DOI 10.15302/J-SSCAE-2022.03.001

Optimizing the Route to the North of the Yellow River for the Eastern Route of the South-to-North Water Diversion Project

Zhao Yong [1, 2], He Fan [1, 2], Wang Qingming [1, 2], He Guohua [1, 2]

1. State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, Beijing 100038, China
2. Department of Water Resources, China Institute of Water Resources and Hydropower Research, Beijing 100038, China

Abstract: Since the approval of the *Overall Planning of the South-to-North Water Diversion Project* 20 years ago, the water resource supply and demand situation and water ecosystem problems in North China have undergone profound changes. Therefore, optimizing the water resource route is crucial for adapting to the new development situation in North China and implementing major national strategies. The Beijing–Tianjin–Hebei region is the major water-receiving area for the follow-up project of the eastern route of the South-to-North Water Diversion Project. Analyses of the long-term supply and demand trend, spatial distribution, and structural characteristics of the Beijing–Tianjin–Hebei region showed that the water resources gap in the region is 3.9×10^9–6×10^9 m^3, and water demand growth is mainly from the central and western urban areas, which are also key areas for implementing national strategies (e.g., the construction of the Xiongan New Area). Moving water supply centers westward by establishing a new route to Beijing via Baiyangdian Lake, while using existing river channels, will allow the route of the project to cover overexploited shallow groundwater areas to the largest extent, which is also conducive to the supply of ecological water for rivers and lakes. This means that the eastern route can satisfy the requirements of the region for high-quality development owing to its comparative advantages of having multiple series of water systems, wide coverage of artesian water, a strong capacity for regulation and storage, and high comprehensive benefits. Considering the new situation of the follow-up project planning and construction, we reviewed the major issues, including the function positioning, overall layout, and route orientation of the project, and proposed a concept for optimizing the follow-up project, thereby providing a reference for promoting the high-quality development of the South-to-North Water Diversion Project.

Keywords: South-to-North Water Diversion Project; Beijing–Tianjin–Hebei region; Baiyangdian Lake; water supply and demand; double route

1 Introduction

Water transfer projects are important means of addressing the uneven spatial distribution of water resources and meeting the water requirements of the population. Globally, there are more than 160 large-scale long-distance water diversion projects. The California Water Diversion Project, built in 1959 in the United States, aims to solve drought and water shortage problems in central and southern California and meet water requirements for urban development. The length of the water transfer trunk line was 1086 km, and the annual water transfer volume was 4×10^9 m^3. The Delance Verton Water Diversion Project, completed in 1983 in France, has a designed irrigation area of 6×10^4 hm^2 and annually generates 5.75×10^8 kW·h of electricity, meeting the comprehensive needs of

Received date: June 28, 2022; **revised date:** August 15, 2022

Corresponding author: He Fan, senior engineer from the Department of Water Resources, China Institute of Water Resources and Hydropower Research. Major research fields is water resources management, planning, and strategy. E-mail: hefan@iwhr.com

Funding program: National Key Research and Development Program (2021YFC3200204); The National Science Fund for Distinguished Young Scholars (51625904); The National Natural Science Foundation project (52061125101)

Chinese version: Strategic Study of CAE 2022, 24 (5): 107–115

Cited item: Zhao Yong. Optimizing the Route to the North of the Yellow River for the Eastern Route of the South-to-North Water Diversion Project, *Strategic Study of CAE.* https://doi.org/10.15302/J-SSCAE-2022.05.013

irrigation, power generation, and water supply in the area. The Snowy Mountains Scheme in Australia, started in 1949, channeled excess water from the Snowy River to the western slope and used the drop to generate electricity along the diversion route, supplying electricity for cities and important industrial areas and promoting the development of agriculture and animal husbandry in the Murray-Darling Basin along the route.

The South-to-North Water Diversion Project in China is the world's largest water diversion project. It connects the Yangtze River, Yellow River, Huaihe River, and Haihe River through three diversion routes (eastern, central, and western), which constitutes a "four horizontal and three longitudinal" layout for the allocation of water resources in along a north–south deployment and east–west interaction. The first phase of the eastern route of the South-to-North Water Diversion Project was completed in November 2013. By May 2021, the cumulative water transfer to Shandong Province exceeded 5.29×10^9 m^3, effectively alleviating water shortages in southern Shandong, the Shandong Peninsula, and northern Shandong, with significant comprehensive benefits [1]. Accelerating the construction of the main skeleton and artery of the national water network to provide a strong water security guarantee for the construction of the modern socialist country has become an objective for high-quality development of the follow-up project of the South-to-North Water Diversion Project [2]. In particular, the planning and construction of a follow-up project of the eastern route of the South-to-North Water Diversion Project is urgently needed.

In the 20 years since the *Overall Planning of the South-to-North Water Diversion Project* was approved, China's economic aggregate, industrial structure, and urbanization level have significantly increased [3,4], and the social principal contradiction has changed. A series of major strategies have been implemented in China, and the situation of major rivers in the north, groundwater overexploitation, and other ecological and environmental issues have evolved dynamically [5–7]. These have all resulted in new requirements for the South-to-North Water Diversion Project. Some studies report that the implementation of the *Overall Plan of South-to-North Water Diversion Project* should be evaluated, and changes in basic conditions should be analyzed to determine new requirements for strengthening and optimizing the supply of water resources [8]. The follow-up project of the South-to-North Water Diversion Project requires the evaluation of overall planning, study of major problems, innovation of engineering systems and mechanisms, and improvement in the preliminary work of the eastern route Phase II and the middle route of the Diversion of the Yangtze River to replenish the Han River, which will promote the construction of major national water network projects [9]. Attention should focus on new requirements of major national strategies and ecological civilization construction to strengthen and optimize water resource supply, scientifically determine the scale and overall layout of the project, and correctly handle the relationships between development and water resource protection, utilization, and restoration [10]. The establishment of the Xiongan New Area and the comprehensive treatment of groundwater overextraction in North China were not considered in the original planned route of the eastern route of the South-to-North Water Diversion Project; therefore, it was difficult to adapt the project to the new development situation in terms of coverage scale and water volume [11,12].

In 2014, we wrote "Suggestions on striving for new water sources to enter Beijing, such as the eastern route of the South-to-North Water Diversion Project", proposing the idea of including Beijing in the water intake area of the follow-up project of the eastern route and the route to Beijing via Baiyangdian Lake. In 2020, we wrote "Suggestions on optimizing the route into Beijing of the phase II of the eastern route of South-to-North Water Diversion Project", where we proposed the necessity and advantages of the eastern route into Beijing via Baiyangdian Lake. Based on the above studies, combined with the new situation in the planning and construction of the follow-up project of the eastern route of the South-to-North Water Diversion project, the current study involves systematically sorting out major problems, such as the functional orientation, overall layout, and route direction of the project, and relevant ideas for optimizing the follow-up project of the eastern route north of the Yellow River are proposed.

2 Water supply and demand in the Beijing–Tianjin–Hebei region

The north of the Yellow River water-receiving area proposed in the *Overall Planning of South-to-North Water Diversion Project* includes the northern area of Shandong Province, parts of Cangzhou City and Hengshui City in Hebei Province, and the Tianjin urban area, with lines mainly laid out in the Tianjin Plain east of the Daqing Rive, the plains east of Heilongjiang in Hebei Province, and the Tuhai–Majia River Plain in Shandong Province. After Beijing is included in the receiving area, the Beijing–Tianjin–Hebei region will become the main receiving area for

DOI 10.15302/J-SSCAE-2022.03.001

the region north of the Yellow River. The pattern of water supply and demand in the Beijing–Tianjin–Hebei region shows three characteristics that must be considered in planning the follow-up project of the eastern route.

2.1 Long-term supply and demand trends for water resources in the Beijing-Tianjin-Hebei region

The shortage of water resources in the Beijing–Tianjin–Hebei region is approximately 3.9×10^9–6×10^9 m^3, which requires an increase in the external water transfer to ensure water security [13]. In the Haihe River Basin, where Beijing, Tianjin, and Hebei are located, water resources have been seriously overloaded [14], with exploitation levels reaching 106% at one point, and water has to be transferred from the water-scarce Yellow River Basin to maintain normal economic and social development. With the opening of the South-to-North Water Diversion Project central route, the overall exploitation rate of the Haihe River Basin has decreased. In 2020, the water transfer from the Yellow River Basin was 5.614×10^9 m^3 and that from the Yangtze River Basin was 5.349×10^9 m^3. The exploitation rate of water resources in the basin has dropped to 90%, which still far exceeds the reasonable threshold of 40%. In terms of per capita water resources, the annual water transfer in phase I of the central route was 9.5×10^9 m^3. After deducting losses along the way, the net water input to the Beijing–Tianjin–Hebei region was 4.95×10^9 m^3. Even if this water is fully utilized, the water resources per capita in the region is only approximately 273 m^3 (1/7th of the national average), and the water scarcity situation has not been fundamentally reversed.

According to the results of the “Beijing–Tianjin–Hebei Water Security Technology Research, Development, Integration and Demonstration Application" project under the 13th Five-Year national Key Research and Development Plan, under the conditions of the current evaluation of water resources, phase I of the central route project, diversion of multi-year average water from the Yellow River, and enhanced water conservation, the Beijing–Tianjin–Hebei region will face the following water shortage scenarios in 2035 to ensure reasonable economic and social water demand: (1) to achieve the minimum balance between ecological water use and groundwater recovery, the water shortage is 2.9×10^9 m^3; (2) the balance between appropriate ecological water usage and groundwater recovery is achieved with a water shortage of 3.6×10^9 m^3; (3) if the groundwater level rises, 1.4×10^9 m^3 of groundwater needs to be replenished every year, with a gap of 5×10^9 m^3 according to the 50-year recovery period. Considering the future probability that large surface water resources in hilly areas will continue to decrease by 1×10^9 m^3, the water resources gap will increase by at least 1×10^9 m^3 to 3.9×10^9 m^3, 4.6×10^9 m^3, and 6×10^9 m^3, for the aforementioned scenarios, respectively [9]. The external water quantity needs to be further increased to ensure the security of regional water resources.

In theory, both the eastern and central route follow-on projects can increase the amount of water transferred out of the region to a certain extent, and this should be done based on comprehensively considering the complementarity of the eastern and central route projects. In particular, if the central route makes full use of existing engineering facilities, adopts measures such as local expansion and improvement, and taps into the flood and engineering potential, it is estimated that the water transfer capacity of the central route can be increased from 9.5×10^9 m^3 in Phase I to 1.15×10^{10} m^3; that is, the water supply capacity can increase by more than 2×10^9 m^3. Even under the tapping option of the central route, the follow-up project for the eastern route will still be required to supply water to areas north of the Yellow River.

2.2 Spatial distribution characteristics of water resources in the Beijing-Tianjin-Hebei region

The focus of land and resource development in the Beijing–Tianjin–Hebei region is on the midwestern pre-mountain plains and the central plains, where the growth point of water demand is located. According to the analysis of the distribution of urban areas, all high-grade cities in the region are concentrated near three geomorphologically divergent junctions in the Beijing–Tianjin–Hebei Plain area [13]. Among these, the cities of Beijing, Shijiazhuang, Xingtai, Handan, and Anyang are distributed on the 100 m contour line at the edge of the pre-mountain plain; Tangshan, Langfang, Baoding, Hengshui, and Dezhou are distributed on the 20 m contour line at the edge of the central plain; and Tianjin and Cangzhou are distributed on the coastal plain.

Since 2012, the pattern of territory development and protection has undergone further changes in the Beijing–Tianjin–Hebei region [15,16]. At the macro level, the coordinated development of Beijing–Tianjin–Hebei and the construction of the Xiongan New Area in Hebei have become major national strategies. The plain areas of Beijing, Tianjin, and Baoding (including the Xiongan New Area) and Langfang are positioned as the central core functional areas of the coordinated development of Beijing–Tianjin–Hebei. At the regional level, Beijing is building Airport Economic Zones at Daxing International Airport and is thoroughly implementing the comprehensive treatment and ecological restoration of the Yongding River, which has formed a group of cities with close economic connections, with Shijiazhuang as the core and Handan, Xingtai, and Baoding as important nodes. It is predicted that with further promotion of the Beijing–Tianjin–Hebei coordinated development strategy, especially the construction and development of the Xiongan New Area [17–19], the focus of Beijing–Tianjin–Hebei territorial spatial development will be more concentrated in the pre-mountain plain and central plain.

However, corresponding to the pattern of territory development, the water resource development pattern in the Beijing–Tianjin–Hebei region has long been relatively restricted owing to long-term water shortages, and there are basically no redundant water resources available for regulation to support new growth points [20,21]. Taking the Xiongan New Area as an example, its development will not only bring about a significant increase in the demand for high-quality water throughout the region, but also put forward higher requirements for ecological water use in Baiyangdian Lake and even the entire Baiyangdian Lake basin [22–24]. According to the *Water Resources Guarantee Plan for Xiongan New Area*, which was compiled with the participation of this research team, the rigid demand for ecological water in Baiyangdian Lake is 2×10^8 m^3 (to compensate for regional evaporation and infiltration), the elastic demand is 2×10^8 m^3 (to improve regional hydrodynamic and ecological conditions), the water demand for economic and social development of the new area in 2030 is approximately 4×10^8 m^3, and the total water demand is between 6×10^8 m^3 and 8×10^8 m^3.

The middle route of the South-to-North Water Diversion Project is the main water source for the economy and society of the Xiongan New Area. In the short term, the existing auxiliary project of South-to-North Water Diversion Project will provide water for the development of the New Area, while in the long term, the Xiongan Main Canal of the middle route of the South-to-North Water Diversion Project will be built to guarantee water for living and production in it. There are two main ways to guarantee a water source in Baiyangdian Lake. On one hand, through the Yellow River Diversion Project to Hebei Lake, the water replenishment scale of Baiyangdian Lake can be increased from the planned 1.1×10^8 m^3 to 2×10^8 m^3. On the other hand, through water exchange in the basin and adjustment of the water use structure, the multi-year average water replenishment from reservoirs upstream of the basin and rivers entering the lake can be approximately 9.2×10^7 m^3. From the perspective of long-term time scales, such as 10 years and 100 years, the future water security of the Xiongan New Area is still very fragile, even if it is developed according to the current plan. With only a single high-quality water source from the middle route of the South-to-North Water Diversion Project, Baiyangdian Lake requires an emergency water supply from the Yellow River to maintain the basic demands of its ecosystems, and it is difficult to solve the problem of river outflow.

A temporary measure is to adjust the regional water consumption index of the middle route of the South-to-North Diversion Project during the empty period, when the project in Hebei Province has not yet reached its effectiveness. Therefore, the New Area will still face strong competition for water in the future. It is obvious that such a water safety situation is not sufficient to meet the requirements of the Xiongan New Area's construction and development. Therefore, if the east route of the South-to-North Water Diversion Project is connected to Baiyangdian Lake, it will not only form a complementary water supply structure in the east and middle routes and greatly enhance the stability of the water supply in the Xiongan New Area, but also fundamentally solve the problems of insufficient ecological water for rivers and lakes and regional ecological degradation, and create guaranteed conditions for building a green, ecologically friendly, and livable new urban area.

2.3 Structural characteristics of water resources in the Beijing–Tianjin–Hebei region

The water demand trends of different industries are significantly different; in particular, the ecological water demand in the central and western parts of the Beijing–Tianjin–Hebei region are more intense. From the perspective of economic and social scale and industrial and social structure, the key driving force of water demand growth in the Beijing–Tianjin–Hebei region has existed for a long time; however, there are significant regional and industrial differences in water demand growth due to the large disparities in the economic and ecological backgrounds of the cities and the obvious differentiation characteristics between regions and industries. The demand for water in Beijing and Tianjin is concentrated on ecology, while Hebei Province is facing water growth demand in domestic, industrial, and ecological areas, meaning that the water supply objects and functional positioning of the east route project need to be optimized according to regional and industrial differences in the water demand structure.

Compared with the forecast scenario of the *Overall Planning of the South-to-North Water Diversion Project*, the largest change in the demand structure is in ecology. Because there is a huge historical ecological debt to be

DOI 10.15302/J-SSCAE-2022.03.001

compensated, the demand for ecological water guarantees for rivers and lakes is growing rapidly. Demand is still concentrated in the pre-mountain plains and central plains in the central and western parts of Beijing–Tianjin–Hebei. In terms of historical ecological debts, the cumulative deficit of groundwater in the North China Plain is 1.8×10^{11} m^3, which causes serious ecological degradation problems. In the case of the South-to-North Water Diversion Project, it is difficult to maintain a balance between overall extraction and replenishment and local groundwater rebound at this stage, and great effort is still required to restore the groundwater to a reasonable level. Regarding the areas with overdrawn groundwater, the shallow groundwater area that can be restored by river and lake recharge measures is mainly located in the pre-mountain plain area of Shijiazhuang, Xingtai, Baoding, and Beijing, whereas shallow groundwater overdrawing in the eastern coastal area is rare, and shallow overdrawing has not occurred in Tianjin, Cangzhou, and other coastal cities.

Regarding the ecological water security of rivers and lakes, there is an urgent need to achieve the ecological recovery of rivers and lakes in the Haihe River Basin. According to data measured in the past 10 years, the current ecological basic flow rate and excellent rate in the Haihe River basin are lower than other basins in China, and the proportion of inflow into the sea is only slightly higher than that of the Yellow River [16]. Among the major rivers in the Haihe Basin, the ecological water satisfaction status of the Luanhe and North Canals is relatively good, while that of the Yongding River, Daqing River, and South Canal is poor. Among these, the ecological water quantity is not satisfactory in four sections of the main tributaries of the Yongding River (the Shuitian Reservoir–Guan Hall Reservoir section of Sanggan River, Huai'an–Guanting Reservoir section of Yanghe River, Lugouqiao–Qujiadian section of the main stream of Yongding River, and Qujiadian–Hekou section of Yongding New River). For the Yongding and Daqing river systems, water needs to be replenished from the pre-mountain plain closer to the upper reaches of the rivers to achieve good effects.

3 Optimization conception of the north of Yellow River in the follow-up project of the eastern route of the South-to-North Water Diversion Project

3.1 Main contents of the route optimization conception

The current planning line is based on the *Overall Planning of South-to-North Water Diversion Projec*, using existing projects such as the Small Canal, the Third Main Canal of the Weishan Yellow River Diversion Project, Zhangwei River, the South Canal, Ziya River, Machangjian River, and the Youth Canal Project and rivers, extending north to the Beidagang Reservoir in Tianjin.

It can be seen from the previous analysis that both urban water demand and ecological water demand are concentrated in the central and western plains of the Beijing–Tianjin–Hebei region. Therefore, the general idea of the line optimization concept is to make full use of existing rivers and channels, turn a single line into double lines, and shift the center of the water supply westward. The project line focuses more on covering the shallow groundwater overload area, which is more conducive to recharging the ecological water of rivers and lakes. Specifically, it is divided into two categories. In the first, the current planned route is retained and still ends at the Beidagang Reservoir in Tianjin, focusing on ensuring the water demands of Tianjin and the Grand Canal. In the second, the western trunk line is constructed, and the water from the eastern route is diverted from the Wei Canal using the Weiqian Canal, enters the Yellow River into Hebei Replenishment Project via Qianqingwa (Hengshui Lake), and is finally transferred into Baiyangdian Lake through the Yellow River Diversion Project.

It should be noted that the water is transferred to Baiyangdian Lake from the Second Phase of the Eastern Route Project by the Yellow River Diversion Project, and overlaps exist between the Second Phase of the Eastern Route Project and the water receiving area of the Yellow River Diversion Project. To facilitate the operation and management of the project, it can be unified in the south of Hengshui Lake to absorb the water originally allocated to the north, while the north of Hengshui Lake is supplied by the Second Phase of the Eastern Route Project.

3.2 Feasibility analysis of diverting water from the eastern route into Baiyangdian Lake

3.2.1 Making full use of the constructed water diversion projects and rivers

Water is transferred to southwest of Beijing via Baiyangdian Lake in Hebei Province, with a straight-line distance of 60 km and an elevation difference of 35 m. It is feasible to transfer water from the eastern route to Baiyangdian Lake through the existing route of the Yellow River into Hebei Project; then, the water can be transferred from Baiyangdian Lake to the upper reaches of the Yongding River in Beijing using the Baigou River channel or by building pipelines, thus directly covering the river and lake systems in most plain areas of Beijing. The current plan is to transfer water to Beijing via the Jiuxuan Gate in Tianjin, which enters the Tongzhou District of Beijing from the southeast in the form of pipelines. The straight distance from Beijing is approximately 100 km and the elevation difference is 38 m. There is little difference in the economic and technical indexes between the two options, so it is feasible to transfer water to Beijing via Baiyangdian Lake in terms of both economy and technology.

3.2.2 Holding the historical opportunity of the construction of the Xiongan New Area to guarantee the quality of water supply

Water quality assurance is the important basis for the eastern route to exert project benefits. Water pollution along the water diversion route was once serious when the First Phase of the Eastern Route Project was launched in 2002. Nansi Lake and Dongping Lake, which are important storage reservoirs and water diversion channels, used to have inferior V water, while they have reached the target of III water quality in the past 10 years of harnessing. The protection and management of the ecological environment in Baiyangdian Lake has increased to an unprecedented height since the establishment of the Xiongan New Area in Hebei Province in 2017. The water quality of Baiyangdian Lake and the entire Daqing River Basin has improved significantly and is expected to improve further. The water quality of Baiyangdian Lake was IV–V for many years before 2017, with prominent eutrophication problems. The annual chemical oxygen demand (COD) and ammonia nitrogen entering upstream were 4.3 times and 14.1 times the total amount of the current discharge limit, respectively. In recent years, the water quality of Baiyangdian Lake has improved each year through the vigorous promotion of urban sewage treatment, ecological treatment and restoration, comprehensive river improvement, and other projects; consequently, the water quality of sections in the Baiyangdian Lake Basin reached III or more by 2021. In the future, the quality of the water supply from the eastern route can be guaranteed under the dual promotion of the Eastern Pollution Control Project and the construction of the Xiongan New Area.

4 Diverting water into Beijing in the follow-up project of the eastern route of the South-to-North Water Diversion Project

4.1 Plan for diverting water into Beijing in the follow-up project

After the inclusion of Beijing in the water-receiving area, the current planned line is to build a water pipeline from the Jiuxuan Gate in Tianjin into the Tongzhou District of Beijing. This option is reasonable and feasible in the absence of a follow-up project on the eastern route to Baiyangdian Lake. If the plan for diverting water into Baiyangdian Lake is determined in the follow-up project of the eastern route, it is suggested that the route entering Beijing via Baiyangdian Lake be considered further, as this transports water to the Yongding River Basin in Beijing using the existing Baigou River channels or pipelines after entering Baiyangdian Lake. The water supply can cover the plains in Beijing, which string up the Xiongan New Area and Beijing Daxing International Airport along the way. A Complete "Double Line" pattern will be formed in the follow-up project of the north of the Yellow River of the eastern route (Fig. 1).

4.2 Advantages of the plan

4.2.1 Connecting Baiyangdian Lake, Yongding River, and other important rivers, lakes, and wetlands covering the Daqing River, Yongding River, and most other river systems to exert ecological benefits more sufficiently

As the largest freshwater lake in the North China Plain, Baiyangdian Lake has a unique natural landscape, and its ecological restoration level is related to the quality of the development of the Xiongan New Area. However, the cutoff of rivers upstream and difficulties in securing ecological water demand have always been bottlenecks that restrict ecological restoration. The Eastern Route Project regards Baiyangdian Lake as an important storage reservoir and water diversion channel to directly and fundamentally promote the ecological water volume and hydrodynamic conditions of the lake. From Baiyangdian Lake to the south, it can link Qianqingwa (Hengshui Lake) and other lakes or wetlands through the eastern line. From Baiyangdian Lake to the north, it enters the upper reaches of the Yongding River, directly supporting the comprehensive management and ecological restoration of the entire Yongding River Basin, which significantly improves the environmental quality of Beijing. From Baiyangdian Lake to the east, it can cover the middle and lower reaches of the Daqing River system, linking East Lake, Wen'an Lake, Tuanbo Lake, Beidagang, and other lakes or wetlands.

DOI 10.15302/J-SSCAE-2022.03.001

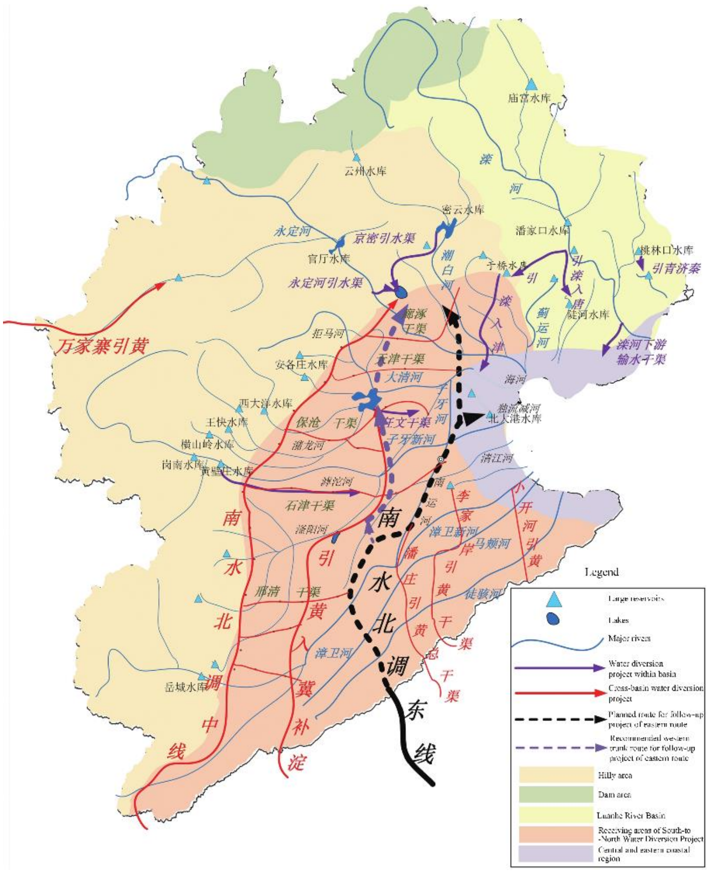

Fig. 1. Schematic of the planned route and route of water diversion to Beijing via Baiyangdian Lake.

4.2.2 The coverage of artesian flow is wide, and its linkage with the middle route of the South-to-North Water Diversion Project is stronge, which is conducive to the construction of a multi-complementary water resource security network in the Beijing–Tianjin–Hebei region

In recent years, after the First Phase of the east and middle routes of South-to-North Water Diversion Project were finished, the coverage of artesian flow played an important role in exerting project benefits, and even directly determined the radius of the project, which was particularly obvious in the treatment of overexploited groundwater resources in the North China Plain. The expansion of the coverage of the artesian flow means a stronger economy, more significantly stronger in the long term, which will directly affect whether the project is sustainable. Compared with the plan to divert water into Beijing via the Jiuxuan Gate in Tianjin, the coverage of the "double-line" plan can be expanded by approximately 78% in the Beijing–Tianjin–Hebei region. The "double-line" scheme will cover new areas, including Wuqiang, Hejian, Xianxian, Renqiu, and other overexploited groundwater counties, playing a more significant role in supporting local water supply and alleviating groundwater pressure from mining. In addition, the route via Baiyangdian Lake is closer to the central line than the original planned route, with the main line combined with the Yellow River in the Hebei Project, and the end point is connected to the Yongding River and Wanjiazhai Water Diversion Project. In the future, it will be possible to build a water resource security network from multiple sources, in which water diversion projects such as the east and middle routes of the South-to-North Water Diversion Project, the Wanjiazhai Water Diversion Project, and the diversion of the Yellow River into the Baiyangdian Lake Project can be formed as axes, linking the water system of the Daqing River and the Yongding River system in the Beijing–Tianjin–Hebei region.

4.2.3 For Beijing, there are clear advantages of the route from Baiyangdian Lake to Beijing, as well as water supply reliability and water use economy

The planned route to Beijing is northward from Jiuxuan Gate in Tianjin to Tongzhou District, the lowest lying district in Beijing. With increasing efforts to control water pollution in Beijing, the water shortage in Tongzhou District is not a serious problem, and there are no storage reservoirs. Compared with the current planning scheme, the route scheme to Beijing via Baiyangdian Lake has three advantages. (1) The storage capacity is greatly enhanced. The 7 m water level in Baiyangdian Lake corresponds to a reservoir capacity of 3.6×10^8 m^3; with future dredging measures, the reservoir capacity at the target water level will increase to 4×10^8 m^3. This part of the reservoir capacity provides the eastern route with a rare storage capacity in North China, and the eastern route water can be transferred to the upper reaches of the Yongding River before entering the Sanjiadian Reservoir and planned Chenjiazhuang Reservoir for storage. (2) This is conducive to the construction of a double-ring water supply pattern in Beijing. After the eastern route water is transferred to the upper reaches of the Yongding River, it can be connected to the second ring of Beijing's water supply, together with the first ring of water supply, which allocates water from the central route of the South-to-North Water Diversion Project and uses the Miyun and Huairou reservoirs for storage. This forms an urban water supply pattern with a double ring overall, which have separate quality under normal conditions, and interconnection and complementarity in emergencies. (3) Ecological and environmental benefits are significantly improved. An annual water volume of approximately 1×10^8 m^3 from the Wanjiazhai Yellow Diversion Project is insufficient to guarantee the current ecological water supply of the Yongding River, which also restricts the level of ecological restoration in the basin. Water from the eastern route water can directly support the comprehensive management and ecological restoration of the entire Yongding River Basin and will also self-flow to most of the major landscape rivers in the urban area to improve urban livability.

4.2.4 The route to Beijing via Baiyangdian Lake goes deeper into the hinterland of the North China Plain, which is conducive to the environmental management of the whole region

The construction of the Xiongan New Area will add traction to the ecological management of the North China Plain. The construction experience of the eastern route of the South-to-North Water Diversion First-Phase Project shows that follow-up projects can "lead the surface with a line," which leads to the ecological management of the entire North China Plain, especially in terms of water protection (Fig. 2). It is not only the South Four Lakes that are difficult to treat; being in the more economically developed eastern region and mainly using the existing Beijing–Hangzhou Grand Canal for water transfer and lake storage, the task of treating pollution along the route is arduous and unique. For example, Shandong Province set nationwide first basin emission standards, in which COD, ammonia, and nitrogen emission standards were significantly stricter than the national industry standards during the same period. These strict local standards not only forced many small serious pollution enterprises to stop, but also forced large enterprises to actively upgrade their production processes. After the transformation, the paper industry in Shandong Province regained its production capacity and turned into a green industry, with low energy consumption and heavy environmental protection, becoming a leader in China. Therefore, it is entirely possible to use the South-to-North Water Diversion Project water quality standard to drive water environmental protection and water ecology management, force industrial restructuring and regional economic layout optimization, and promote the development of circular, green, and low-carbon economies.

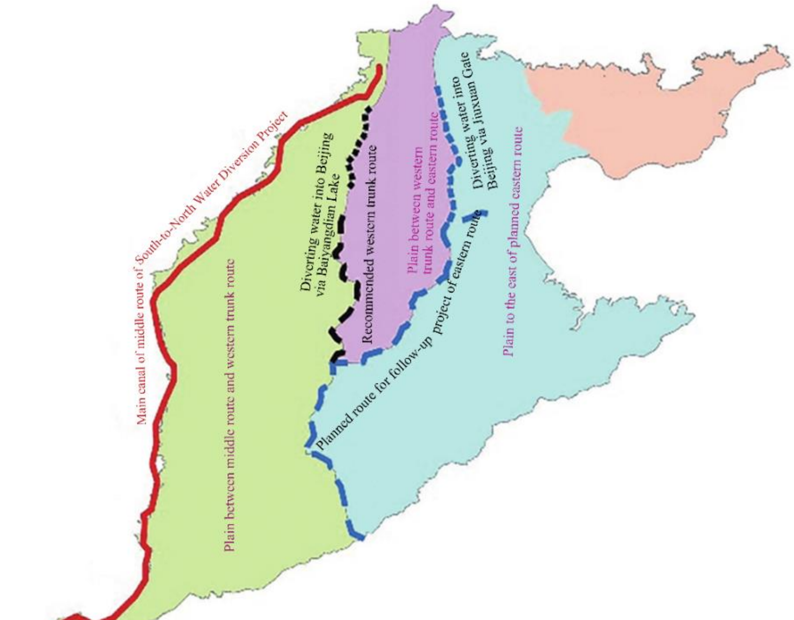

Fig. 2. Schematic of the North China Plain region division.

DOI 10.15302/J-SSCAE-2022.03.001

4.2.5 To a certain extent, avoiding the brackish underground water area is conducive to fully utilizing seepage water and improving the comprehensive benefits of the project

The amount of water seepage from the brackish underground water area north to the Yellow River is also an important factor in the project route selection. According to the planning estimates, the annual loss of water transmission north to the Yellow River is as high as 1.01×10^9 m^3, accounting for approximately 20% of the water volume across the Yellow River. Almost all of the planned water transmission routes are located in brackish underground water areas, where water seepage has an extremely limited effect on groundwater recharge, even resulting in a negative effect in some areas (from soil salinization due to a shallow groundwater table). In contrast, the freshwater area of the western trunk route (including the route to Beijing via Baiyangdian Lake) will increase by 6,847 km^2, and water seepage can become the most economical and favorable storage, which can be effectively used by the local economy, society, or environment.

5 Discussion of the follow-up project of the eastern route of the South-to-North Water Diversion Project

5.1 Optimizing the functional positioning of the follow-up project

The positioning of the properties of the South-to-North Water Diversion Project is a fundamental issue that determines whether the project can be successfully implemented and maintain good operation. Since the commissioning of the eastern and middle routes of the South-to-North Water Diversion First Phase Project, contradictions in the water supply for urban living and industry, where water prices are high, have been greatly alleviated, and contradictions in water supply will mainly manifest themselves in agricultural and ecological water shortages in the future. The follow-up project of the South-to-North Water Diversion Project should take on more public welfare tasks, especially river and lake ecology and groundwater overdraft replacement. Obviously, the public welfare characteristics of the follow-up project are more prominent than those of the First Phase. There is also a need to further improve the water price formation mechanism for different objectives, such as the urban, agricultural, and ecological supply of the South-to-North Water Diversion Project, and to match the optimization of functional positioning, which is an important aspect of the sustainable operation of the follow-up project.

5.2 Strengthening the innovation of technical and institutional mechanisms

During project operation, intelligent management means should be fully adopted to improve the level of automation and intelligence, and the use of clean energy, such as wind power and photovoltaic power generation, should be explored, along with reasonably reducing operation and management costs. The pumping stations of the South-to-North Water Diversion Project are mostly adjacent to lakes and are rich in wind energy resources, thus having a good value for wind energy development. They operate in autumn and winter when wind energy resources are most abundant, providing convenient conditions for energy security. Large storage lakes, which are widely distributed along the route, can act as natural “energy regulators” to smooth out the instability of wind power, photovoltaic power generation, and other new energy outputs, making new energy-pumped storage possible. The water rights transfer across cities and provinces can be promoted, so that cities and regions that have the need and ability to receive more South-to-North water can maximize water consumption in the form of urban water supply and ecological replenishment, further improving the comprehensive benefits of the project’s operation, and enabling areas that have temporary difficulties with consumption to obtain a certain amount of economic income for supporting project construction investment.

5.3 Determining reasonable project advancement timing

As with other economic and social needs, water demand is also a gradual release process, and it is recommended that the construction of the eastern route of the South-to-North Water Diversion Second Phase Project be promoted in accordance with the idea of “commissioning before smoothing.” In view of the fact that the eastern route through the Yellow River Project has already been constructed according to the combined scale of 100 m^3/s of the first and second phases, the eastern route of the South-to-North Water Diversion Second Phase Project can first be planned and constructed according to the 100 m^3/s flow rate through the Yellow River. We should make reasonable use of the condition that the eastern route of the South-to-North Water Diversion First Phase Project through the Yellow River has not reached its full effectiveness, and take the lead in implementing the eastern route of the Second Phase Water Supply Project north to the Yellow River and other key projects, then gradually promote the construction of the projects south to the Yellow River. Through optimizing the timing of project advancement, the first-phase project role will be given full play while the investment intensity is controlled in the near future.

5.4 Conducting the demonstration of single route and double route

The eastern route of the South-to-North Water Diversion Second Phase Project must be considered from the perspective of a 100-year project, integrating all factors and striving to fully support economic and social development and ecological and environmental management of the Beijing–Tianjin–Hebei region, so that the comprehensive benefits can be more extensive and sustainable. It is recommended that the double route option be considered from the comparative and selective options of relevant project planning, and that a comprehensive comparison and preference should be made in terms of project cost, operating cost, water supply scope, regulation capacity, economic benefits, and ecological and environmental benefits.

References

[1] Yang Z T, Huang X F, Fang G H, et al. Benefit evaluation of eastern route of South-to-North Water Transfer Project based on improved cloud mod [J]. Advances in Science and Technology of Water Resources, 2021, 41(4):60-66. Chinese.

[2] Department of Planning and Programming, Ministry of Water Resources. Carefully study and implement the spirit of Xi Jinping's important speech, promote high quality development of follow-up project of South-to-North Water Diversion [J]. Dangjian, 2021(8):18-20. Chinese.

[3] Liu J, Bao Z X, Liu C S, et al. Change law and cause analysis of water resources and water consumption in China in past 20 years [J]. Hydro-Science and Engineering, 2019(4):31-41. Chinese.

[4] Zhang H Q, Qin Y C, Zhang C J. Decomposition and difference analysis of dynamic driving effect of industrial water use in China [J]. Journal of Economics of Water Resources, 2019, 37(6):1-7. Chinese.

[5] Yu H Z, Li L J, Li J Y. Construction of risk assessment model of water resources carrying capacity in Beijing-Tianjin-Hebei Region [J]. Geographical Research, 2021, 40(9):2623-2637. Chinese.

[6] Ma R, Li Y, Jia D D, et al. Evaluation of spatial equilibrium status for the Yellow River Basin based on comprehensive multi-index method [J]. South-to-North Water Transfers and Water Science & Technology, 2021, 19(2):217-225. Chinese.

[7] Gao J D, Feng D. Analysis on the trend of water resources in Haihe River Basin during 1998-2017 [J]. Journal of Irrigation and Drainage, 2019, 38(S2):101-105. Chinese.

[8] Li G Y. Promoting high-quality development of follow-up project of South-to-North Water Diversion Project [N]. People's Daily, 2021-07-29(13). Chinese.

[9] Shi C X. Implementation of the six requirements to strengthen the top-level design and come up with planning and design that can stand the test of history and practice [J]. China Water Resources, 2011(11):1. Chinese.

[10] Shen F S. Solid progress will be made in subsequent engineering planning and design and preliminary work [J]. China Water Resources, 2021(11):7. Chinese.

[11] Tao J H, Bian J X, Ao T Q, et al. Variation characteristics of precipitation and runoff in the water diversion and water-receiving area of the eastern route of the South-to-North Water Diversion Project [EB/OL]. (2021-12-07)[2022-05-15]. https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CAPJ&dbname=CAPJLAST&filename=SZYB20211204000&v=MTYwODBaT3NQWXc5TXptUm42ajU3VDNmbHFXTTBDTEw3UjdxZFplWm5GU2prVzd2UElsaz1Oa mZTYkxHNEhORE5yWTlC. Chinese.

[12] Wang Y S, Chen B. Benefit analysis of water supply in Shandong section of Phase-I of the Eastern Route of South-to-North Water Diversion Project and understanding [J]. China Water Resources, 2022 (9):4-7. Chinese.

[13] Zhao Y, Zhai J Q, Wang Q M, et al. Research and development integration and demonstration application of water resources security technology in Beijing-Tianjin-Hebei [R]. Beijing: China Institute of Water Resources and Hydropower Research, 2021. Chinese.

[14] Han L B, Men B H. Valuation of water resources carrying capacity in Haihe River Basin based on combinatorial game theory [J]. Water Resources and Power, 2021, 39(11): 61-64. Chinese.

[15] Wu K, Wang M. An analysis of spatial pattern of the growing and shrinking areas in the Beijing-Tianjin-Hebei Region from the perspective of major function-oriented zones [J]. Journal of Urban and Regional Planning, 2020, 12(2):183-199. Chinese.

[16] Zhao Y, Wang Q M, He F, et al. Study on water control strategy in Haihe River Basin [R]. Beijing: China Institute of Water Resources and Hydropower Research, 2021. Chinese.

[17] Jiang B L, Geng L H, Lyu L H, et al. Water usage analysis and water demand management measures in the Xiong'an New Area [J]. China Water Resources, 2021(15):29-31. Chinese.

[18] Wang Q, Zhang Y, Yang Y F. Research of evaluation index system of resources and environment carrying capacity in Xiong'an New Area [J]. Environmental Science & Technology, 2020, 43(5):203-212. Chinese.

DOI 10.15302/J-SSCAE-2022.03.001

[19] Gong D X, Mo L, Liu X, et al. Urban water system from conception, methods to planning practice [J]. Water & Wastewater Engineering, 2021, 47(11):62-69. Chinese.
[20] Wang F Q, Ma S Y, Zhao H, et al. A fuzzy comprehensive evaluation of water cycle health in Beijing-Tianjin-Hebei Region based on combined weights of AHP and entropy method [J]. South-to-North Water Transfers and Water Science & Technology, 2021, 19(1):67-74. Chinese.
[21] Qin C H, Zhao Y, LI H H, et al. Assessment of regional water saving potential [J]. South-to-North Water Transfers and Water Science & Technology, 2021, 19(1):36-42. Chinese.
[22] Li C Z, Cui Y J, Ye X C. Water resources change characteristics and water security safeguard strategy in the Baiyangdian Basin [J]. China Water Resources, 2021(15):36-39. Chinese.
[23] Yang W, Sun L X, Wang X, et al. Changes in ecosystem services in Baiyangdian Lake driven by environmental flow releases [J]. Journal of Agro-Environmetn Science, 2020, 39(5):1077-1084. Chinese.
[24] Yang W, Zhao Y W, Liu Q, et al. A systematic literature review and perspective on water-demand for ecology of Lake Baiyangdian [J]. Journal of Lake Sciences, 2020, 32(2):294-308. Chinese.