International Journal of Civil Engineering and Technology (IJCIET)
Volume 10, Issue 1, January 2019, pp.479–497, Article ID: IJCIET_10_01_046
Available online at http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=1
ISSN Print: 0976-6308 and ISSN Online: 0976-6316

OPTIMAL MANAGEMENT OF GROUNDWATER PUMPING RATE AND LOCATIONS OF WELLS: OPTIMIZATION USING TABU SEARCH AND GENETIC ALGORITHMS METHOD

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ABSTRACT

A two-dimensional mathematical, model is developed to simulate the flow regime, of the upper part of Dibdibba Formation. The proposed, conceptual model, which is advocated to simulate the flow regime of aquifer is fixed for one layer, i.e. the activity of the deeper aquifer is negligible. The model is calibrated using, trial and error method. According to the calibration process, the hydraulic characteristics of the upper aquifer has been identified the hydraulic conductivity in the study area ranged (60-200) m/day while the specific, yield ranges, between, (0.08- 0.45).In this research, the obtaining of the optimum management of groundwater flow by linked simulation-optimization model. MODFLOW packages are used to simulate the flow in the system of groundwater. This model is completed with an optimization model which is depending on the Genetic Algorithm (GA) and Tabu Search (TS). Two management cases (fixed well location and flexible well location with the moving, well option) were considered by executing the model with adopting calibrated parameters. In the, first case the objective function is converged to a maximum value of (3.35E+5 m^3/day) by using GA, while this function is closed to 4.00E+5 m^3/day by using TS. The objective function in second case converges to the maximum value (7.64E+05m^3/day) and (8.25E+05m^3/day) when using GA and TS respectively. The choice option for the optimal location of the wells in the second case leads to an increase of 106% of the *total, pumping rates, compared to the first, case. The results of the first and second cases shown that the total value of pumping rate from all pumping wells by using TS is better than the total value of pumping rate by using GA.*

Keywords: Management, Groundwater, Tabu search, Genetic Algorithm *Safwan-Zubair*, Iraq.

Cite this Article: Wisam S. Al-Rekabi, Sarmad A. Abbas and Samar A. Al-khafaji, Optimal Management of Groundwater Pumping Rate and Locations of Wells: Optimization Using Tabu Search and Genetic Algorithms Method, International Journal of Civil Engineering and Technology (IJCIET), 10 (1), 2018, pp. 479–497.
http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=10&IType=1

1. INTRODUCTION

Groundwater hydrology involves the study of the subsurface and of the overall science, of water movement therein. The focus of groundwater, hydrology is water a fascinating and unique substance of all the resources that are critical to life nothing is more important than water. Therefore, water supply to humans is a critical part for the water resources engineering. Water has established the historical development of civilization provided a background for some of the greatest engineering work and continues to present political challenges in many parts of the world (Pinder and Celia, 2006).As a result of increased water demand in recent years especially after drought conditions in Iraq water policies in neighboring countries and the need to expand water use for food security there is a real need to re-evaluate groundwater resources in the light of effective modern technologies.

There are many studies dealt with the groundwater management. (Dougherty and Marryott, 1991) applied simulate annealing to the groundwater optimization problems like other optimization methods; most of the computational effort is expended in flow and transport simulators. They demonstrate the flexibility of the method and indicate its potential for solving the problems of groundwater management. The water resources problems by simulated annealing are new application and its development is immature. (Mckinny and Lin, 1994) incorporated simulation models of groundwater into a genetic algorithm to find solve for three problems in management of groundwater: maximum pumping from an aquifer; minimum cost water supply development and minimum cost aquifer remediation. The results show that genetic algorithms can used to obtain globally optimum solution for these problems effectively and efficiently and these solutions were better than those obtained by nonlinear and linear programming. (El Harrouni et al., 1997) studied the problem of pumping management in a homogenous aquifer by genetic algorithms (GA) and a problem of parameter estimation in a nonhomogeneous aquifer by BEM. In the pumping management problem the objective function evaluation is based on the pre-computed influence function. The computational cost for repeated objective function evaluation is minimal and for the parameter determination problem each evaluation of the objective function requires a direct solution by the dual reciprocity boundary element method (DRBEM). It is found the GA is good suited for parallel processing. With the robustness of the stochastic search and the advent of parallel computers GA can become a natural choice for complex tasks of parameter and optimization estimation in groundwater as good as many other fields. (Mackinny et al., 1996) developed a management of groundwater model by using a nonlinear programming algorithm to obtain the minimum cost design of the combined pumping and treatment, components of a pump-and-treat remediation system and includes the fixed costs of system construction and installation as well as operationand maintenance. The fixed-costterms of the objective function are incorporated into the nonlinear programming formulation using a penalty coefficient method. Results of applying the model, to an aquifer with homogeneous hydraulic conductivity show that a combined well field and treatment process model that includes fixed costs has a significant impact on the design and cost of these systems reducing the cost by using fewer larger-flow rate wells. Previous pump-and-treat design formulations have resulted in systems with numerous low-flow-rate wells because the use of simplified cost functions, that do not exhibit economies of scale or fixed costs. (Erickson et al., 2002) applied a multiobjective optimization algorithm for groundwater quality management problem. They used niched pareto genetic algorithm (NPGA) for remediation by pump-and-treat (PAT) and applied minimize the (1) remedial design cost and (2) contaminant mass, remaining at the end of the remediation horizon. Then they compared performances with signal objective genetic algorithm (SGA) formulation and a random search (RS).the NPGA is demonstrated to outperform both the SGA al-gorithm and the RS by generating a better tradeoff, curve.

Two models applied in the study area. The first model is a numerical model for studying groundwater flow patterns. The second model is an integrated simulation-optimization approach for obtaining optimal pumping rate of wells and their locations in Safwan-Zubair area which is the main objective of this research.

The aim of this research is to develop decision support tools identifying optimal pumping rate of groundwater wells and their locations in Safwan-Zubair area.

2. STUDY AREA

The study area is located in south west of Basrah Province, southern of Iraq. It is covers about 1400 km², which located between longitude-line (47^o30^- – 47^o55^-) and latitude line (30^o03^- – 30^o25^-) as shown in Fig.1. It represents the eastern, part of the western desert of Iraq. This area represents the southern sector of the IraqiDesert an arid region with scarce and limited resources. In the absence of a permanent river groundwater is a major natural resource within the region in question. It is an important agricultural and industrial area in which the groundwater is a prime source for irrigation and domestic. ,

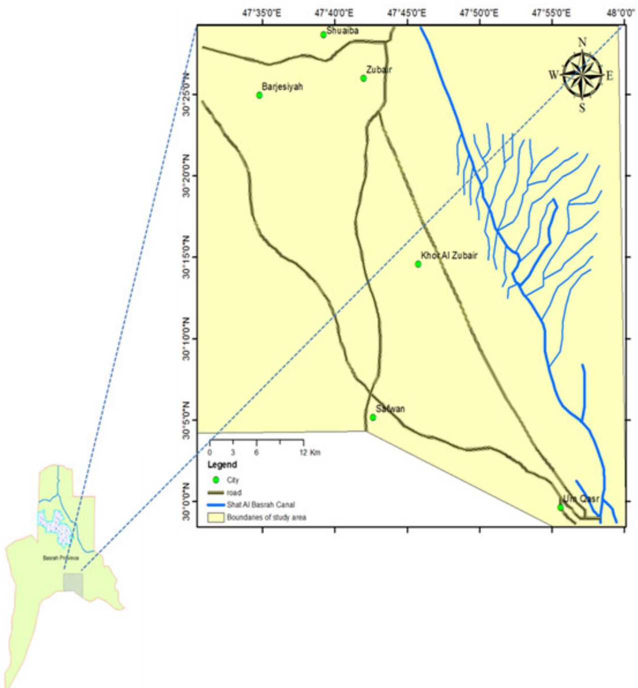

Figure 1 Study area Location in reference to the map of Basrah Province.

3. GROUNDWATER MODELING

A finite difference two dimensional model is used for modeling the groundwater flow for the upper aquifer in Safwan- Al- Zubair area in order to predict groundwater level in the study area. MODFLOW uses finite difference method to solve the groundwater flow mathematical model. The numerical model is based on the following two equations Darcy's law and conservation of mass equation. The combination of these two equations results in a partial differential equation governing the flow of groundwater.

The two dimensional groundwater flow equation used in MODFLOW can be specified for heterogeneous and anisotropic medium (non equilibrium) as follow (Mc Donald and Harbaugh, 1988):

$$\frac{\partial}{\partial x}\left[kxx\,\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[kyy\,\frac{\partial h}{\partial y}\right]-w=Ss\frac{\partial h}{\partial t} \qquad (1)$$

Where:

k_{xx}, k_{yy} :- values of hydraulic conductivity along x and y coordinate axes (L/T)

h: potentiometric head (L)

w: volumetric flux per unit volume representing sources and/ or sinks of water, with w<0.0 for flow out of the groundwater system, and w>0.0 for flow in (T^{-1}).

Ss: specif ic storage of the porous material (L^{-1}).

t: Time (T).

The work included some of the available hydraulic data collected from the previous studies and assigned to MODFLOW to simulate the groundwater flow as shown in the figure (2). Thirteen monitoring wells were used for observing groundwater levels for one year (AL-Aidani, 2015) as shown in Table 1.The valuable data had been identified within covered region for all cells such as horizontal hydraulic conductivity specific yield parameters rate of pumping wells, rate of recharge flux and distribution wells with observation head as cleared in flowchart below. The number of pumping wells in the study area is equal to 350 as f shown in figure (3). According to the calibration process the hydraulic characteristics of the upper aquifer has been identified the hydraulic conductivity in the study area ranged (60-200) m/day, while the specific yield ranges between (8- 45) %.

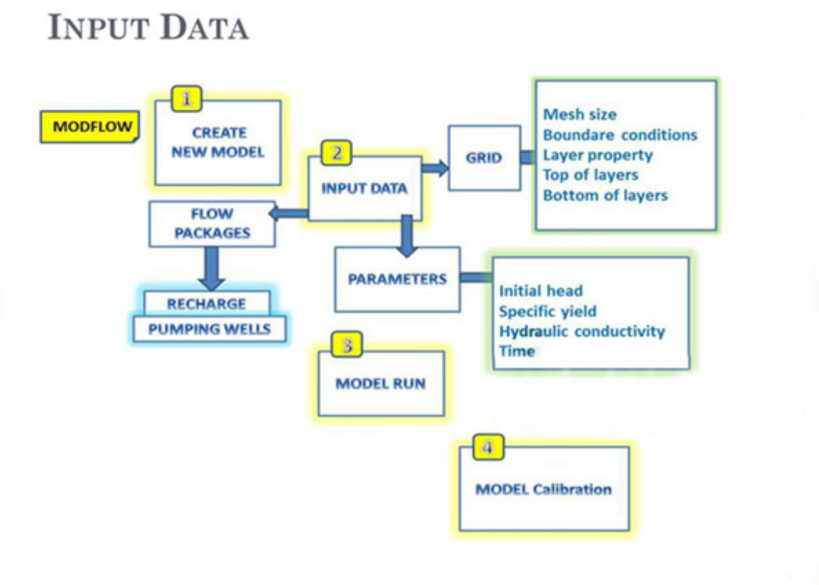

Figure 2 Flow chart of numerical model MODFLOW used for the study area.

Table 1: Locations of observation wells in the study area

Well No.	Location on earth surface		Location on Model grid of MODFLOW	
	UTM (Meter)		Cell	
	X Coordinate East	Y Coordinate North	(J) Column	(I) Row
W1	776073.9	3334454.1	71	76
W2	772401.6	3340151	50	50
W3	769216.9	3347236.6	44	37
W4	768011.6	3349799.7	42	32
W5	763965.4	3359591.9	34	15
W6	759024.7	3362351.1	24	9
W7	760693.4	3354275.8	27	22
W8	760644.6	3348622.2	26	34
W9	766204	3348789.1	38	34
W10	762661.8	3338098.2	30	53
W11	757140	3347548.3	19	36
W12	751284.3	3355403.8	7	22
W13	756100.5	3345517.2	12	45

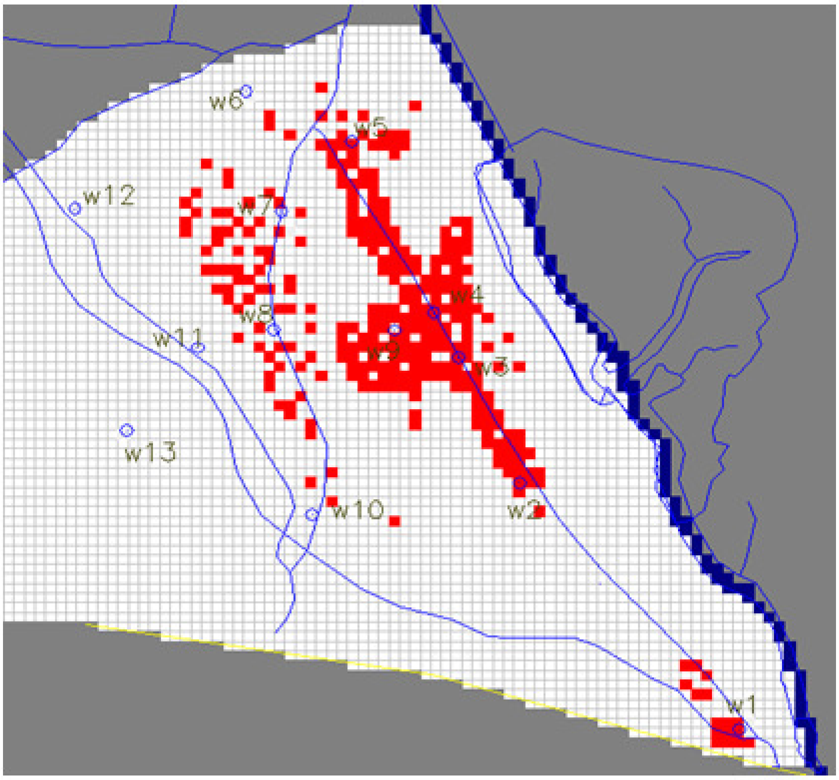

Figure 3 Pumping wells in the study area

3. OPTIMIZATION TECHNIQUES

There are two groups of variables attached with a groundwater management problem decision variables and state variables. One major decision variable is the pumping or injection rates of wells. Other possible decision variables include well locations and the “on/off” status of a well. These decision variables can be managed to identify the better collection of them as well indicate to as the optimal management strategy or schedule policy. The case variables are hydraulic head, which is the dependent variable in the equation of the groundwater flow and solute concentration which is the dependent variable in the transport equation. In a coupled simulation-optimization model the simulation component updates the state variables and the optimization component determines the optimal values for all the decision variables.

The objectives of management must be accomplished within a set of constraints. The constraints may be state variables or decision also may be take the form of equalities or inequalities. A general form of the objective function and a set of commonly used constraints adequate for a wide variety of resources management design problems can be expressed as follows (Zheng and Wang, 2003).

Maximize (or minimize)

$$J = a_1 \sum_{i=1}^{N} y_i + a_2 \sum_{i=1}^{N} y_i d_i + a_3 \sum_{i=1}^{N} y_i |Q_i| \Delta t_i + a_4 F(q,h) \quad (2)$$

Subject to

$$\sum_{i=1}^{N} y_i \le NW \quad (3)$$

$$Q_{min} \le Q_i \le Q_{max} \quad (4) \qquad h_{min} \le h_m \le h_{max} \quad (5)$$

$$h_m^{out} - h_m^{in} \ge \Delta h_{min} \quad (6) \qquad Q_m = A \sum_{i=I1}^{I2} Q_i + B \quad (7)$$

Where,

Objective function as expressed in equation (2),

J is the management objective in terms of the total costs or in terms of the total amount of pumping.

Q_i is the pumping/injection rate of well perform by parameter i (negative for pumping and positive forinjection).

F(q,h,) is any user-supplied cost function which may be dependent on flow rate q, hydraulic head h.

N is the total number of parameters (decision variables) to be optimized.

y_i is a binary variable equal to either 1 if parameter i is active (i.e., the associated flow rate is not zero) or zero if parameter i is inactive (i.e., the associated flow rate is zero).

d_i is the depth of well bore associated with parameter i.

Δt_i is the duration of pumping or injection associated with parameter i (or the length of the management period for parameter i).

a_1 is the fixed capital cost per well in terms of dollars or other currency units;

a_2 is the installation and drilling cost (dollars or other currency units) per unit depth of well bore (e.g., dollars/m); and,

a_3 is the pumping and/or treatment costs (dollars or other currency units) per unit volume of flow (e.g., dollars/m3).

a_4 is the multiplier for an external user-supplied cost function.

Equation (3) is a constraint stating that the total number of actual wells at any time period must not exceed a fixed number, NW, out of the total candidate wells, N.

Equation (4) is a constraint stating that the flow rate of a well at any specific management period must be within the specified minimum and maximum values (Q_{min} and Q_{max}).

Equation (5) is a constraint stating that the hydraulic head at any monitoring location, h_m, must be within the specified lower and upper bounds (h_{min} and h_{max}).

Equation (6) is a constraint stating that the head difference between an “outside” and an “inside” monitoring wells must be equal to or greater than a minimum value, Δh_{min}.

Equation (7) is a constraint stating that the pumping/injection rate of a well at an arbitrary location, Q_m, is proportional to the sum of the optimized flow rates represented by parameters I1 through I2 where A and B are proportional constants.

4.1. Genetic Algorithms

Genetic Algorithms (GAs) are adaptive heuristic search algorithm depend on the evolutional ideas of natural selection and genetic. The basic notion of GAs is designed to simulate processes in natural system needful for estimate specifically those that follow the principal first laid down by Charles Darwin of survival of the fittest. As such they perform a smart utilization of a random search within a defined search space to resolve a problem.

Genetic algorithms were formally introduced in the United States in the 1970s by John Holland at University of Michigan. The continuing price/performance refinements of computational systems have made them appealing for some kinds of optimization. In particular genetic algorithms work very well on mixed (continuous and discrete) problems of combinatorial.

The GA will generally contain the three fundamental genetic operations of chosen, mutation and crossover as shown in figure (4). These operations are used to adjust the selection solutions and choose the most suitable offspring to pass on to succeeding generations. GAs consider many points in the search space simultaneously and have been found to provide a rapid convergence to a near optimum solution in many kinds of problems; in other words, they commonly offer a reduced chance of converging to local minima. GAs suffers from the problem of excessive complexity if it is used for problems that are too large (Holland, 1992).

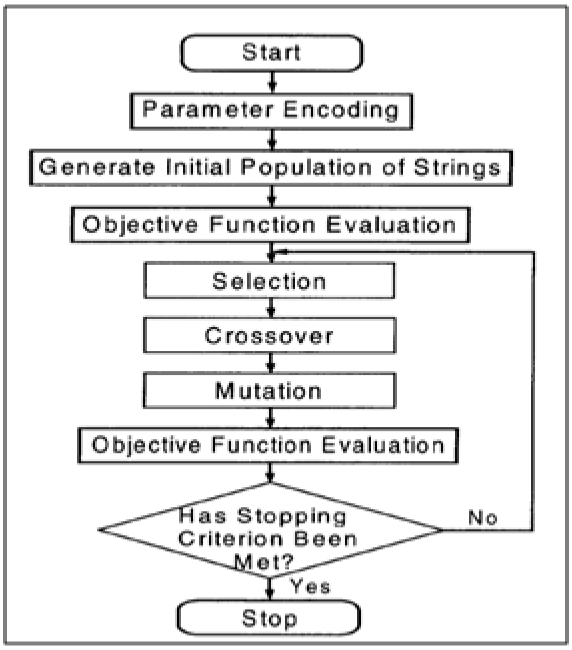

Figure 4 Flowchart of the genetic algorithm based simulation-optimization model (after Zheng and Wang, 2003)

The GA starts with a number of probable solutions, indicate to as the initial population, which are randomly chosen within the predetermined lower and upper bounds of any model parameter to be optimized. Every possible solution in the initial population is indicating to as an individual, typically encoded as a binary string (called chromosome). For each individual, the objective function (also indicate to as the suitability function in GA) is evaluated. During the search course, new decent of individuals are propagate from the old decent through random chosen, crossover, and mutation depend on confirmed probabilistic rules. The chosen is in favor of those temporal solutions with lower objective function values (in a minimization problem). Progressively, the population will evolve towards the optimal solution. The nucleus of GA is three basic operators: crossover, selection, and mutation (See Fig.4).

4.2. Tabu Search

Tabu search (TS) is other heuristic algorithm for global optimization; the "natural" system on which TS is depend in the human memory procedure. The implied strategy of TS is a local search scheme and a number of heuristic rules like long-term memory and short- term memory. One significant component is the short-term memory which is indicating to as the tabu list. The objective of the tabu listing is to force the search away from solutions that are chosen in new iterations so that it will not be trapped in local minima. New solutions are inadmissible if they satisfy conditions specific by the tabu listing.

A simple version of TS works as follows. It starts with a feasible well location or configuration say I_1, and with an empty tabu memory $L = \varphi$. TS compute the objective function of well configuration I_1. Next, it evaluates all the configurations in the neighbors of I_1. A neighbor of I1 means a well configuration that is slightly different from I_1. For example, change one well location from location i to i+1 or i-1. Chosen the neighbor with the lowest objective function value (in minimization) and check the tabu list. If the chosen neighbor satisfies the tabu condition, then the move is prohibited. In t condition again until a move is selected without violating any tabu conditions. At this moment update the tabu status $L = \{I_1\}$ and the search proceeds. A tabu move remains active in the tabu list for a number of iterations depending the length of tabu list L. At each iteration a new tabu move is added and the oldest one expires and thus is eliminated from the tabu list so that the tabu list remains a constant.

The length of the tabu list plays an important role in TS. Short tabu list cannot prevent the search from previously visited solutions causing the search path cycling, while long tabu list results in inefficiency. The size of the tabu list should depend on the size of the variables to be optimized. In addition to the tabu list another important element in TS is the incorporation of an aspiration level function that overrides the tabu moves. Under certain circumstances tabu moves are acceptable. For example, it is wise to accept a new solution with the currently best objective function even though its element is in the tabu list. The procedure of TS is given below.

Step 1 Initialization. The tabu search starts with a feasible well configuration I={I_j,, j=1,…, 2NW}, where NW is the maximum number of wells that can be installed, and Ij are the coordinates of the well locations. Construct the neighborhood set for I and set the tabu list empty L =φ .

Step 2 Evaluation. For each well configuration in the neighborhood set, evaluate the objective function.

Step 3 Updating. Find the better solution in the neighborhood excluding the configurations in the tabu list. Update the tabu list, i.e., add the change between the new solution and the old solution if the tabu list is not full.

Otherwise, delete the oldest element in tabu list and record the change. In addition, construct the new neighborhood set for next iteration.

Step 4 Checking convergence criterion. If the stopping criterion is met, stop.

Otherwise, go to step 2.

5. APPLICATION OF MANAGEMENT MODEL (GA AND TS)

Because the reduction of surface water in arid and semi-arid areas the groundwater becomes significant water resource for agriculture and drinking purposes. In areas of high evaporation and confined rainfall groundwater provides natural storage of water which is protected from surface evaporation it is spatially distributed and it can be developed with confined capital expenditure. On the other hand, groundwater provides a potential storage that can be managed to increase the valuable water resource. However, as noted above in all dry regions groundwater resources are under impendence from over pollution and abstraction. The wide scale deployment of powerful motorized pumps in the loss of effective arrangement has led to major problems of resource depletion declining water levels and impairment of water quality. The work offered here in explain the use of groundwater simulation and optimization to construct a two-dimensional management flow model to carry out resources management forecast for specific hydraulic constraints only. Two management cases were considered by running the model with adopted calibrated parameters. These parameters are determined according to the calibration process of numerical model.

5.1. Case 1- Fixed Well Location

In this case, the objective function is offered in equation (9). There are 350 pumping wells (active number of wells in the study area), the locations of these wells are shown in figure (3). So, the case problem can be formulated as an optimization problem with the following objective function and constraints,

$\text{Maximize } J = \Delta t \sum_{i=1}^{350} |Q_i|$ (8)

Subject to

$h_{min} \leq h_m \leq h_{max}$ (9)

$0 \leq |Q_i| \leq 4000$(10)

Where:

Equation (8), the objective function (J) is expressed in terms of the absolute pumping rates multiplied by Δt, the length of stress period in the flow model.

Equation (9), is head limited constraint requiring that the hydraulic head at any monitoring well location, h_m, must be above h_{min} and below h_{max}, where:

$h_{min} = h_i - 1.0$ (9a)

And

$h_{max} = h_i + 1.0$ (9b)

Where

h_i is the initial hydraulic head.

Equation (10) specified zero as the minimum and 4000 m^3/day as the maximum for the magnitude of each pumping rate to be optimized. Generally, several test runs are needed to select an appropriate value for use as the maximum pumping rate. If it is set too high, the optimization solution may be inefficient.

The objective function converges to a maximum value of (3.35E+05 m^3/day) for GA and for TS, the objective function is equal to (4.00E+05 m^3/day) after a total of 20 descent satisfying all the constraints. The final solution has only three hundred active wells. The distribution of the optimized pumping rates is shown in Table 2 under case 1.

5.2. Case 2-Flexible Well Location with the Moving Well Option

The simultaneous optimization of pumping rates and locations of well can be handled over the moving well choice. The location of well in this choice may not have a fixed location. It is allowed to move everywhere within a user defined zone of the model grid till the optimal location is reached. The objective function formulation is conformable to case 1. In addition to the constraints particular in case 1, a new constraint is added which requires that every of the wells to be optimized must be located within the patterned area (can be specified by the layer, row, column indices of a model cell performing the upper left and the lower right corner of a rectangular area). i.e.

$15 \leq I_w \leq 70$ (11)

$15 \leq J_w \leq 70$ (12)

Where:

I_w and J_w are the row and column indices of the moving well to be optimized.

The number of pumping parameter for case 2 is yet as three hundred and fifty wells to compare with the results of case 1. The objective function converges to a maximum value of (7.64E+05 m^3/day) for GA and (8.25E+05 m^3/day) for TS after a total of 20 generations satisfying all the constraints.

The distribution of the optimized pumping rates is shown in Table 3 under case 2.

6. CONCLUSIONS

A two-dimensional mathematical model is developed to simulate the flow regime of the upper part of Dibdibba Formation. The suggested conceptual model, which is advocated to simulate the flow regime of aquifer is fixed for one layer, i.e. the activity of the deeper aquifer is negligible. The model is calibrated using trial and error procedure. According to the calibration process, the hydraulic characteristics of the upper aquifer has been identified, the hydraulic conductivity in the study area ranged (60-200) m/day, while the specific yield ranges between (8- 45) %. A linked simulation-optimization model for obtaining the optimum management of groundwater flow is used in this research. MODFLOW packages are used to simulate the flow in the groundwater system. This model is integrated with an optimization model which is based on the Genetic Algorithm (GA) and Tabu Search (TS). Two management cases (fixed well location and flexible well location with the moving well option) were considered by executing the model with adopting calibrated parameters. In the first case, the objective function is converged to a maximum value of (3.35E+5 m^3/day) by using GA, while this function is closed to 4.00E+5 m^3/day by using TS. The objective function in second case converges to the maximum value (7.64E+05m^3/day) and (8.25E+05m^3/day) when using GA and TS respectively. The choice option for the optimal location of the wells in the second case leads to an increase of 106% of the total pumping rates compared to the first case. The results of the first and second cases shown that the total value of pumping rate from all pumping wells by using TS is better than the total value of pumping rate by using GA. From the above results of optimization processes for the first and second cases, we recommend using the results of the optimization model in the investigation of the optimum discharge of the wells as well as investigating the appropriate locations for installing the wells, as random drilling wells without a certified mechanism, thus lead to the deterioration of the quantity of groundwater and not to obtain the optimum value for pumping rate.

Table 2 The optimized pumping rates distribution in the study area under case 1.

NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column (j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
1	10	27	-1.120E+03	-1.28E+03	35	19	22	-1.920E+03	-2.08E+03
2	10	28	-1.600E+03	-1.76E+03	36	19	27	-1.280E+03	-1.44E+03
3	11	31	-3.520E+03	-3.36E+03	37	19	31	-1.120E+03	-1.28E+03
4	12	29	0.000E+00	0.00E+00	38	19	32	-1.600E+03	-1.76E+03
5	12	37	-8.000E+02	-1.12E+03	39	19	38	-4.800E+02	-8.00E+02
6	13	22	-3.520E+03	-3.36E+03	40	20	19	-2.560E+03	-2.72E+03
7	13	25	-2.720E+03	-2.88E+03	41	20	22	-1.440E+03	-1.60E+03
8	13	27	0.000E+00	0.00E+00	42	20	25	-1.600E+02	-4.80E+02
9	13	31	0.000E+00	0.00E+00	43	20	26	-8.000E+02	-1.12E+03
10	13	33	-9.600E+02	-1.28E+03	44	20	28	0.000E+00	0.00E+00
11	14	28	-2.720E+03	-2.88E+03	45	20	30	-4.800E+02	-8.00E+02
12	14	32	-4.800E+02	-8.00E+02	46	20	32	-3.680E+03	-3.52E+03
13	15	25	-6.400E+02	-9.60E+02	47	20	36	0.000E+00	0.00E+00
14	15	28	0.000E+00	0.00E+00	48	21	15	-6.400E+02	-9.60E+02
15	15	30	0.000E+00	0.00E+00	49	21	20	-1.120E+03	-1.28E+03
16	16	20	-6.400E+02	-9.60E+02	50	21	24	-2.240E+03	-2.40E+03
17	16	21	-1.600E+02	-4.80E+02	51	21	25	-1.600E+02	-4.80E+02
18	16	33	-2.080E+03	-2.24E+03	52	21	34	-1.600E+02	-4.80E+02
19	16	35	-2.720E+03	-2.88E+03	53	22	22	-6.400E+02	-9.60E+02
20	16	40	-1.600E+02	-4.80E+02	54	22	26	-1.760E+03	-1.92E+03
21	17	17	-1.600E+03	-1.76E+03	55	22	28	-3.200E+02	-6.40E+02
22	17	22	-4.800E+02	-8.00E+02	56	22	29	-1.120E+03	-1.28E+03
23	17	26	0.000E+00	0.00E+00	57	23	20	-8.000E+02	-1.12E+03
24	17	27	-6.400E+02	-9.60E+02	58	23	25	-3.200E+02	-6.40E+02
25	17	28	0.000E+00	0.00E+00	59	23	26	-1.600E+02	-4.80E+02
26	17	32	-1.600E+02	-4.80E+02	60	23	37	-1.600E+03	-1.76E+03
27	18	20	-3.200E+02	-6.40E+02	61	24	17	0.000E+00	0.00E+00
28	18	24	-8.000E+02	-9.60E+02	62	24	28	-1.600E+02	-4.80E+02
29	18	26	-1.440E+03	-1.60E+03	63	24	31	-1.920E+03	-2.08E+03
30	18	27	-8.000E+02	-1.12E+03	64	24	33	-9.600E+02	-1.28E+03
31	18	30	-1.440E+03	-1.60E+03	65	24	35	-4.800E+02	-8.00E+02
32	18	31	-2.400E+03	-2.56E+03	66	25	20	0.000E+00	0.00E+00
33	18	34	-6.400E+02	-9.60E+02	67	25	23	-4.800E+02	-8.00E+02
34	19	21	-1.120E+03	-1.28E+03	68	25	25	-1.760E+03	-1.92E+03

NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
69	25	26	0.000E+00	0.00E+00	108	30	37	-1.600E+02	-4.80E+02
70	25	27	-3.200E+02	-6.40E+02	109	30	39	-1.120E+03	-1.28E+03
71	26	26	-1.600E+02	-4.80E+02	110	31	20	-9.600E+02	-1.28E+03
72	26	27	-1.760E+03	-1.92E+03	111	31	29	-3.200E+02	-6.40E+02
73	26	29	-9.600E+02	-1.28E+03	112	31	31	0.000E+00	0.00E+00
74	26	31	-3.200E+02	-6.40E+02	113	31	35	-3.840E+03	-3.68E+03
75	26	33	-1.120E+03	-1.28E+03	114	31	36	-2.560E+03	-2.72E+03
76	26	36	-1.760E+03	-1.92E+03	115	31	37	-1.920E+03	-2.08E+03
77	26	38	-9.600E+02	-1.28E+03	116	31	43	-2.560E+03	-2.72E+03
78	26	40	-4.800E+02	-8.00E+02	117	32	16	-6.400E+02	-9.60E+02
79	27	18	-2.560E+03	-2.72E+03	118	32	19	-1.600E+03	-1.76E+03
80	27	20	0.000E+00	0.00E+00	119	32	22	-8.000E+02	-1.12E+03
81	27	25	-4.800E+02	-8.00E+02	120	32	26	-3.200E+02	-6.40E+02
82	27	27	-1.600E+03	-1.76E+03	121	32	31	-1.920E+03	-2.08E+03
83	27	30	-4.800E+02	-8.00E+02	122	32	33	-6.400E+02	-9.60E+02
84	28	18	-1.120E+03	-1.28E+03	123	32	35	0.000E+00	0.00E+00
85	28	20	-6.400E+02	-9.60E+02	124	32	36	0.000E+00	0.00E+00
86	28	23	-2.560E+03	-2.72E+03	125	32	37	-4.800E+02	-8.00E+02
87	28	28	-2.400E+03	-2.56E+03	126	32	38	-8.000E+02	-1.12E+03
88	28	31	-4.800E+02	-8.00E+02	127	33	20	-3.200E+02	-6.40E+02
89	28	33	-1.600E+02	-4.80E+02	128	33	24	-3.200E+02	-6.40E+02
90	28	34	-6.400E+02	-9.60E+02	129	33	30	-1.600E+03	-1.76E+03
91	28	35	-3.200E+03	3.36E+03	130	33	31	-3.200E+02	-6.40E+02
92	28	37	3.360E+03	3.52E+03	131	33	35	-6.400E+02	-9.60E+02
93	28	42	-1.760E+03	-1.92E+03	132	33	36	-1.440E+03	-1.60E+03
94	29	20	-6.400E+02	-9.60E+02	133	33	37	-4.800E+02	-8.00E+02
95	29	27	0.000E+00	0.00E+00	134	33	38	-1.600E+02	-4.80E+02
96	29	29	-2.240E+03	-2.40E+03	135	33	40	-1.600E+03	-1.76E+03
97	29	35	-4.800E+02	-8.00E+02	136	34	19	0.000E+00	0.00E+00
98	29	36	3.200E+02	-6.40E+02	137	34	21	-1.120E+03	-1.28E+03
99	29	37	-6.400E+02	-9.60E+02	138	34	22	-6.400E+02	-9.60E+02
100	29	41	0.000E+00	0.00E+00	139	34	26	-9.600E+02	-1.28E+03
101	30	22	-1.440E+03	-1.60E+03	140	34	28	-1.120E+03	-1.28E+03
102	30	24	0.000E+00	0.00E+00	141	34	31	0.000E+00	0.00E+00
103	30	29	-6.400E+02	-9.60E+02	142	34	33	-8.000E+02	-1.12E+03
104	30	31	-1.120E+03	-1.28E+03	143	34	35	-1.600E+02	-4.80E+02
105	30	33	-3.200E+03	-3.36E+03	144	34	37	-2.400E+03	-2.56E+03
106	30	35	-3.200E+02	-6.40E+02	145	34	39	-3.200E+02	-6.40E+02
107	30	36	-3.200E+02	-6.40E+02	146	34	41	0.000E+00	0.00E+00
147	35	24	-9.600E+02	-1.28E+03	186	39	41	-2.080E+03	-2.24E+03
148	35	26	-3.200E+03	-3.36E+03	187	39	43	-4.800E+02	-8.00E+02
149	35	28	-8.000E+02	-1.12E+03	188	39	44	-1.920E+03	-2.08E+03
150	35	30	0.000E+00	0.00E+00	189	40	26	-1.760E+03	-1.92E+03
151	35	34	-3.200E+02	-6.40E+02	190	40	27	-8.000E+02	-1.12E+03
152	35	36	0.000E+00	0.00E+00	191	40	36	-1.280E+03	-1.44E+03
153	35	37	0.000E+00	0.00E+00	192	40	37	-1.120E+03	-1.28E+03
154	35	38	-1.920E+03	-2.08E+03	193	40	38	-1.440E+03	-1.60E+03
155	35	39	-8.000E+02	-1.12E+03	194	40	41	-4.800E+02	-8.00E+02
156	35	42	-9.600E+02	-1.28E+03	195	40	42	-2.560E+03	-2.72E+03
157	35	44	-9.600E+02	-1.28E+03	196	40	43	-1.600E+02	-4.80E+02
158	36	22	-3.200E+02	-6.40E+02	197	40	46	-2.240E+03	-2.40E+03
NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS

159	36	24	-1.920E+03	-2.08E+03	198	41	22	-3.520E+03	-3.68E+03
160	36	25	-9.600E+02	-1.28E+03	199	41	25	-2.400E+03	-2.56E+03
161	36	30	-3.200E+02	-6.40E+02	200	41	26	-8.000E+02	-1.12E+03
162	36	32	-1.600E+02	-4.80E+02	201	41	29	0.000E+00	0.00E+00
163	36	33	-4.800E+02	-8.00E+02	202	41	34	-1.120E+03	-1.28E+03
164	36	38	1.600E+02	-4.80E+02	203	41	39	-8.000E+02	-1.12E+03
165	36	39	3.200E+02	-6.40E+02	204	41	40	-4.800E+02	-8.00E+02
166	36	41	-1.280E+03	-1.44E+03	205	41	41	-1.600E+02	-4.80E+02
167	37	19	-1.120E+03	-1.28E+03	206	42	28	-9.600E+02	-1.28E+03
168	37	21	1.120E+03	-1.28E+03	207	42	31	0.000E+00	0.00E+00
169	37	30	-1.280E+03	-1.44E+03	208	42	41	-9.600E+02	-1.28E+03
170	37	32	-1.600E+02	-4.80E+02	209	42	42	-1.440E+03	-1.60E+03
171	37	37	0.000E+00	0.00E+00	210	42	44	-1.920E+03	-2.08E+03
172	37	39	-4.800E+02	-8.00E+02	211	43	16	-1.600E+03	-1.76E+03
173	37	40	0.000E+00	0.00E+00	212	43	22	0.000E+00	0.00E+00
174	37	42	-2.400E+03	-2.56E+03	213	43	34	-9.600E+02	-1.28E+03
175	37	43	-1.600E+03	-1.76E+03	214	43	38	-6.400E+02	-9.60E+02
176	37	44	-6.400E+02	-9.60E+02	215	43	41	-3.360E+03	-3.52E+03
177	38	18	-1.600E+03	-1.76E+03	216	43	42	-1.600E+02	-4.80E+02
178	38	25	-9.600E+02	-1.28E+03	217	43	46	-3.200E+02	-6.40E+02
179	38	33	-1.120E+03	-1.28E+03	218	44	25	-1.760E+03	-1.92E+03
180	38	35	-8.000E+02	-1.12E+03	219	44	27	0.000E+00	0.00E+00
181	38	41	-1.600E+02	-4.80E+02	220	44	29	-1.600E+02	-4.80E+02
182	39	23	-1.600E+02	-4.80E+02	221	44	36	-8.000E+02	-1.12E+03
183	39	27	-1.440E+03	-1.60E+03	222	44	39	-8.000E+02	-1.12E+03
184	39	39	-2.400E+03	-2.56E+03	223	44	42	0.000E+00	0.00E+00
185	39	40	-1.440E+03	-1.60E+03	224	44	44	-9.600E+02	-1.28E+03
225	45	24	-1.600E+02	-4.80E+02	264	50	47	-1.280E+03	-1.44E+03
226	45	31	-8.000E+02	-1.12E+03	265	50	48	-1.600E+02	-4.80E+02
227	45	33	-1.600E+03	-1.76E+03	266	50	49	-3.040E+03	-3.20E+03
228	45	36	-2.400E+03	-2.56E+03	267	51	21	0.000E+00	0.00E+00
229	45	45	-1.280E+03	-1.44E+03	268	51	32	-1.120E+03	-1.28E+03
230	46	23	0.000E+00	0.00E+00	269	51	44	-3.200E+02	-6.40E+02
231	46	26	-6.400E+02	-9.60E+02	270	51	46	0.000E+00	0.00E+00
232	46	28	-8.000E+02	-1.12E+03	271	51	47	-1.600E+02	-4.80E+02
233	46	38	-1.440E+03	-1.60E+03	272	51	49	-6.400E+02	-9.60E+02
234	46	41	-4.800E+02	-8.00E+02	273	51	52	-1.120E+03	-1.28E+03
235	46	43	-4.800E+02	-8.00E+02	274	52	25	-3.200E+02	-6.40E+02
236	46	47	-2.240E+03	-2.40E+03	275	52	27	-1.600E+02	-4.80E+02
237	46	50	-1.600E+02	-4.80E+02	276	52	39	-2.560E+03	-2.72E+03
238	47	30	-2.080E+03	-2.24E+03	277	52	41	-3.200E+02	-6.40E+02
239	47	33	-2.400E+03	-2.56E+03	278	52	43	-2.240E+03	-2.40E+03
240	47	37	-2.080E+03	-2.24E+03	279	52	46	-1.600E+03	-1.76E+03
241	47	45	0.000E+00	0.00E+00	280	52	51	-3.360E+03	-3.52E+03
242	47	49	0.000E+00	0.00E+00	281	53	36	-1.600E+02	-4.80E+02
243	48	30	-4.800E+02	-8.00E+02	282	53	37	-1.600E+02	-4.80E+02
244	48	35	-1.120E+03	-1.28E+03	283	53	42	-1.600E+03	-1.76E+03
245	48	40	-1.440E+03	-1.60E+03	284	53	48	-2.240E+03	-2.40E+03
246	48	42	-3.200E+02	-6.40E+02	285	53	52	-3.200E+02	-6.40E+02
247	48	46	-1.280E+03	-1.44E+03	286	54	22	-1.600E+02	-4.80E+02
248	48	49	-2.400E+03	-2.56E+03	287	54	32	-2.080E+03	-2.24E+03
249	49	26	-1.280E+03	-1.44E+03	288	54	46	-6.400E+02	-9.60E+02
NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
250	49	32	0.000E+00	0.00E+00	289	54	48	-6.400E+02	-9.60E+02
251	49	35	-6.400E+02	-9.60E+02	290	54	50	-4.800E+02	-8.00E+02

252	49	43	0.000E+00	0.00E+00	291	55	24	-1.600E+02	-4.80E+02
253	49	46	0.000E+00	0.00E+00	292	55	30	0.000E+00	0.00E+00
254	49	47	-3.200E+02	-6.40E+02	293	55	37	-1.280E+03	-1.44E+03
255	49	48	0.000E+00	0.00E+00	294	55	40	-2.400E+03	-2.56E+03
256	49	49	-1.600E+03	-1.76E+03	295	55	51	-1.600E+02	-4.80E+02
257	49	51	-3.040E+03	-3.20E+03	296	56	28	-2.400E+03	-2.56E+03
258	50	29	-9.600E+02	-1.28E+03	297	56	42	-1.440E+03	-1.60E+03
259	50	33	-4.800E+02	-8.00E+02	298	56	45	-1.280E+03	-1.44E+03
260	50	37	-1.120E+03	-1.28E+03	299	56	47	-9.600E+02	-1.28E+03
261	50	39	-1.600E+02	-4.80E+02	300	56	53	-1.280E+03	-1.44E+03
262	50	41	0.000E+00	0.00E+00	301	57	37	-6.400E+02	-9.60E+02
263	50	45	0.000E+00	0.00E+00	302	57	49	-2.240E+03	-2.40E+03
303	57	51	-2.400E+03	-2.56E+03	327	63	53	-3.840E+03	-4.00E+03
304	57	56	0.000E+00	0.00E+00	328	63	58	-4.800E+02	-8.00E+02
305	58	29	-1.120E+03	-1.28E+03	329	64	56	-1.760E+03	-1.92E+03
306	58	43	-9.600E+02	-1.28E+03	330	64	58	-1.120E+03	-1.28E+03
307	58	45	-1.600E+02	-4.80E+02	331	65	58	-1.600E+02	-4.80E+02
308	58	53	-1.600E+02	-4.80E+02	332	65	60	0.000E+00	0.00E+00
309	58	57	-4.800E+02	-8.00E+02	333	65	61	-4.800E+02	-8.00E+02
310	59	32	-1.600E+02	-4.80E+02	334	66	50	-6.400E+02	-9.60E+02
311	59	46	-1.120E+03	-1.28E+03	335	66	56	-2.880E+03	-3.04E+03
312	59	50	-1.920E+03	-2.08E+03	336	67	53	-1.760E+03	-1.92E+03
313	59	55	0.000E+00	0.00E+00	337	67	58	0.000E+00	0.00E+00
314	60	37	-3.200E+02	-6.40E+02	338	68	61	-1.600E+02	-4.80E+02
315	60	43	-8.000E+02	-1.12E+03	339	69	58	-4.800E+02	-8.00E+02
316	60	53	-4.800E+02	-8.00E+02	340	70	63	-1.920E+03	-2.08E+03
317	60	55	-1.600E+02	-4.80E+02	341	70	65	-1.120E+03	-8.00E+02
318	60	57	-1.120E+03	-1.28E+03	342	70	68	-6.400E+02	-9.60E+02
319	61	40	0.000E+00	0.00E+00	343	71	59	-1.600E+02	-4.80E+02
320	61	49	-1.600E+02	-4.80E+02	344	71	60	-4.800E+02	-8.00E+02
321	61	58	-3.840E+03	-4.00E+03	345	72	62	-1.920E+03	-2.08E+03
322	62	52	-1.920E+03	-2.08E+03	346	73	65	-8.000E+02	-1.12E+03
323	62	56	-1.440E+03	-1.60E+03	347	73	67	-4.800E+02	-8.00E+02
324	62	60	-8.000E+02	-1.12E+03	348	75	68	-4.800E+02	-8.00E+02
325	63	42	-9.600E+02	-1.28E+03	349	75	69	-3.200E+02	-6.40E+02
326	63	47	0.000E+00	0.00E+00	350	75	71	-1.120E+03	-1.28E+03

Table 3 The optimized pumping rates distribution in the study area under case 2.

NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
1	10	27	-2.080E+03	-2.24E+03	7	13	25	-1.120E+03	-1.28E+03
2	10	28	-3.200E+02	-6.40E+02	8	13	27	-3.200E+02	-6.40E+02
3	11	31	-2.400E+03	-2.56E+03	9	13	31	-4.000E+03	-3.84E+03
4	12	29	-3.200E+03	-3.36E+03	10	13	33	-1.120E+03	-1.28E+03
5	12	37	-2.720E+03	-2.88E+03	11	14	28	-3.840E+03	-4.00E+03
6	13	22	-2.400E+03	-2.56E+03	12	14	32	-1.760E+03	-1.92E+03

NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
13	15	25	-1.440E+03	-1.60E+03	65	24	35	0.000E+00	0.00E+00
14	15	28	-1.600E+02	-4.80E+02	66	25	20	-3.200E+03	-3.36E+03
15	15	30	-1.440E+03	-1.60E+03	67	25	23	-3.680E+03	-3.84E+03
16	16	20	-4.000E+03	-3.84E+03	68	25	25	-3.360E+03	-3.52E+03
17	16	21	-2.720E+03	-2.88E+03	69	25	26	-9.600E+02	-1.28E+03
18	16	33	-2.880E+03	-3.04E+03	70	25	27	-4.000E+03	-3.84E+03
19	16	35	-3.680E+03	-3.84E+03	71	26	26	0.000E+00	0.00E+00
20	16	40	-1.600E+03	-1.76E+03	72	26	27	-2.880E+03	-3.04E+03
21	17	17	-8.000E+02	-1.12E+03	73	26	29	-1.440E+03	-1.60E+03
22	17	22	-1.440E+03	-1.60E+03	74	26	31	-1.920E+03	-2.08E+03
23	17	26	-3.360E+03	-3.52E+03	75	26	33	-1.920E+03	-2.08E+03
24	17	27	-9.600E+02	-1.28E+03	76	26	36	-1.440E+03	-1.60E+03
25	17	28	-3.680E+03	-3.84E+03	77	26	38	-1.440E+03	-1.60E+03
26	17	32	-1.920E+03	-2.08E+03	78	26	40	-2.400E+03	-2.56E+03
27	18	20	-1.440E+03	-1.60E+03	79	27	18	-2.880E+03	-3.04E+03
28	18	24	-1.760E+03	-1.92E+03	80	27	20	-3.520E+03	-3.68E+03
29	18	26	-2.240E+03	-2.40E+03	81	27	25	-2.560E+03	-2.72E+03
30	18	27	-2.080E+03	-2.24E+03	82	27	27	-3.840E+03	-4.00E+03
31	18	30	-3.200E+03	-3.36E+03	83	27	30	-6.400E+02	-9.60E+02
32	18	31	-2.560E+03	-2.72E+03	84	28	18	-1.920E+03	-2.08E+03
33	18	34	-3.840E+03	-4.00E+03	85	28	20	-3.360E+03	-3.52E+03
34	19	21	-9.600E+02	-1.28E+03	86	28	23	-3.680E+03	-3.84E+03
35	19	22	-1.600E+03	-1.76E+03	87	28	28	-1.280E+03	-1.44E+03
36	19	27	-2.080E+03	-2.24E+03	88	28	31	-9.600E+02	-1.28E+03
37	19	31	-1.600E+02	-4.80E+02	89	28	33	-2.240E+03	-2.40E+03
38	19	32	-3.200E+03	-3.36E+03	90	28	34	-2.720E+03	-2.88E+03
39	19	38	-1.440E+03	-1.60E+03	91	28	35	-3.040E+03	-3.20E+03
40	20	19	-3.200E+03	-3.36E+03	92	28	37	-3.200E+03	-3.36E+03
41	20	22	-3.520E+03	-3.68E+03	93	28	42	-1.600E+02	-4.80E+02
42	20	25	-8.000E+02	-1.12E+03	94	29	20	-1.600E+02	-4.80E+02
43	20	26	-6.400E+02	-9.60E+02	95	29	27	-1.440E+03	-1.60E+03
44	20	28	0.000E+00	0.00E+00	96	29	29	-1.600E+02	-4.80E+02
45	20	30	-8.000E+02	-1.12E+03	97	29	35	-2.240E+03	-2.40E+03
46	20	32	-3.200E+03	-3.36E+03	98	29	36	-9.600E+02	-1.28E+03
47	20	36	-2.560E+03	-2.72E+03	99	29	37	-3.360E+03	-3.52E+03
48	21	15	-3.360E+03	-3.52E+03	100	29	41	-3.840E+03	-4.00E+03
49	21	20	-3.200E+02	-6.40E+02	101	30	22	-3.520E+03	-3.68E+03
50	21	24	-3.200E+03	-3.36E+03	102	30	24	-4.000E+03	-3.84E+03
51	21	25	-3.680E+03	-3.84E+03	103	30	29	-3.840E+03	-4.00E+03
52	21	34	-2.720E+03	-2.88E+03	104	30	31	-4.000E+03	-3.84E+03
53	22	22	-8.000E+02	-1.12E+03	105	30	33	-2.720E+03	-2.88E+03

54	22	26	-2.880E+03	-3.04E+03	106	30	35	-4.000E+03	-3.84E+03
55	22	28	-6.400E+02	-9.60E+02	107	30	36	-2.400E+03	-2.56E+03
56	22	29	-2.400E+03	-2.56E+03	108	30	37	-4.000E+03	-3.84E+03
57	23	20	-1.760E+03	-1.92E+03	109	30	39	-2.880E+03	-3.04E+03
58	23	25	-3.520E+03	-3.68E+03	110	31	20	-3.680E+03	-3.84E+03
59	23	26	-3.680E+03	-3.84E+03	111	31	29	-2.720E+03	-2.88E+03
60	23	37	-3.200E+02	-6.40E+02	112	31	31	-1.760E+03	-1.92E+03
61	24	17	-1.760E+03	-1.92E+03	113	31	35	-1.760E+03	-1.92E+03
62	24	28	-3.520E+03	-3.68E+03	114	31	36	-1.120E+03	-1.28E+03
63	24	31	-2.400E+03	-2.56E+03	115	31	37	-2.080E+03	-2.24E+03
64	24	33	-4.800E+02	-8.00E+02	116	31	43	-1.920E+03	-2.08E+03
NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
117	32	16	-1.600E+03	-1.76E+03	168	37	21	-3.680E+03	-3.84E+03
118	32	19	-3.520E+03	-3.68E+03	169	37	30	-1.760E+03	-1.92E+03
119	32	22	-1.600E+02	-4.80E+02	170	37	32	-1.600E+03	-1.76E+03
120	32	26	-2.080E+03	-2.24E+03	171	37	37	-1.280E+03	-1.44E+03
121	32	31	-4.000E+03	-3.84E+03	172	37	39	-2.720E+03	-2.88E+03
122	32	33	-2.240E+03	-2.40E+03	173	37	40	-1.280E+03	-1.44E+03
123	32	35	-3.040E+03	-3.20E+03	174	37	42	-2.720E+03	-2.88E+03
124	32	36	-1.280E+03	-1.44E+03	175	37	43	-9.600E+02	-1.28E+03
125	32	37	-3.680E+03	-3.84E+03	176	37	44	-3.520E+03	-3.68E+03
126	32	38	-1.760E+03	-1.92E+03	177	38	18	-9.600E+02	-1.28E+03
127	33	20	-1.120E+03	-1.28E+03	178	38	25	-3.680E+03	-3.84E+03
128	33	24	-1.440E+03	-1.60E+03	179	38	33	-9.600E+02	-1.28E+03
129	33	30	-3.680E+03	-3.84E+03	180	38	35	-3.200E+03	-3.36E+03
130	33	31	-8.000E+02	-1.12E+03	181	38	41	-2.560E+03	-2.72E+03
131	33	35	-2.080E+03	-2.24E+03	182	39	23	-8.000E+02	-1.12E+03
132	33	36	-3.200E+03	-3.36E+03	183	39	27	-2.560E+03	-2.72E+03
133	33	37	-3.680E+03	-3.84E+03	184	39	39	-3.840E+03	-4.00E+03
134	33	38	-2.720E+03	-2.88E+03	185	39	40	-1.600E+02	-4.80E+02
135	33	40	-1.600E+02	-4.80E+02	186	39	41	-3.680E+03	-3.84E+03
136	34	19	-1.120E+03	-1.28E+03	187	39	43	-3.840E+03	-4.00E+03
137	34	21	-3.200E+03	-3.36E+03	188	39	44	-1.760E+03	-1.92E+03
138	34	22	0.000E+00	0.00E+00	189	40	26	-2.400E+03	-2.56E+03
139	34	26	-1.440E+03	-1.60E+03	190	40	27	-2.080E+03	-2.24E+03
140	34	28	-1.440E+03	-1.60E+03	191	40	36	-3.360E+03	-3.52E+03
141	34	31	-1.920E+03	-2.08E+03	192	40	37	-1.280E+03	-1.44E+03
142	34	33	-1.920E+03	-2.08E+03	193	40	38	-3.040E+03	-3.20E+03
143	34	35	-1.600E+02	-4.80E+02	194	40	41	-3.680E+03	-3.84E+03
144	34	37	-9.600E+02	-1.28E+03	195	40	42	-4.000E+03	-3.84E+03
145	34	39	-2.560E+03	-2.72E+03	196	40	43	-3.680E+03	-3.84E+03
146	34	41	-2.720E+03	-2.88E+03	197	40	46	-3.200E+03	-3.36E+03
147	35	24	-4.800E+02	-8.00E+02	198	41	22	-3.200E+02	-6.40E+02
148	35	26	-1.920E+03	-2.08E+03	199	41	25	-2.880E+03	-3.04E+03
149	35	28	-3.840E+03	-4.00E+03	200	41	26	-1.440E+03	-1.60E+03
150	35	30	-3.840E+03	-4.00E+03	201	41	29	-1.600E+03	-1.76E+03
151	35	34	-1.600E+03	-1.76E+03	202	41	34	-3.520E+03	-3.68E+03
152	35	36	-2.560E+03	-2.72E+03	203	41	39	-1.120E+03	-1.28E+03
153	35	37	-4.800E+02	-8.00E+02	204	41	40	-2.560E+03	-2.72E+03
154	35	38	-1.120E+03	-1.28E+03	205	41	41	-2.400E+03	-2.56E+03
155	35	39	-1.760E+03	-1.92E+03	206	42	28	-3.200E+03	-3.36E+03
156	35	42	-3.040E+03	-3.20E+03	207	42	31	-2.400E+03	-2.56E+03
157	35	44	-3.680E+03	-3.84E+03	208	42	41	-1.280E+03	-1.44E+03
158	36	22	-9.600E+02	-1.28E+03	209	42	42	-2.560E+03	-2.72E+03
159	36	24	-2.720E+03	-2.88E+03	210	42	44	-4.000E+03	-3.84E+03

160	36	25	-3.680E+03	-3.84E+03	211	43	16	-1.600E+02	-4.80E+02
161	36	30	-2.720E+03	-2.88E+03	212	43	22	-3.200E+02	-6.40E+02
162	36	32	-8.000E+02	-1.12E+03	213	43	34	-3.200E+02	-6.40E+02
163	36	33	-2.880E+03	-3.04E+03	214	43	38	-4.000E+03	-3.84E+03
164	36	38	-9.600E+02	-1.28E+03	215	43	41	-2.560E+03	-2.72E+03
165	36	39	-3.840E+03	-4.00E+03	216	43	42	-3.680E+03	-3.84E+03
166	36	41	-9.600E+02	-1.28E+03	217	43	46	-3.360E+03	-3.52E+03
167	37	19	-1.920E+03	-2.08E+03	218	44	25	-1.920E+03	-2.08E+03
NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)		NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day)	
			GA	TS				GA	TS
219	44	27	-3.200E+02	-6.40E+02	271	51	47	-2.880E+03	-3.04E+03
220	44	29	-1.120E+03	-1.28E+03	272	51	49	-1.920E+03	-2.08E+03
221	44	36	-3.200E+02	-6.40E+02	273	51	52	0.000E+00	0.00E+00
222	44	39	-2.720E+03	-2.88E+03	274	52	25	-2.720E+03	-2.88E+03
223	44	42	-4.000E+03	-3.84E+03	275	52	27	-3.040E+03	-3.20E+03
224	44	44	-1.600E+03	-1.76E+03	276	52	39	-1.760E+03	-1.92E+03
225	45	24	-1.120E+03	-1.28E+03	277	52	41	-2.880E+03	-3.04E+03
226	45	31	-3.680E+03	-3.84E+03	278	52	43	-1.120E+03	-1.28E+03
227	45	33	-1.440E+03	-1.60E+03	279	52	46	-9.600E+02	-1.28E+03
228	45	36	-8.000E+02	-1.12E+03	280	52	51	-8.000E+02	-1.12E+03
229	45	45	-4.800E+02	-8.00E+02	281	53	36	-1.600E+02	-4.80E+02
230	46	23	-4.800E+02	-8.00E+02	282	53	37	-3.680E+03	-3.84E+03
231	46	26	-2.720E+03	-2.88E+03	283	53	42	-2.080E+03	-2.24E+03
232	46	28	-1.280E+03	-1.44E+03	284	53	48	-3.200E+03	-3.36E+03
233	46	38	-6.400E+02	-9.60E+02	285	53	52	-1.920E+03	-2.08E+03
234	46	41	-2.880E+03	-3.04E+03	286	54	22	-1.440E+03	-1.60E+03
235	46	43	-3.040E+03	-3.20E+03	287	54	32	-4.000E+03	-4.16E+03
236	46	47	-1.920E+03	-2.08E+03	288	54	46	-3.200E+03	-3.36E+03
237	46	50	-2.240E+03	-2.40E+03	289	54	48	-3.520E+03	-3.68E+03
238	47	30	-1.760E+03	-1.92E+03	290	54	50	-3.360E+03	-3.52E+03
239	47	33	-2.880E+03	-3.04E+03	291	55	24	-3.680E+03	-3.84E+03
240	47	37	-2.720E+03	-2.88E+03	292	55	30	-3.840E+03	-4.00E+03
241	47	45	-2.080E+03	-2.24E+03	293	55	37	-2.880E+03	-3.04E+03
242	47	49	-3.360E+03	-3.52E+03	294	55	40	-4.000E+03	-3.84E+03
243	48	30	-8.000E+02	-1.12E+03	295	55	51	-2.240E+03	-2.40E+03
244	48	35	-2.560E+03	-2.72E+03	296	56	28	-2.240E+03	-2.40E+03
245	48	40	-1.440E+03	-1.60E+03	297	56	42	-2.240E+03	-2.40E+03
246	48	42	-1.760E+03	-1.92E+03	298	56	45	-6.400E+02	-9.60E+02
247	48	46	-3.200E+03	-3.36E+03	299	56	47	-3.360E+03	-3.52E+03
248	48	49	-2.880E+03	-3.04E+03	300	56	53	-2.720E+03	-2.88E+03
249	49	26	-1.440E+03	-1.60E+03	301	57	37	-1.440E+03	-1.60E+03
250	49	32	-3.200E+03	-3.36E+03	302	57	49	-3.520E+03	-3.68E+03
251	49	35	-1.920E+03	-2.08E+03	327	63	53	-2.240E+03	-2.40E+03
252	49	43	-1.440E+03	-1.60E+03	328	63	58	-1.600E+02	-4.80E+02
253	49	46	-2.560E+03	-2.72E+03	329	64	56	-3.200E+03	-3.36E+03
254	49	47	-4.800E+02	-8.00E+02	330	64	58	-8.000E+02	-1.12E+03
255	49	48	-2.880E+03	-3.04E+03	331	65	58	-2.240E+03	-2.40E+03
256	49	49	-6.400E+02	-9.60E+02	332	65	60	-3.200E+02	-6.40E+02
257	49	51	-9.600E+02	-1.28E+03	333	65	61	-4.000E+03	-3.84E+03
258	50	29	-1.280E+03	-1.44E+03	334	66	50	-2.240E+03	-2.40E+03
259	50	33	-1.440E+03	-1.60E+03	335	66	56	-9.600E+02	-1.28E+03
260	50	37	-6.400E+02	-9.60E+02	336	67	53	-1.440E+03	-1.60E+03
261	50	39	-3.680E+03	-3.84E+03	337	67	58	-2.880E+03	-3.04E+03
262	50	41	-2.400E+03	-2.56E+03	338	68	61	-2.400E+03	-2.56E+03
263	50	45	-3.680E+03	-3.84E+03	339	69	58	-2.880E+03	-3.04E+03
264	50	47	-1.600E+03	-1.76E+03	340	70	63	-1.760E+03	-1.92E+03

NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day) GA	TS	NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day) GA	TS
265	50	48	-2.560E+03	-2.72E+03	341	70	65	0.000E+00	0.00E+00
266	50	49	-1.600E+03	-1.76E+03	342	70	68	-2.240E+03	-2.40E+03
267	51	21	-8.000E+02	-1.12E+03	343	71	59	-1.760E+03	-1.92E+03
268	51	32	-3.360E+03	-3.52E+03	344	71	60	-1.600E+03	-1.76E+03
269	51	44	-2.400E+03	-2.56E+03	345	72	62	-2.720E+03	-2.88E+03
270	51	46	-2.080E+03	-2.24E+03	346	73	65	-1.600E+03	-1.76E+03
NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day) GA	TS	NO.	Row (i)	Column(j)	Optimal pumping rate (m^3/day) GA	TS
347	73	67	-3.200E+03	-3.36E+03	349	75	69	-3.520E+03	-3.68E+03
348	75	68	-2.720E+03	-2.88E+03	350	75	71	-3.200E+02	-6.40E+02

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