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An Integrated Assessment of China's South-North Water Transfer Project

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Abstract

China's South-North Water Transfer Project (SNWTP) is a vast and still expanding network of infrastructure and institutions that moves water from the Yangtze River and its tributaries to cities in North China. This article aims to assess the SNWTP's impacts by beginning to answer seven questions about the project: How is the management of the SNWTP evolving? What are the problems to be resolved when managing SNWTP water within jurisdictions? What is the status and management of water quality in the SNWTP? What are the consequences of resettlements caused by the SNWTP? How is increased water supply affecting regional development? Is the SNWTP achieving its stated environmental goals? What are the sustainability credentials of the SNWTP? Drawing on primary and secondary data, the paper demonstrates that the opportunities and burdens of the project are highly uneven and that management systems are evolving rapidly in an attempt to enforce strict water quality targets. Furthermore, while the SNWTP may be helping to resolve groundwater overexploitation in Beijing, it is highly energy intensive, raising questions about its sustainability. Our analysis highlights the need to continue to interrogate the socio-economic, environmental, and political implications of such schemes long after they are officially completed.

Keywords: interbasin transfer; water governance; water pollution; resettlement; groundwater; regional development

Introduction

China's South-North Water Transfer Project (SNWTP) is the world's largest interbasin transfer. Its two routes have a combined capacity of 4.5 billion m^3 of water per year, with plans for further expansion. Water drawn from the Yangtze River and its major tributaries has been supplying the municipalities of Beijing and Tianjin with drinking water since 2013 (Eastern Route) and 2014 (Middle Route), as well as other water users in the provinces of Shandong, Jiangsu, Hebei, Henan, and Anhui.

The SNWTP's management apparatus and infrastructure continue to evolve and expand, in response to the additional water made available through the transfer scheme and to changes in the demand and supply of water from existing sources. Even though the operational and management systems of the SNWTP have been in place for a number of years, the boundaries of the SNWTP keep shifting, its management is still being negotiated (see Wang & Li 2019), and its socio-economic and environmental effects are still being determined. As such, this massive and still expanding scheme offers an opportunity to improve our understanding of the impacts of interbasin transfers.

The broader scholarship on interbasin transfers extends to projects in Thailand, Brazil, China, Iran, Australia, Canada, and the United States (de Andrade, *et al.* 2011; Ghassemi & White, 2006; Gohari, *et al.* 2013; Roman, 2017) and discusses the effects of transfer schemes on water demand, compares approaches to pricing and management between different schemes, and outlines ecological impacts such as habitat loss and changes to flow regimes and sediment loads. However, while it is recognised that interbasin transfers are prone to deep conflicts of interest, and trigger many questions about the distribution of environmental, social and economic impacts between donor and receiving areas (Rinaudo & Barraqué, 2015; Yevjevich, 2001), hydrologic or other environmental analyses have been poorly integrated with political and socio-economic analyses. There are studies that examine the economic and political processes through which large-scale interbasin transfers reconfigure river basins and rework scale and politics (Sneddon, 2003), but they are not typically paired with an examination of ecological effects. And, unlike the extensive literature on large dams (see for instance Tilt *et al.*, 2009), discussion of the social impacts of interbasin transfers is limited. One study (Gupta & van der Zaag, 2008) does develop an integrated set of five criteria for evaluating interbasin transfers (real surplus and deficit, sustainability, good governance, balance existing rights with needs, and sound science), but with the aim of assessing whether or not a project should go ahead, not understanding subsequent impacts as they evolve over time.

The literature on China's SNWTP largely reproduces this division between physical and social consequences. Early research on China's SNWTP focused primarily on its economic viability and projected social and environmental effects (Wilson *et al.* 2017 have a full review), while in recent years, there have been two primary lines of enquiry in English-language publications. The first is about the SNWTP's politics, situating the infrastructure and institutions of the SNWTP amidst broader questions about the governance of water in China, institutional change, and hydropolitics (Barnett *et al.*, 2015; Crow-Miller, 2015; Crow-Miller & Webber, 2017; Moore, 2014; Pohlner, 2016; Rogers *et al.*, 2016; Webber *et al.*, 2017; Wang & Li, 2019). While these studies do point to the far-reaching and unequal social, economic, political, and environmental effects of the SNWTP, particularly in source regions, their focus is the power struggles embedded in the SNWTP. The second line of enquiry concerns the SNWTP's physical impacts, primarily the modelling or direct measurement of hydrological impacts (see Ma *et al.*, 2016; Webber *et al.*, 2015; Yan *et al.*, 2012; Ye *et al.*, 2014;) and pollution flows (Zhang *et al.*, 2018). There is limited dialogue between those undertaking such approaches, and as a result, no integrated account of the geographic implications, both human and physical, of this massive interbasin transfer.

This article aims to develop a more comprehensive account of the impacts of large interbasin transfers by beginning to address seven questions about China's SNWTP. These questions cover the main concerns that have either arisen in the years since the SNWTP's two routes began operation or have remained unresolved since planning and construction. Bearing in mind the disjunction in the existing literature and the lack of ongoing analysis after construction, the seven questions concern the project's (1) overall governance, (2) management within receiving areas, (3) water quality, (4) resettlement in source regions, (5) effects on regional development, (6) environmental effects in terms of groundwater replenishment, and (7) broader sustainability credentials. We provide an assessment of the SNWTP against these seven issues, and draw two more general conclusions: first, analyses of interbasin transfers must examine both human and physical effects and their interactions, and second, the far-reaching impacts of these complex socio-technical systems need to be followed well beyond initial modelling or impact assessment.

In the following section we briefly introduce the SNWTP as it currently operates. We then organise our results section around the seven questions. Our answers to these questions are based on data collected from two main sources. The first is secondary sources, including Chinese-language statistical yearbooks which provide data on water supply, water use, groundwater levels, and pollution indicators, as well as government and media reports both from local and provincial jurisdictions who supply and receive transferred water and from central government institutions that manage the SNWTP. The second source is site visits made by the authors to infrastructure sites along both routes, in which a small number of interviews with water managers and government officials in Jiangsu and Shandong (Eastern Route), and Hubei and Henan (Middle Route) were conducted. Interview participants were identified with the assistance of our partners at Nanjing's Hehai University and the Changjiang Water Resources Commission and took place in 2017 (Eastern Route) and 2018 (Middle Route). In these interviews we sought to piece together the governance arrangements for the SNWTP at different scales and to examine how particular jurisdictions manage the introduction of a new supply of water and increasingly strict targets for water quality.

China's South-North Water Transfer Project in operation

Figures 1 and 2 show the current physical extent of the SNWTP. The Eastern Route's (Figure 1) main canal pumps water north thorough a series of pumping stations and a tunnel under the Yellow River in Shandong. Local jurisdictions have built reservoirs, canals and water treatment facilities to draw and use the water. Planned extensions in Phase II will take the water to Tianjin. The gravity-fed Middle Route (Figure 2) moves water from the heightened dam at the Danjiangkou Reservoir through a main canal and a tunnel under the Yellow River at Zhengzhou, with local infrastructure enabling withdrawals from the main canal.

FIGURES 1 & 2 HERE

The SNWTP has also prompted additional diversions, either to replenish rivers or lakes threatened by increased withdrawals, or projects initiated by provinces to better secure their own resources. An example of the first is the compensatory diversion from the Yangtze River at Jingzhou to the lower reaches of the Han River (引江济汉 *yin jiang ji han* – see Figure 2), which has a capacity of 13 million m^3/day (Jingchu News, 2015). An example of the second is the tunnel currently being constructed through the Qinling Mountains to draw water from a tributary of the upper Han to supply Xian, Xianyang, and other locations in central Shaanxi that currently rely on the Wei River (引汉济渭 *yin han ji wei* – Figure 2) (Ministry of Water Resources, 2016). This diversion is not formally part of the SNWTP but is a provincial initiative that seeks to balance SNWTP withdrawals from the Han River.

As Table 1 shows, the SNWTP moves large amounts of water, and for most receiving areas, is slowly building up to full capacity. Phase II of the Eastern Route is yet to be built and the source of the Middle Route (the Danjiangkou Reservoir) is not yet at full capacity, so we would expect these volumes to increase in the future. Our assessment is therefore of a complex scheme that continues to evolve.

TABLE 1 HERE

Results

How is the management of the SNWTP evolving?

To facilitate the transfer of water, a multi-scalar, cross-provincial governance system is being assembled. The SNWTP is partly about the provision of a public good and partly about commercial returns. It therefore has two parallel systems of authority: a government bureaucracy and a new bureaucracy of commercial (state-owned) enterprises, with the aim of separating government and enterprise. SNWTP government offices have been established at all levels of government in water source and receiving areas. These offices are supervised by one upper-level SNWTP official, and one local government official and this network is responsible for coordinating the SNWTP's operation with other relevant government bodies. However, routine water supply is managed by a parallel network of state-owned enterprises.

Two state-owned enterprises manage water transfers along the main canals (Eastern and Middle Routes), both headquartered in Beijing. The SNWTP Eastern Route Corporation has two branches (Shandong and Jiangsu), with eleven sub-branches at the prefecture level and various pumping stations and reservoir management offices. The Construction and Administration Bureau of the SNWTP Middle Route has five branches (Beijing, Tianjin, Hebei, Henan, and Taocha) and 55 local stations. These are all administered by the SNWTP central government office. The third state-owned enterprise (Water Source Co. Ltd) is administered by the Yangtze Water Resource Commission in Wuhan, but is owned by the Ministry of Water Resources. This third state-owned enterprise comprises local water supply companies that are responsible for constructing additional infrastructure such as water treatment plants and local infrastructure to draw and store water from the main canal. Combined, these state-owned enterprises facilitate the commercial operations of the SNWTP.

Originally established to drive construction and resettlement projects, the network of SNWTP offices manoeuvred in such a way that they took on ongoing management responsibilities. Until recently, then, there were two water authorities in SNWTP regions: the line agencies of the Ministry of Water Resources, and the SNWTP offices, both ranked at the same level in China's governance hierarchy. However, with the March 2018 restructuring of China's bureaucracy, the SNWTP offices were placed under the Ministry of Water Resources, while pollution responsibilities have been transferred to the new Ministry of Ecological Environment (Yu, 2018). Whether this rearrangement presages less fragmentation in water management and stronger enforcement of pollution control remains to be seen.

What has not been resolved by this restructuring is the blurring of lines between government offices and state-owned enterprises. In Henan and Jiangsu, the provincial SNWTP officials also serve in the state-owned enterprise branch (that is, they have two titles), while in several cities, the two bodies are housed together. Rather than separating government and enterprise, the SNWTP seems to be creating opportunities for vested interests by combining the need to generate profit with the need to supply a public good. As of 2018, administration of the two state-owned enterprises has notionally been transferred to the Ministry of Water Resources, but it is unclear whether further changes will separate government and enterprise more completely.

What are the problems to be resolved when managing SNWTP water within jurisdictions?

While the system as a whole must be governed, once SNWTP water arrives in a local jurisdiction, it has to be integrated into existing supply systems. Local jurisdictions need to decide how supplies of water from different sources are going to be integrated into a single water-supply system and how prices for water from the different sources are going to be set.

The complexity of these issues is revealed by Qingdao's situation. Qingdao has local surface water, groundwater, water from a Yellow River diversion, recycled water, desalinated water and now SNWTP water. The cost differences between the city's various water sources are significant: local surface or groundwater can be produced for less than 1.5 RMB/m^3, water diverted from the Yellow River costs about the same, recycled water would cost about 2 RMB/m^3 (Wen *et al.*, 2017), and SNWTP water is 1.65 RMB/m^3 (SNWTP Construction Committee Office, 2015). Note that this SNWT price does not include annual costs for pollution control, water purification, canal maintenance or pumping (meaning the actual cost of transferred water is much higher). These sources also provide water of differing quality. So, Qingdao must decide which sources to prioritise and who should pay for them. Wen *et al.* (2017) recommend that local water sources and diverted water be used for drinking water supply, while recycled water be used for urban greening and industrial use. The implication is that residents, institutions, and corporations in different areas of the city will receive water of different quality, of different energy intensity, and with very different costs of production. While we not yet know how places like Qingdao are resolving these critical questions of supply and pricing, clearly the SNWTP introduces further complexity into water pricing and management.

What is the status and management of water quality in the SNWTP?

Delivering higher quality water to North China has always been a fundamental goal of the SNWTP. Water quality in China is reported against the central government's *Environmental Quality Standards for Surface Water (GB3838–2002)*, which contains 24 measures. The overall grade is decided by the *lowest* of the 24 measures. These thresholds are now in line with World Health Organization standards (Zhao *et al.*, 2016).

Water quality along the Middle Route is primarily assessed by water delivered to the outlet of the Danjiangkou Reservoir (the Taocha canal head), as the canal itself is supposedly protected from contamination. The three monitoring sections in the Reservoir show water at Grade IV, which cannot be consumed. However, this low grade is due to the fact that total nitrogen exceeds the Grade III threshold. In all other measures of water quality, Middle Route water is Grade I or Grade II (China National Environmental Monitoring Centre, 2017). As a result, nitrogen is the major focus of pollution control efforts at Danjiangkou. Two new pollution concerns have emerged for the Middle Route: pollution spills and phytoplankton. The Middle Route canal is isolated from natural streams, but is threatened by chemical spills and vehicle accidents on the thousands of bridges that cross the canal. Recent modelling (Tang *et al.*, 2016; Wang *et al.*, 2016) shows that a cyanide spill at one bridge could contaminate long sections of the canal. Phytoplankton is emerging as another problem as the water in the Middle Route is exposed to light for most of its length. Water treatment plants in Beijing are not equipped to treat phytoplankton (Tao *et al.*, 2017).

Water quality along the Eastern Route is worse and more complicated than along the Middle Route. While the Middle Route canal is fenced off from access, much of the Eastern Route is open, with multiple connecting canals and regulating lakes. The water quality in these regulating lakes directly affects the quality of transferred water. There are three pollution sources in these lakes: rivers, pollution released from contaminated bottom sediments, and fish farming. Rivers contribute most of the pollutants and the most important measures of pollution of the Eastern Route are chemical oxygen demand, total nitrogen, and total phosphorous (China National Environmental Monitoring Centre, 2017).

After four years of operation, remarkable improvements of water quality are being reported. For example, the proportion of monitoring stations along the Eastern Route with water better than Grade III rose from three per cent in 2003 to 100 per cent in 2013 (People's Daily, 2017a). In the Jiangsu and Shandong sections of the Eastern Route, in 2003 only three of the 17 water quality monitoring stations reached water quality of Grade III or better, but by 2013 all stations had done so (China Economic Net, 2017).

Shandong's Nansi Lake (Figure 1) provides a more concrete example. Both the upper and lower sections of the lake have experienced an improvement in water quality, from Grade V between 2008 and 2010, to Grade III between 2011 and 2014, as assessed by dissolved oxygen, chemical oxygen demand, permanganate index, biochemical oxygen demand, ammonia, total phosphorous, fluoride, and total nitrogen (total nitrogen is only available for the lower section of the lake) (Wang, 2016; Xie, 2016). This improvement occurred before the SNWTP was completed, and is due to catchment management. Improvement in measures of ammonia, total phosphorous, and total nitrogen has continued since the SNWTP began operating in 2013 (Chen, 2017). However, the lack of continuous data at some sites and changes in the list of variables assessed makes it premature to conclude that water quality is experiencing such remarkable improvement. Furthermore, the SNWTP has changed the original direction of flow within the lake, which may disturb pollutants stored in the lake's sediments and thus encourage the release of those pollutants (Xie, 2016). For Jiangsu's Hongze Lake and Luoma Lake, sediment has become an issue of growing concern about water quality as sand mining activity has expanded (Zou, 2017).

Across the catchments of the SNWTP a raft of water quality initiatives are evolving, including clearer accountability for water quality and punitive consequences for declining water quality. For instance, 2993 River Chiefs have been appointed in Ankang, Shaanxi, in the catchment of the Danjiangkou Reservoir, and the system now covers all rivers in Jiangsu Province (People's Daily, 2017b; Shaanxi News, 2017). The River Chiefs system is driven by a set of financial rewards and penalties. In Henan, 40,000 RMB is awarded to county governments when drinking water sources are assessed at Grade I, and 200,000 RMB to prefectural governments. County governments are fined 400,000 RMB when water is assessed as below Grade III, and prefectural governments fined two million RMB (Zhengzhou Daily, 2017).

The stakes for pollution management are clearly rising, but how the River Chiefs system and its tough penalties will play out across the SNWTP remains unclear. One possible outcome is that poorer quality water is diverted away from the SNWTP to other lower priority areas. In Jiangsu, wastewater that used to be discharged into rivers and lakes along the Eastern Route is now being diverted to wetlands or discharged directly into downstream sections of the Yangtze River (at Yangzhou) or the ocean (for instance from Huai'an) (Jiangsu SNWTP Office, 2014a, 2014b). The River Chiefs system may therefore provide incentives for local leaders to pursue short-sighted approaches to meet their assigned targets (Chien and Hong, 2018).

What are the consequences of resettlements caused by the SNWTP?

The uneven distribution of burdens in a mega-project like the SNWTP is immediately apparent in the scale of involuntary resettlement. As well as short- and long-term effects on those displaced, there are significant fiscal consequences for local governments who pay for resettlement projects, and broader implications in terms of China’s evolving resettlement practice.

The SNWTP has resulted in two primary types of resettlement. The first is resettlement as an immediate result of dam heightening at Danjiangkou and other infrastructure construction. At Danjiangkou, 340,000 people were resettled from six counties in Hubei and Henan for the dam, while the construction of canals along the Middle Route also involved resettling 62,000 people in Hebei (State Council SNWTP Construction Committee Office, 2015b). Resettlement on the Eastern Route appears to have been smaller: approximately 8,000 people were relocated in the Shandong section (People’s Daily, 2011). The second type is resettlement as part of ongoing pollution control in the Middle Route’s water source. In southern Shaanxi’s Ankang, Hanzhong, and Shangluo prefectures, by 2014 880,000 people had been resettled for the combined goals of poverty relief, disaster relief and pollution control upstream of the Danjiangkou Reservoir (State Council SNWTP Construction Committee Office, 2015a). Resettlement will continue until 2020 under the Southern Shaanxi Relocation and Settlement Project. These far more extensive resettlements are primarily for poverty alleviation purposes, but are also described as being part of the ‘glorious mission and political responsibility’ of ‘a river of clean water supplying Beijing and Tianjin’ (Ministry of Environmental Protection, 2016, np).

The resettlement project that took place at the Danjiangkou Reservoir between 2008 and 2012 has been described by external observers as ‘optimal’ and achieving the ‘best results’ (China News Service, 2012, np). There is little independent, academic research on the socio-economic impacts of this resettlement project, though one study found the income of resettlers in Henan had increased from 4481 RMB to 7,436 RMB (Yan *et al.*, 2016). Similarly, there is little research on the larger Shaanxi resettlements. One study suggests that there has been no benefit to households in the short term (they lose land, lose savings, and incur debt), but that in the longer term, access to better infrastructure will make these households better off (Li *et al.*, 2015). This study also argues that it will take 15 years for local government to recoup the costs of resettlement. Given that these resettlements result in millions of RMB of avoided water treatment in receiving cities, a key consequence of resettlements is the burden placed on county governments in source areas which effectively subsidise the cost of pollution control in larger cities. The fiscal implications for county governments in the Danjiangkou catchment, many of which are nationally designated poverty counties, is yet to be studied, so our understanding of the effects on displaced people and on county governments in source regions remains inadequate.

For the first type of resettlement at least, some of the problems associated with the Three Gorges Dam resettlement—high levels of outmigration, inadequate compensation, ineffective job training, dissatisfaction, and income decline immediately following resettlement (Wilmsen, 2016)—do seem to have been resolved. There is evidence of post-livelihood support such as greenhouse vegetable production, pig raising, and off-farm employment in transport, restaurants, and agricultural processing (Li & Li, 2015). However, while evidence suggests that the Danjiangkou "best practice" resettlements did not adversely affect households financially, in southern Shaanxi the problem of post-resettlement financial losses has not been resolved (Li *et al.*, 2015). In sum, while certain administrative changes seem to have improved resettlement practice (at least in the highly visible, politically important resettlement projects at Danjiangkou), there is limited evidence with which to evaluate the long-term impact of these resettlements, particularly in Shaanxi.

How is increased water supply affecting regional development?

In North China, the default development setting is water scarcity (Levitt, 2014). Now, after years of thinking about adjusting economic development, discouraging high water-using industries, and pushing farmers and irrigation districts to raise the efficiency of their water use, prefecture and county governments along the two routes of the SNWTP are free to think more expansively about future economic development in their region. Governments of all levels are responding by producing new development plans for their jurisdictions. Here we provide two examples at different scales.

The first example is Dezhou (Figure 1), a prefecture-level city in Shandong of 5.5 million people that lies at the current (late 2018) terminus of the Eastern Route. This terminus is marked by the Datun Reservoir, which now supplies about 110 million m^3 per year to Dezhou. As well as ecological and domestic uses, the water will be used for the Tianqi Industrial Park and a high-speed rail-connected new industrial area, thereby 'breaking the bottleneck' of Dezhou's water resources (Xinhua, 2017, np). The 2011–2020 plan for Dezhou's development calls for 'more work … to build a sponge city and protect ecological function areas' (State Council, 2017, np), while Dezhou's municipal government is stepping up efforts to attract investment. The intention is clearly to use SNWTP water not just for drinking water but to drive economic development activities and urban greening.

At a completely different scale is the proposed development of the city of Xiong'an, established in April 2017 about 100 kilometres southwest of Beijing, in Hebei (see Figure 2). Beijing's non-government functions will be relocated to Xiong'an to relieve the pressure on Beijing's water resources and transport facilities (People's Daily, 2017). Long-term planning envisages a population of at least five million people. The area's current water needs are met almost entirely from local groundwater sources, at a rate that is 47 per cent over the maximum sustainable use (Liu, 2017). Evidently, if groundwater resources are to be used sustainably, and if an additional five million people are to be housed, then water will have to be imported—most obviously, from the SNWTP. In principle, if Xiong'an is rationalised as relieving the resource and transport constraints on Beijing, then that SNWTP water should come from Beijing's existing allocation, but it remains unclear if this is to be the case.

The effects of the SNWTP on regional development in water *source* areas appear very different. We have already noted the considerable focus on pollution control, including around the Danjiangkou Reservoir. This region is relatively poor: of 43 counties, 34 are national-level poverty counties. Their development opportunities are now limited to zero-pollution development. Over 1,000 factories in this region have been closed down, including turmeric processing facilities, while farmers' use of chemical fertilisers is being curtailed (Gov.cn, 2014). Beijing and Tianjin are providing financial assistance to water source regions as they reorganise their development, but the level and impact of their contributions is unclear. Water source regions will not get rich quickly in the way that their eastern counterparts did as their economic development paths are increasingly shaped by zero-pollution forms of activity and aid from appointed partners. The long-term consequences of these restrictions are unclear, but the cases discussed demonstrate that we are only just beginning to understand the major socio-economic effects, both positive and negative, of this newly available diverted water on regional development in both source and destination regions.

Is the SNWTP achieving its stated environmental goals?

One of the key rationales for the SNWTP was that it would have environmental benefits through alleviating groundwater exploitation on the North China Plain, but particularly in Beijing, which has suffered rapid declines in groundwater levels. Chinese media has reported that groundwater levels in Beijing are recovering, directly attributing this change to the SNWTP (see China.org.cn, 2017). We evaluate these claims through analysis of recent data on Beijing's changing groundwater levels, water use, and rainfall.

Figure 3 shows changes in annual mean groundwater levels in Beijing from 1956 to 2016. The fastest declines were in 1999 and 2000, when groundwater levels dropped by 1.9 metres per year. There has since been a rapid turnaround with groundwater levels rising by 0.52 metres per year in 2015 and 2016. Rainfall is one possible explanation for this groundwater replenishment, but as Figure 3 shows, there is no clear relationship between rainfall and reduced groundwater levels. As such, this turnaround must be attributed to declining consumption of groundwater. Figure 4 shows changes in annual groundwater supply and also water use for 1986–2016. Groundwater use has indeed been steadily declining since 2004.

FIGURES 3 & 4 HERE

If Beijing is using less groundwater, can we attribute this to newly available diverted water? In 2016, diverted water accounted for 27.4 per cent of total supply, recycled water 25.77 per cent, and groundwater 45.1 per cent (Beijing Water Authority, 2016). There has certainly been a rapid increase in the use of diverted water (from 7.39 per cent in 2010), but also a steady increase in recycled water. This shift suggests that while the SNWTP is contributing to reduced groundwater exploitation in Beijing, it is not the only factor—the growing use of recycled water is also important. Furthermore, Beijing is still using large amounts of groundwater, and the alternatives (diverted or recycled water) are far more expensive. Whether this cost will constrain further groundwater replenishment in the North China Plain is yet to be seen.

What are the sustainability credentials of the SNWTP?

Besides groundwater replenishment and pollution control, there has been little interrogation of the broader sustainability of the SNWTP. While the Middle Route is gravity-fed, the Eastern Route relies on a network of pumping stations (Figure 1) that lift the water from the Yangtze River to its destinations. It requires massive energy and virtual water inputs, and results in significant carbon emissions, but there has yet been no calculation of the scale of these environmental consequences nor how they compare to other sources of water. Here we offer calculations of electricity consumption and carbon emissions to better understand the sustainability of interbasin transfers.

Data on annual electricity consumption of pumping stations are not publicly available. Table 2 shows our own calculations. Energy consumption on the Eastern Route is huge, accounting for 2.1 per cent, 6 per cent, and 2.6 per cent of total electricity consumption in Jiangsu, Anhui and Shandong respectively in 2016. The energy intensity of water production is highest in Shandong (0.24–0.25 kWh/m^3), followed by Jiangsu (0.14–0.15 kWh/m^3) and Anhui (0.08–0.09 kWh/m^3). As points of comparison, this energy intensity is higher than water sourced from reservoirs (0.05 kWh/m^3), groundwater (0.09 kWh/m^3), and rivers (0.12 kWh/m^3) in the UK, but lower than the average for wastewater reuse (0.49 kWh/m^3) in the UK and groundwater irrigation in China (0.47 kWh/m^3) (Reffold *et al.*, 2008, Wang *et al.*, 2012). However, our estimates are only for conveying water along the canal; they do not include energy used for purification, distribution or wastewater treatment at the local level, all of which require additional energy inputs.

TABLE 2 HERE

The estimated carbon emissions were highest in the water transfer period of 2016–2017 (0.88 Mt CO_2e) and may reach 0.94 Mt CO_2 equivalent by 2030. The totals per province are mostly lower than estimates provided by Wang *et al.* (2012) of annual emissions from groundwater pumping: 0.13 Mt CO_2 equivalent in Jiangsu, 0.16 Mt CO_2 equivalent in Anhui, 3.84 Mt CO_2 equivalent in Shandong, and 33.1 Mt CO_2 equivalent nationally. While these are only emissions for conveying water along the Eastern Route canal, diverting water does not appear to be as energy or carbon intensive as groundwater extraction, though emissions will rise as the quantities transferred continue to increase. Reductions in energy use could of course be achieved through improving pumping efficiency and reducing water loss.

This preliminary analysis raises questions about growing reliance on an energy and carbon-intensive water source. Further research is needed that examines the relative energy intensity of various sources of water in particular places, and the energy used for purification, distribution, and wastewater treatment.

Discussion and conclusion

Ghassemi and White (2006) argue that jurisdictions such as Australia, Canada, and the United States no longer pursue interbasin water transfer projects because of their high cost and adverse social and environmental impacts, preferring demand management measures. They conclude by writing that 'inter-basin water transfer is an option when all other methods of satisfying demand are inadequate' (Ghassemi & White, 2006, p.358). But in China and India the construction of, or at least plans for, massive interbasin transfer schemes continue apace. And there are early signs that China's expertise in interbasin transfers will have impacts well beyond its borders: in 2016, PowerChina and the Lake Chad Basin Commission agreed to a feasibility study for an interbasin transfer of up to 50 billion m^3 per year from the River Congo to Lake Chad (Lake Chad Basin Commission, 2016). The extent to which the SNWTP is a renewed demonstration of the benefits of interbasin transfers and will catalyse an export industry is a key area for future research (in the way that the Three Gorges Dam did for China's hydropower industry—see Webber & Han, 2017).

Assessing the far-reaching human and physical effects of interbasin schemes such as the SNWTP therefore remains a critical task, not just during social and environmental impact assessment or cost-benefit analysis before construction, but in operation, as the impacts of such schemes continue to manifest. Through a geographic lens, this article has sought to develop a more integrated understanding of the physical and human effects of interbasin transfers by analysing the ongoing evolution of the South-North Water Transfer's management structure and its unresolved and new operational problems following several years of transfers. In what follows we discuss these new findings and sketch out a roadmap for continuing empirical assessments of the effects of the SNWTP. Where relevant, we also highlight implications for the broader literature on interbasin transfers.

The management of the SNWTP demonstrates how the governance of interbasin transfers must evolve through planning, construction, operation, and expansion, in response to anticipated and unanticipated challenges. The SNWTP's management initially seemed to confirm China's "heavy construction, light management" approach, but on closer inspection management is now the priority, and much of it is highly adaptive. One of the most obvious signs of adaptation is the clarification of water management functions in March 2018, through which the SNWTP network was absorbed into the Ministry of Water Resources, therefore resolving two conflicting lines of authority. That said, there are still questions about reconciling government and state-owned enterprise responsibilities and goals and coordinating water pollution responsibilities, both of which require further detailed investigation.

Another sign of adaptation is the rapid emergence of the River Chiefs system, which seems to confirm a shift in Chinese water governance identified elsewhere (see Nickum *et al.*, 2017) to strictly regulating water use and water quality. For the SNWTP punitive measures for poor water quality will likely drive improved water quality, but the key question is *where.* Given the priority to deliver cleaner water to North China through the SNWTP system, pollutants and polluted water are being diverted to other places. While pollution control may no longer be taking a back seat to water supply, institutional and political factors could still significantly constrain the effectiveness of initiatives like the River Chiefs. It is also worth further investigating the veracity of the remarkable improvements in water quality being recorded across the SNWTP system. While specific to China's hierarchical Party-state political system, these adaptations and ongoing problems point to how interbasin transfer projects are shaped by the institutional and political structures in which they are built, but also prompt changes to these structures.

The socio-economic consequences of the SNWTP further reinforce the notion that the distribution of benefits and costs in large water projects is highly uneven (Rinaudo & Barraqué, 2015). Our assessment provides a clearer picture of the many scales at which these inequities manifest. Some places, such as Dezhou, are taking advantage of newly available water to stimulate their local economies. This immediate stimulus is positive but also raises questions about longer-term sustainability and the role of interbasin transfers in raising demand, thereby creating new conditions of scarcity and the need for additional interbasin transfers (Gohari *et al*., 2013). Other places and people, particularly those resettled for the construction of the SNWTP, have fared less well. Many lessons have been learned from past resettlement experience, and resettlement practice has improved, but the success of the SNWTP rests on impacts in source areas that are yet to be fully assessed. Local governments in relatively poor inland regions are bearing a double burden of both managing resettlements and long-term pollution control. The implications of the SNWTP on resettled people, closed-down or displaced factories, and fiscally insecure local governments warrant much more attention. These long-term effects highlight just how difficult it is for pre-construction impact assessments to properly account for the actual socio-economic impacts of interbasin transfers. Impacts stemming from project construction, project expansion, and interventions to improve water quality need to be documented, long after the first successful transfers occur.

Our assessment offers new insights into the sustainability of the SNWTP, but also highlights the need for more detailed examinations of groundwater replenishment and the water-energy nexus. Having operated for several years, it does appear that alongside growing use of recycled water, and as intended, the SNWTP is helping to resolve the problem of groundwater overexploitation, thus bringing long-term environmental benefits to places like Beijing. The provision of diverted water is also less energy intensive than groundwater extraction and produces fewer carbon emissions, though this does not account for embodied energy. But water provision is not simply a choice between groundwater extraction and interbasin transfers. There are other options with long-term environmental benefits that do not require the large energy and carbon inputs of transfers, namely cleaning up local surface water so that it is suitable for consumption. China has still prioritised transfers between basins over addressing pollution of local supplies in places such as Beijing, Tianjin, and Hebei. An important implication of this analysis beyond the SNWTP is that any assessment of the sustainability of interbasin transfers must account for not just immediate hydrological impacts, but energy use, carbon emissions, displaced pollution, and delayed rehabilitation in places where a new, cleaner source has been introduced.

In conclusion, China's system of water management continues to adjust to new political demands for increased quality and quantity of supply. Bearing in mind this ongoing evolution, we find that the SNWTP's administrative infrastructure is gradually catching up to its technical infrastructure, but that problems remain with the management of transferred water within jurisdictions and the top-down imposition of strict water quality targets. We also find contradictions in the environmental performance of the SNWTP, and note that complex regional effects are emerging as some jurisdictions take advantage of a new abundance of water, while others face the long-term consequences of displacement and constrained economic development. As the world's largest water transfer, and effectively an experiment in redistributing water resources at a national scale, the SNWTP improves our understanding of the sustained, multi-scalar effects of interbasin transfers and further problematises their role in sustainable water supply.

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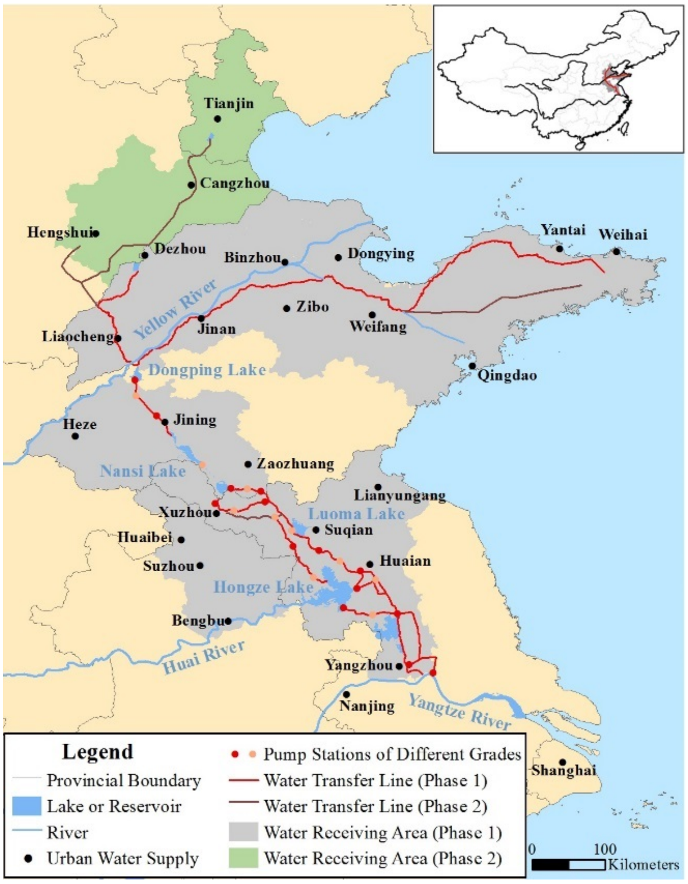

Figure 1: The Eastern Route

Figure 2: The Middle Route

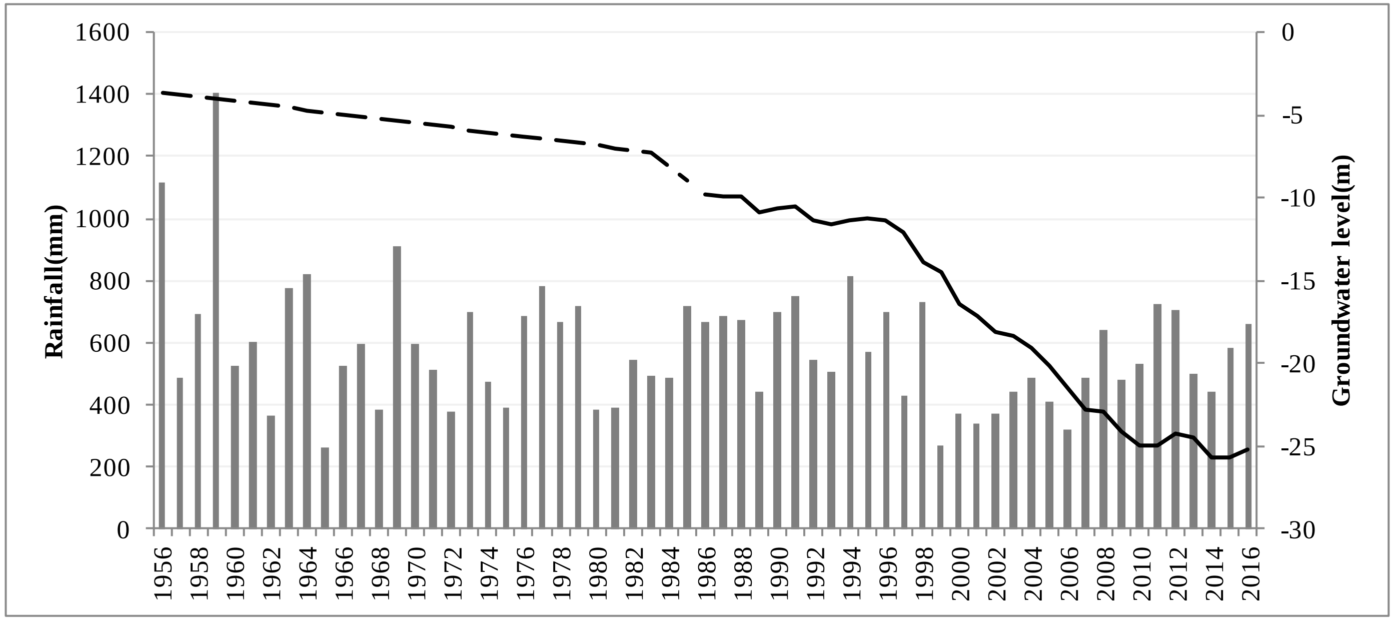

Figure 3 Relationship between the annual rainfall and the annual average groundwater level in Beijing (1986-2016)

Source: Beijing Water Authority (various years)

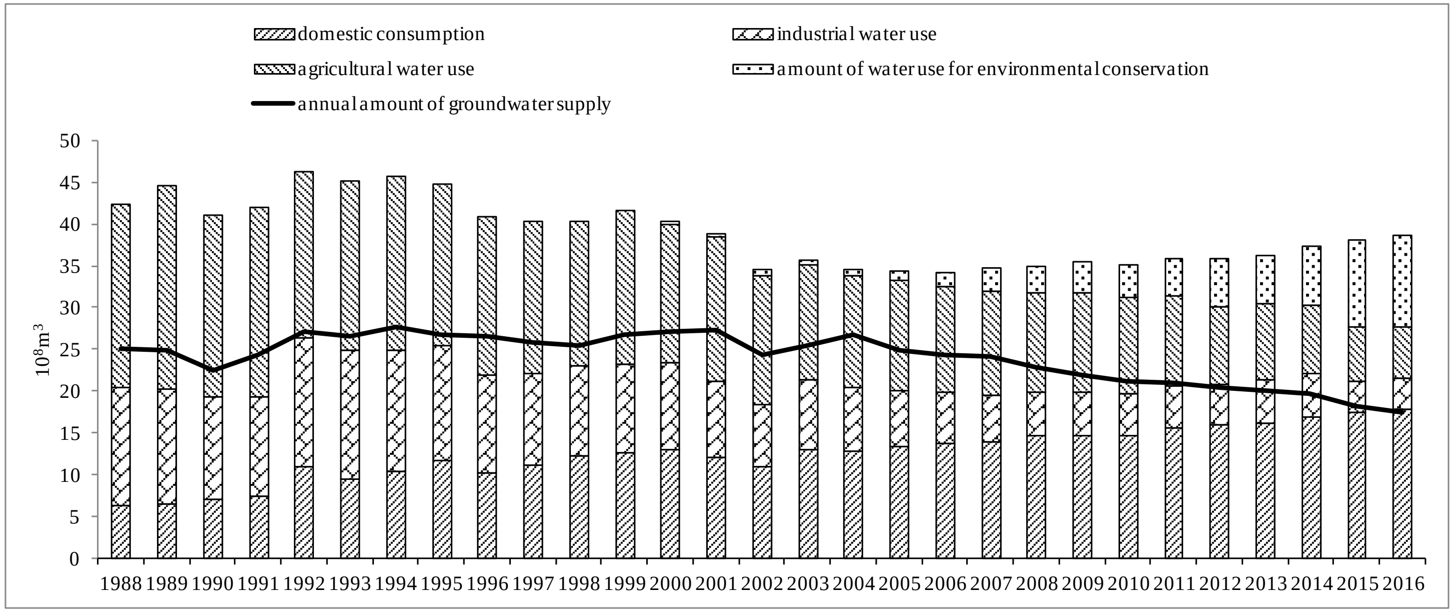

Figure 4 Changes of annual groundwater supply and water consumption structures in Beijing (1986-2016)

Source: Beijing Water Authority (various years)