). In confined aquifers, standard methods have been used to analyze pumping test data. The expectations in Jacob or Theis methods were resulting to meet the most

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cases in confined aquifers. While, generally these methods are not suited for unconfined aquifers and the reason might back to two points: first is phenomenon of delayed yield, the second is drawdowns being that occasionally bigger to the aquifer's primary saturated thickness. Boulton (1954 and 1963) through introducing delayed yield's concept, he established an analytical solution for the unconfined aquifer flow equation. Depend on Boulton method by using graphical procedures Prickett (1965) introduced systematic approach to determine hydraulic parameter. Cooley and Case (1973) point to the Boulton's equation that defined a flow system with a rigid phreatic aquitard on top of the main aquifer which the effect of the unsaturated zone above the phreatic surface was neglected. A solution is developed by Neuman (1972, 1974) to consider elastic storage affection and aquifer's anisotropy on the behavior of drawdown. Another development of procedure graphical type curve match was showed by Neuman (1975) for determination unconfined aquifer's parameters. A combination of two models Boulton and Neuman for flow directed to well in an unconfined aquifer was documented by Moench (1995).

There are many articles provided to demonstrate the flow through the water table aquifers, for instance Grimestad (2002) found that a part of the water pumped from aquifers had been obtained from other sources. Zhan and Zlotnik (2002) addressed how a solution can be found for flow to a horizontal or slanted well in an unconfined aquifer. Hunt (2006) used a significant aquifer parameter instead of an empiric constant in the Zhan and Zlotnik (2002) equation to describe the flow to a well when a number of overlying aquitards exist between the pumped aquifer and the free surface. Mishra and Neuman (2011) determined saturated and unsaturated flow to a well with storage in a compressible unconfined aquifer. And also Malama (2011) proposed alternative linearization of water table kinematic condition (Moench, 2004; Tartakovsky and Neuman, 2007; Ni et al., 2015). Until then, there is rarely water table (Phreatic) aquifer investigation in Kurdistan of Iraq.

Waterloo Hydrogeological Incorporated used computer and developed software for aquifer test, then all parameters for pumping test are calculated by this software (Hui, 2011). Also, this software can be specially used for processing data, analyzing data, obtain graphical parameters, and data analyzing of pumping test.

This software can be used for calculating data, display results and then printing results of parameters. The Aquifer Test pro-2016 software was used to determine aquifer parameters based on formula of two models Boulton and Neuman through using pumping test data.

1.1 AREA OF STUDY

This study was conducted in Kabat/Khabat district (Kurdish: Qazay Xabat). It is located in the west of Erbil Governorate Iraq. Khabat district includes 64 villages and three main sub-districts, which are Darashekran, Rizgary and Kewrgosk. Geographically, Khabat situated longitude (36∘16′20.48 ″), latitude (43°40′ 23.99″) and 37 km far from Erbil city. The elevation of this location varies between (200 to 400 m) above sea level as shown in Figure 1.

The pumping test exercise was carried out on a single well within the Kabat area, with a constant discharge of 267 Gpm (1730.2 m^3/day). The pumping well is 250 m depth. The aquifer saturation thickness is 214 m and the original static water level is 36 m and other data presented in Table 1.

2. METHODOLOGY

2.1 Boulton (1963) Type-curve Method

Boulton (1963) supposed that derived water volume from storage in unconfined aquifer contain 2 modules. The first component the amount of water release instantly from storage at this situation aquifer acting like confined. The last factor is the amount of water release as delayed yield. In unconfined aquifers the formula is written basically with 2 components (Batu, 1998). The assumptions are given below (Boulton, 1954):

1. The aquifer is homogeneous and anisotropic, infinitely lateral and underlined by an impermeable horizontal bed.
2. Well completely penetrates the aquifer and is unlined.
3. The specific yield (Sy) is constant.
4. The flow in the aquifer obeys Darcy's law.
5. The water table is initially horizontal.
6. The well is pumped from the moment t=0 at a steady pace.
7. The contribution to the flow by water and aquifer compression may be neglected, except during the very early period of pumping.

8. The drawdown of the water table is small compared with the saturated thickness of the aquifer.

The general solution of that equation is complex which symbolically, and in analogy to the Theis equation, may be written as:

$$s = \frac{Q}{4\pi T} W(U_{AB}, r/D) \qquad (1)$$

$$\alpha = \frac{T}{S_y D^2} \qquad (2)$$

$$\frac{r}{D} = r\sqrt{\left(\frac{\alpha S_y}{T}\right)}, \qquad \alpha t = \left(\frac{r}{D}\right)^2 \frac{1}{4 U_B}$$

Equation (1) defines the first section of the time drawdown curve under early stages and is converted to:

$$s = \frac{Q}{4\pi T} W(U_A, r/D) \qquad (3)$$

Where

$U_A = \frac{r^2 S}{4Tt}$, [unit less]

Equation (1) discusses the third section of the time-drawdown curve under late-time criteria and decreases it to:

$$s = \frac{Q}{4\pi T} W(U_B, r/D) \qquad (4)$$

Where

$U_B = \frac{r^2 S_y}{4Tt}$, [unit less]

Boulton provided W (U_{AB}, r / D) values for the practical U_A, U_B, and r / D ranges. Parameters of W (U_{AB}, r / D) were graphed on logarithmic paper against values of l/U_u and 1/U_B and two types of curves were built. The type curves on the left side of the r/D values are called "Type A curves." Early time-drawdown information is analyzed using them. The type curves on the right side of the r/D values are called "Type B curves" and are used to evaluate delayed time-drawdown information.

2.2 Neuman (1975) solution

Neuman (1972, 1974, 1975, and 1987) documented water table aquifer solution and

consist of two main parts: the first part related to the time when pumping just started, the second part is for time after pumping. This solution occurs when water flows below gravity drainage (Fetter, 2001). Depending on these assumptions of (Batu, 1998) this method increases to:

1. The (Q) pumping rate is constant for well.
2. Well's diameter significantly small, and the well fully penetrates the aquifer thickness.
3. The aquifer stays saturated at all periods, and the law of Darcy applies.
4. The unconfined aquifer is lateral infinite and sits on a horizontal layer that is impermeable.
5. The aquifer is homogeneous but anisotropic and its main hydraulic material.
6. Water expansion and gravity drainage water is removed from free surface storage by compaction of the aquifer.
7. The well can be handled as a sink in the row, meaning that the face of the sink is ignored.
8. It is possible to neglect the capillarity impacts above the water table. This implies that water is released from the unsaturated zone immediately.
9. The water table drawdown is low compared to the aquifer's saturated thickness.

Conductivity is parallel to the axes of the coordinates. The suggested water table aquifer equation is the well-functioning W (U_A, U_B, /) for three distinct stages and the equation drawdown:

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \Gamma) \qquad (5)$$

Initial period: This acts as an elastic storage and is equal to the value u:

$$u_A = \frac{r^2 S}{4Tt} \qquad (6)$$

Time of transition: This operates as an aquifer known as Leaky by:

$$\Gamma = \frac{r^2}{b^2} \frac{K_v}{K_h} \qquad (7)$$

Late time: this acts as drainage of gravity:

$$u_B = \frac{r^2 S_y}{4Tt} \qquad (8)$$

In the early stages, water is removed from elastic storage (S) when drawdown follows a matching Theis type curve, and then a flat curve and a gap in the derivative changes. A second Theis curve corresponds to the water released from the drainage of the unsaturated zone (Sy) for the subsequent moment as shown in Figure 2.

2.3 Applying of Boulton and Neuman solution throughout Aquifer test program

Aquifer test software package known as a simple to use for visualizing pumping test, data analysis, and interpreting. It has been designed for hydro-geologists. This test is provided nearly all essential tools to get accurate results and interpret data under different conditions, types of test, and aquifer types.

Boulton and Neuman have created a technique that can be helpful in determining water table (Phreatic) aquifers ' elastic storage coefficient (S), transmissivity (T), specific yield (Sy), and horizontal and vertical hydraulic conductivity. This solution involves matching drawdown information gathered during the pumping test.

3. Result and discussion

Formula of Neuman well contains unconfined aquifer or aquifer's basement. The aquifer is constant gravity specific yield, homogeneous, and anisotropic. The formula of Boulton well needs the weathered aquifer to be isotropic and homogeneous. The pumping test results data analyzed by Neuman and Boulton methods that are showed in Fig. 3 and Fig. 4. The result of specific yield (Sy), Storage Coefficient (S) and transmissivity (T) are in Table 2. Both Neuman (1975) and Boulton (1963) solutions are applied for analyzing pumping test data of unconfined aquifer, as it is in Xabat area, and the solution required to monitoring drawdown form observation well, since, the test was conducted on the pumped well (single well test), may cause to get unreliable values of the particular yield, which is out of the range of (0.01 to 0.3).

The solution gives the transmissivity values of (213 m^2/day) by Boulton method and (236 m^2/day) by Neuman method which can be classified according to (Table 3) from high to intermediate.

4. Conclusion

Pumping test data from Xabat area was evaluated by Boulton and Neuman methods. Neuman and Boulton methods gave values of transmissivities and specific yield that are relatively close to each other. The delayed water table response process in homogeneous anisotropic unconfined aquifer can be simulated by using constant values of specific storage S, and specific yield Sy. The delay process mathematical model is found without using unsaturated flow theory, simply through treating the unconfined aquifer as a compressible stem and the phreatic surface as a moving material boundary. Boulton's integral transformation as used as a free-surface condition in three-dimensional, axisymmetric boundary value problems for water table aquifer flow.

The development of Boulton equation lead to analyze Neuman equation, the major different is the application program and the software has the major impact of giving different results, however another reason forgetting different value of parameters is the location and the equipment measure at the site. And the hydrogeological formation of the area has another impact, and the main point of the thickness of the aquifer application is always suitable for unconfined aquifers of high thickness. There are many difficulties with a water table of a few meters thickness, so Neuman's program recommended for northern Iraq, since most of unconfined aquifers and reservoirs of high thickness, in fact, Neuman carried out and developed an analysis based on Boulton's principle of unconfined aquifer analysis.

Table 1 Pumping test data results obtained from Ministry of Agriculture and Water Resource/ Directorate of Erbil Groundwater.

Name of abstraction well: well no.(55) in Mamsinjy city					
Place of well: Qazay Xabat			Date of test: 27/8/2017		
Well depth: 250 m			Length of pipe test: 120 m		
Static water level: 36 m			Radius of pipe test: 3 in		
Dynamic water level: 45 m			Type of test equipment: 22-SP46 4 in		
Discharge: 267 (g/min), 1.2015 (m^3/min)			Inside raduis of pipes: 8 in		
Time (min)	**Depth to water level (m)**	**Drawdown (m)**	**Time (min)**	**Depth to water level (m)**	**Drawdown (m)**
0	36	0	9	44.9	8.9
0.5	38	2	10	45	9
1	40	4	15	45	9
1.5	42	6	20	45	9
2	44	8	25	45	9
3	44.2	8.2	30	45	9
4	44.4	8.4	40	45	9
5	44.6	8.6	50	45	9
6	44.7	8.7	60	45	9
7	44.8	8.8	80	45	9
8	44.9	8.9	100	45	9

Table 2 Results of both Neuman and Boulton solution

Aquifer parameter	Neuman	Boulton
Transmissivity (T) (m^2/day)	2.36×10^2	2.13×10^2
Storativity (S)	2.67×10^{-5}	2.93×10^{-5}
specific yield (Sy)	2.67×10^{-3}	2.93×10^{-3}
Kv/Kh	1×10^{-2}	1×10^{-2}

Table 3 Classification of Transmissivity value according to (Krásný, 1993).

Coefficient of Transmissivity (m²/day)	Classification of Transmissivity magnitude	Designation of Transmissivity magnitude
>1000	I	Very high
100 to 1 000	II	High
10 to 100	III	Intermediate
1 to 10	V	Low
0.1 to 1	IV	Very low
<0.1	VI	Imperceptible

Figure 1 Satellite image of Khabat Sub-district from Google earth.
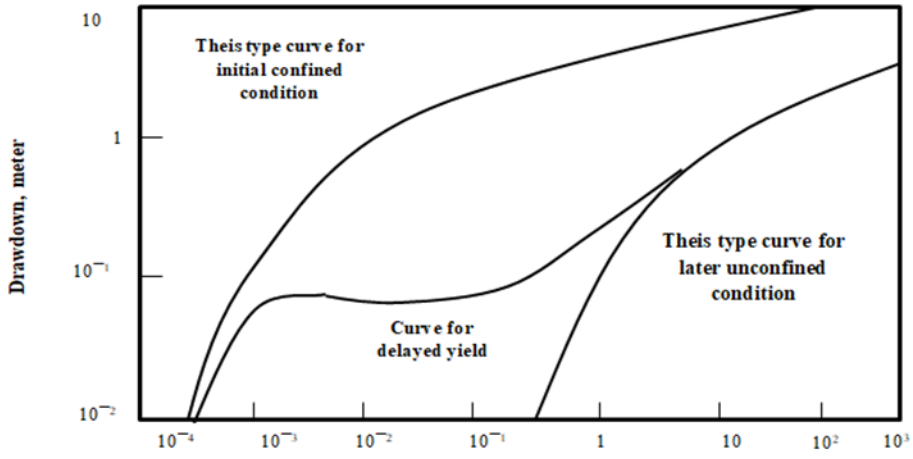
Figure 2 Type curves of drawdown versus time illustrating the effect of delayed yield for pumping tests in unconfined aquifers.
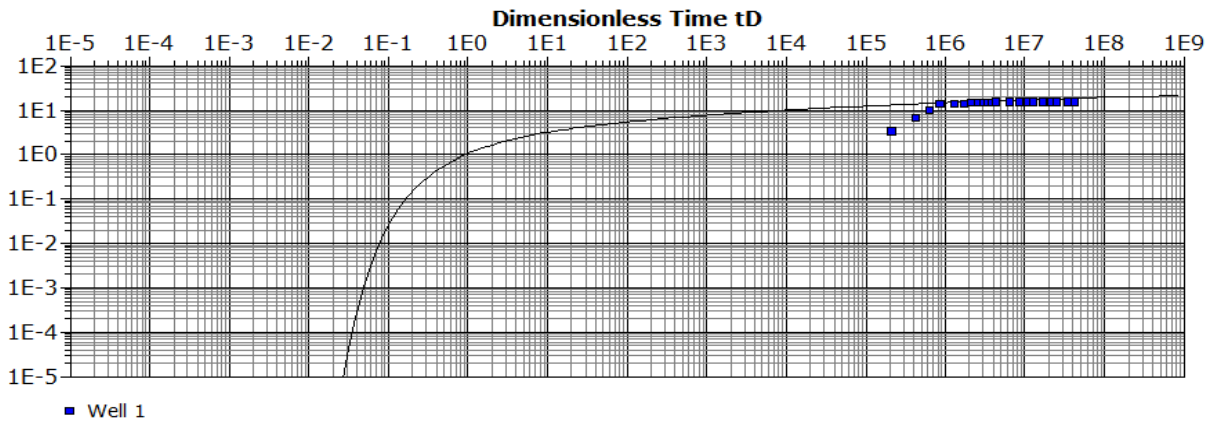

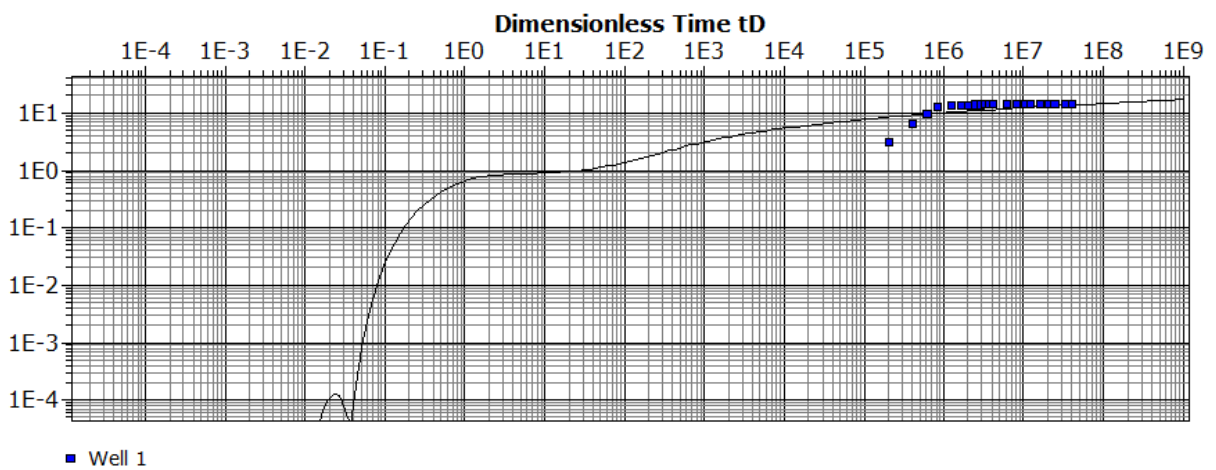**Figure 3 Neuman's solution by aquifer test program**

Figure 4 Boulton's solution by aquifer test program

Notation:

s: Drawdown, [L]

Q: Flow rate, [L^3/T]

T: Aquifer Transmissivity, [L^2 / T]

W (U_{AB}, r/D) = Boulton's well-function [unit less]

α is Boulton delay index curve.

S: Storativity, [unit less]

T: Time, [T]

Sy: Specific yield [unit less].

W (u_A, u_B, Γ): is Neuman well function.

Γ: Neuman parameter of type curve [unit less].

r: radial distance from pumping well, [L].

b: is the initial saturated thickness of aquifer, [L].

Kh: Horizontal hydraulic conductivity, [L / T].

Kv: Vertical hydraulic conductivity, [L / T].

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