HYDROGEOLOGICAL EVALUATION AND MANAGEMENT OF SARVESTAN BASIN, BY UNGW MODEL

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Abstract

The alluvial plain of Sarvestan bears the sole source of potable water in Sarvestan county, Fars Province, Iran. In recent years, due to extended heavy pumping, the groundwater storage has been reduced continuously. The UNGWM (United Nation Ground Water Model) is used to evaluate the hydraulic characteristics of the Sarvestan aquifer and its future response to various regimes of recharge and discharge. The model is a finite difference solution of differential equations for the two-dimensional, isotropic, nonhomogeneous transient flow of water in a porous medium. The aquifer parameters are determined through a combination of visual and rational comparison of simulated and observed groundwater contour maps while adjusting the aquifer boundary inflow-outflow rates at the aquifer recovery period. To validate the parameter values several simulated isopotential maps are compared with observed ones by optimizing the infiltrated rainfall rate into the aquifer. Using the established parameters values, boundary inflow-outflow rates and infiltrated rainfall rate, the annual well hydrographs were simulated. A very good match was found between simulated and observed hydrographs in terms of trend, fluctuations and values. The response of the aquifer to some dictated regimes of discharge and recharge was predicted. The critical zones where pumpage must be prevented are specified and the location of production wells to be drilled in the future is also defined. The UNGWM is validated as a valuable tool for groundwater resource assessment.

Introduction

The alluvial plain of Sarvestan is located at 85km SE of Shiraz, Fars Province, Iran. It is the most important groundwater reservoir of the region. This reservoir produces almost all the water used for agricultural purposes. Because of the overpumping of 446 production wells, in recent years the ground water storage has been reduced continuously. The rate of the water table decline ranges from 0.2 to 0.5 meter per year [3].

Keywords: Groundwater; Evaluation; Management; Modeling

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In this study, the United Nation Ground Water Model (UNGWM) is employed to evaluate hydrogeological parameters of the Sarvestan aquifer, and also manage and predict its response to various dictated regimes of recharge and discharge which may be practiced in the future.

The United Nations Ground Water Model (UNGWM)

The UNGWM (1989) was created by J. Karanjac and D. Braticevic under a Special Service Agreement with the Water Resources Branch of the United Nations, Department of Economic and Social Development (UN/DESD), formerly the Department of Technical Co-operation for Development (UN/DTCD). The program has been tested, used, expanded and improved under a United Nations Development Program (UNDP) project in Nepal and executed by UN/DTCD. Version one of this software was released in two volumes. The second volume, "Ground Water Mathematical Models" includes finite-difference Models for confined and unconfined aquifers and a small island. The model for unconfined aquifer is used in this work. This model is developed by super-imposing an equidistance finite-difference grid upon the map of an aquifer. The program code written in FORTRAN 77 language and compiled with Ryan McFarland Corporation's Fortran compiler is based on differential equation for the two-dimensional isotropic, nonhomogeneous, transient flow of the compressible fluid in a porous medium, that is:

$$\frac{\partial}{\partial x}\left(Kh\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kh\frac{\partial h}{\partial y}\right)=S_y\frac{\partial h}{\partial t}+W \qquad (1)$$

where K is hydraulic conductivity (LT^{-1}), h is the head (L), S_y is specific yield (L^{-1}), t is time (T), W is source/sink (L^3T^{-1}), and x and y are rectangular coordinates.

A numerical solution of Equation 1 through an iterative, ADIP (alternating direction implicit procedure) finite difference approach results to:

$$u_{i+1,j}^{n+1}+u_{i-1,j}^{n+1}+u_{i,j-1}^{n+1}+u_{i,j+1}^{n+1}+\left(-4-\frac{a^2S_y}{K_{i,j}\sqrt{u_{i,j}^{n}\Delta t}}\right)u_{i,j}^{n+1}$$
$$=-\left(\frac{a^2S_y}{K_{i,j}\sqrt{u_{i,j}^{n}\Delta t}}\right)u_{i,j}^{n}+\frac{2a^2W_{i,j}}{K_{i,j}} \qquad (2)$$

where $u=h^2, a=\Delta x=\Delta y$, n is the time step and i and j are row and column index. The ADIP solution of the program code is a modification of an early Prickett and Lonnquist model [4].

The general input data to the model include the number of columns and rows in the finite element mesh superimposed over the map of the aquifer, length of one cell, number of cells, length and number of time steps, maximum number of iteration, convergence criterion, number of cells in which well hydrograph data is stored. The distributed input data required to run the model include: a) land surface and bottom aquifer elevation, b) measured initial water level at peizometers, c) recharge from infiltrated rainfall in each cell, d) evaporation data, f) pumping cells and their locations, h) constant-boundary inflow and outflow nodes, and i) permeability, storage coefficient, and transmisivity of the aquifer.

Geological Setting

Sarvestan plain, with an approximate surface area of 800 km^2, is located southeast of Shiraz (52°50′ to 52°30′ *E*, 29°0′ to 29°5′ *N*). Mount Ahmadi, with a maximum height of 2,470 m, and Maharlu lake, with an altitude of 1,460 m, represent the highest and lowest points of the plain. The main geological features are presented in Figure 1. It can be seen that Sarvestan plain is surrounded by three major anticlines, namely Ahmadi to the north, Panal to the east and Gar to the south and southwest. The exposed geological formations; in decreasing order of age, consist of Sarvak limestone, Pabdeh-Gurpi shales and marls, Sachun gypsiferous marls, Asmari-Jahrum limestone and dolomite, Razak evaporites, Aghajari sandstone, and Bakhtiari conglomerates. The detailed lithology of these formations is described by James and Wynd [1]. In addition to the above-mentioned formations, two prominent salt domes of Infracambrian age (Hormoz series) also protrude in the northeast and southeast of the plain. The exposed domes are predominantly made of halite with some minor quantities of gypsum and other evaporitic minerals.

Tectonically, the area falls in zone three (simply folded belt) of the Zagros Orogeny [2], and the overall trend of the surrounding anticlines follows the general NW-SE trend of the Zagros Orogeny. Four major faults occur in the region, one in the east (Nazarabad fault), one in the south and southwest (Mount Gar Fault), and two parallel faults in the north (Mount Ahmadi Faults). Of these, Nazarabad Fault has resulted in the exposure of Mount Panal Core (comprising Sarvak, Gurpi and Tarbur Formation, in ascending order). The occurrence of the aforementioned salt domes on the Nazarabad Fault line is also noticeable. Mount Gar and Mount Ahmadi Faults have also played a significant role in exposing the core of their respective anticlines. Ghale Gorikhte synclinal high, composed of Bakhtiari conglomerate and left over by differential erosion in the northwest of the plain, is the last structural feature of interest to be noted in the area.

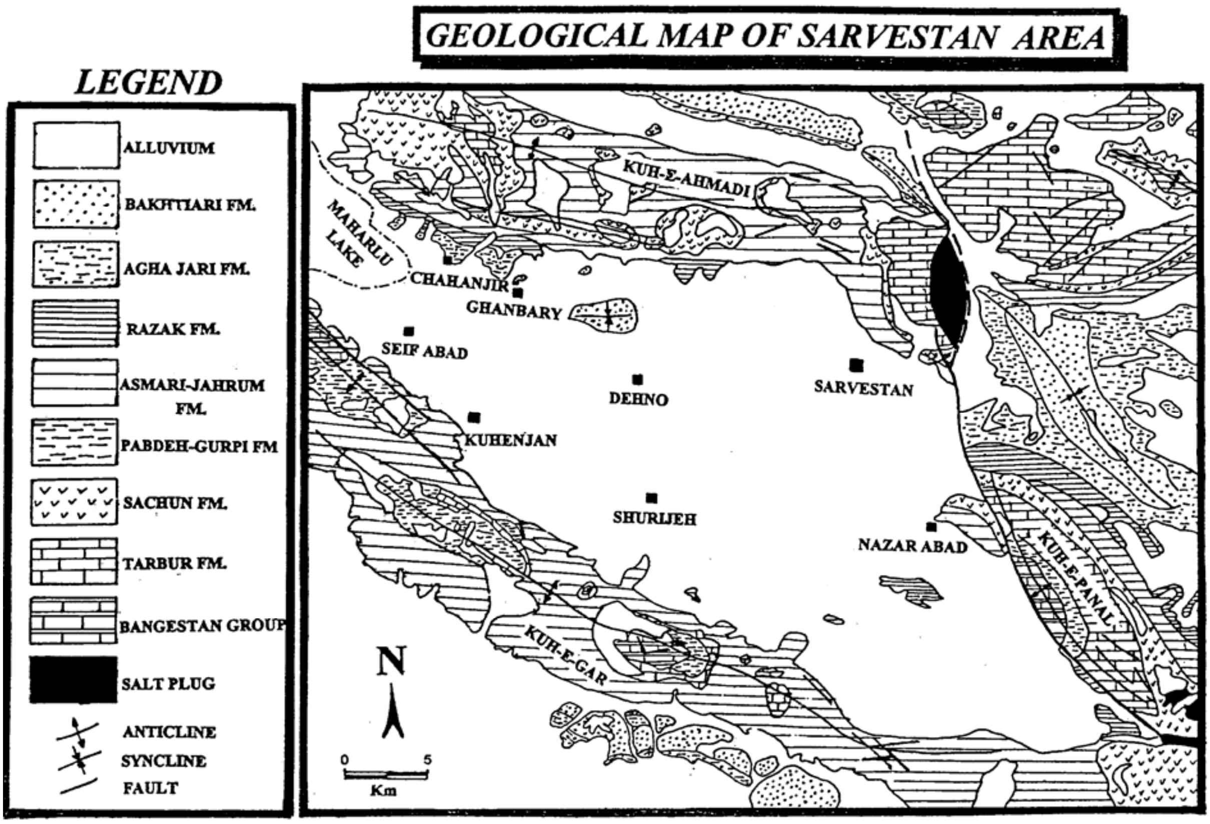

Figure 1. Geological map of the study area (after Raeisi and Moore, 1993).

Lithologically, Sarvestan aquifer is made of a Quaternary alluvium that consists of medium to fine-grained clastic material brought about by stream and flood wash of the surrounding geological units. Several alluvial fans of varying size and lithology are also seen to occur at the foot of the surrounding mountains. Two studied fans in the vicinity of Ghanbary and to the north of Chah Anjir (Fig. 1) were found to consist of coarse-grained erosion products of Asmari and Aghajari Formations, along with some fine-grained material of similar lithology (Raeisi and Moore 1993).

Hydrology and Hydrogeology

The climate of region is semi-arid. The average annual precipitation over the plain is 250 mm. The rain falls during six months of the year from December to May. The infiltrated rainfall is less than 20% because of fine grained soil surface texture [3].

The catchment of Sarvestan has no perennial stream, but temporary flood ways joining the Nazarabad flood way drain seasonal floods into the Maharlu lake. These drains originate from alluvial fans in highlands around the plain.

About 82.2%, 17.4% and 0.4% of pumping water through shallow and deep wells were being used for agricultural, domestic, and industrial purposes, respectively [3]. The pumping season extends from April to September in any water year.

The isopotential map of Sarvestan aquifer is presented in Figure 2. This map was prepared by plotting the water table elevation at 32 observation wells measured in December 1992. This map clearly indicates that the general direction of flow is downdip from southeast to northwest. Toward the northwest of the plane, that is to the south of Ghale Gorikhte, the overall direction of flow breaks into two separate components of flow, moving to the south and north of the main flow, respectively. It is believed that this separation of flow is artificially produced by the extensive pumping of production wells unevenly concentrated along the northern and southern border of the aquifer [5].

In the next section the isopotential map and geological data are used to allocate the aquifer inflow-outflow boundaries.

Application of the UNGWM to Sarvestan Aquifer

Figure 3 is the finite difference mesh superimposed upon the map of the aquifer. The area of each cell is 1 square kilometer. The total number of cells failing within the aquifer boundaries are 480, thus the modeling

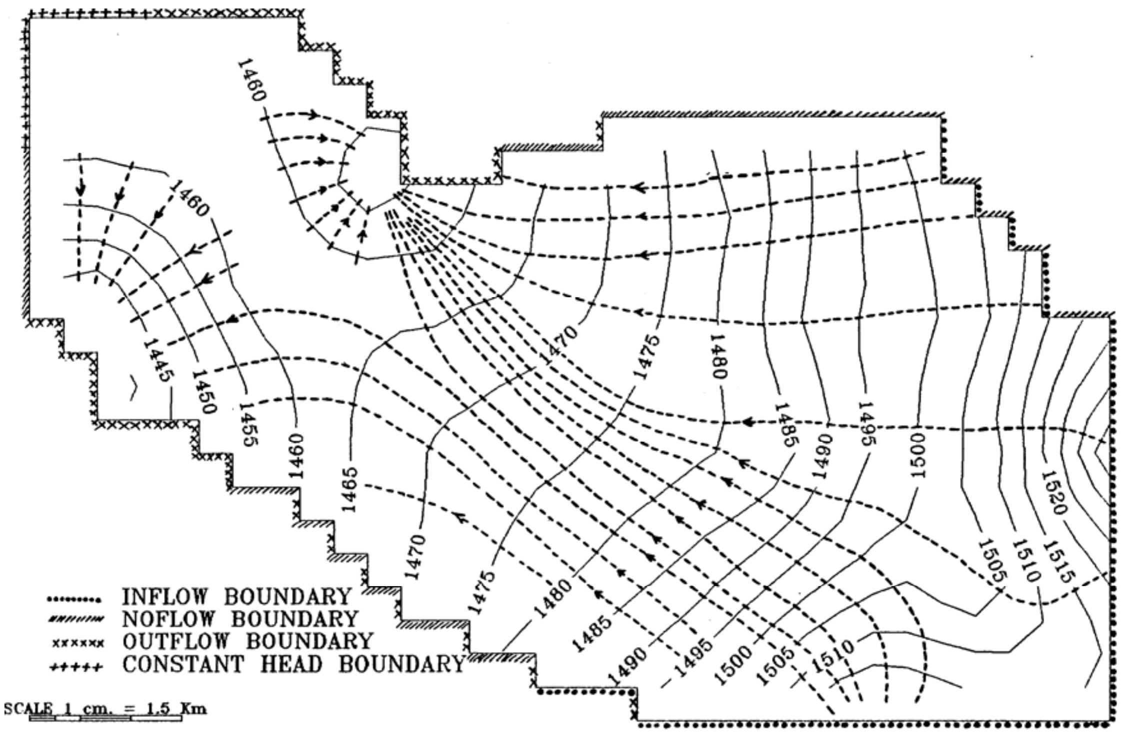

Figure 2. Isopotential map and aquifer boundaries.

area is 480 km^2.

The elevation of aquifer bottom or aquifer bed rock was determined by the NIOC geological map, its cross sections together with the logs of observation wells and also the available data from two deep exploration wells drilled in the vicinity of the town, Sarvestan and the village of Kuhenjan. The land surface elevation within the modeled area estimated from the 1:50,000 topographic map of Sarvestan.

Considering the discharge/recharge regime of the aquifer in a water year, December is the first month of recovery period when pumping wells are switched off and infiltration from rainfall or irrigated return flow is zero. As a result, it seems logical to use the isopotential map of December (Figure 2) as the target for simulation of the water table map by the model.

The evaporation rate from the water table depth is less than 2 m is assumed to be 0.003 m/day [3].

No pumping test has been conducted to evaluate the hydraulic conductivity and specific yield of the aquifer. Therefore, the logs of observation wells are used to estimate the values of these parameters. The values are corrected in the course of model calibration by improving the match between observed and simulated well hydrographs.

Based on water table maps and patterns of flow lines together with geological evidence (Figs. 1 and 2), various types of boundaries are assigned to limit the aquifer. The boundary of modeled area where flow lines originate is selected as an inflow boundary. An outflow boundary is assigned where the flow lines converge. The boundary parallel to the flow lines is assigned as a no flow boundary. At the boundary between the plain and the Maharlu lake a constant head boundary is allocated. These boundaries are shown in Figure 2. Some approximate values of inflow and outflow rates were supposed for each boundary and optimized in the calibration stage. Due to the lack of accurate data on pumping rate, the discharge rate of production wells were estimated and optimized. Similarly the percentage of rainfall infiltrated into the aquifer is also optimized.

Model Calibration

Model calibration involves selecting a set of aquifer parameters and boundary conditions to get a good match between observed and simulated isopotential maps. The average value of head differences in observation wells is another match criterion. To control the process of calibration the following terminology is used:

RUN: one computer process from start to the termination.

ITERATION: calculation of heads in all columns and rows of the model once.

ERROR: the user assigned convergence criterion, also the maximum allowable sum of the absolute values of the differences between calculated ($h^c_{i,j}$) and

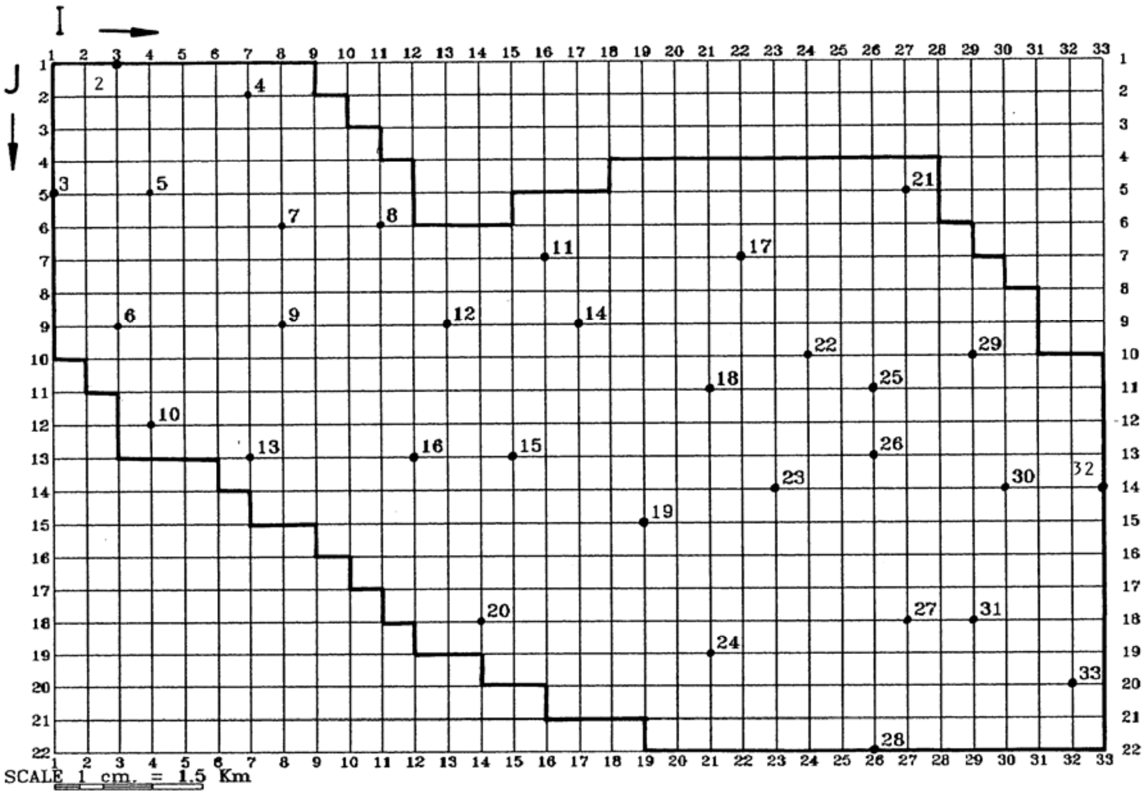

Figure 3. Finite difference grid superimposed over the map of the aquifer and location of piezometers.

observed ($h^o_{i,j}$) head at all $n \times m$ nodes during an iteration, that is:

$$ERROR = \sum_{i=1}^{n} \sum_{j=1}^{m} \left| h^o_{i,j} - h^c_{i,j} \right| \quad (3)$$

One computer run will terminate in one of two ways, provided that the processing is not interrupted due to some error.

(1) If convergence of the solution is achieved within specified maximum permissible iterations (ITMAX). ITMAX is a parameter assigned by the user when prompted by the program. This is a normal termination, completely controlled by the user. In other words you have assigned a small ERROR value and the program solution has converged to acceptable accuracy.

(2) If the number of iterations is equal to ITMAX but the error in the solution is still greater than the ERROR criterion assigned by the user. For example, you may limit the number of iterations to 40, and give the value of 0.2 m to the convergence criterion ERROR. Yet the computer error at the end of 40th iteration is greater than 0.2 m, say 0.25 m. In this second case, the termination is the same as in the first one, and you have all options to print or view the output. Yet, the final error may not be acceptable. You have then two alternatives for he next run: a) to increase ITMAX and let the model's solution converge to less than ERROR, b) to modify model parameters (hydraulic conductivity, storage, boundary conditions, etc.) to eliminate some problematic assumptions.

Starting with a set of initial values of heads at grid points and using the isopotential map of December 1992 as a target the model was run under the steady state condition. The calibration process proceeded until the assigned value of ERROR was achieved. If the assigned ERROR value was reached but the visual match between simulated and observed isopotential maps (in terms of the contour lines pattern) was not acceptable, the graphical match between simulated and observed isopotential contours was manually used as the final calibration criterion. For this, K and Sy in some nodes and/or inflow-outflow rate from boundary nodes were adjusted and the process was repeated again. The result of this process is shown in Figures 4 and 5. The average absolute errors in heads are 14.83 m and 0.76 m in the first and the last run respectively.

At the end of calibration process the hydraulic conductivity, specific yield, and inflow-outflow rates distribution were determined as they are shown in Figures 6 and 7 and Table 1. The hydraulic conductivity values are lower in the center of the plain and higher

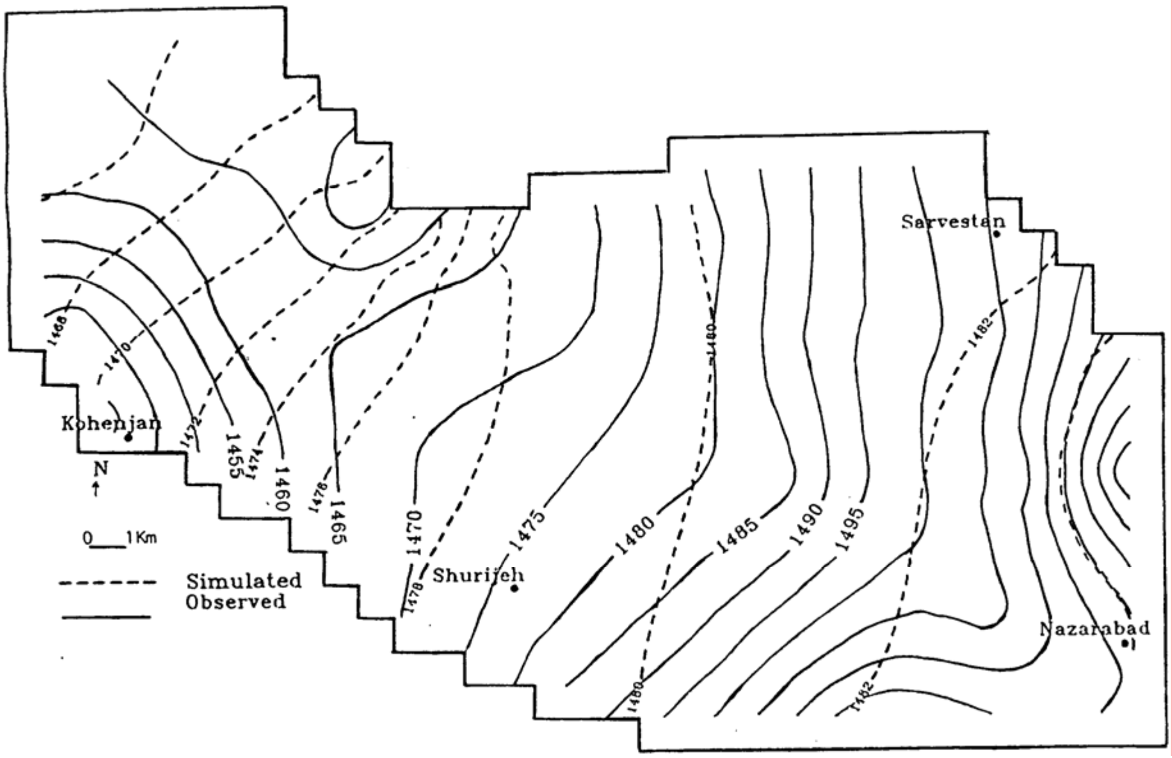

Figure 4. Calibration run no. 1 (steady state condition).

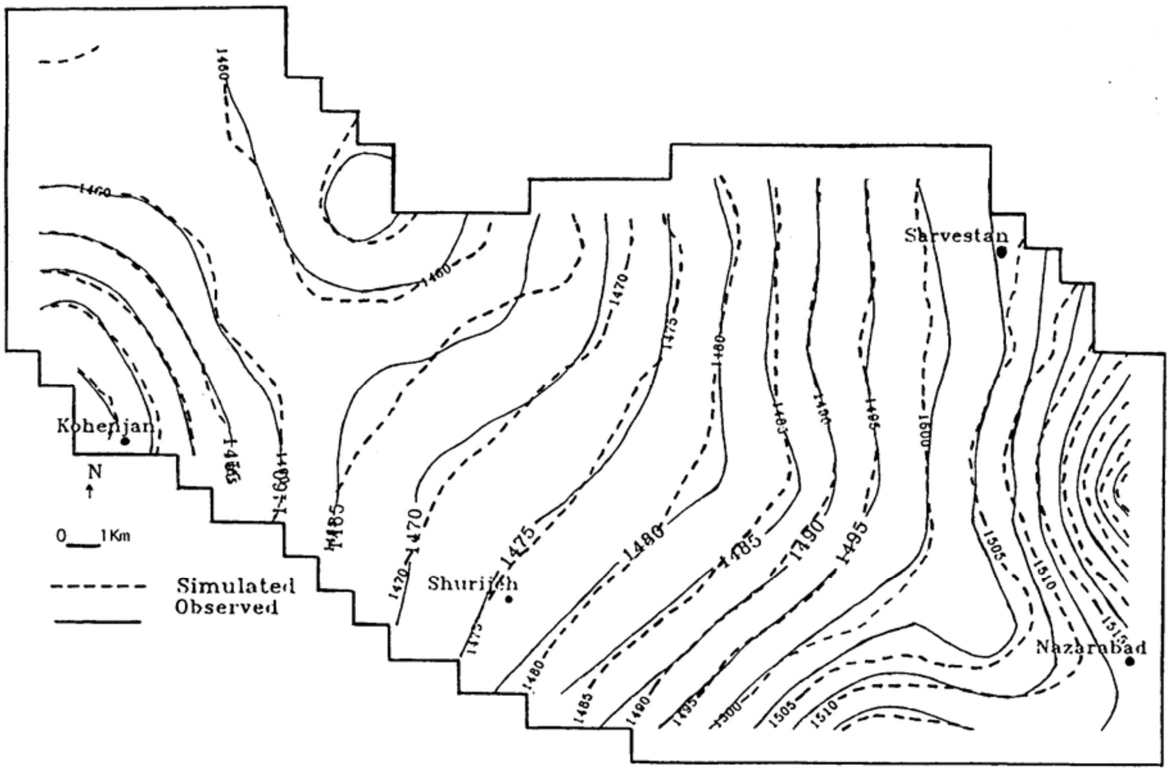

Figure 5. Calibration, final run (steady state condition).

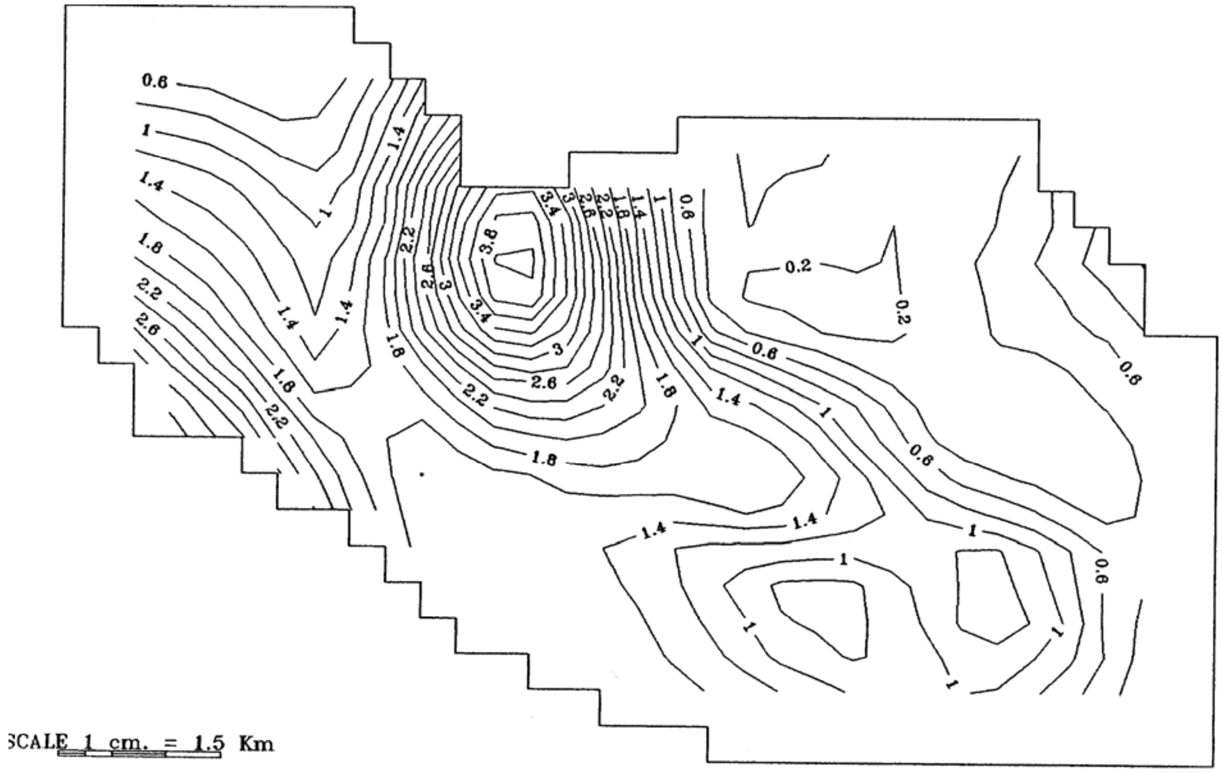

Figure 6. Hydraulic conductivity distribution map.

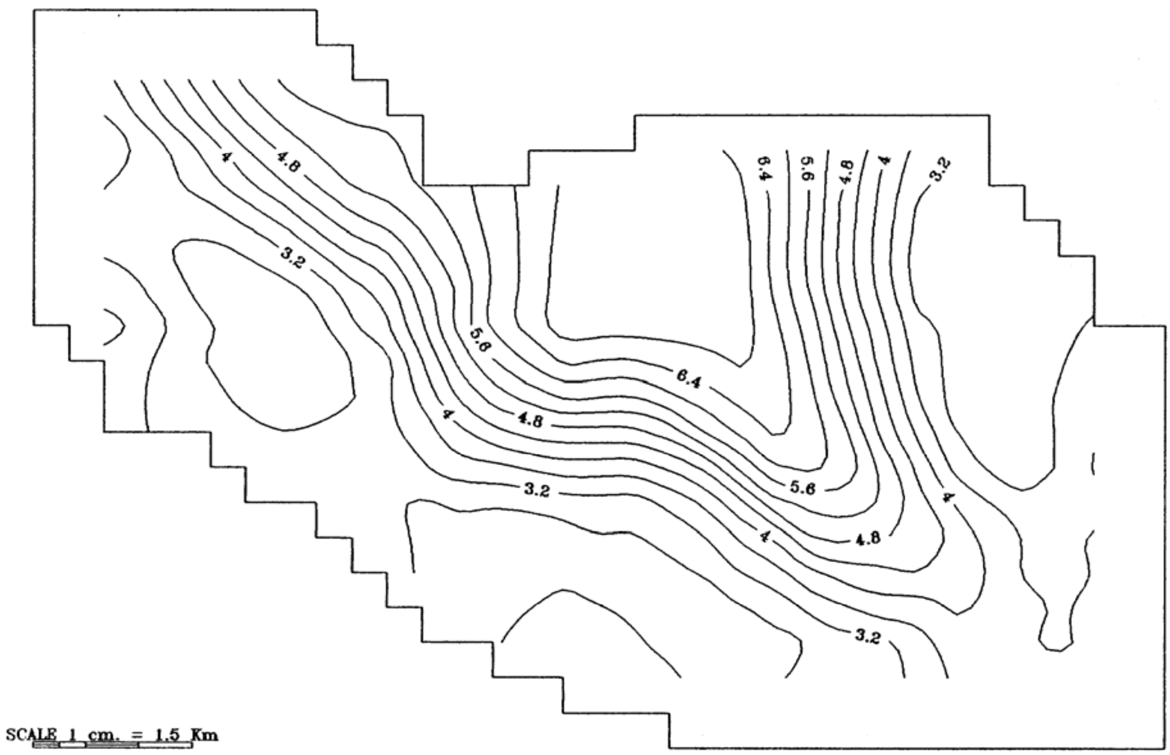

Figure 7. Specific yield distribution map.

Table 1. Rate of inflow-outflow from/to aquifer boundaries (– sign for inflow)

i	j	m^3/day/km	i	j	m^3/day/km	i	j	m^3/day/km	i	j	m^3/day/km
28	5	-19	33	20	-2	31	22	-2	1	8	310
28	6	-23	33	21	-2	32	22	-3	2	9	415
29	7	-13	33	22	-2	3	1	4	3	8	250
30	8	-30	17	20	-60	4	1	5	3	9	420
31	9	-27	18	20	-60	5	1	1.9	3	10	495
31	10	-28	19	20	-137	6	1	1.5	4	9	60
32	11	-9	20	20	-330	7	1	1.5	4	10	145
33	12	-11	21	21	-150	8	2	2	4	11	335
33	13	-31	22	21	-605	9	3	2	4	12	470
33	14	-580	23	22	-100	11	6	650	5	12	3
33	15	-10	24	22	-200	12	7	2010	7	13	400
33	16	-30	25	22	-520	13	7	570	8	14	70
33	17	-4	26	22	-960	14	7	600	9	14	50
33	18	-15	27	22	-510	15	7	410	10	15	200
33	19	-5	28	22	-230	21	5	1	11	16	100

near the boundaries. In the South of Ghale Gorikhte the K values are much higher than other parts of the plain that is probably due to coarse grained materials that are the erosion product of Bakhtiari conglomerate and Aghajary Sandstone. This point may also be observed in Figure 8 where the soil texture in well logs is consistence with the values of K.

The specific yield is higher near the northern border and lower near southeastern and southern parts of the plain. In the calibration period it was seen that the pattern of isopotential curves are effected mainly by permeability changes, but their values are effected mainly by changing inflow-outflow rates. The specific yield changes have negligible influence on isopotential curves.

The Accuracy of Aquifer Parameter Values

To evaluate the accuracy of K and Sy values established by the steady state runs, the model was executed under an unsteady condition without pumpage. The water table maps for January, February and March 1993 were simulated and compared with observed ones. As can be seen from Figure 9, the match for January is excellent. A similar match was achieved for February and March. The results of these tests verify the accuracy of established K and Sy values. In these runs the inflow and outflow from respective boundaries are assumed to be equal to those of December. In addition to that, the percent of rainfall infiltrated to the aquifer is manually changed and optimized to achieve the best match between observed and simulated head values in respective months. The infiltration rate measured by a double ring infiltrameter (in 17 locations), was used as the initial value for the process of optimization. The distribution of percent infiltrated rainfall resulted in the best match is given in Figure 10. It is low at the centre of the plain because of fine grained soil surface texture. In contrast, it is high near the boundaries where the alluvial fans have a coarse grained texture.

Annual Hydrographs

To simulate annual hydrographs of observation wells, the annual variations of discharge/recharge regime of the aquifer as inputs to the model has to be known. Recharge includes inflow from aquifer boundaries and infiltrated rainfall. Inflow from boundaries was optimized and determined in the course of steady state runs and listed in Table 1. The average rainfall infiltrated into the aquifer was also determined for the January to March period when rain falls over the plain, see Figure 10. Discharge includes pumping rate from production wells, outflow from and evaporation from the water table. Outflow from boundaries was already determined and it is assumed to be constant through out the water year (Table 1). Evaporation takes place with a rate of 0.003 m/day where the water table is high to a depth of 2 m or less.

Due to the lack of accurate information about the pumping rate of production wells simulated for various rate of pumping. At the best match between simulated and observed hydrographs an average pumping rate of 3 lit/sec was optimized for each production well for a pumping period which began in June and continued until September. Figure 11 presents the distribution of production wells in the Sarvestan plain together with the number of wells in each cell. As examples, the simulated and observed annual hydrographs of four observations wells are presented in Figure 12.

Aquifer Management Practices

To predict the future response of the Sarvestan aquifer to some dictated regimes of discharge and recharge, the following cases are considered:

1. The future aquifer response to present inflow-

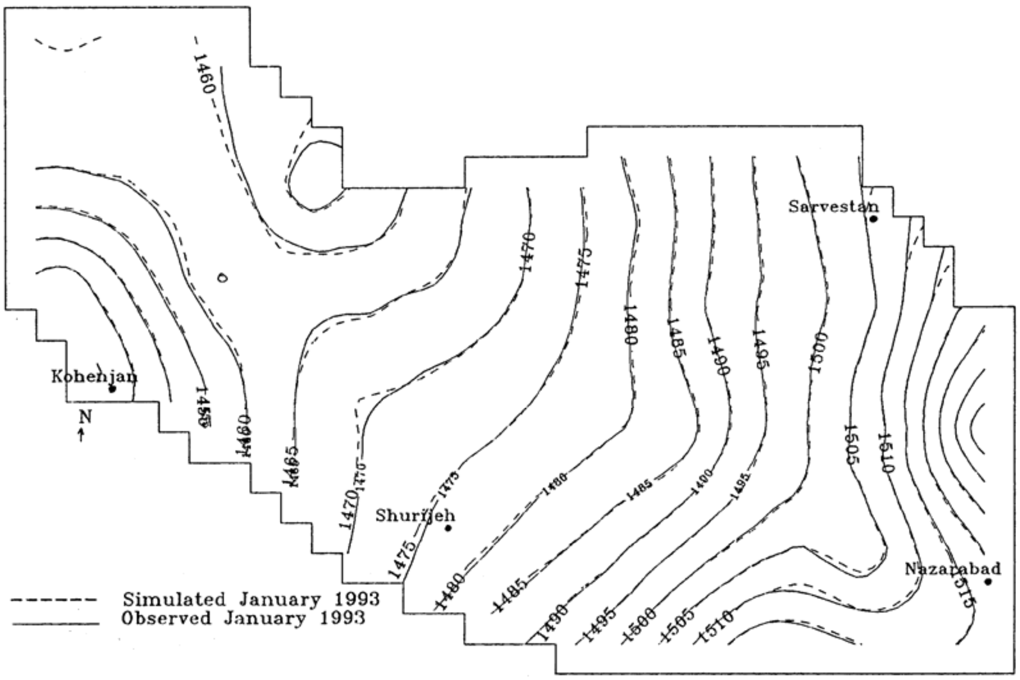

Figure 8. The unsteady state verified water table map.

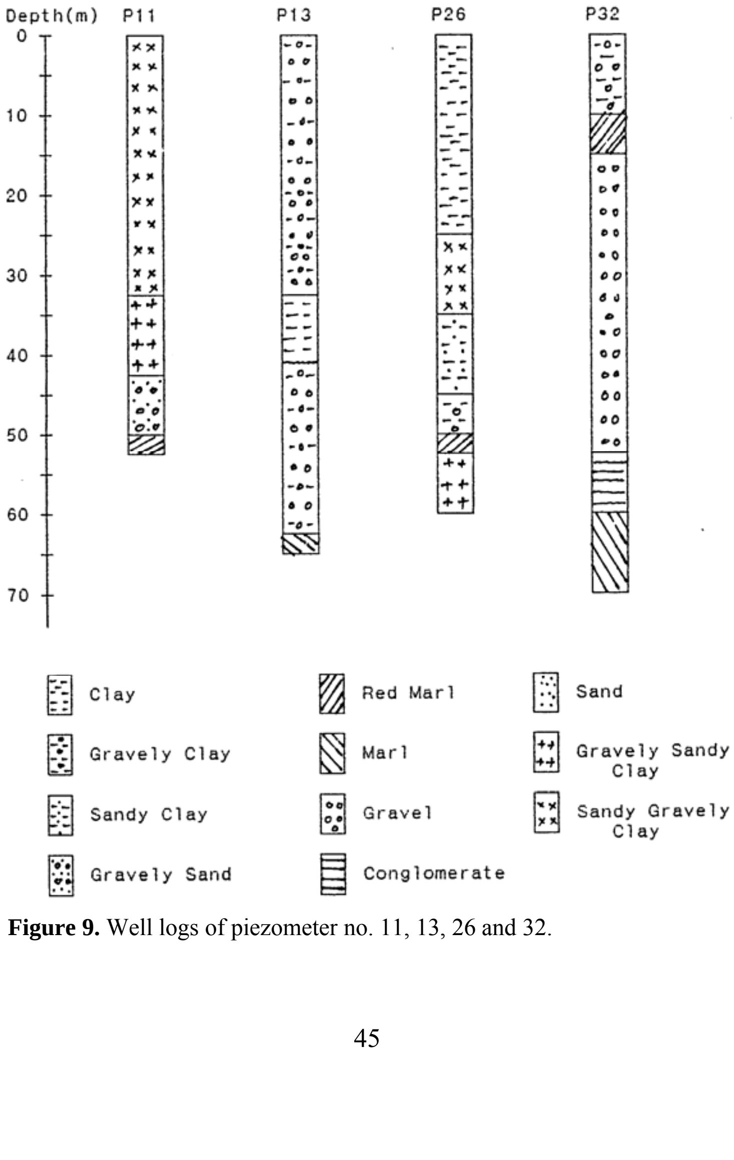

Figure 9. Well logs of piezometer no. 11, 13, 26 and 32.

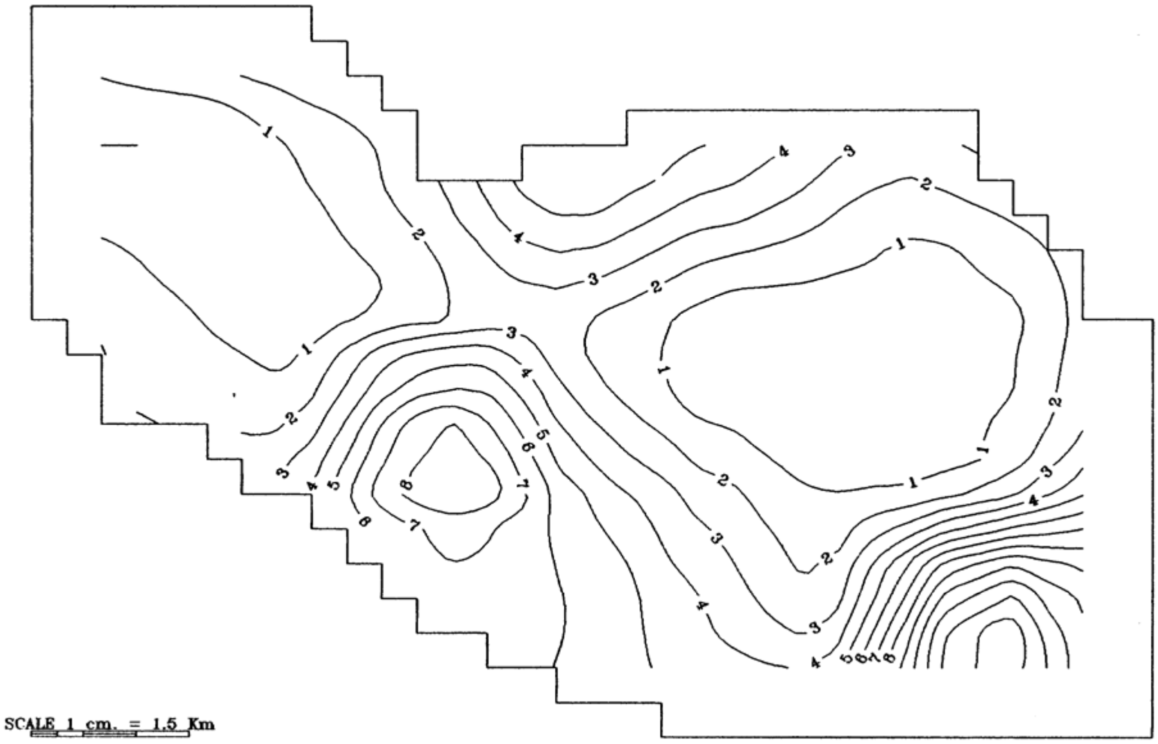

Figure 10. Percentage of infiltrated rainfall map.

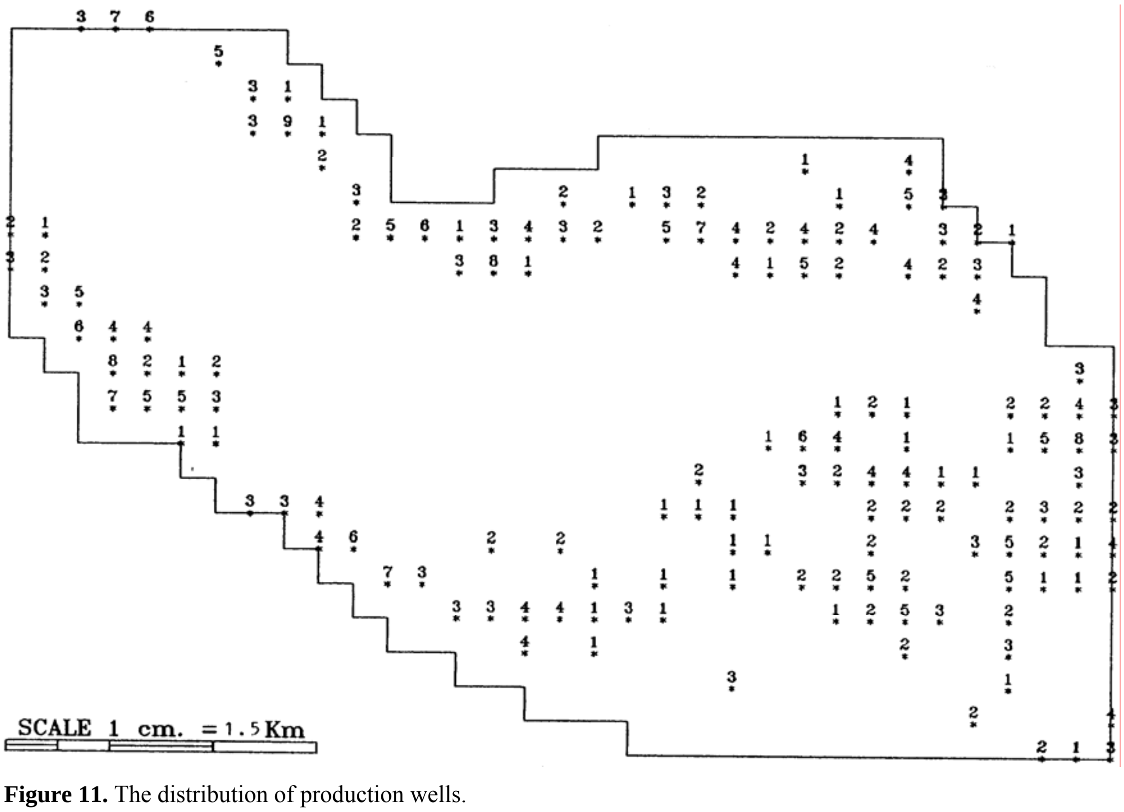

Figure 11. The distribution of production wells.

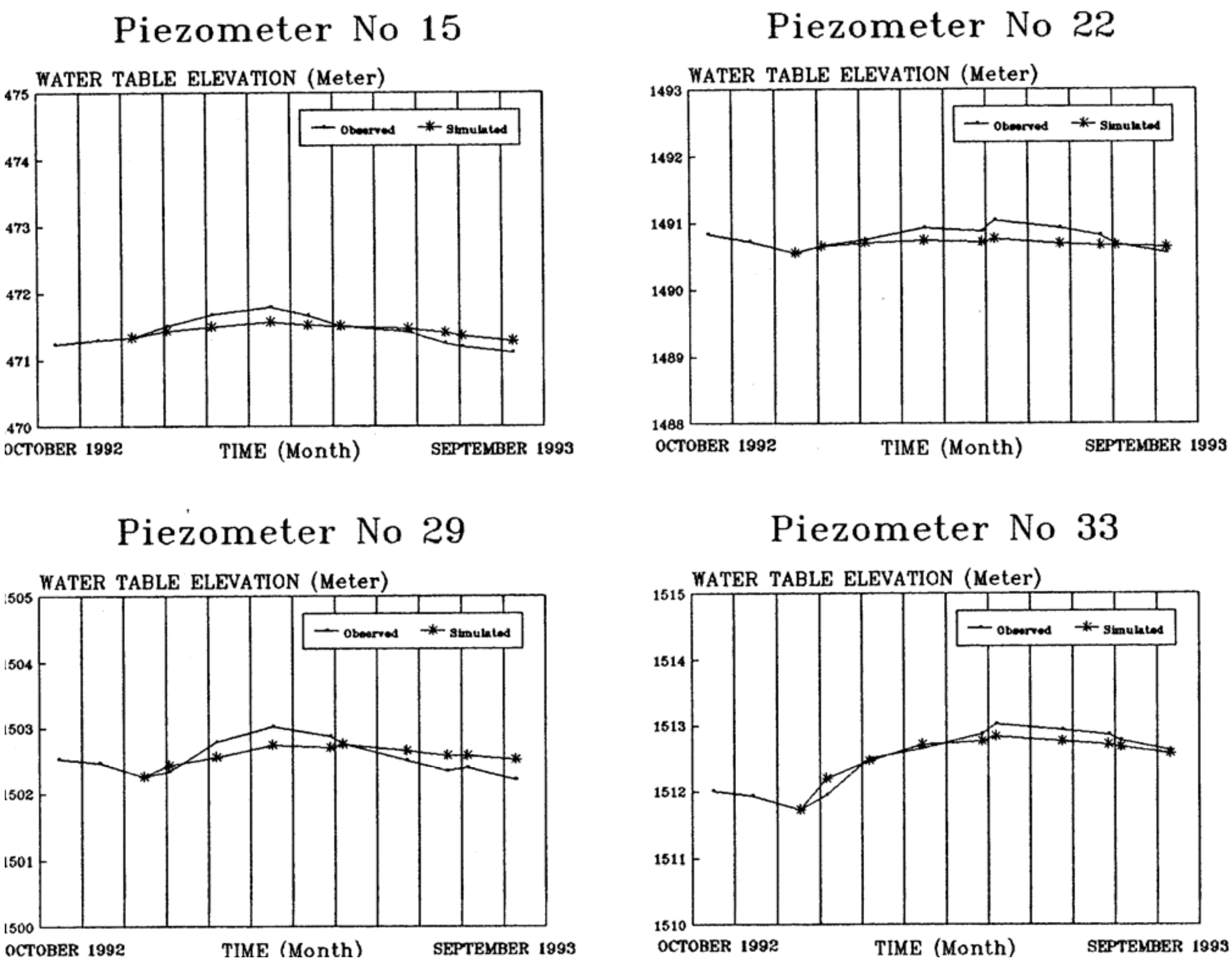

Figure 12. Annual observed and simulated well hydrographs.

outflow regimes,

2. The effect of decreasing pumpage in the NW of the aquifer,

3. The effect of artificial recharge in the NW of the plain, and

4. The effect of increasing number of production wells.

In a five year forecasting period that is from October 1993 to September 1998, it is assumed that the monthly precipitation, evaporation from water table and the inflow-outflow from aquifer boundaries are the same as those of 1991-1992. The water table decline in the first case was found to be 5.0 m, the critical zones (Figure 13) where pumpage must be prevented is specified and the location of production wells to be drilled in future is also defined. The artificial recharge was effective well near the centre of the plain, but further to the right a lower rate of drawdown was observed.

Conclusion

The UNGWM has been validated for the Sarvestan aquifer. The model calibration is conducted through a combination of visual and rational querying. The distribution of aquifer parameters is determined by comparison of simulated and observed water table maps, while adjusting aquifer boundary inflow-outflow rates. The aquifer parameter values are validated for several water table maps associated with the aquifer recovery period when pumping wells are switched off and infiltrated rainfall is optimized in the course of model calibration. The distribution of optimized infiltrated rainfall rate coincides very well with the soil surface texture.

Utilizing the established aquifer parameter values, boundary inflow-outflow rates and infiltrated rainfall rate, the annual hydrographs for all observation wells are simulated and compared with observed ones. The

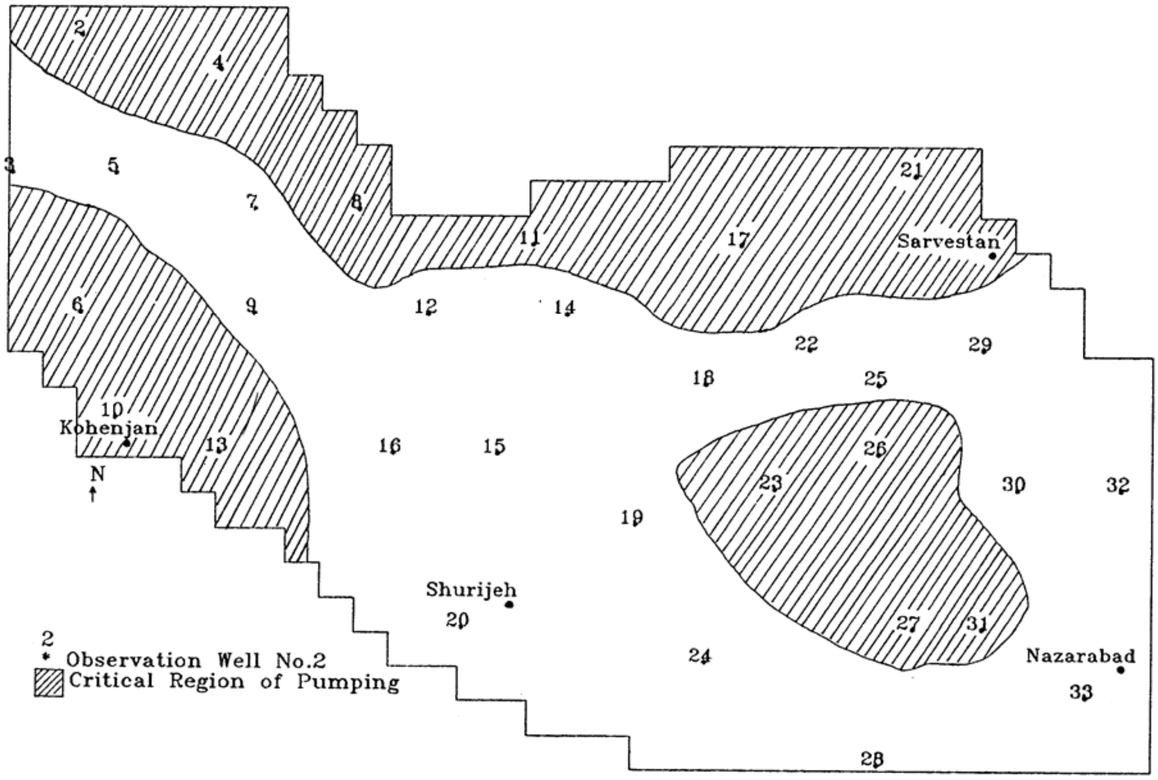

Figure 13. Critical zones of Pumpage.

best match was found at an optimized pumping rate of 3 lit/sec per production well.

The response of aquifer to some dictated regimes of recharge/discharge for a five year forecasting period was predicted. The critical zones where pumpage must be prevented were specified and the location of production wells to be drilled in future was also defined.

Finally it should be concluded that field measurements of K, Sy and boundary inflow-outflow rates are required to put further refinement on the hydraulic characteristics of the aquifer determined at various stages of model Calibration.

Acknowledgements

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