Environ Dev Sustain (2018) 20:2415–2426
https://doi.org/10.1007/s10668-017-9996-7

Environment and sustainability of the Middle Route, South-to-North Water Transfer Project in China: a close look

Xiang-Zhou Xu[1] · Guo-Dong Song[2,3] · Tian-Min Dang[4] · Jian-Wei Liu[1] · Hong-Wu Zhang[2] · Hang Gao[1] · Ya-Kun Liu[1]

Received: 30 November 2016 / Accepted: 14 June 2017 / Published online: 20 June 2017
© Springer Science+Business Media B.V. 2017

Abstract In many arid and semiarid regions, water scarcity, population increase and frequent droughts are exerting great pressures on water resources. Presently, the Mid-route of the South-to-North Water Transfer Project (MRSN) was built to mitigate the water crisis in the north of China by long-distance transfer of water from the Yangtze River in southern China. This study investigated the running condition of the MRSN, including operation management, freezing situation and water quality. Water samples were also taken from different sites and then analyzed in laboratory. Results suggest that the project was reasonably designed and the project management was excellent. Closed management was adopted in the project to protect water quality. The sediment concentrations and water turbidities of the water samples were in the range of 0.2–0.8 kg/m^3 and 0.8–1.7 NTU, respectively, which met or were close to the standards of drinking water in China. Water freezing is also not a problem, since the thickest ice was only 0.9 cm even in the coldest season as the authors measured the investigation, and at the same time, the ice booms worked well. In the future, it is promising that to effectively integrate the methods of self-rescuing and water importing could fundamentally conquer water shortage, reasonably allocate water resources and finally achieve the harmonious development of economics, ecology and society.

Keywords MRSN · Water quality · Freezing · Operation management

✉ Xiang-Zhou Xu
xzxu@dlut.edu.cn

[1] School of Hydraulic Engineering, Dalian University of Technology, Dalian 116024, China

[2] State Key Laboratory of Hydroscience and Engineering, Tsinghua University, Beijing 100084, China

[3] Key Laboratory of River Regulation and Flood Control of MWR, Yangtze River Scientific Research Institute, Wuhan, China

[4] College of Natural Resources and Environment, North West Agriculture and Forestry University, Yangling 712100, Shaanxi, China

1 Introduction

How to overcome water shortages in northern China? The country selected the South-to-North Water Diversion Project. With global trends of population growth, urbanization and climate change, water is becoming increasingly difficult to procure in sufficient supply and quality to meet urban demand (Prichard and Scott 2014; Molle 2007). Several provinces in China experience moderate to severe water shortages, affecting municipal, industrial and agriculture needs. The total national shortage in 2030 is forecasted to be nearly 200 billion m^3, with more than 25% for domestic needs (Avrin et al. 2015; Addams et al. 2009). On the other hand, due to an uneven distribution of annual rainfall, most water resources are concentrated in the south and southeast of the river basins, resulting in a large water-deficient area in northern China (Wang and Jin 2006; Liu and Zheng 2002). In 2003, the government of China began constructing the Mid-route of the South-to-North Water Transfer Project (MRSN), aimed to mitigate the water crisis in the north of China (Wang et al. 2015; Stone and Jia 2006; Chen et al. 2007).

To alleviate water resource problems such as water shortages and uneven distribution, large-scale inter-basin water transfer projects have been adopted worldwide, e.g., the Central Valley Project in the USA, the Alqueva Project in Portugal, the Majes Project in Peru, the West to East Water Transfer Project in Egypt, the Snowy Mountains Scheme in Australia and the Dujiangyan Irrigation System in China. From an engineering perspective, these projects are, no doubt, substantial successes. The Central Valley Project furnishes about 740 million m^3 for municipal and industrial use—enough to supply the water needs of close to 1 million households in the USA each year (Lofman et al. 2002). The Central Valley Project also improves Sacramento River navigation, generates electric power, conserves fish and wildlife, creates opportunities for recreation and enhances water quality (Wikipedia 2016). In the south of Portugal, the Alqueva Project is a multipurpose project that aims at social and economic development of the Alentejo region by setting up a strategic water reserve and providing a guaranteed water supply for irrigation, population and industry (Lobo et al. 2002; Antunes et al. 2009). Compared with those of modern engineering, the irrigation system of Dujiangyan was appropriately arranged in accordance with the terrain and topography of the Minjiang River and Chengdu Plain, thus successfully solving the problems of sand discharge, flood control and water distribution (Cao et al. 2010; Li and Xu 2006). Meanwhile, no obvious sediment or freezing problem exists in the projects mentioned, which has great significance for reference to construction of the MRSN. However, engineering construction usually causes some negative impacts in the initial stage, which clearly highlights the need for developing sustainable water management policies. For instance, the Central Valley Project had a problem at the outset because it never could move enough water to achieve its main irrigation objective (Taylor 1949). Furthermore, the Alqueva Project has negative environmental and social impacts mostly due to the submersion of a very large area that includes important ecological values and habitats; other important impacts are related to the Guadiana estuary and the quality of water for irrigation (Lobo et al. 2002). The Snowy Mountains Scheme had also a disparate impact on the surrounding area, characterized by uneven growth without a consolidation of regional roles (Domicelj 1980). In general, the negative effects exposed in these projects can be attributed to two issues: One is mainly about water delivery problem, and another is determined by flaws in management. These are also the issues that should be considered in water transfer projects in China.

Managing water resources in transboundary rivers, in terms of both quality and quantity, is a difficult and challenging task that requires efficient cross-border cooperation and transparency (Elias et al. 2014). The MRSN tries to mitigate the water crisis in the north of China due to rapid development of the economy and the explosion of the city's population by long-distance transferring water from the south to the north. It transfers water from the Danjiangkou Reservoir on the Hanjiang River, a large tributary to the middle reaches of the Yangtze River, to Hubei, Henan and Hebei Provinces, and ultimately to Beijing and Tianjin (Chen and Xie 2010; CWRC 2001). About 213 billion yuan RMB has been spent on the engineering construction projects of the MRSN until July, 2015, which accounts for 99% of the total investment (SNTPO 2015). With a length of 1277 km, the MRSN transferred water to nearly 150 cities and 151 thousand hectares of land via open channels, culverts and pipes. The region is highly urbanized with rapid economic development in the past decade, resulting in large amount of waste water discharges and chemical oxygen demand. Thus, the quality of the water had a decisive effect on the entire MRSN (Tang et al. 2014). Implementation of the project will no doubt foster rapid economic development along the canal, but in the meantime, the project might also bring the possibility of water pollution (Zhang 2009; He and Zhang 2007) and other problems. Hence, it is of great importance to solve the existing problems of water resources and achieve their optimal use.

Management theories on sustainable development, with natural resources limitation including water limitation, must be seriously taken into account (Tabari and Yazdi 2014). From previous experiences reported in the literature, water management has been identified as a key factor that influences the success or failure of a project's implementation. With the increasing demands of the study area and excessive withdrawal for water supply demands, the condition of natural resources will gradually deteriorate (Tabari and Yazdi 2014). Consequently, if this status is not correctly and fundamentally managed, in the near future, the crisis of water resources will worsen. For example, in the Central Arizona Project, the water planners made a number of important technical mistakes that caused an imbalance between supply and demand (Hanemann 2002). Hence, management modes and suitable schemes must be developed based on objectives that are compatible with the region for correct management of existing water resources and their rational use. To conform to the real situation, it is necessary to study the operating conditions of water transfer and water quality by field investigation.

Existing literatures specially report field ice monitoring (e.g., Wen et al. 2015) or water pollution simulation (e.g., Tang et al. 2014) on the MRSN. From a more macro-perspective, the objectives of this paper are to study the current situation of the MRSN and address the problems of water quality and freezing that are attracting public concern. The authors took a field observation in the Beijing–Shijiazhuang section of the MRSN and then determined the sediment concentrations and water turbidities of the water samples in laboratory. Several management suggestions are also presented based on the local situation.

2 Field investigation and laboratory test

Based on field investigations and laboratory tests, this paper determines water transfer and water quality in the Beijing–Shijiazhuang section of the MRSN.

2.1 Field observations

A field investigation was carried out in the downstream of the MRSN crossing Shijiazhuang of Hebei Province during 27–28 of December 2014. The reason to select the sector as the study site is as follows: (1) The structure of the canal in Shijiazhuang sector is a representative one for the total MRSN. Compared with the natural river, all channels in different sectors were newly excavated and their structures are almost similar in different canal reaches. (2) The temperature in Shijiazhuang, 270 km away from Beijing, is the coldest area of the channel coverage area. Water in the channel may freeze in winter because of the low temperature. (3) Pollution in the Shijiazhuang area is more serious than those in other areas along the MRSN. Air pollution here is very serious. Polluted rain may fall into the main canal and then influence the quality of water in the channel because the MRSN is openly constructed. Additionally, constructions along the canal cut through the original roads and hindered people from traveling freely. Thus, many bridges were constructed to make up for the inconveniences, which may increase the likelihood of vehicular accidents and let fuel oil run into the main canal (Fig. 1).

To investigate possible differences for various types of sluices, field studies were conducted at five sites along the Beijing–Shijiazhuang section of the MRSN: (1) Huachai Underdrain, (2) Taitougou Inverted Siphon, (3) Underdrain of Ancient Canal and Tianzhuang Diversions (a waste sluice), (4) Shangzhuang Diversion Sluice and (5) Drainage Inverted Siphon in the Sloping Area of Taitougoubei. Four main tasks were accomplished in this investigation. Firstly, laser range finder (Fig. 2a) and angulometer (Fig. 2b) were

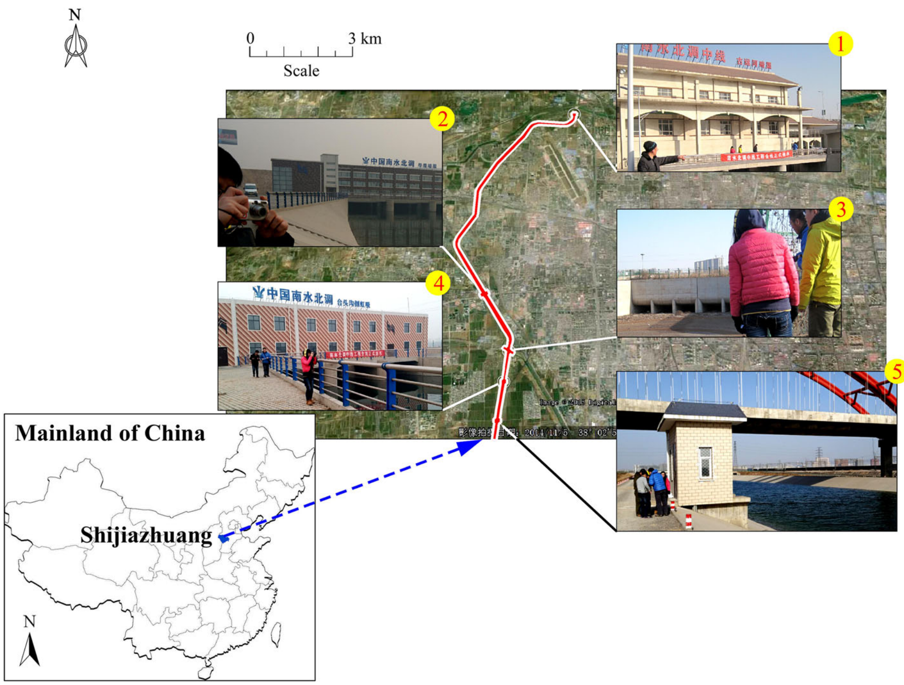

Fig. 1 Study area: Beijing–Shijiazhuang section of the MRSN in China. *1* Underdrain of the Ancient Canal and Tianzhuang Diversion, *2* Huachai Underdrain, *3* Inverted Siphon Drainage in the Sloping Area of Taitougoubei, *4* Taitougou Inverted Siphon and *5* Shangzhuang Diversion Sluice

Fig. 2 Channel profiles, water temperature and ice thickness were measured on site: **a** measurement of the channel length and width with laser range finder, **b** measurement of the channel slope with an angulometer, **c** observation of the water temperature using a thermometer tied to a stone and **d** investigation of the thickness of the ice collected from the thick ice layer

used to measure the contour and slope angle of the channel, respectively. Secondly, a thermometer tied with a stone was used to test the temperature of the trunk stream in the channel (Fig. 2c). Thirdly, a steel tape was employed to explore ice thickness. Ice samples were collected from the thick ice layers, put on the embankment and then measured for their thicknesses with the steel tape (Fig. 2d). Finally, water samples were collected at the Taitougou Inverted Siphon, the Shangzhuang Diversion Sluice and the Underdrain of Ancient Canal.

2.2 Analyzing water quality

Sediment concentrations and water turbidities of the water specimens were measured in the laboratory of Institute of Environmental and Water Resources, Dalian University of Technology. Water turbidity was measured using a spectrophotometer, and at each sampling site it was expressed by the mean of five replicates of analysis per sample. Sediment concentration was determined based on the increase in density contrasting tested water with clear water using an electronic balance at a sensibility of 1 mg and pycnometers each at an inner volume of approximate 100 ml (Xu et al. 2007). The experimental setup used is shown in Fig. 3, including a FA214 electronic balance, some pycnometers and a UV-7504 spectrophotometer.

3 Results and discussion

3.1 Project management

The project aims to efficiently transport water in high quality. The channel had no direct hydraulic connections between internal and external structures for all channels were newly excavated and concrete-lined. The whole channel in Beijing–Shijiazhuang section of the MRSN was an open channel designed at 7.5 m depth of water and 15.5–20.5 m width at the bottom. A geomembrane with a smooth and glossy surface was fixed between the concrete lining and the drainage systems, which included the bedding, drainage pipe and check valve. In the lock chamber crossing the main canal, sector gates were equipped to control the stream flow. Meanwhile, the stream flows to cities yearning for water via outlets along with the channel.

The Administration Bureau of the MRSN was established to effectively manage the project and guarantee its safe operation. The whole project was under closed management—no outsider was allowed to visit without permission from the authority. Isolation regions with width of 8 m at both sides of the channels were set up to prevent intruders from approaching the canal. Supporting facilities of this project were running well. Thus, water in the canal was clear and no garbage could be found anywhere. In addition, inside the lock chamber, a sluice gate control system was on duty 24 h a day to monitor the engineering devices and ensure normal running of the sluices. Nets were fixed outside the lock chamber to keep birds off and ensure the security of the sluices. Nevertheless, soil

Fig. 3 Instruments used in the experiments on water quality analysis. *1* FA214 electronic balance, *2* pycnometer and *3* UV-7504 spectrophotometer

from farmlands located at higher areas on the periphery of the main canal might run into the channel during a rainfall event.

3.2 Freezing in winter

Previous studies have shown that channel water delivery capacity will be significantly reduced when the canal operated under ice cover (Beltaos. 2008). A major consequence of ice cover formation in the rivers of northern China is the jamming that occurs during the transitional periods of freeze-up and breakup (Sui et al. 2002). These effects have repercussions in many operational and design problems such as the overturning moment on river structures due to moving ice, forces on ice booms, flooding, and so on. In addition, jams often extend for many kilometers along a river and can attain aggregate thickness of several meters. To pass the incoming flow, the river has to rise considerably so as to accommodate both the keel of the jam and the extremely large hydraulic resistance of its underside (Beltaos. 2008).

The investigation, from December 27 to 28, was carried out in the freeze-up period of Shijiazhuang. According to the daylight field measurement, the air temperature ranged from −1 to 10 °C and the water temperature ranged from −3 to −1.5 °C (Fig. 4). Water had frozen beside the embankment at the Underdrain of the Ancient Canal and Tianzhuang Diversions, etc. The thickest ices on the water surface were 0.9 cm, but they did not affect water delivery in the canal. The ice booms spanning the canal worked well on the water surface (Fig. 5).

In fact, a relatively large ice height, up to 9.9 cm, is found by other scientists in the sector of Anyang Inverted Siphon to Beijumahe Underdrain from January to February, 2015 (Wen et al. 2015). Consequently several effective schemes are suggested to ensure the water supply during freeze-up stage. Besides the ice booms above mentioned, a thermal anti-ice system is also equipped on the channel gate of the pump station to ensure the flowrate control of water division in the freezing seasons. On the other hand, non-engineering measures are also recommended. For example, to transfer water on a high water level but low flow rate mode is an effective way in winter (Zhou et al. 2016). Hence, even if ice covers existed in some sectors of the MRSN in the particularly cold days, water transport would be not interrupted in virtue of the structural practices and engineering measures.

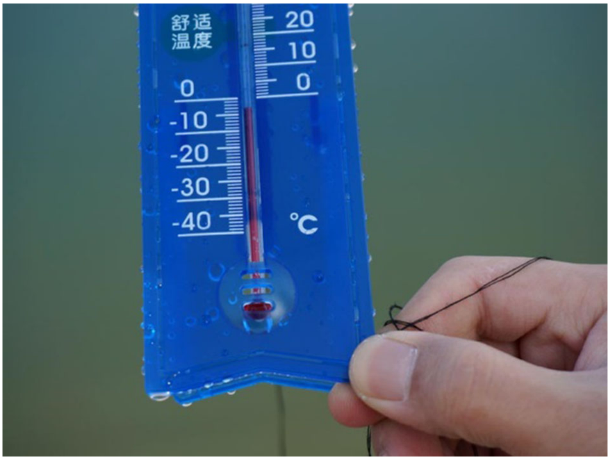

Fig. 4 Temperature of the freezing water (−3 °C)

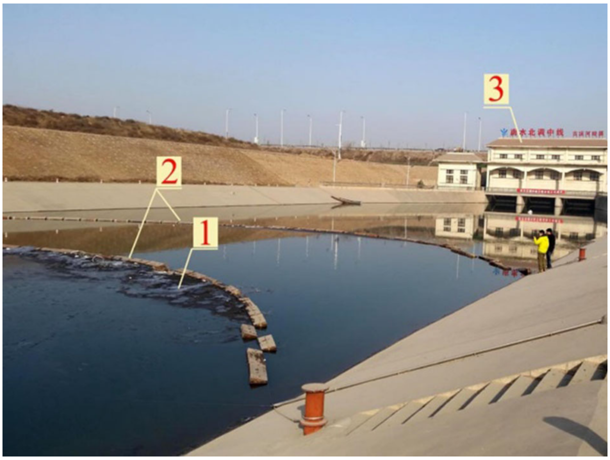

Fig. 5 Ice booms in operation. *1* ice, *2* ice booms and *3* sluice gate

3.3 Water quality

Sediment concentration and water turbidity are two regular indices for water quality evaluation. Water quality at three sites is displayed in Table 1. Sediment concentration was in the range between 0.2 and 0.8 kg/m^3, and water turbidity was in the range between 0.8 and 1.7 NTU. According to the Chinese Standards for Drinking Water Quality (GB 5749-2006), total dissolved solids should be less than 1000 mg/L, namely 1.0 kg/m^3, and the turbidity should be less than 1 NTU. Thus, the test data for both criteria nearly satisfied water quality requirements for drinking water. As shown in Fig. 6, the water samples in the left three bottles taken from the MRSN are clean and barely distinguishable from the tap water of Dalian City and the unopened Wahaha purified water. The project managers also told us water quality of the project met Class II of Chinese Surface Water Quality Standard according to the test by the Construction and Administration Bureau of the MRSN, and the water even could be drunk directly from canal and tasted better than the tap water of Shijiazhuang.

3.4 Implications and improvements

The MRSN is not only an ambitious engineering project to transfer water inter-basin, but also a program with huge ecological and social benefits. The project has several advantages. (1) It will relieve the water shortage in the receiving area and alleviate the problem of heterogeneous distribution of water resources in China. Furthermore, the project will

Table 1 Water qualities at three different sites

Site	Water quality	
	Sediment concentration (kg/m^3)	Water turbidity (NTU)
Taitougou Inverted Siphon	0.37	1.71
Underdrain of the Ancient Canal	0.51	0.77
Shangzhuang Diversion Sluice	0.34	1.01

Fig. 6 Comparison of clearness of tap water, pure drinking water and water sampled from the channel. No difference was found among them via direct eye observation. Water sampled at *1* Taitougou Inverted Siphon, on 17:10, 2014-12-27, *2* Underdrain of the Ancient Canal, on 15:07, 2014-12-28, and *3* Shangzhuang Diversion Sluice, on 13:20, 2014-12-28. *4* Tap water sampled at Dalian University of Technology, on 16:30, 2015-01-20 and *5* pure drinking water bought from a supermarket at Dalian University of Technology, on 2015-01-20

fundamentally resolve people's water woes in areas that are short of water. (2) It can also relieve desertification to a large extent, have a greater impact on regional climate and mitigate the severe reliance on groundwater in northern China (Chen and Du 2008). (3) Money invested in this project will stimulate economic growth in China. (4) Water transfer could promote the development of agriculture and industry at the water transferring and importing regions in the south of the Yellow River, which have experienced rapid economic development in recent years but might suffer from water shortages (Liu and Zheng 2002). However, because the MRSN unprecedentedly transfers inter-basin water on a large scale, it will smooth out the natural distribution of water both spatially and temporally (Changming 1998) and thus must face many problems. Hence, to resolve these problems and find better solutions to mitigate the water crisis in northern China, several aspects of the water transfer project deserve further study. Firstly, a substantial amount of water diverted from the Hanjiang River will cause reductions in runoff in the downstream sections of that river, which may in turn worsen the existing eutrophication problem there (Shao et al. 2003). It might also further affect the local ecology and sustainable development of water resources. Secondly, construction of the water diversion projects might increase pressure on the overall environment, especially the river ecosystem in the country (Shao et al. 2003). Thus, it is needed to further balance the relationship among project construction, economic development and environmental protection. Countermeasures include the following aspects: (1) establishing water resource conservation, strengthening legal construction and enhancing environment protection to reduce damage to the surrounding environment in the water source and (2) implementing compensation policy and financial support to the exporting region to improve poor pollution control due to the weak economy.

3.5 The way forward

Water scarcity could be solved in two ways: (1) self-rescuing includes a wide range of methods such as reducing water losses, developing rainwater harvesting, increasing water use efficiency and enhancing waste water recycling and (2) water importing. Engineering measures are encouraged, e.g., the MRSN. However, with the new waterway, water importing presents new challenges such as protection of water quality from unforeseen natural risks. Hence, much more work still needs to be done to improve the project. Furthermore, many areas in northern China lack adequate water treatment facilities and have lagging technology on rainwater utilization and waste water recycling. Thus, more research is needed to do on self-rescuing methods and use them in production and life. In the future, it is promising that to effectively integrate the methods of self-rescuing and water importing could fundamentally conquer water shortage, reasonably allocate water resources and finally achieve the harmonious development of economics, ecology and society. That also conforms to the principles proposed by Chinese President Xi (2014): Water saving goes before water transferring, pollution controlling goes ahead of channel opening and environmental protection precedes water use.

So far, the policy of the same water with the same price is still implemented in Beijing, and the government document on raising water prices has not been issued in other provinces. It is expected that the local government will execute water price policies and improve supporting facility management while the MRSN runs stably in the near future. The project shall be a cost-effective approach that deserves government efforts and promises that citizens can drink high-quality and low-cost water. If the target is achieved, the MRSN will become a great project that possesses large potential to improve the ecology, has a far-reaching impact on the sustainable development of the country and offers huge benefit to both current and future generations.

4 Conclusions

Results of the field investigation and laboratory tests show that the MRSN was rationally designed and rigorously managed. Water in the canal was clean with sediment concentration and water turbidity nearly meeting drinking water standards, and ice damage in winter was effectively prevented. The MRSN will ease the water shortage in the north of China plain as well as in the cities of Beijing and Tianjing. Consequently, the project will greatly improve the ecological and investment environment in the areas and prominently promote economic development in the middle of China.

Acknowledgements This study is supported in part by the Foundation of Changjiang River Scientific Research Institute, CWRC (CKWV2016388/KY), Program for Excellent Talents in the Universities of Liaoning Province (LR2015015), National Key R & D Project (2016YFC0402504), National Industry Major Project of the Ministry of Industry and Information Technology of China (2014ZX03005001-004) and National Natural Science Foundation of China (51479022). The authors would also like to thank Dr. Wu-Xiong Zhang, Mr. Yan-Fei Li, Mr. Yu Li, Mr. Si-Fan Jin and Ms. Fen Li for their work in the field investigation.

References

Addams, L., Boccaletti, G., Kerlin, M., & Stuchtey, M. (2009). *Charting our water future: Economic frameworks to inform decision-making*. New York, USA: McKinsey and Company.

Antunes, P., Kallis, G., Videira, N., & Santos, R. (2009). Participation and evaluation for sustainable river basin governance. *Ecological Economics, 68,* 931–939.

Avrin, A. P., He, G., & Kammen, D. M. (2015). Assessing the impacts of nuclear desalination and geo-engineering to address China's water shortages. *Desalination, 360,* 1–7.

Beltaos, S. (2008). Progress in the study and management of river ice jams. *Cold Regions Science and Technology, 51*(1), 2–19.

Cao, S., Liu, X., & Er, H. (2010). Dujiangyan Irrigation System–a world cultural heritage corresponding to concepts of modern hydraulic science. *Journal of Hydro-Environment Research, 4,* 3–13.

Changjiang Water Resources Commission (CWRC). (2001). *General planning, in Project Programming of the Middle Route of South-to-North Water Transfer Project*. Wuhan, China: Technical Report. **(in Chinese)**.

Changming, L. (1998). Environmental issues and the south–north water transfer scheme. *The China Quaterly, 156,* 899–910.

Chen, H., & Du, P. (2008). Potential ecological benefits of the middle route for the south–north water diversion project. *Tsinghua Science and Technology, 13,* 715–719.

Chen, H., Guo, S., Xu, C.-Y., & Singh, V. P. (2007). Historical temporal trends of hydroclimatic variables and runoff response to climate variability and their relevance in water resources management in the Hanjiang basin. *Journal of Hydrology, 344,* 171–184.

Chen, F., & Xie, Z. (2010). Effects of interbasin water transfer on regional climate: A case study of the Middle Route of the South-to-North Water Transfer Project in China. *Journal Geophysical Research, 115,* D11112.

Domicelj, S. (1980). The Australian Snowy Mountains Scheme: National growth and regional development. *Habitat International, 5,* 601–616.

Elias, D., Angeliki, M., Vasiliki, M., Maria, T., & Christina, Z. (2014). Geospatial investigation into groundwater pollution and water quality supported by satellite data: A case study from the Evros River (Eastern Mediterranean). *Pure and Applied Geophysics*, *171*, 977–995.

Hanemann, W. M. (2002). The central Arizona project. Department of agricultural and resource economics, UCB. https://escholarship.org/uc/item/87k436cf. Accessed October 01, 2002.

He, Z.-H., & Zhang, Q.-F. (2007). Assessment of the south-to-north water transfers project (middle-route) on the invasion of plant species. *Journal of Wuhan Botanical Research*, *25*, 335–342. (**in Chinese**).

Li, K., & Xu, Z. (2006). Overview of Dujiangyan Irrigation Scheme of ancient China with current theory. *Irrigation and Drainage, 55,* 291–298.

Liu, C., & Zheng, H. (2002). South-to-north water transfer schemes for China. *International Journal of Water Resources Development, 18,* 453–471.

Lobo, G., Videira, N., Antunes, P., Santos, R., & Pereira, Â. G. (2002). The Alqueva project: A review of the evaluation process. In: III Congreso Ibérico sobre Planificación y Gestión del Agua, Sevilla, pp 76–79. http://www.researchgate.net/publication/242418384. Accessed February 21, 2014.

Lofman, D., Petersen, M., & Bower, A. (2002). Water, energy and environment nexus: The California experience. *International Journal of Water Resources Development, 18,* 73–85.

Molle, F. (2007). Scales and power in river basin management: The Chao Phraya River in Thailand. *The Geographical Journal, 173,* 358–373.

Prichard, A. H., & Scott, C. A. (2014). Interbasin water transfers at the US–Mexico border city of Nogales, Sonora: Implications for aquifers and water security. *International Journal of Water Resources Development, 30,* 135–151.

Shao, X., Wang, H., & Wang, Z. (2003). Interbasin transfer projects and their implications: A China case study. *International Journal of River Basin Management, 1,* 5–14.

South-to-North Water Transfer Project Construction Committee Office of the State Council (SNTPO). (2015). Investment of the South-to-North Water Transfer Project. http://www.nsbd.gov.cn/zw/zqxx/tzjh/201508/t20150814_379064.html. Accessed July 2015. (**in Chinese**).

Stone, R., & Jia, H. (2006). Going against the flow. *Science, 313,* 1034–1037.

Sui, J., Karney, B. W., Sun, Z., & Wang, D. (2002). Field investigation of frazil jam evolution: A case study. *Journal of Hydraulic Engineering Division of the American Society of Civil Engineers, 128*(8), 781–787.

Tabari, M. M. R., & Yazdi, A. (2014). Conjunctive use of surface and groundwater with inter-basin transfer approach: Case study Piranshahr. *Water Resource Management, 28,* 1887–1906.

Tang, C., Yi, Y., Yang, Z., & Cheng, X. (2014). Water pollution risk simulation and prediction in the main canal of the South-to-North Water Transfer Project. *Journal of Hydrology, 519,* 2111–2120.

Taylor, P. S. (1949). Central Valley Project: Water and Land. *The Western Political Quarterly, 2,* 228–253.

Wang, X. C., & Jin, P. K. (2006). Water shortage and needs for wastewater re-use in the north China. *Water Science and Technology, 53,* 35–44.

Wang, W., Xing, W., & Shao, Q. (2015). How large are uncertainties in future projection of reference evapotranspiration through different approaches? *Journal of Hydrology, 524,* 696–700.

Wen, S., Yang, J., Duan, W., & Huang, G. (2015). Ice prototype monitoring of Middle of Route Project of South-to-North Water Diversion in winter of 2014 to 1015. *Yangtze River, 22,* 99–102. **(in Chinese)**.

Wikipedia. (2016). Central Valley Project. https://en.wikipedia.org/wiki/Central_Valley_Project. Accessed March 29, 2016.

Xi, J. P. (2014). The South-to-North Water Diversion Project should conform to the principles that pollution-controlling goes ahead of channel opening and environment-protecting precedes water using. People.cn. http://politics.people.com.cn/n/2014/1212/c1001-26198939.html. Accessed December 12, 2014. (**in Chinese**).

Xu, X.-Z., Zhang, H.-W., Zhang, L., & Li, Z.-M. (2007). Study on methods of sediment yield measurement in model tests of soil and water conservation. *Soil and Water Conservation in China, 1,* 35–37. **(in Chinese)**.

Zhang, Q. (2009). The South-to-North water transfer project of China: Environmental implications and monitoring strategy. *Journal of the American Water Resources Association, 45,* 1238–1247.

Zhou, M., Lian, J., Cheng, X., & Zhao, X. (2016). Study on measures for main canal operation of Middle Route Project of South-to-North water diversion during ice period. *Yangtze River, 21,* 106–109. **(in Chinese)**.