A Research of the Section Layout of the Second Phase of the Eastern Route of South-to-North Water Diversion Project: from Hongze Lake to Luoma Lake

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Abstract: The south-to-north water diversion project is a major strategic project in China to construct the overall pattern of the water resources allocation according to the principle of “four horizontal and three vertical, north-south allocation and east-west mutual aid”. On the one hand, the first phase of the eastern route of the south-to-north water diversion project started construction in December 2002 and was completed in November 2013. After completion, it has played an important role in alleviating the contradiction between supply and demand of water resources due to consecutive drought years in Shandong Province, especially in the Shandong Peninsula, which has ensured the economic and social development and improved the ecological environment in recent years. On the other hand, the second phase of the eastern route will further improve the allocation of water resources in China, ensure the security of water supply in important areas such as Beijing and Tianjin, and further improve the water ecological environment along the route. While the section from Hongze Lake to Luoma Lake is listed as the second section of the eastern route of this project (among 11 sections in total), the water layout, officially approved in the early stage, contradicts the one recommended by Jiangsu Province. On this basis, the key to ensure the smooth implementation of the project of this section is to study its scheme of water distribution in combination with the regional water system, coordinate the functions of flood control, drainage, water supply, navigation and ecology, and put forward an economical, reasonable and technically feasible scheme of water distribution.

1. Overview

1.1. Project Background

The south-to-north water diversion project is a major strategic project in China to construct the overall pattern of the water resources allocation according to the principle of “four horizontal and three vertical, north-south allocation and east-west mutual aid”. Since the completion of its first phase of the eastern route in 2013, the south-to-north water diversion project has transferred 4 billion m³ of water to Shandong Province until June 2019, which has played an important role in alleviating the contradiction between supply and demand of water resources due to consecutive drought years in Shandong Province, especially in the Shandong Peninsula, to ensure the economic and social development and improve the ecological environment in recent years.
With the rapid development of China’s economy and society, there have been great changes in the demands of social and economic situation for water, the engineering conditions and other factors which were determined by the “Overall Planning” \cite{1} for the water supply area of the eastern route project, and new development concept, economic pattern and water management thought, especially the implementation of the national strategy of Beijing-Tianjin-Hebei coordinated development, has put forward higher requirements and updated challenges for the eastern route project. In 2012, at the Sixth Meeting of the South-to-North Water Diversion Project by the Construction Committee of the State Council, it was clearly required to speed up the demonstration work of the follow-up projects of the eastern and central routes. In the same year, according to the deployment of the South-to-North Water Diversion Construction Committee of the State Council, the Ministry of Water Resources organized and started the planning work of the follow-up eastern route of the south-to-north water diversion project, based on the urgent requirements of the economic and social development in the north for the construction of the eastern route of the south-to-north water diversion project of the second and third phases, as well as the changes in working and water conditions since the approval of the overall plan \cite{2}.

1.2. Status of the First-Phase Project

According to the first phase of the eastern route of the south-to-north water diversion project, the water scale of the section from Hongze Lake to Luoma Lake has been designed to be 350 m$^3$/s from Hongze Lake and 275 m$^3$/s into Luoma Lake. By using the double routes of Xuhong River and Luonan Grand Canal to carry water, the water has been transported through Sihong County, Siyang County, Sucheng District, Suyu District and Lakeside New District in Suqian City of Jiangsu Province, and also through Suining County in Xuzhou City, Pizhou City and Sixian County in Anhui Province. In the first phase of the project, the 116.4-kilometer-long Xuhong River and the 7-kilometer-long Fangting River have been used to design the water transfer scale of 120-100 m$^3$/s, and three hubs of cascade pumping stations, namely Sihong Station (120 m$^3$/s), Suining Station (110 m$^3$/s) and Pizhou Station (100 m$^3$/s), have been built along the route. The 146.8-kilometer-long Luonan Grand Canal has been used to design the water transfer scale of 230-175 m$^3$/s and three cascade pumping stations, namely Siyang Station (230 m$^3$/s), Liulaojian Station (230 m$^3$/s) and Zaohe Station (175 m$^3$/s), have been built along the route.

1.3. Layout Principles of the Second-Phase Project

In implementing the layout of the section from Hongze Lake to Luoma Lake of the second phase of the eastern route of south-to-north water diversion project, what should be considered include the actual water diversion projects already in the region and the combination of water diversion with flood control and navigation. The layout of the project should not only consider the economic rationality of the water diversion project, but also pay attention to the relationship with other surrounding water conservancy projects. The main layout principles of the project are as follows:

(1) The project layout should be based on the existing water conservancy projects such as watercourses and lakes in the region, and the existing watercourses, lakes and buildings should be fully utilized to save the project investment.

(2) The layout of water transfer routes should comprehensively consider the planning requirements of flood control, drainage, shipping and ecology \cite{3-4}, etc., and the scale of the excavated watercourse should comply with the requirements of the flood control planning for the watercourses, while safeguard measures should be put forward, if its scale is inconsistent with the flood control planning.

(3) The layout of water transfer routes should fully consider the principles of saving land \cite{5-6} and protecting the environment, rationally utilize the existing water conservancy land and original facilities, reduce the number of new construction land, and rationally optimize the layout to avoid the sensitive areas of the ecological environment.

(4) The layout of the project should give full consideration to the principle of combining with the project of first phase. On the premise of technical feasibility and economic rationality, the layout of the project should be integrated with the facilities of the first phase of the project as far as possible, and the operation of the first-phase project and the safety of the surrounding buildings should not be affected.
(5) The layout of the project should fully consider the local original water rights\cite{7-8}, and the implementation of the project of the second phase should not increase the local pressure of flood control and drainage.

2. Research of the Second-Phase Section Layout

2.1. Necessity of the Research of the Section Layout

The major watercourses running north and south within the section from Hongze Lake to Luoma Lake include Xuhong Lake (including Fangting River), Luonan Grand Canal and ancient yellow river. According to the “Overall Planning” approved by the State Council in 2002, the eastern route of the south-to-north water diversion project should be completed in three phases. In the first phase, the double-route water diversion within the section from Hongze Lake to Luoma Lake should be carried out by Xuhong River and Luonan Grand Canal, with a total volume of 350-275 m$^3$/s. In the second phase of the project, the water transfer scale should be increased by 100 m$^3$/s, and the total water transfer scale should meet the demand of 450-350 m$^3$/s by expanding Xuhong River. On the basis of the second phase, the water transfer scale of the third phase should be increased by 175 m$^3$/s, and Luonan Grand Canal should be expanded to meet the demand for the total scale of 625-525 m$^3$/s. As the section from Huaiyin Sluice to Siyang Sluice of Luonan Grand Canal is restricted by the embankments on both sides of the river, it is difficult to expand and excavate, so Chengzixin River from Hongze Lake to Siyang should be excavated with a water transfer scale of 175 m$^3$/s. At the same time, the supporting project pumping stations along the route should also be performed.

In January 2016, the Ministry of Water Resources proposed to combine the second and third phases of the eastern route into “the second phase of the eastern route”. The Jiangsu provincial government made it clear that “the water supply scope and water consumption of the second phase of the south-to-north water diversion project in Jiangsu shall not be increased”, and combined with local opinions, it proposed that “the subsequent projects in Jiangsu shall be constructed according to the relatively single route scheme of delivering the water out of the province”.

According to “Planning Report of the Eastern Route of the Second Phase of the South-to-North Water Diversion Project (Summitted for Approval)” (2019.12) (hereinafter referred to as “Planning for the Second-Phase Project”), the plan should be adopted that both Luonan Grand Canal and Xuhong River should be used to expand the water transfer scale in the water route of the second phase of the project from Hongze Lake to Luoma Lake. However, according to the actual situation of Jiangsu Province, Xuhong River mainly runs through rural districts, and it is relatively easy to enlarge and excavate the expropriated land and to make coordination, while the water route of Luonan Grand Canal and Chengzixin River is busy with dense coverage of villages along its watercourse, and it is difficult to select sites for the construction of pumping stations. In addition, long-term water delivery with a high water-level increases the risk of engineering for flood control, navigation safety and waterlogging effects, as a result of which it is suggested that the single-route plan of expanding and excavating Xuhong River should be adopted in the second phase of the project.

In studying the layout of the water transfer project in this section, it is necessary to comprehensively consider the water transfer capacity of Xuhong River and Luonan Grand Canal and the reserved scale of the first phase of the project, the influence of the land occupied by the residents to be removed, the construction conditions and the project investment of the first phase of the project, etc., at the same time of taking the recommended scheme of “Planning for the Second-Phase Project” and the opinions of Jiangsu Province into account.

2.2. Research of the Section Layout of the Second-Phase Project

According to the distribution of the regional water system, the main south-to-north watercourses which connect the two lakes from Hongze Lake to Luoma Lake include Xuhong River, Luonan Grand Canal and the ancient Yellow River. Among them, Xuhong River and Luonan Grand Canal are the watercourses that are used in the project of the first phase to transfer water. At the initial stage of the
planning, the local government proposed that the second phase of the project should adopt the double-route water transfer scheme with Xuhong River and the ancient Yellow River, mainly considering to serve the economic development and the construction of the ecological corridor along the ancient Yellow River in the urban area of Suqian. Considering that most of the soil along the ancient Yellow River is sandy loam soil with poor water retention and serious leakage, and that it belongs to the newly utilized watercourse in the second phase with imperfect supporting projects along the river, which increases the difficulty of ensuring the water quality and the complexity of managing the project, at the same time of leading to the increase of total project investment and other problems, the scheme comparison and selection of this section of project of the second phase is still carried out on the basis of the two water transfer watercourses, on the premise of making full use of the existing river transfer capacity in the first phase.

The Luonan Grand Canal runs through the main urban areas of Suqian City, and it is difficult to expropriate the land and remove the residents, so the construction impact is relatively large. According to this situation, the river expansion and excavation should be mainly based on the dredging in the dike. At the same time, the Chengzixin River should also be dredged in combination with the waterway project of Chengzixin River completed by the Waterway Department in 2014 (the current situation of water transfer is about 82 m³/s). On the other hand, along the Xuhong River are mainly the agricultural areas, so it is easy to expropriate the land and remove the residents with relatively small influence on the construction, so that the scale of river expansion and excavation can be determined according to the requirements of the water transfer scale of the second-phase project.

In combination with the regional water system and the situation of first-phase project, two water transfer schemes are proposed for comparison and selection for this section. The first scheme is to maintain the the first-phase scale of Luonan Canal and expand the water transfer scheme of Xuhong River (hereinafter referred to as the “single-route water transfer scheme of Xuhong River”). The second scheme is to expand the water transfer scheme of both the Luonan Grand Canal and Xuhong River (hereinafter referred to as the “double-route water transfer scheme of Xuhong River and Luonan Grand Canal”).

![Figure 1. Schematic Diagram of Water Diversion Routes from Hongze Lake to Luoma Lake for Comparison and Selection](image-url)
3. Comparison and Selection of Layout Schemes

3.1. Design Water Level
How to design the water level from Hongze Lake to Luoma Lake influences how to determine the scale of watercourse excavation and how to choose the comparison and selection scheme. In all the comparison and selection schemes for the water route of this section of the project, the water route is expended on the basis of the project of the first phase. All of them consider that the pressure of flood control and drainage to the regions along the route should not be increased in the construction of the second phase. Moreover, in the design of first-phase project, sufficient demonstration has been carried out to design the water level, and its design is coordinated with the functions of navigation, waterlogging drainage, water supply along the watercourse and so on. At the same time, in the running process of the first phase, the water transfer of each project runs smoothly. Therefore, the water level of the second phase, designed for the second-phase project, should be the same with the one of the first phase.

3.2. Alternative Options

3.2.1. Scheme I: Single-Route Water Transfer Scheme of Xuhong River
The planned addition of 340-320 m³/s from Hongze Lake to Luoma Lake will all be transferred by Xuhong River, and the water transfer scale will increase from 120-100 m³/s in the first phase to 460-420 m³/s. The water will be pumped into Fangting River through Sihong Steps, Suining Steps and Pizhou Steps and then into Luoma Lake or to the north through the Luonan Grand Canal. The water transfer scale of Luonan Grand Canal will remain the same as 230-175 m³/s in the first phase.

Figure 2. Scheme for the Layout of Single-Route Water Transfer of Xuhong River from Hongze Lake to Luoma Lake

The main engineering constructions in this scheme include: the emissary digging trenches of Xuhong River; the expansion of watercourses, supporting and protection, embankment reinforcement, management and dispersion of roads and other projects in the whole route of Xuhong River and Fangting River (Liuji Wave-Grand Canal); the construction of the three cascade pumping stations: Sihong Station II, Suining Station III and Pizhou Station II; the expansion, demolition and construction of affected sluice gates across the river, buildings across the embankment and bridges across the river along the
route; the projects to deal with the surroundings that impact flood control and drainage.

3.2.2. Scheme II: Double-Route Water Transfer Scheme of Xuhong River and Luonan Grand Canal
In the scheme for the section from Hongze Lake to Luoma Lake of the second phase, an additional water of 340-320 m$^3$/s is planned. The added water of 100 m$^3$/s will be pumped from Siyang Steps, Liulaojian Steps and Zaohe Steps and transferred into Luoma Lake through Chengzixin River and Luonan Grand Canal. Xuhong River will add the water of 240-220 m$^3$/s, which will be pumped into Fangting River respectively by Sihong Steps, Suining Steps and Pizhou Steps and then transferred into Fangting River, so as to be transferred into Luoma Lake through Grand Canal or to the north.

Figure 3. Scheme for the Layout Double-Route Water Transfer of Grand Canal from Hongze Lake to Luoma Lake.

The main engineering constructions in this scheme include:
- **The Route of Xuhong River:** The constructions of this project are the same as those in Scheme I, only the project scale is reduced by 100 m$^3$/s in comparison with that of Scheme I.
- **The Route of Luonan Grand Canal:** The emissary digging trenches of the Chengzi River; the dredging within the embankment, the supporting and protection, the embankment reinforcement, the management and dispersion of roads and other projects in the whole route of Chengzi River and Luonan Grand Canal (including Pihong River); the construction of the three cascade pumping stations: Siyang Station III, Liulaojian Station III and Zaohe Station III; the expansion, demolition and construction of the affected sluice gates across the river along the route; the projects to deal with the surroundings that impact flood control and drainage.

3.3. Scheme Comparison
The comprehensive comparison and selection of the two schemes should be carried out from the aspects of the topographic and geological conditions, the lands occupied by the removed residents, the construction conditions, the assurance for water quality, the project management and the project quantity and investment [9-12], so as to reasonably determine the scheme for the the water transmission route of this section.
3.3.1. Topographic and Geological Conditions
According to the topographic and geological conditions along the route, cohesive soil, sandy soil and soft soil are widely distributed in both of the two engineering areas, and the thickness of the soft soil and the sandy soil is relatively high in certain areas. The foundation soil of Xuhong River and Luonan Grand Canal has some engineering geological problems in such aspects as anti-sliding stability, settlement deformation, seepage deformation, scoured river slopes and collapsed banks, so that corresponding measures to deal with engineering in certain areas should be taken. In addition, there are no engineering constraints.

3.3.2. Land Occupied by the Removed Residents
Scheme I: The project will permanently expropriate 9,231 mu of collective land and 88,409 mu of temporary land. The demolition will affect 33,026 people, 1.7979 million square meters of houses and 35 industrial enterprises. Then investment to the expropriation and removal of residents will be 13.274 billion yuan.

Scheme II: The project will permanently expropriate 7,617 mu of collective land and 85,078 mu of temporary land. The demolition will affect 28,363 people, 1.7099 million square meters of houses and 39 industrial enterprises. Then investment to the expropriation and removal of residents will be 12.436 billion yuan.

The workload of the expropriation and relocation of the water transfer route in Scheme I is slightly larger, while the difficulty of the two schemes in this aspect is basically similar on the whole.

3.3.3. Construction Conditions
Both schemes are technically feasible and there is no essential difference between them. However, scheme I is better than scheme II in terms of the construction diversion, the water supply, the enclosing of foundation pits and the supporting and protection.

3.3.4. Assurance of Water Quality
Compared with Scheme II, Scheme I uses the watercourses of Xuhong River and Luonan Grand Canal for water transfer. Scheme II uses the watercourses of Xuhong River and Luonan Grand Canal (with Chengzixin River added) for water transfer, and scheme II has slightly larger difficulty in ensuring water quality.

3.3.5. Environmental Factors
In the aspects of ecological environment and water environment, there are constraints in both schemes, and the constraints in scheme II are slightly more than those in scheme I. The adverse effects of environmental constraints occur only during the construction period and will disappear after the completion of the project.

3.3.6. Project Management
There are relatively more entrances along the route of Luonan Grand Canal, the pressure of ensuring the water yield transferred to the north during the peak period is also heavy, and the difficulty in management is relatively large in the current water transfer during the first phase of the project. In scheme II, on the basis of the first-phase project, the water transfer scale of 100m³/s will be increased by Luonan Grand Canal, which will further increase the management difficulty during the water transfer period. At the same time, six new pumping stations will be needed to be built, so it is relatively difficult to coordinate the dispatch and the operation during the water transfer period. In scheme I, all the newly added water should be transferred to the north by Xuhong River. Along the route of Xuhong River, there are mainly agricultural areas, and there are few water users and tributaries entering the river. Therefore, it is relatively easy to manage during the water transfer period. At the same time, only a new three-stage pumping station is needed to be built, so the difficulty of coordinating the dispatch and the coordination of the project is relatively small.
3.3.7. Project Quantity and Investment

In scheme I, the amounts of excavated earthworks, the amount of filling works and the land occupation are slightly larger than those in scheme II, but the distance of earthwork transportation is longer, as the Luonan Grand Canal passes through the urban area of Suqian City. In addition, compared with scheme I, the influenced projects along the route of Luonan Grand Canal increase in scheme II, and the total project investment also increases slightly.

Table 1 Comparison Table of Economic and Technical Indicators for the Comparison and Selection of the Schemes for the Section from Hongze Lake to Luoma Lake

| Serial number | Project Description                                      | Scheme I   | Scheme II  |
|---------------|----------------------------------------------------------|------------|------------|
| 1             | Excavated earth (ten thousand square)                    | 8552       | 7179       |
| 2             | Filling earth (ten thousand square)                      | 378        | 313        |
| 3             | Supporting and protection works (ten thousand square meters) | 1174       | 1441       |
| 4             | Permanently expropriated land (mu)                       | 31035      | 26891      |
| 5             | Temporarily occupied land (mu)                           | 77862      | 73171      |
|               | Investment to the land occupied by the removed residents (one hundred million yuan) | 114.39 | 102.44 |
|               | Investment to the watercourse project (one hundred million yuan) | 76.21  | 93.44      |
|               | Subtotal (one hundred million yuan)                      | 190.60     | 195.89     |
| 1             | Permanently expropriated land (mu)                       | 5485       | 6892       |
| 2             | Temporarily occupied land (mu)                           | 10547      | 11907      |
|               | Investment to remove the residents around the pumping stations (one hundred million yuan) | 13.06 | 16.73 |
|               | Subtotal (one hundred million yuan)                      | 114.93     | 125.64     |
|               | Total investment to the main projects (one hundred million yuan) | 305.53   | 321.53     |
|               | Investment to the influenced projects (one hundred million yuan) | 1.38    | 8.78       |
|               | Total investment to the main projects + the influenced projects (one hundred million yuan) | 306.91 | 330.31 |

3.3.8. Advantages and Disadvantages of the Project

Table 2 Comparison and Analysis Table for the Advantages and Disadvantages of the Compared and Selected Routes from Hongze Lake to Luoma Lake

| Project Analysis of the advantages and disadvantages | Scheme I: single-route water transfer scheme of Xuhong River | Scheme II: double-route water transfer scheme of Xuhong River and Luonan Grand canal |
|-----------------------------------------------------|----------------------------------------------------------|------------------------------------------------------------------------------------------------|
| 1) The added water is transferred in the centralized mode, with the relatively small influence to the areas along the route. | 1) It makes full use of the present water transfer capacity of Luonan Grand Canal and Chengzi xincRiver (25m³/s), and the excavation quantity of Xuhong River is relatively small. |
| 2) There are fewer water users along the watercourse and less discharge outlets into the river via branch rivers, and both the quantity and the quality of the water are ensured. | 2) There is less land to be excavated and fewer residents to be removed. |
| 3) It is easier to manage the project. | 3) It is easier to manage the project. |
4) With mainly agricultural areas distributed along the watercourse, it is relatively easy to expropriate and remove the residents.

Disadvantages

1) The amounts of excavated earthworks, occupied land and project investment of Xuhong River are relatively large.
2) The water carrying capacity (25m³/s) of the existing channel of Luonan Grand Canal cannot be fully utilized.
3) The investment to the newly-built projects of the pumping stations of Luonan Grand Canal are relatively large, and the project management is relatively complex.
2) There are relatively more entrances along the route, and the water yield transferred to the north during the peak period cannot be ensured.
3) The influence range of the watercourses is large, and there will be relatively more influenced projects along the Luonan Grand Canal.
4) The annual water supply forbids the embargo of dangerous chemicals, which has a great impact on the industrial development, social economy and social stability in the areas along Luonan Grand Canal.

3.4. Conclusion of the Scheme Comparison

Through the comprehensive comparison and selection of the above two schemes, it is concluded that in scheme I, the added water is transferred in the centralized mode in the second phase of the single-route water transfer scheme of Xuhong River. It is implemented with lower investment, fewer newly built pumping stations, convenient project operation and management, fewer water users along the watercourse, less discharge outlets into the river via branch rivers, and a higher degree of water assurance in both quantity and quality. Moreover, with mainly agricultural areas distributed along the watercourse, it is relatively easy to coordinate for the land expansion and expropriation. In scheme II, the double-route water transfer scheme of Xuhong River and Luonan Grand Canal, the water transfer route of the second-phase project has a wide range of influence, the investment is relatively large, the water supplied to the north is difficult to be ensured in its quantity and quality during the peak irrigation period, and the annual water supply forbids the embargo of dangerous chemicals, which has a relatively great impact on the shipping benefits of Luonan Grand Canal.

Considering comprehensively, the total project investment of Scheme I is less, the influence scope is smaller, and the project management is simpler. Therefore, Scheme I, the single-route water transfer scheme of Xuhong River is recommended.

4. Suggestions and Opinions

The eastern route of the south-to-north water diversion project is a major strategic project to construct the pattern of the water resources allocation in China, which plays a significant role in satisfying the demands for the industrial and agricultural water and the filling water of lakes and wetlands in the Beijing-Tianjin-Hebei region as well as implementing the management of the overuse and the refilling of the groundwater source, etc. On the other hand, it also needs to take into account the water rights and the local government’s opinions and suggestions along the refilling water, and coordinate the functions of flood control, drainage, water supply, navigation and ecology, etc., so as to ensure the smooth implementation of the second-phase project.

Acknowledgments

Key Project of Water Conservancy Science and Technology, Jiangsu Province of China: Analysis of the Impact of the Second Phase of the East Route of South-to-North Water Transfer Project on the Water Resources Allocation Pattern in Northern Jiangsu Province and Study on the Improvement Countermeasures of Water Supply Engineering System in Northern Jiangsu Province (2019027).

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