Study on the Layout of the Section from Yangtze River to Hongze Lake of the Second Phase Project of the East Route of South-to-North Water Diversion Project

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Abstract: In the section from the Yangtze River to Hongze Lake of the east route of the South-to-North Water Diversion Project, the river system, irrigation and drainage system are complex, and the responsibility and power limits of the industry management and control are not clear. As a result, the layout of the water conveyance project in this section is difficult, and there is a large space for the optimization of the water conveyance scheme. In order to better realize the water conveyance task of this section (current water conveyance scale is 500–450m³/s, and newly added water conveyance scale is 370m³/s), optimize investment, save land, form convenient management and control, and ensure ecological safety, in this research, the layout of the water conveyance project in this section is studied, and the Liaojiagou whole lake water conveyance scheme, the Mangdao River whole lake water conveyance scheme, the semi-special channel water conveyance scheme, the special channel water conveyance scheme, and the Sanyang River-Tonghe River water conveyance scheme are proposed. Five schemes are compared from the elements of environment, shipping, construction, management and economy, and the optimal scheme is determined to be the West Liaojiagou whole lake water conveyance scheme.

1. Introduction
The South-to-North Water Diversion Project is a major national strategic project to construct an overall water resources allocation pattern of “four horizontals and three verticals, north-south allocation and east-west mutual aid”. Since the idea was put forward in the 1950s, after more than half a century of preliminary work, extensive and in-depth research and demonstration have been carried out on the east, middle and west routes, forming the overall pattern of planning¹. The east route of the South-to-North Water Diversion Project starts from the Yangtze River in the south and reaches Beijing in the north. It supplies water to Beijing, Tianjin, Hebei, Jiangsu, Shandong and Anhui provinces (cities). All of these are the regions with concentrated population and relatively developed economy and culture in China. The first phase of the east route of the South-to-North Water Diversion Project was completed and put into operation in December 2013, which has played an important role in alleviating the contradiction between supply and demand of water resources in the supplied areas, ensuring economic and social development and improving the ecological environment. In 2017, the Ministry of Water Resources fully started the preparation of the planning for the second phase of the east route of the South-to-North Water Diversion Project. In November 2019, Premier Li Keqiang chaired a meeting on the follow-up project
of the South-to-North Water Diversion Project, and required the construction of the follow-up project to be advanced. In November 2020, Chinese President Xi Jinping inspected the planning and construction of the east route of the South-to-North Water Diversion Project in Yangzhou, urging the construction of the east route of the South-to-North Water Diversion Project to be done well.

The section from the Yangtze River to Hongze Lake of the east route of the South-to-North Water Diversion Project is the source section of the east route of the South-to-North Water Diversion Project, and it is also one of the sections with the highest water surface ratio, the most complicated water system and the most difficult management.

2. Basic Information

2.1. Regional Overview
Located in the lower reaches of the Huaihe River basin, the section from Yangtze River to Hongze Lake of the east route of the South-North Water Diversion Project spans the two major water systems of the Yangtze River and the Huaihe River, involving Yangzhou, Huaian and Tianchang (Anhui Province), with a regional GDP of over 400 billion yuan. The region is located in the Yellow River flood plain and the plain of the lower reaches of Huaihe River. It is located in the climate transition zone between the north and the south. The average annual precipitation is about 950mm, and the average annual evaporation is about 1500mm. Precipitation mainly occurs from June to September, and evaporation mainly occurs from May to August. Except for July, evaporation is greater than monthly precipitation in every month of the year.

2.2. River System
The main river systems along the section from the Yangtze River to Hongze Lake of east route of the South-to-North Water Diversion Project include: the Yangtze River, Huaihe River, waterway of Huaihe River which leads to Yangtze River, Beijing-Hangzhou Grand Canal (Li Canal, Gaoshui River, etc.), Liaojiagou River, Sanyang River, Shaobo Lake, Gaoyou Lake, Hongze Lake, etc. According to the layout of flood control works and related flood control rules, this area could be divided into three flood control areas: Gaobao Lake Area of Baima Lake, Li Xia River Area and Riverside Area of Northern Jiangsu. The waterlogging in the Gaobao Lake area of Baima Lake is mainly discharged into the Yangtze River through the waterway of Huaihe River which leads to Yangtze River, and some of the water is discharged into the Lixia River. The drainage layout of “upper pumping, middle stagnation and lower drainage” has been basically formed in the Lixia River Area, which can be discharged into the Yangtze River or the sea. The area along the Yangtze River in Northern Jiangsu has basically formed a drainage layout of “self-drainage as the main part, and pumping drainage as the auxiliary part”, mainly discharging water into the Yangtze River. The layout principle of main water supply systems of this region is “Mutual aid of Yangtze River and Huaihe River, combination of storage and conveyance, and water conveyance from Yangtze River to make up the source”. In addition to the east route of South-to-North Water Diversion Project, the main water supply projects include “North Water Diversion Project of Yangtze River”, “East Water Diversion Project of Yangtze River”, “Tongyu River Water Supply Project” and so on.

2.3. Overview of First Phase Project
The first phase of the east route of the South-to-North Water Diversion Project was completed and put into operation in December 2013. The current water conveyance scale of the section from the Yangtze River to Hongze Lake is 500m³/s from the Yangtze River and 450m³/s to Hongze Lake. The water conveyance line in this section is about 401km long. It diverts water from Sanjiangying of the Yangtze River through Jiajiang River and Mangdao River to West Sluice of Jiangdu. It is designed to divert 950m³/s from the Yangtze River through West Sluice of Jiangdu to Xintongyang Canal, in which 400m³/s is pumped from Jiangdu Station to the north through the Li Canal. In addition, 550m³/s of water is sent through East Sluice of Jiangdu to Yiling, in which 100m³/s of water is pumped from Baoying Station to
Li Canal through Sanyang River and Tong River, and then the water is sent all the way to the north along the Li Canal after converging in Baoying and pumped into the main irrigation canal in Northern Jiangsu through Huaian Station, and then 300 m³/s of water is pumped into Hongze Lake from Huaiyin Station. Then, the water was pumped to the west via Jinhao Channel and Sanhe River, and 150 m³/s of water is pumped into Hongze Lake in Hongze Station. Third-level pumping stations are arranged on the water conveyance lines in this section, including fourteen pumping stations, namely, Jiangdu No. 1, No. 2, No. 3 and No. 4 Stations and Baoying Station, Huaian No. 1, No. 2, No. 3, No. 4, Jinhu Station, and Huaiyin No. 1, No. 2, No. 3 Stations and Hongze Station. These pumping stations increase the intake water level from 0.53 m to 12.93 m, with pumping head up to 12.4 m. Since the operation of the first phase of the project, it has not only effectively alleviated the continuous drought in Northern China and the contradiction between supply and demand of water resources, but also participated in the flood and waterlogging control, shipping dispatch, environmental protection and other areas along the water conveyance line, which has promoted the local economic development and improved the regional environment.

3. Research Tasks

3.1. Study Scale
The east route of the South-to-North Water Diversion Project was originally planned to be divided into the first, second and third phases\(^1\). At present, the first phase of the east route has been constructed and under operation. According to the *Project Planning Report of the Second Phase of the East Route of the South-to-North Water Diversion Project* (2019), the second and third phases of the east route of the South-to-North Water Diversion Project will be merged into the second phase of the east route of the South-to-North Water Diversion Project. After the implementation of the second phase of the project, the total scale of pumping from Yangtze River shall be 870 m³/s, and the amount of water pumped into Hongze Lake shall reach 810 m³/s, that is, 370 m³/s of pumping from Yangtze River will be added in the second phase, and 360 m³/s will be diverted into Hongze Lake.

3.2. Necessity of This Study
According to the *Project Planning Report of the Second Phase of the East Route of South-to-North Water Diversion Project* (2019), the new water conveyance plan from the Yangtze River to Hongze Lake adopts the newly approved scheme of the whole lake water conveyance line in the west of the Beijing-Hangzhou Grand Canal. The newly added water will be pumped into Shaobo Lake by the newly built Guangling Station through Jiajiang and Liaojiagou, then be pumped into Hongze Lake through Gaoyou Lake, Dongpianhong of the waterway of Huaihe River which leads to Yangtze River and Xinsanhe.

Because the second phase of the east route of the South-to-North Water Diversion Project is mainly water supply for living and industry, the requirement of water quality guarantee and guarantee rate of water supply is high and continuous water supply time is long. The Northern Jiangsu section of Beijing-Hangzhou Canal is a golden inland waterway connecting the north-south shipping in China, a key flood discharge channel in Yihusi region of Huai River, and an irrigation water source for the Grain Storehouse in Northern Jiangsu. The distribution of towns and industries along the route is dense, and there are problems such as prominent contradiction between water diversion and shipping, relatively large pollution risk, and poor water supply stability during the peak period of irrigation. At present, there is a certain space for optimization of the water conveyance layout in the section from the Yangtze River to Hongze Lake. Considering the economic rationality, ecological security and convenience in management, it is very necessary to study the water conveyance layout in this section.

3.3. Research Principles
First phase of the east route used a large amount of existing water conservancy projects, and most of the main lines of water conveyance and related control project has flood control, water supply, shipping, ecology and other comprehensive functions. Considering the various factors like economy, land and
management, the layout of the second phase of the project should also make use of the existing river and lake water systems and other water conservancy projects to meet the requirements of relevant water diversion scale, and take into account the requirements of flood control and waterlogging control, ecological navigation, etc.\cite{2-4} The main principles of the layout study of the project are as follows:

(1) The project layout should be based on the existing water conservancy projects such as rivers and lakes, and make full use of the existing river and lake systems and related hydraulic structures to optimize the project investment and land space resources\cite{5, 6}.

(2) The project layout should comprehensively consider the current situation and planning needs of water supply, flood control, shipping and ecology. The design standard and scale of the project should not only meet the requirements of water supply, but also meet the requirements of flood control and waterlogging control, and take into account the requirements of shipping at the same time. If it is difficult to take into account in local areas, safeguard measures should be put forward\cite{7}.

(3) The principle of land saving, environmental protection and ecological sustainability should be fully considered in the project layout, and the project design scheme should be rationally optimized to reduce the new construction land and avoid the sensitive areas of the ecological environment.

(4) The layout of the project should fully consider the principle of convenient operation and management\cite{8}. Due consideration should be given to partly manage channels, office equipment, personnel, etc., so as to reasonably determine the scope of project management and avoid water disputes as far as possible\cite{9}.

(5) The engineering layout should fully consider the principle of combining with the first phase of the project. On the premise of technically feasible and economically reasonable, the engineering layout should be integrated with the facilities of the first phase of the project as far as possible, and the operation of the first phase of the project and the safety of the surrounding buildings should not be affected.

4. Layout Research

Currently available river and lake systems in the section from Yangtze River to Hongze Lake of the Second Phase Project of the East Route of South-to-North Water Diversion Project include: Jiajiang, Liaojiagou, Mangdao River, Jinwan River, Sanyang River, Tong River, Jinbao Channel, Sanhe, Shaobo Lake, Gaoyou Lake and so on. According to the research principles of engineering layout, five layout schemes of water conveyance lines\cite{4} are preliminarily formulated, which are as follows:

4.1. Scheme I. The Whole Lake Scheme through Liaojiagou

Newly added 370m$^3$/s of water conveyance. The water from Jiajiang River will be pumped into Shaobo Lake through Liaojiagou, combined with Guangling Station (370m$^3$/s), the newly built pumping station of Wanfu South Sluice. The water will be pumped into Gaoyou Lake through the newly built Gaoyou Station (370m$^3$/s) outside the Embank of Yangzhuang Control Sluice. Water will be pumped into the Xinsanhe River by the newly built Jinhu Second Station (370m$^3$/s) after passing the Xipianhong. Then the water will be pumped into Hongze Lake through the newly built Hongze Second Station (360m$^3$/s) after passing the Xinsanhe River to the west.

Project construction content mainly includes river engineering, sluice station engineering, impact engineering and so on. They are as follows: (1) The Shaobo Lake pumping channel project is 26.5km, the Gaoyou Lake pumping channel is 31.9km, expanding excavation of Xipianhong channel into Yangtze River is 16.2km, and dredging of Xinsanhe is 36km. (2) Newly built Guangling Station 370 m$^3$/s, newly built Gaoyou Station 370m$^3$/s, newly built Jinhu Second Station 370 m$^3$/s, newly built Hongze Second Station 360 m$^3$/s\cite{10-12}. Two treatment projects for dilapidated water-gates. (3) The compensation project for the influence of east-leading of Lixiahe on the dredging of Mangdao River and the influence project of Guangling junction.
4.2. Scheme II. The Whole Lake Scheme through Mangdao River

Water is transported from Jiajiang River, Mangdao River and Jinwan River. Guangling Station, a newly built pumping station near Jinwan Sluice, pumps water into Shaobo Lake. The newly built Gaoyou Station (370m³/s) outside Yangzhuang Control Sluice Embank pumps water into Gaoyou Lake. Water is pumped into the Xinsanhe by the newly built Jinhu Second Station after passing Xipianhong. Water is pumped west along the Xinsanhe into the Hongze Lake through the newly built Hongze Second Station.

Project construction content mainly includes river engineering, gate station engineering, impact engineering and so on. They are as follows: (1) Expanded dredging and protection of Mangdao River. Expanded dredging and protection of Jinwan River. Pumping channel of Shaobo Lake. Pumping channel of Gaoyou Lake. Expanded excavation of the waterway of Xipianhong which connects Yangtze River. Dredging of the Xinsanhe, etc.. (2) Newly built Guangling Station 370m³/s, newly built Gaoyou Station 370m³/s, newly built Jinhu Second Station 370m³/s, newly built Hongze Second Station 360m³/s, dilapidated watergate project, etc.. (3) Bridge reinforcement and transformation project, relevant water system adjustment project of Guangling Station, and impact project of water conveyance of the Canal, etc.
Figure 2: Schematic Diagram of Whole Lake Water Conveyance Route through Mangdao River

4.3 Scheme III. Semi-special road scheme

Newly added water conveyance from the Sanjiangying. Water conveyance through Jiajiang River, Mangdao River and Jinwan River. The water will be pumped into Shaobo Lake through Guangling Station, a newly built pumping station near Jinwan Sluice. The separation dike built in east beach of Shaobo Lake and the west dike of the canal form a channel to send water into Gaoyou Lake. Diversion section of Jingou of Xipianhong which leads to Yangtze River divert water from Gaoyou Lake to Xinsanhe through the cascade pumping of Jinhu. Then the water will be pumped into Hongze Lake by cascade pumping. There are three steps in the section from the Yangtze River to Hongze Lake: Guangling Station, Jinhu Station and Hongze Station.

The construction content of the project mainly includes river course (including embankment) project, sluice station project, impact project, etc. They are as follows: (1) The expanded dredging and protection of Mangdao River, the expanded dredging and protection of Jinwan River, the inner separation dike of newly built Shaobo Lake, the expanded excavation of Shenhong River, the avulsion of Shaobo Lake, the pumping channel of Gaoyou Lake, and the dredging of the Xinsanhe. (2) Newly built Guangling Station 370m³/s, newly built Jinhu Second Station 370m³/s, newly built Hongze Second Station 360m³/s, newly built underground culvert through Beijing-Hangzhou Canal, dismantled and constructed lakeside overflow sluice, newly built communication sluice for dikes. (3) Bridge reinforcement, demolition and construction, reinforcement and demolition and construction of dilapidated watergate, impact project of dikes of Shaobo Lake, water system adjustment project of Guangling Station, diversion impact project of the Canal, etc.
4.4. Scheme IV. Special Channel Scheme

Newly added water diversion from the Sanjiangying. The newly built Guangling Station will be built near Jinwan Gate. The water will be pumped from Jiajiang River, Mangdao River and Jinwan River to the special channel of Shaobo Lake and Shenhong River. After the cascade pumping through Gaoyou special channel, the water will get into the Jinbao Channel through the south gate of Dashanzi. After cascade water lifting in Jinhu, the water will be sent to Hongze cascade through Sanhe Section of waterway of Huaihe River which leads to Yangtze River, then the water will be pumped into Hongze Lake by cascade pumping.

The engineering measures involved in the water conveyance scheme which utilizes special channel include: (1) The expanded dredging and protection of Mangdao River, the expanded dredging and protection of Jinwan River, the newly built separation dike in Shaobo Lake, the avulsion of Xinmin Beach, the expanded excavation of Shenhong River, the newly built separation dike within the Gaoyou Lake, the expanded excavation of Jinbao Channel, and the dredging of the Xinsanhe. (2) Newly built Guangling Station 370m³/s, newly built Gaoyou Station 370m³/s, newly built Jinhu Second Station 370m³/s, newly built Hongze Second Station 360m³/s, newly built Jinhu Hub, newly built communication sluice for separation dike, newly built South Sluice of Dashanzi. (3) Treatment project of dike-crossing buildings, bridge reinforcement and demolition & construction works, excavation and pressure impact of special channel formed by separation dike in Shaobo Lake, adjustment project of excavation and pressure water system of Guangling Station, and water conveyance impact of the Canal, etc.
4.5. Scheme V. Plan of Sanyang River and Tonghe River in the East of Beijing-Hangzhou Grand Canal

The newly added water is transported from the Sanyang River and Tonghe River in the east of Beijing-Hangzhou Grand Canal to the Baoying cascade, and the water is pumped into Jinbao Channel through the underground culvert of the Li Canal, and then the water is lifted in the Jinhu cascade to the Sanhe section of waterway of Huaihe River which leads to Yangtze River. Then the water is pumped into Hongze Lake in Hongze cascade.

The main construction contents of the scheme of Sanyang River and Tonghe River in the east of waterway of Huaihe River which leads to Yangtze River are as follows: (1) Expanded excavation of Hongqi River, Xintongyang Canal, Sanyang River, Tonghe River, Yetian River, Dasanwang River, Sanhe River, etc. (2) Newly built Riverside Hub of Hongqi River, newly built Baoying Second Station 370m³/s, newly built Jinhu Station, newly built Hongze Second Station 360m³/s, demolition and construction of Dashanzi Hub, newly built Jinhu Hub and sluice project.(3) Bridge reinforcement, demolition & construction, existing adjustment of irrigation and drainage system, etc.
5. Research and Comparison of Layout

According to the research principle of project layout, the research schemes are compared one by one from six aspects: immigration, construction, environment, shipping, management and investment:

5.1. Environmental factors

Scheme I, II, III, IV and V all involve 3 protection areas of drinking water sources, which have environmental constraints, but the adverse effects will disappear after the completion of the project.

The first and third schemes involve 27 ecologically sensitive areas[13], and the second and fourth schemes involve 28 ecologically sensitive areas. Schemes I, II, III and IV all involve Wetland Nature Reserve of Gaoyou Lake (core area, buffer area and experimental area). In addition, the first and second schemes will affect the natural reserve during the construction period, and the impact will be gradually eliminated after the completion of the project. In the third and fourth schemes, permanent separation dikes will be constructed, which will affect the protection area during the construction period and operation period.

5.2. Shipping Impact

About 8.5 km of Yangzhou section of Beijing-Hangzhou Canal waterway overlaps with Shaobo Lake. The annual volume of goods passing through the Northern Jiangsu section of Beijing-Hangzhou Canal accounts for 80% of the whole section, and this section has become the busiest section of the whole line.

The cost of water transportation is only one-sixth of that of rail and one-twenty-eighth of that of road. It is estimated that the annual logistics cost will increase by 18.15 billion yuan if the transportation efficiency is reduced by the transition of water transportation to land transportation, and the pollution to the atmosphere will also increase. Carbon emissions will increase by 500,000 tons and sulfur emissions will increase by 1,050 tons each year, and other indirect economic impacts will be greater.
The normal diversion of water from the south to the north will lead to the embargo of hazardous chemicals almost throughout the year, which will cause the Beijing-Hangzhou Canal to lose the transportation capacity of hazardous chemicals. It is estimated that replacing the transportation of hazardous chemicals by water with land transportation will directly increase the logistics cost of 1.67 billion yuan.

In scheme I, the water flow is intersected with the waterway at a small angle, the water flow velocity meets the shipping requirements, and it has an impact on the shipping efficiency during the construction period, while it basically has no impact on the shipping during the operation period. In the second, third and fourth schemes, the overpass between the water flow and the waterway has a great influence on the shipping during the construction period, but basically has no influence on the shipping after the completion of the project. In the fifth scheme, the Tonghe River and Sanyang River are far from the Beijing-Hangzhou Grand Canal, so the influence is minimal.

5.3. Construction Conditions
The construction method of scheme I and scheme II is relatively simple, and the construction is less restricted by the surrounding environment. The construction method of the special channel in the third and fourth schemes is relatively complex, and the construction quality of the water dumping is difficult to control. The construction of the underground culvert across the Beijing-Hangzhou Canal is difficult. The investment of the temporary construction works is large, and the flood pressure of the project itself is large during the construction. In Scheme V, the water conveyance line is long, the project quantity is large, the temporary construction area is large, the construction is greatly restricted by the existing buildings, and the workload of resettlement and demolition in the construction preparation stage is large, which has a great impact on the construction progress. From the perspective of construction organization, scheme I and scheme II are better, but compared with scheme II, scheme I has less project amount, less temporary construction land and less project investment14, 15.

5.4. Project Management
Scheme I and scheme II are water conveyance of the whole lake of Gaoyou Lake and Shaobo Lake, and four-level pumping stations are needed for both of them. During water conveyance period, it is relatively difficult to control the water quality of tributaries of the two lakes and to manage the drainage outlets. Scheme V needs to lay out three-level pumping stations. The water is transported through the water network area of Lixia River, and there are many breakwater gaps along the line, so it is relatively difficult to manage during the water conveyance period. In the third scheme, a special water conveyance channel is formed on the east side of Shaobo Lake. Compared with the whole lake water conveyance scheme, it is less difficult to manage the surrounding areas of Shaobo Lake during the water conveyance period. The three-stage pumping station needs to be arranged, and the difficulty of dispatching and operation coordination is slightly less. Scheme IV needs to arrange four-stage pumping stations, and compared with other schemes, it is the least difficult to achieve the water conveyance target during water conveyance period16, 17.

5.5. Quantity and Investment
The earthwork of scheme I ~ scheme V is about 100 ~ 200 million square meters, among which the earthwork of scheme V is the largest, and the earthwork of other schemes is basically the same. The permanent land requisitioned in the first to the fifth schemes is about 0. 5-55,000 mu, among which the fourth and fifth schemes are the largest, and the other schemes are almost the same. The investment in river courses and buildings of scheme I to scheme V is about 27. 5 billion to 53 billion, among which scheme III and IV are the largest and scheme I the smallest. The investment of the scheme I ~ scheme V are 33. 65 billion, 32. 37 billion, 33. 53 billion, 39. 77 billion and 57. 05 billion respectively. Obviously, the investment of the fourth and fifth programs is larger, while the investment of other schemes is basically the same.
6. Conclusions
The first and second schemes make full use of the water conveyance capacity of Shaobo Lake and Gaoyou Lake and improve the regional flood control and drainage conditions. The investment of the second scheme is smaller than that of the first scheme, but the second scheme needs to cut the island of Jufeng Island, which involves the heritage area and buffer zone of the protection of the Grand Canal World Cultural Heritage. Scheme 1 and scheme 2: The pumping channel of Gaoyou Lake and the dredging of Sanhe River involve the protection zone of water source, and the core area and the buffer zone of the natural reserve. In the scheme III and scheme IV, the river and lake water conveyance capacity cannot be fully utilized. In the scheme III, the pumping channel of Gaoyou Lake and the dredging of the Sanhe River involve the protection zone of water source, and the core area and the buffer zone of the natural reserve, and Gaoyou Lake involves Jiangsu and Anhui provinces. The scheme IV runs through the outer edge of the core area of Natural Reserve of Gaoyou Lake, which has relatively little impact on the core area, and the dredging of Sanhe River involves the protection zone of water source. Scheme IV has a relatively large amount of investment in the main project, but the investment in pollution control is the least[18], and both water quantity and water quality are guaranteed. Scheme V has the largest project investment, with a large amount of demolition, and its implementation is difficult. Considering comprehensively, the scheme I is recommended for the layout of the new water conveyance project from the Yangtze River to Hongze Lake in the east route of the South-to-North Water Diversion Project, namely, the whole lake water conveyance scheme through Liaojiagou in the west of the Canal.

In order to study the layout scheme of water conveyance project, it is necessary to coordinate the requirements of flood control, waterlogging control, water quality, ecology and shipping, etc. This paper focuses on the coordination between water conveyance project and flood control and waterlogging control, shipping irrigation and ecology, and further study is needed on the water quality changes of the water conveyance channels during water conveyance period.

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