The Libyan Journal of Agriculture: volume 9, 1980

Application of the Computer Method for Analysis of Pumping Test Data

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ABSTRACT

The hydrogeological parameters are most important for the quantitative study of any hydrogeologic system, and for optimal utilization of groundwater resources. Pumping-test analyses are mostly graphical; erroneous results of the computation of the hydrogeological parameters of an aquifer are generally due to individual judgement in the graphical analysis. Application of computers for aquifer evaluation comes under the inverse analysis technique and is based on the principle of least squares. The sum of weighed squares of differences between the observed drawdowns, and the drawdowns calculated using theoretical equations for the flow system under consideration, is minimized. The hydrogeological parameters in this case are treated as decision variables. This method can be applied to any flow system for which analytical expressions for the potential distribution are known. In this paper the method was applied to three pumping tests from aquifers of different flow systems. The values of storage coefficient and transmissivity arrived at, using analytical and digital computer methods, are tabulated (Table 1). The percentage differences are computed for both cases.

INTRODUCTION

The optimal control and exploitation of groundwater resources requires an accurate quantitative evaluation of the aquifer system and its response to various demands and recharges. Prediction of the behaviour of an aquifer is possible only if the hydrogeological parameters of the aquifer are known accurately.

Pumping test is one of the most common and useful means of determining the hydrogeological parameters of water-bearing systems, namely transmissivity, storage and leakage coefficients. During the last few decades great progress has been made in developing several methods for pumping tests analysis. Most of the available methods are graphical and require either curve matching, or finding inflection points, or in special cases, fitting straight lines to the pumping test data.

The reliability of the results obtained by these methods requires considerable judgement and there is a considerable chance of error in individual judgement in the graphical analysis. Application of a computer eliminates not only errors of individual judgement but can also be used for complex hydrogeological cases. More data normally yield better results by this method.

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MATERIALS AND METHODS

The main theoretical basis of this method is that the sum of the weighed squares of differences between the observed drawdowns and the theoretical drawdowns, calculated using theoretical drawdown equations for the flow system under consideration, is minimized treating the aquifer parameters as decision variables and, therefore, is a typical nonlinear programming problem (4). The method can be applied to any flow system for which analytical expressions, to calculate drawdown corresponding to the observed drawdowns, are known. The above principle has been applied independently by Haimes *et al.* (5) for the evaluation of aquifer parameters in a hypothetical case. In this paper the application of this principle to actual pumping tests is attempted.

The equation of the objective function θ which is to be minimized as:

$$\theta(T, V, B) = \sum_{i=1}^{M} \sum_{j=1}^{N_i} Wij[dij - Sij(T, V, B)]^2 \quad (1)$$

Where

M, N = total number of observation wells and total number of observations in each observation well, respectively. (N is different for each well.)
i, j = running indices for M and N respectively.
d, S = observed and theoretical drawdowns respectively.
T = transmissivity of the aquifer.
β = r/B, where r is the distance from the pumped well and β is the leakage factor and is equal to $\sqrt{T/(K^1/b^1)}$ where K^1/b^1 is the leakage coefficient.
V = hydraulic diffusivity of the aquifer and is defined as T/S^1, where S^1 is the storage coefficient of the aquifer.
W = Weight to be assigned to each observation.

The values of the hydrogeological parameters which minimize the objective function are the required values.

The objective function defined by (1) is for flow systems where T, S^1 and B are to be determined. If the drawdown is dependent on parameters other than the above three, they can also be considered as components of the set comprising the decision variables, and these parameters must be appropriately expressed in the analytical expression for the drawdown.

The computer program consists of a main routine and two subprograms.

The subprogram *FUNCT* computes the theoretical drawdown and the objective function as needed to the subprogram *FMINI*.

The subprogram *FMINI* calculates the first derivatives of the objective function with respect to the various parameters and calculates the minimum through iterations.

This subprogram performs the most important task of minimizing the objective function. The main routine simply reads the input data and prints the results. An outline of the flow diagram and the data input format will be used as a basis for the brief discussion of steps in the solution of the mathematical model or equation. Each block in the flow diagram may be represented either as an individual instruction to the computer or many individual instructions.

The first step after starting the program comes in block (1), involves arrangement of the complete program instructions in designated locations in the memory. Block (2) inserts values of t and s as input data and blocks (3) and (4) inserts values of r and table of Q respectively. Instruction blocks 3 and 4 are used several times during analysis; with block (4) functioning more frequently than block (3). Increments of drawdown for given values of Q and t for different observation wells are given identification numbers (ID numbers) or running indices.

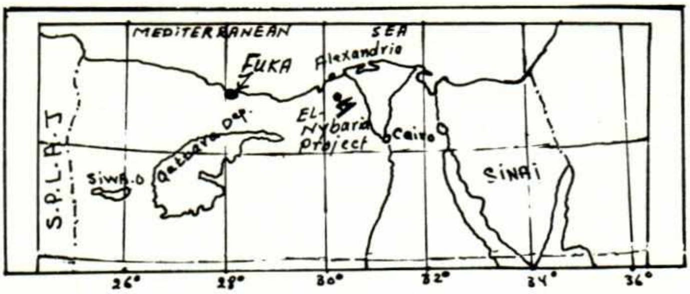


Fig. 1(A). Location map of the areas of pumping tests; El-Nybaria and Fuka areas (Egypt).

Instructions given in block (5, 9, 17 and 18) ensure proper identification of the many drawdowns. Block (5) functions more times than the other input blocks in providing sets of identification numbers for use during analysis. The printing of T and S also provides identification and segregates groups of values in the output format.

Examples of Application

The method was applied to three pumping tests which have been analyzed by different analytical and graphical methods and the result of some of these tests are already published in the literature. These pumping tests were conducted in different aquifers with different flow systems. The locations of these tests are shown in Figs. 1(A) and 1(B). A concise summary of the hydrogeological conditions in the site of these tests is as follows:

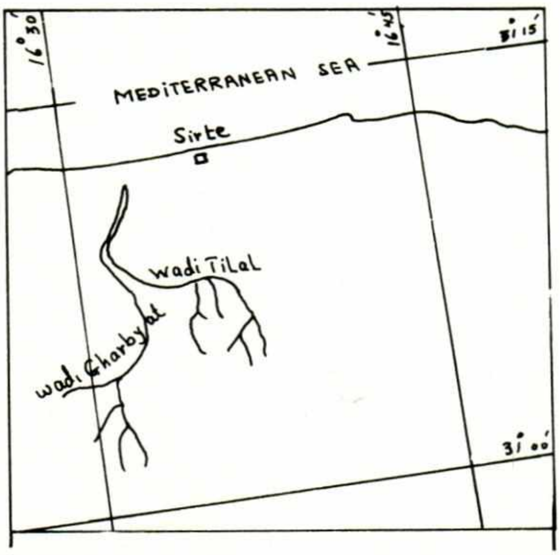


Fig. 1(B). Location map of Wadi Tilal–Wadi Charbyat area, Sirte zone.

1. West El-Nybaria Agricultural Project

West El-Nybaria Agricultural Project is considered as one of the biggest agricultural projects of West Rosetta-Nile branch and Nybaria canal. It occupies the area south of Alexandria and lies to the west of the Cairo–Alexandria highway until it reaches the Borg-El-Arab area.

The Quaternary alluvial gravels and calcereous sands with some silt lenses are the main water-bearing formations and make the main aquifer—with thickness ranging from 15 to 30 m.

The bottom of the reservoir is considered to be formed of impervious clay, conglomerate clay and beach conglomerates.

Due to the presence of some extensive clay lenses, some wells tap confined aquifers while others are in free water-table or unconfined aquifers. The feeding of the reservoir is due mainly to the local rainfall during winter time and due to the upward leakage from the deep groundwater bearing formation to the upper reservoir through the fault.

The direction of groundwater flow is from south to north towards the sea and from west to east. Results of pumping test for well number 22 penetrating the confined aquifer and for well number 29 penetrating the unconfined aquifer were analyzed using Jacob and Theis methods (Figs. 2 and 3) and (Table 1) showing the method and the results of analysis for the tested wells (22) and (29) respectively.

2. Fuka Basin

The Fuka area, about 80 km east of Mersa Matruh, consists of approximately 280 sq. km. The alluvial plain sediments are the source of water in several shallow wells north of Alexandria–Mersa Matruh highway. The Miocene limestones lying below the main water table produce water wherever they are tapped in the Fuka area.

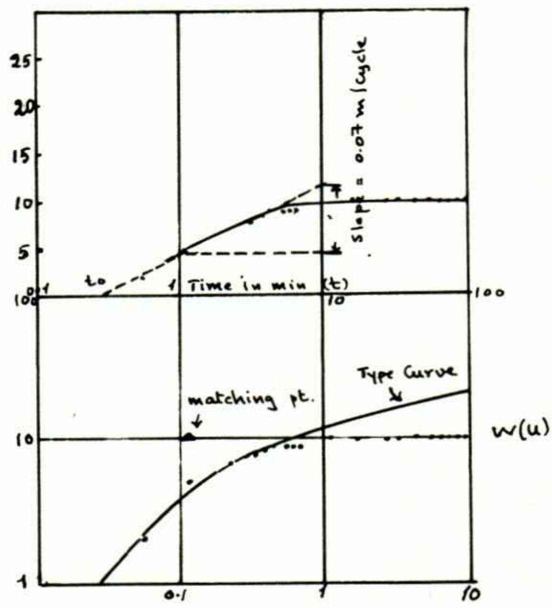


Fig. 2. Time drawdown curve Well No. 22, El-Nybaria area. Aquifer type: Confined; Total discharge $Q = 0.5\ M^3/min$; Aquifer thickness: 14.0 M.

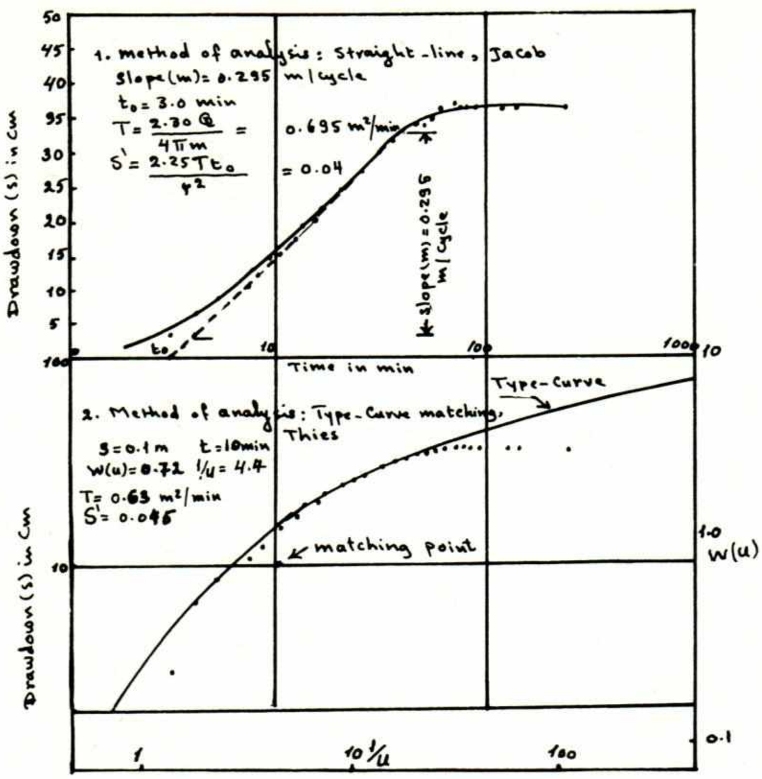


Fig. 3. Time drawdown curve Well No. 29, El-Nybaria. Total discharge $Q = 1.1\ M^3$/min; Aquifer thickness = 15.7 M; Aquifer type: Water table.

The recharge to the alluvial sediments and the Fuka basin aquifer occurs mainly due to the infiltration of rainfall to the water table and into the Miocene limestones.

Hydrologic estimations indicate that the basin may also receive water from other sources—it is possible that the basin is being recharged by inflow from other similar aquifer at higher elevations.

Six wells fully penetrating the aquifer are located on a straight line along the axis of the Fuka syncline.

Two pumping tests were conducted. The first test was run by pumping simultaneously from four wells number 1, 2, 4 and 5 and observing the drawdown in well number 3 (Fig. 4). The second test was run by pumping well number 3 and observing in piezometers 3A and 3B respectively (Fig. 5).

3. Wadi Tilal Al-Gharbiyat; Sirte zone

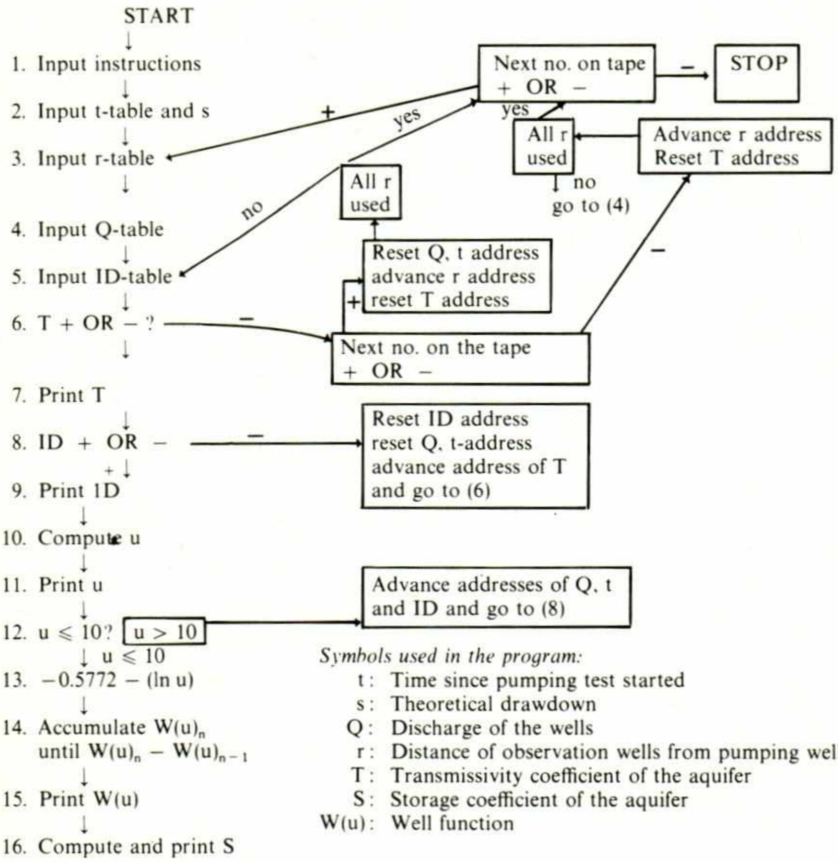
The water bearing formation in Wadi Tilal belongs to oligo-Miocene. The lithology of this formation is marly at its base overlain by limestone. This formation is heterogeneous and the impermeable marly formations are interbedded with more or less permeable limestone formations. The most permeable formations is the coquinoid limestone crossed by boreholes S2 and S5.

Table 1 Comparison of the hydrogeological parameters.

Aquifer type	Location of the aquifer	Hydrogeological Parameter			Difference in % from analytical	Analytical method
			Analytical	Computer		
Confined aquifer Well No. 22	El-Nybaria Area	T	1425	1500	3.3	Jacob
		S^1	7.8×10^{-3}	8.8×10^{-3}	12.8	
Unconfined (water-table) aquifer Well No. 29	El-Nybaria Area	T	1000	928	7.2	Theis
		S^1	4.5×10^{-2}	4.7×10^{-2}	4.4	
Semi-confined aquifer	Fuka	T	4672	4720	1.02	Straight-line (Inflection-point)
		S^1	3.5×10^{-2}	3.15×10^{-2}	10	
Semi-confined aquifer	Fuka	T	4990	4117	17.6	Straight-line (Inflection-point)
		S^1	4×10^{-2}	4.12×10^{-2}	3.15	
Confined aquifer	Wadi Tilal Al-Gharbiyat (Sirte zone)	T	5184	5300	4.1	Jacob
		S^1	1.6×10^{-2}	1.5×10^{-2}	6.2	

Note: T = Transmissivity coefficient in m^2/day.
S^1 = Storage coefficient.

Flow Diagram for Generating the Problem of Determination the Hydrogeological Parameters of Artesian Aquifer.



Symbols used in the program:

t: Time since pumping test started
s: Theoretical drawdown
Q: Discharge of the wells
r: Distance of observation wells from pumping well
T: Transmissivity coefficient of the aquifer
S: Storage coefficient of the aquifer
W(u): Well function

```
      SUBROUTINE SOLVE (N)
      DIMENSION A(20,21),ID(20)
      COMMON ATA(20,20),ATB(20),QEW(20),ICHECK
      ICHECK = 0
      M = N
      NN = N + 1
      D01I = 1,M
      A(I,NN) = ATB(I)
      ID(I) = I
      D01J = 1,N
    1 A(I,J) = ATA(I,J)
      K = 1
    2 NR = K
      NC = K
      B = ABS(A(K,K))
      D04I = K,M
      D04J = K,N
      IF(ABS(A(I,J)) - B)4,4,3
    3 NR = I
      NC = J
      B = ABS(A(I,J))
    4 CONTINUE
      IF(NR - K)7,7,5
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 5 D06J = K,NN
   CC = A(NR,J)
   A(NR,J) = A(K,J)
 6 A(K,J) = CC
 7 CONTINUE
   IF(NC - K)10,10,8
 8 D09I = 1,M
   CC = A(I,NC)
   A(I,NC) = A(I,K)
 9 A(I,K) = CC
   I = ID(NC)
   ID(NC) = ID(K)
   ID(K) = I
10 CONTINUE
11 IF(A(K,K))12,18,12
12 KK = K + 1
   D014J = KK,NN
   A(K,J) = A(K,J)/A(K,K)
   D014I = 1,M
   IF(K - I)13,14,13
13 A(I,J) = A(I,J) - A(I,K)*A(K,J)
14 CONTINUE
   K = KK
   IF(K - N)2,11,15
15 CONTINUE
   D017I = 1,N
   D017J = 1,N
   IF(ID(J) - I)17,16,17
16 QBW(I) = A(J,NN)
17 CONTINUE
   G0T020
18 WRITE(6,19)
19 FORMAT(10X, 'NO UNIQUE SOLUTION')
   ICHECK = 1
20 RETURN
   END
```

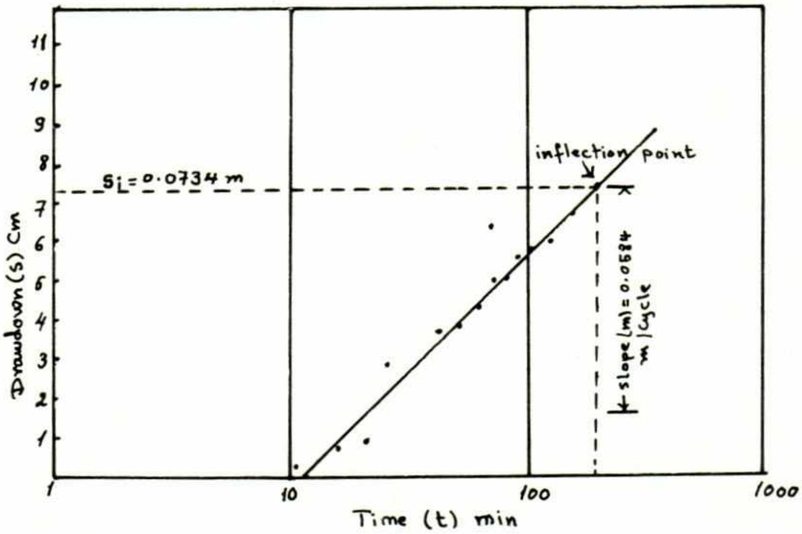

Fig. 4. Time drawdown curve of Fuka area. Pumping Wells No. 1, 2, 4, 5; Observation Well No. 3; Total discharge Q = 1.2 M^3/min.

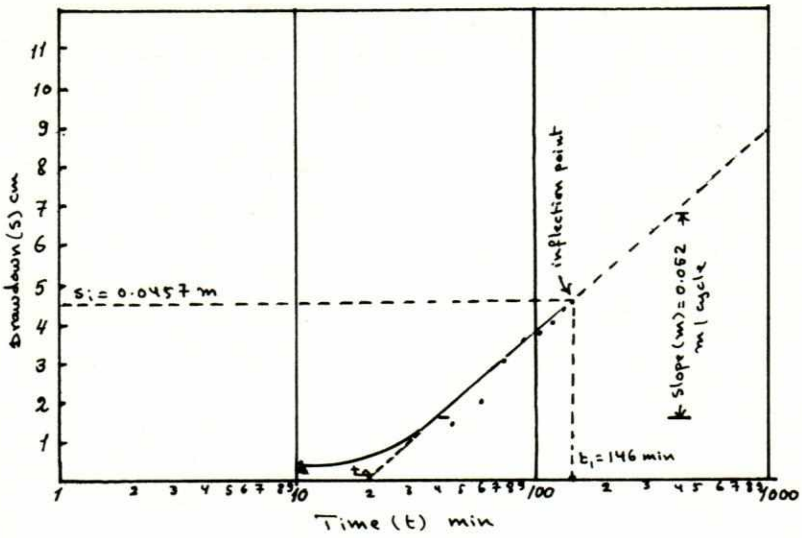

Fig. 5. Time drawdown curve. Pumping Well No. 3, Fuka area. Observation Well No. 3A and 3B; Total discharge Q = 0.9 M^3/min; R = 13 M, R^1 = 35 M.

The aquifer throughout Sirte zone is practically horizontal. The aquifer in this area is considered as confined in some areas and partially confined in others.

A large number of pumping tests have been carried out in Wadi Tilal Project and computations were made by Gefli in 1972 and by W. Ogilbee in 1961. The pumping test data from well No. 52 and 53 was analyzed by Theis and Jacob methods and observation was made in piezometer No. P18. The well discharge was 4.3 and 10 l/s consequently. The calculated transmissivity coefficient equal to 6×10^{-3} m^2/sec and the storage coefficient about 1.6×10^{-2}.

RESULTS AND DISCUSSION

1. Contours of the objective function θ, as a function of the aquifer parameters T and S^1 for the pumping test at El-Nybaria area shown in Fig. (6). To compare the hydrogeological parameters obtained both by the graphical type curve method and the computer methods, their values were plotted on Fig. (6). and shown in Table (1).

The computer method was also applied to determine the hydrogeological parameters of Fuka basin and Wadi Tilal Al-Gharbiyat project. The boundary conditions of intake areas of Fuka basin was approximated to a semifinite aquifer and infinite in areal extent aquifer for Wadi Tilal Al-Gharbiyat project. The average values for storage coefficient and transmissivity of the intake areas which were obtained by both the graphical and computer method are shown in Table (1) and Figs. (4, 5 and 7).

The difference in percentage between both values obtained by computer and graphical methods are also shown in Table (1).

2. The application of computer for aquifer evaluation is a very rapid and accurate method and dispenses with curve matching, finding inflection points and other techniques of graphical analysis. Less reliable observation can be assigned less weight. The method is useful because analytical expressions for drawdown or head distribution are available for several flow systems.

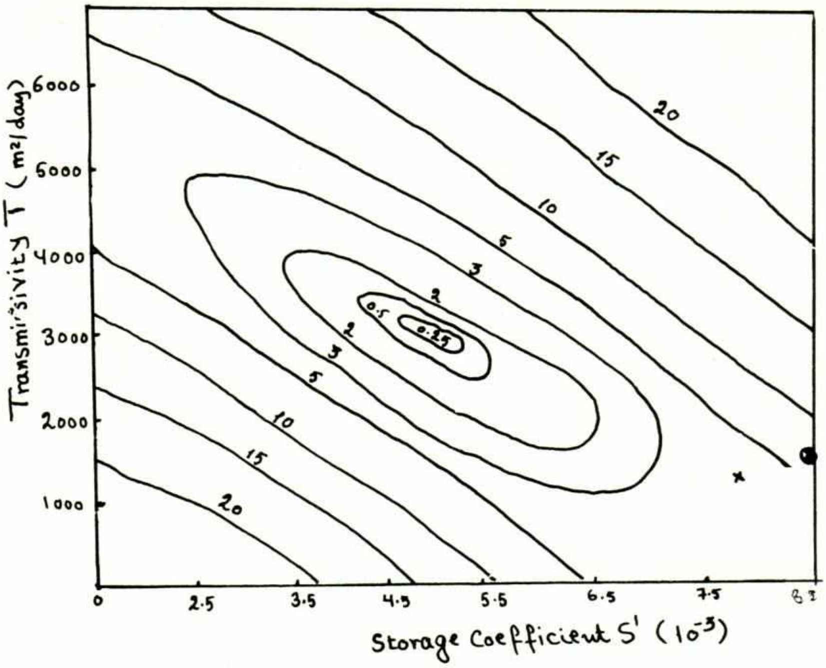

Fig. 6. Contours of the objective function (O) of El-Nybaria pumping test, Well No. 22. x Values of T and S^1 received by graphical method. ⊗ Values of T and S^1 received by computer method.

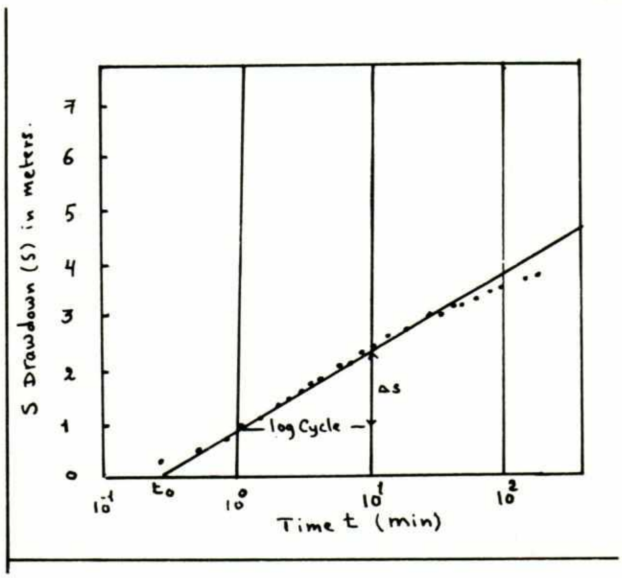

Fig. 7. Time-drawdown curve Well No. 52. Wadi Tilal–El-Gharbyiat area; Sirte zone.

3. The computer method is very useful in solving problems with complicated boundary conditions such as aquifer with hydraulic boundaries influencing the distribution of the fluid potentials i.e., aquifer bounded by canal, river, stream, etc., or with impervious boundaries i.e., dyke, etc.

Also this method is useful in analyzing pumping test data from anisotropic aquifers where transmissivity is different in different directions i.e., Tx, Ty, Tz; and for analysis pumping test data from aquifers with different flow systems, i.e., whether the system is leaky, non-leaky, confined, semi-confined or free water table conditions.

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استخدام الحاسب الآلكترونى لتحليل نتائج الضخ الاختبارى

د. محمود سعيد السلاوى*

ملخص

الغرض من هذا البحث هو دراسة امكانية استخدام الحاسب الالكترونى لحساب المعاملات الهيدروجيولوجيه للخزانات الجوفيه المختلفة والتى تعتبر أساسا لحساب كميات المياه الجوفيه المخزونه فى الخزان الجوفى اللازمه لتخطيط مصادر المياه فى المشاريع الزراعية لأغراض الرى، وكذلك كميات المياه التى يمكن استغلالها واستخراجها اقتصاديا وبدون أن تتأثر فاعلية الخزان الجوفى.

تم استخدام طريقة الحاسب الالكترونى لحساب معامل السريان ومعامل التخزين من نتائج ثلاث تجارب للضخ الاختبارى فى مناطق مختلفه وهى منطقة مشروع وادى تيلال بالمنطقة الوسطى (سرت) بالجماهيرية العربية الليبية الشعبية الاشتراكية وكذلك منطقة فوكه على الساحل الشمالى الغربى على بعد ٨٠ كم شرق مرسى مطروح ومنطقة مشروع غرب النوباريه بجمهورية مصر العربية وكذلك تم حساب المعاملات الهيدروجيولوجيه السابقة الذكر بالطرق التحليلية والبيانيه العاديه وقورنت نتائج هذا التحليل بالنتائج المستخلصه من الحاسب الالكترونى وكانت الخلاصة أن الحاسب الالكترونى يوفر كثيرا من الوقت والجهد وكذلك يجنبنا العديد من الأخطاء الشائعة فى حالة الحسابات التحليلية والبيانية.

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