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Estimation of Transmissivity in Two Wadis in the Kingdom of Saudi Arabia Using an Alternative Approach

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ABSTRACT. Estimation of the parameters which describe groundwater flow continues to be an important topics. Transmissivity and hydraulic conductivity are the most important aquifer parameters in any study of groundwater problems. The availability and accuracy (reliability) of such information are essential for groundwater management and development studies. Methods of determining the magnitude of certain aquifer parameters are well established, however, these methods are very costly and time consuming. Thus some researchers and investigators turn to other techniques to determine these parameters in an indirect way. One of these techniques is the use of specific capacity approach which is considered in this paper. Case studies are presented which illustrate parameter estimation dealing with pumping test and specific capacity data of ten wells in both Wadi Tabalah and Yiba near the town of Bishah. Available pumping test data are used in the calculation of transmissivity values by Cooper-Jacob's method. The recommended approach showed that the technique is valid, and versatile and can be used in estimating the aquifer parameters, especially in the case of scarce and limited data.

1. Introduction

Transmissivity T is one of the most important aquifer characteristics. Although the determination of the transmissivity can be obtained by various techniques[1-3], the data necessary for the calculation are not easy to obtain and are not always available. The use of specific capacity tests to determine transmissivity is a simple, quick and inexpensive method. Generally speaking, high specific capacities indicate an aquifer having high transmissivity and vice versa. However, a precise correlation between the specific capacities of the wells and the transmissivity values of the aquifers they tap has not yet been established.

Specific capacity involves pumping a well at a constant rate and time, and measuring the drawdown within the well at the end of the test period when the water level in the well reaches a state of equilibrium. Specific capacity is defined as the discharge divided by the drawdown in the well, and the units used are cubic meter per day per meter of drawdown (m^3/day/m). Theis *et al.*[3] presented a method for estimating transmissivity from specific capacity data-test, and utilized a graphical solution to estimate transmissivity.

Ogden[2] applied Theis's method by assuming that the coefficient of storage has small effects on the calculated transmissivity.

Bradbury and Rothchild[4] developed a computer program for estimating transmissivity of aquifers from specific capacity data and claimed that this computerized technique is quite rapid and accurate compared to the conventional graphical techniques.

In this paper, transmissivity of ten groundwater wells in Bishah area is determined by computerized techniques using the specific capacity approach and accounting for the well losses and neglecting the partial penetration effect due to lack of data.

Razack and Huntely[5] derived the statistical relations between specific capacity and aquifer transmissivity for hetrogeneous alluvial aquifers. The best fit regression line for the data set of Haouz plain (Maghreb) is $T = 0.36\,(\,Q/s\,)^{0.67}$ for transmissivity and specific capacity both in units of sq. meter/second.

Al-Turbak and Al-Othman[6] analyzed delayed yield phenomena in an unconfined aquifer from five wadis southwest of the Kingdom of Saudi Arabia using Boulton, Streltsova, and Neuman methods. They concluded that the values of transmissivity of Boulton and Neuman approachs are more accurate than that of Streltsova approach.

2. Geologic Setting of the Area

The study area of the two Wadis under consideration (Fig. 1) is underlined predominantly by metamorphosed volcanic and sedimentary rocks and platonic rocks of late proterozoic age. Volcanic and sedimentary rocks of the broadly contemporaneous (Bishah) group were formed in an ensimatic inland 800 to 1000 million years (Ma) ago[11]

Wadi Tabalah Basin is situated partly in Asir region and is located in the southern part of the Kingdom (Fig. 2). A major part of the wadi is located east of the Asir escarpment physiographic region. Approximate boundaries of the basin are bounded between 19°0′-20°13′N latitudes and 41°52′-42°35′E longitudes. Wadi Tabalah is a tributary of Wadi Bishah. It runs in the east direction until it joins Wadi Bishah. Most of the downstream of the wadi is flat and suitable for agricultural development. The catchment area is estimated to be 2400 sq. km. The upstream and downstream parts

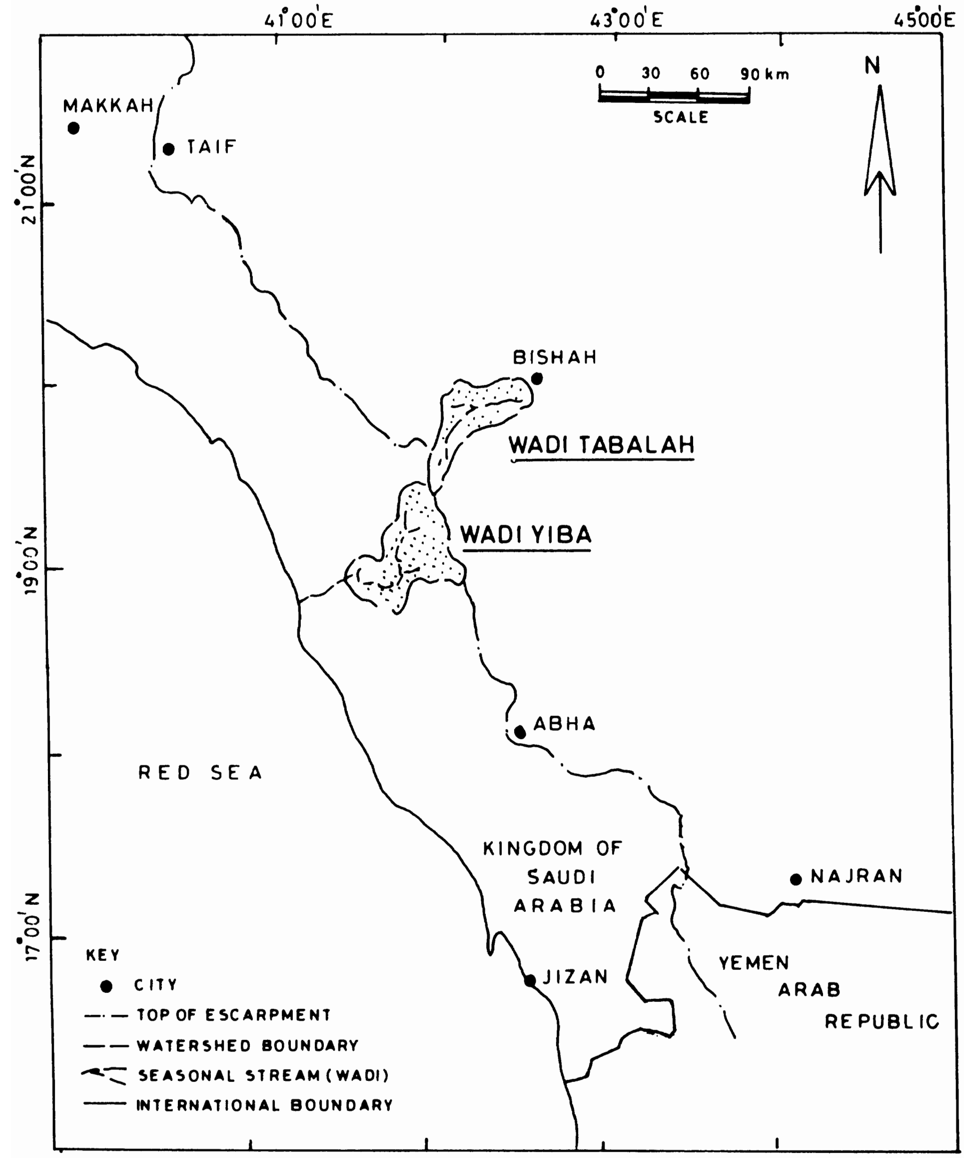

FIG. 1. Location of representative basins.

of the wadi differ considerably from topographical and hydrometeorological points of view. This wadi is located in a subtropical climatic region.

Yiba basin is located within the Scrap mountain physiographic region of the Arabian Shield. It is underlain by Precambrian crystalline rocks; predominantly metamorphosed sedimentary and volcanic rocks including schists, quartzites slates

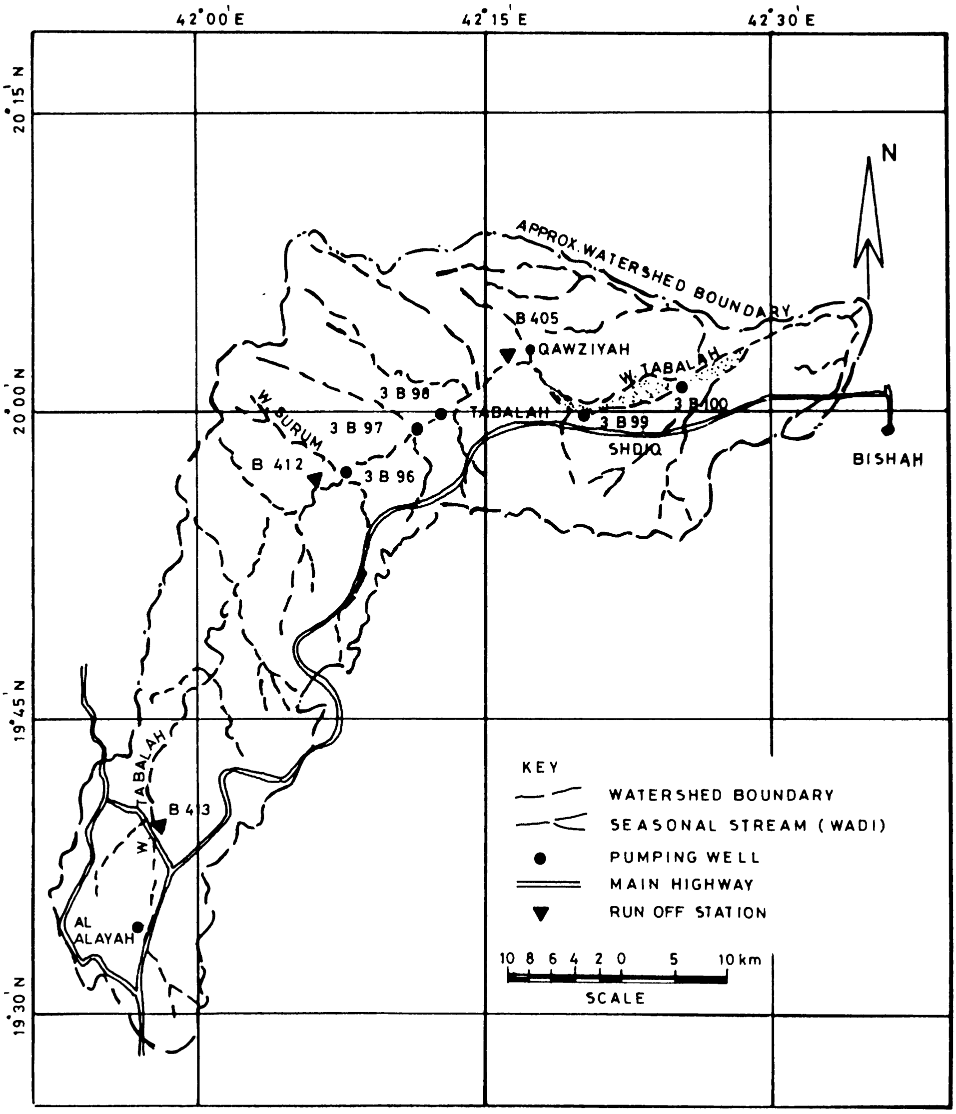

FIG. 2. Wells locations in Wadi Tabalah basin.

and marbles (Fig. 3). The approximate boundaries of the basin are bounded between 19°00′-19°30′N latitudes and 41°30′-42°00′E longitudes. It runs west meeting the Red Sea near the City of Habil. The lower reaches toward the west where Wadi Yiba basin merges into the Tihama coastal plain form a suitable aquifer system for future development. Wadi Yiba Basin has similar topographic and hydrometeorological conditions to those of Wadi Tabalah.

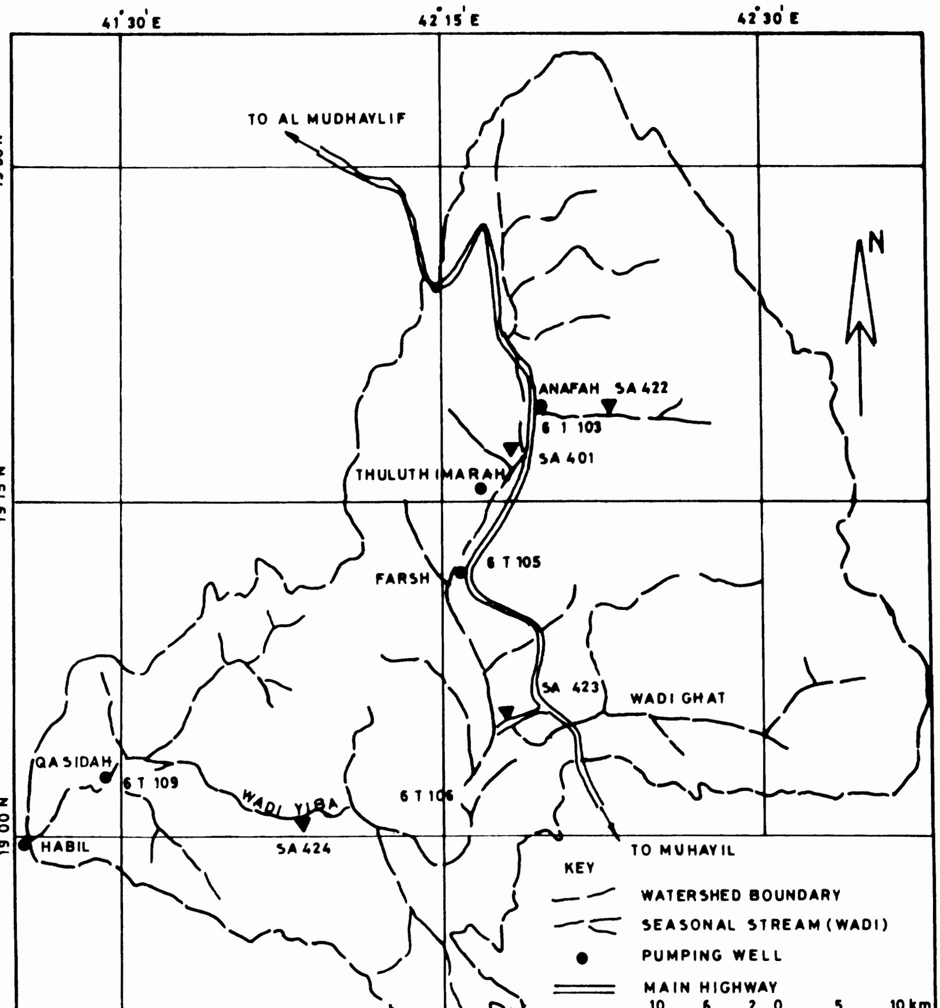

FIG. 3. Wells locations in Wadi Yiba basin.

The principal wadi alluvium in Yiba varies in thickness from a few meters to twenty meters. However, the depth to the water table level from the ground surface varies from one to six meters. On the other hand, saturated thickness of the aquifer in Wadi Tabalah basin ranges from approximately ten meters to thirty meters, and the depth to the water table from two meters to nine meters.

3. Methodology

The modified version of Cooper-Jacob equation[7] for transient well flow in a confined aquifer including the formation loss and well loss as well as the additional drawdown due to partial penetration is developed by Bradbury and Rothchild[4], and is presented as follows

$$T = \frac{Q}{4\pi(S - S_w)} \left[\ln \left(\frac{2.25\ Tt}{r_w^2\ S_c} \right) + 2\ S_p \right] \tag{1}$$

where,

S = Drawdown in the well (L)

S_w = Well loss (L)

S_p = Partial penetration factor (dimensionless)

Q = Discharge (L^3/T)

T = Transmissivity (L^2/T)

t = Pumping period (T)

r_w = Radius of the well (L)

S_c = Storage coefficient (dimensionless)

The partial penetration factor is given by Brons and Marting[8] as,

$$S_p = \frac{1 - (L/b)}{(L/b)} \left[\ln (b/r_w) - G \right] \tag{2}$$

where,

L = Well penetration depth (L)

b = Saturated thickness (L)

The G function is given by Bradbury and Rothchild[4] as,

$$G = 2.948 - 7.363\ (L/b) + 11.447\ (L/b) - 4.675\ (L/b) \tag{3}$$

Equation 1 can be solved graphically by matching the specific capacity data to a family of curves[3&9]. But this solution is very limited and requires a set of curves for every combination of pumping period, storage coefficient, and well radius. A computer program was developed to solve Equation 1. The program solves Equations 2 and 3 first and then solves Equation 1 iteratively using an initial estimate of T. All the relevant data of pumping discharge, step drawdown test, storage coefficient, and well and aquifer characteristics for the two wadis were taken from Ref. [10]. Input data and aquifer characteristics are shown in Table 1. The well loss constant was evaluated by curve fitting the drawdown test data using GRAPHER software that uses Kriging method for best fit, then the drawdown due to well loss is calculated by

$$Q/s = 1/(C_f + C_w Q) \tag{4}$$

where,

Q/s = Specific capacity

C_f = Formation constant (T/L^2)

C_w = Well loss constant (T^2/L^5)

TABLE 1. Aquifer characteristics and input data.

Wadi Yiba basin							
Well no.	Well diameter (meter)	Depth to bedrock (meter)	Saturated thickness (meter)	Pumping			Well loss coeff.
				Pumping rate (m^3/day)	Duration time (hours)	Draw-down (meter)	
6-T-103	0.203	–	–	2,190	36	1.7	5.16E-07
6-T-105	0.203	21.0	14.8	213	36	10.36	4.00E-04
6-T-106	0.203	9.7	3.9	60	36	1.26	2.50E-03
6-T-108	0.203	–	26.0	1,915	29	4.93	4.91E-08
6-T-109	0.203	32.5	31.0	2,736	36	6.58	1.15E-07
Wadi Tabalah basin							
Well no.	Well diameter (meter)	Depth to bedrock (meter)	Saturated thickness (meter)	Pumping rate (m^3/day)	Duration time (hours)	Draw-down (meter)	Well loss coeff.
3-B-96	0.203	35.0	28.94	1,040	36	9.4	4.71E-06
3-B-97	0.203	14.4	11.98	684	36	5.2	2.51E-05
3-B-98	0.203	21.0	17.53	295	36	11.27	1.00E-04
3-B-99	0.203	17.0	10.35	1,368	36	5.85	2.01E-06
3-B-100	0.203	29.5	20.20	104	24	5.6	3.54E-04

The transmissivity was calculated with and without well loss effect. The results were plotted in a contour map using SURFER software. Three-Dimensional graphs of the transmissivity were plotted as well.

4. Results and Discussion

Specific capacity technique is one of the method that can be used in a hydrogeological study for estimating the transmissivity of the aquifer. In this study the specific capacity has been evaluated for the pumping wells distributed over the Yiba and Tabalah basins. The transmissivity values were calculated using the specific capacity values obtained at those pumping wells allocated throughout the study area. The transmissivity distribution over the entire wadi's basin are estimated using Kriging method from which contour maps were cosntructed and plotted. In addition, the saturated thickness contour maps were plotted in an effort to physically make the reader visualize and understand the variation of transmissivity values in the study area.

Wadi Tabalah has an average thickness of saturated material ranging from 20 meters in the west and midwest and decreasing to 10 meters at well No. 3-B-99 and then increasing to 20 meters at well No. 3-B-100 as shown in Fig. 4. By examining the contour maps of the transmissivity in Fig. 5 and 6 and in view of the saturated thickness in Fig. 4, it is clear that the transmissivity is highest at well No. 3-B-99 and decreases in radial pattern away from the well. Consequently hydraulic conductivity has a similar pattern.

The lower reaches of Wadi Yiba form extensive aquifer systems with average saturated thickness of 20 meters (Fig. 7). The area to the southeast of this region forms a thin (with thickness about 6 meters) and narrow alluvium resulting in limited groundwater resources. From the contour map of the transmissivity shown in Fig. 8 and in view of the saturated thickness (Fig. 7), the hydraulic conductivity increases toward the west with an average value of 20 m/day, which indicates that the aquifer system in this region is good for exploration and development. However, comparing the transmissivity values, based on the consideration of well loss contribution to the drawdown, of Fig. 4 and Fig. 8, it can be concluded that neglecting the well loss will undeestimate the true values to about less than 50%. In addition, the variations of transmissivity and hydraulic conductivity demonstrated by Fig. 5, 6, 8, and 9 and shown in Table 2, are due to the fact that the main alluvium channels are underlined by permeable fracture systems that are limited to the upper 25 meter depth of bedrock[10]. They are also due to the variation of drawdowns at the selected wells and the negligence of the delayed yield in the computations as well as the variation of the extensive pumpage operational schedule. Figures 10 and 11 show the transmissivity variations in 3-D.

From the foregoing discussion, it is evident that the pumping wells in Yiba basin are highly productive as reflected by the specific capacity values ranging from 2825.9 to 7.74 m^3/d/m while in Tabalah basin the values range from 654.37 to 58.66 m^3/d/m due to aquifer material being relatively fine. Using the specific capacity approach to estimate the aquifer's parameters of transmissivity and hydraulic conductivity is ıdequate and accurate enough to provide the necessary information that draws the 'uidelines for aquifer developers and future exploration of the Wadis' basins.

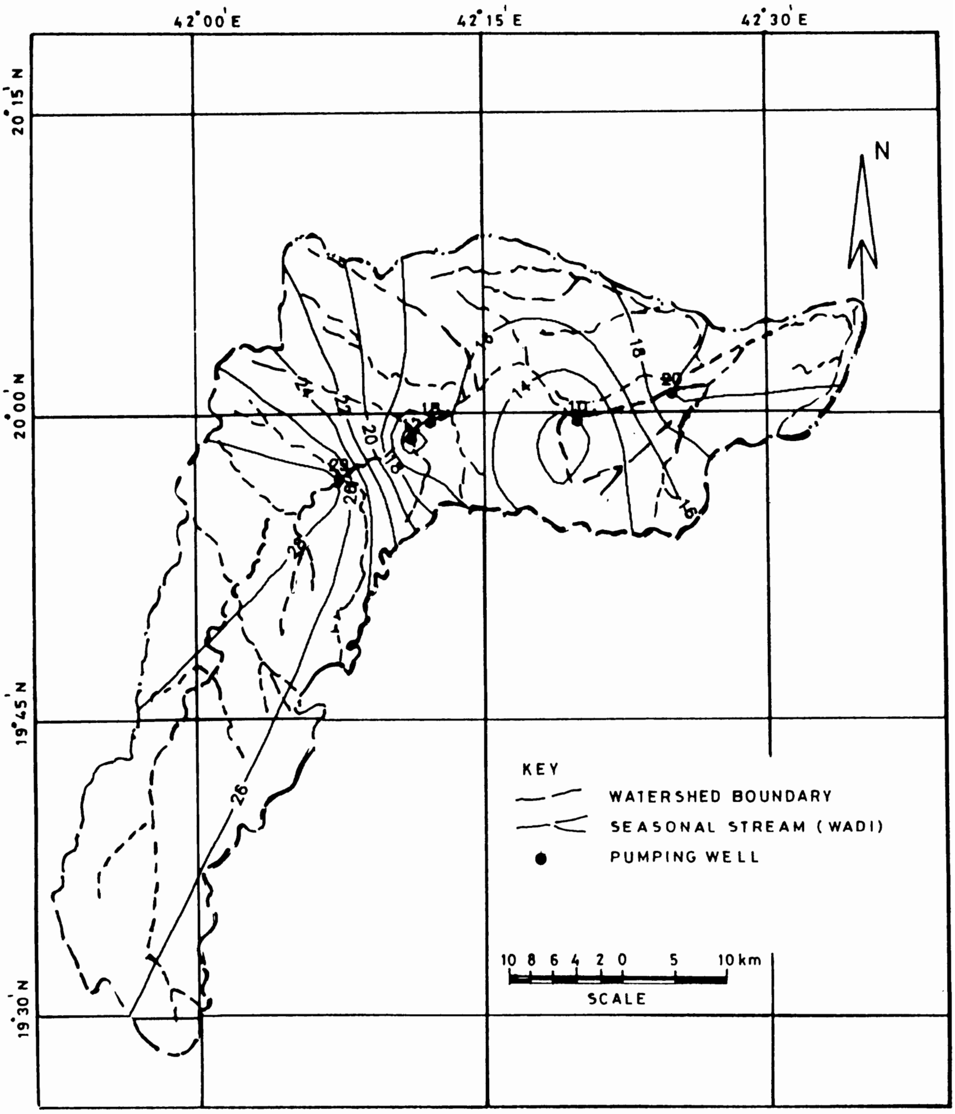

FIG. 4. Contour plot of saturated thickness, m for Wadi Tabalah basin.

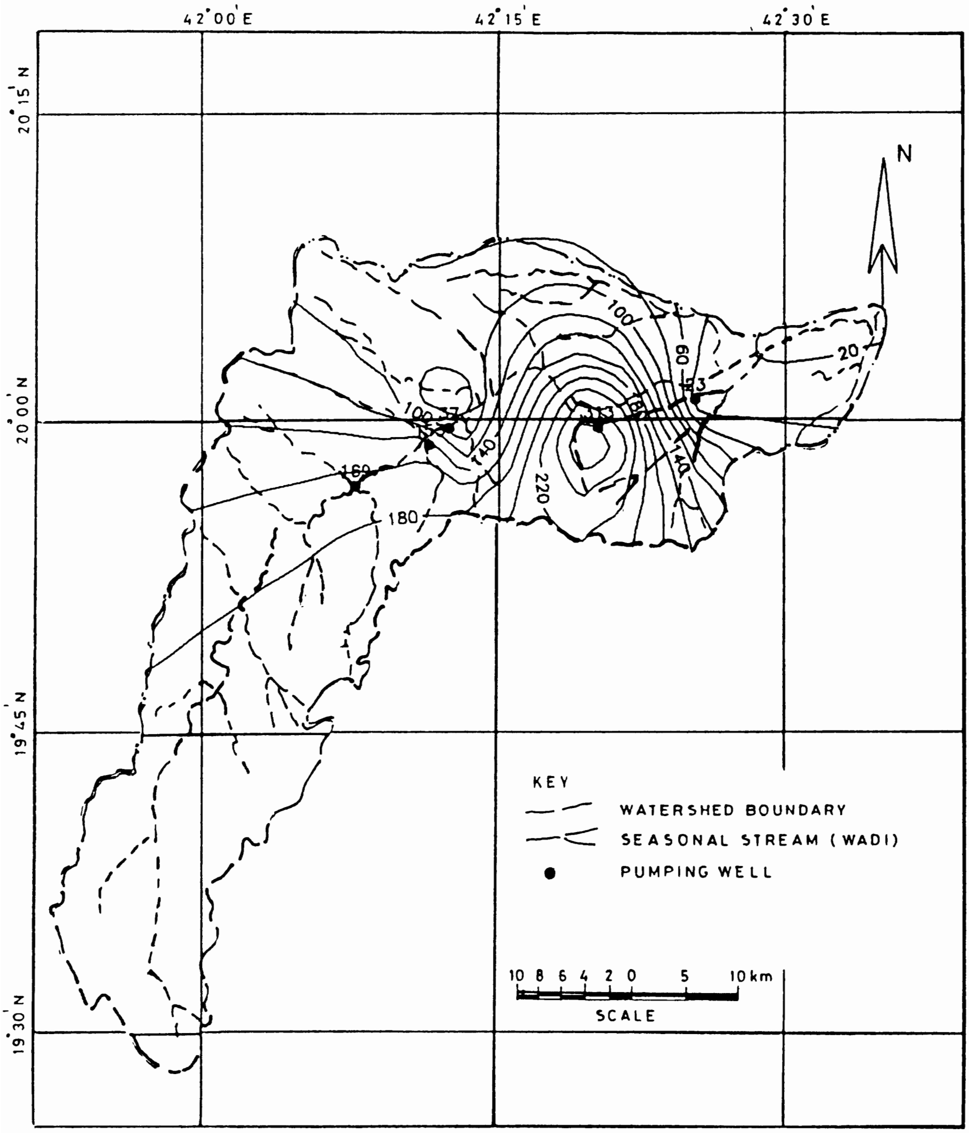

FIG. 5. Contour plot of transmissivity, m^2/d for Wadi Tabalah (neglecting well losses).

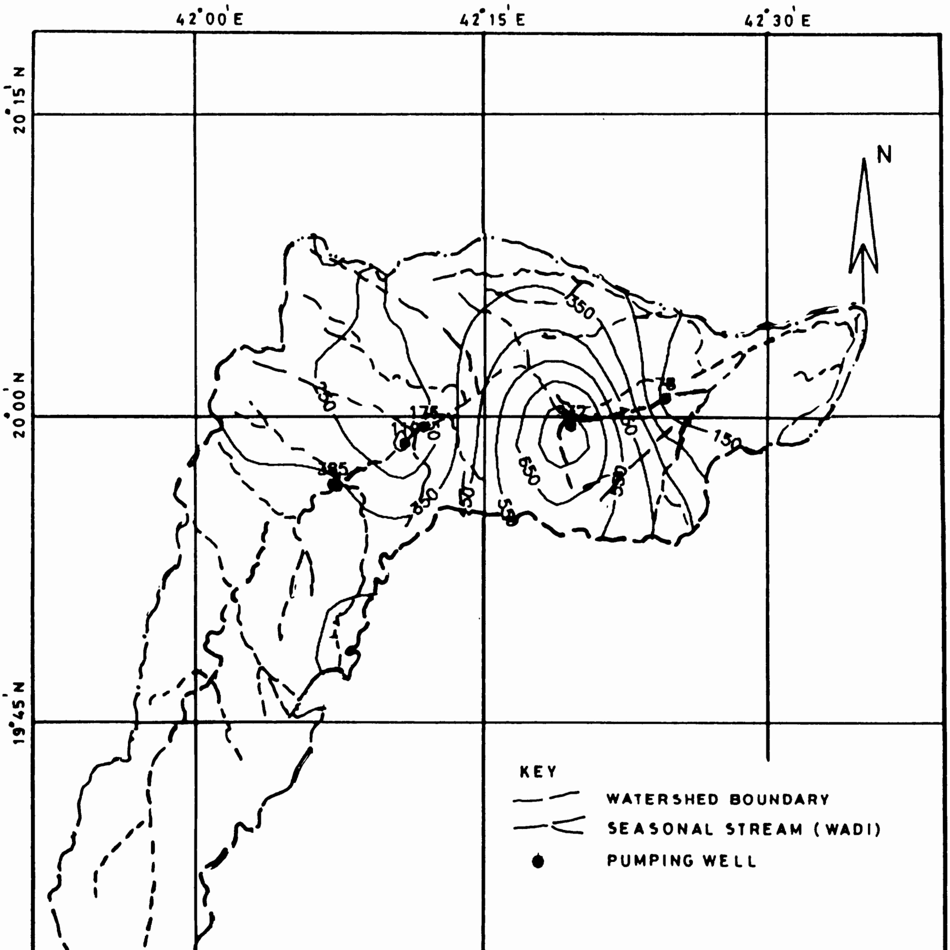

FIG. 6. Contour plot of transmissivity, m^2/d for Wadi Tabalah basin (including well losses).

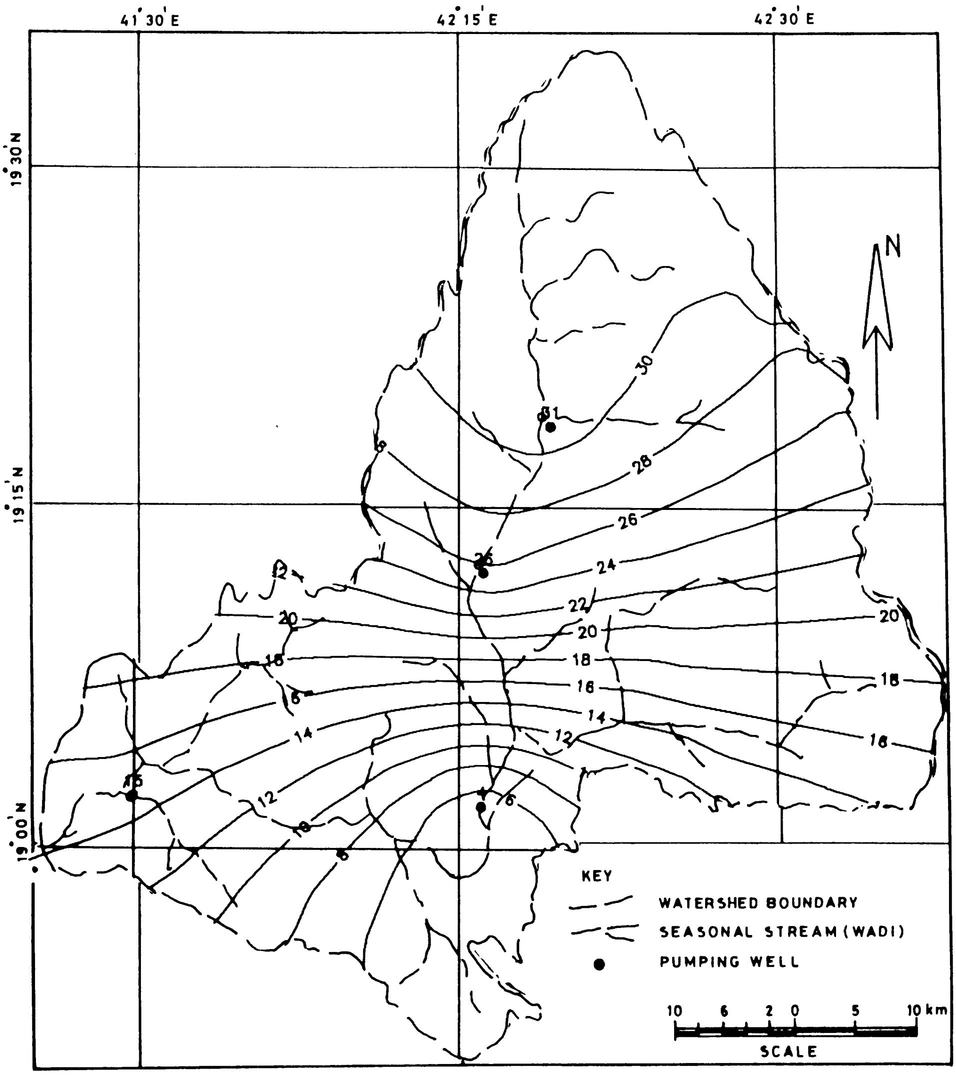

FIG. 7. Contour plot of saturated thickness, m, for Wadi Yiba basin.

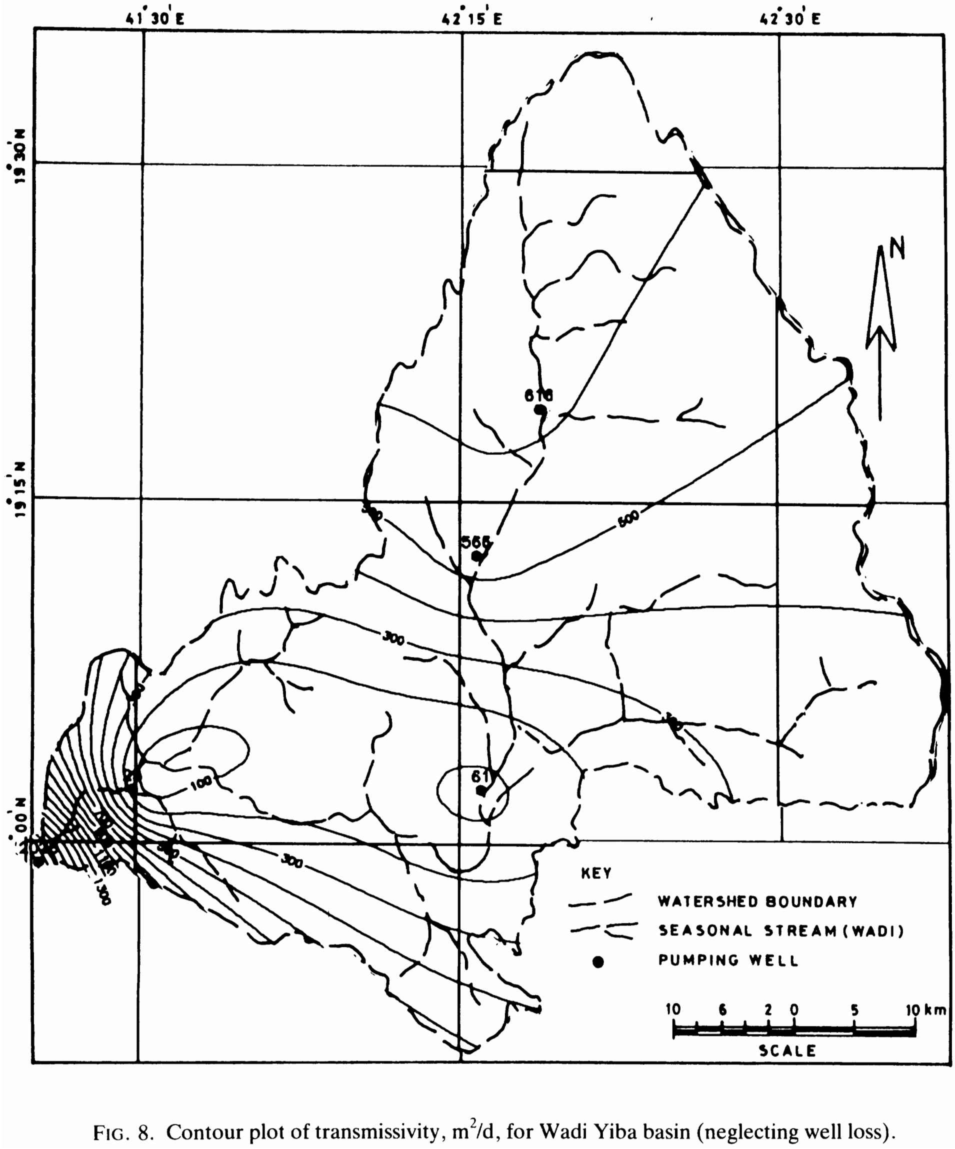

FIG. 8. Contour plot of transmissivity, m^2/d, for Wadi Yiba basin (neglecting well loss).

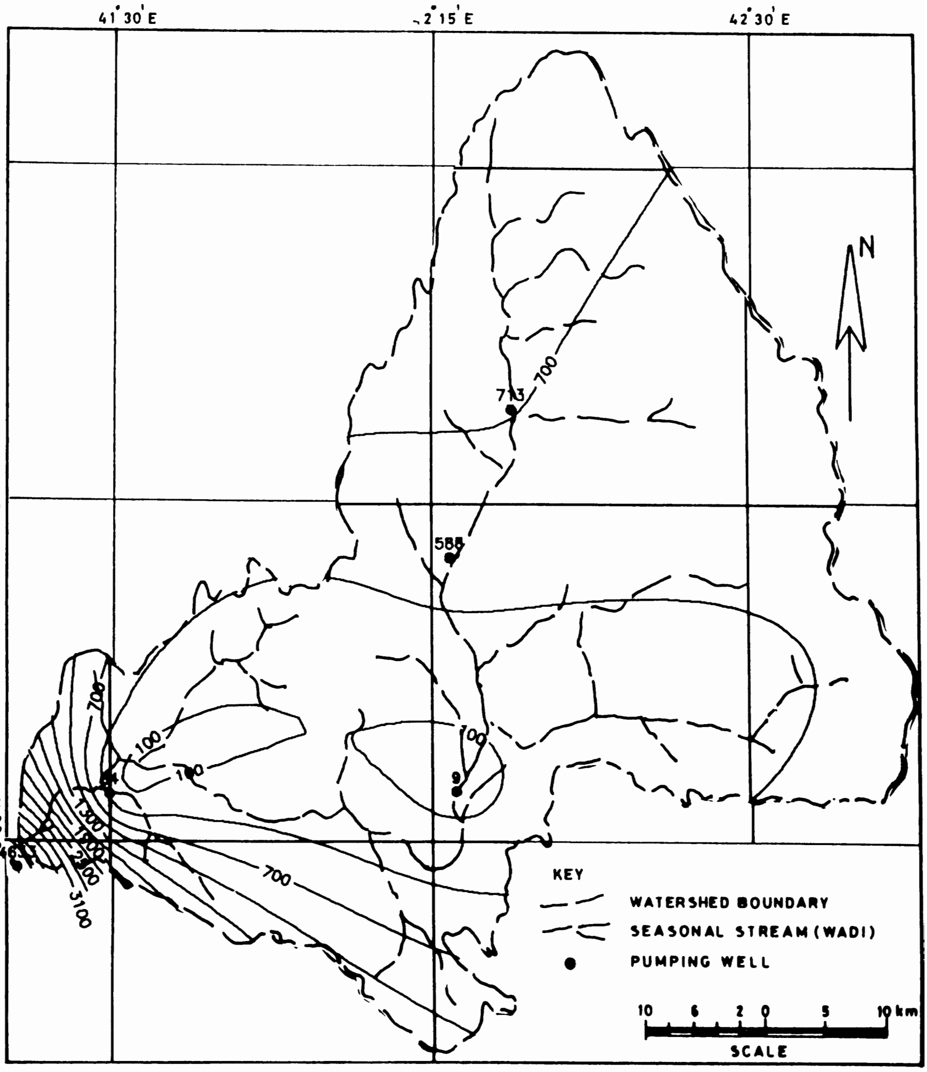

FIG. 9. Contour plot of transmissivity, m^2/d, for Wadi Yiba basin (including well losses).

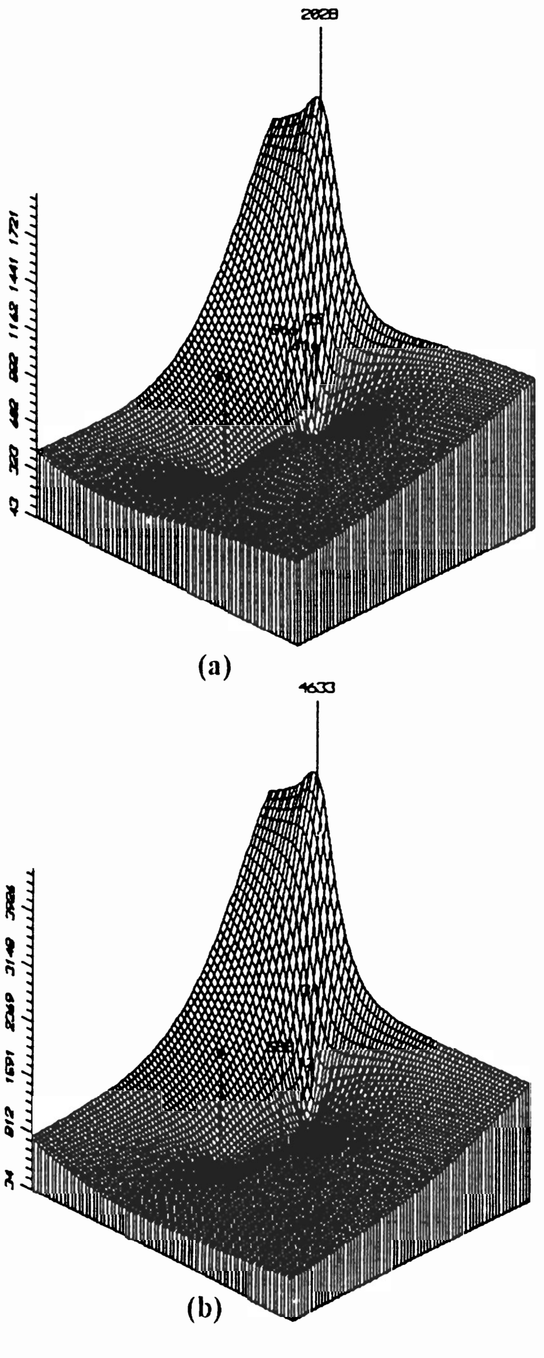

Fig. 10. Transmissivity in 3-D for Wadi Yiba basin: (a) Neglecting well losses, (b) Including well losses.

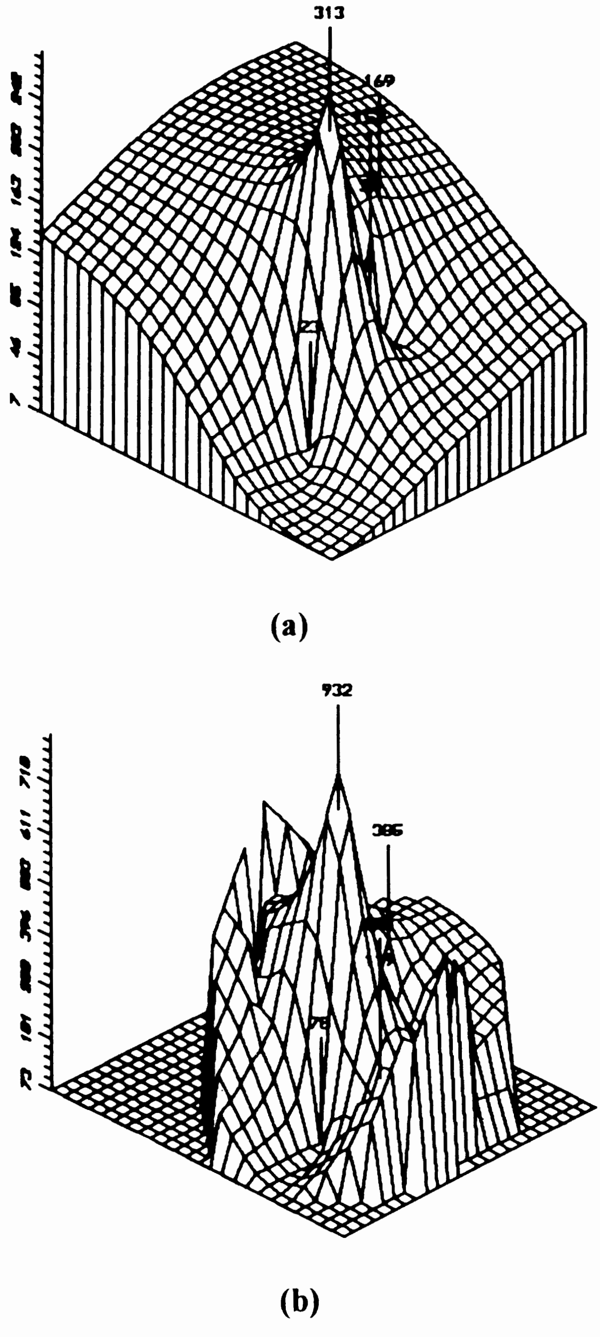

FIG. 11. Transmissivity in 3-D of wadi Tabalah basin: (a) Neglecting well losses, (b) Including well losses.

TABLE 2. Transmissivity for Wadi Yiba and Wadi Tabalah.

Wadi Yiba basin		
Well no.	Transmissivity (m^2/day) without well loss	Transmissivity (m^2/day) with well loss
6-T-103	2028	4633
6-T-105	25	34
6-T-106	61	9
6-T-108	566	588
6-T-109	616	713
Wadi Tabalah basin		
3-B-96	169	385
3-B-97	153	119
3-B-98	37	176
3-B-99	313	932
3-B-100	23	78

5. Conclusion

This paper has been concerned primarily with an alternative approach based on limited pumping tests data to estimate certain aquifer parameters over the entire basin. The study concluded that the specific capacity approach to calculate the transmissivity is simple, efficient, practical and inexpensive especially where data is scarce and limited. Rather than constructing new wells to obtain data needed for estimating aquifer parameters, it is advisable to combine the specific capacity technique with the available pumping tests data, which produces an adequate way of understanding the aquifer response. The gaining of this understanding can take many years.

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تقدير النفاذية لواديين بالمملكة العربية السعودية باستخدام طريقة بديلة

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قسم الهندسة المدنية ، كلية الهندسة وقسم الهيدرولوجيا وإدارة موارد المياه ، كلية الأرصاد ، جامعة الملك عبدالعزيز ، جدة ، المملكة العربية السعودية

المستخلص . إن تقدير القيم المحددة التي تصف حركة المياه الجوفية من المواضيع المهمة في علم المياه الجوفية . ومن أهم القيم المحددة لدراسة مشاكل المياه الجوفية : النفاذية ومعامل التوصيل الهيدرولي . إن توافر المعلومات ودقتها هو من الضروري بمكان لدراسات تنمية وإدارة المياه الجوفية . وحيث إن الطرق الشائعة المستخدمة لتقدير هذه القيم غالبا ما تحتاج إلى وقت وتكلفة عالية ، ولذا فقد لجأ كثير من الباحثين إلى طرق غير مباشرة لتقدير القيم المحددة . ومنها طريقة السعة النوعية التي تم تطبيقها على واديي يبة وتبالة (Yiba & Tabalah) ، وذلك باستخدام المعلومات المتوافرة لعشرة آبار لحساب النفاذية باستخدام طريقة كوبر/جاكوب (Cooper-Jacob method) . وأثبتت الدراسة جدوى وفعالية هذه الطريقة لتقييم القيم المحددة للخواص الهيدرولية للمياه الجوفية ، وخاصة في حالة عدم توافر المعلومات الكافية والمحددة .