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Numerical simulation of groundwater of large-scale irrigation in Northern China: Case of Baoyang Irrigation Area, Shaanxi, China

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The numerical simulation of groundwater for the single aquifer layer system of Baoyang irrigation area was performed. Visual MODFLOW was carried out to estimate the sustainability of the groundwater resource and to delineate suitable plan for future groundwater use. The conceptual model was built by analyzing the hydrogeological data, aquifer properties, pumping wells, head observations; etc. A groundwater model for Baoyang Irrigation Aquifer was developed, calibrated, and validated using observed groundwater levels for the period of 2006 to 2009. The reliability of the model is tested by long series historical groundwater monitoring data and the model is then used to predict the impact of groundwater exploitation until 2048, during this period; all parameters and well exploitation of 2009 were maintained constants. The water balance was checked for differences between the volume of water that is leaving and entering into the system. Calibration model was performed by adjusting the input parameters; the optimization results of parameters were calibrated automatically during the model processing using the Parameter Estimation Package "PEST". The results show that the computed water heads fit into with perfectly the measured data, which indicate that the conceptual model and the parameters used in the model can reflect the actual physical system of the study domain. Also the results found that the water table in the aquifer is slightly falling down due to continuous withdrawal of water. Finally, the model applications were reported.

Key words: Numerical simulation model, finite difference method, groundwater, MODFLOW, Baoyang irrigation, Shaanxi, Northern China.

INTRODUCTION

The Baojixia Yangmaowan irrigation district (hereinafter referred to as Baoyang irrigation). It is located in Xianyang district west of GuangZhong Plain; Shaanxi Province; a part of loess plateau, and an important part of loess platform. Extending from the steep valley of the Wei River in the west to the Jing River in the east. It is a unique landform of Loess Plateau in Northern China, which is also relatively short in water resources. In this area; the surface water resources cannot meet the growing demand of water for the development of domestic, industrial supply, crop irrigation, transport, recreation, sport and commercial fisheries, power generation and so on. Therefore, scientific and effective groundwater utilization becomes increasingly important. In addition, the loess has good water-retaining property and forms a good water-rich aquifer, which makes it

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possible to use and develop groundwater. For these reasons, even disregarding the potential threats due to the climate change, this situation appears as one of the biggest challenges of the current era. If the actual trends of development, and population growth does not change. So, this study focused on Numerical Simulation of Groundwater, using Visual MODFLOW Model. The requirement, to develop the numerical modeling of groundwater, to ensure appropriate response and sustainable of the aquifer and make decisions in perspective, the current and historic water use and management in to the existing knowledge of the hydrologic cycle in the area. Compare between the observation and estimation levels of groundwater, and calibrate parameters to show the optimization results, etc. This may help in water resources planning and management and may lead to improvements and managing in water resource, in the present and future.

A groundwater model is any computational method that represents an approximation of an underground water system (Anderson and Woessner, 1992). Generally, mathematical model is the common in groundwater - surface water analysis; it is the best method to develop the main equation of ground water, such as Darcy's law and the partial differential equation of ground water flow in two or three-dimension, the solution of partial differential equation for transient three- dimensional groundwater; requires for the use of a numerical method, such as a finite difference method; Visual MODFLOW is a famous computer program that simulates groundwater using finite difference solution; developed by the U.S. Geological Survey (McDonald and Harbaugh, 1988). A mathematical model (e.g. analytical model and Numerical model) describes the physical processes and boundaries of a groundwater system using one or more governing equations. Numerical models are usually solved by a computer and more computationally demanding than analytical models, (Barnett et al., 2012). The numerical models are widely used for the analysis of basin-scale groundwater hydrology and to quantify the water exchange between different aquifer levels (McDonald and Harbaugh, 1984). Among the numerical methods for solving groundwater flow and transport equations: finite difference method (FDM) and finite volume method (FVM) seem to be more popular for their relative simplicity and ease of implementation (Ataie et al., 1999; Moldrup et al., 1996). The finite difference method (FDM) was applied in this study.

The water resources of the rainfall, runoff of Weihe River and Qi shui he River through five irrigations channels (streams) as main source gravity irrigation is used (Yacor, 2003), and groundwater as the subsidiary (Zhang and Wei, 2007). Agricultural irrigation is the main water utilization. Groundwater is also used for irrigation, in addition to a little living and production water. In 1975, the two schemes (Baojixia and Yang mao irrihation area) were merged to form the Baoyang irrigation scheme.

Modeling software selection

After hydrogeological characterization of the site has been completed and the conceptual model developed, computer model software is selected (Visual MODFLOW-2000), which is a computer program that numerically solves the three-dimensional groundwater-flow equation for a porous medium using the finite-difference method. It is being extensively used worldwide to carry out research in the field of groundwater resource management. The advantages of MODFLOW include numerous facilities for data preparation, easy exchange of data in standard form, extended worldwide experience, continuous development, availability of source code, and relatively low price and forth. A full description of the capabilities of MODFLOW can be found in (McDonald et al., 1988, 2000).

Many hydrological studies and projects have been carried out on this aquifer system. For instance, by using FEFLOW and GIS as a platform, a numerical simulation model fort Typical Irrigation has been established by (Liu, 1991). The high degree of dispersion of groundwater level has been published by (Hao and Junmin, 2011) in his M.Sc Dissertation. Chen (2011) found that the water consumption can generally be satisfied, but there are many potential problems. In the groundwater quantity, there is no water shortage, but the growth of groundwater capacity has slowed down considerably, and decreases in the last two year. A simplified multi-objective optimization model for optimal allocation of water resources in Baojixia; up-tableland irrigation district has been established by Hong et al. (2009). The current model described in this study was conceptualized by identification of the objective, data collection and screening, conceptual model, mathematical model (computer code) was selected; model was designed and run, and model calibration with certain parameters. Finally, model sensitivity, uncertainty, validating,and predictive for future forecasting was reported.

Study area

The study area; Long: 107° 50′ ~108° 50′ E, Lat: 34° 12′ ~34° 35′ N; of the Baojixia Yangmaowan irrigation district (hereinafter referred to as Baoyang irrigation). It located in Xianyang district in the west of GuangZhong Plain; Shaanxi Province, a part of loess plateau, and an important part of loess platform, extending from the steep valley of the Wei River in the west to the Jing River in the east. Its is a unique landform of Loess Plateau in Northern China, which is also relatively short in water resources (Figure 1). It is one of the biggest irrigation districts in Shaanxi and an important agricultural production area in China. Climatically, this area belongs to continental monsoon climate, the scheme situated in semi-arid and sub-humid region, which is featured with four clear seasons with rains in spring and autumn, hot in summer and cold in winter. This region was characterized by variant landforms. In general, it is high in the south and north, and low in the center. Moreover, this area is also declining from the west to the east in elevation. Topographically, the area is situated at an elevation in the Guanzhong Basin in the south as 400 to 800 m a.s.l. with open forest vegetation (Zhao et al., 2003). The total area is about 1758.26 km^2 (175826 ha), and the cultivate area (agricultural acreage) is about $12*10^4$ ha (1200 km^2); (Liu et al., 2001).

MATERIALS AND METHODS

To carry out this simulation, there are 6 gauging stations of rainfall, and two stations for meteorological data within the area were selected, with record data ranged from 1981 to 2009 years in length. As well as more than 60 observation wells were selected. The gauging stations covered most area. In addition, the data belong to the streams (channels), Aquifer properties, hydraulic conductivity, and forth were gained from College of Water Resources and Architectural Engineering, Northwest A & F University and previous studies (Liu et al., 1991, 2001). A mathematical formulation that consist of appropriate differential equations for the system, and their solutions, was used for simulation. The steps in mathematical modeling are: Examination of physical problems and understanding the physical behavior of system in relation to cause and effect to formulate a conceptual model of how the system operates (Domenico, 1972). Translation of physical problem into mathematical terms, making appropriate simplifying assumptions, developing governing equations, Calibration and valiadation for reliability, and application of the mathematical results in terms of physical problems that require solution.

The reference evapotranspiration “ETo” in the area was calculated using meteorological data of two stations within the area; with monthly record data, which ranged from 1981 to 2009 in length (Table 1), this period was chosen preliminary to develop groundwater of the area as the part of study plan of Numerical simulation of groundwater.

Model design and input parameters

A conceptual model was created to represent the aquifer system beneath the Baoyang aquifer. Model design includes all parameters that are used in the development and calibration. The input parameters involve: model grid size and spacing; the model was assumed as single layer, and divided in to 100 rows, 151 columns, the total number of cells is 15100 cells, the length unit is meter and time unit is day (Fingure 2). Lithological data along with top and bottom elevations of the Aquifer layer were gained from the Google earth and literature reviews (Liu and Yang, 1989). Figure 3 presents the top and bottom elevations as contour lines. The thickness of the Aquifer is varying between 80 to 260 m depth. Boundary conditions consists of Stream flow (Channels irrigation); streams data were gained from College of Water Resources -Northwest A&F University-, the initial recharge was assumed as percentage of rainfall, while the evapotranspiration was calculated from meteorological data using the FAO-56 application of the Penman-Monteith equation (Allen et al.,1998). ET_O calculator software was applied. Aquifer properties including horizontal, vertical hydraulic conductivities, specific yield (specific storage for confined aquifer) were collected from previous studies (Liu et al., 1991, 2001) and the global standard values. The optimizations values of recharge, hydraulic conductivity, and the specific yield are adjusted automatically by PEST method during the calibration process until the measured groundwater levels match the calculated values. During calibration the primary storage coefficient is 0.037 and 0.0246 is estimated by model, hydraulic conductivity along rows is 7.68, the estimated is 5.012. There are 5 artificial perennially Irrigation Channel (like small streams) in the area were coded as 1, 2, 3, 4, and 5 (Figure 2). The stream data consists stream stage and are difference from time to time according to the discharge. Some information about the stream that are used in the model are presented in Table 2. The stream conductance were calculated automatically by MODFLOW; using the formula described below.

$$C = \frac{L \times W \times K_z}{T.el - B.el} \quad (1)$$

Where; C: is the Streambed conductance, L: is the reach length of stream line in each grid cell, W: is the Stream width in each grid cell, K_z: is the Streambed hydraulic conductivity, T.el: is the streambed top elevation, and B.el: is the Stream bottom elevation.

The irrigation requirement in the area

In Baoyang irrigation area, the irrigation requirement has been calculated directly by the law of irrigation quota. This water-saving irrigation system was established according to actual situation in irrigation district. The major crops grown in the area are: winter wheat, maize, grain, cotton, oil and other cash crops. Many researchers, (Zhang and Wei, 2007; ZHANG and Li, 2008) had used it and so on. Researchers used the irrigation efficiency 0.552. By computing, the total irrigation requirement was 322 and 502 million m^3 in normal and dry year respectively. Based on analyzing climatic material of Baoji gorge irrigation district from 1981 to 2003, result shows that the range of perennial average winter wheat water requirement in the district is 459.5~ 559. 6 mm, the range of maize water requirement is 454.6~ 528. 3 mm, the range of cotton water requirement is 609.2~ 681. 3 mm. The spatial distribution of crop water requirement for these three kinds of crop has similar regulation, (LI et al., 2010). According to 2009 total water consumption is about 1021.5 Mm^3, for irrigation, animals and industrial. 31% (314.67 Mm^3) of them from groundwater withdrawn per year and about (752.73 Mm^3) is withdrawn for irrigation purposes 27% (203.75 Mm^3) from groundwater. Likewise, according to 2010 about 725.46 Mm^3 is withdrawn for irrigation purposes, 27.7% (200.88 Mm^3) from groundwater.

The flow equation and finite differential equation

Groundwater modeling begins with a conceptual understanding of the physical problem. The next step in modeling is translating the physical system into mathematical terms, various numerical solution techniques have been established after (Freeze and Witherspoon, 1966, 1967; Bredehoeft and Pinder, 1973). In general, the results are the familiar groundwater flow equation and transport equations. Among the most approaches were used in groundwater modeling; Finite Difference Method, Finite Element Method, and Analytical Element Method. All techniques have their own advantages and

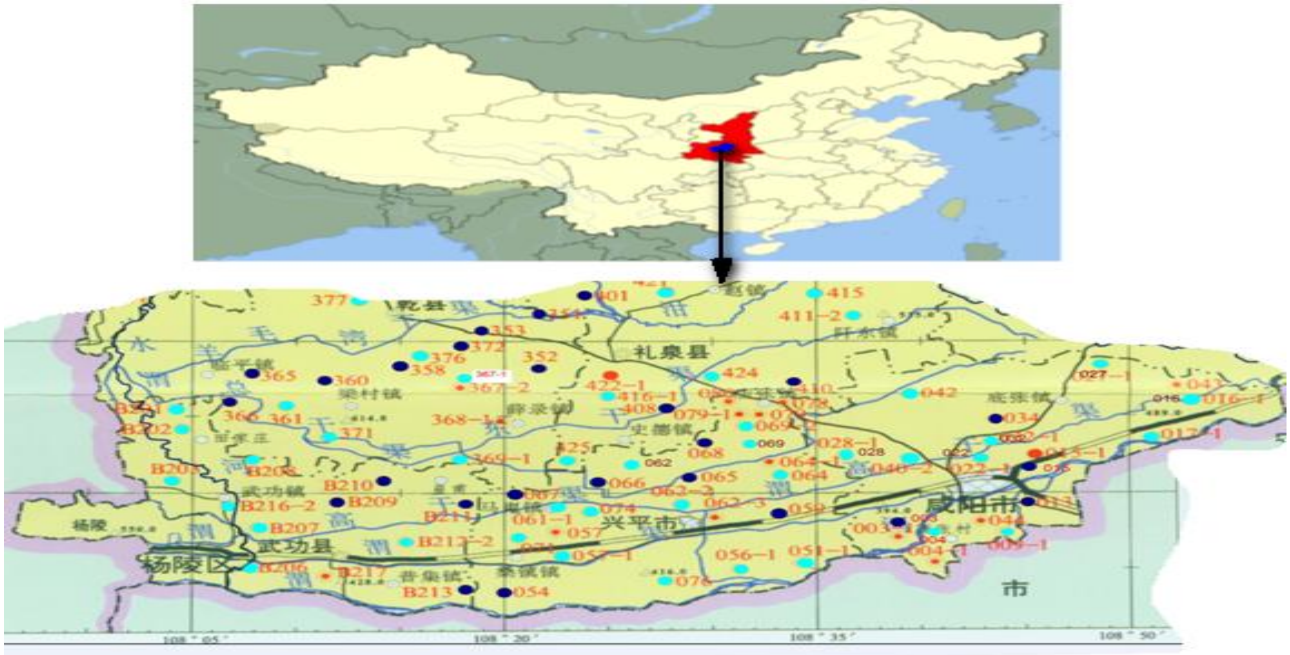

Figure 1. Study area location-the numbers within the map refer to the wells and the blue lines refer to streams

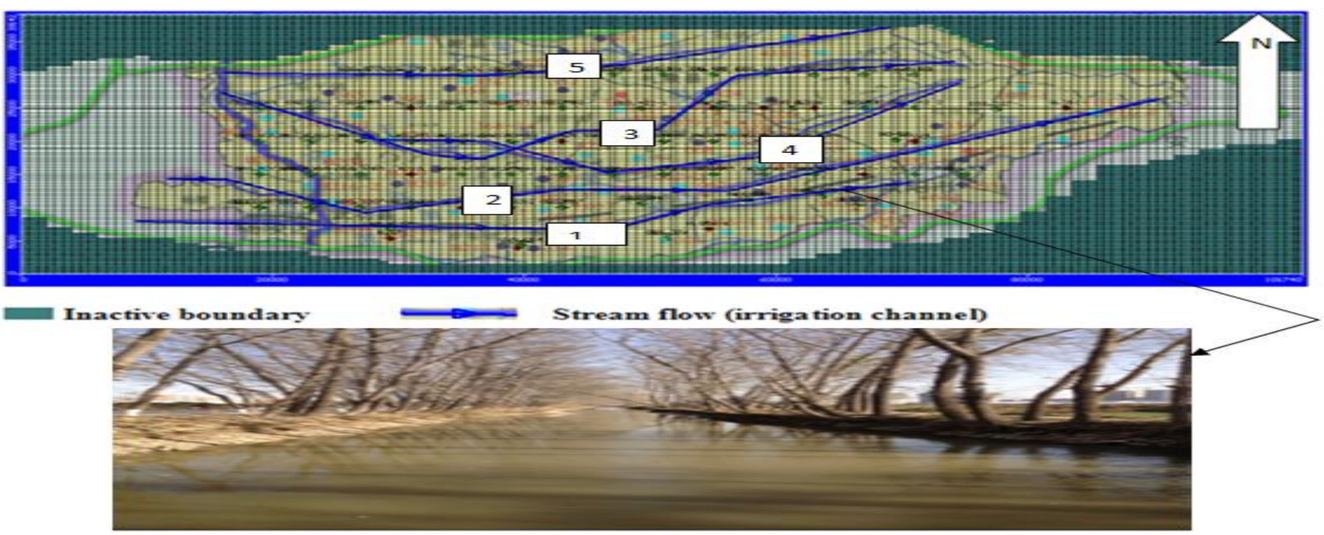

Figure 2. Map showing location of the stream flow and grid lines and size in the area

Table 1. Meteorological data of two stations (Xing and Wuging, 1981-2009).

Type of data	Period	Length of data (years)
Monthly mean relative humidity %	1981-2009	29
Monthly mean wind speed (m/s)	1981-2009	29
Monthly mean air temperature (^{o}C)	1981-2009	29
Monthly mean air pressure (Kpa)	1981-2009	29
Sunlight (Hours)	1981-2009	29

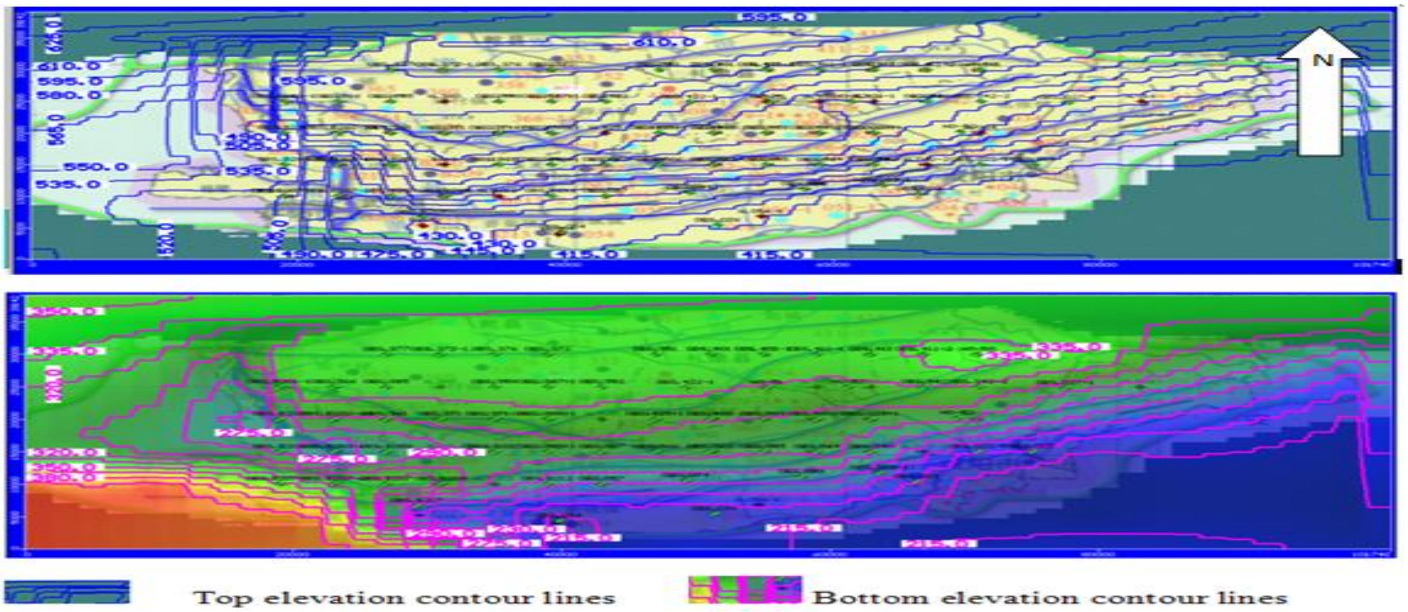

Figure 3. Map presents the Top and Bottom elevations contour lines**.**

Table 2. Presentes the streams parameters and conductances that calculated by V.MODFLOW

Name of stream (Chanal)	Code	Width (m)	Initial flow (m^3/s)	K_z (m/day)	Calculated conductance (m^2/day)	
					Min	Max
Wei qu	1	6.5	44	0.022	2.574	60.47
Wei gao gan gu	2	5.5	25.3	0.022	0.439	57.69
Zong dong gan qu	3	6	25	0.022	3.506	51.52
Wei zong gan qu	4	5.6	12.5	0.022	0.1055	68.58
Yangmao wan gan qu	5	6.5	20	0.022	5.84	65.4

disadvantages with respect to availability, costs, user friendliness,applicability, and user background. In this study Finite Difference Method was carried (Remson et al., 1971). This method has been preceded by replacing the derivatives in the differential equations by finite difference approximations (LeVeque, 2004; Luka, 2008). These approximations are algebraic in form, and the solutions are related to grid points.

Water balance method for groundwater evaluation

The water balance is merely a detailed statement of the law of conservation of matter, which states simply that matter can neither be created nor destroyed, but can only be changed from one state or location to another. Water balance also means the balanced relationship between mean annual values of groundwater recharges and discharges in the evaluated area (Liu and Jin, 2004; Chen, 2010). In this paper, evaluated area is the agricultural irrigated region as mentioned earlier. The groundwater balance evaluation in 2008 and 2009 are taken as an example. The mass (water) balance for shallow aquifer in the area can be determined as: Inflow - Outflow = Change in storage; the equation can be written as:

$$W_{str\,l} + W_{rech} + W_{sto} - (W_{str\ out} + ET + W_{well}) = \pm \Delta S \qquad (2)$$

Where; $W_{str\,l}$ and $W_{str\ out}$ are the stream (Irrigation channels) Leakage in and out respectively. W_{sto}: is the water storage, W_{rech} is the water recharge to the aquifer, ET is the total evapotranspiration, and W_{well}: is the amount of water withdrawn from the wells, and ΔS is the change of storage. The calculating terms of recharge and evapotranspiration are mentioned above.

MODFLOW - model calibration and parameter estimation

Model calibration is the process of adjusting the input parameters and boundary conditions of a model to achieve a close fit to observed data in a real groundwater system (Ye, 2011). After the first run of a model, model results may differ from field measurements, this is expected because modeling is just a simplification of reality and approximations and computational

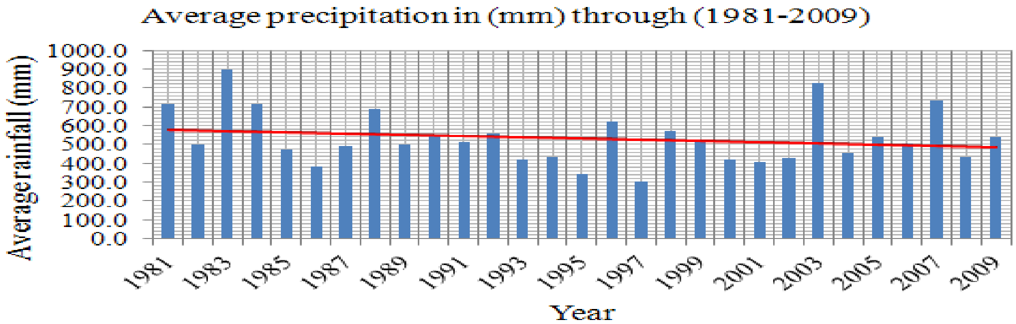

Figure 4. The average precipitation for six stations through (1981-2009).

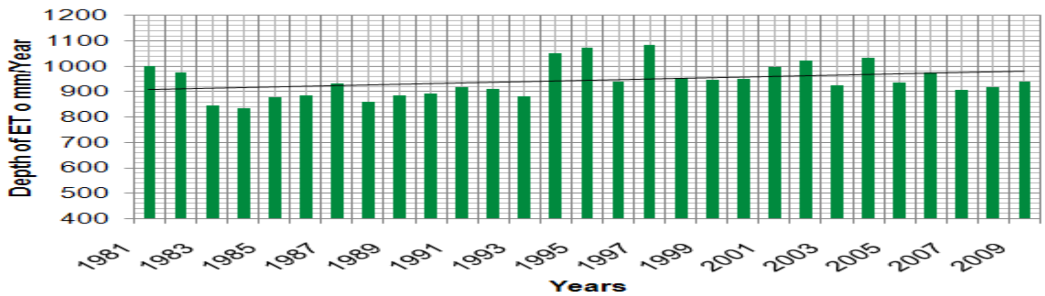

Figure 5. The mean annual reference evapotranspiration (1981-2009)

errors are inevitable. Calibration can be done manually or automatically. Software like Parameter Estimation Package "PEST" (Doherty et al., 1994) and UCODE (Poeter and Hill, 1998) can be used for automatic calibration. In this research the PEST is carried out to calibrate the parameters (hydraulic conductivity, specific yield and groundwater recharge). Drawdown for each grid cell is calculated as the difference between the initial (starting) head value and the calculated head value, at each grid cell. To illustrate the calibration process of a groundwater model, consider the groundwater head measurements (h_{obs}) i at the observation point i, the simulated head at the same point is (h_{sim}) i. The root mean square error of the residual is given by:

$$RMSE = \left[\frac{1}{n}\sum_{i=1}^{n}(h_{obs} - h_{sim})^2\right]^{1/2} \quad (3)$$

RESULTS AND DISCUSSION

Statistic analysis of rainfall

The precipitation data from a number of stations can be used to depict the isohyetal line, or isohyets, which joints all points that receive the same amount of precipitation. In this paper, the result of statistic analysis found that the maximum and minimum annual precipitation of Baoyang irrigation district through (1981 to 2009) according to available data are ranged between 895 mm in 1983, and 303.4 mm, in 1997 (Figure 4). The average of rainfall such as: maximum, minimum and mean is 603.4, 475.9, and 534.9 mm. The standard deviation (SD), Variation (VAR), Skew and the Coefficient of variance (CV) were found as 47.6, 2802, 0.2 and 0.01 respectively. Generally, the trend line was slightly decreasing by the resent years, which indicate that the rainfall is decreasing recently. While the Evapotranspiration was calculated using the FAO-56 application of the Penman-Monteith equation is visualized in (Figure 5). the trend line indicated that the mean annual reference evapotranspiratin was increased by resent years, this may due to increasing the temperature and climate changes as general.

Groundwater-level fluctuations

The groundwater of the Baoyang irrigation Aquifer System generally occurs under unconfined conditions. So, the water table is not stable and fluctuates according to wet and dry seasons and also according to the withdrawal rate of groundwater. Many wells were used to monitor the water level fluctuations of the aquifer. These wells have total depths of about 20 to 185 m. The water levels were presented (Figure 8a and b) as example, the results found that in some well there are no change in head during predictive period, but as general, the groundwater level was decreasing by resent years, and will be rose in autumn when precipitation and streams stage were high, and declined during winter; spring and summer when precipitation and streams stage were low and water demand for agriculture were increasing. The water table level is falling (see cross-sections in Figure 6) during 30 days, 360 days and 720 days [calibration period (2008 to 2009)]. Clearly, the water table is slightly falling down due to continuous withdrawal of water. The maximum and average drawdown during the calibration and predictive periods were presented in Table 2. The result also found that the movement of Groundwater is from north to south, meanwhile to the east and west. The comparison between the simulated and the observed head, as well as groundwater direction (Figure 7).

Model calibration, validation and predictive

Model validation is the next step after calibration and defined as the comparison of model results with numerical data independently derived from laboratory experiments or observations of the environment (ASTM, 1984). The term “validation” is not completely true when used in groundwater modeling (Oreskes et al., 1994) asserted it is impossible to validate a numerical model because modeling is only approximation of reality. The objective of model validation is to check that if the calibrated model works well on any dataset. In this research the calibration and validation process were performed by comparing results, which yielded from the Visual MODFLOW model with recording data for years 2008 to 2009 as calibration period and 2006 to 2007 as the validation period. Registered historical data from monitoring locations in the study area were used for these purposes. A statistical analysis was did automatically by Visual MODFLOW. Statistics used for this purpose includes; the correlation coefficient (R^2), Root Mean Square Error (RMSE), Normalized Root Mean Square Error (N.RMSE) and Recharge. Uncertainty in groundwater modeling is inevitable for a number of reasons,evaluated computing confidence intervals at a 0.05 significance level was carried in this model., according to (Baalousha and Köngeter, 2006).

A model was used to predict some future forecasting scenarios of groundwater simulation of Baoyang irrigating area; the predictive was carried for 40 years (that is, 2009 to 2048) during this period, all parameters and well exploitation of 2009 were maintained constants. The results of this simulation can be used to study the behavior of Baoyang irrigation aquifer system versus continuous exploitation. The maximum and average drawdown of some well-selected as examples- were scheduled in Table 3. The model may also be used to evaluate different remediation alternatives. However, errors and uncertainties in a groundwater flow analysis and solute transport analysis make any model prediction no better than an approximation. For this reason, all model predictions should be expressed as a range of possible outcomes that reflect the assumptions involved and uncertainty in model input data and parameter values.

The calibrated and predictive model can be used to derive components of the groundwater budget and to estimate the response of the regional system to new stresses, such as increased groundwater withdrawals due to increasing demand of water for the development of industry, agriculture, and daily life. These results may lead to sufficient enough information, and Water-resource managers can use these informations to make informed decisions when planning for future groundwater development. The uncertainty associated with inaccuracies in the groundwater-flow model is carried forward to the model applications.

The statistics summary of model calibration and validation

For the ground-water level calibration and validation, the results found that the minimum and maximum Standard Error of Estimation (SEE) of all heads is ranged between 1 and 2.365 m for calibration and 1.011 to 1.065 for validation, root mean square error (RMSE) of the observation wells is 11.17 m to 19.5 m, and 7.878 m to 11.241 m for calibration and validation respectively. The minimum and maximum normalize root mean square error (N.RMS %) is 6 to 10.48, and 4.235 to 6.043 for calibration and validation respectively. Generally, the results showed that the values are increased during the time period (2008 to 2009), and decreasing during (2006 to 2007) this may be due to the difference in conditions or for reasons that are mentioned by Oreskes et al. (1994). The correlation coefficient (R^2) is ranged between 0.98 and 0.93, the average values of SEE, RMSE, N.RMSE and R^2 are 1.8 m, 16.2 m, 8.7 and 0.9% respectively (Table 4). The water levels, a spatial comparison between the measured and simulated head of the observations wells were mentioned in Figure 8a and b. Multiple ground-water-flow systems are not well simulated by a single layer (layer 1) where all properties; ground-water levels, and flows are average values. As a result, there may be little differences between measured and simulated head in some wells. The time interval of the model during calibration and validation process is divided as monthly.

Sensitivity analysis

Sensitivity analysis refers to the assessment of the dependence between model inputs and outputs, and specifically, how the latter respond to perturbations in the former. Sensitivity analysis is important for calibration,

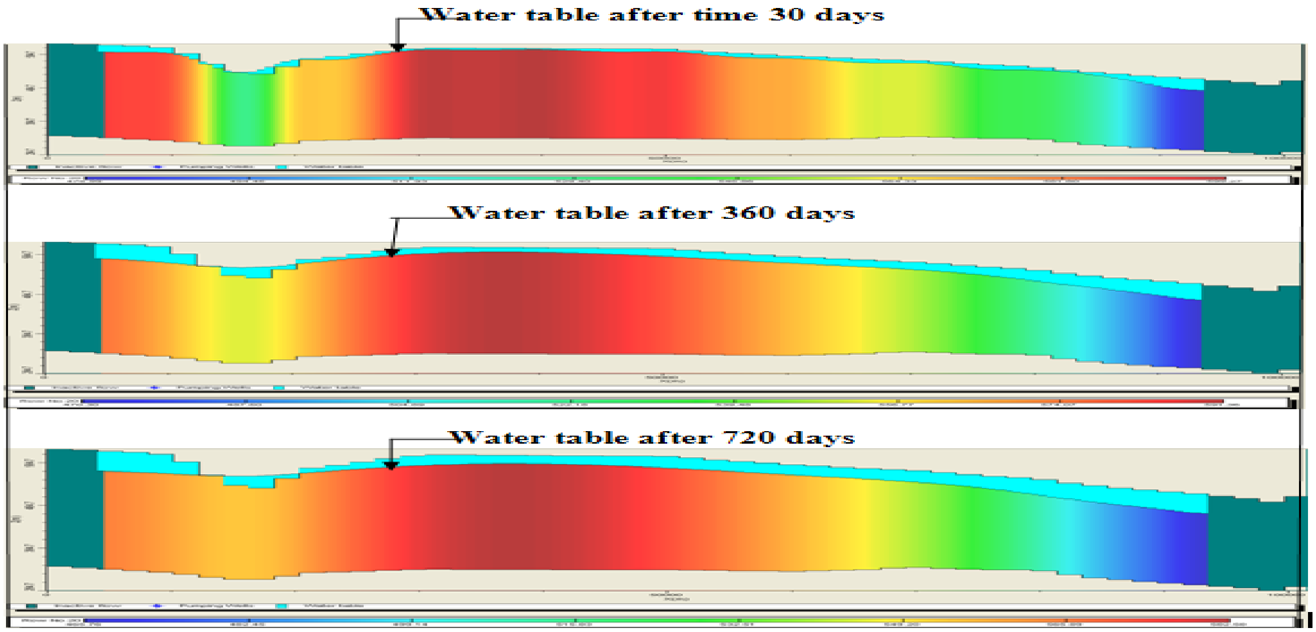

Figure 6. Cross-sections presente the falling in water table during the calibration period (2008-2009).

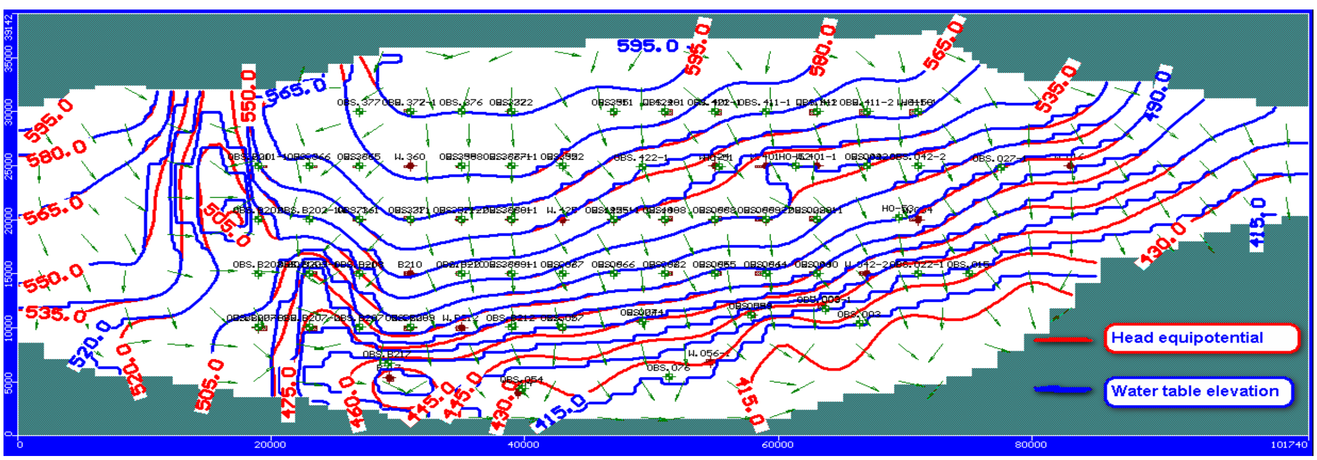

Figure 7. Map showing the velocity direction of groundwater in the domain and comparison between the simulated and the observed head, the observed is appear as red ,while the blue is the calculated.

optimization, risk assessment and data collection. In regional groundwater models, there is a large number of uncertain parameter, coping with these uncertainties is time-consuming and requires considerable effort. Sensitivity analysis indicates which parameter(s) have greater influence on the output. Parameters with high influence on model output should get the most attention in the calibration process and data collection. In this research, the optimization results of parameters (hydraulic conductivities, specific yield and recharge) were calibrated during the model processing. The results showed that the horizontal hydraulic conductivity "K_x" and specific yield "S_y" have the large values of sensitivity, so that, they have high influence in the model (Table 5). The initial values of recharge and optimization results were presented in Figure 9. The magnitude of recharge rates varied by node which ranged from 0.035 to 17.29 mm/year; and 0.035 to 11.105 mm/year; estimated and observed respectively, and the average values of recharge rates is 4.62 mm/year (observed) and 7.89 mm/year

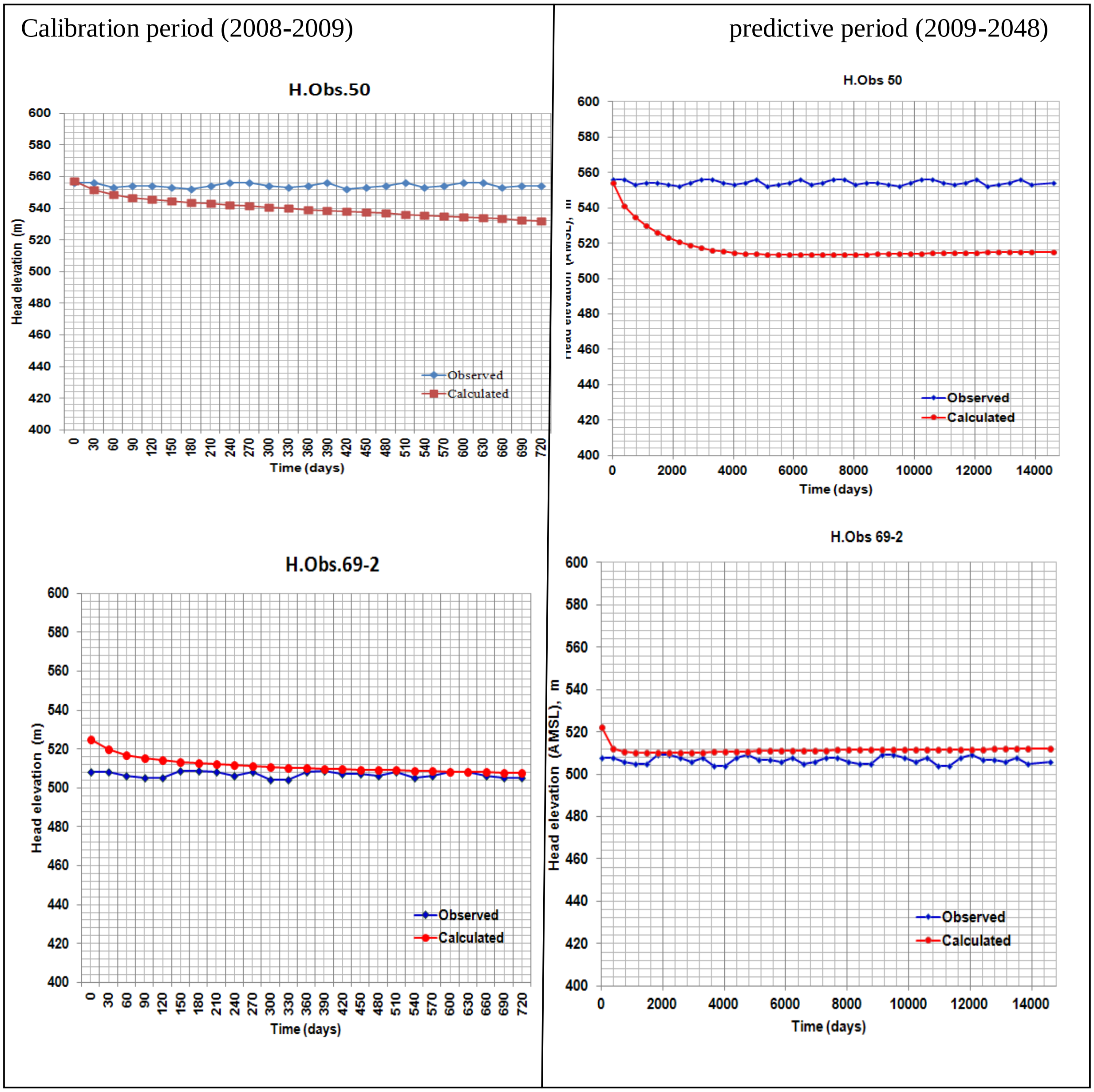

Figure 8a. Illustrated the head elevation during the calibration and predictive period for head observations .H.obs.50 and H.Obs.69-2

as estimated for the calibration period (2008 to 2009), the time interval divided as monthly.

Water balance of the system

Finally, the water balance was checked as differences between the volume of water leaving and entering intothe system. An approximate water cumulative volume during the study period of calibrated model (2008 to 2009) results by Visual MODFLOW, there are three major sources of inflow to the ground-water flow system; recharge from precipitation, stream leakage and groundwater flow to the storage. As cumulative volume, recharge accounts for about 6.38% (0.444×10^8 m^3). Channels (stream leakage) accounts for about 3.82% (0.266×10^8 m^3), and groundwater flow (storage inflow) accounts for about 89.8% (6.25×10^8 m^3). While the water out flow consist; total evapotranspiration (ET) accounts for about 26.16% from the total out flow (1.82

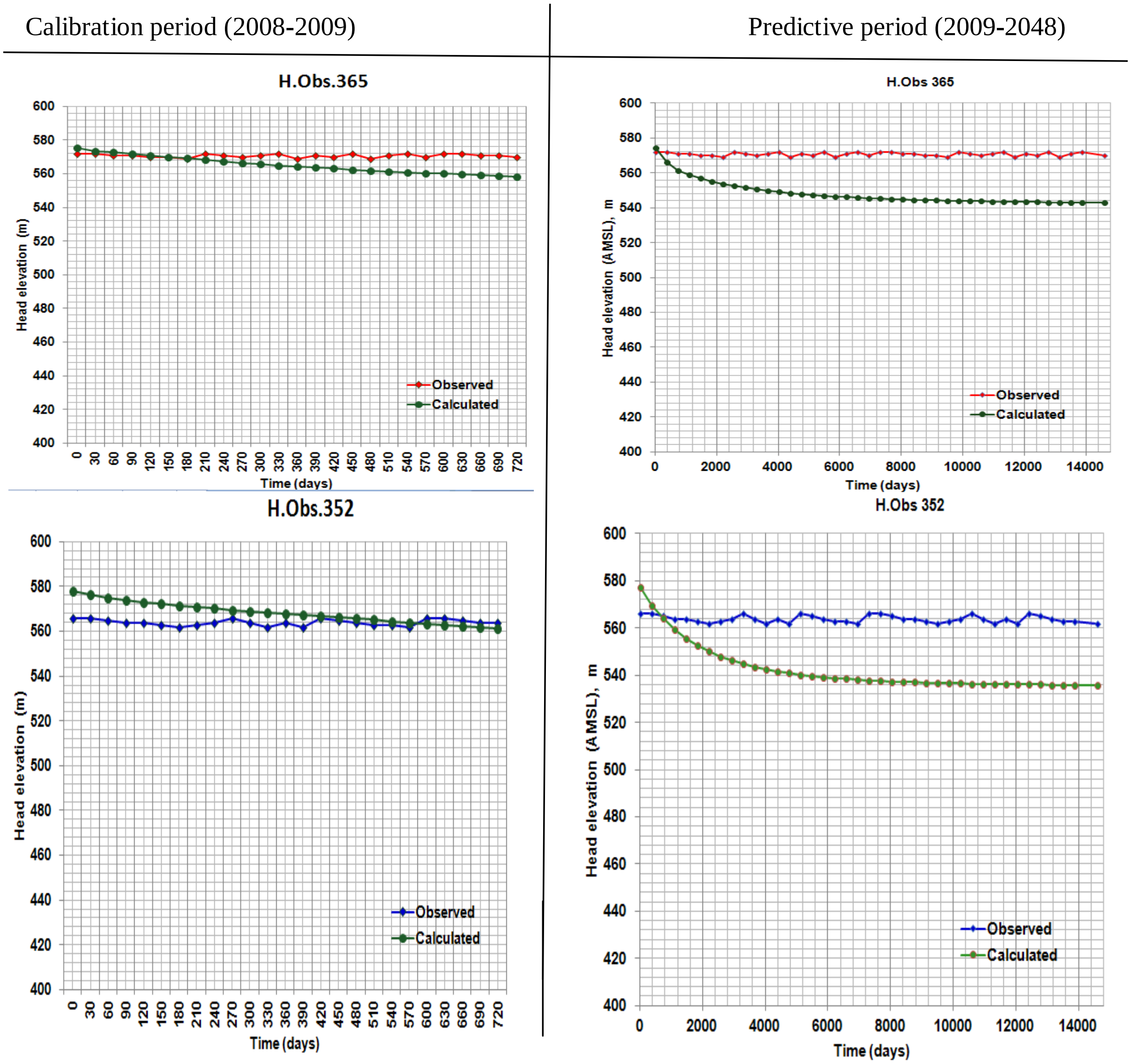

Figure 8b. Fit the head elevation during the calibration and predictive period for head observations .H.obs.365 and H.Obs.352.

$\times 10^8$ m^3), stream leakage out flow is accounts about 1.02% (0.071 × 10^8 m^3) , the pumping wells withdrawn is about 0.5% (0.035 $\times 10^8 m^3$), and groundwater out flow (storage out flow) is about 72.31% (5.03 × 10^8 m^3). The total inflow is about 6.96 × 10^8 m^3 and the total out flow is about 6.956 × 10^8 m^3. Hence, the total inflow minus total out flows about 0.004 × 10^8 m^3. The cumulative of volumes into and out of the system during (2008 to 2009), which were employed in V.MODFLOW indicated that there were no negative impact between the volume in flow and out flow. However, the difference between inflow and out flow is decreasing by increasing time; it is indicated that the water out from the basin is relatively large in amount than water into the basin. The mass balance error for simulation of about 0.01% is considered acceptable.

Conclusions

A groundwater model for Baoyang Irrigation Aquifer Region (BIAR) in the centre of Guanzhong Basin was developed, calibrated, and validated using observed groundwater levels for the period of 2006 to 2009. During the study we found that the maximum and minimum annual precipitation through (1981 to 2009) according to

Table 3. Illustrated the maximum, and average drawdown for 12 wells during the calibration and predictive periods (2008-2009, 2009-2048).

Well no.	Location		Calculated DDW (2008-2009)		Calculated DDW(2009-2048)	
	Longitude	Latitude	Max (m)	Average (m)	Max (m)	Average (m)
50	108° 19' 54"	34° 13' 29"	25.87	17.65	44.62	40.32
28−1	108° 42' 54"	34° 22' 11"	15.17	11.94	12.3	8.35
69−2	108° 29' 18"	34° 16' 7"	14.86	10.95	12.55	11.01
352	108° 21' 13"	34° 28' 05'	16.13	9.14	41.57	35.01
361	108° 09' 29"	34° 25' 42"	9.17	4.55	12.4	9.77
365	108° 07' 50"	34° 27' 50"	11.46	4.59	26.89	21.65
366	108° 06' 46"	32° 25' 56"	5.9	2.84	14.85	10.82
371	108° 10' 41"	34° 22' 40"	28.93	20.39	36.75	33.2
401	108° 22' 47"	34° 33' 0"	21.74	13.79	53.72	45.74
411	108° 33' 39"	34° 26' 50"	14.9	8.74	38.25	33.17
B201-1	108° 03' 54"	34° 32' 33"	36.28	31.64	34.19	31.05
B203	108° 03' 14"	34° 20' 52"	33.78	28.03	27.8	13.6

Table 4. Statistics report of calibration (2008-2009) and validation (2006-2009) processing.

Variable	Time (days)	Well No.	Calibration results				Validation results			
			SEE (m)	RMSE (m)	N.RME%	R^2	SEE (m)	RMSE (m)	N.RME%	R^2
Head	0	61	1.000	11.177	6.009	0.98	1.015	11.241	6.043	0.978
Head	30	61	1.082	11.477	6.171	0.98	1.026	10.917	5.87	0.978
Head	60	61	1.277	12.965	6.971	0.97	1.037	11.193	6.018	0.978
Head	90	61	1.418	14.161	7.655	0.96	1.047	10.498	5.675	0.978
Head	120	61	1.516	14.923	8.023	0.96	1.038	9.904	5.325	0.978
Head	150	61	1.596	15.46	8.312	0.95	0.991	9.203	4.948	0.98
Head	180	61	1.626	15.771	8.389	0.95	0.961	8.827	4.695	0.98
Head	360	61	1.908	16.749	9.103	0.94	0.974	8.238	4.477	0.98
Head	390	61	1.954	16.928	9.151	0.94	0.982	8.445	4.565	0.98
Head	480	61	2.08	17.799	9.621	0.94	1.06	8.687	4.696	0.976
Head	510	61	2.161	18.202	9.786	0.93	1.065	8.567	4.606	0.976
Head	540	61	2.164	18.386	9.938	0.93	1.052	8.598	4.647	0.976
Head	600	61	2.221	18.001	9.678	0.93	1.011	7.878	4.235	0.978
Head	660	61	2.281	18.612	10.006	0.93	1.029	8.165	4.39	0.978
Head	690	61	2.316	19.043	10.293	0.93	1.013	8.164	4.413	0.978
Head	720	61	2.365	19.506	10.487	0.93	1.011	8.693	4.674	0.978
Average			1.800	16.200	8.700	0.90	1.020	9.200	4.950	0.980

the available data are ranged between 895 mm in 1983, and 303.4 mm, in 1997, respectively. The statistic analysis through the time period showed that the average of rainfall such as maximum, minimum and mean is 603.4, 475.9, and 534.9 mm respectively. Also, the result found that the water table in the aquifer is slightly falling down due to continuous withdrawal of water, and the Groundwater in the model area discharges to the QiShihe River, and Wei He River. Calibration of the conceptual model was performed by adjusting the input parameters such as hydraulic conductivity, specific yield and recharge rate. Performance statistics indicated that simulated groundwater levels followed trends and magnitudes in the observed historical groundwater levels in the underlying Baoyang Aquifer. Overall, calibration results yielded average coefficients of determination of 0.9 and 0.98 and average RMSE 16.2 m and 9.2 m, N.RMSE% is 8.7 and 4.95, SEE is 1.8 and 1.02 for the

Table 5. Optimization Records (Initial conditions) and Optimization Results of Parameters.

Parameter name	Start time (day)	End time (day)	Initial values	Estimated values	Sensitivity	Rel. sensitivity
Kx_1	0	720	7.68	5.012	0.4099	0.2869
Ky_1	0	720	7.68	7.68	0.000	0.000
Kz_1	0	720	0.23	0.23	0.000	0.000
Ss_1	0	720	0.00001	0.00001	0.000	0.000
Sy-1	0	720	0.037	0.0246	0.3840	0.6177
Recharge	0	720	0.035-11.105	0.035-17.29	$9.9*10^{-5}$-$1.3*10^{-4}$	$2.1*10^{-6}$-$6.6*10^{-4}$
Average of recharge			4.62	7.89		

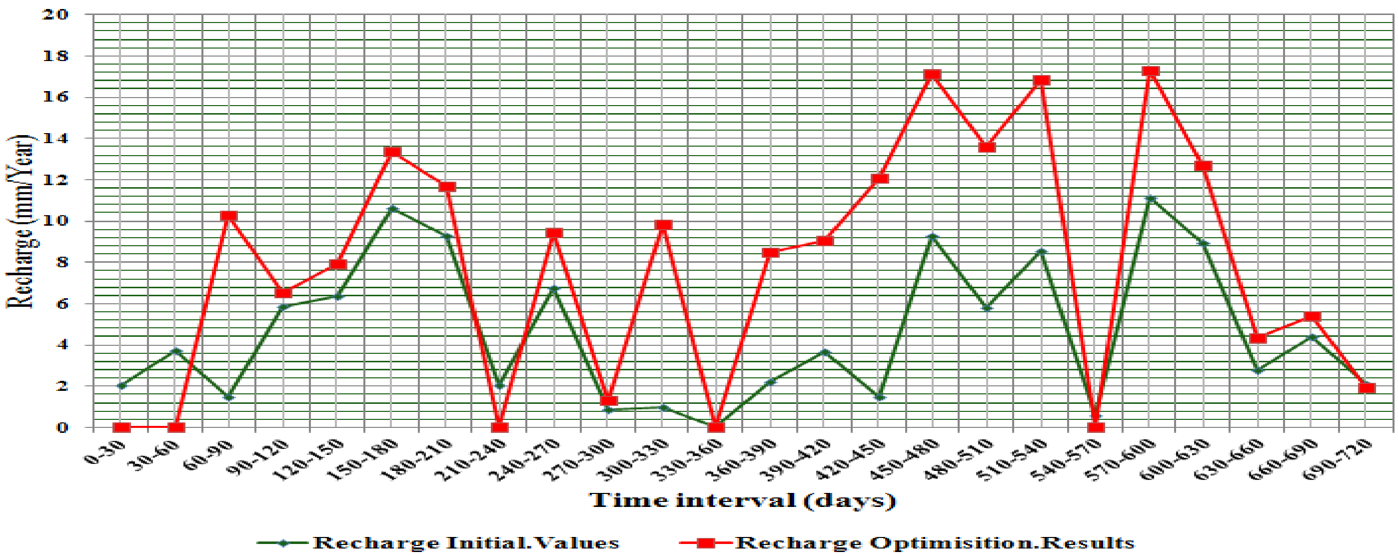

Figure 9. The initial values and optimization results of recharge (mm/year), 2008-2009.

calibration and validation processes, respectively. These results are indicative of a good agreement between predicted and observed groundwater levels. The water balance was checked for differences between the volume of water leaving and entering into the system. The cumulative of water volume into and out of the system during 2008 to 2009 is about 6.96 × 10^8 m^3 and the total out flow is about 6.956 × 10^8 m^3 respectively. The optimization results of parameters were calibrated automatically during the model processing using the Parameter Estimation Package “PEST”. The initial values of all parameters, which are calibrated and comparison with estimated values were presented in Table 5. While the initial values of recharge and optimization results were visualized in Figure 7. The predictive was carried for 40 years (that is, 2009 to 2048) during this period; all parameters and well exploitation of 2009 were maintained constantlly. According to 2009 total water consumption about 1021.5 Mm^3, for irrigation, animals and industrial. 31% (314.67 Mm^3) of them from groundwater withdrawn per year and about 752.73 Mm^3 is withdrawn for irrigation purposes 27% (203.75 Mm^3) from groundwater. Likewise, according to 2010 about 725.46 Mm^3 is withdrawn for irrigation purpose; 27.7% (200.88 Mm^3) of them is from groundwater.

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