Middle-East Journal of Scientific Research 8 (5): 975-983, 2011
ISSN 1990-9233

Numerical Study of Groundwater Flow in Iranshahr Plain Aquifer, Iran

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Abstract: Iranshahr plain is located in the Sistan and Baluchestan province in the southeast of Iran and the Jazmurian depression. During recent years, high exploitation from the aquifer declines the quantity as well as quality of this water resource. The Iranshahr aquifer consists of an unconfined layer. First hydro-geological aspects of the Iranshahr plain were studied using the results of the pumping test, geological logs of the observation and exploration wells, geo-electrical studies and field observation. Then the groundwater flow model was made. We simulated groundwater flow of the Iranshahr aquifer in a conceptual model. This model is a suitable tool for management of groundwater system and would also be effective when applied in other countries. Steady state condition has been considered in Nov. 2008 because of low fluctuation in groundwater level in this period. Then unsteady state condition considered for one year (Nov. 2008 to Nov. 2009). Also verification accomplished for period of Nov. 2007 to Nov. 2008. In this study, we constructed the conceptual model of Iranshahr aquifer, which is important and applicable in environmental studies. The results of the model show a good fit between observation and simulated values. The optimized values and the zonation of the hydraulic parameters of the aquifer showed the best areas for developing and extracting groundwater from the aquifer taking the optimized hydraulics values into account.

Key words: Iranshahr Plain · Aquifer · Conceptual model · Simulation · Modflow · Calibration · Sensitivity analyze · Verification

INTRODUCTION

Comparing to average precipitation of the earth, Iran with about 280 mm per year is classified as an arid and semi arid region of the world. Iranshahr plain with average precipitation about 100 mm per year is among the arid locations with low- rainfall in Iran. Groundwater resources are the main resources securing water in Iran that their study and management is very serious. This research concentrated on groundwater and extreme abstraction of the water of aquifers among this plain. In order to simulate different stress conditions in this region a mathematical model was employed.

Nalbantis *et al.* [1] tried to apply integrate groundwater models within a decision support system (DSS) which was designed to assist large multi-reservoir system (MRS) management, which would help managing conjunctive use schemes. The DSS is currently used for the water supply of Athens, Greece. They used three models of different levels of complexity. The first model was a multi-cell model that simulates surface flows within the basin coupled to subsurface flows. The second model was a conceptually-based lumped model while the third model was a pre-existing distributed groundwater model based on the MODFLOW package. Tests with various management scenarios allow drawing conclusions regarding model efficiency and suitability for use within a DSS.

Zheng and Wang [2] described the application of a new general-purpose simulation-optimization code referred to ModularGroundwater Optimizer (MGO) to optimize an existing pump-and-treat system at the Umatilla Army Depot in Oregon. Two optimization formulations were developed to minimize the total capital and operational costs under the current and possibly expanded treatment plant capacities.

Samani *et al.* [3] used MODFLOW for groundwater numerical models with conventional rectilinear grid geometry which generally have not been used to simulate aquifer test results at a pumping well because they are not

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designed or expected to closely simulate the head gradient near the well. A scaling method is proposed based on mapping the governing flow equation from cylindrical to Cartesian coordinates and vice versa. A set of relationships and scales is derived to implement the conversion.

Lautz and Siegel [4] used three-dimensional MODFLOW model, paired with MT3D, to simulate hyporheic zones around debris dams and meanders along a semi-arid stream. Modeling results indicated that movement of surface water into the hyporheic zone was predominantly an advective process. They showed that debris dams were a key driver of surface water into the subsurface along the experimental reach, causing the largest flux rates of water across the streambed and creating hyporheic zones with up to twice the cross-sectional area of other hyporheic zones. Hyporheic exchange was also found in highly sinuous segments of the experimental reach, but flux rates were lower and the cross-sectional areas of these zones were generally smaller. Their modeling approach simulated surface and ground water mixing in the hyporheic zone and thus provides numerical approximations that were more comparable to field-based observations of surface-groundwater exchange than standard particle-tracking simulations.

Methodology: The methodology followed in this research can be summarized as follows:

- Data collection, which includes physical parameters such as hydraulic conductivity, aquifer thickness, recharge, pumping rates, geological boundary, distribution of geologic formation, topographic and bedrock maps, long-time statistics of observation wells, weather statistics of the Iranshahr synoptic station and groundwater flow directions;
- Identification of the geological and hydrological setting of the study area;
- Dividing the study area into a grid mesh;
- Estimation of the model parameters by manual adjusting until a reasonable match between computed and observed water levels obtained;
- Sensitivity analysis of the calibration results in steady and unsteady state;
- Verification of the model results with the observed data;

Study Area: Iranshahr watershed, is located in the Sistan and Baluchistan province, in the southeast of Iran and the Jazmurian depression, Iranshahr aquifer is within the area bounded by latitude 60° 25' - 61° 25' N and longitude 52° 53' - 53° 8' E. (Fig. 1). This area is located in the north of

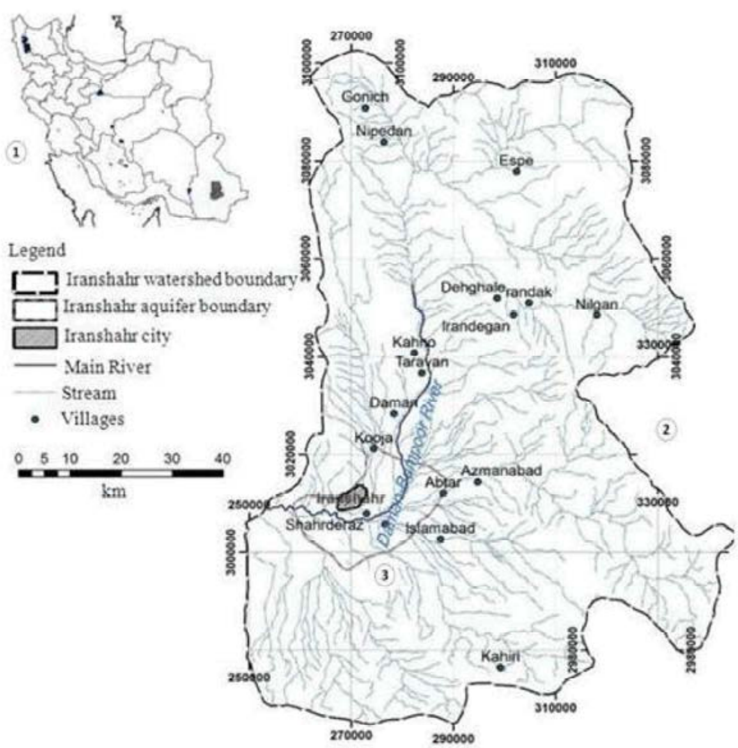

Fig. 1: Islamic Republic of Iran, Sistan & Baluchestan province (1), Iranshahr watershed (2), Iranshahr plain (3)

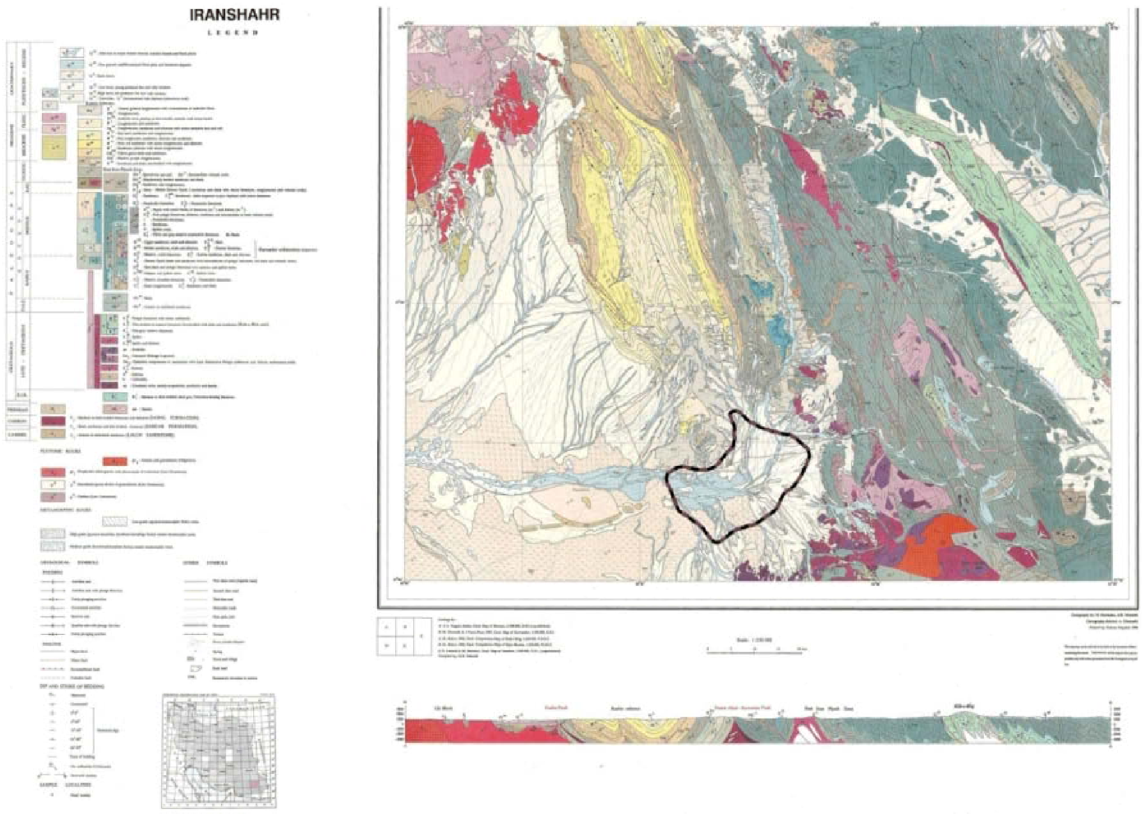

Fig. 2: Geology map of Iranshahr plain

Makran [5] and in the east of Zagros mountain Range [6, 7]. Iranshahr city is the main population center in the area. The watershed area is 8018 km2, of which 6882 km2 are in sharp reliefs against the 1136 km2 of alluvial plains. The highest point of the area has an elevation of 2720 m to the northeast and the lowest point has an elevation of 500 m to the west near the Bampour River. Average annual temperature in statistic period is 27.2°C, also the warmest month is June by average temperature 44.6 °C and the coldest month is December by average temperature 8.45°C (recording period of 1996-2009).

Annual average precipitation is about 99.09 mm/year (recording period of 1996-2009) with average maximum of monthly of 19.56 mm/year in February and average minimum of monthly 0.46 mm/year in September. Average annual evaporation in this watershed is 3242.2 mm (recording period of 1996-2009) with annual average moisture of 29.6 percent. This region from climatology viewpoint is considered as an arid and low rainfall places in Iran.

Conceptual Model: Iranshahr plain has an unconfined aquifer The geological formations consist of sedimentary [8] and igneous rocks [9] in the north and south of the plain respectively [10, 11]. In the southeast, the lithology consists of about 8 kilometers thick Bazman granite. Most of the geologic formations around the Iranshahr plain are impermeable.

The main surface water features in the watershed are seasonal rivers (Daman and Saradan) that drain the runoff from north, east and southeast. The Bampour perennial river has been drained from the aquifer (Fig. 1). Iranshahr watershed has eight subbasins that drain the surface water to the plain and aquifer surface. The main subbasins are Daman (number 2) and Saradan (number 4) (Fig. 3). Table 1 shows the properties of these subbasins.

Groundwater flow direction is the same as surface water, i.e. from north, east and southeast to the west and discharge to Bampour River (Fig.4). The most important sources of the aquifer’s recharge are the direct recharge from precipitation and especially from subsurface flow of seasonal Daman and Saradan rivers (Fig.4). Returned water from wastewater and irrigation also recharge the groundwater. Groundwater is extracting from 221 shallow and deep wells and 12 Qanat strings (underground artificial channels) in the aquifer area,

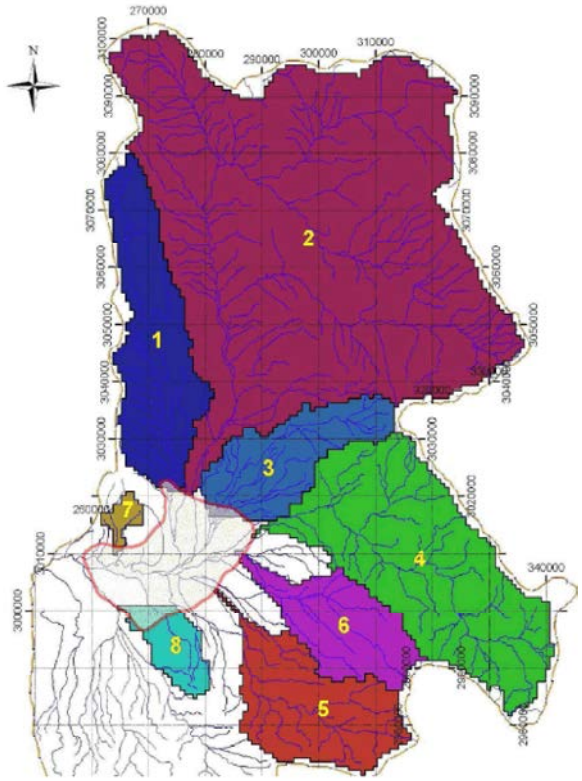

Fig. 3: Iranshahr watershed subbasins

Table 1: Properties of Iranshahr watershed subbasins

Subbasin	Average elevation	Perimeter (m)	Area (m^2)
1	1061.1	171338.5	589057335.8
2	1300	378126.3	3293812269.4
3	880	121118.6	387250655.9
4	1052.8	214173.1	1091392341.6
5	1230.7	149182.6	493608230.5
6	1040	128503.9	352888978
7	600	38403.5	38179642.1
8	677	66467.5	138537558.6

mostly for agricultural and drinking use. Depths of the wells vary between 10-120 m. By using data from the Sep. 1996 to Dec. 2006 the unit hydrograph of the plain was prepared (Figure 4).

Model Application: To simulate the existing condition with different input parameters a model must attend generality, capability, speed and easy to use. Also model preference in different stage of data import and export, consequences regulation and presentation by using graphic tools by approbation precision is necessary. In this research considering all mentioned requirements MODFLOW model, version MODFLOW-2000 was applied.

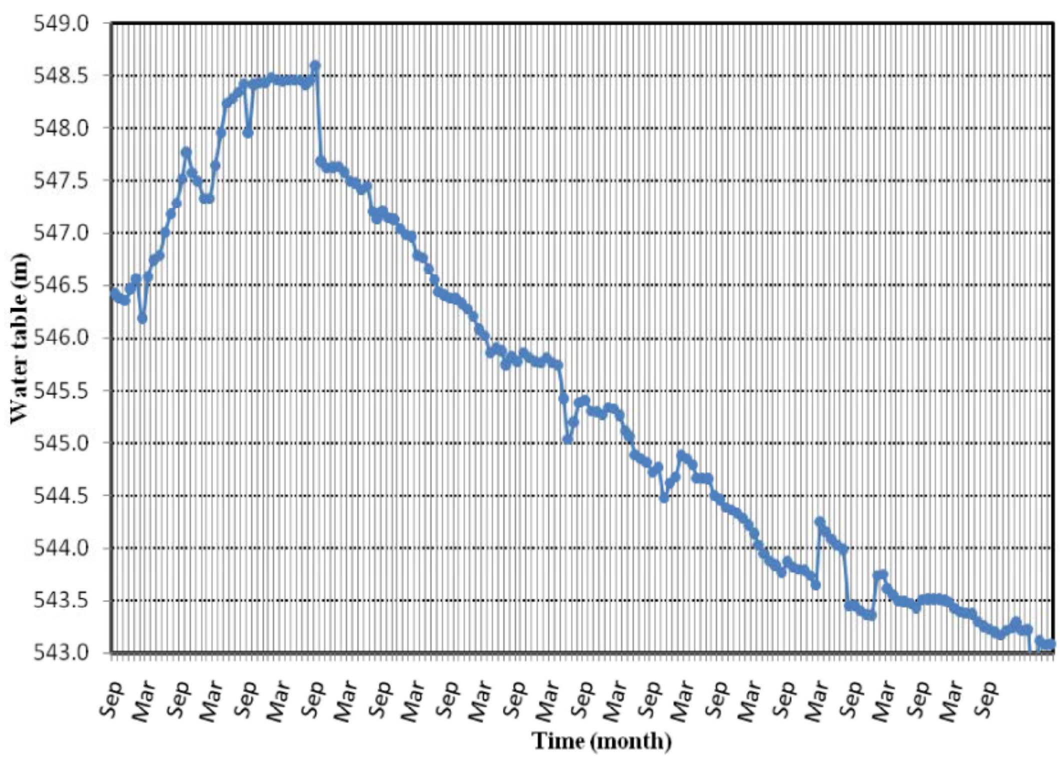

Fig. 4: Unit Hydrograph of Iranshahr plain

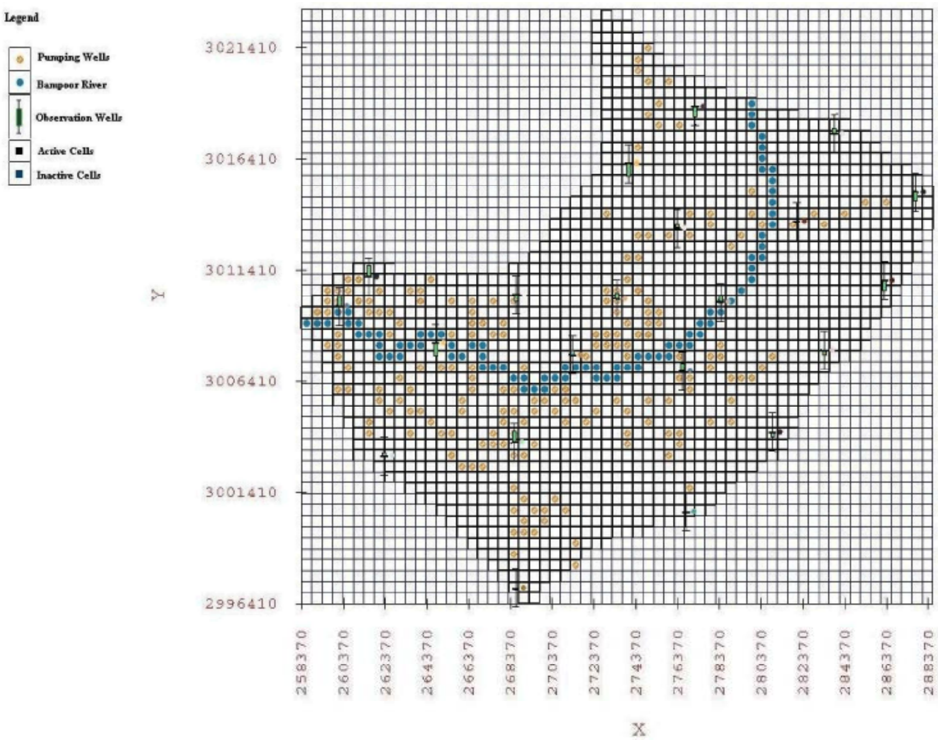

Fig. 5: Location of pumping, observation wells and Bampoor River

Topographical and bedrock contour maps were used to determine the top and bottom of the layer for each cell. The wells is only and the biggest sinks in the Iranshahr plain that their number is 221 ring in modeling limit that extract about $8.3*10^6$ m^3/year. In the Iranshahr plain since extracted water from agriculture wells used in the environs, therefore 20% from the pumping water considered for reverb water and negative of water quantity pumping of wells. The number of observation wells was 21 rings in the Iranshahr plain therefore modeling limit considered around the observation wells. The natural recharge quantities due to the rainfall fluctuation by studies of regional water company are considered to quantity 10% and import to model to figure monthly period. Location of pumping and observation wells showed in Figure 5.

Cells dimension by attention to plain extent and available data, considered to length 500 meter that consist from 54 rows and 61 columns. Water table of the aquifer is considered in a topic upon boundary and bedrock in a topic bottom boundary. In the research area to cause lack physical boundary such mountain and plain or perennial river only may use from hydraulic and artificial boundary. Considering unit hydrograph, steady state condition was taken in Nov. 2008 because of low fluctuation in groundwater level in this period. Therefore in steady state used boundary by constant head, because on the supposition that variation of water table in this month is minimum.

Transient (unsteady state) condition considered for one year (Nov. 2008 to Nov. 2009). The selected simulation time are 12 successive months (12 stress periods) with 21 head observations at the end of each stress period. One recharge zone was considered at the surface of the aquifer for direct recharge. The input and output boundaries were simulated using the General Head Boundary (GHB) package. The simulation was run for both transient and steady.

Calibration: The steady state condition is a condition that existed in the aquifer before any development had occurred. Since low fluctuation of water table in November 2008 was observed, it was chosen for calibration as steady state condition. Matching the initial heads observed for the aquifer with the hydraulic heads simulated by MODFLOW is called steady state calibration. Trial and error calibration was used to adjust the hydraulic conductivities during the sequential model runs to obtain the best match between calculated and observed piezometer heads. Hydraulic conductivities, estimated from well logs and previous study, were used an initial guess for the calibration.

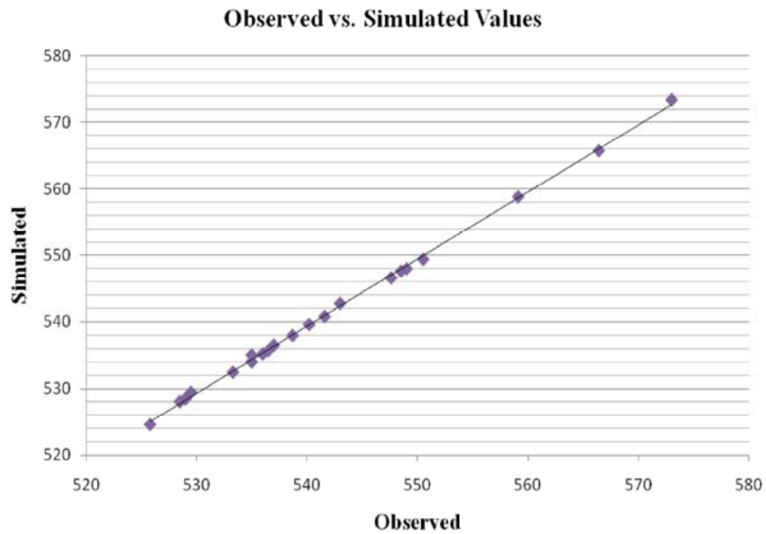

Fig. 6: Value of RMSE at steady state condition

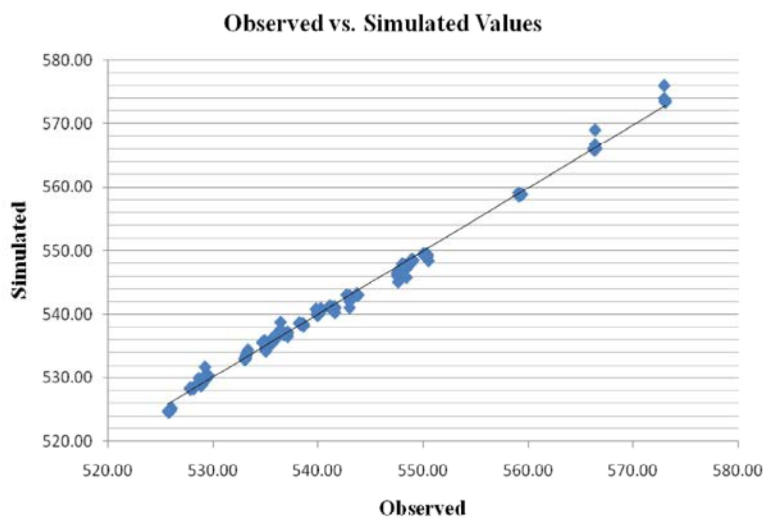

Fig. 7: Value of RMSE at unsteady state condition

The RMS obtained was about 0.998 that is acceptable (Fig 6). Most values of the hydraulic conductivity are ranged between 10 m/d in the North and North-East of Iranshahr plain to 45 m/d in the southwest.

Successful transient calibration depends mainly on good estimation of hydraulic conductivities and boundary conditions obtained from the steady state calibration. Generally, specific yield for unconfined aquifers and storage coefficient for confined aquifers are the main parameters that are changed during the transient calibration. The model was calibrated for period of Nov. 2008 to Nov. 2009. Twelve stress periods were selected to cover this year time period. The unsteady state calibration was firstly done by assigning initial values of the specific yield to the model. These values are taken from previous studies. Then, the initial values of the specific yield were changed several times by performing several computer runs until acceptable matches were obtained between the observed and simulated observation heads. At last, RMSE obtained about 0.996. Fig 7 shows the comparison of observed and simulated water table in the observation wells. As Fig 7 shows, the model successfully simulates the water table where close agreement was obtained between the observed and simulated water table in all observation wells. The range of the resulted specific yield after the final calibration is found to be varying from 0.01 to 0.1.

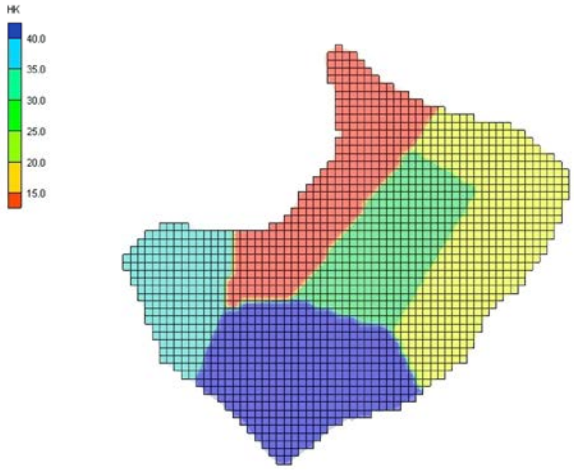

Fig. 8: Optimized hydraulic conductivity

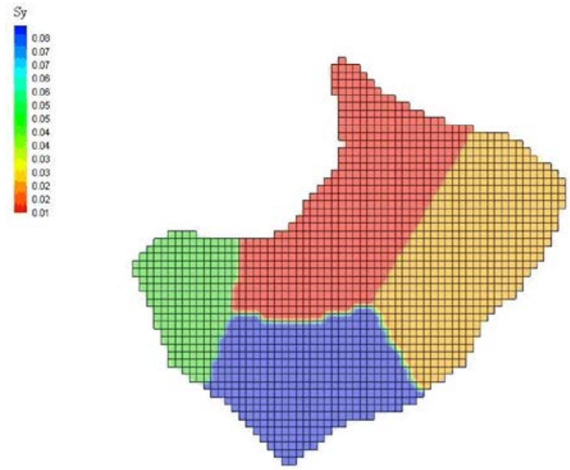

Fig. 9: Optimized specific yield

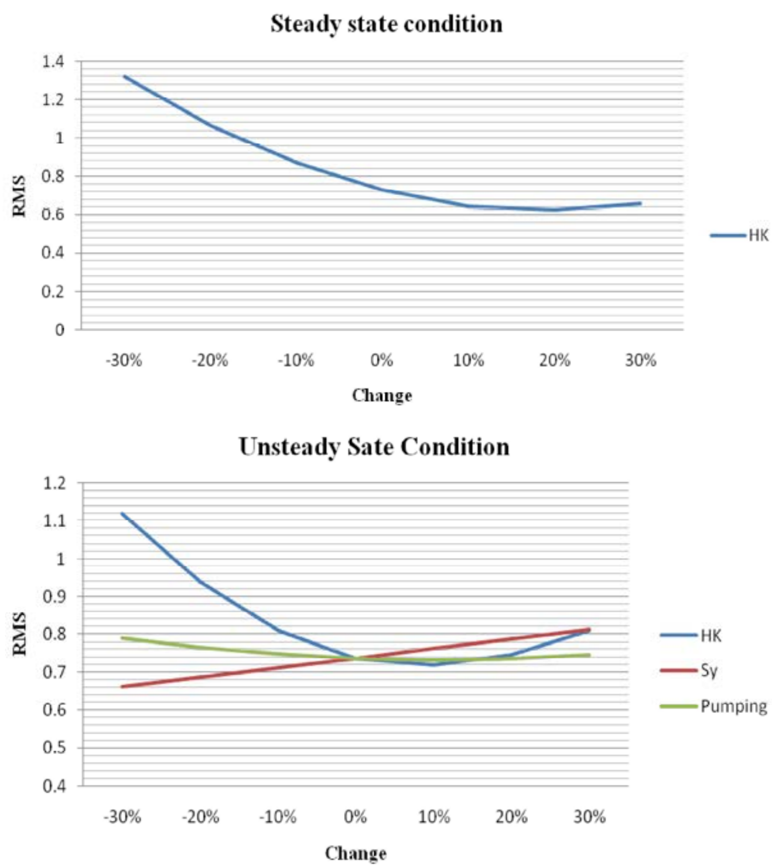

Fig. 10: Variation of RMSE into the several parameters at steady and unsteady conditions

Sensitivity Analysis: We assessed the model sensitivity to hydraulic conductivity (K) at steady state and hydraulic conductivity (HK), pumping rate (P), specific yield (S_y) at unsteady state. For the sensitivity analysis, value for K, P, S_y, were increased and decreased in the range -30% to +30%. The model reacted most sensitivity to hydraulic conductivity at steady and transient state. This response is due to high porosity of aquifer, because with increase of hydraulic conductivity, the groundwater escapes from aquifer and quantity error increase. Fig 10 shows variation of RMSE into these parameters.

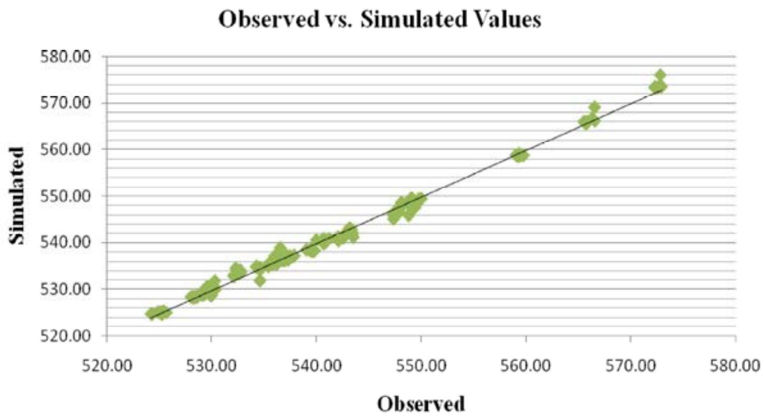

Fig. 11: Value of RMSE at verification state

Verification: Model validation is in reality an extension of the calibration process. Its purpose is to assure that the calibrated model properly assesses all the variables and conditions which can affect model result. While there are several approaches to validate a model, perhaps the most effective procedure is to use only a portion of the available record of observed values for calibration. Once the final parameter values are developed through calibration, simulation is performed for the remaining period of observed values and goodness-of-fit between recorded and simulated values is reassessed. This type of split-sample calibration/validation procedure is commonly used and recommended, for many groundwater flow modeling studies. Model credibility is based on the ability of a single set of parameters to represent the entire range of observed data. If a single parameter set can reasonably represent a wide range of events, then this is a form of validation. Verification of model was performed for the period Nov. 2007 to Nov 2008. The period was divided into 12 stress periods (12 month). Reasonable agreement between the observed and simulated water table in the observation wells was obtained as is evident from Fig 11. The RMSE obtained about 0.995. These results indicated that the calibrated parameters (such as hydraulic conductivity and specific yield) are acceptable.

Summary and Conclusions: Groundwater models (especially with automated calibration capability) are good tools for identifying hydraulic parameters such as hydraulic conductivity and specific yield. To prepare the conceptual model of Iranshahr aquifer, geological information, drilling logs, exploration logs, pizometric data and other information have been used and the groundwater flow was simulated by using GMS 7.1(MODFLOW-2000). The results of the model show a good fit of observation and simulated values. Hydraulic parameters of the aquifer have been estimated by using the automated calibration procedure. Optimized values and zonation of the hydraulic parameters of the aquifer indicate that the best area for development and extraction of groundwater of the aquifer are zones 3 and 4 respectively regarding the optimization of hydraulics values

ACKNOWLEDGEMENT

We would like to thank the Sistan and Baluchestan Regional Water Organization for allowing us information use of this research.

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