Decision Support System of Regional Water Resources

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Abstract— **It is very important to dispose the water resources rationally. Rational disposition of water resources is the nucleus of sustainable water resources utilization, and is the important way to solve the district water resource shortage and raises utilization efficiency of water resource. A decision-making variable model is established by groundwater, surface water and precipitation. Water resources managing decision support system in handan is developed on the language of visual basic, with the usage of database-access and the map-object GIS groups. And the system has the functions including managing function of data and files and editing function of images. During the model built, idea of decision-making variable deduction is adopted to transform three kinds of water to get the results of sustainable utilization of water resources. Finally Visual software is programmed Using GIS and VB language, and the rational blue print of water resources in this region can be decided applying optimized model . The system plays an important role in the water resources management.**

Index Terms—**decision-making variable deduction; water resources; decision support system; handan**

I. INTRODUCTION

Water resource is one of the basic substances for human survival and development which is an indispensable natural. Since the latter half of 20th century, along with social development and economic growth and rising living standards, it is obvious for contradictions between water supply and water demand, and it is even more acute to earn water between industrial and agricultural. However, water shortage, pollution and rampant flooding is restraining global economic and social development, but also is one of the constraints faced in the process of building a moderately prosperous society. Throughout human history of development and utilization of water resources can be found that socio-economic development of water demand is far less than the amount of available water resources in the primitive stage of water resources, because of low levels of social productive forces, sparsely populated. Water seems " misdischarge ". In the traditional stages of development and utilization of water resources, human take large-scale construction of water conservancy prohrct as the main measures to meet the needs of socio-economic development on water resources. Along with the water shortage, floods, water pollution and other issues, inconsistent relationships among the water resources and social, economy and environment have become increasingly prominent. Traditional way of development and utilization of water resources has faced a great challenge to force the sustainable use resources development of ideological transformation. The water problem in Handan city is very pendent. There are also three major water problems. The first is the contradiction between water supply and demand, the second is the flood disaster and the third is water quality pollution, namely the so-called water sparsity, water flowage and water pollution. There is close relationship the realization of water resources' sustainable utilization and the natural, social and economic factors in this region it's bound to carry out the specific region [5]. The region is a complicated system with regional disparity and hierarchy. To the complicated system, a lot of research is to be done. In this paper, according to the sustainable development strategy, based on the systematic engineering theory and water resources systematic analysis, we studied this decision system. It will supply scientific basis to the reasonable utilization of the regional water resources in agriculture and water resources protection.

II. STUDY AREA

The annual rainfall in handan is 558.8mm, among them, it is 587.6mm in Fuyang land area, and 578.7mm in Zhanghe Mountain, 530.1mm in West Fuyang , 554.7mm in Weihe plain. Precipitation in eigvenvalue statistics and different assurance can be seen in table 1.

TABLE I. PRECIPITATION IN EIGVENVALUE STATISTICS AND DIFFERENT ASSURANCE

Subarea	Eigenvalue			Precipitation in different assurance		
	均值	Cv	Cs/Cv	50%	75%	95%
City wide	558.8	0.3	2.0	542.0	435.9	312.9
Fuyang Land area	587.6	0.34	2.5	558.2	440.7	317.3
Zhanghe mountain	578.7	0.3	2.0	561.3	451.4	324.1
West Fu plain	530.1	0.32	2.5	508.9	402.9	296.9
Zhang WEihe plain	554.7	0.3	2.0	538.1	432.7	310.6
Black dragon harbor plain	545.8	0.29	3.0	524.0	431.2	332.9
Majia River plain	561.5	0.29	2.0	544.7	443.6	325.7

TABLE II. ANNUAL RUNOFF CHARACTERISTIC VALUE AND RUNOFF IN DIFFERENT ASSURANCE

Subarea	Characteristics value			Runoff in different runoff		
	average	Cv	Cs/Cv	50%	75%	95%
City wide	6.9108	0.75	2.0	5.6741	3.1081	1.0360
Fuyang Land area	2.5813	0.88	2.0	1.9370	0.9285	0.2057
Zhanghe mountain	1.9922	0.54	2.0	1.7919	1.1946	0.6166
West Fu plain	0.8819	1.30	2.0	0.4589	0.1222	0.0100
Zhang WEihe plain	0.6382	1.15	2.0	0.3887	0.1349	0.0121
Black dragon harbor plain	0.7266	1.2	2.0	0.4202	0.1301	0.0136
Majia River plain	0.0906	1.26	2.0	0.0491	0.0137	0.0011

III. QUANTITAVE MODEL OF REGIONAL WATER RESOURCES

The amount of regional water resources is the production of surface and underground water. Available water resources in handan area include Zhang river, Weihe river, fuyang river, etc. No major regulating reservoirs in this region, uneven distribution of precipitation, the river are not only transited for community, also need to optimize the allocation of water resources.

Evaluation of regional water resources is generally based on balance principle of land surface water, along considering a landscape situation and groundwater depth in plain area. Therefore, calculation of water resources is a complex and cumbersome task, requiring consideration of surface water, groundwater, precipitation and transforming relationship among them.

A. calculation of groundwater resources

Calculation of groundwater resources require the simulation model of groundwater, which belongs to conceptual model. Based on the hydrogeological conditions of the region, the groundwater system can be taken into single dive-confined groundwater system. Groundwater flow can be generalized as two-dimensional surface flow, and the aquifer is non-homogeneous medium, and the flow state is steady. Therefore, the mathematical model of groundwater system in handan region can be expressed as followings:

$$\begin{cases} \mu\dfrac{\partial h}{\partial t}=\dfrac{\partial}{\partial x}\left[(h-b)K_x\dfrac{\partial h}{\partial x}\right]+\dfrac{\partial}{\partial y}\left[(h-b)K_y\dfrac{\partial h}{\partial y}\right]+W & (x,y)\in\Omega\,0<t\le T \\ h(x,y,t)\big|_{t=0}=h_0(x,y) & (x,y)\in\overline{\Omega}\,t=0 \\ (h-b)K\dfrac{\partial h}{\partial n}\bigg|_{\Gamma_2}=q(x,y,t) & (x,y)\in\Gamma_2,0\le t\le T \end{cases} \quad (1)$$

Where h is water level, b is lower confining bed level; W is supply water in unit time and unit area; μ is aquifer storage coefficient; $q(x,y,t)$ is unit discharge; k is permeability coefficient; n is outside normal direction.

B. Establishment of sustainable quantitative model of water resource

Sustainable quantitative model of water resources is a large and complex optimization model. The more difficult question is how to coordinate the relationships among precipitation-surface water- groundwater water to achieve scientific and reasonable utilization. In this paper, hierarchical analysis and decision variable subtraction are introduced to solve the water resources.

Decision variable subtraction method is that the meteoric of precipitation or surface water supplies should be subtracted from the decision variable of groundwater exploitation, then to optimize the decision variables.

Decision variable subtraction can be expressed as followings

$$Q_g=\begin{cases} \le Q_d, & \Delta Q_d=Q_d-Q_r>0 \\ 0, & \Delta Q_d=Q_d-Q_r\le 0 \end{cases} \quad (2)$$

Where rainfall is abundant and the surface water and groundwater are lack.

$$Q_g=\begin{cases} \le \Delta Q_d & \Delta Q_d=Q_d-Q_r>0 \\ =0 & \Delta Q_d=Q_d-Q_r\le 0 \end{cases} \quad (3)$$

Where surface water is abundant while rainfall and groundwater is lack

$Q_g=Q_d$ where groundwater is abundant while rainfall and surface water is lack.

Where Q_r net flow of precipitation

Q_s surface water flow; Q_g groundwater flow; Q_d water requirement

Above equation is how to dispose the decision variable in any grid. Decision variable subtraction can be seen as one preprocess. The construction of the model can be expressed as followings
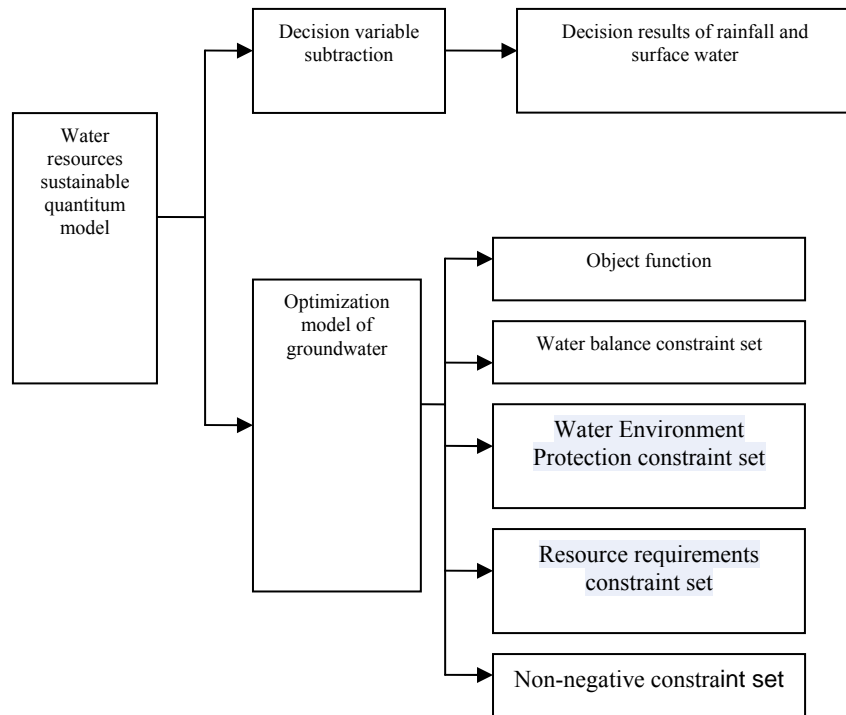
Figure 1.   structure of sustainable water resources quantitative model

C. Optimization model of water resources

Two-dimensional finite difference flow simulation model is adopted to integrate the model and simulation model, which can be seen as water balance constraints dived to the optimization model directly. The optimized model includes

1) Goal Function

①Economic goals

The direct economic benefits brought by the development and utilization of water resources in the region are as the main economic goals. The economic goals can be expressed as followings

$$\max Z = \sum_{k=l}^{T} \sum_{l} \lambda_l f(H_i^k, C_s^k, Q_w^k, Q_r^k) \quad (4)$$

Where k is phase loop variable; l is target loop variable; λ_i is target selection coefficient; f is composition relations of decision variables; $H_i^k, C_s^k, Q_w^k, Q_r^k$ is water level, pollutants concentration; development and utilization of water and artificial water recharge decision variable set.

②Social goals

In essence, the purpose of all economic activity is minimal consumption of resources for maximum national benefit. Water crisis enlighted us that the goal of government is to use renewable and limited water resources sustainable, and to create the greatest benefit for our country. Therefore, in theory, social economic can be measured using social welfare, Pareto standard can be used to determine the basic criteria of social welfare to improve. Because it is difficult to measure the social welfare and to express welfare function, in order to meet the operability requirements, the total water volume of the smallest are chosen to directly reflect the social objectives. Because the size of the regional water shortage and water scarcity directly impact the social development, reflecting increased water quality and quantity of services growth and increasing social needs of adaptation, which is directly related to the sustainable development of social security and social stability.

Assuming the regional water supply

$$x(t) = f(x_{lk}(t), x_{pk}(t), x_{ek}(t))$$

Volume scarcity $SO(x(t))$, throughout the entire process of development and utilization of water resources, the social objectives can be expressed as

$$\min\{TSO = \sum_{t=t_0}^{t_N} SO(x(t))\} \quad (5)$$

If domestic water consumption is $D_{lk}(t)$, water demand for production is D_{pk}, ecological water requirement is D_{ek}, then the $SO(x,t)$ can be expressed as followings

$$SO(x(t)) = \sum_{k=1}^{K} (D_{lk}(t) + D_{pk}(t) + D_{ek}(t)$$
$$- \sum (x_{lk}(t) + x_{pk}(t) + x_{ek}(t)) \quad (6)$$

③*Environment benefits goal*

To the water resources directly related to environment issues, the smallest amount of sewage can

be measured. In general, the emissions of major pollutants can be selected as expression.

If the regional water supply $x(t) = f(x_{lk}(t), x_{pk}(t), x_{ek}(t))$ resulting the emmision of major pollutants as $BO(x(t))$ in t period, then the environment benefits objectives cam be expressed as followings in the whole process of water resources development.

$$\min\{TBO = \sum_{t=t_0}^{t_N} BO(x(t))\} \qquad (7)$$

Further, $BO(x(t))$ can be expressed as

$$BO(x(t)) = \sum_{k=1}^{K} 0.01[d_{lk}(t)h_{lk}(t)x_{lk}(t) + \qquad (8)$$
$$d_{pk}(t)h_{pk}(t)x_{pk}(t) + d_{ek}(t)h_{ek}(t)x_{ek}(t)]$$

Where : d_{lk}, d_{pk}, d_{ek} respectively the content of main pollutants in sewage waste water in living, production, and ecological water in k region. Generally, BOD,COD, Tod can be as indicators of water quality. h_{lk}, h_{pk}, h_{ek} is the emission factor of ecological water and sewage water.

2) Constraints

① Conservation constraint

Conservation constraints are the simulation model of water resources system based on the mass conservation and energy conservation, as an aspecet of constraints, its mathematical formulation is as follows

$$[A][H] + [B][H] + g[Q_w^k, Q_r^k] = 0$$

$$[P][C] + [R][C] + f[Q_r^k, C_{sr}] = 0 \qquad (9)$$

Where $[A]$ $[P]$ $[B]$ $[R]$ is coefficient matrix.

② Water restriction

$$\sum_{w \in \pi} Q_w^k \geq D^k \qquad \text{D}^k\text{------water requirements in k}$$

stage.

③ Water system constraints[3]

a $\sum_{r \in \psi} Q_r^K \geq WL^K$ WL^K----sewage water capacity

in k stage

b $H_i^k \geq H_i'$ $i \in \Delta$, H_i'--- controled water level，Δ---set of control point

c $C_{SW}^K \leq C_{SW}'$ $w \in \pi$, $C_{S,W}'$ ---control values of regional concentration

d $C_{S,r}^K \leq C_{S,r}'$ $r \in \psi$, $C_{S,r}'$ ---control values of pollution concentration

e resources constraints

$$Q_W^K \leq Q_W' \quad w \in \pi, \ v\ k$$

$$Q_r^K \leq Q_r' \quad r \in \psi, \ v\ k$$

F Non-negative constraints $H_{i,}^K C_{S,}^K Q_W^K, Q_r^K \geq 0$

IV. WATER RESOURCES MANAGEMENT DECISION SYSTEM

(1) In order to depict water resources information vividly, figure management system is developed by Visual Basic program, MapInfo and surfer software.

(2) SURFER is coupled into VB program by OLE to make up underground water flow field model. Equivalent-value line can be drawn automatically by SURFER to depict the state of groundwater vividly.

(3)The aim is to get the largest water resources quantity of the study area, and the decision-making variable is to artificially using water resources quantity. The state variable is ground water flow, the limiting set is water-quantity equilibrium equation. Prepare for flood, deduce draught-disaster protect water resources from pollution. Sustainable water resources model is made up.

(4).The decision system is made up of prediction model and optimize model. It can be seen in Figure1

The following two objectives of this system are establishment of spatial information database and attribute information database of water resources in handan to share information resources; coupling the numerical simulation and GIS to provide a scientific basis for water resources decision-making in handan. The main functions are as followings.

A. Function of decision system

1) Map management

The features of this module are designed for water resource information management. Users can edit the map in this module. Users can directly control the display of layers, zoom in or out. Users can also increase the layers and add data types. The whole process is easy, fast and intuitive. And users can also control the displayer of various layers or not

2) Automatic Mesh Function

According to the users' request, the system can automatically divide the study area into different numbers of square grid and can be numbered and display. Fig.3 is the 110 grid by automatic mesh.
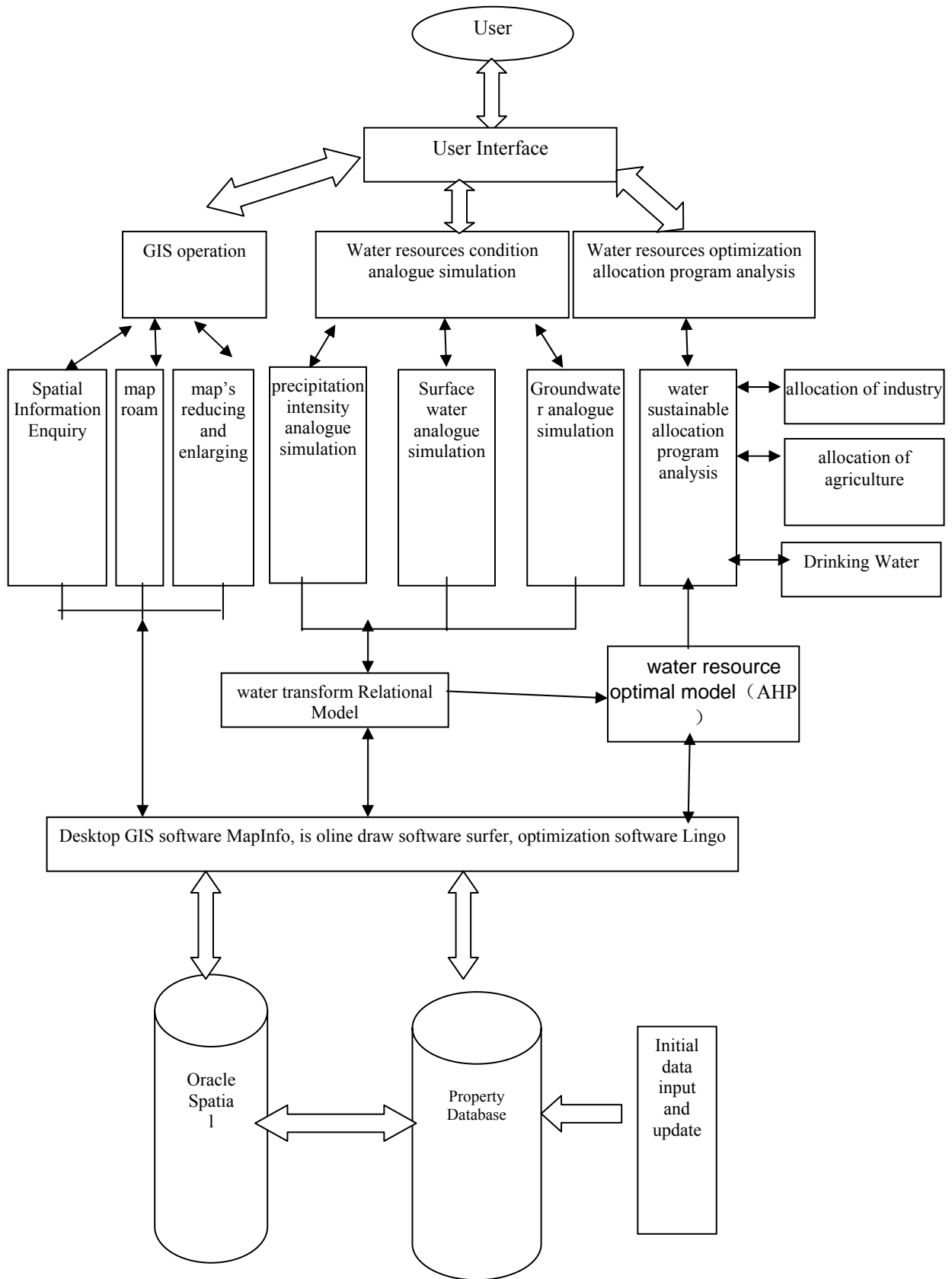
Figure 2.   the plan of regional water resources management decision system
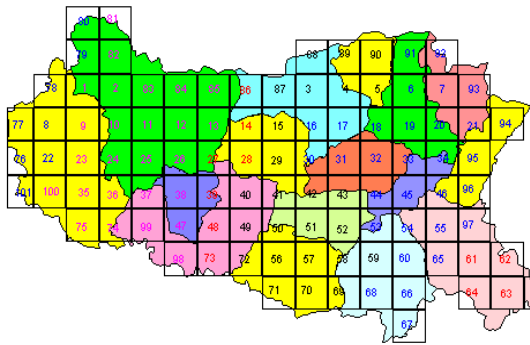
Figure 3.　　　　　The Grid of Regional Area of Study

3) Resources situation

The system can display the situation of groundwater(Fig.6) , surface-water (Fig.5) and rainfall(Fig.4)
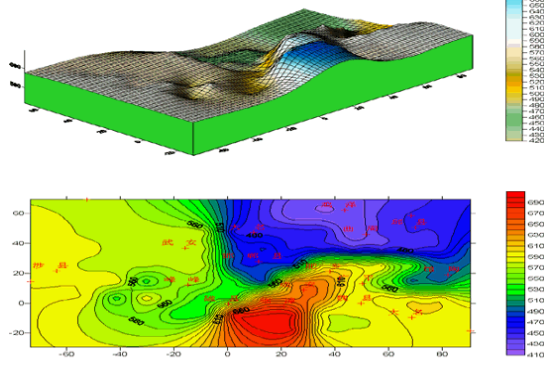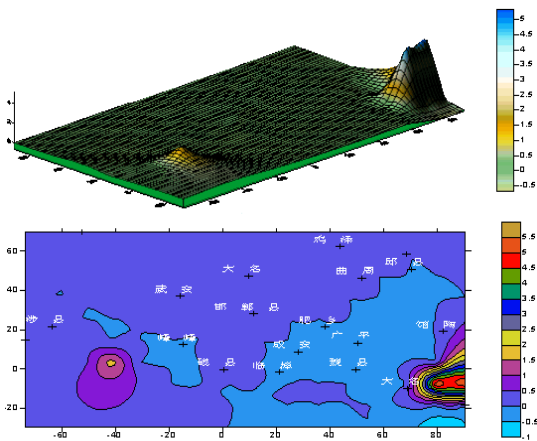

Figure 4.　　　　Distribution of precipitation

Figure 5.　　　　distribution of surface runoff

4) simulation and rendering of groundwater contour

The function of this module is to simulate the changes of groundwater levels when the exploitation quantitum

changes. By simulation, users can intuitively understand the trend of water level. According to the changes of groundwater extraction, groundwater contour can be drawn for finding the contour changes. Fig.7 is the distribution of simulated groundwater level , and Fig.8 is the distribution of observed groundwater level. Fig.9 is the comparison of simulated level with observation level, By comparison , the results is reasonable.
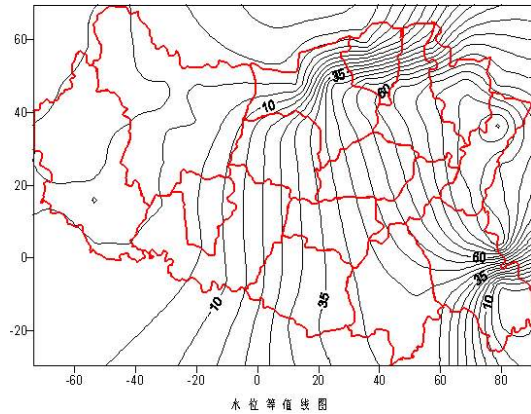

Figure 6.　　　　　distribution of groundwater level
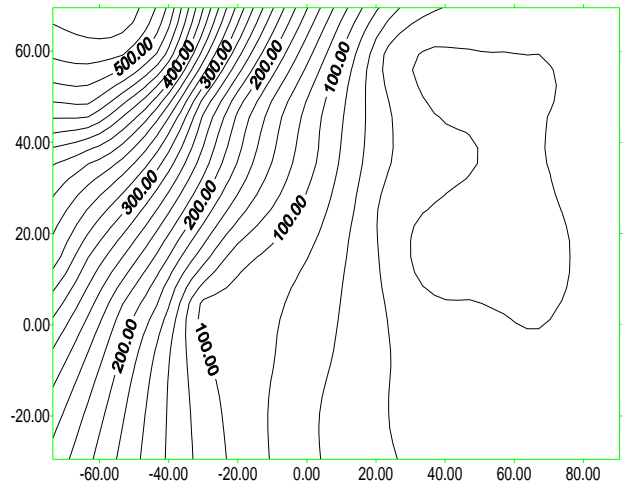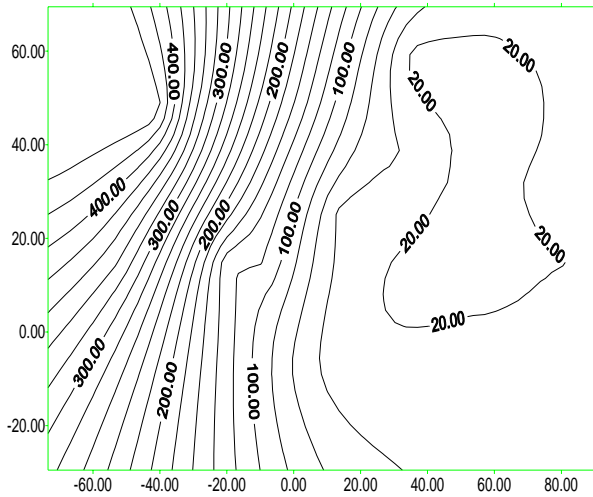

Figure 7.　　　　Distribution of groundwater (Simulation)

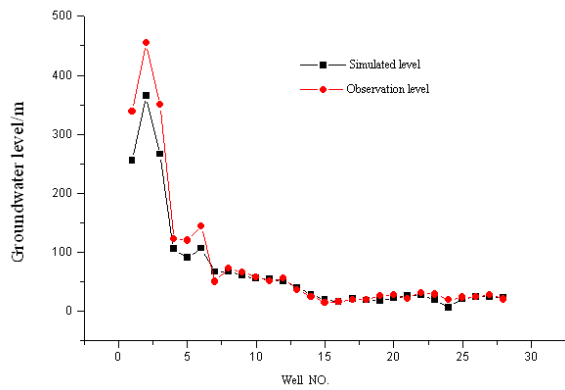Figure 8.   Distribution of groundwater(observation)

Figure 9.   Comparison of groundwater level with simulation
and observation

B. Optimization of water resources

Water resources management decision system in Handan city is a computer system based on the development-making of groundwater resources, surface water and atmospheric water. The system breaks through the existing results that most were only based on the existing fixed data of the data base to decide. Based on the existing data and according to the decision-maker's idea, choosing the project, exploitation time, site and quantity, using the groundwater numerical simulation prediction model and estimation decision module ; respond the landing condition exploiting quantity condition and groundwater flow field condition when exploiting , and supply dynamic and convenient groundwater resources management decision. In the decision-making process, whether the regional groundwater numerical simulation prediction model is exact or not, it will directly influence the reliability of the decision results. So, building up the exact regional groundwater numerical simulation prediction model is the key to carry through the right regional groundwater resources management decision. In this paper, the sub area method is adopted to effectively solve the calculation problem of the great area groundwater

resources using the computer. In the process of three kinds water translation first adopt idea of decision – making variable deduction to solve the three kinds water treatment method that puzzled people in the long time. Fig.10 is the optimization result. Seen from the fig.10 the system's running results afford the water resources management decision project of Handan city: by means of optimization collocation, we can get that west mountainous area is basically atmosphere water, while east plain is basically groundwater and the area including the river is basically river. So according to the management system, we can get the best plan for the utilization of water resources.
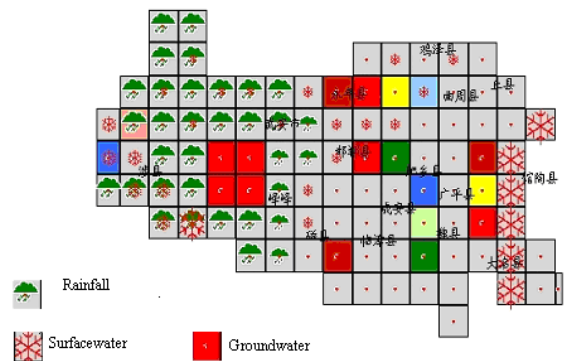

Figure 10.   distribution of water resources utilization

V.   CONCLUSION

According to the introduction of water resources decision support system's structural framing, the principle of design and the basic function, Some Characters are summarized as follows:

The system design has manifested face the question principle.

The system has certain applicable scope. It can carry on significant industrial policy for the related water resources development   and   appraisal of the environmental policy adjustment to provide decision-making and the early warning information .

The decision support system function is complete. Namely it has the functions of simulation, prediction, optimization, the analysis and management .

System's organizational structure is quite reasonable. The system is made up of model base, the database and the interactive contact surface. Data transfer completes through the database between the models. The man-machine interaction contact surface provides the information to the policy-maker by the electronic forms, the graph and the document, the policy-maker may carry on the transfer, the establishment and the revision by revising the parameters.

REFERENCES

[1] Zhang Y.Q, Miao Q.L.(2001). "Calculation and prediction of regional water resources". Scientia Geographoca Sinica, Vol. 21, NO.3, pp.457-462.(in Chinese)

[2] Dong J., Li S.Q., Mao W.B.(2007). "Study on the regional carrying capacity and optimization of water resources". China Rural water and Hydropower,Vol.11, pp.77-80.(in Chinese)

[3] Costa , Leonardo FSB (2001). "Control of water use in north-west Portugal (Spain) ". Dissertation Abstracts International. Vol.79, NO.7, pp.156 - 180

[4] RiJiberman (2000). "Deferent approaches to assessment of design and management of sustainable urban water system". Environment Impact Assessment Review , Vol. 129, NO.3, pp.333 – 345.

[5] Huang M.L.(2007)."Study of optimal allocation model of regional water resource in sustainable development". Water Conservancy Science and Technology and Economy, Vol.13, NO.9, pp.661-662.(in Chinese)

[6] Loucks D P.(1995). "Developing and implementing decision support systems a critique and a challenge". Water Resources Bulletin, Vol.31, NO.4, pp.571～582.

[7] Recio B, Iba′ez J , Rubio F, et al.(2005). "A decision support system for analyzing the impact of water restriction policies". Decision Support Systems, NO.39 , pp.385-402.

[8] Fassio A , Giupponi C, H iederer R, et al.(2005). "A decision support tool for simulating the effects of alternative policies affecting water resources: an application at the European scale". Journal of Hydrology, NO.304,pp.462-476.

[9] Qin Ju, Zhongbo Yu, Zhenchun Hao, Xi Chen, Chao She. Integration of artificial neural networks with a numerical groundwater model for simulating spring discharge [A].2010 4th International Conference on Intelligent Information Technoogy Application[C]. Institute of Electrical and Electronics Engineers, Vol.2, p361-364.

[10] Yeh YL, Su MD, Tsou I (1995). Forecasting of groundwater level using grey modeling. J Taiwan Water Conservancy 43: 66–73 (in Chinese)

[11] Hogg RV, Tanis EA (1988) Probability and statistical inference. Macmillan Publishing Company, New York

[12] CHEN Xi, LIU Chuan-jie, HU Zhong-ming, et al. Numerical modeling of groundwater in a spring catchment and prediction of variations in the spring discharge[J]. Hydrogeology and Engineering Geology, 2006, 2:36-40.

[13] Ju, Q., Z. Yu, Z. Hao, et al, 2009, Division-based Rainfall-Runoff Simulations with BP Neural Networks and Xinanjiang models [J]. Neurocomputing, 72, 2873-2883.

[14] Parkin, G., S. J., Birkinshaw, P. L., Younger, et al, 2007, A numerical modelling and neural network approach to estimate the impact of groundwater abstractions on river flows, Journal of Hydrology, 339, 15-28.

[15] Birkinshaw, S. J., G. Parkin and Z. Rao, 2008, A hybrid neural networks and numerical models approach for predicting groundwater abstraction impacts, Journal of Hydroinformatics, 10(2):127-137.

[16] Demissie, Y., K., A. J. Valocchi, B. S. Minsker, et al, Integrating a calibrated groundwater flow model with error-correcting data-driven models to improve predictions, Journal of Hydrology, 364 , 257－271.

[17] Garcia, L., A., A. Shigidi, 2006, Using neural networks for parameter estimation in ground water, Journal of Hydrology , 318, 215–231.

[18] McDonaldM, C., and A.W. Harbaugh, 1988. A modular three-dimensional finite difference ground-water flow model: U.S. Geological Survey Techniques of Water Resources Investigations[R]. Book 6, Chapter A1, 586.

[19] Douglas P. Dufresne, and Charles W. Drake, 1999. Regional groundwater flow model construction and wellfield site selection in a karst area, Lake City, Florida [J]. Engineering Geology, 52(1):129-139.

[20] Chen X., and X. Chen, 2003. Stream Water Infiltration, Bank Storage, and Storage Zone due to Flood Storages in Channels[J]. Journal of Hydrology, 280, 246-264.

[21] CHEN Xi, CHEN Xun-hong. Numerical modeling of groundwater flow and analysis of water budget in Nebraska Sand Hills, USA[J]. Advances in Water Science, 2004, 15:94 -99.

[22] Qin Ju, Zhongbo Yu, Zhenchun Hao, et al, 2007. Hydrologic Simulations with Artificial Neural Networks [A]. Angela Burgess. Third International Conference on Natural Computation [C]. Los Alamitos: IEEE Computer Society Publications, 2:22-27

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