Study on Simulation System of Water Distribution in Water Receiving Area of Hanjiang-to-Weihe River Diversion Project based on Topological Water Network

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Abstract: According to the characteristics and allocation rules of water resources in the water receiving area of Hanjiang-to-Weihe River Diversion Project, this paper constructs a topological water network based on "water source-water plant-water user" water supply network by using topological relationship diagram. On this basis, based on the integrated platform, the component and knowledge visualization technology are used to construct the simulation system of dynamic water allocation in the water receiving area of the Hanjiang-to-Weihe River Diversion Project based on the topological water network. The application results show that the simulation system can realize dynamic allocation and scheme optimization of water resources, which can better meet the changing demand of allocation and the preference of decision-makers for the preferred scheme, overcome the problems of low operability and unable to realize dynamic allocation of traditional water resources allocation mode.

1 INTRODUCTION

In recent years, in order to meet the needs of social and economic development in Guanzhong region of Shaanxi Province, the development of regional water resources has been intensified, resulting in the excessive development and utilization of surface water, groundwater and other water resources in the area of 595km² centered on the city along the Weihe River. To ensure water security in the Guanzhong region, sustainable socio-economic development and improve the regional ecological environment, the Hanjiang-to-Weihe River Diversion Project (Hereafter uniformly referred to as HWT Project) was proposed. Although the HWT Project has improved the plight of water shortage in the Guanzhong region to a certain extent, one of the main ways and effective measures to solve the water shortage problem is the rational allocation of water resources.

Rational allocation of water resources is the premise and foundation to promote social and economic development and ecological construction, Carvalho and Magrini (2006) proposed a strategy selection method for the water transfer problem of two river basins in Brazil; Emery and Meek (1960) established an optimization model when solving practical problems in the operation of reservoirs in the Nile River Basin; Yu and Haimes (1974) solved the complex problem of joint optimal allocation of regional groundwater and surface water resources; Romijn & Tamigam (1982) proposed a new method of alternative value weighing method to solve multiple objective functions, which fully considered the multiple values of water resources; Sadegh et al (2010) proposed a method based on the fuzzy game to optimize the distribution of water in inter-basin water transfer projects. There is much research on the optimal allocation of water resources, sustainable development and the optimal allocation of the HWT Project (Yang, 2006; Chang & Jiang, 2011; Su et al., 2008). However, with the continuous improvement of research on water resource allocation models and the continuous development of software development technology, the problems exposed by traditional

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water resources allocation models are becoming more and more prominent. The main problems are: difficulty to achieve dynamic allocation, unable to adapt to development and change, and poor operability.

In response to the above problems, this article generalizes the water supply system of the water receiving area by the HWT Project according to the network structure of "water source-water plant-water user", constructed a multi-objective configuration model. Based on the integrated platform, using component technology to componentize the configuration model method, using the topological knowledge graph and components to quickly and flexibly build a water resource allocation system. Only need to modify the knowledge graph and customize the corresponding components to deal with the dynamic changes of the allocation environment.

2 STUDY AREA

The HWT Project spans the Yangtze River and the Yellow River, and is a large-scale cross-basin water transfer project in Shaanxi Province (Gao et al., 2020). The project consists of three parts: Huangjinxia hydro-junction, Sanhekou hydro-junction and Qinling water conveyance tunnel. The total storage capacity of the Huangjinxia Water Conservancy Project is $2.21\times10^8 m^3$, the normal storage level is 450m, and the dead water level is 440m. The total storage capacity of the Sanhekou Water Control Project is $7.1\times10^8 m^3$, the adjusted storage capacity is $6.5\times10^8 m^3$, the normal storage level is 643m, and the dead water level is 558m. The project adopts the construction plan of "one project approval and water distribution by stages", which provides conditions for the allocation of water resources in Shaanxi Province, alleviates the water shortage problem in Guanzhong area of Weihe River Basin, and improves the ecological environment of Weihe River Basin.

Water shortage in the Guanzhong region is serious, and the amount of water transferred into the Guanzhong from the HWT Project cannot fully meet the needs. Therefore, following the water use principle of "near water near use, high water high use, excellent water optimal use", determine the water recipients. It is divided into four important cities, five new cities, eleven small and medium-sized cities, and two industrial zones, a total of 22 cities and industrial zones (Shi et al., 2017). The specific contents of the recipient water objects are shown in Table 1.

Table 1: Water recipients in the guanzhong region of the HWT project.

User Type	Water recipient
Important City	Xi'an, Xianyang, Weinan, Yangling District
New City	Qinghan New City, Fengxi New City, Fengdong New City, Konggang New City, Jinghe New City
Small and medium-sized City	Hu County, Changan District, Xingping, Wugong County, Sanyuan County, Zhouzhi County, Yanliang District, Fuping Districe, Lintong District, Gaoling District, Hua County
Industrial Zone	Jingwei Industrial Zone, Weibei Industrial Zone

3 METHODS

3.1 Generalization of the Water Supply Network in the Receiving Area of the HWT Project

The key to water allocation is to understand the relationship between water users and water sources. The water receiving area of the HWT Project studied in this article is a complex system that combines multiple water sources to supply water and multi-users to take water. Therefore, simple and reasonable generalization of the complex water supply system is the basis for optimal allocation of water resources.

This article will generalize the water supply network by using the topology diagram method. The topological relationship diagram refers to the graphical representation of the water supply network using graphical elements of points, lines, and surfaces. The principle of topological geometry is introduced to describe the mathematical relationship among the elements of the network and to show the logical relationship diagram.

3.1.1 Generalization Principle

The water supply network diagram is the basic basis for guiding the preparation of water resources allocation models, determining the relationship between water sources, water users, and water conservancy projects, and maintaining the harmony of the three aspects. It is based on the simplification and abstraction of water resource allocation system, generalizes it by the basic concept of the system network. Its generalization should meet the following principles:

(1) The principle of water balance. From the perspective of supply and demand, the water source is the water supply side of the water resources allocation system, and the life, production and ecology of the water users are the water demand side of the water resources allocation system. The supply and demand sides reach balance through water conservancy projects and water conveyance systems. Any node on the water supply network diagram should satisfy:

$$Q_i - Q_s - Q_l = \Delta Q \qquad (1)$$

Where Q_i is the amount of water input from the previous node to the node; Q_s is the amount of water lost during the process of supplying water to the node and the next node; Q_l is the amount of water supplied from the node to the next node; ΔQ is the amount of water stored at the node.

(2) Joint deployment of multiple water sources. When generalizing the water supply network for water resources allocation, it is necessary to simplify and abstract multiple water sources, and understand the conversion and transmission relationships between multiple water sources.

(3) Calculate and transmit between nodes in the water supply network. The relationship between water sources and water users is complex and has many influencing factors. Therefore, it is necessary to simplify and abstract the water sources, water transmission lines, water users, and establish the relationship between the main influencing factors.

3.1.2 Generalization Method

The topological water network is constructed based on the above water supply network generalization principle. The generalization method of the topological water network includes the following four steps:

(1) The surface elements of water sources such as basin, groundwater, reclaimed water, and external transfer water are simplified into node elements such as hydraulic engineering, groundwater sources, reclaimed water plants, and external transfer water pools.

(2) The three-node elements of domestic water, production water and ecological water are simplified into one node element of the water object.

(3) According to the supply relationship between the water source, the water plant and the water object, the water pipeline is generalized into a straight-line connection.

(4) Because the surface water, groundwater and reclaimed water of the local water source have a stable water supply system with the water object, it is simply generalized as a direct connection between the water source and the water object.

3.1.3 Realization of Topological Water Network

To realize a topological water network, it is first necessary to generalize the elements in the water network. For the water-receiving area of the HWT Project, the generalized objects mainly include water supply plants, water distribution lines, water conveyance routes, etc. The specific generalized graphic elements and content are shown in Table 2.

Table 2: Generalized diagram of water supply network.

No.	Figure Element	Generalized elements	Note
1		Water supply plant	The water plant responsible for the water supply planning of the water-receiving area of the HWT Project
2		Water recipients	Water Recipients of the HWT Project
3		Main line of water diversion from HWT	Main lines for water transmission and distribution
4		Distribution line of water diversion from HWT	The water supply line from the water outlet on the main line to the corresponding water supply plant
5		Other water lines	Surface water source, groundwater source, reclaimed water to the water supply pipeline
6		Water supply reservoir	Reservoir projects to undertake the task of supplying water
7		Reclaimed water source	Sewage treatment plant, providing recycled water

No.	Figure Element	Generalized elements	Note
			supply to the receiving objects
8		Groundwater source	Groundwater water source shall provide groundwater water supply to the objects receiving water
9		Outlet	The water outlet set up on the main distribution line, from the main line through the branch line to the water supply plant

To treat the water supply network into a form in which the water resource allocation model can be applied, the direction of water flow in the water supply network is described more finely. Generalize the water supply system in the receiving area of the HWT Project according to the network structure of "water source-water plant-water user", and take special treatment according to the actual situation:

(1) The water diversion from the HWT Project is directly simplified to the amount of water supplied by Huangchigou. Huangchigou connects the water supply plant, and the connection between the water plant and the water object indicates the supply relationship.

(2) Projects and reservoirs are directly simplified to local sources of water.

(3) Without considering the regulation ability of the reservoir, the water source is directly connected to the water plant, the water plant and the water object are directly connected.

(4) Except for water diversion from the HWT Project, there are already complete water supply channels in the water receiving area, so the supply relationship with the water object is directly expressed by linear connection.

The final determination of the water supply network structure of the water-receiving area of the HWT Project is shown in Figure 1:

As shown in Figure 1, various water sources supply water to "22 water objects and 3 types of consumers" in the water receiving area of the HWT Project, and 5 major reservoir projects are involved in water supply. Surface water sources are allocated to users through their respective supporting projects, reclaimed water and groundwater are all used by the groundwater sources and sewage treatment plants built locally, as well as supporting projects allocated to water users. The HWT Project passes through the water supply line at the water diversion point of Huangchigou, and distributes the water volume to each user of each water object.

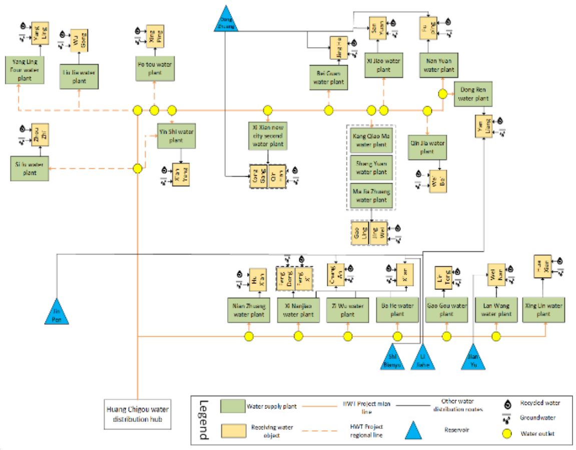

Figure 1: Simplified diagram of water supply network in the water-receiving area of the HWT Project.

3.2 Research on the Model of Water Resources Allocation in the Water-receiving Area of the HWT Project

In the context of providing theoretical support for water distribution in the water-receiving area of the HWT Project, constructing a multi-objective allocation model of water resources based on the "water source-water plant-water user" water supply network. Its allocation principle obeys the principle of unified allocation, mutual allocation of multiple water sources, water supply priority, priority use of water sources, and overall optimality.

The construction of the water resources allocation model of the HWT Project needs to consider the three aspects of social, economic and production benefits. Therefore, the social benefit target, economic benefit target, and ecological benefit target function are defined as follows:

$$\begin{cases} \operatorname{Min} f_1(x) = \sum_{k=1}^{K} \sum_{l=1}^{L} \frac{D_{(k,l)} - x_{(k,l)} B_{k,l}}{D_{(k,l)}} \\ \operatorname{Max} f_2(x) = \sum_{k=1}^{K} \sum_{l=1}^{L} W_{k,l} x_{(k,l)} \\ \operatorname{Min} f_3(x) = \sum_{k=1}^{K} \sum_{l=1}^{L} 0.1 d_{k,l} p_{k,l} \, x_{(k,l)} \end{cases} \quad (2)$$

Where K, L, G are the number of water recipients, water users, and water plants, $D_{(k,l)}$ is k water recipient l user water demand; $x_{(k,l)}$ is the water volume of k water recipient l user; $B_{k,l}$ is the relationship matrix of k water recipient and l water user; $W_{k,l}$ is the water supply benefit of k water recipient and l user, m³/yuan; $d_{k,l}$ and $p_{k,l}$ are respectively the standard of discharge amount of waste water pollutants per unit of water for k water recipient and l user water, ton/m³ and sewage discharge coefficient.

Among them: the social benefit mainly considers the fairness of water resources allocation, and the minimum water shortage rate in the study area is taken as the goal of social benefit. The economic benefit mainly takes into account the principle of high efficiency of water distribution, and the economic benefit goal is to maximize the output value of the unit water supply in the study area. Ecological benefits mainly take into account the principle of sustainable development of water resources, and the ecological goal is to minimize the COD emission of wastewater into the river in the study area.

The constraint conditions of the model include the balance constraint of water user supply and demand, the constraint of the water input and output of the water plant node, the constraint of the pipeline water conveyance capacity, and the variable non-negative constraint, the specific constraint expressions are as follows:

$$\begin{cases} x_{j,(k,l)} \leq D_{(k,l)} \\ \sum_{k=1}^{K}\sum_{l=1}^{L} x_{(k,l)} B_{(k,l)} = \sum_{g=1}^{G} GC_g \\ x_{(k,l)} \leq BC_{(k,l)} \\ x_{(k,l)} \geq 0 \end{cases} \tag{3}$$

Where $x_{j,(k,l)}$ is the amount of water allocated to the user of k water recipient l user from the water source j of the water intake plant; GC_g is the total water supply in each period of the g water plant; $BC_{(k,l)}$ is the total pipeline water supply capacity of k water recipient and l user in each period; the remaining parameter definitions are the same as the above definitions.

Aiming at the above-mentioned multi-objective function solution method, this paper uses the NSGA-II algorithm to solve it, genetic algorithm has a strong global optimization ability. The global optimization characteristics of the multi-objective genetic algorithm (Lai et al., 2003) are compatible with the solution of multi-objective optimization problems. With the vector evaluation genetic algorithm (Schaffer, 1984), non-dominated sorting genetic algorithm (Srinivas & Deb, 1994), non-dominated sorting genetic algorithm with elite strategy (Deb et al., 2002) and other methods have been proposed one after another, genetic algorithm is quickly and widely used in solving non-inferior solutions of multi-objective optimization problems (Wang et al., 2017).

4 APPLICATION ANALYSIS

4.1 Water Distribution Simulation System

Based on the comprehensive integration platform and generalized topological water network of water receiving area, the simulation system of water distribution in water receiving area of the HWT Project is constructed by using component technology and knowledge visualization technology. The system includes water demand prediction calculation, available water supply calculation, water resources allocation and other functions to realize dynamic application and guide the application of water allocation work allocation scheme, and provide support for decision makers to optimize the allocation scheme. The key technologies of simulation system include integrated platform, knowledge visualization technology and component development technology.

The construction of a simulation system is based on the integrated platform (Yu & Zhang, 2016; Xie & Luo, 2010), includes support layer, resource layer, integrated the four levels of layer and user layer, can be set up by means of service composition specific business application system, which makes the water in water resources deployment system flexibility on the building, is the realization of real-time and dynamic water allocation business foundation.

Use knowledge visualization techniques. In the visualization construction of water distribution simulation system in water receiving area of the HWT project, point and line elements are used to simplify and abstract the water distribution system. The supply relations and logical relations among water sources, water objects and water conservancy projects in the water resources system of the water receiving area are expressed by means of points, lines and relevant words.

Component technology has the characteristics of high reusability, good interoperability, transparent implementation details, high interface reliability and stability, good scalability, plug and play. By establishing the mapping relationship between nodes and components in the knowledge graph (Yan, 2003), based on the comprehensive integration platform, the business application of water resources can be realized.

4.2 Water Demand Forecast and Water Supply Calculation

The calculation and query services of this application mainly include the prediction calculation and query of water demand, the statistics and query of available water supply and other basic data for water resources allocation. See Figure 2 for the statistical results of water demand and available water supply. Click "Water demand Prediction Statistics" and "Available water supply Statistics" in the knowledge graph to get the corresponding calculation results.

The left part is the main interface of water resource allocation simulation system for the HWT Project water supply area, and the upper right part is the calculation of the available water supply of groundwater, reclaimed water and surface water in 2030. The lower right part is the calculation of the forecast statistics of water demand in 2030 for the HWT Project water supply area, which is based on the prediction and statistical calculation of water demand in life, production and ecology.

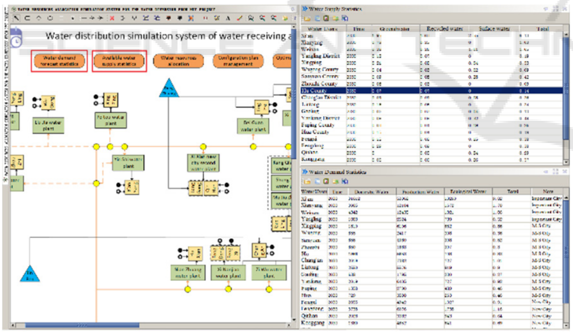

Figure 2: Water demand forecast and available water calculation result interface.

4.3 Dynamic Allocation of Water Resources

The dynamic application of the simulation system is mainly reflected in two aspects: The first is the dynamic allocation of water resources that changes with the external social and economic indicators, water supply indicators, allocation model objectives and constraints. The second is the water allocation decision-makers choice of water allocation in the non-inferior solution of water resources allocation based on preference.

Figure 3 is the water resources configuration interface, three aspects of society, economy, and ecology are provided for the selection of decision-making goals. The selection of algorithm provides NSGA-II and VEGA algorithms. The dynamic allocation of water resources is mainly reflected in the selection of decision-making objectives and model solving algorithms. The system can perform real-time dynamic calculation according to the selected results to obtain the results of water resources allocation under different conditions. In this paper, social goals and ecological goals are selected as the objective function. NSGA-II algorithm was selected to solve the multi-objective water resource allocation model. NSGA- II algorithm was selected to solve the multi-objective water resource allocation model. Regarding the parameter setting, the population size is set to 200, the max number of iterations is set to 2000, the crossover probability is set to 0.5, and the mutation probability is set to 0.05. After the setting is completed, the model can be solved.

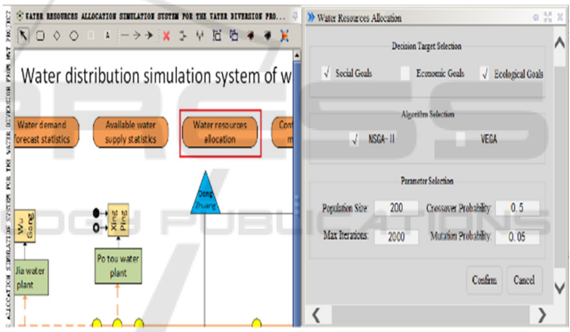

Figure 3: Water resources configuration application page.

Solving multi-objective problems often results in multiple solutions. The upper left part of Figure 4 is the solution result of water resource allocation scheme solved by NSGA-II algorithm in this paper. Click "View" to display the result of corresponding solution. In this paper, scheme 6 is selected to display and explain the configuration results. The upper right corner is the water resources configuration results of the water receiving area under the condition of water diversion from the HWT Project under Scheme 6, and the lower right corner is the water distribution results of the objects in the water receiving area more intuitively displayed through the bar chart. As can be seen from the figure, Compared with other water-receiving objects, Xi 'an city has the most water distribution, with a water distribution volume of 313 million m^3. The pie chart shows the percentage of water distribution after classifying the water distribution results of the water recipients according to the city scale. It can be seen from the chart that the water distribution of the HWT Project is mainly distributed to important cities and small and medium-sized cities, with important cities accounting for 38% and small and medium-sized cities 31%.

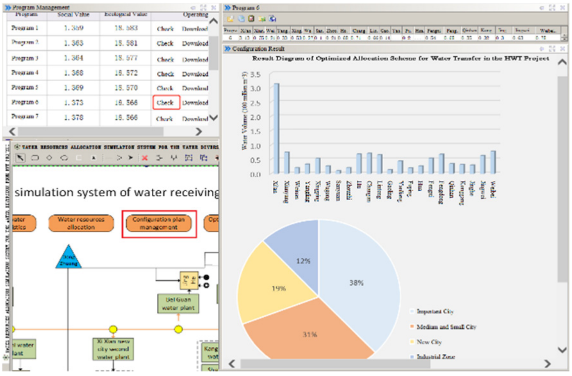

Figure 4: Program results and analysis application interface.

4.4 Water resources Allocation Plan Optimization

The allocation of water resources is related to the social, economic and ecological interests of each water object. Decision-makers can add corresponding weight values (the sum of weights is 1) based on the non-inferior solutions given by the above-mentioned water resources allocation, filter them to achieve the purpose of water resources allocation plan optimization.

As shown in Figure 5, the top solution filter screen lists 70 alternatives. In the program management interface in the middle left, decision-makers assign weights to goals according to individual needs. Assign the weight of social goals to 0.7 and ecological goals to 0.3, and click "Filter"; System according to the weight of each target of select one or more suitable solution, in the lower left plan optimization interface, by the target of the importance of different, concentrated in the water resources allocation of filter solutions 50 to 70 between the seven solutions, choose plan 50 and 59 and 70, and then click "ok", You can view the specific values of plan 50, 59, and 70. Select all the values of the three schemes and "right click" to view the histogram of the analyzed water amount of each water receiving object of the three schemes in the interface of water allocation scheme analysis on the lower right, making the difference of water amount allocated by each scheme more intuitive.

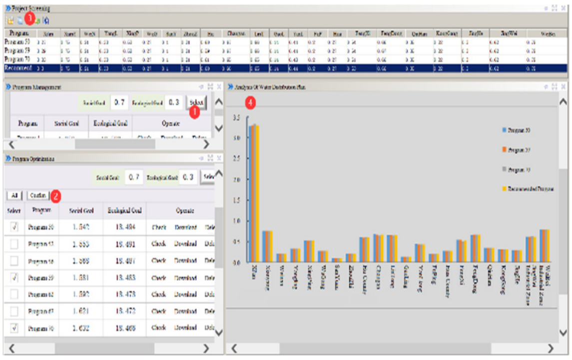

Figure 5: Application interface for decision-makers' program selection.

5 CONCLUSIONS

This article in view of the HWT Project the real-time and dynamic water distribution tapping, correlation, such as demand. According to the principle of water transmission and distribution connection, topological water distribution network of water receiving area of the project is constructed, multi-objective water resource allocation model is established, and water distribution simulation system of water receiving area of the HWT project is built based on comprehensive integration platform and topological water network. The main research results and conclusions are as follows:

(1) Aiming at the HWT project, the relationship between water receiving object and water source and water plant supply is analyzed. Based on topology theory, the water source - water plant - water user water supply network is generalized, and the topological water distribution network of water receiving area is constructed.

(2) The model of water resources allocation in the water receiving area should take into account the three aspects of society, economy and production benefit comprehensively to provide theoretical basis and support for water allocation in the water receiving area of the HWT Project, so as to realize the sustainable utilization of water resources in the water receiving area and the sustainable development of the society.

(3) Based on the comprehensive integration platform and topological water network, the simulation system of water distribution in the water receiving area of the HWT Project is built by using knowledge visualization technology and component development technology. Through the system, water demand prediction and available water supply calculation can be carried out, and dynamic allocation

of water resources and optimization of allocation scheme can be realized.

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REFERENCES

Carvalho, R., & Magrini, A. (2006). Conflicts over Water Resource Management in Brazil: A Case Study of Inter-Basin Transfers. *Water Resources Management*, *20*(2), 193-213.

Chang, J., & Jiang, J. (2011). Water Dispatch of the South-to-North Water Transfer Project in Shaanxi Province. *Journal of Natural Product and Plant Resources*, *26*(01), 110-118.

Deb, K., Pratap, A., and Agarwal, S., & Meyarivan, T. (2002). A fast and elitist multi-objective genetic algorithm: NSGA-II. *IEEE Transactions on Evolutionary Computation*, *6*(2), 182-197.

Emery, D., & Meek, B. (1960). *The Simulation of the Complex Reservoir System*. Paris: Dunod.

Gao, C., Ren, M. Z., Liu, D. F., & Huang, Q. (2020). Risk Evaluation of Multi-objective Dispatching Scheme for Shaanxi Hanjiang-to-Weihe River Diversion Project. *Pearl River*, *41*(10), 81-87.

Lai, H., Dong, P., & Zhu, G. (2003). A Pareto Multi-Objective Genetic Algorithm for Multi-Objective Programming Problem. *Systems Engineering*, *5*, 24-28.

Romijn, E., & Tamigam, M. (1982). Multi-objective optimal allocation of water resources. *Journal of Water Resources Planning and Management, 108*(1), 133-143.

Sadegh, M., Mahjouri, N., & Kerachian, R. (2010). Optimal Inter-Basin Water Allocation Using Crisp and Fuzzy Shapley Games. *Water Resources Management*, *24*(10), 2291-2310.

Su, D., Fei, L.J., & Yang, X.R. (2008). Optimal allocation of water resources in Hanjiang-to-Weihe River Project. *Journal of Water Resources and Water Engineering*, *4*, 46-49.

Schaffer, J. D. (1984). Multiple Objective Optimization with Vector Evaluated Genetic Algorithms. In *Proceedings of the 1st International Conference on Genetic Algorithms. L. Erlbaum Associates Inc.*

Srinivas, N., & Deb, K. (1994). Multiobjective function optimization using the non-dominated sorting genetic algorithms. *IEEE Transactions on Evolutionary Computation*, *2*(3), 221–248.

Wang, X., Chang, J., & Wang, Y. (2017). Research on multi-objective operation based on improved NSGA-II for the lower Yellow River. *Journal of Hydraulic Engineering*, *48*(2), 135-145+156.

Shi, X. Y., Huang, Q., Li Y., & Liu, D. F. (2017). Investigation on the Water Allocation of Water Imported Areas of Hanjiang-to-Weihe Water Transfer Project Based on Multipe Model and Stability Evaluation. *Journal of North China University of Water Resources and Electric Power (Natural Science Edition)*, *38*(02), 1-6.

Xie, J., & Luo, J. (2010). Integrated Service Platform for the Information Explosion Process in Water Resources Industry and its Application Pattern. *Water Resources Informatization* ,*4*, 18-22.

Yan, Q. (2003). Technology of components and its comparison. *Computer Engineering Design*, *2*(7), 13-17.

Yang, X. (2006). Research on optimal allocation of water resources in receiving area of Hanjiang-to-Weihe River Project based on theory of large-scale system decomposition and coordination. *Shaanxi Water Resources Hydropower Technology*, *2*, 6-13+64.

Yu, W., & Haimes, Y.Y. (1974). Multilevel optimization for conjunctive use of groundwater and surface water. *Water Resources Research*, *10*(4), 625-636.

Yu, Z., & Shang, S. (2016). Multi-objective optimization method for irrigation scheduling of crop rotation system and its application in North China. *Journal of Hydraulic Engineering*, *47*(9), 1188-1196.