PARAMETER ESTIMATION OF PUMPING TEST DATA USING GENETIC ALGORITHM

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ABSTRACT

Proper management of ground water requires estimation of hydraulic properties for aquifer systems such as transmissivity, hydraulic conductivity, storage coefficient and leakage. The pumping test is the standard technique for determining these hydraulic properties, for which graphical methods are widely used. In the present research, the effectiveness of an optimization technique called genetic algorithm (GA), which usually ensures near optimal or optimal global solution, is presented to determine aquifer parameters from the pumping test data. The objective function in this minimization problem is the summation of the square error between observed drawdown field data and the calculated ones due to estimated values for the unknown aquifer parameters. A FORTRAN program was written to estimate hydraulic parameters of different types of aquifers, under steady or unsteady conditions, using the GA. The fitness of the GA results is compared with the corresponding fitness of the graphical methods for several pumping tests field data. The results proved that the GA is an efficient and reliable method for estimating the hydraulic parameters of different types of aquifers.

Keywords: Pumping Test, Graphical Methods, Optimization, Aquifer Parameters

INTRODUCTION

A prior knowledge of aquifer parameters is indispensable for successful and reliable modeling results, and thereby ensuring proper management of vital groundwater resources. Pumping tests are the most widely used technique for estimating different hydraulic parameters of the aquifers. Traditionally the graphical approach is adopted to analyze the steady or unsteady drawdown pumping test data by using several nonlinear analytical models. These analytical models depend on the type of the aquifer and the hydraulic conditions. It must be noted that when the graphical approach matching with observed data is poor, the estimated aquifer parameters are not reliable. Calculated drawdown data based on optimal aquifer parameters must simulate the observed data as close as possible. Consequently, a nonlinear optimization technique must be adopted, instead of the graphical method, to minimize the differences between calculated and observed drawdown data in piezometric heads.

Two different optimization approaches can be used to solve the present problem. The first one is the deterministic approach which consists of different nonlinear optimization techniques, Larry [1,2], and Robert [3]. Traditionally, these techniques are inefficient and converge to a local minimum. The second approach is the stochastic optimization techniques such as the genetic algorithm (GA) and the simulated annealing (SA) methods. The main advantages of the stochastic techniques are the randomness procedure during the search which enables the optimization process to jump or release from any trapped local minimum to a lowest one, which increases the probability of catching the global minimum. Difficulties adherent with the deterministic approach due to the necessity of accurate calculation for the first and/or second derivatives of the objective function are avoided within the stochastic approach, Gen and Cheng [4].

Genetic Algorithms (GAs) can handle a wide range of difficult optimization problems. There are numerous researchers have applied GAs to a diverse range of water resources management problems.

Design of a successful and efficient surface irrigation system involves land grading as its first step. Reddy et al. [5] presented a nonlinear optimization model for land grading design based on genetic algorithms. The results indicated efficiency and robustness of the developed model.

Vairavamoorthy and Ali [6] proposed an optimal design methodology for the design of water distribution systems based on genetic algorithms. The objective of the optimization was to minimize the capital cost, under a compulsory constraint that ensures adequate pressures at all nodes. The method was tested on several networks and showed to be efficient and robust.

Wu and Simpson [7] applied the messy genetic algorithm to the New York tunnel problem to enhance the efficiency of an optimization procedure. That research showed that the number of the design trials required by the messy genetic algorithm was considerably fewer than the required trials by other genetic algorithms, and thus the messy GA provided a competent approach for optimizing water distribution systems. Messy GA enables optimal design and rehabilitation solution to be achieved for a large-scale water distribution system in a rapid manner.

Dandy et al. [8] used an improved genetic algorithm technique to find optimal design of the New York tunnel problem. The new GA used variable power scaling of the fitness function, a creeping mutation operator was introduced, and gray codes rather than binary codes were used. The improved GA was found to be the lowest cost feasible solution presented in the literature.

Abdel-Gawad [9] studied the effect of different types of selection, crossover and mutation on solving a network optimization problem. Different alternatives for GA were presented. For the studied network, the best formulation was composed from uniform crossover, modified uniform mutation, constant value of penalty and finally tournament strategy for both of selection/reproduction and replacement steps. The best GA formulation reached to optimal solution in far fewer generations than any previous GA. One significant advantage of the best formulation of GA was its robustness for wide range of operators (crossover and mutation).

The remediation of groundwater contamination by pumping and injection is generally a long term and an expensive strategy. Aquifer cleanup time is highly nonlinear and non-convex function of pumping rates. Maskey et al. [10] used the genetic algorithm method to minimize both cleanup time and cleanup cost taking pumping rates and/or well locations as decision variables. The results were satisfactory and showed that GA can be widely applied in groundwater remediation strategy and planning.

Samuel et al. [11] studied the estimation of aquifer parameters from pumping test data using the genetic algorithm as optimization technique. The aquifer parameters were also estimated by the graphical method using Aquifer Test software, and were compared with those obtained by the GA technique. A GA-based computer program with interactive window was developed in that study that can be served as a teaching and a research tool.

Katiyar [12] used a GA technique to find minimum annual cost of a water supply system. The system consists of two parts: 1) number of wells located in an unconfined aquifer which withdraw fresh groundwater, and 2) a pipe network which convey the pumped water to urban zones. The objective function was minimizing the summation of the equivalent annual cost of fixed parts of the system (pipes, wells, pumps) and annual cost required for operating the pumps. The permissible drawdown within the aquifer was restricted to a pre-specified level. Water pressure at consumers must be greater than a specified head. Katiyar mounted a GA code on two softwares to handle that problem (MODFLOW to predict the groundwater response due to different pumping rates from different random well locations within the aquifer and EPANET to analyze the pipe system).

Ezz-Eldin [13] studied the reliability based optimal design for water distribution networks subjected to different levels of uncertainty within the input data. A methodology, based on GA technique, was developed to find the optimal construction cost of the network system for a pre-specified level of reliability.

The purpose of the present study is to find optimal magnitudes of aquifer parameters, which simulate as close as possible the observed drawdown field data due to pumping.

PROBLEM FORMULATION

The main purpose of the present research is to find a more adequate and representable magnitudes for the unknown aquifer parameters. In case of pumping test the logical objective function is to minimize the differences between the observed field drawdown data in piezometric heads due to pumping and the corresponding calculated ones from using the analytical models. In the present work, the objective function was selected to minimize the summation of the square differences between observed and calculated drawdown in piezometric heads. The adopted objective function can be represented as follows:

$$Min\ obj = \sum_{i=1}^{n} \left(s_{ci} - s_{oi}\right)^2 \tag{1}$$

where, *obj* represents the objective function *(L^2)*, *n* is total number of observed data *(dimensionless)*, *i* is the rank of the observed data *(1 to n)*, s_{oi} is the observed filed drawdown data in piezometric head due pumping *(L)*, s_{ci} is the calculated drawdown by using a pre-specified analytical model *(L)*. The calculated drawdown s_{ci} is a function of the unknown aquifer parameters (decision variables). Consequently the objective function is also depending implicitly on the aquifer parameters.

Unknown aquifer parameters must be restricted in a bounded region within upper and lower limits. In case of investigating homogeneous isotropic aquifer the unknown hydraulic parameters can be summarized in determining the hydraulic conductivity, storativity, and leakage factor (or hydraulic conductivity of the confining layer). Lower and upper magnitudes of these parameters can be estimated reasonably by taking into consideration, the probability of all aquifer materials from soft clay to coarse gravel. Consequently the additional constraints that restrict the solution space, of the objective function, can be described as follows:

$$K_l \geq K \leq K_u \tag{2}$$

$$K'_l \geq K' \leq K'_u \tag{3}$$

$$S_l \geq S \leq S_u \tag{4}$$

$$Sy_l \geq Sy \leq Sy_u \tag{5}$$

where, *K* and *K'* are hydraulic conductivity of the aquifer and the confining layer respectively *(L/T)*, *S and Sy* are the storage coefficient for confined aquifers and specific yield for unconfined aquifers respectively *(dimensional)*, *l and u* are subscripts indicate lower and upper limits of the different decision variables respectively. Table (1) shows different magnitudes used for upper and lower limits of different decision variables, Todd, [14].

Table (1) Expected upper and lower limits of the aquifer parameters

Aquifer parameters	Lower limit	Upper limit
Hydraulic conductivity K (m/d)	0.00008	450
Storativity coefficient S	0.00005	0.005
Specific yield Sy	0.03	0.44
Hydraulic conductivity K' (m/d)	0.00008e10-5	5

The following analytical models were adopted to calculate the drawdown data, s_{ci}, for different pumping tests, Bear [15], Bowuer [16], and Hunt [17]:

- Theis model for pumping from confined aquifer under unsteady state condition:

$$s(r,t) = (Q_w/4\pi T).W(u), \quad T=KB, \quad u=r^2S/4Tt$$
$$\text{and } W(u) = -0.5772 - Ln\,u + u - u^2/(2*2!) + u^3/(3*3!) + \dots\dots \text{ for } u < 1.0 \tag{6}$$

where, $s(r,t)$ is the drawdown in piezometric head at radial distance r and time t (L), T is the unknown transmissivity (L^2/T), Q_w is the constant well discharge (L^3/T), $W(u)$ is the well function (dimensionless), K is the unknown hydraulic conductivity (L/T), S is the unknown storage coefficient *(dimensionless)* and B is the constant thickness of the aquifer (L). Theis model can be relaxed to Jacob model if $W(u)$ is taken equal to only $(-0.5772 - Ln\,u)$.

- Corrected Theis model for pumping from unconfined aquifer under unsteady state condition:

$$s'(r,t) = \{s(r,t) - [s^2(r,t)/(2H_0)]\} = (Q_w/4\pi T).W(u), \ T=K\,H_o \tag{7}$$

where, $s(r,t)$ represents the drawdown in the water table at radial distance r and time t, and $s'(r,t)$ is the corrected drawdown, and H_0 is the initial saturated thickness of the unconfined aquifer before pumping (L).

- Hantush model for pumping from leaky confined aquifer under unsteady state condition:

$$s(r,t)=(Q_w/4\pi KB).W(u,r/L),$$
$$W(u,r/L)=2K_0(r/L) - W(u), \ L=(KBC')^{1/2}, \ u=Tt/L^2S,$$
$$\text{and } W(u)=((exp(-u))/u).\{1-1/u+2/u^2-6/u^3+\dots\dots\} \quad \text{for } u > 1.0 \tag{8}$$

where, L is the unknown leakage factor (L), $C' = (B'/K')$ is the hydraulic resistance of the confined layer (T), B' represents the aquitard thickness (L), K' is the unknown hydraulic conductivity of the confined layer (L/T), $W(u, r/L)$ is Hantush well function, and K_0 is a modified Bessel function of the second kind and of zero order (Hankel function).

- Thiem model for pumping from confined aquifer with steady state condition:

$$h(r_1) - h(r_2) = (Q_w/2\pi T).Ln(r_2/r_1), \quad T=KB \tag{9}$$

where, $h(r_1)$ and $h(r_2)$ are piezometric heads at radii r_1 and r_2 respectively (L).

- Thiem-Dupuit model for pumping from unconfined aquifer under steady state condition:

$$s'(r_1) - s'(r_2) = (Q_w/2\pi KH_0).Ln(r_2/r_1) \tag{10}$$

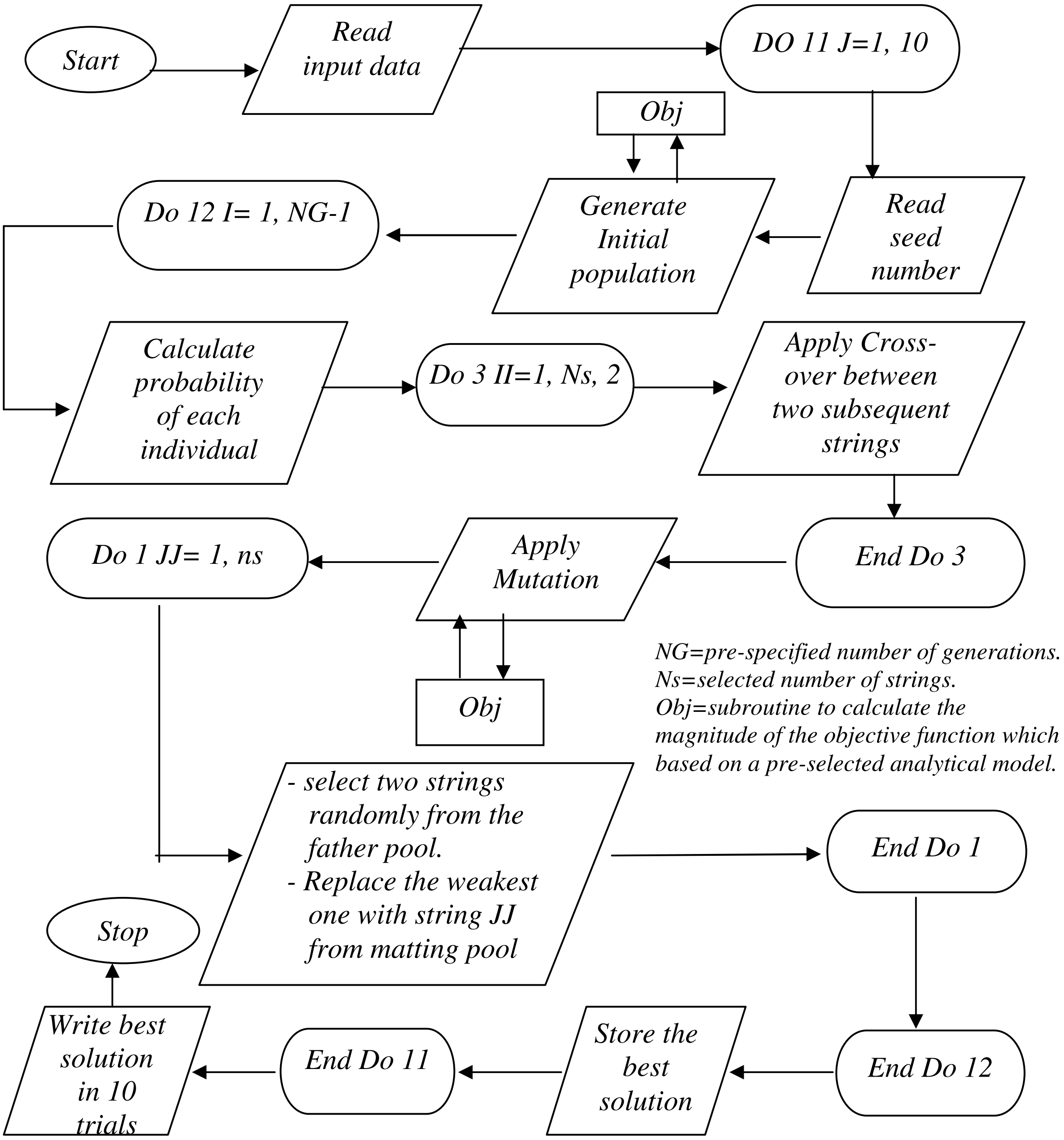
where, $s'(r_1)$ and $s'(r_2)$ are corrected drawdown at radii r_1 and r_2 respectively (L).

- De Glee model for pumping from leaky aquifer with steady state condition:

$$s(r, t) = (Q_w/2\pi KB).K_0(r/L) \tag{11}$$

GENETIC ALGORITHM (GA)

Genetic algorithm is a search technique developed by Holland and Goldberg [18] that uses the mechanism of natural selection to search through the decision space for optimal solution. The following are the main steps adopted in this research to formulate the present GA technique, Figure (1):



NG=pre-specified number of generations.
Ns=selected number of strings.
Obj=subroutine to calculate the magnitude of the objective function which based on a pre-selected analytical model.

Figure (1) General Flow Chart of the FORTRAN Codes

1- Generation of initial population: the genetic algorithm randomly generates an initial population of chromosomes/ solutions, which consist from number of genes equal to number of unknown aquifer parameters (decision variables). Real value coding is selected here. Consequently, every gene represents the created real value of one aquifer parameter. The generation process starts with creating a uniform random number for every gene between *0* and *1*. By setting the lower limit of the decision variable at *0* and the upper limit at *1* a new created magnitude of the decision variable can be calculated by linear interpolation. The real value coding is an efficient code in representing continuous decision variables like the unknown aquifer parameters. Any value between upper and lower limits of the decision variable has a uniform chance to be created.

2- Computation of the objective function for every string in the initial population: consequent magnitudes of drawdown in piezometric heads must be calculated for the suggested aquifer parameters (decision variables). A suitable analytical model must be selected to simulate the piezometric heads within the pumped aquifer. The analytical models are depending on type of the aquifer and the steadiness condition.

3- Computation of fitness: the fitness of each string must be taken as a function of the objective function. In this work, the GA technique computes the fitness for each proposed chromosome as the inverse magnitude of the objective function (1/obj).

4- Calculation of probability: every chromosome assigns a probability of selection to be a parent in the next generation/population. Chromosomes attached with a high fitness value have a strong probability to be elected more than one. In contrast, strings which have a small fitness magnitude may be skipped. The attached probability to every string is equal to the fitness of that string divided by the summation of total fitness for all strings within the whole population.

5- Selection: the roulette wheel principle was selected here. Imagine a roulette wheel where each chromosome in the population is associated with a segment in the roulette wheel. The size of the segment is proportional to the probability of selection of the associated chromosome. Fitter chromosomes have larger segments and therefore a greater probability of being selected.

6- Crossover: for every two subsequent neighborhood strings within the mating pool a crossover is permitted only if a generated uniform random number is lower than or equal to a pre-specified ratio of the crossover. Otherwise the two strings are left without change. If we have only one decision variable, that means one gene, the crossover process must be skipped (case of pumping from confined or unconfined aquifer under steady state condition).

7- Mutation: uniform random generation must be applied for every gene, within the mating pool, to create a new magnitude for the decision variable, only if a generated uniform random number is less than or equal a pre-specified ratio of mutation. Generally, mutations enable the strings /solutions to discover new regions in the feasible domain.

8- Reproduction: the idea of this step is to generate a new stronger population/ generation. The binary tournament is adopted here by selecting randomly two strings from the father population and replacing the weakest one with a string/solution from the matting pool. It must be noticed that the selected strings from the father population based on considering an equivalent probability of selection for all strings in the population equal to *1/Ns*, where *Ns* is number of strings in each generation. Once that new string is replaced by the father string, it must be treated as a father solution in subsequent replacements. Therefore, its fitness must be calculated for the purpose of comparison. This procedure is repeated several times equal to *Ns*. At the end of the replacement process we have, the stronger solutions from the previous father population and the present matting pool, in the new updated father population. Again, the reproduction process must be skipped in problems contain one decision variable.

9- Stopping rule: every mathematical optimization method needs a stopping criterion to terminate the solution process. GA creates a subsequent generations of solutions till a pre-specified number of generations is reached. The program must be terminated with a final solution equivalent to the fittest solution in last generation.

10- The written program repeats steps 1 to 9 for ten different seed numbers to increase the probability of catching the global minimum.

RESULTS AND DISCUSSION

1- Pumping from Confined Aquifer with Steady State Condition

Measured pumping test data, under steady state condition, from a confined aquifer was treated here for four monitoring wells, Batu [19]. The steady flow rate was $540\ m^3/d$. Batu analyzed the pumping test data by using the Thiem model. Two approaches were considered: 1) first one based only on using any two drawdown observations, consequently different combinations of dual observations were considered to calculate repeatedly the unknown magnitude of the transmissivity, six concluded values for the transmissivity were found between $0.17\ m^2/min$ and $0.2979\ m^2/min$ with arithmetic mean equal to $0.20625\ m^2/min$, 2) second approach based on using all observed data, by plotting the logarithm of the radial distances of the monitors against the corresponding observed drawdown and finding the slope of the straight line which passes through these points, the calculated transmissivity was found equal to $0.183\ m^2/min$. Magnitude of transmissivity obtained by GA was found equal to $0.2753\ m^2/min$ ($396.4\ m^2/d$) which has a relatively higher fitness than the corresponding ones to the graphical methods, Table (2).

Table (2) Comparison between results of the graphical and the GA techniques

Method	Transmissivity (m^2/min)	Fitness (m^{-2})	Improvement
Graphical(1)	0.20625	11.819400	1.176
Graphical(2)	0.183	22.629220	0.136
GA	0.2753	25.721680	

In the present research, the improvement ratio was considered equal to absolute difference between fitnesses of the GA technique and the graphical method divided by the minimum one.

2- Pumping from Unconfined Aquifer with Steady State Condition

The data of this example was taken from Lohman (1972) (as referenced by Batu, [19]), for pumping from unconfined aquifer with constant rate equal to *1000 gpm* (*0.063*m^3*/s*). The period of pumping was *18 days* and the initial saturated thickness of the aquifer was *26.8ft (8.17m)*. The pumping test data were analyzed graphically with the Thiem-Dupuit analytical model. Jacob's drawdown correction scheme was adopted to consider the effect of the thin saturated layer. Table (3) shows the calculated values of the hydraulic conductivity from both the graphical process and the GA technique. Results of GA show insignificant improvement of fitness with respect to the graphical method. The calculated values of the hydraulic conductivity by the two methods are approximately the same.

Table (3) Comparison between results of the graphical and the GA techniques

Method	Hydraulic conductivity (m/min)	Fitness (m^{-2})	Improvement
Graphical	0.02018	9.144	0.005
GA	0.0198	9.19	

3- Pumping from Leaky Confined Aquifer with Steady State Condition

Pumping test was conducted for a leaky confined aquifer under steady state condition, (Batu, [19]). The steady state pumping rate was *350* m^3*/day*. The De Glee analytical model was selected to analyze the pumping test data. The unknown aquifer parameters are transmissivity of the confined layer and leakage factor *(L)*. Table (4) shows different results from both the GA algorithm and the graphical method. The GA reached a stronger solution than the one obtained by the graphical method. Small discrepancies can be seen between calculated magnitudes of the aquifer parameters by the two methods. Figure (2) shows the observed steady drawdown at different observation wells and the corresponding calculated ones. Minor discrepancies can be noticed between the calculated drawdown by the two methods and the observed data. In general, the GA results match the observed data a little bit more accurately.

Table (4) Comparison between results of the graphical and the GA techniques

Method	Transmissivity (m^2/min)	Leakage Factor (m)	Fitness (m^{-2})	Improvement
Graphical	0.7736110	680	4502.071	0.67056
GA	0.8251098	780.8227	7521.016	

The second example was taken form (Karath, p.166) [20]. A fully penetrating well was constructed at Usmanwala, Ferozepur district, Punjah. The aquifer was overlain by *13m* of clay beds. Steady state drawdown attained in six observation wells located at distances ranged from *5 to 610m* from the pumped well. The steady state pumping rate was $5010\ m^3/d$ for *10,000 min*. Table (5) presents results of the two methods. GA generates a better solution, with percentage of improvement equal to 67%, than the one obtained with the graphical process. Minor differences can be noticed between the aquifer parameters estimated from the two techniques. Figure (3) shows the drawdown in piezometric heads from both GA and graphical methods against the observed field data. It can be seen that for the two methods the calculated drawdown match the observed field drawdown data very well.

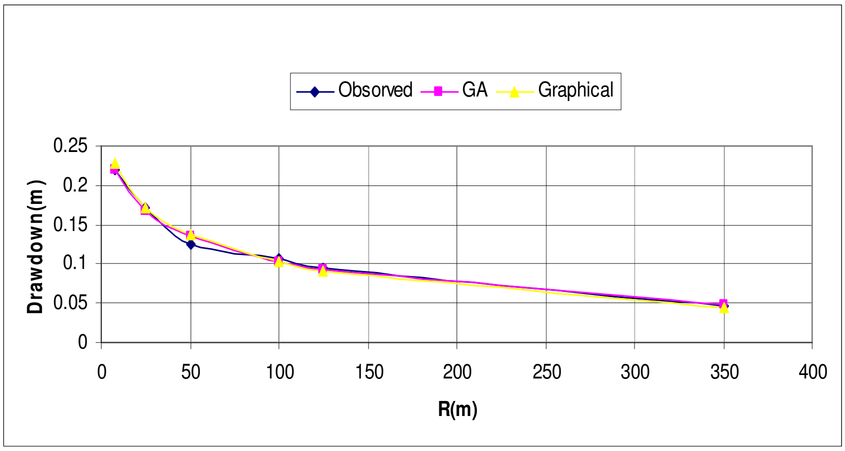


Figure (2) Comparison between different magnitudes of drawdown with respect to radial distance (leaky aquifer with steady drawdown)

Table (5) Comparison between results of the graphical and the GA techniques

Method	Transmissivity (m^2/min)	Leakage Factor(m)	Fitness (m^{-2})	Improvement
Graphical	0.6514	380	36.17765	0.672874
GA	0.6816	438.0294	60.52065	

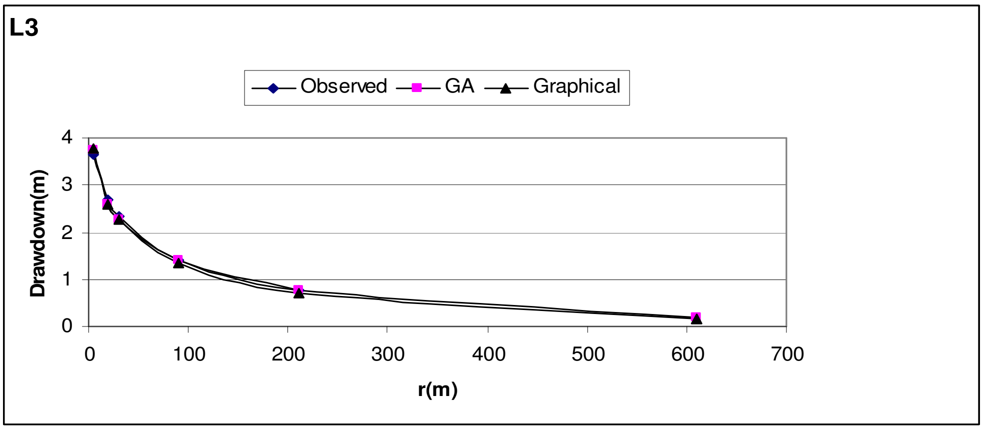


Figure (3) Comparison between different magnitudes of drawdown with respect to radial distance (leaky aquifer with steady drawdown)

4- Pumping from Unconfined Aquifer with Unsteady State Condition

This pumping test applied in Negria well field, Tonk district, Rajasthan. Drawdown was recorded in observation well located *20m* away from the pumped well (Karath, [20]). The steady pumping rate was *1662* m^3/day. The unconfined aquifer was *5.8m* in thickness, compromising coarse sand and boulder gravel all through. At the end of *1440min* of pumping the drawdown was observed to be *0.334m*, which forms about *6%* of the initial saturated thickness. The corrected Theis model was considered to analyze the pumping data. Table (6) presents results of both the GA and the graphical methods. A large discrepancy can be noticed in magnitude of fitness for the two solutions. GA reached a stronger solution than the one founded by the graphical method. Figure (4) shows the drawdown from both GA and graphical methods against the observed field data. It can be seen that the calculated drawdown data by the GA method match the observed field drawdown very well. Calculated drawdown by the graphical method has significant deviation from the observed data.

Table (6) Comparison between results of the graphical and the GA techniques

Method	Transmissivity (m^2/min)	Specific Yield (Sy)	Fitness (m^{-2})	Improvement
Graphical	1.351	0.08	18.785030	61.62305
GA	2.087277	0.076325	1176.376	

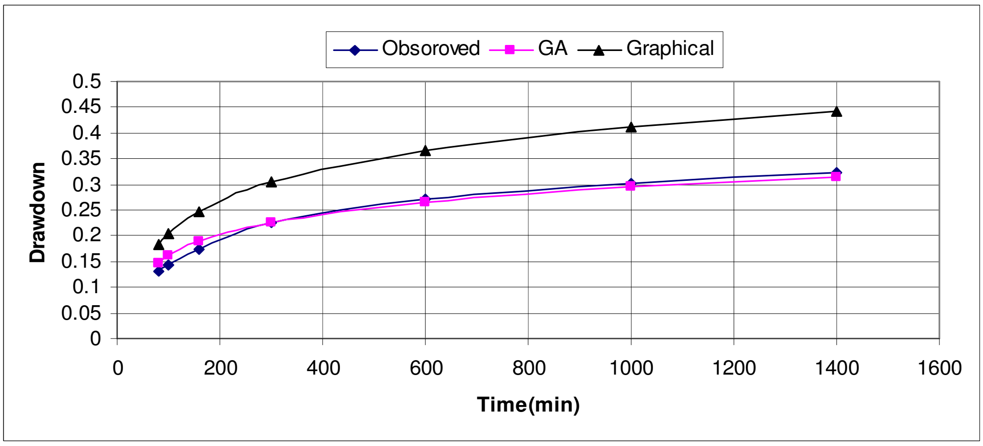


Figure (4) Comparison between different magnitudes of drawdown with respect to elapsed time (unconfined with unsteady drawdown)

5- Pumping from Leaky Confined Aquifer with Unsteady State Condition

This test is adopted from Hantush (as referenced by Batu, [19]), for pumping from leaky confined aquifer under unsteady state condition. The drawdown data determined from an observation well on the Moutrays farm in the Roswell artesian basin, New Mexico. The steady pumping rate was $8147\ m^3/day$ and the observation well was $323m$ away from the pumped well. The maximum or steady-state drawdown (s_m) was found equal to $5.7m$. Thicknesses of both the confined and the leaky layers are not given. Consequently, a proper estimation is required to these unknowns to determine the upper and lower limits of the transmissivity (T) and the resistance factor (B'/K'). The upper and lower limits of the unknown transmissivity were taken equal to 0.00055 and $2.3\ m^2/d$, and equal to *0.87 and 181818 d* for the resistance factor. The pumping test data analyzed with the Hantush's type curve method. The same data were utilized by the GA to predict the optimal parameters of the aquifer. Table (7) presents different results. Figure (5) shows the observed drawdown data against the calculated ones from both graphical and GA methods.

It must be noticed that the drawdown data calculated from the graphical parameters have a significant differences from the observed ones. That means, within the graphical process, a bad matching occurred between observed drawdown data and the selected Hantush type curve. It is worth to be mentioned that as the number of type curves is more than one, it is very difficult to get a proper matching. Hence, erroneous results are most likely by the graphical method. Figure (5) shows that the GA results approximately coincide with the observed drawdown field data.

Table (7) Comparison between results of the graphical and the GA techniques

Method	Transmissivity (T) (m^2/min)	Storativity (S)	Leakage Factor (m)	Fitness (m^{-2})	Improvement
Graphical	0.382	0.00008	3230	1.311464	0.289
GA	0.1454	0.000245	599.1478	1.6906	

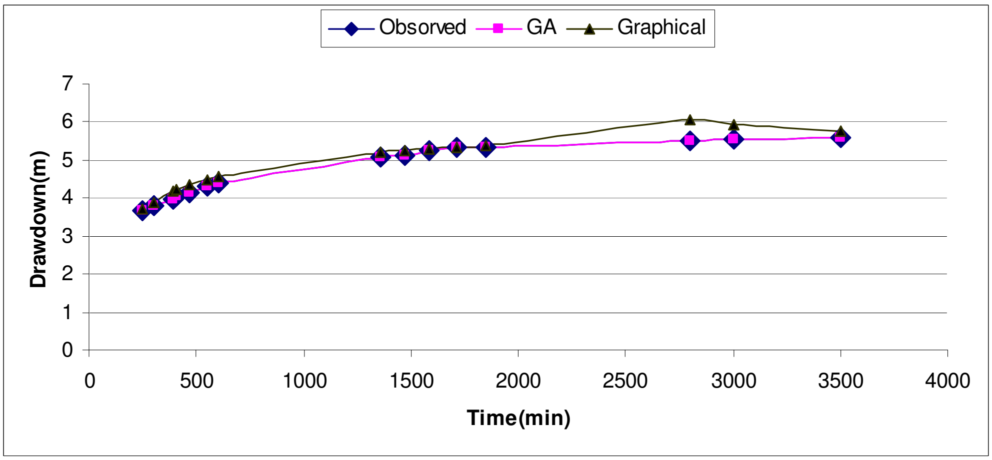


Figure (5) Comparison between different magnitudes of drawdown with respect to elapsed time (leaky with unsteady drawdown)

6- Pumping from Confined Aquifer with Unsteady State Condition

Pumping test was conducted for a confined aquifer under unsteady state condition (Batu, [19]). The drawdown data were measured at two observation wells having *25m and 75m* radial distances from the pumping well. The steady state pumping rate was *540* m^3/d. Theis model was adopted to determine transmissivity (*T*) and storage coefficient (*S*) of the aquifer using measured drawdown data at the two observation wells. Table (8) shows different values of aquifer parameters obtained by the graphical method and the GA technique. The results of different aquifer parameters are relatively close. GA produced a stronger solution than the one obtained by the graphical method.

Figure (6) shows a comparison between observed drawdown data and the calculated ones against different elapsed time intervals. The calculated drawdown curve from the GA is more close to the observed curve than the calculated curve based on the graphical solution.

Table (8) Results of the graphical and the GA techniques. (Theis Model)

Method	Transmissivity (m^2/min)	Storage Coefficient	Fitness (m^{-2})	Improvement
Graphical	0.1298	0.000426	2.20025	0.8138
GA	0.1506077	0.0002695501	3.9910	

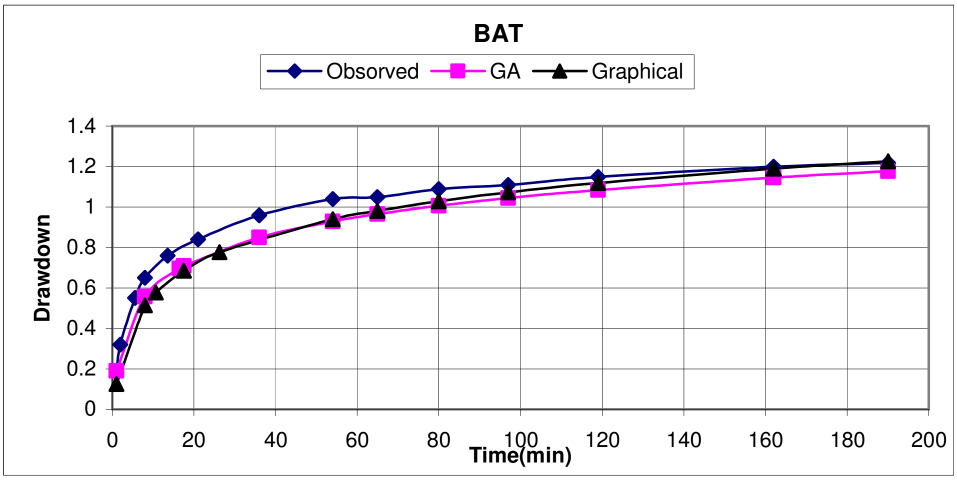
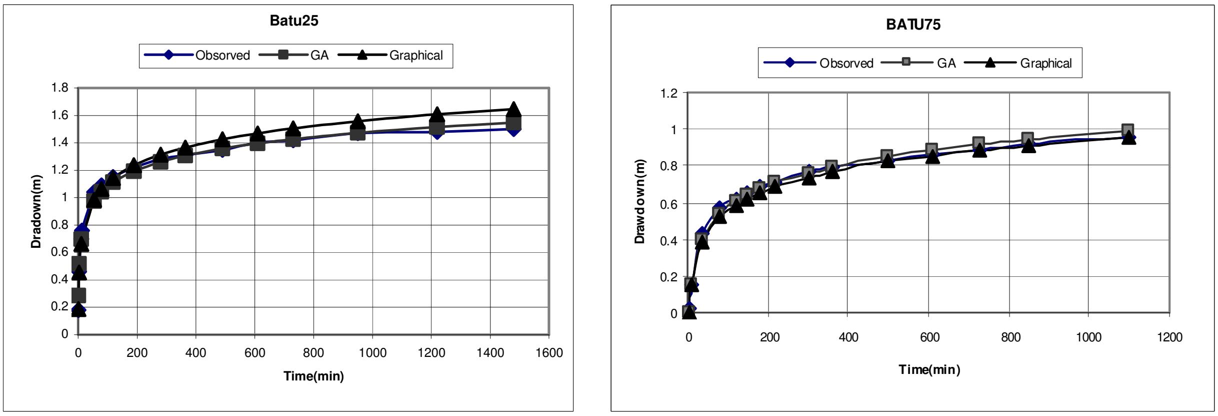


Figure (6) Comparison between different magnitudes of drawdown with respect to elapsed time due to data at two observation wells (r= 25 and 75m). (Theis model)

The above pumping test reanalyzed using the Jacob model. Table (9) shows different results for the aquifer parameters. It must be noted that the calculated magnitudes of transmissivity using the GA technique for two different drawdown data at the observation wells are approximately the same. In the other hand, considerable differences can be noticed between the magnitudes of transmissivity estimated using the graphical method. Thus it can be concluded that GA can produce a more reliable, accurate and unique solutions. Figures (4-7 a, b) show a comparison between observed drawdown data and the calculated ones. Drawdown curves based on the GA solutions match the observed data very well. Percentage of improvement for the GA solutions, with respect to the graphical solutions, equal to *47.9% and 95.502%* respectively.

Table (9) Results of the graphical and the GA techniques. (Jacob Model)

Radial distance (m)	Method	Transmissivity (m^2/min)	Storage Coefficient	Fitness (m^{-2})	Improvement
25	Graphical	0.1493	0.00021	10.53057	0.479
	GA	0.172394	0.000119	15.57476	
75	Graphical	0.1805	0.00025	51.35612	0.9502
	GA	0 .173384	0.000247	100.1569	



(a) r=25m **(b) r=75m**

Figure (7) Comparison between different magnitudes of drawdown with respect to elapsed time due to data at observation wells (r= 25, 75m). (Jacob model)

CONCLUSIONS

In this paper the efficacy of the GA optimization technique is examined for estimating the hydraulic properties of three aquifer systems (confined, unconfined, and leaky confined) under steady and unsteady state conditions. Similar to the graphical method, the pumping test field data were utilized within the optimization process and optimal results were compared with calculated ones based on the graphical method. The following points can be concluded:

1) For all pumping tests the GA technique behaves more accurately than the graphical method and proved to be an efficient, reliable method for estimating the hydraulic parameters of different aquifer systems, particularly in the situation when the graphical matching is poor.
2) The GA technique can reach to a unique solution of the aquifer parameters based on field drawdown data at different observation wells, see Table (9). Uniqueness of different solutions, due different data, supports the sensation of reaching the global minimum at these solutions.
3) The GA technique reached a more accurate drawdown curve than the one obtained by the graphical method especially in case of analyzing aquifers under unsteady state condition.
4) With the availability of high speed and large memory PCs, the use of the GA technique is recommended for estimating aquifer parameters from the pumping test data instead of the traditional cumbersome graphical method.

REFERENCES

1. **Mays, L.W., and Tung, Y-K.,** Hydrosystems engineering and management, McGraw-Hill Inc., pp. 587, 1998.
2. **Mays, L.W.,** Water resources handbook, McGraw-Hill, pp. 33-35, 1996.

3. **Corbett, R.A.,** Standard hand book of environmental engineering, McGraw-Hill Inc., p. 109, 1990.
4. **Gen, M., and Cheng, R.,** Genetic algorithms and engineering optimization, John Wiley and Sons Inc., p. 495, 2000.
5. **Reddy, S.L.,** Optimal land grading based on genetic algorithms, Journal of Irrigation and Drainage Engineering, ASCE, Vol. 122, No. 4, pp. 183-188, 1996.
6. **Vairavamoorthy, K., and Ali, M.,** Optimal design of water distribution systems using genetic algorithms, Computer-Aided Civil and Infrastructure Engineering, Vol. 15, pp. 374-382, 2000.
7. **Wu, Z.Y., and Simpson, A.R.,** An efficient genetic algorithm paradigm for discrete optimization of pipeline networks, MODSIM 97, International Congress on Modeling and Simulation, Modeling and Simulation Society of Australia, Hobart, Tasmania, Australia, Dec. 1997.
8. **Dandy, G.C., Simpson, A.R., and Murphy, L.J.,** An improved genetic algorithm for pipe network optimization, Water Resources Research, Vol. 32, No. 2, pp. 449-458, 1996.
9. **Abdel-Gawad, H.A.A.,** Optimal design of pipe networks by an improved genetic algorithm, pp. 155-163, Proceedings of the Sixth International Water Technology Conference IWTC 2001, Alexandria, Egypt, March 23-25, 2001.
10. **Maskey, S., Jonoski, A., and Solomatine, D.P.,** Groundwater remediation strategy using global optimization algorithms, Journal of Water Resources Planning and Management, Vol. 6, No. 6, pp. 431-440, 2002.
11. **Samuel, M.P., and Jha, M.K.,** Estimation of aquifer parameters from pumping test data by genetic algorithm optimization technique, Journal of Irrigation and Drainage Engineering, ASCE, pp. 348-359, September 2003.
12. **Katiyar, V.,** Production well operations optimization in water distribution system using genetic algorithm, M. Sc. Thesis, Department of Civil and Environmental Engineering, Michigan, USA, p. 127, March 2007.
13. **Ezz-Eldin, R.M.,** Reliability based optimal design model for water distribution networks, M. Sc. Thesis, Irrigation and Hydraulics Departement, Civil Engineering, Faculty of Engineering, Mansoura University, Egypt, 2007.
14. **Todd, D.K.,** Ground Water Hydrology, John Wiley & Sons, p. 535, 1980.
15. **Bear, J.,** Hydraulics of groundwater, McGraw-Hill Inc., p. 569, 1978.
16. **Bouwer, H.,** Ground water hydrology, McGraw-Hill Publishing Company, p. 480, 1978.
17. **Hunt, B.,** Mathematical analysis of groundwater resources, Butterworths, p. 273, 1983.
18. **Goldberg, D.E.**, Genetic algorithms in search, optimization, and machine learning, Addison-Wesley, MA, USA, 1989.
19. **Batu, V.,** Aquifer hydraulics, A comprehensive guide to Hydrogeologic data analysis, John Wiley & Sons, p. 727, 1998.
20. **Karanth, K.R.,** Groundwater assessment, development, and management, Tata McGraw-Hill Publisher Company Limited, New Delhi, p. 720, 1987.