

The South-to-North Water Diversion Project in China: An Engineering Solution to Socio-environmental Challenges

By Xin He, Jun Guo and Jindong Cai

China's South-to-North Water Diversion Project (SNWDP) is one of the most ambitious and significant water infrastructure projects in the world. The proposal for this great undertaking was initiated in the 1950s to address severe water scarcity issues in the northern regions of China by diverting water from the south, where water resources are relatively abundant. After decades of planning, where more than 50 proposals were compared, the Chinese central government decided to implement this unprecedented project in 2002. SNWDP comprises three routes located in the east, central, and west of the country, extending over 4,350 km and designed to divert 44.8 billion m³ of water. This article explores the engineering marvels and remarkable results of this project after the first phase of the East Route and Middle Route became fully operational in 2013 and 2014, proving the project's indispensable role in China's water management.

Three routes with different solutions

Three water diversion areas were identified in the lower, middle, and upper reaches of the Yangtze River as the water sources. Ultimately, three artificial canals, each in the east, middle, and west of the country, constituted the magnificent project, connecting four natural rivers: the Yangtze River, Huaihe River, Yellow River, and Haihe River. This forms an overall pattern of a "four horizontal lines and three vertical lines national water grid", which later becomes the skeleton of China's National Water Network. The three water diversion routes are:

East Route

The East Route utilizes the existing Beijing-Hangzhou Grand Canal to transport water from Jiangsu Province. The East Route draws water from the lower reaches of the Yangtze River and uses 13 pumping stations to lift the water northward step by step. It connects Hongze Lake, Luoma Lake, Nansi Lake, and Dongping Lake, using these lakes along the way as water regulation and storage facilities. After exiting Dongping Lake, water is transported in two ways: one branch to the north, crossing the Yellow River through a tunnel near Weishan and sending the water to Tianjin, while the other branch heads east, sending water to Yantai and Weihai along the economic south of the Jiaodong Peninsula. The total length of the main water transmission line is 1,466.5 km in the first phase of the project, which became operational on 15 Nov. 2013. The planned function of the East Route is for domestic water supply, and at the final stage of the project, it is expected that 14.8 billion m³ will be diverted on this route.

Middle Route

The Middle Route diverts water from the head gate of the Taocha Canal, connecting to the expanded Danjiangkou Reservoir. The main canals extending to the north are excavated along its path. The Middle Route passes through the western part of

the Tangbai River Basin and the Fangcheng Pass, which serves as the watershed divide between the Yangtze River Basin and the Huaihe River Basin. Along the western edge of the Huanghe-Huaihe-Haihe Basin, the Middle Route crosses the Yellow River near Licun, Zhengzhou, and continues further north along the west side of the Beijing-Guangzhou Railway. Water in the Middle Route is gravity-driven open channel flow that spontaneously follows the topography from south to north. The total length of the main water transmission line is 1,431.9 km, and its first phase became fully operational on December 13, 2014. It is expected that, at the final stage, 13 billion m³ of water will be diverted on the Middle Route, primarily for domestic and industrial water supply, as well as occasional ecological water replenishment.

West Route

The West Route is still under study. Reservoirs will be built in the upper reaches of the Tongtian River, tributaries of the Yalong River, and Dadu River in the upper reaches of the Yangtze River. Water will then be diverted from the Yangtze River to the upper reaches of the Yellow River using mountain tunnels through the Bayan Har Mountains. The water supply target of the West Route is primarily to address the water shortage problem in six provinces, including Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, and Shanxi, situated in the upper and middle reaches of the Yellow River and the Guanzhong Plain.

Engineering marvels

A large number of innovative engineering solutions emerged during the construction of the first phase of the SNWDP. These solutions encompassed new materials, devices, computer software, and more. In total, 13 national technical standards were established, and hundreds of patents were filed throughout the process. Some of the noteworthy engineering innovations are as follows.

Large-diameter water conveyance tunnel

The SNWDP Middle Route Crossing the Yellow River project pioneered the design of a double-layered tunnel, which is 4,250 meters long with inner and outer layers of lining. The inner diameter of the tunnel is 7 meters, and the outer layer is 0.4 meters thick. Pipe segments are reinforced with concrete prestressed lining, and the two layers of lining are separated by a permeable bedding in between. The SNWDP Middle Route Crossing the Yellow River project boasts the largest water conveyance tunnel across a major river in China in terms of both length and diameter. Additionally, the SNWDP also features the world’s first large-diameter water conveyance tunnel that passes through the lower part of a subway at a close distance in the Beijing Section of the Middle Route.

Deep shaft for water diversion

The SNWDP boasts the deepest water diversion shaft in China, situated at the point where the Middle Route intersects the Yellow River. The site is located approximately 30 km west of Zhengzhou City in Henan Province. The primary objective is to transfer water from the south bank of the Yellow River to the north bank, while also facilitating the replenishment of the Yellow River during periods of excess water from the south. The vertical shaft on the north bank is a substantial cylindrical structure with an inner diameter of 18 meters and a depth of 50.5 meters. It is constructed in the sandy and highly permeable floodplain of the Yellow River. The designed flow rate is 265 m³/s, and the increased flow rate is 320 m³/s. The shaft’s wall features a double-layered structure, with the outer layer being 1.5 meters thick and extending to a depth of 76.6 meters, while the inner layer is 0.8 meters thick.

U-shaped water conveyance aqueduct

The SNWDP utilized the world’s largest U-shaped water conveyance aqueduct project of its time, namely the Tuanhe Aqueduct project on the Middle Route, which spans over 10 km. Both the Tuanhe Aqueduct and the Shahe Aqueduct on the Middle Route are three-way prestressed U-shaped aqueducts, boasting an inner diameter of 9 meters, a single span of 40 meters, and a maximum flow rate of 420 m³/s. Trenching machines were employed for on-site concrete construction.

Dam heightening

The SNWDP at the Danjiangkou Reservoir is the largest dam heightening project in China, which started in 2005 and was completed in 2014. The site is located 800 meters downstream of the confluence of the main stream of the Han River and its tributary, the Danjiang River, in Danjiangkou City, Hubei Province. It is a concrete structure that heightens the original dam body by 14.4 meters, including concrete dam heightening and core earth-rock dam heightening.

After the dam heightening project was completed, the dam crest elevation increased to 176.6 meters, and the dam crest axis is 3,442 meters long. The dam heightening increased the normal water storage level from 157 meters to 170 meters, subsequently increasing the reservoir storage by 11.6 billion m³. The construction of the heightened dam, including crack inspection and repair, was executed without affecting the normal operation of the original dam, making it one of the most challenging dam heightening projects in the world.

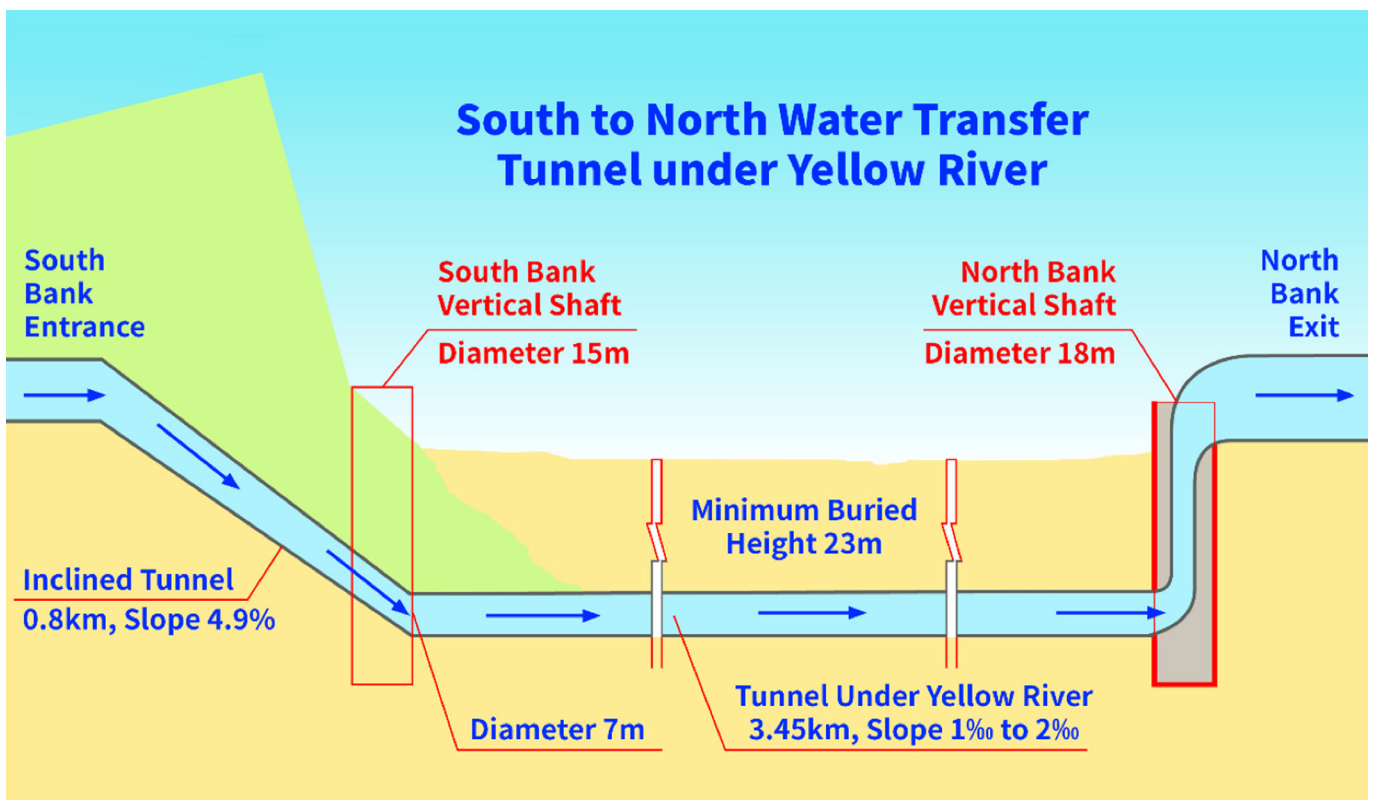


Figure 1 | SNWDP crossing the Yellow River.

PCCP pipelines

The Prestressed Cylinder Concrete Pipe (PCCP) in the Beijing section of the Middle Route has achieved several notable milestones. For instance, a complete set of design parameters and material standards for PCCP was proposed. Additionally, a set of technical parameters for cathodic protection of PCCP pipes was established. A novel steel wire anchoring method was developed to address the issue of electrical connections in PCCP cathodic protection. Furthermore, a mechanized spraying process for the external anti-corrosion coating of PCCP was invented. The deployment of an ultra-large diameter PCCP gantry crane in the trench marked a significant breakthrough. Moreover, installation processes and quality control standards for ultra-large diameter PCCP installation in trenches and tunnels were introduced.

Sewage interception mission

For a long time, water pollution in the rivers and lakes along the East Route has been a concern, as wastewater, whether

treated or untreated, is discharged into rivers that directly connect to the main water pathway of the East Route. The sewage interception mission is a collection of 426 local pollution control facilities that safeguard the quality of water sent to the north, making it a crucial component for the success of the East Route. These engineering measures consist of four steps: water gathering, treatment, reuse, and redirection. The mission primarily utilizes existing river channels, and some new channels are excavated to intercept and redirect reclaimed sewage water to the sea.

To achieve the aforementioned engineering success, cutting-edge scientific research results were applied in the engineering design and construction, playing a critical role in ensuring the project's quality. Key scientific research topics were integrated into the national science and technology plan, and close collaboration was established with researchers from Tsinghua University, Wuhan University, Hohai University, and the China Institute of Water Resources and Hydropower Research.



Figure 2 | Major engineering projects in SNWDP.

Results after operation

By December 2022, the first phase of the East Route and the Middle Route of the SNWDP has been fully operational for 8 consecutive years. Over the years, the project has transferred a total amount of 58.6 billion m³ of water, serving more than 280 counties (districts) in 42 large and medium-sized cities along the routes, directly benefiting more than 150 million people, and exerting enormous social, economic, and ecological impact.

The SNWDP has helped optimize the national water resources allocation, safeguarded drinking water supply, improved ecological and environmental conditions, and boosted the regional and local economies.

In addition, the SNWDP increased resilience to climate change in some areas. It has effectively adjusted the regional microclimate, as the water flowing in the open canals evaporates, increasing the air humidity in the dry north. The project has also demonstrated significant flood control benefits. Since its operation, it has weathered heavy rainfall from multiple typhoons, such as Ambi, Capricorn, and Umbia, when the storage capacity of the lakes along its path played a critical role in alleviating flood damage. Furthermore, after the enlargement of the Danjiangkou Reservoir, it has helped increase the storage

capacity of floodwater by approximately 3.3 billion m³. Regarding drought resistance, cities such as Yantai, Weihai, and Qingdao were severely affected by the drought in 2016 and 2017. The East Route of SNWDP operating in conjunction with local reservoirs, ensured water supply security for the entire Jiaodong Peninsula.

Conclusions

The South-to-North Water Diversion Project (SNWDP) in China addresses critical water scarcity issues in the northern regions of the country, standing as a testament to Chinese ingenuity in hydraulic engineering. The project overcomes numerous engineering challenges due to its immense scale and complexity. For instance, it involves crossing large rivers, heightening existing large dams, and maintaining water quality. Meanwhile, it also underscores the importance of careful planning, environmental responsibility, and the use of sustainable engineering practices to minimize potential risks. The project undeniably offers a set of significant positive impacts, including optimized water resources allocation, increased water security, economic growth, improved environmental restoration, enhanced water quality, and climate resilience. The SNWDP will continue to shape the future of water management in China and serve as a case study for similar projects worldwide.



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