Water table response to a pumping test in the hinterland core area of the Taklimakan Desert, China

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Abstract

Wei, Y., Fan, J., Xu, X., & Lei, J. (March-April, 2017). Water table response to a pumping test in the hinterland core area of the Taklimakan Desert, China. *Water Technology and Sciences* (in Spanish), *8*(2), 151-158.

In this article, hydrogeological parameters were determined by a single well pumping test. Over the course of the study, BETCO was used to eliminate the effects of atmospheric pressure changes on water level based on the regression deconvolution method. The aquifer test was used to analyze data and to calculate hydrogeological parameters. Finally, from the three unconfined aquifer models, though the Boulton model cannot successfully gain well-fitting results, the Theis model with Jacob correction and the Neuman model results obtained hydrogeological parameters by curve-fitting. Additionally, permeability coefficient of the two models is in good agreement with previous research, which can provide a reference for further study in the hinterland of the desert, especially for the construction of hydrological modeling research.

Keywords: Pumping test, aquifer test, pressure correction, hydrogeological parameters.

Resumen

Wei, Y., Fan, J., Xu, X., & Lei, J. (marzo-abril, 2017). Respuesta de la capa freática a una prueba de bombeo en el área interior central del desierto de Taklimakan, China. Tecnología y Ciencias del Agua, *8(2), 151-158.*

En el presente artículo se determinaron los parámetros hidrogeológicos mediante una prueba de bombeo de un solo pozo. Durante el estudio se utilizó BETCO para eliminar los efectos de los cambios de presión atmosférica en el nivel del agua con base en el método de regresión-deconvolución. Se utilizó la prueba de acuíferos para analizar los datos y para calcular los parámetros hidrogeológicos. Finalmente, de los tres modelos de acuíferos confinados, aunque el modelo Boulton no puede arrojar resultados bien ajustados, el modelo Theis con corrección de Jacob y el modelo Neuman obtuvieron resultados de parámetros hidrogeológicos mediante ajuste de curvas. Además, el coeficiente de permeabilidad de los dos modelos concuerda bien con investigaciones anteriores, las cuales pueden servir de referencia para estudios posteriores en el interior del desierto, especialmente para la investigación de modelos hidrológicos.

Palabras clave*: prueba de bombeo, prueba de acuíferos, corrección de presión, parámetros hidrogeológicos.*

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Introduction

A comprehensive and accurate understanding of aquifer hydraulic properties is the basis for efficient management of groundwater resources, which can be developed by pumping test determining aquifer hydrological parameters for groundwater modeling, aquifer vulnerability assessment, among others (Wen, Wu, Yeh, & Tseng, 2010; Li, Qian, & Wu, 2014; Criollo, Velasco, Vázquez-Suñé, & García-Gil, 2016). The accuracy of data derived from pumping test is of concern to parameters calculation, which fluctuating along with the variety of barometric pressure, sea tides and so on (Guo & Jiao, 2008; Guo, Jiao, & Weeks, 2008). In the process of studying, hydrogeologists devoted themselves to theoretical and practical work on pumping tests, it was found the influence of barometric pressure on water level cannot be ignored, that pressure efficiency is expressed by a simple linear equation at first (Jacob, 1940). After long time duration of studying, for the pumping test process, it was found that the groundwater level (especially the deep well water level) response is not linear, but rather a complex nonlinear response, which makes it inappropriate to use a linear regression method for the pressure correction (Quilty & Roeloffs, 1991; Seo, 2001). Among lots of researchers, Rasmussen and Crawford (1997) used a regression deconvolution method to determine pressure correction and achieved good results.

The hinterland of the Taklimakan Desert, which belongs to a sedimentary area in the southern section of the Tarim Basin, is an ancient alluvial flood plain that formed from many rivers in the northern slope of the Kunlun Mountains. Precipitation and condensed water supply no recharge to groundwater basically (Yu, 1992), which is mainly affected by the Kunlun Mountain piedmont plain groundwater lateral runoff recharge. There are rich oils and natural gas resources, but the climate is extremely dry, and the precipitation is below 50 mm with an annual evaporation of 3 000 mm, no surface water exists generally (Xu, Li, Zhou, & Zhou, 2001). Therefore, the water used for production and living comes entirely from the exploitation of groundwater, unconfined water, particularly, which is formed by river infiltration and lateral groundwater infiltration belonging to pore water stored in Quaternary deposits, whose main hydrochemical types are Na-Mg-Cl-SO_4 and Na-Cl-SO_4 (Wei, Fan, Xu, Jin, & Zhou, 2016), and salinity is 3-10 g/l. The depth of groundwater between longitudinal dune usually is 1-5 m, and over 20 m at top of ones. It was found that when the groundwater depth is less than 1.5 m, the groundwater is affected by strong evaporation (Fan *et al*., 2010), coincide with the terrain trend, the water table is relatively flat, with a flow velocity measured between 21 m/year and 205 m/year (Lei, Li, Jin, & Xu, 2008).

In this paper, a single-well pumping test established at the core area of pumping in the hinterland of the Taklimakan Desert was used to calculate the hydrogeological parameters, in order to provide a reference of the future groundwater research, especially the construction of hydrological modeling.

Methods and experiments

We observed the water level of the whole year and conducted single-well pumping test from 2009 Jul. 27th to Aug. 12th day in the core area of water supplying in the oil field with observation time interval was every 30 min. The pumping well is located in the hinterland of the Taklimakan Desert (38° 58′ 20.77″, 83° 39′ 39.60″) (figure 1), with the observation well (38° 58′ 21.78″, 83° 39′ 37.35″) logging in the northwest at a distance of r = 58.6 m (figure 2). The elevation of pumping well is 1 104.9 m. The thickness and effective thickness of unconfined aquifer are 66.00 and 40 m, respectively in the study area where the depth of groundwater is 6m, the formation is single fine sand of Quaternary. The casing pipe of the partial penetrating observation well is hard PVC material and depth was measured by Solinst Levelogger Model 3001. In the experiment, discharge rate was set as 32 m^3/h and it was regarded as having achieved stable state when the fluctuation of the drawdown was not more than 1% (Wang *et al*., 2013). The regression deconvolution was performed in order to adjust the groundwater level using BETCO from Sandia Labs (USA). The hydrogeological parameters were calculated by Aquifer Test 2011.1 designed by Waterloo Hydrogeologic Inc. (incorporated into Schlumberger Water Services since 2005) to provide a reference for the construction of hydrological modeling.

Barometric pressure correction

In measuring groundwater level, many natural forces have important theoretical and practical significance to the borehole water level (Guo & Jiao, 2008). In particular, when the impact of

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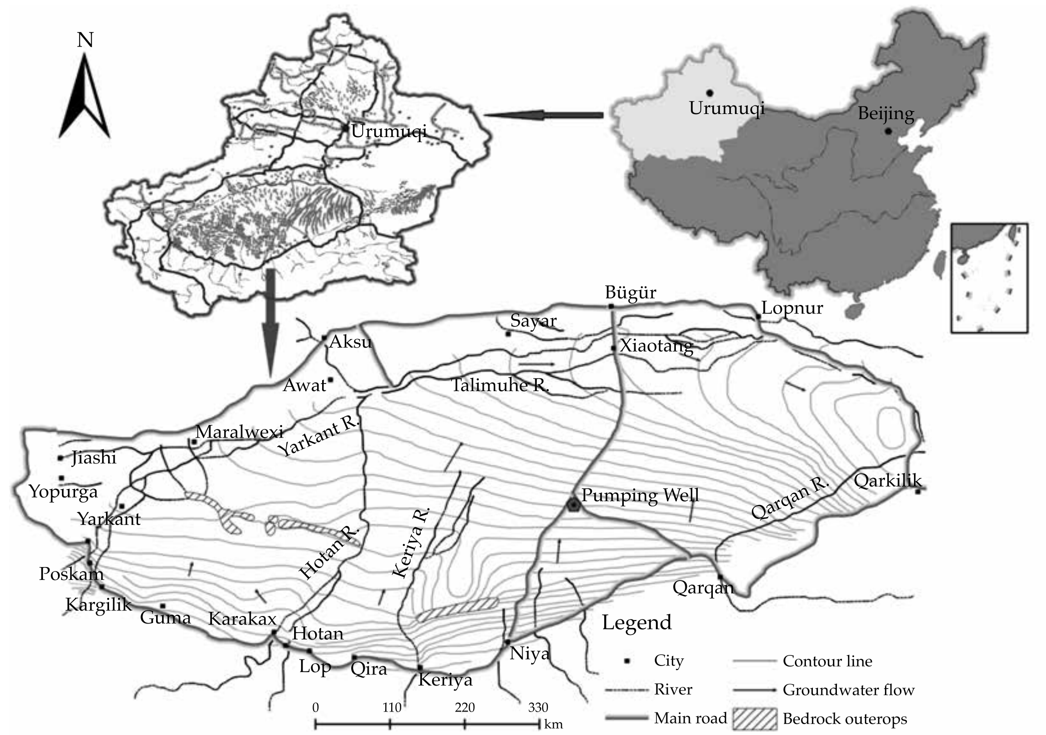

Figure 1. The location of Pumping Well in the Taklimakan Desert.

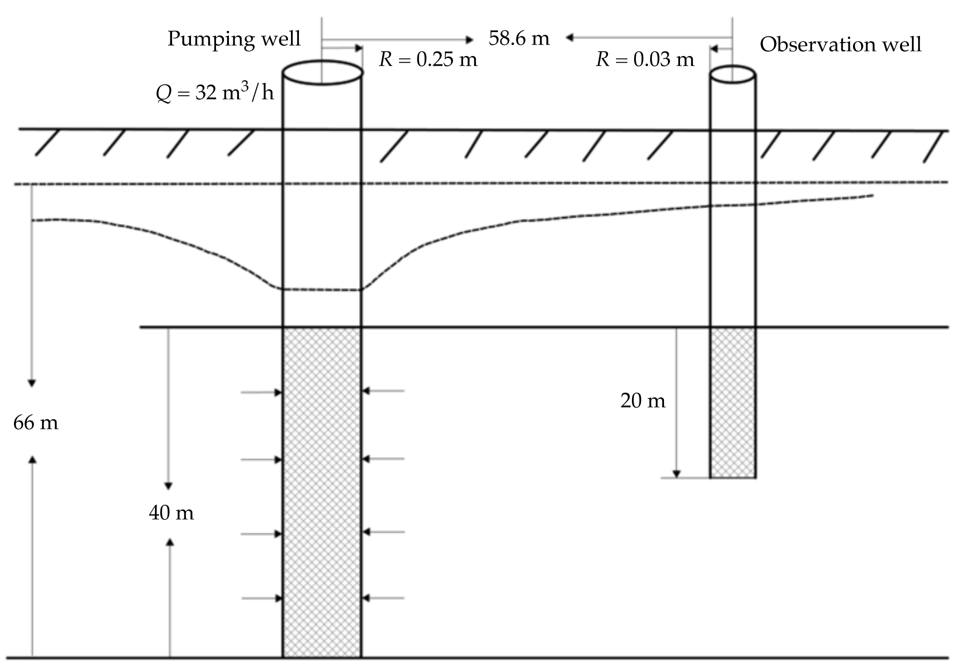

Figure 2. The geometry of the pumping and observation wells.

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barometric pressure on the water level cannot be ignored compared to the larger circumstances (such as the late period pumping test), it is important to perform barometric pressure calculations in order to obtain accurate aquifer parameters (Wang *et al*., 2012). During an extended period of pumping test processes, the delayed response, due to the transmission of the barometric pressure perturbation through the unsaturated zone and borehole storage or skin effects, causes a water level difference between the aquifer and the pumping well. Rasmussen and Crawford proposed the regression deconvolution method could be used to correct the groundwater level in order to eliminate the influence of barometric pressure (Rasmussen & Crawford, 1997). After the response function $\delta(i)$ to a barometric pressure pulse is obtained by using ordinary least square method linear regression, the step response $\boldsymbol{\alpha}(j)$ can be found by summing the impulse responses:

$$\alpha(j)=\sum_{i=0}^{j}\delta(i) \quad (1)$$

Then, it was following correction variables of the water levels that being found (Toll & Rasmussen, 2005):

$$\begin{bmatrix} W^*_m \\ W^*_{m+1} \\ W^*_{m+2} \\ \ldots \\ W^*_n \end{bmatrix} = \begin{bmatrix} \Delta B_1 & \Delta B_2 & \Delta B_3 & \ldots & \Delta B_m \\ \Delta B_2 & \Delta B_3 & \Delta B_4 & \ldots & \Delta B_{m+1} \\ \Delta B_3 & \Delta B_4 & \Delta B_5 & \ldots & \Delta B_{m+2} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \Delta B_{n-m+1} & \Delta B_{n-m+2} & \Delta B_{n-m+3} & \ldots & \Delta B_n \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_2 \\ \ldots \\ \alpha_m \end{bmatrix} \quad (2)$$

where W^* is the corrected variable for each observation within time t from m to n; ΔB_t is the change in the barometric pressure at time t; m is the maximum lag selected by the user, and n is the total number of observations in the dataset.

To gain more accurate data of the water level, we corrected the observed pumping test data by BETCO, which is the application of the regression deconvolution (Toll *et al*., 2005).

Calculation of hydrogeological parameters

In Aquifer Test, methods for unconfined aquifer analysis usually are either Neuman or Boulton. Theis with Jacob correction can also be used for late-time of the pumping test. Due to unsteady flow within the pumping tests by the artificial control of water stability, we need to determine the water level changes with time in order to obtain hydrogeological parameters in an unconfined aquifer of unstable movement. In this paper, the Neuman model, the Boulton model, and the Theis model with the Jacob correction (Theis with Jacob) for unconfined aquifer are used to fit the water level variation curve of the pumping process.

Jacob (1940) proposed the following correction:

$$s_{cor} = s-(s^2/2D) \quad (3)$$

Where s_{cor} is the corrected drawdown, s is the measured drawdown, and D is the original saturated aquifer thickness. There are no additional type curve parameters for this solution method.

The equation developed by Neuman representing drawdown in an unconfined aquifer is given by (Neuman, 1975):

$$s=\frac{Q}{4\pi T}W\left(u_A,u_B,\beta\right) \quad (4)$$

Where $W(\mu_A . \mu_B . \beta)$ is known as the unconfined well function; $\mu_A = r^2s/4Tt$ is the Type A curve for early time steps; $\mu_B = r^2S_y/4Tt$ is the Type B curve for later time steps; $\beta = r^2K_v/K_H$, K_V, K_H: vertical and/or horizontal permeability; r is the distance to the observation well; S is storativity; S_y is *specific* yield, usable probe volume; T is transmissivity.

The method developed by Boulton (1963) can be performed as follows:

$$s_D=\frac{2\pi T(H-D)}{Q} \quad (5)$$

Where H is defined as the average head along the saturated thickness, and other parameters defined as mentioned above.

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Results and discussions

Barometric pressure correction results

From the figure 3, we can conclude that, at the period of Jan. 1st to Feb. 21st and Sep. 23rd to Dec. 31st, the water level was roughly stable, which is consistent with the main water use period of the project from March to November. Though the pumping well was performed in a production well, the test was started after the water level reaching stable judged by long time observation of recovery period.

The previous researchers have done so many about barometric pressure correction (Spane, 2002; Dong, Shimada, Kagabu, & Yang, 2015) and hydrogeological parameters' calculation (Lubczynski & Roy, 2005; Samuel & Jha, 2014), But for the combination of the two methods, relevant research is relatively small (Allen, 2008; Vilhelmsen, Christensen, Behroozmand, & Søltoft, 2014), and most of them used barometric efficiency (Acworth & Brain, 2008; Delcourt-Honorez & Scholz, 2014) to correct the influence of barometric pressure, which didn't consider the delay effect to vadose zone soil layer. The delay effect is considered in BETCO software, and the result of pressure correction is more accurate.

The regression deconvolution method is used to correct the deviation that barometric pressure variation causes the measured groundwater level, and the results seem to be good. And it is easy concluded that barometric pressure correction is crucial to the accuracy of groundwater level in pumping tests, which is of great concern to delay factor. In the BETCO, though we conduct that maximum response time as 12, it can be noticed that at the preliminary stage of observation, there are still exits the phenomenon of delaying. After the correction for barometric pressure, the annual water depth has been changed; the maximum of the initial water depth was 8.518, though, with the correction, it was 8.491.

It is important to note that other natural conditions, such as tidal, meteorological, and hydrological factors will also affect the water

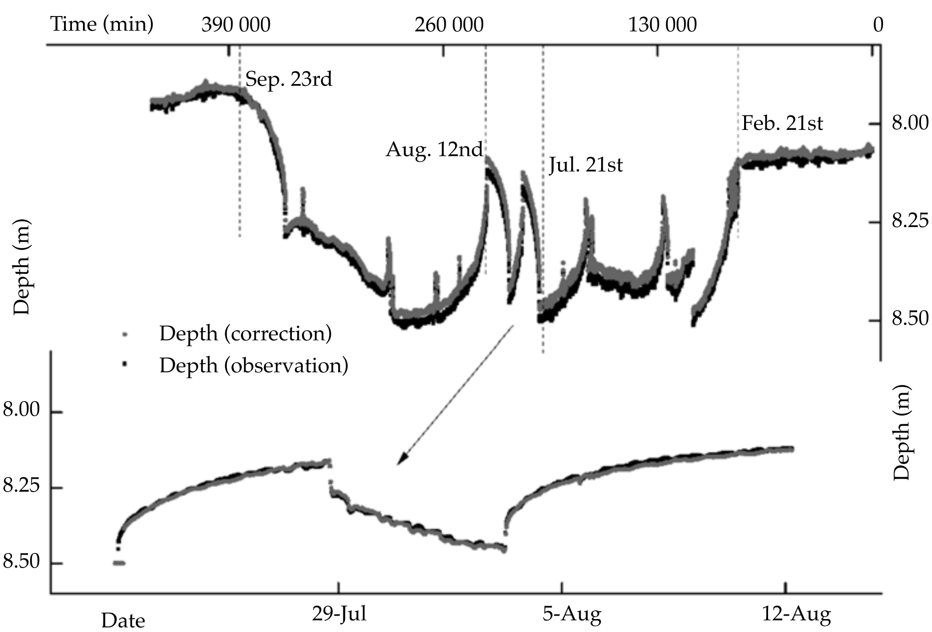

Figure 3. The comparison of the water depth with data reconciliation.

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level fluctuation. If these effects are taken into consideration for correction, we can determine a more accurate water level correction.

The upper graph is the observation water depth of whole year, and the inferior graph is the depth during the pumping test.

Hydrogeological parameters

The Boulton model does not achieve fitting results. The remaining two models are more successful and achieve the results shown in figure 4.

Through curve fitting, the hydrogeological parameters of the Theis model with the Jacob correction are as follows:

$$T = 8.96E2(\text{unit:m}^2/d) \quad (6)$$

$$S = 6.11E-2 \quad (7)$$

And the hydrogeological parameters of the Neuman model are as follows:

$$T = 8.76E2(\text{unit:m}^2/d) \quad (8)$$

$$S_y = 5.00E-1,\ K_v/K_H = 1.12E-3,\ S_y/S = 1.00E1 \quad (9)$$

The permeability coefficient of the two models calculated is 13.6 m/d and 13.3 m/d, which is good agreement with previous K = 12.85 m/d (Fan *et al*., 2010) and K = 13.32 m/d (Fan, Jin, Lei, Xu, & Zhou, 2013). These hydrogeological parameters are calculated using the water level process curve model fitting based on the pumping test, and the results are useful for the construction of the hydrological model.

Conclusions

In this paper, for the unsteady flow pumping test in an unconfined aquifer, three kinds of

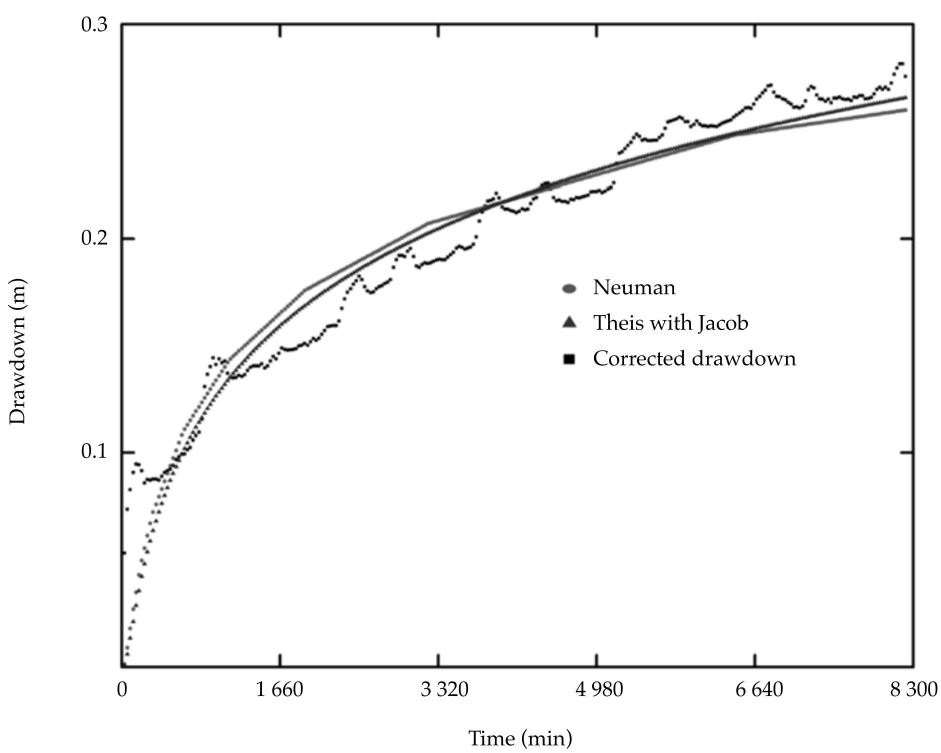

Figure 4. Groundwater level fitting of the Theis with Jacob correction and Neuman Models during pumping.

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unconfined models were used to calculate hydrogeological parameters. Boulton cannot successfully gain the results, the parameters that Theis with Jacob calculated are T = 8.96 E2 m^2/d, S = 6.11 E -2 and those calculated by Neuman are T = 8.76 E2 m^2/d, S_y = 5.00 E-1, K_v/K_H = 1.12 E-3, S_y/S = 1 .00 E1, the permeability coefficient calculated by two models is 13.6m/d and 13.3 m/d. From the calibration results in this paper, considering the unsaturated zone delay effect, the results are closer to the true value. But in the pumping test, the study area is used as a homogeneous isotropic field. The calculated permeability coefficient is one of the point values of the region, which can't reflect the heterogeneity of the scale. However, these parameters results provide a certain reference value to further study on hydrogeological conditions in the study area and the methods used in this paper can provide solutions to the problems that may be encountered in similar projects.

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