Simulation of Water Resources in Irrigation Areas using Modflow Coupling Optimization Algorithm

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***Abstract* — For rational use of surface water and groundwater resources to improve the ecological environment of irrigation area, this paper provides the basis for the realization of the most stringent water management schemes. Taking People's Victory Canal irrigation district as the research area, we: i) use ArcGIS to analyze the People's Victory Canal irrigation district groundwater utilization status, ii) use Matlab optimization model with the goal of maximizing the net irrigation benefit, iii) propose the establishment of surface water and groundwater joint scheduling and crop structure optimization model coupled with MODFLOW model, iv) establish a fully irrigated three dimensional flow numerical simulation model. Our results show detailed values for the well-canal irrigation proportions which can significantly improve the irrigation area of groundwater funnel status quo and the trend of the underground water level serious decline. The results of the study provide a scientific basis for irrigation water management and the sustainable development of agriculture.**

Keywords- well-canal irrigation district; groundwater depth; the coupling optimization model; wells layout; the well-canal irrigation proportion; planting structure

I. INTRODUCTION

At present, there are some problems in most well-canal combined irrigation areas in China, such as contradiction between supply and demand of water resources, unreasonable pumping well layout, severe overexploitation of groundwater and etc. [1] In order to realize the most strict water resource management, economize the water resource, obtain the maximum comprehensive benefits and improve ecological environment in irrigation area, it is very necessary to carry out optimizing of water distribution scheme and optimizing of crop planting structure with combined use of groundwater and surface water in irrigation area and researching on rational layout model of pumping well, which has attracted wide attention from the scholars at home and abroad and made a lot of research work. On the aspect of research methods for optimization allocation of water resource in irrigation area, there mainly is stochastic programming, genetic algorithm and ant colony optimization and etc.; for example, Fu Yinhuan et al. use the method of stochastic programming of stage 2 of interval to establish optimization allocation model of united operation of surface water and groundwater[2]; Chen Nanxiang et al. make the problem of optimal allocations of eater resources simulated as the problem of biological evolution by using genetic algorithm[3]; Hou Jingwei et al. introduce the multi-objective shoal of fish-ant colony algorithm in the model to make optimal allocation for water resource in Zhenping County, Henan Province[4]; Ma Jianqin et al. apply the particle swarm algorithm of immune evolution to Puyang irrigation area, which provides theoretical basis for water resource allocation in irrigation area[5]; Mohammad Reza BazarganLar et al. make allocation for surface water and groundwater in Tehran by using non-dominated sorting genetic algorithm[6]. On the aspect of research on optimization method of crop planting structure in irrigation area, there mainly is linear programming method, nonlinear programming method, multi-objective programming method and etc., for example, Liu Xiao et al. introduce the fuzzy concept in multi-objective linear optimization model, and make optimization for crop planting structure by using fuzzy multi-objective linear optimization model for various crops in Minqin County, Gansu Province[7];on the aspect of optimal operation for agricultural water system and water resource system in irrigation area, linear programming, non-linear programming, multi-objective programming[18], stochastic programming, ant colony algorithm and etc. mainly are adopted at present; however, there are few researches on making nested coupling for MODFLOW model, optimization algorithm and GIS technique so as to make space optimization for surface water resource, groundwater resource and crop planting structure. Therefore, the simulation is made by taking People's Victory Canal Irrigation Area as research object and adopting the MODFLOW model and coupling the optimization algorithm and reasonable allocation of water resource in irrigation area so as to determine optimal well-canal ratio of water utilization, pumping well layout and optimization and adjustment scheme for crop planting structure, which has important guiding significance for sustainable development and utilization of water resources in irrigation area.

II. STATUS ANALYSIS ON GROUNDWATER IN PEOPLE'S VICTORY CANAL IRRIGATION AREA

People's Victory Canal Irrigation Area is one of the main grain producing areas in Henan Province, the irrigation area is located in the north shore of Yellow River of Henan Province, with east longitude 113°31′—114°25′ and north latitude 35°0′—35°30, which mainly includes 7 counties and 1 suburb of Xinxiang County, Xinxiang Suburb, Yuanyang, Huojia, Yanjin, Weihui, Wuzhi, Hua County; designed irrigation area in the irrigation area is 99,200hm2, and the area of effective gravity irrigation is 56,500 hm2 and area of source compensation irrigation is 22,200 hm2, which makes about 2,470,000 people[18] benefited. Multi-year average annual precipitation in irrigation area is about 600mm, and precipitation is unequally distributed, which mainly concentrated in June-September and accounts for 70%-80% precipitation of the whole year. The terrain in irrigation area is flat and its ground slope is not large and average slope is about 1/4000, and the main geomorphic types are Yellow River beach, depression back to Yellow River, Ancient Yellow River beach, depression back to ancient Yellow River, piedmont connected depression of Taihang Mountain and sand dune sandbeach of yellow River old riverway[19].

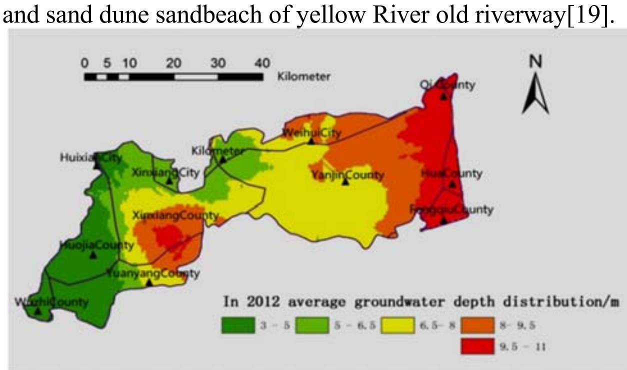

Figure 1. Distribution diagram of groundwater depth in people's victory canal irrigation area

People's Victory Canal Irrigation Area belongs to mainstream sediment on the middle and upper part of alluvial fan, and its aquifer mainly is gravel and medium and fine sand and its thickness is 12~25m, depth of roof for aquifer is 50~20m, the specific capacity is 10～30m³/(h*m) and hydraulic conductivity (K) is 10～30m/d. Storage condition of water level for People's Victory Canal Irrigation Area in the region of Wuzhi County-Xinxiang-Yanjin is very well, and its lithological character is single layer structure dominated fine sand and silt-sand, and the specific yield μ is between 0.065～0.1 and transmissibility is great and the coefficient of transmissibility T is more than 1000m³/d. Water storage condition in the region of Qiliying-Hua County-Neihuang is great, its specific yield is 0.05 generally and coefficient of transmissibility T is in 500～1000m³/d generally. In the region of Yanjin and Xinxiang between Wei River and Yellow River, its lithological character is dominated by sub-fine sand and loam, specific yield μ is between 0.036～0.04 and coefficient of transmissibility T is about 500m³/d.

In recent years, with the development of economy and society, the problem of water resources shortage is increasingly severe; in order to meet irrigation water demand of crop in irrigation area, quantity of groundwater exploitation become larger and larger, as shown in Fig. 2.

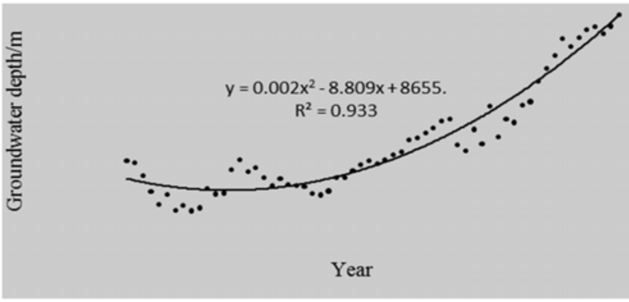

Figure 2. Variation diagram of groundwater depth in people's victory canal irrigation area

Seen from Fig. 2, average underground depth of People's Victory Canal Irrigation Area overall shows rapid growth tendency; average depth of groundwater in irrigation area even is more than 7m in 2013 and part of pumping well has dried up from 1953 to 2013. If the overexploitation of groundwater is made constantly, the groundwater level will continue to decline and wide-range groundwater depression cone will happen and ecological environment of irrigation area will be further deteriorated [20]. Therefore, it is a matter of great urgency to design and prepare optimization scheme of reasonable development and utilization of groundwater in irrigation area.

III. GROUNDWATER DYNAMIC SIMULATION BASED ON MODFLOW AND MATLAM

A. Unit Division of Groundwater Calculation in Irrigation Area

According to the data of 228 observed well points of the whole irrigation area, Chris King interpolation method of ArcGIS is used to get average depth diagram of groundwater in irrigation area. According to the depth status of groundwater, divide unit division of groundwater calculation of calculation unit; and the irrigation area can be divided into 6 areas according to depth condition of groundwater, as shown in Fig. 3.

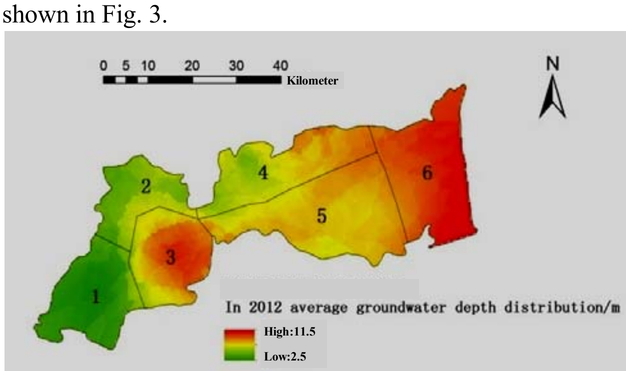

Figure 3. Calculation unit division of people's victory canal irrigation area

Seen from Fig. 5, there is uneven distribution for groundwater depth status in irrigation area, and there is severe overexploitation in some places, such as Area 3 and

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Area 6, and groundwater depression cone has even been formed in Area 3; there is development potential in some places, such as Area 1. Average depth of groundwater of whole irrigation area is declining year by year, and the average depth of groundwater from 2007 to 2013 for each area can be calculated according to statistical functions of each area of ArcGIS, which can know that groundwater depth in Area 2 and Area 6 of middle and downstream area shows an increase tendency all the time except to Area 1, in which, there are biggest change for Area 6 in the middle and downstream area, and its linear incline ratio is 0.358 m/a; followed by the Area 3 and Area 5 in the midstream, and its linear incline ratio respectively is 0.228 m/a and 0.206m/a.

B. Establishment of Optimization Model

(1) Objective function

The purpose of optimization is to make limited water resource play the maximum economic benefits and improve ecological environment at the same time. Take the irrigation amount from Yellow River, quantity of groundwater exploitation of each area and each period of irrigation area and crop planting area of each area as decision variable and take minimum and maximum water consumption in irrigation area as objective to construct model of optimal allocation of multiple water resource, which can be expressed as the difference of irrigation costs of economic benefit of crop and canal water and irrigation by well water. People's Victory Canal Irrigation Area is typical irrigation area with well and canal, and its source of main water supply is irrigation amount from Yellow River and groundwater. Dry crops and rice mainly are planted in irrigation area, and dry crops include wheat and maize, in which, crop rotation is made for wheat and maize; take one month as a period, adopt precipitation and evaporation capacity in 2013 to calculate irrigation benefit of one year to obtain the optimal irrigation amount from Yellow River, groundwater quantity of each month and each area and the crop planting area of each area. Objective function of model is shown as follow:

$$\max Z = \sum_{i=1}^{6}\sum_{j=1}^{2} P_j y_j A_{ij} - \sum_{i=1}^{6}\sum_{t=1}^{12} Q_{qti} C_1 - \sum_{i=1}^{6}\sum_{t=1}^{12} Q_{gti} C_2 \quad (1)$$

Where: Z is total economic benefit of irrigation area (yuan); y_1 is yield per unit of planted wheat and maize (kg/m2); P_1 is the unit price of wheat and maize (yuan/kg); y_2 is the unit price of planted paddy (kg/m2); P_2 is the unit price of paddy (yuan/kg); C_1 is the unit price of irrigation amount from Yellow River (yuan/m); C_2 is unit price of pumping groundwater (yuan/m3); Q_{qti} is irrigation amount from Yellow River in subarea i at t period (m3) and Q_{gti} is pumping amount of groundwater in subarea i at t period (m3).

(2) Constrain condition.

1) Constraint of irrigation water requirement: the sum of canal water and groundwater and effective precipitation shall meet water requirement of crop; irrigation water requirement of each division for each month can be obtained according to planting structure and irrigation norm in People's Victory Canal Irrigation Area.

$$\sum_{i=1}^{6}\sum_{t=1}^{12} n_{tj} A_{ij} - \sum_{i=1}^{6}\sum_{t=1}^{12} Q_{qti} - \sum_{i=1}^{6}\sum_{t=1}^{12} Q_{gti} \le \alpha \sum_{i=1}^{6}\sum_{t=1}^{12} P_{ti} \quad (2)$$

Where, n_{tj} is irrigating water quota of jth type of crops within t period (m3/m2); A_{i1} is the area of planted wheat and maize in area i (m2); A_{i2} is the area of planted wheat and maize in subarea i (m2); P_{ti} is the precipitation in subarea i at t period, and i =1, 2, …, 6; j=1, 2; t=1, 2, …, 12. According to research result of water-saving reform in Henan People's Victory Canal Irrigation Area, the effective utilization coefficient α of precipitation is 0.1.

2) otal canal water constraint: because the canal irrigation of People's Victory Canal Irrigation Area is from water diverted from the Yellow River, total water consumption of canal irrigation is equal to irrigation amount from Yellow River.

$$\sum_{i=1}^{6}\sum_{t=1}^{12} Q_{qti} = Q_q \quad (3)$$

Where: Q_q is total irrigation amount from Yellow River (m3), i=1, 2, …, 6; t=1, 2, …, 12.

3) Constrain of groundwater resources amount:

$$\sum_{i=1}^{6}\sum_{t=1}^{12} Q_{gti} \le \beta_1 \sum_{i=1}^{6}\sum_{t=1}^{12} Q_{qti} + \beta_2 \sum_{i=1}^{6}\sum_{t=1}^{12} Q_{gti} + \beta_3 \sum_{i=1}^{6}\sum_{t=1}^{12} P_{ti} + \sum_{i=1}^{6}\sum_{t=1}^{12} \mu_i s_i h_{ti} \quad (4)$$

Where: β_1 is coefficient of infiltration replenishment of irrigation field (-); β_2 is regression coefficient of well irrigation (-); β_3 is the coefficient of precipitation infiltration (-); μ_i is specific yield in subarea i (-);s_i is control area in subarea i (m2); h_{ti} is the added value of groundwater depth of the ith subarea within t period (m), and i =1, 2, …6; t =1, 2, …, 12. According to research result of water-saving reform in Henan People's Victory Canal Irrigation Area, coefficient β_1 of infiltration replenishment of irrigation field can be determined as 0.35, regression coefficient β_2 of well irrigation can be determined as 0.1 and replenishment coefficient $\beta_3$of precipitation infiltration can be determined as 0.18.

4) Constrain of planting area: planting area of dry crops and paddy for each area shall be less than control area of each area.

$$\sum_{i=1}^{6}\sum_{j=1}^{2} A_{ij} < \sum_{i=1}^{6} s_i \quad (5)$$

Where: i=1，2，…，6；j=1，2.

5) Nonnegative constrains of variable:

$$A_{ij} > 0,\ Q_{qti} > 0,\ Q_{gti} > 0 \quad (6)$$

The optimal irrigation amount from Yellow River, groundwater intake quantity of each area for each month and planting area of dry crops and paddy of each area can be obtained by using matlab programming.

Numerical Simulation Model of Groundwater

Model calculation of the paper adopts finite difference method, and partial differential equation of motion model of groundwater unsteady flow is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_S\frac{\partial h}{\partial t} \quad (7)$$

Where: K_{xx}, K_{yy}, K_{zz} is hydraulic conductivity of main infiltration direction of groundwater flow, and dimension is (); Ss is ratio storativity of pore medium and its dimension is (L^{-1}). Specific yield μ in formula (4) is equal to the product of aquifer thickness m and unit storativity Ss, that is μ＝mSs. t is time (T), h is underground water head, and its dimension is (L); W is source sink term (T^{-1}), which is used to represent the water quantity of flowing into converging or from the source, and mainly includes infiltration replenishment of canal irrigation, infiltration replenishment of well irrigation and precipitation infiltration replenishment.

(1) Mesh subdivision

According to hydrogeological map and topographic map in research area and seen from the drilling data, the aquifer of infiltration area is single aquifer and the type of groundwater is driving property; therefore, the calculation layer in model is set as one and actual control range of People's Victory Canal Irrigation Area is taken as the boundary in research area; make mesh subdivision for infiltration area, which can be subdivided by 160 lines and 74 rows and the total of it is 11840 square units, as shown in Fig. 4. Geometric model is generated and mesh is subdivided according to location and range of irrigation area; as shown in Fig. 6, green mesh is invalid unit and white mesh is valid unit:

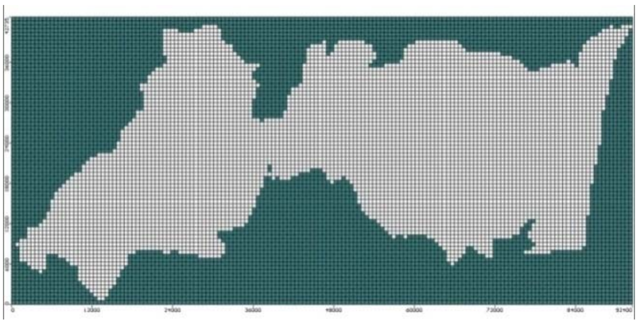

Figure 4. MODFLOW mesh subdivision

(2) Period division

According to years of the data of measured data, precipitation and irrigation volume and exploitation quantity of groundwater level of monitoring well of the People's Victory Canal collected by Xinxiang Hydrology and Water Resources Survey Bureau, in 2011 and 2012, the depth data of groundwater is quite complete and 2011 and 2012 are selected as calibration period of model and 2013 is selected as the verification period of the model; this research takes month as stress period and time step is calculated by day.

(3) Initial condition

According to period division, the January 2011 is taken as the initial velocity field for calculating and evaluating the groundwater resources. According to actual observational data of existing observation well, initial water level of phreatic aquifer can be obtained by using interpolation of Kring Universal Kriging Method.

(4) Boundary conditions

The boundary of MODFLOW is divided into horizontal and vertical boundary. As shown in Fig. 7, southwest direction of irrigation area is set as constant head and northeast direction is set as water head, and boundary replenishment rate or output can be automatically calculated by GHD and GHB subroutine package. Vertical replenishment is mainly infiltration replenishment of canal irrigation, infiltration replenishment of well irrigation and precipitation infiltration replenishment; vertical output is mainly phreatic water evaporation and groundwater exploitation; Fig. 5 is equipotential line diagram on boundary conditions and initial water head of MODFLOW model and the location of observation well is marked.

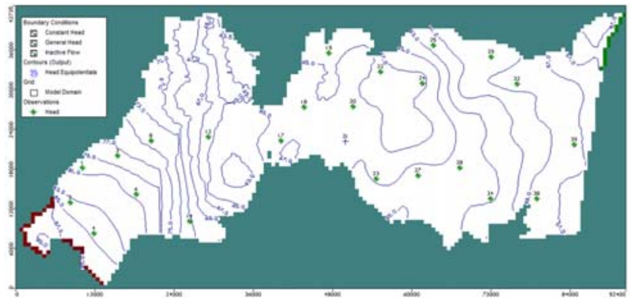

Figure 5. Equipotential line on boundary conditions and initial water head of MODFLOW

C. Calibration and Verification of Subsurface Model

Ground elevation of irrigation area is actual ground elevation; according to investigation and survey condition of pumping test and research area, the initial hydrogeological parameter can be determined, which can be determined as K_{xx}, K_{yy}, K_{zz} and S_S; hydrogeological parameter is calibrated by using actual measured groundwater level data in 2011 and 2012, and is verified by using actual measured groundwater level data in 2013.

During calibration period and verification, the location of observation well of the whole irrigation area is shown in Fig. 5, and scatter diagram of value of simulation and observed value of groundwater is shown in Fig. 6 and calculation result of error indicator is shown in Table 1. Simulated result is shown in Fig. 8. It is thus clear that each point is evenly distributed nearby 1:1 both sides of correlation line; all calculated level is compared with original water level of observation point, and the errors are within acceptable level; therefore, it is proved that established generalized hydrogeological model of groundwater conforms to actual condition of research area, and established numerical model of groundwater can be used to predict variation trend of groundwater flow field in People's Victory Canal Irrigation Area.

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TABLE 1. CALCULATED VALUE OF GROUNDWATER LEVEL AND ERROR INDICATOR OF OBSERVED VALUE (MODFLOW MODEL, CALIBRATION PERIOD AND VERIFICATION PERIOD)

Error indicator	Mean residual RM/m	Mean absolute residual ARM/m	Standard error estimation /m	Root mean square RMS/m	Ration of standard root mean square NRMS/%	Correlation coefficient
Calibration period	0.09	0.478	0.118	0.574	2.086	0.997
Verification period	0.149	0.458	0.108	0.539	1.959	0.998

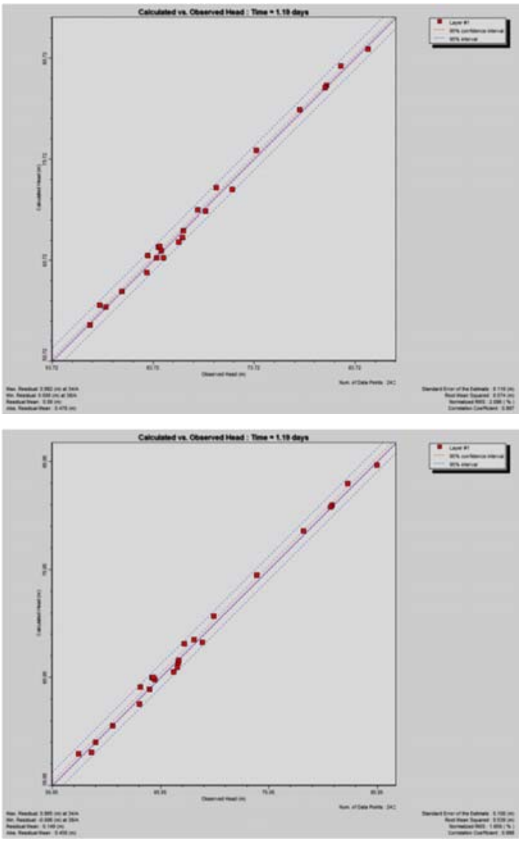

Figure 6. Simulated results of calibration period and verification period for modflow model

D. *Coupling of Optimization Model and MODFLOW Model*

Quantity of groundwater exploitation and irrigation amount from Yellow River of each area for each month can be calculated according optimization model and the exploitation quantity of pumping well and infiltration replenishment of irrigation and etc. in MODFLOW model can be further determined; precipitation infiltration replenishment, infiltration replenishment of canal irrigation and infiltration replenishment of well irrigation of source sink term W in MODFLOW simulation model formula of groundwater (7) can be determined by adopting the precipitation and evaporation capacity in 2013, precipitation and P_{ti} and MATLAB optimization model formula (2), and calculation formula is shown as below. Q_{qti} and Q_{gti} respectively are the irrigation amount of water diverted from the Yellow River and groundwater of each area for each month calculated by MATLAB optimization model formula (1).

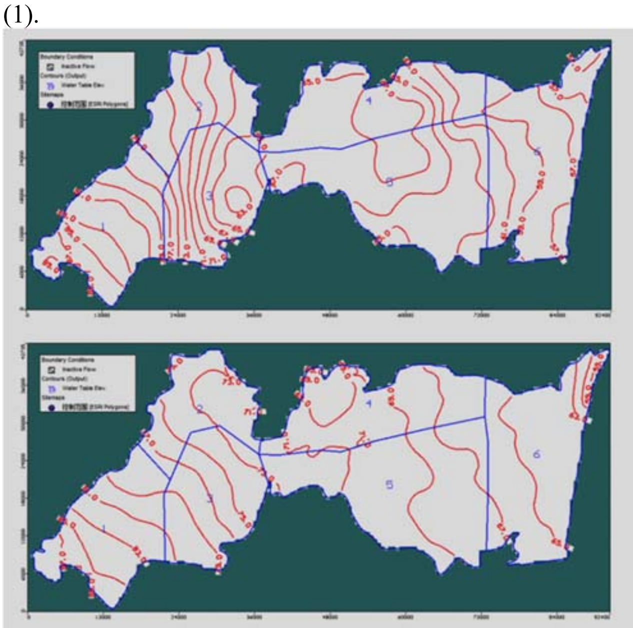

Figure 7. Groundwater level contours at beginning of simulation and simulation after one year

Infiltration replenishment of canal irrigation of each area for each month is:

$$Q_{canal\ irrigation} = \beta_1 \sum_{i=1}^{6} \sum_{t=1}^{12} Q_{qti}\text{, } i=1,2,\ldots,6;\ t=1,2,\ldots,12; \quad (8)$$

Infiltration replenishment of well irrigation of each area for each month is:

$$Q_{well\ irrigation} = \beta_2 \sum_{i=1}^{6} \sum_{t=1}^{12} Q_{gti}\text{, } i=1,2,\ldots,6;\ t=1,2,\ldots,12; \quad (9)$$

Precipitation Infiltration replenishment of each area for each month is:

$$Q_{Precipitation} = \beta_3 \sum_{i=1}^{6} \sum_{t=1}^{12} P_{ti}\text{, } i=1,2,\ldots,6;\ t=1,2,\ldots,12; \quad (10)$$

Groundwater replenishment of each area for each month is:

$$Q_{\text{replenishment}} = Q_{\text{canal irrigation}} + Q_{\text{well irrigation}} + Q_{\text{Precipitation}} \tag{11}$$

Where: β_1 is coefficient of infiltration replenishment of irrigation field (-); β_2 is regression coefficient of well irrigation (-); β_3 is the coefficient of precipitation infiltration (-); according to research result of water-saving reform in Henan People's Victory Canal Irrigation Area, coefficient β_1 of infiltration replenishment of irrigation field can be determined as 0.35, regression coefficient β_2 of well irrigation can be determined as 0.1 and replenishment coefficient β_3 of precipitation infiltration can be determined as 0.18.

After calculating the groundwater replenishment, it can be transferred by MODF model with the mode of data sharing; and after the quantity of groundwater exploitation is calculated by matlab optimization model, generalized method is used to calculate quite even area with average exploitation intensity according to distribution condition of wells group in irrigation area and arrange well point of exploitation by partition in MODFLOW model.

After operation of optimization model after one year, the contour line of groundwater level is shown in Fig. 9, from which it can be seen that the change of overall form of groundwater flow field is not large, water level of water source for concentrated exploitation of groundwater generally rises, the range of cone of depression reduces, contour of water table rises and its state of overexploitation of groundwater has been improved after making optimal allocation for surface water, groundwater, and crop planting structure.

E. Calculation Results

Statistics to calculation results calculated by optimization is shown in Table 2.

TABLE 2. CROP AREA AND PLANNING TABLE OF WELL NUMBER OF EACH DIVISION IN IRRIGATION AREA

Division	Upstream	Midstream				Downstream	Total
	1	2	3	4	5	6	
Planning area of dry crops/104 m2	28311.93	20068.75	19268.14	31702.75	49456.37	37033.54	185841.49
Existing area of dry crops/104 m2	10246.04	15274.99	19745.98	19563.47	40744.40	37603.10	143177.98
needed to be newly increased for paddy/104 m2	18065.89	4793.77		12139.27	8711.97		43710.90
needed to be cut down for dry crops/104 m2			477.84			569.56	1047.39
Planning area of paddy/104m2	689.88						689.88
Existing area of paddy/104 m2	14850.06		101.95				14952.02
Area needed to be cut down for paddy/104 m2	14160.18		101.95				14262.13
Number of planning well/aperture	1088	1207	1277	1906	2964	2600	11042
Number of existing well	824	2657	6363	3122	2293	5002	20261
umber of well needed to be increased and decreased	264	-1450	-5086	-1217	671	-2402	-9219
Amount of water diverted from the Yellow River/104 m3	3449.87	2373.27	2163.76	3754.32	5866.85	4336.32	21944.40
Quantity of groundwater exploitation	1983.72	1235.09	1246.48	1948.78	3035.20	2300.40	11749.68
Ratio of water utilization of well canal	0.58	0.52	0.58	0.52	0.52	0.53	0.54

Optimization algorithm is used to adjust and analyze the crop planting structure, in which, there is maximum development potential for groundwater in Area 1, and the planting area of wheat and maize can be increased by 180,658,900 m2; there is development potential in Area 2, 4 and 5, and the planting area can respectively be increased by 47,937,700 m2, 121,392,700 m2 and 87,119,700 m2, and planting area in Area 3 and 6 needs to be cut down. Most paddies in irrigation area are planted in Area 1, because the water consumption of paddy is more, planting area of paddy can be decreased and the planting area of dry crops can be increased in order to effectively use the water resources in irrigation area; planting area of optimization and adjustment of paddy is shown in Table 1, in which, the planting area of paddy in Area 1 and 3 that needs to be cut down respectively is 148,500,600 m2 and 1,019,500 m2. It can be known that the upstream of irrigation ratio of upstream well canal is adjusted as 0.58, and Area 2, 3, 4, 5 of midstream respectively are adjusted as 0.52, 0.58, 0.52, 0.52 and Area 6 of downstream is adjusted as 0.54 by calculation of optimization algorithm.

IV. CONCLUSION AND DISCUSSION

(1) In recent years, the problem of water resources shortage in People's Victory Canal Irrigation Area is increasingly severe; in order to meet irrigation water demand of crop in irrigation area, quantity of groundwater exploitation become larger and larger and groundwater depth shows an increase tendency. When the irrigation ratio of well canal in irrigation area is between 0.5~0.6, exploitation and replenishment balance can be realized basically for groundwater in irrigation area. The larger the water utilization of well canal is, and the more quantity of groundwater exploitation is[21]; affected by the change of environment, the irrigation ratio of canal irrigation in irrigation area is too large, the groundwater is overexploited and groundwater depression cone has been formed in some areas. If the state of overexploitation of groundwater in irrigation area is not changed, the ecological environment in irrigation area will be further deteriorated.

(2) The paper combines the simulation model and optimization model of groundwater, makes optimization for allocation of irrigation amount from Yellow River and the planting area of crops by adopting MATLAB programming, which improves the accuracy of the results. The simulation results show that if the scheme of optimizing water used and crop planting area is adopted, the water level of the area where groundwater level seriously declined can be raised, especially the groundwater level of the area where its groundwater seriously declined of Area 3 in midstream and Area 6 in downstream, the range of cone of depression can be reduced and the state of groundwater depression cone can be improved. After the adjustment of optimization algorithm, the Area 1 is adjusted as 0.58, Area 2, 3, 4, 5 can respectively be adjusted as 0.52, 0.58, 0.52 and 0.52 and Area 6 in downstream is adjusted as 0.53 for its irrigation ratio of well canal, which can realize exploitation and replenishment balance of groundwater. There is development potential in Area 1 in upstream and Area 2, 4 and 5 in midstream, so the planting area of wheat and maize can be increased by 437,109,000 m2 in total; planting area of wheat and maize in Area 3 in midstream and Area 6 in downstream needs to be reduced by 10,473,900 m2. Planting area of paddy in Area 1 in upstream and Area 3 in midstream needs to be reduced by 149,520,200 m2 in total. Number of pumping well planned in irrigation area is adjusted from 20261 to 11042, which can obviously improve the statue of groundwater depression cone and tendency of serious declined groundwater level in irrigation area.

(3) Statistic calculation is made with Arc GIS according to years of actual measured date in irrigation area, and dynamic simulation model of groundwater in well-canal combined irrigation area is established combined with MODFLOW, calculated water level of simulation is compared with original water level of observation point and each point is evenly distributed nearby 1:1 both sides of correlation line and the errors are within acceptable level, which shows that determined hydrogeological parameter can objectively reflects conceptual model of actual geology; MODFLOW model can be used to simulate spatial variation of groundwater in People's Victory Canal Irrigation Area.

(4) Coupling model established in the paper is to nest MODFLOW and optimization algorithm and ArcGIS, which can not only expand the functions the model and improve accuracy of the model, but also simulate the condition of development and utilization of groundwater. Because of difference of hydrogeology condition for each area, MODFLOW model parameter needs to be identified and verified combined with local hydrogeological condition if the model is applied to other areas.

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