Review of water scarcity in Northern China: why is the water scarce, and what can be done about it?

VICTORIA LAM ▪ ENVR 200 ▪ APRIL 6, 2012

ABSTRACT

China has an uneven geographical distribution of water; while water resources in the central and southern regions tends to be ample, the water scarcity in the North is alarming—many Northern provinces have less than 500m^3 of water per capita and are classified as water-scarce. Water is scarce in the north due to its naturally arid climate (which is exacerbated by climate change), increased water pollution, overexploitation of water resources and water wastage. To mitigate the water crisis, the Chinese government has implemented the South-North Water Diversion Project (SNDP) which physically transfers water from the central Yangtze Drainage Basin to the three drainage basins in the north (Hai, Huai and Yellow); there are many issues posed by the SNDP, namely water pollution and reduction in the Yangtze River Delta, but the project is already under construction and it is well-agreed that the SNDP will indeed alleviate the water crisis in the North. Other mitigation strategies proposed by researchers include desalination of water, water pricing and international food trade, but more studies will need to be conducted in these areas to investigate their socioeconomic and technical feasibilities.

1. Introduction

1.1 Background: is China water-scarce?

China has been undergoing rapid economic growth in the recent decades, leading to an accelerated demand of water for industrial, agricultural and household uses. The question is whether China has adequate water resource to supply such growth. Official figures in 1998 indicate that China had an annual total available water resource of 2812.4 billion m^3 for a total population of 1.281 billion (SSB (1999) cited in Yang and Zehnder). In other words, there was an average water availability of 2195m^3 per capita (Yang and Zehnder, 2001).

A common classification system for water resource endowments around the world, developed by Falkenmark and Widstrand (1992), states the following:

- Available water volume of 1700m^3 per capita represents sufficient water,
- 1000 to 1700m^3 per capita represent water stress,
- 500-1000 m^3 per capita represent water scarcity,

- Below 500m^3 represent absolute water scarcity.

Thus, a weighted average of the official statistics seems to indicate that China is not water-scarce. However, a look at Figure 1 would reveal that China is, in some parts, water scarce. It has a very uneven spatial water distribution-- water is classified as *sufficient* in the south and range from *water-stress* to *absolute water-scarce* in the northeastern provinces along the Yellow River Basin.

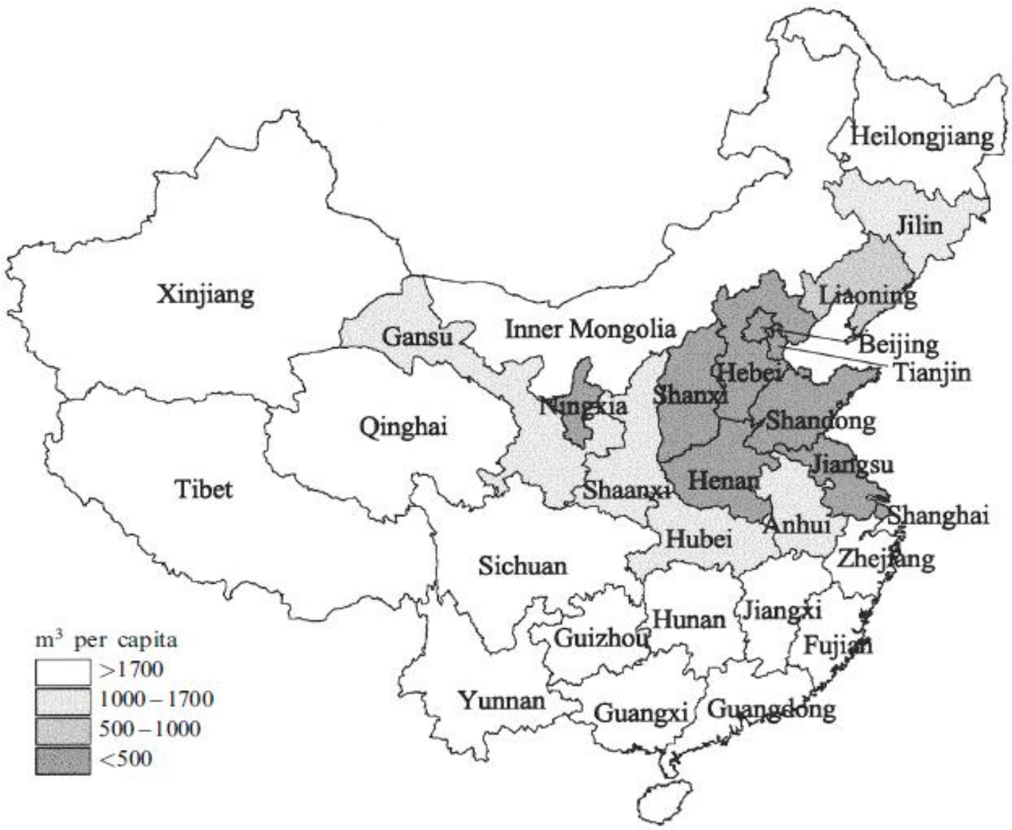


Figure 1. China's water availability per capita by province. From Yang and Zehnder (2001).

1.2 Why water scarcity is alarming

Water resource availability is closely linked to physiological, ecological and agricultural needs. Depending on the nation's financial capacity, it may also influence foreign policies (e.g. extent of import) and industrial growth (due to distribution of water) (McBeath and McBeath, 2009; Yang *et al.*, 2003). It is projected that water demand in the Northern China will increase to roughly 8m^3 billion by 2020, so measures to secure water availability is important and of both civilians and government officials' interests (Yang and Zehnder, 2001).

In this paper, we are interested in examining the causes of China's regional water scarcity and mitigation strategies. Specifically, we will pay special attention to the South-North Water Diversion Project (SNWP) which is currently being implemented by the Chinese government. Several other strategies proposed by researchers will also be briefly discussed.

2. Issues concerning water scarcity in Northern China

2.1- Climate

Historical records show that Northern China has always been affected by drought (Qian and Zhu, 2001). Figure 2 indicates the drought pattern in different parts of China from 1950s to 1990s, showing an increase of drought in the recent decades, particularly in Northeastern China. This is congruent with Ma and Fu's (2003) findings through analyzing official statistics of Northeastern China's surface humid index. In addition, the Yellow River Delta region typically has a low precipitation of 560 mm per year (Zhang *et al.*, 2011).

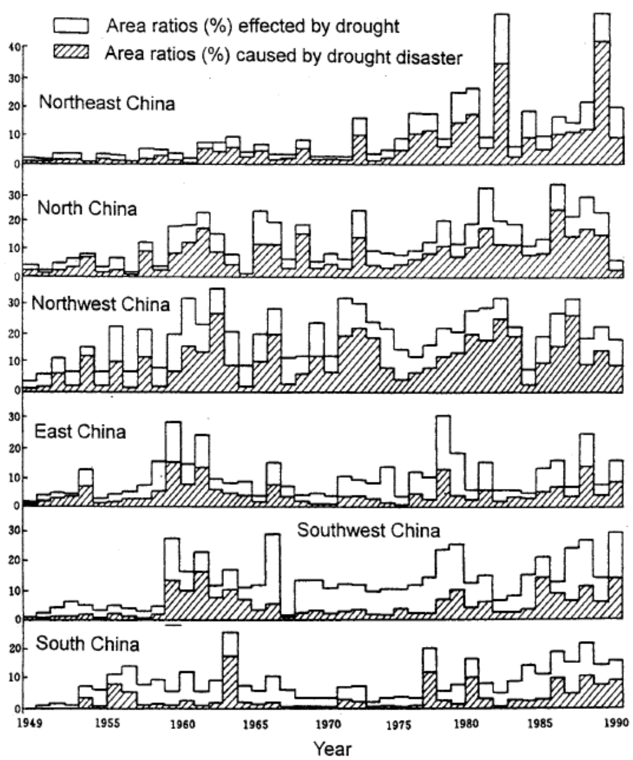


Figure 2. The area ratios (%) effected by drought and the area ratios (%) experiencing drought disaster from 1949 to 1990 in different regions. From Qian and Zhu (2001).

As such, water from the Yellow River is mostly responsible for water use in the region (Zhang *et al.*, 2011). Unfortunately, studies have shown that recent anthropogenic activity has intensified climate change, which as a result reduced water flow in Yellow River; water supply therefore becomes very scarce, and the limiting water supply becomes a bottleneck for socioeconomic development (Qian and Zhu, 2001; Zhang *et al.*, 2011).

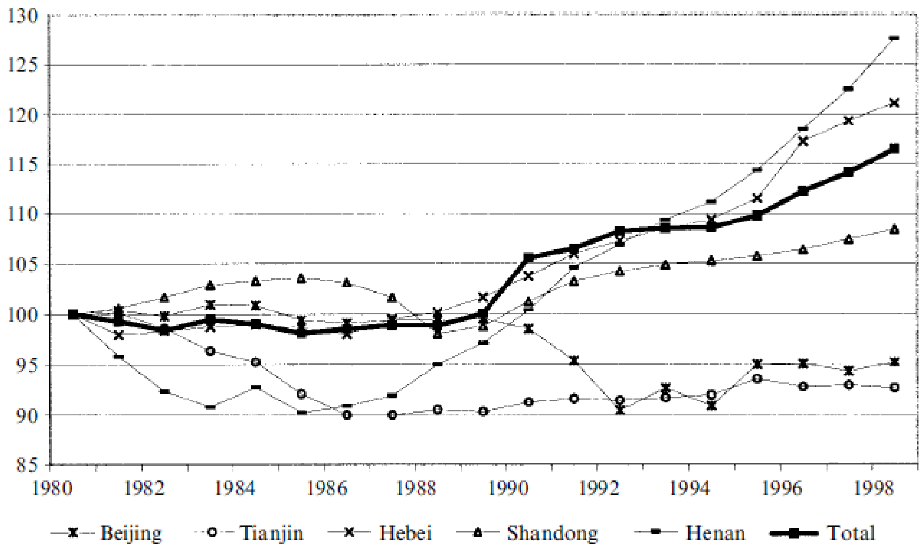
2.2- Water pollution

16 of the world's 20 most polluted rivers belong in China, and this can be largely attributed by industrial contaminants, chemical pesticides, fertilizers, household wastewater, etc. (McBeath and McBeath., 2011). The Yellow River received 4.3 billion tons of sewage water in 2005 as a result of untreated household waste. Chemical spills occurred in the Heilongjiang region in 2006, earning the river water a level 5 water quality, the poorest quality level which is equivalent to raw sewage (Fangchao (1999) cited in McBeath and McBeath; Zhu *et al.*, 2008). It is estimated that 90% of groundwater supply in China, the alternative water source after river runoff, is polluted (Turner and Otsuka (2006) cited in McBeath and McBeath). It is questionable whether such polluted water is drinkable, or even usable for irrigation, without harming public health, food supply, industries and the environment. Overall, water pollution tightens the already limited existing water supply (as a result of climate), inducing an urgent need for implementing mitigation strategies.

2.3- Overexploitation of water resources and water wastage

70 to 80% of China's water demand sources from agriculture, and the Northern China produces over 40% of China's total grain supplies (McBeath and McBeath, 2011). While the water supply tightens, the agricultural sector continues to expand as a result of economic growth (Figure 3).

Figure 3. Changes in irrigated area in North China Plains provinces. From Yang and Zehnder (2001).



This not only further depletes the scarce surface water resources, but also indicates a need for an alternative water source, so groundwater is utilized for irrigation; 7% of the total water supply in the Yellow River Delta Region is now groundwater (Zhang *et al.*, 2011). However, groundwater irrigation is unsustainable when discharge over-exceeds discharge— Zhang *et al.* found that the water tables beneath North China Plain has fallen on average 1.5 m per year since 2005 (Zhang *et al.*, 2011; Yang and Zehnder, 2001). Thus, a countermeasure is necessary to prevent the exhaustion of aquifers and subsequently both ecological issues and food crisis.

Water wastage is another issue concerning water shortage in Northern China. The low water price appears to encourage farmers, civilians and industries to consume more water resources than necessary; this in turn produces more demand and wastage (Chen *et al.*, 2002). The standard for facilities in irrigational channels is very low, with the coefficient of effective water use being 0.5; to put this number in perspective, irrigation in the region uses about 3000 to 3750m^3 per hectare (Zhang *et al.*, 2011). Reuse rate of industrial water is only about 20%, with about 50% of water is lost between urban water diversion site and purifying station (Zhang *et al.*, 2011).

3. Mitigation Strategies

3.1- South-North Water Diversion Project

As discussed in the earlier sections, China has regional water shortage: in the Northeastern provinces water is scarce, whereas in the central and southern regions water resource is ample. Thus, to address the alarming dryness and water shortage in the North, Mao Zedong, the Chairman of Chinese Communist Party in 1952, proposed the South-North Water Diversion Project (SNDP), which tackles the problem by physically transporting water from the South to the North (Zhang *et al.*, 2011). The project has been in discussion and planning stages for decades; some parts of the project is currently under construction and some are still in pre-engineering stage (Zhang *et al.*, 2011).

3.1.1- Overview: What is the South-North Water Diversion Project?

There are 4 large drainage basins in China: Haihe, Yellow, Huaihe and Yangtze (Table 1), and the SNDP works by diverting water from the Yangtze River Basin to the three other drainages located in Northern China. Statistics in Table 1 indicates that the Yangtze indeed has ample water resources as compared to the three drainage basins in the North.

Drainage basin	Area (km2)	Population (million)	Precipitation (mm/year)	Surface water (billion m^3/year)		Sewage in 1999 (billion m3/year)
				Average	1999	
Haihe	264 000	125	550	26.3	9.20	5.62
Yellow	752 000	98	466	56.0	52.38	2.70
Huaihe	270 000	165	888	62.1	34.65	6.00
Yangtze	1 800 000	412	1100	968.4	1112.70	20.66
Total	3 086 000	800		1112.8	1208.93	34.98

Sources: Water Resource Ministry (1999) and Haihe River Water Conservancy Commission (1999).

Table 1. Basic information about the 4 drainage basins in China. From Chen *et al.* (2002).

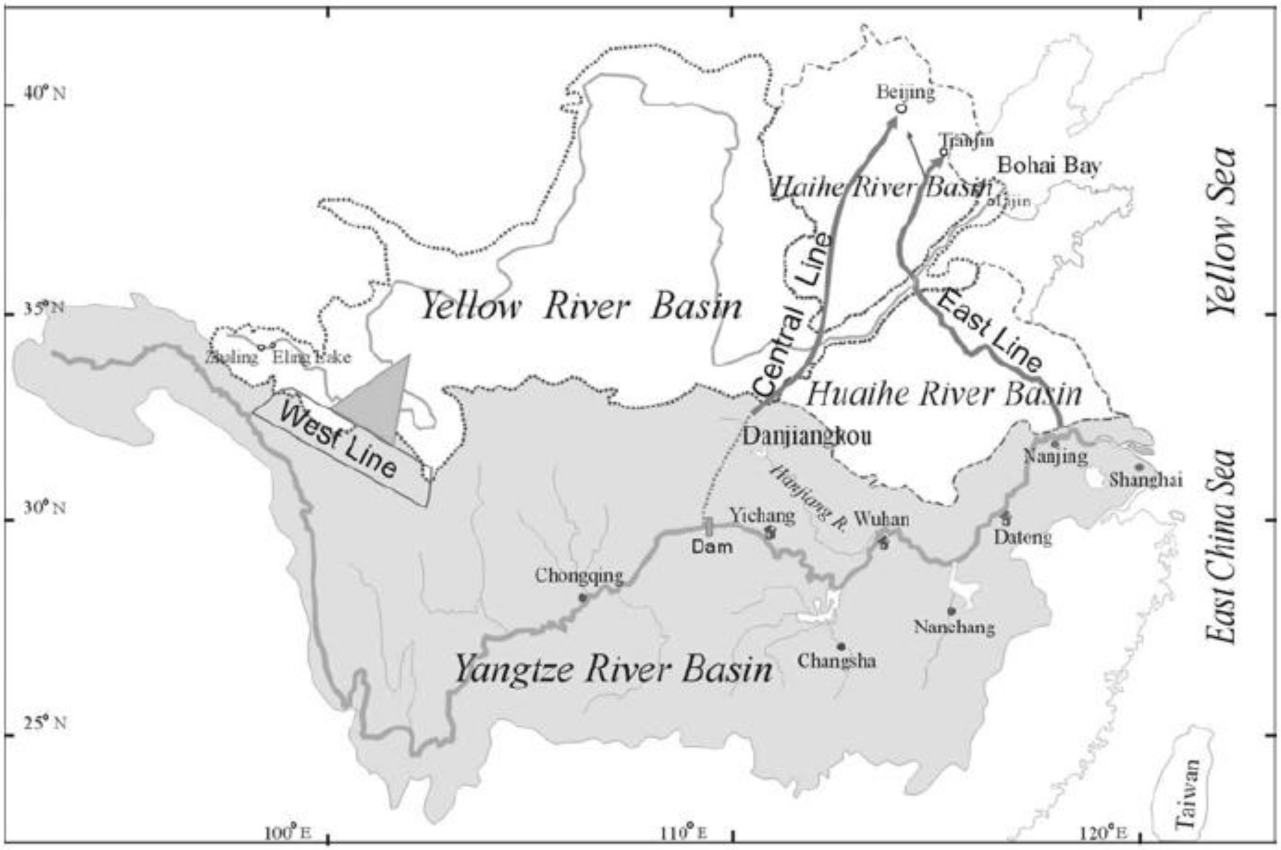


Figure 4. Sketch map of the SNDP with the river basins in Northern China. From Chen *et al*. (2002).

The SNDP consists of 3 main water diversion routes: the Eastern Route, the Central Route, and the Western Route (Figure 4). The Eastern Route diverts water from the lower Yangtze northward to Tianjin with an estimated length of 1150 km and discharge of 800 to 1000m^3/s; its construction has begun in late 2002 and is expected to complete before 2020 (Chen *et al.*, 2002). The Central Route stretches 1241 km from the upper Hanjiang River to Beijing and Tianjin, with an estimated discharge of 800-1000m^3/s, and it is estimated to take longer to complete (Chen *et al.*, 2002). The Western Route stretches from the upper Yangtze to upper Yellow; due to geographical constraints of the Qinghai-Tibetan Plateau region as well as controversy of diverting water from India's Brahmaputra River, the route is still under investigation and many believe it will not be built (Chen *et al.*, 2002; Zhang *et al.*, 2011). The SNDP has a projected cost of $72 billion RMB as of 2007, and the engineering investments sources from the central government (Chen *et al.*, 2002).

3.1.2- Issues with the SNDP

As SNDP involves physical diversion of water from one region to another, the project has sparked much controversy among citizens and environmentalists, especially concerning the Yangtze River Basin.

Zhu *et al.*'s (2008) studies estimate that the mean annual river discharge of the Han tributary (largest tributary of the Yangtze) will reduce by 28.5% after implementing the SNDP; this directly leads to an increased pollution concentration due to reduced dilution and increased hydraulic retention time, both of which not only deteriorates water quality of the Yangtze, but also favour algal bloom (Zhu *et al.*, 2008). It is estimated that during the period from 2003 to 2010, the concentration of biological oxygen demand increased by 31%, ammonium nitrogen by 57%, total nitrogen by 49%, and total phosphorus by 48% (Zhu *et al.*, 2008). The water quality will only get worse from the negative feedback cycle of reduced dissolved oxygen and increased pollutants (many of which are nutrients). This is alarming for the aquatic ecosystem as the carrying capacity will become much lower, threatening the biodiversity. Chen *et al.* (2002) also indicate that as the water discharge reduces, saltwater intrusion in the Yangtze will heighten, causing the available aquifers to become more saline and decreasing the usable water in the central regions of China.

The length of time that SNDP construction requires is also problematic. The river basins' conditions are subject to change with the environmental changes, decreasing the feasibility of the project. Chen *et al.* (2002) states that 50% of Yangtze's discharge comes from the upper basin, where hydrological processes have shown notable changes in the recent decades; glaciers in the headwater area, for example, retreated rapidly from 1970 to 1990 as a result of global warming, which substantially decreased the discharge of the Yangtze. Increased soil erosion and deforestation also reduced water discharge from tributaries to the Yangtze (Chen *et al.*, 2002).

Due to the projected decrease in water availability and quality in the Yangtze, the socio-economic development in the Yangtze River Delta may also be impeded, and this will not only affect the inhabitants of the region but also the financial status of China-- 22.6% of the total revenue of China's central government comes from the Yangtze River Delta region (Chen *et al.*, 2002). Due to a decreased supply, it is expected that there will be an increase in water price in the Yangtze River Delta region as well, causing protests of the inhabitants in the region (who are already dissatisfied with being displaced from construction regions). Many also worry that the SNDP will shift attention away from water pollution control (as water pollution is a major contributor to water shortage) and encourage water wastage (Chen *et al.*, 2002).

3.2- Other means to increase supply or reduce demand

While SNDP is a nationwide project that is currently being implemented, the mitigation strategies that will be briefly discussed below are merely suggestions from various researchers and are not being implemented in China at the moment. More studies will need to be conducted in these areas to investigate their feasibilities in China.

3.2.1- Desalination of Water

3.2.1.1- Description of Desalination

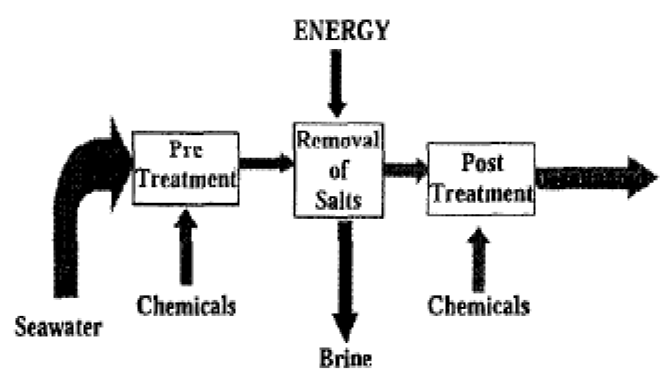


Figure 5. General flow diagram of water desalination. From Tsiourtis (2001).

97% of Earth's available water resources are in the oceans—in other words, there is a potentially unlimited supply of seawater, which may be used to alleviate water stress in water-scarce regions, particularly for industrial and municipal uses (Zhou and Tol, 2005). Desalination desalts seawater and/or brackish water by thermodynamic and/or membrane processes using energy input, leaving behind the brine which may then be disposed into the sea, saline aquifers, etc (Figure 5). Currently, desalination technologies are widely implemented in the Arabian Gulf States, and are undergoing rapid technological development and market expansion due to an increased water shortage and demand (Tsiourtis, 2001).

3.2.1.2- Issues with Desalination

One of the main constraints of desalination is cost. However, due to the market expansion of desalination and the innovation of technology, capital cost of equipment and energy cost (due to improvements in efficiency) have been greatly reduced (Tsiourtis, 2001). The cost of desalination dropped from $9/m3 in 1960 to $1/m3 now, and is projected to further drop in the future, increasing its affordability (Zhou and Tol, 2005).

There are some environmental impacts of desalination which needs to be addressed site-by-site. The brine in each of the desalination plants must be carefully disposed in appropriate, assessed sites in order to have minimal impacts on the ecological environment. Due to the vast energy input needed to sustain the processes (the energy input consists of 25 to 50% of a plant's total cost), greenhouse gas emission may be another issue with desalination (Tsiourtis, 2001). The energy source should be optimized by not only its efficiency and cost-effectiveness, but also its environmental implications.

As desalination sites have specific geographical requirements (such as proximity to water) and associated transportation costs, more studies is needed to assess its feasibility in China as well as a concrete cost should it be implemented.

3.2.2- Governmental Policies

Recommendations of policies require extensive knowledge and consideration of the political and socioeconomic environments of China, which is beyond the scope of this paper. However, these mitigation strategies have potential if properly executed, so a few two of them will be briefly discussed in this section.

3.2.2.1- Water Pricing

The price of water is low and undervalued, so some believe that in order to optimally allocate the resource, market-based water-pricing is necessary for farmers and the industries; however, this sparks much debate because many believe that water should be treated as basic human rights instead of economic good as it serves physiological needs with no possible substitutions (Shen and Lein, 2010; Yang and Zehnder, 2001). Moreover, water fee policies have been previously implemented in some regions in China (e.g. Xinjiang) with no success—water pricing policies has not led to fairer and more efficient use of water by farmers and industries as it should in theory, and rather it is used by local governments to achieve their political and economic goals, earning financial benefits and strengthening their existing bureaucracies (Shen and Lein, 2010).

In theory, water pricing and management practices encourages the development of water-saving society, so farmers and industries will comply and save water where possible; however, the actual situation is much more complex; the political realities should be realized and taken into consideration (Zhang *et al.*, 2011). Thus, it is a mitigation strategy that is easier said than done.

3.2.2.2- International Food Trade

As discussed in section 2.3, 70 to 80% of China's water demand is sourced from agriculture; Yang and Zehnder (2001) state that it is possible for irrigation efficiency to improve by at most 11%, but it is still debatable whether farmers will pay for an improved cost for higher irrigational efficiency. As such, alternative means to reduce agricultural demand has great potential in mitigating the water crisis of Northern China.

Using official statistics of China, Yang and Zehnder (2001) find that roughly 1 kg of grain uses 1 m^3 of water-- so if an additional 10 million tonnes of grains can be imported from the international market rather than planted (and irrigated) in the Northern China, around 10 billion

m^3 of water can be saved. However, international food prices may rise as a result; this mitigation strategy also requires Chinese officials and civilians to comply with importing foreign food—many Chinese people prefer if China can be self-sufficient in its own grain production, and in fact an emotional debate has once been sparked on this subject matter (Yang and Zehnder, 2011). More studies will need to be conducted to determine the feasibility of international food trade as a mitigation strategy for China's water crisis.

4. Conclusion

In summary, water is scarce in the north due to its naturally arid climate (which is exacerbated by climate change), increased water pollution, overexploitation of water resources and water wastage. Currently the Chinese government is implementing SNDP to relieve the water crisis, while other researchers propose alternative methods to aid the alleviation of water stress: water desalination, water pricing and international food trade.

Due to technical constraints, there are many other potentially feasible mitigation strategies that I have not addressed in this paper: wastewater treatment, water rights, education, etc. (Ringler *et al.*, 2010). Due to my knowledge constraints of the socioeconomic and political environment of China, this paper also did not looked into possible recommendations of water management practices (e.g. irrigation management reform), which may encourage a more efficient use of water on a local scale and may be of great potential in the long run should it be properly implemented.

As the Eastern Route of SNDP completes, it would be interesting to study if the water crisis in the North is actually mitigated as it should in theory, and whether the benefits of SNDP to the north indeed outweighs its negative impacts to the central Yangtze River Delta region. This will directly determine whether the rest of the SNDP (the Central and Western Route) will be constructed, as well as which direction China will head to mitigate the water crisis in the North.

References

Chen, X., Zhang, D., & Zhang, E. (2002). The south to north water diversions in china: review and comments. *Journal of Environmental Planning and Management, 45*(6), 927-932. doi:10.1080/0964056022000024415

Duan, G., Zhao, J., Liu, G., Ke, B., Xiao, H., Wu, G., & Deng, H. (2004). Eco-environmental benefit assessment of china's south-north water transfer scheme--the middle route project. *Journal of Environmental Sciences (China), 16*(2), 308-315.

Falkenmark, M., & Widstrand, C. (1992). Population and water resources: A delicate balance. *Population Bulletin, 47*(3), 1.

Ma, Z., & Fu, C. (2003). Interannual characteristics of the surface hydrological variables over the arid and semi-arid areas of Northern China. *Global and Planetary Change, 37*(3), 189-200. doi:10.1016/S0921-8181(02)00203-5

McBeath, J., & McBeath, J. H. (2009). Environmental stressors and food security in China. *Journal of Chinese Political Science,14*(1), 49-80. doi:10.1007/s11366-008-9036-4

Qian, W., & Zhu, Y. (2001). Climate change in China from 1880 to 1998 and its impact on the environmental condition. *Climatic Change, 50*(4), 419-444. doi:10.1023/A:1010673212131

Ringler, C., Cai, X., Wang, J., Ahmed, A., Xue, Y., Xu, Z., ... (2010). Yellow river basin: Living with scarcity. *WATER INTERNATIONAL, 35*(5), 681-701. doi:10.1080/02508060.2010.509857

Shen, Y., & Lein, H. (2010). Treating water as an economic good: Policies and practices in irrigation agriculture in Xinjiang, China. *GEOGRAPHICAL JOURNAL, 176*(2), 124-137. doi:10.1111/j.1475-4959.2009.00345.x

Tsiourtis, N. X. (2001). Desalination and the environment.*Desalination, 141*(3), 223-236. doi:10.1016/S0011-9164(01)85001-3

Yang, H., Reichert, P., Abbaspour, K. C., & Zehnder, A. J. B. (2003). A water resources threshold and its implications for food security. *Environmental Science & Technology, 37*(14), 3048-3054. doi:10.1021/es0263689

Yang, H., & Zehnder, A. (2001). China's regional water scarcity and implications for grain supply and trade. *ENVIRONMENT AND PLANNING A, 33*(1), 79-95. doi:10.1068/a3352

Zhang, J., Chen, G., Xing, S., Shan, Q., Wang, Y., & Li, Z. (2011). Water shortages and countermeasures for sustainable utilisation in the context of climate change in the Yellow River Delta region, China. *INTERNATIONAL JOURNAL OF SUSTAINABLE DEVELOPMENT AND WORLD ECOLOGY,18*(2), 177-185. doi:10.1080/13504509.2011.556814

Zhou, Y., & Tol., R. (2005). Evaluating the costs of desalination and water transport. *Water Resources Research,41*(3), W03003. doi:10.1029/2004WR003749

Zhu, Y. P., Zhang, H. P., Chen, L., & Zhao, J. F. (2008). Influence of the South–North Water Diversion Project and the mitigation projects on the water quality of Han River. *Science of the Total Environment, 406*(1), 57-68. doi:10.1016/j.scitotenv.2008.08.008