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Numerical simulation of groundwater level using MODFLOW software (A case study: Narmab watershed, Golestan province)

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ABSTRACT

To evaluate the effects of the current situation and future development on Source groundwater whether quantitative or qualitative point of view, simulation computer resources, a powerful tool in the optimal utilization of source is considered. Year recent several model of math and computer simulation of hydraulic behavior of underground water resources focus is located. Like making mathematical phenomenon hydraulic set of algebraic relations, differential and integral that the groundwater flow hydrodynamics and its relations with aquifer levels to show. In this study, like making Narmab aquifer located in Golestan province, using a mathematical model Visual Mudflow 3.1 was performed. Changes of water level data from 15 wells piezometer water table in the study area, were evaluated. Results with coefficient estimates 97 percent representation for all to month showed that the water level model with acceptable accuracy similar building and to model groundwater flow in the aquifer above the complex nature of her is. Predictedresults indicate that the probability of the next few years the water leveldrops in the aquifer, in the case of a large harvest process, will be verysevere.

Key Words: Simulation, Groundwater, Visual Mudflow, Aquifer

INTRODUCTION

Water is the lifeblood and has an important role in urban and rural comprehensive development. Rapid population growth in recent 20 years, development of agricultural and urban regions and limited surface water resources caused by excessive withdrawal of groundwater aquifers, have will result in irreparable damage to the natural resources of the country, especially in the coming years. Using computer models of groundwater has considerable progress as a cheap and fast method in the study of movement, balance evaluation and operational management of groundwater. Using mathematical models has started since

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1800 A.D. In consequence of developing advanced computers in the 1960s, using mathematical models with numerical solution has become an appropriate approach in the study of groundwater. Numerical solution of fluids flow problems in porous media was used in oil industry for the first time, before 1950 (Stalk, 1959; Mazrooei, 2003). Hybrid models were produced after 1972, and these models simulated saturated and non-saturated environments simultaneously. Among those who have developed such models Vaklyn, Khanji and Vakad can be mentioned. Since these models are complicated as well as resolving equations are time-consuming, the models were usable for small areas (Safari Moghadam & Mazrooei, 2003). A model that has great potential in the study of groundwater is 3D finite-difference model named MODFLOW which has been presented in 1998 has been applied by researchers in a wide range throughout the world. Abrishami et al. (1999) studied the quantitative modeling of groundwater in the wet of Tabas Desert. In this study, groundwater quantitative model of the region was calibrated and evaluated using advanced simulation system to estimate parameter of aquifer hydraulic conductivity and to simulate flow by automatic parameter estimation program of MODFLOW. Ahmadi (2001) used Visual MODFLOW V.2.6 to simulate groundwater flow and to identify aquifer hydrological system, to forecast the future status of the aquifer affected by tensions and to assess various management options including possibility of artificial recharge performance in Izeh plain. اماک et al. (2002)produced a 3D model for upper and middle Aquifer of Trinity located in Texas Hill Country with aim to identify hydrogeological system and to help estimation of the amount of water and water level fluctuations relative to pumping and future drought potential. They used the numerical model of MODFLOW 96. In this research, calibration for steady flow has been conducted for 1995 conditions as well as for unsteady flow the calibration has been done for 1996, 1997 conditions. Also using this model, the values of vertical hydraulic conductivity storage coefficient were calibrated for the aquifer. Water level in the model has shown the maximum sensitivity to recharge, horizontal hydraulic conductivity of the middle layer, and hydraulic conductivity of the upper layer. The results showed that, 20% of the aquifer recharges moves toward south (Edwards Aquifer). Kazemi (2002) calibrated a model based on related data in steady and unsteady state in Shirvan-Quchan plain using MODFLOW 2000. The results showed that, the effect of recharge by 50% of the water of Tabarakabad dam will have amoderating impact on groundwater level in order to supply fresh water of Quchan city. Dehghan (2000) accomplished simulation of groundwater flow and the management strategies for safe keeping aquifer in Shahr-e-Kord plain using Visual MODFLOW V5.2 and determined the suitable and critical areas considering water table by study of water table trend during several consecutive years in the mentioned plain. Mazrooei (2001) studied groundwater resources of Azarshahr plain using MODFLOW model then he presented the management strategies for optimum use of this aquifer. Shahsavari (2003) could determine the direction of groundwater movement in water deficiency periods using MODFLOW model as well as both GIS and RS technologies. Saeedifar (2004) conducted a hydraulic groundwater simulation in Yasouj plainas well as assessment of distribution and transport of contaminants in that using PMWIN software. In the first part of this research, information about springs and wells located in the aquifer of Yasouj plain considering ownership (public or private), type of well, depth and other hydraulic properties were collected and studied. Then with regard to hydraulic information of the springs and wells, it was attempted for hydraulic simulation of the aquifer using PMWIN software, and in the following, the aquifer parameters such as hydraulic conductivity coefficient (K) and aquifer specific yield coefficient (S_y). The results indicated a high consistency between calculated and observedhydraulic heads as well as positive annual groundwater balance in the plain, therefore it can be stated that, the plain has a potential for more groundwater extraction in the long-term. In the second part of this study, information about contaminant sources and groundwater quality in terms of physical, chemical and biological was briefly studied in Yasouj plain. Distribution and transport of contamination in Yasouj plain was simulated using PMWIN software. The results showed high influence of wet springs on the motion of particles (contaminants) and it can be very dangerous in the long-term. Shahabifard (2004) studied the effects of water withdrawal of the aquifer of Iranshahr plain on the base flow rate of Bampour River using MODFLOW model. Sadeghirad (2005) could study the use of aqueduct system to drop groundwater level in Shiraz plain. Chitsazan et al. (2005) studied the application of the mathematical model of MODFLOW in assessment of different options of water resources of Ramhormoz plain. Mathematical model of MODFLOW was studied and used as an efficient and cost-effective tool to assess various management options. At first, meteorological, hydrological, geological and hydrogeological data of the region have been collected and analyzed. After producing the conceptual model, required data were defined in various software packages of MODFLOW V then, model calibration has been confirmed by software code of PEST. Ultimately, various management choices including continuing current trend of withdrawal, aquifer development by digging new wells, the effects of drainages in drained areas and assessment of aquifer operation by water transport and irrigation have been used. Hence, the results of simulation have shown that, continuing current trend of withdrawal is not an acceptable option in terms of management while digging wells in eastern and central areas of the plain as well as drainages in south and north of the plain are suitable options to combined use of surface water and groundwater resources. Mozaffarizadeh et al. (2006) corrected the hydrodynamic coefficients of aquifer using finite-differences model (MODFLOW) and Kriging method. An effective method in the study of groundwater resources is to use numerical modeling. In this study, the aquifer of Getvand plain located in Shooshtar city was simulated using finite-differences numerical method and PMWIN3.5 software. One of the problems of this plain is inappropriate distribution of hydraulic conductivity (K) in the plain area. So firstly, hydraulic conductivity was interpolated using data of pumping tests of the region and by Kriging method and was entered the model with initial values in 7 zones. Then, using inverse modeling and comparison of groundwater levels in observation wells model response (model calibration), initial data of (K) were optimized and corrected. Salari (2007) studied the impact of dam constraucted on the aquifer of Ladiz plain and management of the mentioned aquifer by mathematical model of Visual MODFLOW premium 2.4, he also identified the best place and the most proper time to inject collected water behind the dam. He suggested constructing an artificial recharge pond to inject water to aquifer andMarch, April, May and June months as superior options. With regard to the presented contents and considering that, Golestan province is an agricultural hub and has high water consumption in agriculture also this province has a great talent for agricultural development if the water is supplied, and on the other hand, groundwater resourcesare the main water supply of many parts of the province, as well as almost its maximum capacity is used for various tasks, so it is necessary to control water table drop based on permitted level by conducting the study of groundwater variations and performing management conditions in order to prevent the major source of water not to be faced with serious risks.

MATERIALS AND METHODS

Geographic area and its features

The study area has been located in the north of Iran, Golestan province and in the middle part of Gorgan River watershed, on the left bank of the river and 120 km far from northeast of Gorgan city between northern latitudes of 37˚ 5′ to 37˚ 18′ and eastern longitudes of 55˚ 7′ and 55˚ 20′. This area forms a part of Gorgan River overhead. Its northern boundary is Qolitappeh River and Gorganrood as well as its northeastern boundary is Alborz highlands. The region also is restricted by اگریکال from the west. Khormaloo and Chehelchay Rivers are located in the study area. The study area is about 300 km^2. In terms of thermal, different parts of the study area are from semi-warm (Gonbad) to semi-cold (mountainous points). Totally, the region is temperate. Annula mean temperature in the area varies from

14˚C to 18˚C and its meaning is thermal equilibrium in the region. Generally, the mean total number of frost days during the year is about 30 days or one month. Coverage materials in the study area include alluvial terraces, debris slope, and remaining soils from erosion, loess and alluvial stream bed. Materials forming the riverbed alluvial deposits have a maximum thickness of 64.5 m consisting of fine and coarse layers which mostly include clay, silt, sand, gravel, rubble and boulders rarely. Figure(1) shows the location of the study area.

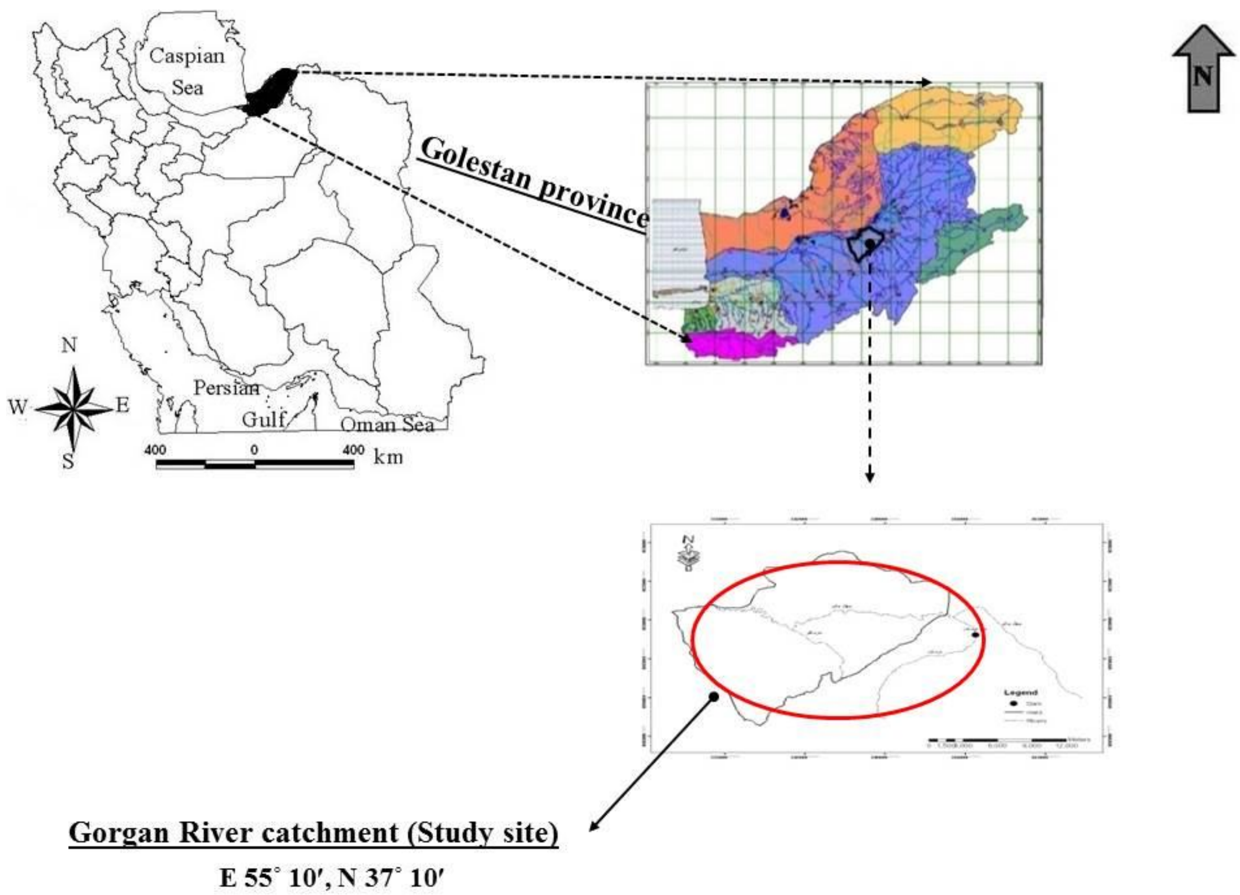

Figure 1: location of study area in the Golestan province, northeast of Iran

Aquifer characteristics

The study area is a part of Gorgan plain located in Golestan province with an area about 300 km^2 which is supposed as a one-layer free aquifer. Results of pumping tests of 15 wells which has done in the plain area, have presented the mean storage coefficient for the entire region by 3% which was modified in the calibration stage in this study. The amount of aquifer permeability varies from 0.5 to 3 meter per day. The depth of groundwater is different from 3m (minimum) to 21 m (maximum). Groundwater flow direction is southeast to northwest (report of the 2^{nd} stage of Narmab dam studies, 2002).

Research method

According to the area of the region and existence of Khormaloo and Chehelchay Rivers and their important role in recharging and discharging the aquifer and importantly, multiple inflows and outflows streams from the aquifer, the network has been considered 1000 m by 1000 m. some data such as Elevations (topography), statistics of the water level in piezometers, maps of portability, map of the depth of aquifer bed rock, discharge rate of the plain wells, the rivers flow, etc. were studied and confirmed and were applied to the flow model through following steps: Active and inactive cells were determined in the study area. Topography of ground surface was transferred to the model using topography maps of mapping organization of the country with scale of 1/25000 and after reviewing. In this region, the highest and lowest parts are located in the east and northwestern respectively. By having bedrock topography map and using Arc GIS Desktop software, the thickness of each cell was achieved. Mean of observed water tables in 15 piezometers in October 2003 (due to its minimum fluctuations) was considered as applied initial hydraulic head in the stream model in steady condition. Portability and hydraulic conductivity values of the aquifer were measured (meter per day) in some points by water organization experts. According to the experts' recommendation and the type of studied aquifer, the specific flow rate in the aquifer of Narmab plain has been considered 0.03. Geographic coordinates and observed water tables in 15 piezometers placed in the study area were applied. Calculation of underground inflows was carried out using portability and Darcy equation. According to produced statistics of tapping wells since 2003 in the study area, there are 54 wells which extract 32 million m^3 of groundwater resources per year. Achieved data entered the model. Water table of the rivers in the study area was determined using existing statistics also, using conductance coefficient (C), recharge of the riverbed was calculated and applied to the model. Stream model calibration in the study area was conducted using observed and simulated water table. After transporting data, the stream model was performed and then the model was calibrated using the results (simulated water table). Among input data of the model, hydraulic conductivity and specific flow have the highest importance and sensitivity in model calibration. The desired result was achieved after 20 implementations of flow model. Table (1) shows the location of observation wells.

General characteristics of Visual Modflow model

MODFLOW model has been presented to assess and modeling of groundwater flow in three dimensions by USGS institute. This model was produced by McDonald Herburg (1998) using programming language of Fortran 77. Programming structure of this software is modular which cause to adjust data entry and exit to the program and data exchange between its various parts. Also, modular structure makes it possible to develop the software significantly so that, since 1998 to date, this program has been evolving constantly.

The general equation applied in this software is as equation (1) which in fact is Richards's equation:

$$\frac{\partial}{\partial x}\left[K_{xx} b\frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial y}\left[K_{yy} b\frac{\partial h}{\partial y}\right] + \frac{\partial}{\partial z}\left[K_{zz} b\frac{\partial h}{\partial z}\right] - W = S_s\frac{\partial h}{\partial t} \quad (1)$$

Where, K_{xx}, K_{yy} and K_{zz} are hydraulic conductivity values in the directions of X, Y, Z. h is groundwater head, W is flow volumetric flux per unit volume (indicates the flow source and sink), S_s is aquifer specific storage and t is the time. Equation above along with appropriate initial and boundary conditions form an equation system by which resolving, h value is achieved in different times and places. Used discretization method in the software is finite-difference method which is supported by various options to resolve matrix equations (SIP, SOR, PCG2, LMG, WHS, and PCG4). Also various options have been placed in Modflow to simulate complexity of the aquifer such as heterogeneity in aquifer and relationship between groundwater and lake.

Table 1: location of wells

wells	UTMx	UTMy	altitude
Aghchi Bala	336294	4116387	555/0119
Nezem Abad	336936	4111512	588/87
Chay Boein - Gonbad	337161	4121557	538/635
Araz Mohamad Akhond	339150	4118275	549/882
Edareh Abe Gonbad	339662	4123694	540/368
Pashmak Toghtamesh	339818	4113891	576/181
Shargh Ghazalche Agh Emam	341596	4111453	595/019
Pashmak Panad	343808	4122114	554/049
Eymar Mohamd Gholi	344361	4127104	549/439
Mrajan Abad	345153	4124622	554/035
Baloch Abad	346321	4114234	566/729
Ghavitli	348752	4121359	576/305
Eyghdar Olia	350315	4124685	583/6
Ghalami	350535	4118137	590/012
Minodasht	354131	4121300	629/257

RESULTS AND DISCUSSION

Statistics of water table fluctuations were studied since 1991-1992 to 2008-2009. Considering that, in the year 2003-2004 a detailed inventory of water resources has been conducted and the most complete information compare with the other years so, this year was selected as the base year for modeling. After studying precipitation statistics of the year 2003-2004 it was found that, this year is a moderate year considering climate. In the steady state, the model time was considered one month (October) or 30 days.

In order to observe groundwater level variations, mathematical model was used. Application of mathematical models to simulate aquifers requires long period data and statistics as well as an accurate understanding of aquifers hydrodynamic properties. Is the information is available, using these models after calibration can effectively help planners and experts to evaluate aquifer potential, recharge study, increasing withdrawal or providing optimal operation model and future status of the aquifer.

Model calibration

In order to calibrate the model, the statistics of October 2003 to October 2004 were used. By having hydrodynamic coefficient and assumption of constant amount of pumping wells discharge, the model was calibrated and the amount of plain recharge was estimated. Recharge values was introduced to code PEST by the number of parameter and using recharge package and the initial guess. The results of calibration were shown in Figure (2) as comparison of calculated and observed water head in the observation wells. The results show that, the model has been able to adapt itself with the nature conditions by automatic calibration. Table (2) shows correlation coefficients between calculated and observed values.

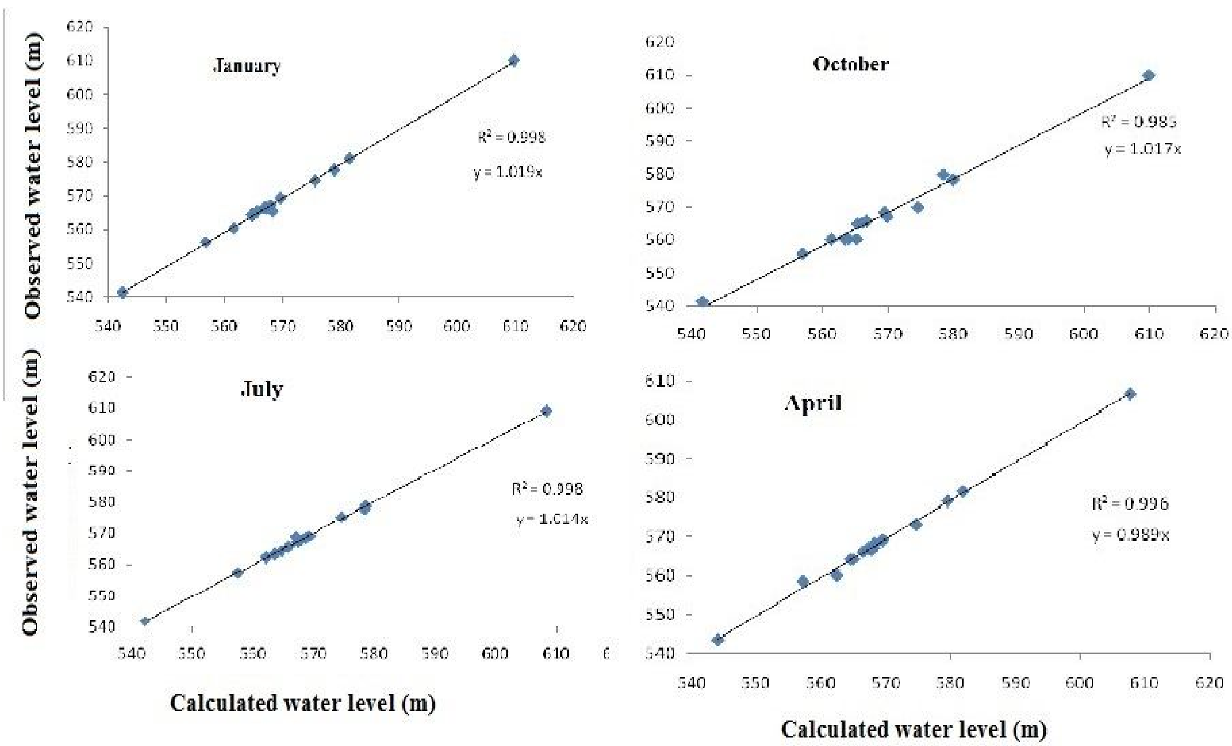

Figure 2. Comparative graph between observed water head values in the region and calculated water head values by the model

Table 2. Correlation coefficient between calculated and observed values

September	August	July	June	May	April	March	February	January	December	November	October	months
0.97	0.97	0.97	0.97	0.97	0.97	0.96	0.96	0.96	0.97	0.97	0.97	R^2

Validation

After calibration, validation of model determines the truth or falsity of applied parameters combination. In the stage of validation if the model is able to simulate the events of the period other than the calibration period so, the applied parameters combination is true. In order to study the truth or falsity of the model, the needed information layer a next year (October 2003 to October 2004) entered the model assuming that, changes in tension is as previous years. The results of forecasting water table variations in this year and their comparison with observed values in the wells have been shown in Table (3).

Sensitivity analysis

After adapting the developed model on the aquifer in steady and unsteady states, the model sensitivity to variation of the models affecting groundwater level, was studied and assessed. If the model sensitivity to the change of values of the parameters affecting the aquifer is high so, there is a need for more accurate measurement in the field. For this purpose the developed model sensitivity to the change of important parameters such as hydraulic conductivity (K), specific flow rate (Sy) and withdrawal flow rate (Q) was assessed. These two parameters were selected due to their maximum influence and uncertainty in modeling. Firstly, K, Sy and Q values were increased and decreased by 20%, 10% and 30% then, new values were entered the model and the model was performed according to the new values. By comparison of calculated groundwater level in the recent situation with measured values, the developed model sensitivity to the parameters above was studied. Figure (3), (4) show water table variations affected by changing parameters K, Q respectively, at the levels of 10%, 20% and 30%. The results showed that, the estimated K values in the study area is mostly consistent with natural conditions of the aquifer, also the model sensitivity to this parameter is low.Figures (5), (6) show the variations of water table affected by specific flow rate at the levels of 10%, 20% and 30% around piezometers 1, 13. The results showed that, the specific flow rate has not significantly affected groundwater level. So, it can be concluded that the estimated values of specific flow rate considering recommended flow rate by water organization experts in unsteady conditions is consistent with the real values of aquifer. A table 3, 4, 5 shows the Mean Square Errors (MSE) of calculated values relative to the measured values.

Table 3. Comparison of calculated and observed water table values at the end of validation stage

Percentage of water table difference	Observed water table (m)	Calculated water table (m)	X	Y	Well number
0/12	544/819	544/13	336294	4116387	1
0/15	584/44	583/52	336936	4111512	2
0/15	530/15	530/98	337161	4121557	3
0/17	542/28	541/34	339150	4118275	4
0/31	538/99	537/32	339662	4123694	5
0/01	566/35	566/26	339818	4113891	6
0/27	581/02	582/63	341596	4111453	7
0/11	544/42	545/04	343808	4122114	8
0/17	537/21	536/28	344361	4127104	9
0/34	548/1	546/19	345153	4124622	10
0/1	561/63	562/19	346321	4114234	11
0/25	569/48	568	348752	4121359	12
0/23	574/6	573/25	350315	4124685	13
0/02	581/89	581/77	350535	4118137	14
0/2	607/66	609/14	354131	4121300	15

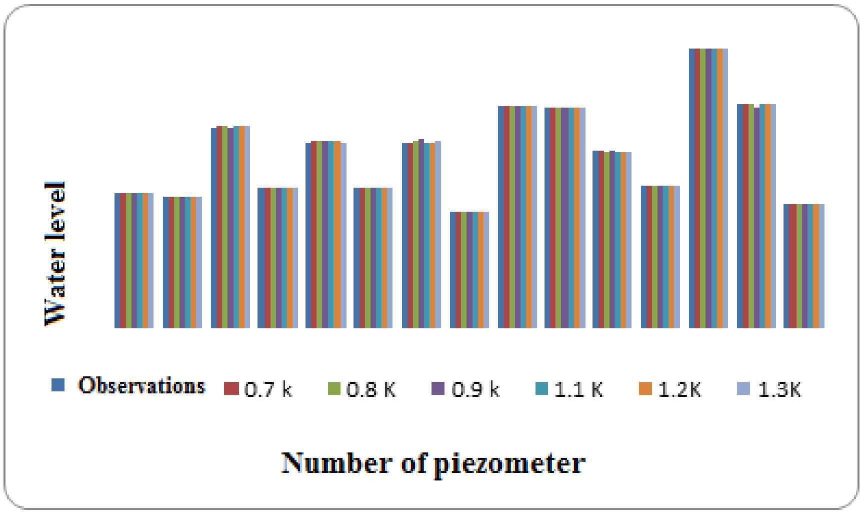

Figure 3. Groundwater level variations affected by change of parameter K at the levels of 10%, 20% and 30%

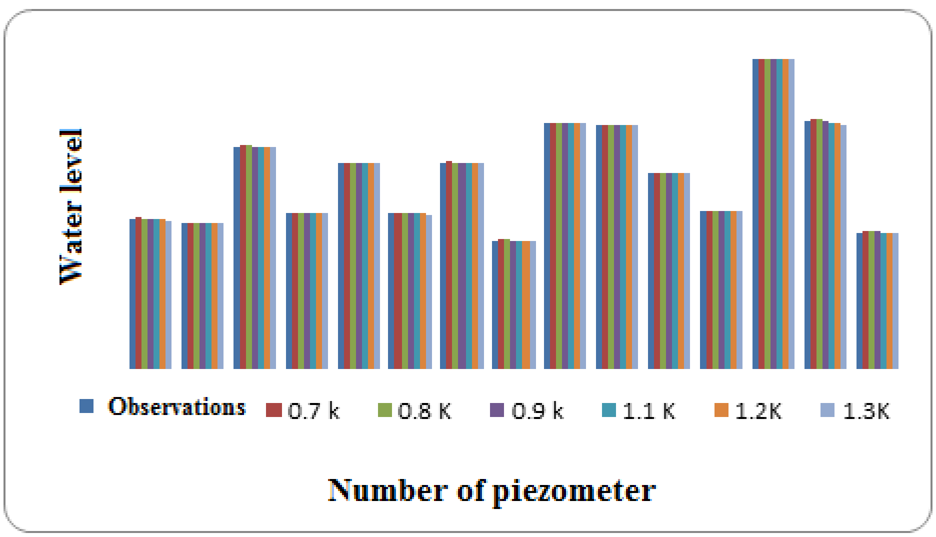

Figure 4. Groundwater level variations affected by change of parameter Q at the levels of 10%, 20% and 30%

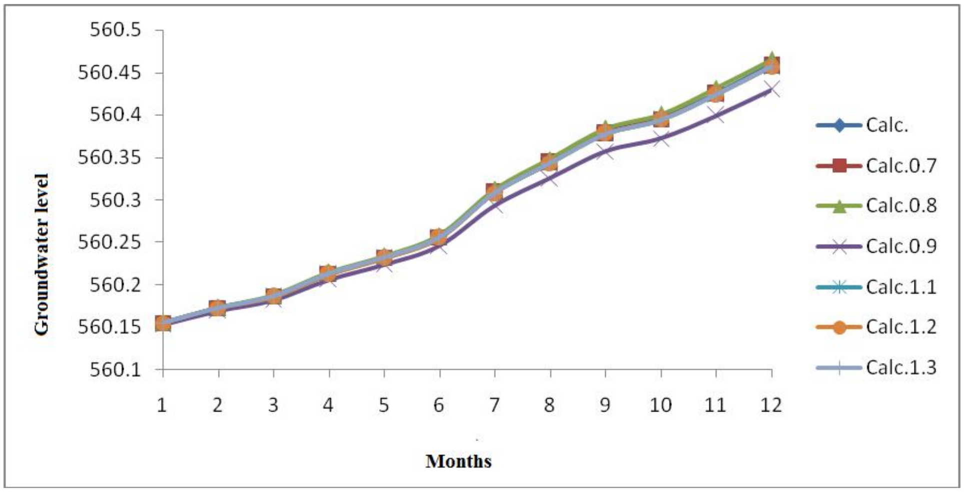

Figure 5. Groundwater level variations affected by change of specific flow rate at the levels of 10%, 20% and 30%, piezometer (1)

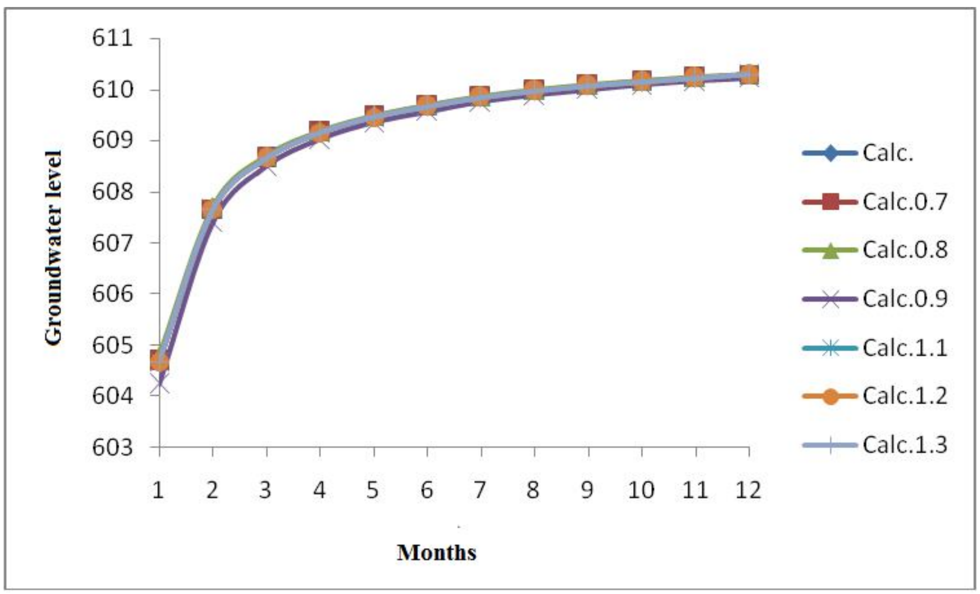

Figure 6. Groundwater level variations affected by change of specific flow rate at the levels of 10%, 20% and 30%, piezometer(13)

Table 4. Mean Square Errors (MSE) of calculated hydraulic conductivity coefficient values relative to the measured values

1.3 K	1.2 K	1.1 K	0.9 K	0.8 K	0.7 K	K value
0.15	0.11	0.12	1.7	0.17	0.29	MSE value

Table 5. Mean Square Errors (MSE) of calculated withdrawal flow rate values relative to the measured values

1.3Q	1.2Q	1.1Q	0.9Q	0.8Q	0.7Q	Q value
0.4	0.27	0.14	0.13	0.25	0.38	MSE value

Table 6. Mean Square Errors (MSE) of calculated specific flow rate values relative to the measured values

Sy value						Number of aquifer
1/3Sy	1/2 Sy	1/1 Sy	0/9 Sy	0/8 Sy	0/7 Sy	
0/001	0/002	0/002	0/017	0/003	0/001	1
0/001	0/001	0/001	0/016	0/003	0/001	2
0/063	0/065	0/075	0/825	0/132	0/048	3
0/034	0/035	0/04	0/459	0/07	0/026	4
0/024	0/024	0/028	0/302	0/05	0/018	5
0/001	0/001	0/001	0/016	0/003	0/001	6
0/001	0/001	0/001	0/016	0/002	0/001	7
0/003	0/003	0/003	0/035	0/005	0/002	8
0/008	0/008	0/009	0/101	0/017	0/006	9
0/019	0/019	0/022	0/253	0/039	0/014	10
0/057	0/059	0/068	0/76	0/118	0/043	11
0/001	0/001	0/001	0/012	0/002	0/001	12
0/014	0/014	0/016	0/186	0/028	0/01	13
0/001	0/002	0/001	0/015	0/003	0/001	14
0/021	0/021	0/025	0/282	0/043	0/016	15

Forecasting groundwater level

One objective of this study is to forecast the future status of groundwater level drop. In order to forecast the aquifer status, the probable conditions must firstly be defined for the model. These conditions can be created considering specific goals or normal situation. In this study, the system behavior has been forecasted according to the system behavior during previous years. Required information layers were produced based on variations trend of previous years. With regard to the climate change as well as the high probability of drought occurrence in the coming years, model fore casting has been designed based on arid year. The results of forecasting have been presented in Figures 7, 8 as a graph of water table relative to the time for both observation wells. The results show that, the water table will faced with a sharp drop in the coming years so lack of attention to this issue as well as increasing withdrawal, the aquifer will lose its capability of extraction.

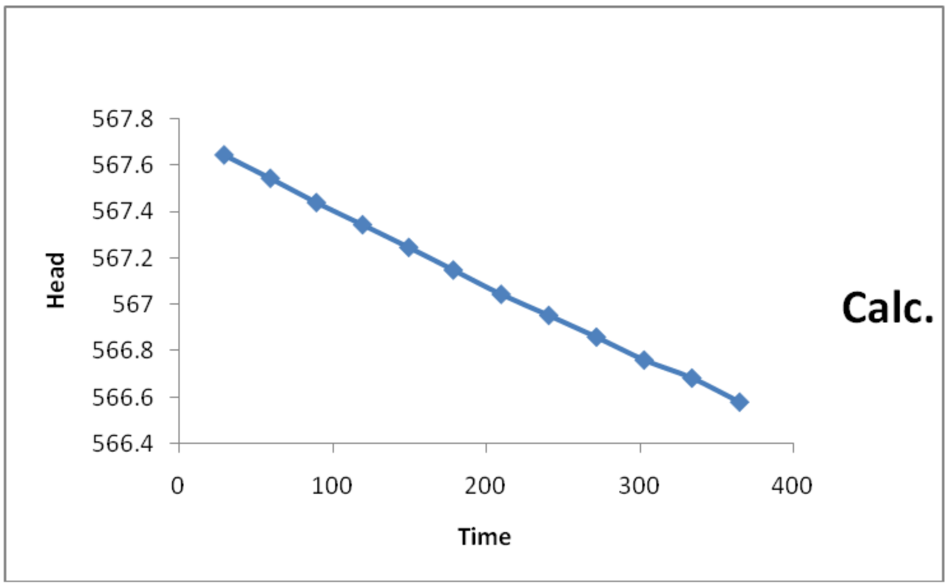

Figure 7. Calculated water table for observation well number 9

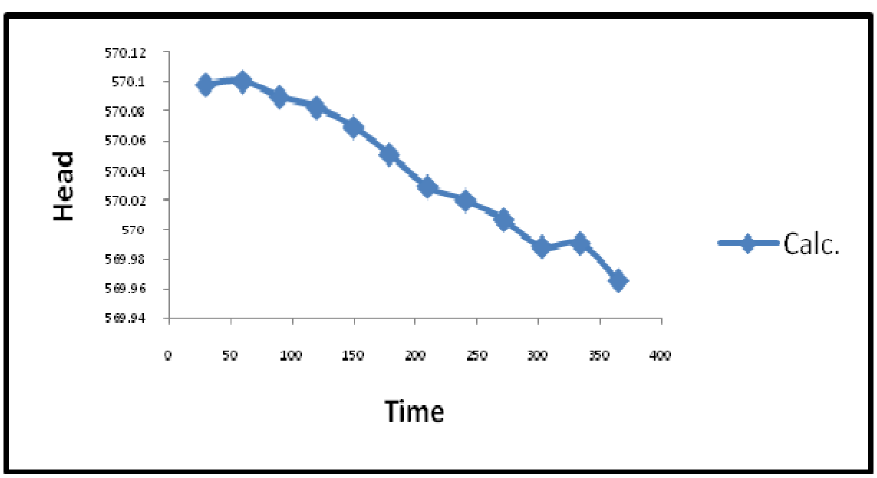

Figure 8. Calculated water table for observation well number 13

Groundwater balance

Based on the results of model, groundwater balance of Narmab water shed is almost zero which explains that, the aquifer has high capacity for water extraction and is able to meet the water need of the region. Model output for the year 2003-2004 has been presented in Table (7) and Figure (9).

Table 7. Summary of the aquifer water balance of Narmab watershed in the year 2003-2004

0.242820million m^3	Total inflow
0.242810million m^3	Total outflow
- 0.00001 million m^3	Balance

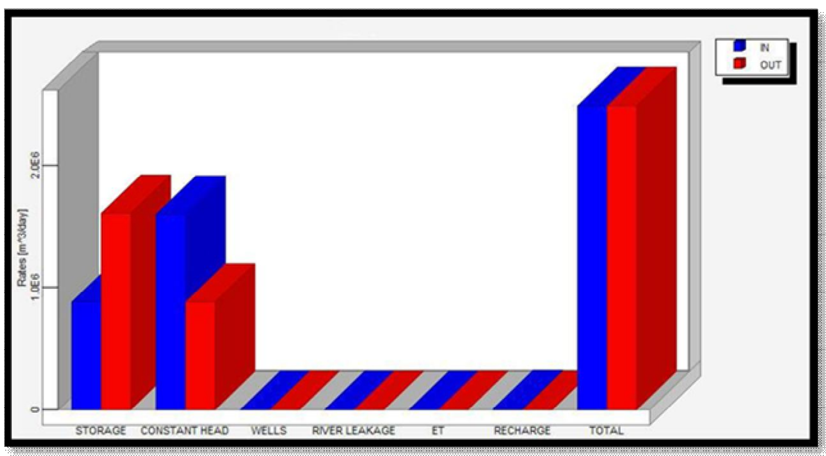

Figure 9. Aquifer water balance status of Narmab watershed in the year 2003-2004

Conclusion

Simulator model of groundwater flow in the free aquifer of Narmab watershed was produced using Visual Modflow. The created model simulates the free aquifer behavior properly. During the periods of the model performance, calculated water table values by the model where the piezometers are placed, are in accordance with observed groundwater level in the piezometers. Using the suggested model it is possible to forecast the aquifer status if the values of aquifer discharge and recharge are specified. Calculated balance by the model explains suitable situation of Narmab aquifer to access groundwater. Considering the results as well as high ability to extract water from the aquifer it is suggested that, water requirement of the region can be covered by groundwater. Available surface water also can be transported to downstream using water transport networks.

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