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Interbasin transfer projects and their implications : A China case study

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ABSTRACT
In large countries with sharp temporal and spatial variation in water resources, interbasin water transfer projects seem to be an ultimate solution to ease water shortage and secure a balanced economic development among different regions. However, such projects are prone to problems and controversies, and may challenge the established basin management, legal system and policy making procedure which are taken for granted until such projects are put under consideration. This paper presents a review of interbasin water transfer projects in China and recent developments in the feasibility study of the South-to-North water transfer project involving the Yangtze River and the Yellow River basins. Its impacts on the water law, policy-making procedures, existing basin management method, as well as on the natural environment, are also discussed.

Keywords: Interbasin water transfer; China; water resources; Yangtze River.

1 Introduction

China's water endowment is very poor, with only a quarter of the world average in per capita water resources (World Bank, 2002). The long-term averaged total renewable water resource of China is estimated at 2812 km^3 per year (MWREP, 1987), accounts for only 6.6% of the mean value of renewable global water resources, estimated at 42,750 km^3 per year (Shiklomanov, 2000). Such a figure conceals the wide regional disparities within China and each major river basin has to be studied separately to appreciate the seriousness of the problem of water scarcity. Figure 1 shows the extreme variation of long-term averaged precipitation (Qian and Zhang, 2001). The many natural drainage basins in China have been grouped into 9 regions based on the variation in water resources and geographical characteristics, as shown in Figure 2 (NHRI and IWHR, 1999). More detailed hydrological, social and economical characteristics of each of these regions are listed in Table 1, in which the hydrological data is collected during the period of 1956–1979. Some parts of the total water resources were counted twice as both runoff and groundwater, and the repeated part has been deducted from the amount of total renewable water resources.

2 Water scarcity in Northern China

According to Qian and Zhang (2001), the Northern Part of China (NPC) refers to an area including the Haihe, Huaihe, Huanghe (Yellow River) basins and the northern part of the inland river basin (i.e. regions 2, 3, and 4 plus the northern part of region 9 in Figure 2). From Table 1 it can be seen that the per capita annual renewable water resources in this area, a mere 700 m^3, equating to just 1/3 of that in the Changjiang (Yangtze River) basin, while the population and total area of cropland in this part of China account for 36.8% and 45.1% of the national total, respectively. China cannot maintain food security without irrigation, because 75% of China's grain production comes from irrigated land, which accounts for 40% of China's total arable land (Jin and Young, 2001). Serious fluctuations in hydrological conditions, such as sustained drought, may lead to the fall of crop production in the entire NPC area, and worries have been voiced that such a scenario could be crucial for the future world food provision problem (e.g. Brown and Halweil, 1998).

Table 2 is a summary of cropland area, total water demand and the actual amount of total water supply for the 9 major regions during the year 1997 (Qian and Zhang, 2001). As the total amount of water available for supply at a given guarantee rate (usually between 75–95%) is much smaller than the long-term averaged value listed in Table 1, water deficits are expected in 7 out of the 9 regions, and about 68% of the total water deficit is found in the NPC area. Such a situation leads to an increase in groundwater withdrawals, desiccation of rivers (including the Yellow River and Huaihe River, China's second and third largest, among others), heavy water pollution, and the deterioration of riparian and estuarine ecosystems in the NPC.

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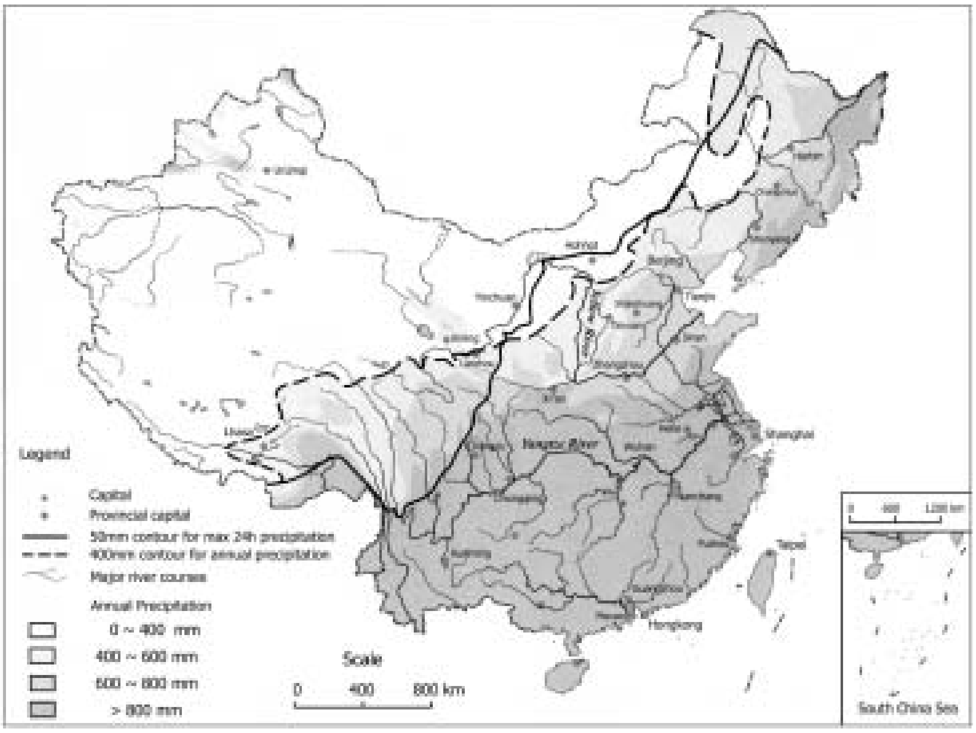

Figure 1 Long-term averaged annual precipitation in China (from Qian and Zhang, 2001).

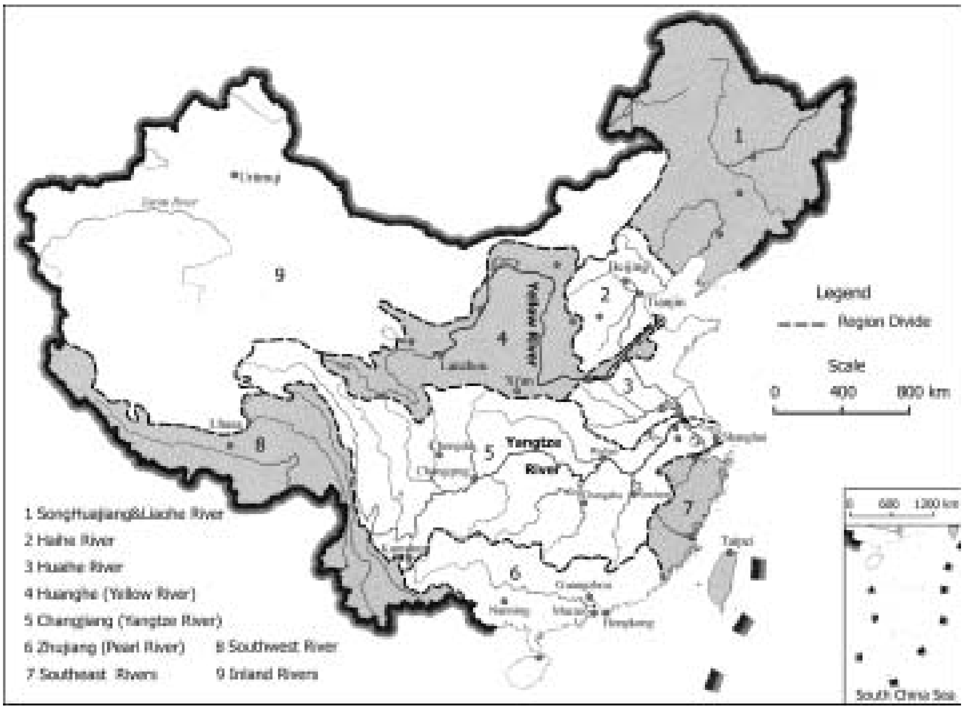

Figure 2 Major regions based on drainage systems and water resource variations (from NHRI and IWHR, 1999).

To evaluate the sustainability of water resources in these regions, an indicator called water utilization ratio is commonly used, which is defined as the result of the actual amount of water supply less the amount of diverted water, the recycled water and collected rain water, etc., then divided by the long-term averaged water resources in that region. In 1997, the water utilization ratio was 59.1% in the Huaihe River basin, 66.5% in the Yellow River basin and 89.4% in the Haihe River basin. The exhaustion of surface runoff makes the share of groundwater in the total water supply larger and larger. According to 1997 statistics, the percentage of (more expensive) groundwater in total water supply was 28% in the Huaihe River basin, 33% in the Yellow River basin and 61% in the Haihe River basin. In contrast, the utilization ratio in the Yangtze River basin was 18.6% (close to the national average of 20%) and the share of groundwater in total water supply was 4.2% in the year 1997.

Estimated agricultural water demand will increase when a higher guarantee rate of irrigation water supply is required for a

Table 1 Long-term averaged annual water resources in China (1956–1979).

Region (numbered as in Figure 2)	Area ($\times 10^3$ km^2)	Population ($\times 10^6$)	Annual precipitation (mm)	Annual Runoff (km^3)	Upper aquifer groundwater (km^3)	Total renewable water Resources (km^3)
1 Songhuajiang & Liaohe River	1248.4	117.2	511	165.3	62.5	192.8
2 Haihe River	318.2	122.7	560	28.8	26.5	42.1
3 Huaihe River	329.2	197.4	860	74.1	39.3	96.1
4 Huanghe (Yellow River)	794.7	105.3	464	66.1	40.6	74.4
5 Changjiang (Yangtze River)	1808.5	420.0	1071	951.3	246.4	961.3
6 Zhujiang (Pearl River)	580.6	145.9	1544	468.5	111.6	470.8
7 Southeast Rivers	239.8	68.2	1758	255.7	61.3	259.2
8 Southwest Rivers	851.4	19.9	1089	585.3	154.4	585.3
9 Inland Rivers						
Northern	2747.0	26.7	35	93.3	69.8	105.7
Others	627.4	0.0	696.5	23.1	16.4	24.7
Total	9545.2	1223.3	648*	2711.5	828.8	2812.4**
NPC (= 2 + 3 + 4 + Northern part of 9)	4189.1	452.1	—	262.3	176.2	318.3
Percent of national total (%)	43.9	36.8	—	9.7	21.3	11.3

* National average; ** Amount of repeatedly counted water resource has been deducted.

Table 2 Statistics of cropland area, water demand and supply (based on 1997 data).

Region (numbered as in Figure 2)	Cropland area ($\times 10^6$ hm^2)	Irrigation area ($\times 10^6$ hm^2)	Water demand (km^3)			Growth of supply 1980–1997 (%)	Actually supplied (km^3)	Total water deficit (km^3)
			Agricultural*	Industrial	Total**			
1 Songhuajiang & Liaohe River	26.26	4.87	45.0	12.7	62.6	74.7	62.0	0.6
2 Haihe River	14.69	7.22	35.2	6.7	46.6	13.7	43.4	3.2
3 Huaihe River	19.76	10.01	52.3	9.7	68	25.6	66.7	1.3
4 Huanghe (Yellow River)	16.77	4.79	34.0	5.9	42.9	12.9	40.5	2.4
5 Changjiang (Yangtze River)	30.81	14.6	107.3	49.2	175.2	28.5	173.9	1.3
6 Zhujiang (Pearl River)	8.71	4.19	53.3	19.4	83.5	26.7	83.6	—
7 Southeast Rivers	3.25	1.94	19.9	6.7	29.7	49.3	28.8	0.9
8 Southwest Rivers	2.34	0.75	8.0	0.4	9.1	117.9	8.7	0.4
9 Inland Rivers	7.41	3.89	51.4	1.5	53.8	−2.3	54.7	—
Total	130.0	52.26	406.4	112.2	571.4	26.9	562.3	10.1
NPC (= 2 + 3 + 4 + Northern part of 9)	58.63	25.91	172.9	23.8	211.3	12.1	205.3	6.9
Percent of national total (%)	45.1	49.6	42.5	21.2	37.0	—	36.5	68.3

* Moderate dry year, with a guarantee rate of 75% for irrigation supply; ** Includes domestic water demand.

dry year. The estimated total water demand therefore varies significantly with assumed hydrological conditions, as agricultural water demand accounts for over 75% of the total water demand. A guarantee rate of 50% is used for an average year and 75% for a moderate dry year. The total water demand in the year 2010 is expected to increase by 24.2 km^3 or 35.8 km^3 in the NPC area, for an average year or a moderate dry year, respectively (Qian and Zhang, 2001), on the bases of actual water supply in 1997. However, with limited availability of local water resources, the growth rate of water supply (= 12.1%) was substantially smaller in the NPC area during the 1980–1997 period, compared with a national average value of 26.9%. Unless an efficient cross-regional allocation of water resources is established, society's demand for water will soon exceeds its availability in the NPC area.

3 Interbasin water transfers in China

In China, several major interbasin water transfer projects have already been put into operation to ease water shortage. The East Route of the South-to-North water transfer will make use of a provincial project in Jiangsu Province, which has been built since 1961 and delivered a total of 10 km^3 water to Huaihe River basin during the 2000 drought (Wang, 2001). The construction of the Middle Route will be started in the year 2003, which has been planned for about 50 years, beginning in the 1950s. The West Route, the most controversial one, has been postponed for further studies. Table 3 is a summary of some of the operating and planned interbasin water transfer projects in China, with the routes being sketched in Figure 3, in which projects 12A, 12B and 12C are the proposed east, middle and west routes of the South-to-North water transfer project.

As has been pointed out, interbasin water transfer is a multidisciplinary problem (e.g. Yevjevich, 2001). The South-to-North water transfer is different from other existing interbasin transfer projects in China because it will cover 4 major regions. The Middle Route alone will cross about 200 river channels or canals, including the Yellow River, on its way to Beijing.

While interbasin projects within a region can be effectively coordinated by the local government and regional river administration, water transfer involving more than one region will be more difficult to manage and may bring about more fundamental issues concerning the social, economical, administrative and legislative aspects in present-day China.

4 Routing the South-to-North water transfer

The general principle of routing for interbasin water transfer, especially that regarding the geomorphology and hydrology aspects of a specific project, can be found in a summary by Yevjevich (2001). It was based on such principles that Lin Yishan, then head of the Yangtze River Commission, proposed the Middle Route to Chairman Mao Zedong in 1953, in response to Mao's question about the possibility of South-to-North water transfer (Lin, 2001). That was followed by a 50-year long period of study on the South-to-North water transfer project, carried out mainly by the Ministry of Water Resources (MWR) and the Yangtze River Commission (YRC). Table 4 is a summary of the major progresses and events related to the project during this period.

In October 2002, MWR formally announced the approval on principle of the General Plan of the South-to-North Water Transfer Project by China's State Council, in which the East, Middle and West Routes have all been recommended. The East and Middle Routes will be constructed first, as 80% of the water deficits occur in the Huang-Huai-Hai Area (i.e. regions 2, 3, 4 in Figure 2), of which urban and industrial consumptions take a share of 60%. Water transfer to this area is therefore expected to

Table 3 A summary of interbasin water transfer projects in China.

No. in Figure 3	From (River)	To (river/city)	Number of regions involved	Volume diverted (km^3/yr)	Diversion discharge (m^3/s)	Length of transfer (km)	Number of reservoirs	Pump stations	Irrigated area ($\times 10^6$ hm^2)	Date of construction
1	Yangtze	Huaihe	2	—	470	400		21	2.80	1961
2	Dongjiang	Hong Kong	1	0.62	—	83	2	0	0.03	1964
3	Luanhe	Tianjin	1	2.0	140	286	4	0	—	1982
4	Yellow	Tsingdao	1	0.64	75	262	1	3	0.09	1986
5	Biliuhe	Dalian	1	0.13	—	150	2	5	—	1982
6	Datonghe	Yongdeng	1	0.04	36	70	—	0	0.06	1980
7	Qinglong	Qinhuangdao	1	0.17	14	63	1	0	—	1989
8	Yellow	Baiyangdian	2	1.25	320	779	—	—	—	Planned
9	Songhua	Liaohe	1	4.4	500	656	7	2	0.24	Planned
10	Yellow	Taiyuan	1	1.4	48	453	1	5	—	Planned
11	Yangtze	Huaihe	2	—	300	269	—	2	0.97	Planned
12A	Yangtze	Yellow,	4	150	1000	1150	10	23	2.26	Planned
12B		Huaihe, Haihe	4	130	800	1240	40	0	2.32	Planned
12C		Yellow	2	170	—	700	7	10	2.33	Planned

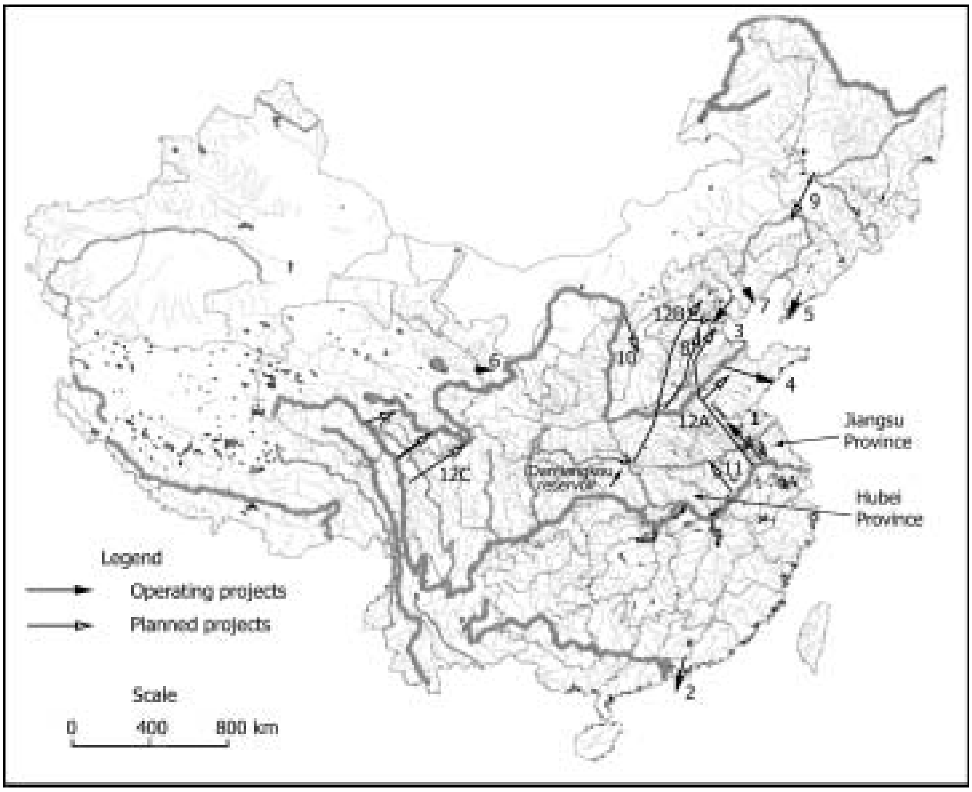

Figure 3 Operating and planned interbasin transfer projects in mainland China.

Table 4 The decision making process of the South-to-North water transfer project.

Year	Activities	Organizer	Progresses	Natural events
1956	Conceptual phase	YRC	Construction of Danjiangkou reservoir proposed	1955–1957: drought in North China
1959		YRC	The east, middle and west routes first planned	Drought in middle and lower Yellow River
1968	Construction of key reservoir	MWR	Main structure of the Danjiangkou reservoir completed	Drought in Northern China
1973		MWR	Diversion structure of the Danjiangkou reservoir completed	
1979	Planning phase	YRC	Plan for the middle route outlined	1978–1980: severe droughts in China
1980		MWR	Detailed field survey and investigation	
1985–1987		YRC	Middle Route Planning Report completed	Serious droughts of 1986 and 1988
1990–1994	Feasibility study	MWR,YRC	Feasibility study completed in 1994	1990: serious drought in north and south China
1993–1995		MWR, NEPB*	Environmental impact study completed in 1995	
1996–1997		SPC**	Proposal for South-to-North water transfer project approved	1997: severe drought in the Yellow River basin
1997–2001		YRC and local governments	Field survey for detailed design finished; detailed design is underway	Drought in the NPC area; Yangtze river flood
Oct. 2002	Beginning of the construction phase	MWR	Formal announcement of the beginning of project construction by MWR	

* National Environmental Protection Bureau of China; ** State Planning Commission of China.

have greater positive social and economical impacts. According to the announcement, the cost of the first phase of the East and Middle Routes construction is estimated at 18.7 billion in US dollar terms. The total cost of all the three routes, including all phases, is estimated at 60 billion US dollars. Engineering works to be started first includes two sections of the diversion canals for the East Route and the heightening of the Danjiangkou Dam for the Middle route. The East Route is expected to begin operation in 2005 and the Middle Route in 2010. The planned total amount of water transfer by the three routes will be 44.8 km^3 per year by the year 2050.

The East Route (project no. 12A in Table 3 and Figure 3) is based on an existing inter-basin water transfer project in Jiangsu Province (project no. 1 in Table 3 and Figure 3), in which the water is diverted from the Yangtze River through several steps of pump stations near the River Mouth. This route plans to use the Beijing-Hangzhou navigation canal as the main transfer channel, with four natural lakes and several planned reservoirs for storage and detention purposes. The Yellow River crossing of this route will be a siphon-type structure.

The Middle Route plans to divert water from the Danjiangkou Reservoir on the Hanjiang River (project no. 12B in Table 3 and Figure 3). To serve that purpose, the existing Danjiangkou Dam has to be elevated to 176.6 m (above sea level) from the present level of 162 m, and the normal pool level will be 170 m instead of the present 157 m. Additional relocation of residents in the reservoir area is expected. The water will be transferred through a newly built diversion channel with a maximum design capacity of 800 m^3/s, using anther siphon-type structure at the Yellow River crossing in this route.

The West Route diverts water from three major tributaries of the Yangtze River in the headwater zone of its catchment to the Yellow River (project no.12C in Table 3 and Figure 3), and consists of three sub-routes of tunnels though mountain ranges on the Tibetan Plateau. High dams must be constructed to raise water level because the elevation of the upper reaches of the Yellow River is above that of those tributaries. Compared with the East and Middle Routes, the West Route has better water quality and very limited needs for population relocation, but is more difficult to construct due to the harsh natural conditions on the Tibetan Plateau. Detailed planning, routing and feasibility studies of the West Route, particularly the cost-benefit analysis and development of technical method to overcome the practical difficulty in structural engineering, has been suggested to start soon (Qian and Zhang, 2001).

4.1 *Principal environmental-geological problems in the middle route*

It has been pointed out by Wang and Ma (1999) that the Middle Route will be affected by several environmental-geological problems, such as the slope stability of swelling clay and rock, soil salinization as a result of the rise of the groundwater table due to channel leakage, the settlement of ground surface in the coal mining area, liquefaction of sand, drainage through the left bank of the canal and frozen heave problems.

Sections of the transfer channel with problems of swelling soils and rocks have a total length of 160 km, about 12% of the entire project. The channel excavation rebound, weathering and moisture variation in soil as well as movement of water will intensify the swelling behavior of the soils and eventually result in slope failures of channel dykes in the form of collapse, slide and sludging. Channel sections with these soil types have to be excavated and built with a bank slope ratio of 1 : 4 (vertical : horizontal), which will substantially increase the excavation work and make repair job very difficult should failures take place. The key factor that causes the failure of swelling soil (rock) is the presence of water, and the major countermeasures to be taken include smaller slope angle, slope vegetation, drainage ditch and masonry protection. Grouting, anchoring and masonry may be needed during excavation for sections of clay-stone with swelling potentials.

In some earth-fill sections of the transfer channel, leakage will result in the formation of swamped land, or wetting belts along the lower areas located alongside the channel. Over-recharge of groundwater by channel seepage will result in the rise of groundwater table, as it is an influent channel by design, which may lead to salinization and swampiness problems in a large-area along the Middle Route. Proposed measures for seepage control mainly include the installation of a clay blanket or a geomembrane.

The Middle Route will pass through seven coalmine areas, with a total length of 51km of the transfer channel to be affected. Surface subsidence, collapse and ground fissure are expected in these areas, under the combined influence of coal mining and channel seepage. Where encounter with coalmines cannot be avoided, artificial cushion foundation for the channel will be made by compaction or compacted filling. Geomembrane and chemical grouting as well as cement-modified soil can be used for seepage control, so that soil deformation can be prevented.

Silty materials in river valleys and on flood plains in the NPC area, especially the Yellow River basin, have very fine and uniform particle size and quite limited clay content. The low mechanical strength of such material when saturated can easily lead to piping, internal scouring, and structural failure of the channel. Liquefaction and collapsing may occur under seismic shocks if the channel is built with silty sand close to its bottom. Proposed preventive measures include drainage, channel leakproofing, masonry protection, chemical grouting, as well as deep foundation. In regions of high seismic intensity, anti-earthquake provisions are also needed. The Middle Route channel is to be opened through cut-and-fill, in the form of a long dike above ground level, which may affect the drainage system in the river valleys it cuts through. Once the local flood is held back by the channel, the left-hand side channel dyke would face water on both of its sides, as the natural runoff drains from the channels' left-hand side to its right-hand side. This may cause additional problems in the slope stability of the dyke.

The stability of the dykes may also be affected by the cold weather in the NPC area, because of the freezing and thawing of soil. Diversion channel may not be able to operate due to frozen failures of the channel dykes. Again, the presence of water in soil is the cause of frost heaving and its destructive effect.

Sufficient seepage control measures that keep the dyke dry are therefore regarded as the most effective measure against frost failures. It has been proposed that the Middle Route channel be lined with continuous full-face concreting or cement to avoid the frost heaving problems.

5 Environmental and health hazards

In an examination of interbasin water transfer projects in southern Africa, Snaddon *et al*. (1998) pointed out that despite the high cost and "high profile" of such river basin manipulation measures, in terms of the complex engineering and technical inputs they require, the ecological and social implications of such schemes are inadequately addressed. In the case of China's South-to-North water transfer project, the environmental and ecological implications of the South-to-North water transfer are twofold, i.e. impact on the area from which water is diverted and impact on the area receiving the diverted water.

Firstly, a substantial amount of water will be diverted from the Hanjiang River in the Middle Route Plan, causing reductions of runoff in the downstream sections of that river, which in turn may lead to the worsening of existing eutrophication problem there. This became the primary concern in the environmental impact study of the Middle Route project (Yin *et al*., 2001). Table 5 is a summary of the water quality indicators in the lower Hanjiang River reach observed in recent years. Stream eutrophication can result in excessive algal mats and oxygen depletion at times of decreased flows and higher temperatures. Furthermore, excessive plant growth can occur in streams at apparently low ambient concentrations of nitrogen and phosphorus because the stream currents promote efficient exchange of nutrients and metabolic wastes at the plant cell surface. According to the study by Yin *et al*. (2001), sufficient solar radiation and elevated phosphorus or nitrogen levels can easily lead to algae blooms in the lower reaches of Hanjiang River during the spring season, when discharge is small ($< 500\ m^3/s$), flow is slow (< 0.8 m/s), and water temperature is high (10.5–12.8°C). So far three major events of widespread algae bloom in the lower reaches of Hanjiang River were recorded in the year 1992, 1998 and 2000.

Research results indicate that an increase in discharge in the lower Hanjiang River reach during the spring season will put the eutrophication situation under control. Such a measure will require proper regulation of the Danjiangkou reservoir from which water will be diverted into the main transfer channel of the Middle Route. Another engineering measure is being considered which will transfer a certain amount of water from the Yangtze River to the Hanjiang River to keep an adequate discharge and flow velocity during the spring season. As upstream water use on the Yellow River has already resulted in serious flood control problems on its lower reaches (Shao and Wang, 2002), detailed study and precautions are needed to make sure similar problems do not repeat itself on the Hanjiang and Yangtze River.

Secondly, there have been serious doubts about the feasibility of the East Route Plan of the South-to-North water transfer, because of the water pollution situation in the navigation canal and detention lakes to be used as part of the water transfer system, which may result in environmental and ecological problems in the area receiving the transferred water. Water quality monitoring and pollution control measures are needed along the East Route to improve water quality in the transfer system in a step-by-step manner. Transferred water with various quality standards in the immediate future may be sent to different users to meet different water quality requirements.

If the transfer channel has a water stage above the local water table and becomes an influent channel, the East Route water transfer may also result in secondary salinization problems like the Middle Route. Countermeasures such as proper drainage systems and lower water stages in the transfer channel will be necessary.

Also carefully studied was the possible proliferation of parasitic diseases, such as schistosomiasis, to the northern area due to the East Route water transfer from the infected area in Jiangsu Province. During the period of 1989–1998, a total of 7772 cases of acute schistosomiasis infection were reported in Hubei Province alone (Li *et al*., 2000). It has been found out that drifting pieces of reed carrying snails from the infected area can lead to the development of new snail habitats in the riparian area of lower reaches of the Yangtze River (Jiang and Gong, 1998). A recent survey shows that the total area of snail habitat in Jiangsu Province is 162 km^2 (Huang *et al*., 2000). Since snail hosts are a crucial link in the life circle of *Schitosoma*, development of snail habitat area is regarded as a chief indicator of the spreading of schistosomiasis. Observations and laboratory studies show that snail habitat development will not be able to cross the latitude

Table 5 Water quality in the lower reaches of the Hanjiang River in February (Yin *et al*., 2001).

Year	Water temperature (°C)	pH	DO (mg/L)	Total phosphorus (mg/L)	Total nitrogen (mg/L)	COD_{Mn} (mg/L)	BOD_5 (mg/L)
1989	7.0	8.2	11.0	0.179	—	2.63	—
1990	8.2	8.0	10.9	0.190	—	2.72	1.6–2.0
1991	7.5	8.2	11.4	0.087	—	3.12	—
1992	10.5	8.4–9.0	12.0–13.6	0.093–0.131	1.96	2.47	2.42
1993–1997	6.8–8.6	7.6–8.1	10.2–11.1	0.098–0.184	0.20–1.42	2.68–3.84	1.97–2.44
1998	—	—	—	0.193	—	4.36	—
2000	12.8	7.9–8.4	11.3	0.075	2.47	3.39	—
2001	10.6	8.0	9.8	0.179	1.82	3.02	1.57

of 33°15′ (i.e. Baima lake in Jiangsu Province) because snails cannot survive the cold climate further north, and 90% of the snails are found to be dead within 30 days after being put under a constant temperature of −2°C (from Qian and Zhang, 2001). Therefore the chance of the infected area extending further north due to the water transfer project is small, but close monitoring of the situation is still needed during future operation of the project.

Awareness of longer-term impacts lead to studies on the progradation rates of tidal flats at the Yangtze River mouth, which could be greatly slowed down when the sharp reduction in riverine sediment caused by the Three Gorges project and the South-to-North water transfer coincide with the rapid relative sea-level rise (Yang *et al.*, 2001). The operation of the two projects together will lead to slightly longer time and distance of saltwater encroachment up the Yangtze River mouth during the month of October, November and December, but the effect is negligible for the rest of the year (Wu and Wang, 2002). Chen and Zong (1998) believed that coastal erosion along the deltaic shoreline will become inevitable, resulting in a great stress on the land resource and coastal protection for Shanghai in the coming decades, based on an estimate of 10–20% decrease in sediment discharge into the Yangtze River delta due to operation of the three engineering works, i.e. the Three-gorges Dam, the South-to-North water transfer and the deepwater navigation channel at Shanghai.

6 Financing the project and pricing the supplied water

In an external review of China's water policy, Boxer (2001) has noticed a major 1999 policy shift from emphasis on structural engineering solutions to a broader resource-defined concept of water resources management, in line with a vigorous campaign over the past two decades to drastically reshape water development and management policies in the context of ambitious market reforms and a major reassessment of the legal, ideological, scientific and technical foundations of the water economy. Another important step taken by the Chinese government is the institutionalization of water rights and water markets at the legislative level in the year 2002. Transferred water is now perceived as a critical commodity, rather than public goods as before. To promote efficiency of water management and market-oriented reform, a new Water Law was put into effect on October 1, 2002, which prohibits the *de facto* free use of water by riverine users in various sectors of the economy, and stipulates for state-owned water rights, centralized river basin management, government license for water use, basic prices for water quota according to local conditions, and a progressive penalty price for water uses exceeding the quota, which is considered a major incentive for users to save water. In agricultural sectors, owners of reservoirs and other water projects, such as wells and irrigation channels, may automatically possess the right of water use associated with those projects that were funded and built by themselves. Though the system is based on the framework of riparian and prior appropriation doctrines, water demands for basic urban household and industrial needs are still the top priority. In the latter half of 2002, runoff in the lower Yellow River has been diverted to Qingdao and Tianjin to ease the urgent water shortage situation in the two major cities, in spite of the severe drought in the riparian agricultural regions.

Urban users are among the first to feel the impact of this legal move, since metering has been used as an effective tool for domestic water use reduction in most of the cities, as costs are not high for meter installation. While lawn sprinkling may be a major source of water consumption in developed and less populated countries such as the USA (Flack, 1984), domestic water conservation in China stresses the use of water-saving household devices (e.g. low-flush toilet, low flow showerheads), which can be very effective in reducing water use without inconvenience on the part of the customer. Some services, such as carwashes, are discouraged by putting a higher price for commercial water uses.

Implementation of these legal and policy changes will be brought to real test as the South-to-North water transfer project is started. The project will be built as part of the infrastructure of national economy, with the three routes running through a number of provinces that have their own administrative powers and economic interests. A well-structured system of water property rights is needed to avoid inefficiency of the project and to obtain maximum economic, social and ecological benefits. These would all be impossible goals to achieve if such a project were to be built within a system of planned economy, in which government failures were experienced in terms of allocation of surface runoff in a semi-arid area.

Jin and Young (2001) indicated that increasing water use efficiency in agriculture is the most promising approach to address both food security and water scarcity problems in China. The traditional way of meeting irrigation water demand by expansion of water supply has faced ever-increasing water scarcity difficulties. The very low water use efficiency in China's agriculture leaves farmers significant room to obtain more water simply through water conservation measures. With the new Water Law as an "incentive-to-conserve", government investment in efficient irrigation and other water saving measures in the domestic and industrial sectors could have a very high payoff, which should be put into place before the new water diversion project is constructed, as many experts have suggested (Qian and Zhang, 2001).

It has been proposed that the construction of the backbone structures (headwork, main diversion channel, etc.) will be financed through the establishment of a construction fund to cover the construction, interest and maintenance costs, which will be shared by each user province in the form of purchase of water right transfer (Wang, 2001; Liu, 2002). It then becomes natural that the larger the volume of water transfer a province will receive, the more share of construction fund that province will have to bear. Each province may raise the shared fund by charging individual users for their water withdrawals, in the form of water price adjustment. The MWR also proposed a system of preferential use, or a value hierarchy of uses, in order to establish allocation priorities across categories of water. Domestic water use for concentrated urban centers is regarded as top priority since it affects the everyday life of a huge population and could have an impact on social stability. The second priority is agricultural water use, which is directly linked to food security. Instream flow and ecological needs come third on the priority list, as awareness of environmental and ecological costs is growing and the importance of sustainability has been generally recognized. An efficient allocation of transferred water may be attempted without breaking these restrictions. For instance, after a number of bumper harvest years, a transfer of water from irrigated agriculture to industrial or urban commercial uses would raise net benefits, if regulatory restrictions do not inhibit such transfers among different users or provinces within the project.

However, it has been a textbook case that the existing mixed system of prior appropriation rights coupled with quite restrictive regulations will diminish the degree of transferability (e.g. Tietenberg, 2000, chapter 10). During the transitional period from a planned economy to a market economy, market failure is equally possible as government failure in terms of the efficient management of China's South-to-North water transfer. As the smooth operation of this water transfer project is vital to food security and social stability in China, it has been suggested that a quasi-market type of management will be adopted in the process of pricing and transfer of water rights, which could be a combination of market behavior, political consultation and government regulation (Wang, 2001). In view of the complexity of the problem, further studies are under way to establish a system of water property rights to promote efficient allocation of water which can also meet social and political needs (Liu, 2002).

7 Concluding remarks

Throughout the Northern Part of China, the need for more water is crucial to the goals of economic development, industrialization and elevating standards of living. Water resources in the NPC area have been nearly fully utilized within the physical limitations, with extensive mining of non-renewable water resources from deeper aquifers, resulting in increasing pressure on the overall environment and the river ecosystem in particular. A major transition is taking place with respect to water, i.e. from water engineering and water resources development to better management of basin-wide or regional water resources, by increasing water use efficiency and adopting water-saving technology. In addition to the existing provincial interbasin water transfer projects, the South-to-North water transfer has been regarded as a major project that can add significantly to the available water supply in the NPC area.

Though the construction of the project is technically possible with acceptable environmental impacts, several serious problems remain to be solved regarding the current water use practice in China. As have been pointed out by many researchers, the magnitude and complexity of this task is daunting, especially when China is going through a transitional period from planned to market economy. Implementation of water rights and market transfers will require additional government regulation and political consultation. Land and water use practices need further improvement to be sustainable, and the present irrigation efficiency should be increased. The current water use doctrine in China, similar to many regions around the world, fails to provide adequate protection for the instream use of water, which is crucial to maintain the proper functioning of such large rivers as the Yellow River, whose runoff has been too low to transport the huge amount of sediment yield from its middle reaches. As construction of the new water transfer project is getting started, new ways of thinking and acting are also being explored in a concerted large-scale effort to achieve long-term benefits of sustainable water use.

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