Implications of desalination to water resources in China - an economic perspective

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Abstract

China is a country with severe water shortages. Water becomes scarcer due to population growth, industrialization and urbanization. Recent studies show that by the next 50 years water resources per capita will go down to around 1700 m^3, which is the threshold of severe water scarcity. Especially in North China, water shortage has become a critical constraint factor for the socio-economic development in the long run. To solve or eliminate water shortage problems, seawater desalination draws more and more attention as an alternative water supply source. The objective of the study is to assess the potential of desalination as a viable alternate water source for China through analysis of the costs of desalination, the water demand and supply situation as well as water pricing practices in China. Based on the investment costs and estimated operation and maintenance costs, an economic appraisal for the costs of desalination for two main processes, MSF and RO, has been conducted. The study shows that there is a decline of unit cost of desalination over time and the average unit cost of RO process has been lower than that of MSF process. A unit cost of 0.6 $\$/m^3$ for desalting brackish water and 1.0 $\$/m^3$ for seawater are suggested to be appropriate for the potential application of desalination in China. The future trends and challenges associated with water shortages and water prices are discussed, leading to conclusions and recommendations regarding the role of desalination as a feasible source of water for the future.

Keywords: desalination, cost analysis, water shortage in China, water demands, south-north water transfer

1. Introduction

China is a country with great variations in the spatial and temporal distribution of its water resources. There is more than sufficient water in the south and deficient water in the north. North China has suffered from water shortages since a couple of decades, and due to the population growth and economic development, this region has now reached the level of severe water scarcity. Poor water condition has been a factor restricting the socio-economic development and causing environmental deterioration. Traditional water supply could not help to provide more water to meet growing demands. The South-North Water Transfer Scheme attempts to ease water problems by transporting water from the Yangtze River in the south to rivers in the north, which is the choice out of no alternatives. The project is by far the largest infrastructure construction of China in terms of investment and complication [1].

However, the improvements of desalination technology may pave the way to more accessible water. China's population and economy are concentrated in the coastal zone, which makes desalination a good alternative source of water as many coastal cities face water shortage. This study analyses the implications of desalination to water resources in China from an economic perspective in order to answer the question: "Is it economically and practically feasible to apply desalination in China?" Since desalination plants have not been constructed on a reasonable scale in China, the costs for two main desalination processes, MSF and RO are analyzed, using data available for desalination plants all over the world. The research also evaluates the water situation and future projections of China. The results of the study provide an overview of the projected costs of desalination, current and future water shortage in China, and potential applications of desalination in China. It also serves as a basis for developing governmental plans, strategies, and policies for future applications of desalination.

2. Current state of desalination

Desalination of seawater and brackish water has grown rapidly in recent decades. This has allowed socio-economic development to continue in many arid, semi-arid and other water-short areas. The application has been very noticeable in parts of the Middle East, North Africa, the Arabian Gulf and some islands where traditional water supply cannot meet the needs. Desalted water has become an alternative to traditional water supply and has increasingly been explored by many regions. The installed capacity of desalination plants has expanded rapidly worldwide, from 8000 m^3/day (till 1970) to about 32 million m^3/day (by 2001). Non-seawater desalination plants contributed with 13.3 million m^3/d, whereas the capacity of the seawater desalination plants reached 19.1 million m^3/d [2]. The development is driven by the increasing stress of the water sector, which cannot satisfy the ever-growing demands for water generated by population growth, economic growth and more water-consuming lifestyles. It is also driven by the reduction of costs of desalination due to technological improvements and improved management and experience.

Various distillation and membrane technologies are available for seawater and brackish water desalination, including multiple effect distillation (MED), multistage flash distillation (MSF), reverse osmosis (RO) and electrodialysis (ED). The first two are based on distillation process whilst the latter two use membrane technology. The most important and popular processes are MSF and RO, which account for 84% of the whole capacity of the world [3]. Most of above-mentioned processes can apply to desalt seawater, while RO and ED are often used for brackish water desalting. The selection of different technology essentially depends on the purposes of desalination, economics, the physical conditions of the plant site, raw water and product water qualities, and local technical know-how and capacity.

3. Desalination costs

One of the most important factors determining desalination decisions is economics: costs and benefits. However, it is not easy to analyze and compare the costs of different desalination plants, because the costs strongly depend on the capacity and type of plants, the region, the quality of raw and product water, the period and assumptions about capital and labor costs. Fortunately, there is indeed a trend that the cost of desalination is declining over years. To get a general understanding of the costs and their trends, it is important to conduct a cost comparison of existing desalination plants. There are a few studies that have conducted a cost comparison analysis, but these studies either compare a limited number of plants with a single process, compare different technologies in a single plant, or compare plants on a regional basis [4-8]. Park has conducted a comprehensive cost comparison using 1990 unit cost for analyzing the potential of desalination in Korea, but used plant data of only the period from 1982 to 1991 [8]. The Desalination Economic Evaluation Program (DEEP) developed by the International Atomic Energy Agency has been applied to some studies for economic evaluation and screening analyses of various desalination and energy source options in the world [9]. In China there are very few desalination plants of a reasonable scale in use at present, therefore it is not feasible to make a cost analysis based on them. This study reviews and analyzes the average costs of various desalination plants in countries all over the world based on simple assumptions, and then illustrates the trends of decline in order to make a suggestion to the potential application in China. A huge number of desalination plants are considered and classified into several groups based on desalination technologies. The main data of desalting plants in this study are obtained from 2002 IDA Worldwide Desalting Plants Inventory Report No.17 [2]. Since MSF and RO are to date the most often used processes, account for most of the capacity, plants using these two processes are selected and their costs are analyzed and compared. For the purpose of this study and simplicity, the plants are only classified by process, disregarding the location, the quality of source and product water, and other specific conditions.

The major costs elements for desalination plants are capital costs and annual operation and maintenance costs (O&M). Capital costs can be divided into direct and indirect costs. The direct costs include the costs of purchase of equipment, land, construction charges and pre-treatment of water. The indirect costs mainly refer to the interest, insurance, construction overheads, project management and contingency costs. Annual operation costs are those expenses incurred during actual operation, such as labor, energy, chemicals, consumables and spares. Calculations of unit product costs depend on the process, the capacity, site characteristics and design feature.

For this study, all the plants using MSF and RO processes in IDA Report No. 17 are included, which contain about 3000 data points from 1950 up to now. The data set includes country, location, total capacity, units, process, equipment, water quality, user, contract year and investment costs. The investment costs should firstly be amortized, which can be obtained by multiplying these costs by an amortization factor. The formula is as follows:

$$A = P \times \left\{ \frac{i \times (1+i)^{n-1}}{(1+i)^n - 1} \right\}$$

where A is amortized annual capital cost, P is the value of investment in the original year, i is the annual discount rate, and n is the economic plant life. In this study, a discount rate of 8% and a plant life of 25 years are assumed for amortization for all cases as these figures are usually used in this sector in both China and other countries [2, 10]. Due to the lack of data for operating costs, 60% of total cost is assumed to be operating costs for all the cases [2]. For the purpose of comparison, all costs must be evaluated based on the same year level. As all the costs have been converted to US dollar, the base year 1995 is selected and all costs are converted according to the United States Consumer Price Index. The costs data include investment costs, amortized capital costs, O&M costs, total unit cost, conversion rate and 1995 unit costs (see appendix).

3.1 Cost comparison of MSF process

MSF process accounts for the second largest installed desalting capacity for the world. The major consumers for MSF are in Saudi Arabia, United Arab Emirates and Kuwait. Fig. 1 shows the yearly distribution of the unit costs of desalting plants in the world. The unit costs decline over time, from about 9 $\$/m^3$ in 1960 to about 0.9 $\$/m^3$ in 2000. Since MSF process is mostly applied for seawater desalination plants, the costs reflect the value of desalting seawater. The trend indicates that the desalting costs of seawater are expected to decrease further in the future. Based on the exponential projection presented in Fig 1, the average cost will go down to about 0.3 $\$/m^3$ in 2025. As the costs have fallen by a factor of 10 in 40 year's time, a further cost decrease by a factor of 3 in 25 years is entirely feasible. This value, however, is associated with great uncertainty because of the crudeness of the underlying data described in section 2. As China is a country which lacks experiences in seawater desalination, the current estimated cost would be a bit higher than the average world level, perhaps about 1.0 $/m^3 would be an appropriate cost of MSF process in China at the moment, and lower in the future.

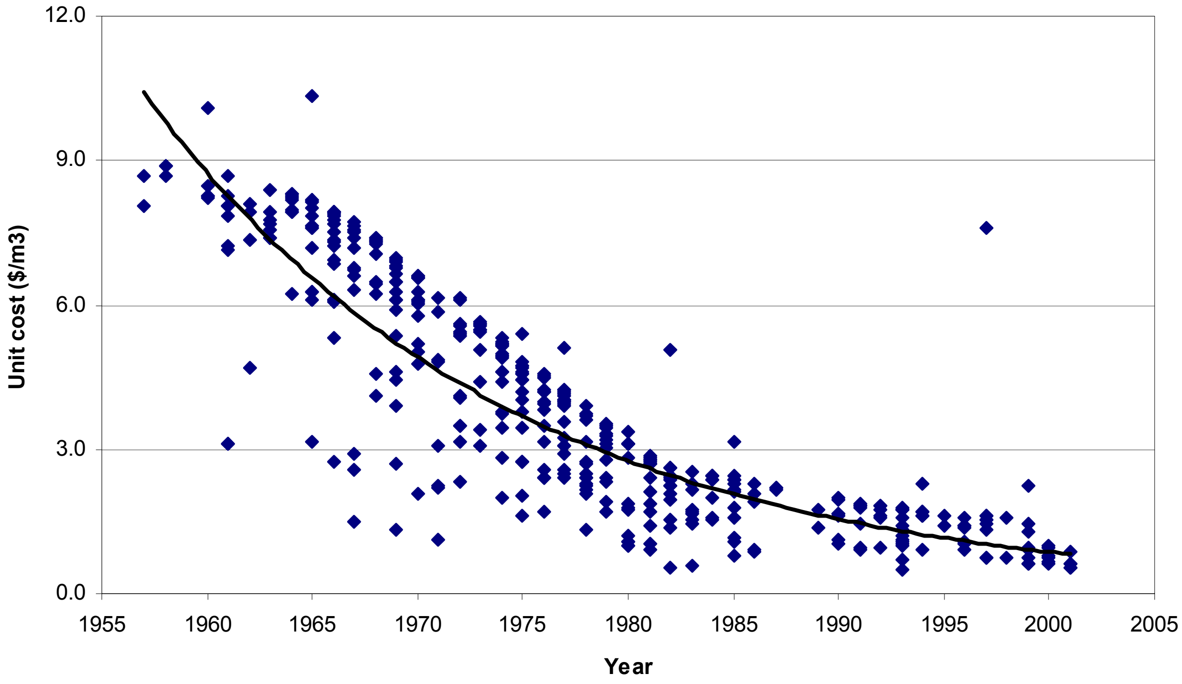


Fig.1 Yearly distribution of the unit costs by MSF process

Fig. 2 illustrates the trend of unit costs with plant capacity. As shown, there is a decline of cost with the increase of plant capacity due to economies of scale. However, the trend is not pronounced as the points are distributed dispersedly along the trendline for plants with a capacity less than 50000 m^3/d. This may result from many other influencing factors besides capacity, such as the quality of raw and product water, the costs of labor and energy.

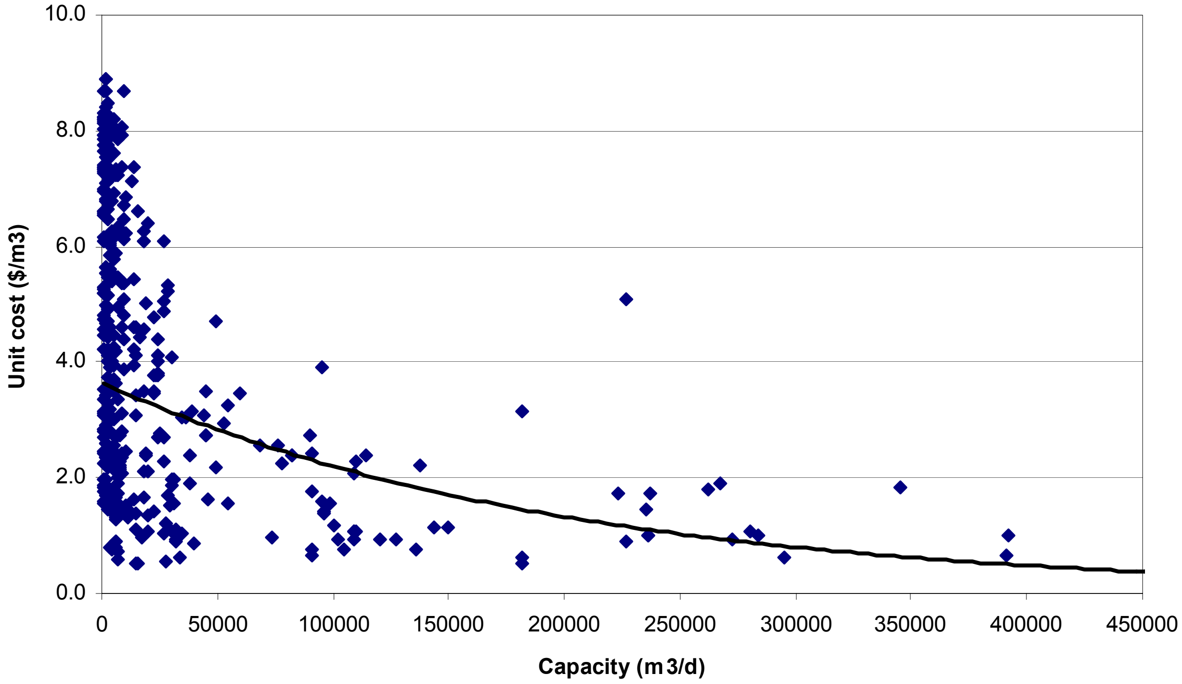


Fig. 2 Distribution of the unit costs with plant capacity by MSF process

3.2 Cost comparison of RO process

RO process has become more popular during the last decades due to a significant achievement in improving technology. At present, RO process has the largest share of the total installed capacity in the world. The operating cost of RO plants has been reduced thanks to two developments: 1) lower-cost, higher-flux, higher salt-rejecting membranes that can operate efficiently at lower pressures and 2) the use of pressure recovery devices [3]. Fig. 3 shows the distribution of the unit costs with the total installed capacity by RO process. As shown, the unit costs have declined with the cumulative installed capacity as a result of the technological development and gained experiences. Compared to the costs of MSF process, the costs of RO process have been much lower. According to the trend, the unit cost will continue to decrease, as more and more desalting plants will be built in the future.

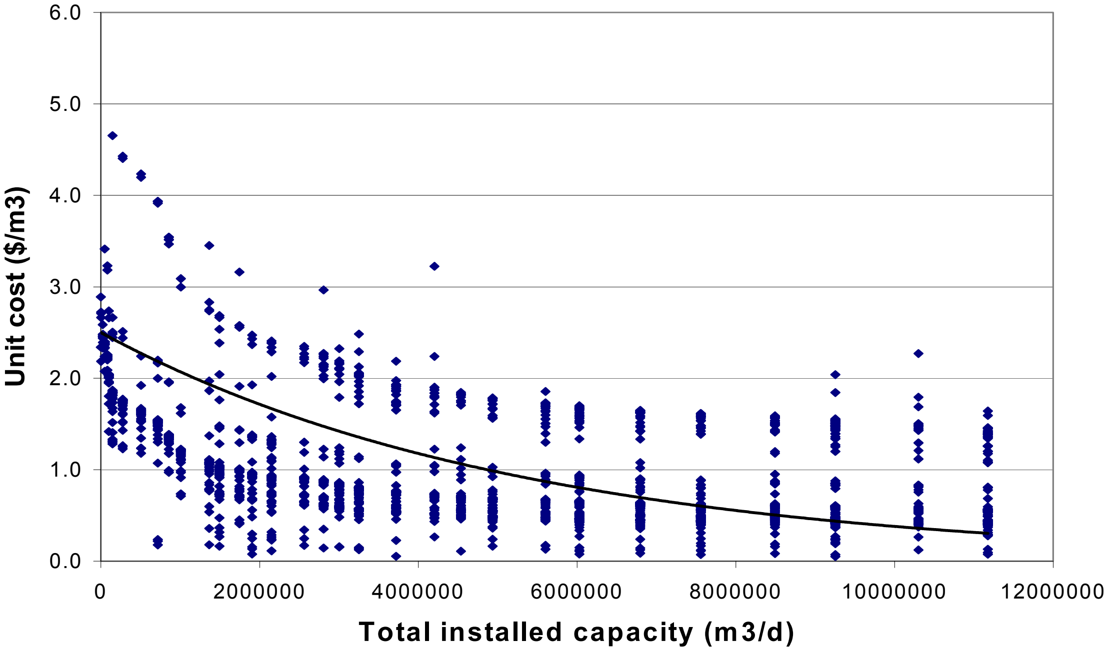


Fig. 3 Distribution of the unit costs with total installed capacity by RO process

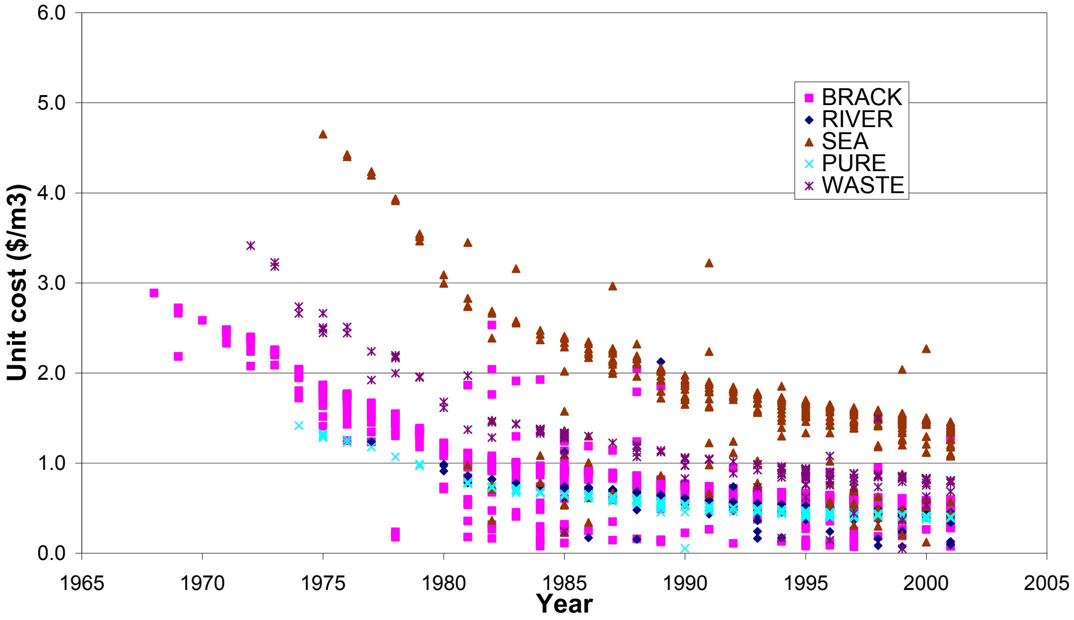


Fig. 4 Yearly distribution of the unit costs by raw water quality for RO process

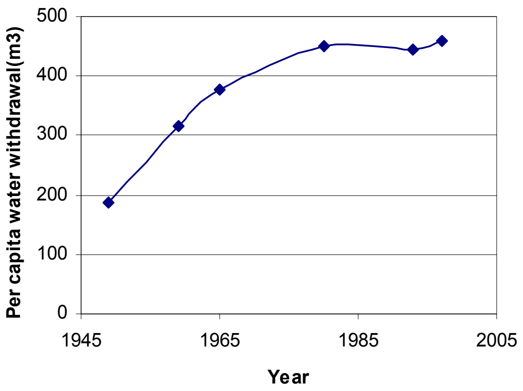
Unit costs vary with the raw water quality, location, capacity and so on. Fig. 4 shows the variation of unit costs with different raw water qualities, namely brackish-, sea-, river-, waste- and pure water. The unit costs have declined considerably over time. The average cost of desalting by RO process goes down to about 0.7 $/m^3$ in 2000. RO process is used more often to desalt brackish water, river and pure water although it is also increasingly applied to seawater. From our calculation, we can see that the average costs for desalting brackish water are lower than for seawater and wastewater desalting, but higher than for river and pure water. The costs of seawater desalting have been going down, however still above 1.0 $/m^3$ in 2000. For brackish water, the average cost has decreased to about 0.5 $/m^3$ today. Great interest and efforts have been put in seawater RO research in the last decade, which makes its costs, especially on a larger scale, reduced considerably. Recent tenders' lower costs of large SWRO plants indicate that RO has great potential to become the most economical process for seawater desalination. Most of the RO plants have a smaller capacity than MSF plants in general. Given the fact that the desalination plants with small or medium scales will be the most suitable at the beginning of desalination in China, RO process is likely to be the first choice. Today a cost of 0.6 $/m^3$ for desalting brackish and wastewater and a cost of 1.0 $/m^3$ for desalting seawater by RO would be valid in China.

4. Implications of desalination to water resources in China

4. 1 Water resources in China

China has a total amount of 2800 km^3 of water resources. According to the 1997 population statistics, the average volume of water resources per capita is only 2220 m^3. Based on this index, the country ranks as the 121st place among all other nations in the world [11]. By the next 50 years, the volume is estimated to go down to around 1700 m^3, which reaches the threshold of water stress [11]. The absolute value, however, does not reflect the reality of water resources because water is not evenly distributed in both spatial and temporal terms in China. For example, about 80% of the total volume of water is located in the Yangtze River and its southern part of China, where the population accounts for 53.6% of the total and the area is only 35.2% of the whole country [11]. The per capita water resources in the south are much greater than in the north. With regards to the temporal variation, 70% of the total precipitation concentrates mostly in four months of a year [12].

The water withdrawal has increased dramatically in recent decades, from 443.7 km^3 in 1980 to 556.6 km^3 in 1997 [11]. The water withdrawal per capita is illustrated in Fig. 5, increasing to 458 m^3/year in 1997. The utilization ratio (the percentage of water withdrawal out of water resources) has also risen from 16.1% in 1980 to 19.9% in 1997 [11]. In North China, water resources are over exploited and the utilization rate reaches 50% or more, including Huang River, Huai River and Hai River (Fig. 6). According to the international criteria, more than 40% withdrawal can be regarded as a threshold of severe water scarcity. The overdraft has resulted in discontinuous flow, declined groundwater table, and degradation of the ecological system. The future growing demands and requirements will further deteriorate the water situation, thus constrain the socio-economic development of the region.



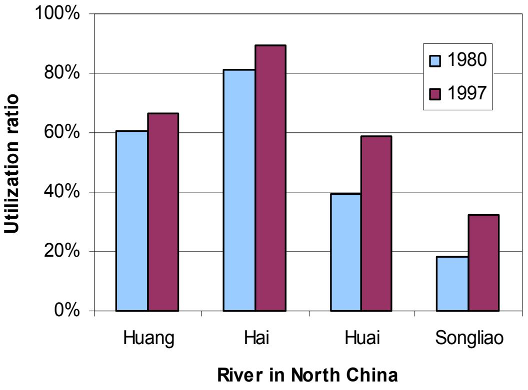
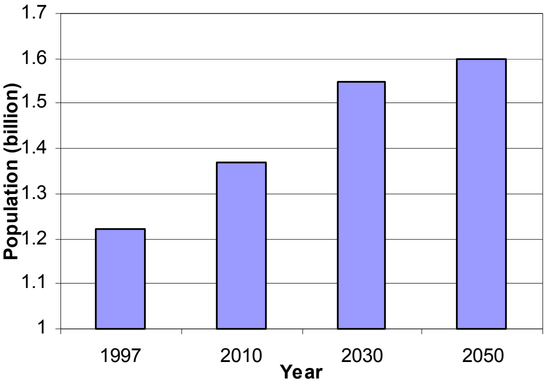


Fig. 5 Water withdrawal per capita (m^3/per/yr)

Fig. 6 Utilization rate of water in North China

4.2 Water demands in the future

To assess the future potential of water resources, it is not feasible to merely rely on the volume data. It is equally important to forecast future water use including changes human activities. Report from the Chinese Academy of Engineering has recently been released, projecting water resources and water demands for the next 50 years [11]. The projection includes industrial demand, domestic demand and agricultural demand, taking into consideration the population growth and socio-economic development (urbanization, industrialization, change of industrial structure, etc). Three scenarios are applied for the projection (Table 1), namely high economic growth (HG), moderate economic growth (MG) and low economic growth (LG). Different assumptions regarding economic development, government policy, and increase of irrigation area are given for these three scenarios. The population projection is shown in Fig. 7, and GDP projections for the three scenarios are illustrated in Fig. 8. As shown, in 2050 the population in China will grow to 1.6 billion, and GDP will increase to about 100 trillion Chinese RMB ($12 trillion) under moderate growth.



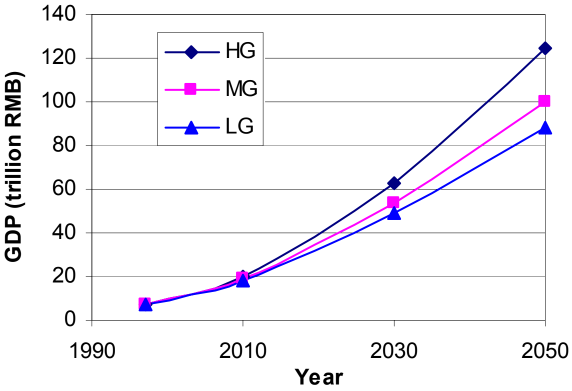


Fig. 7 Population projection in China [10]

Fig. 8 GDP projection under three scenarios [10]

As shown in Table 1, the water demands in 2050 are projected to reach 800 km^3 under high economic growth and about 700 km^3 under low development. The increase in water demand in comparison with current level is estimated to be between 130 to 230 km^3, which is a huge amount of water. The Chinese government has built many dams, reservoirs and other infrastructure to exploit water in the past, which makes the expansion of storage capacity difficult because many infrastructures have been in place and developing more hydraulic projects tends to be costly. This implies that the future water resources are increasingly difficult to meet the growing needs. Under the moderate growth scenario the water demands in 2050 will be 730 km^3, with per capita demand of 457 m^3/yr. The structure of future water demand will change as follows: agriculture will use comparatively less water while the industrial and residential sector will increase water demands. It is estimated that in 2050 the ratio of using water in agriculture-industry-domestic sectors will be 57:27:16 as compared to the 1997 ratio of about 71:20:9 [11].

Table 1
Water demands projection in the next 50 years (km^3/yr) [11]

Year	High Growth			Moderate Growth			Low Growth		
	Total	North	South	Total	North	South	Total	North	South
1997	571.4	273.9	297.5	571.4	273.9	297.5	571.4	273.9	297.5
2010	659.1	310.6	348.5	642.4	303.7	338.7	630.5	297.4	333.1
2030	757.3	346.9	410.4	711.9	330	381.9	688	319.1	368.9
2050	806.3	366.2	440.1	731.9	337.1	394.8	702.7	323.1	379.6

There are several other projections regarding population and GDP growth of China. We use two of them for a sensitivity study of future water demands. Within this study, two of the IPCC SERS scenarios [13] are taken in comparison with China's projection. Under the context of this study, only population varies between different scenarios whilst all the other variables are kept constant. Table 2 shows that under scenario A_1, in which population grows slowly, water demands will fall by 7.5% (55 km^3) in 2050 in comparison to China's projection. With the higher population projection of scenario A_2, water demands will increase by 13.1% (96 km^3). From this sensitivity study and the sensitivity analysis on economic growth (GDP) reported above, we see that the uncertainty about future water demands of China is high.

Table 2
Sensitivity analysis of water demands under different population scenario

Year	China scenario		IPCC scenario A1			IPCC scenario A2		
	Population billion	Demands km^3	Population billion	Demands km^3	Deviation %	Population billion	Demands km^3	Deviation %
2010	1.37	642.4	1.35	638.6	0.6	1.45	655.0	2.0
2030	1.55	711.9	1.41	685.0	3.8	1.76	749.9	5.3
2050	1.60	731.9	1.32	676.8	7.5	2.09	827.7	13.1

Apparently water resources can not grow symmetrically with increasing demands for water consumption, hence water shortage will become strikingly severe, especially in North China where the utilization ratio of water is already extremely high at present. Table 3 shows water demand and supply conditions of three main river basins in North China, namely Huang River, Huai River and Hai River. The data of water availability include the potential utilization of surface and groundwater, potential wastewater reuse as well as current water transfer capacity of 15 km^3 per year. However, it does not include the future water transfer from other rivers. Table 3 shows that water shortage will be 46 km^3/yr under the HG scenario, 31 km^3/yr under the MG scenario and 25 km^3/yr under the LG scenario in 2050. If population growth is higher than expected, shortages would increase even further.

Table 3
Water shortage analysis for Huang, Huai and Hai River basin (km^3/yr) [11]

River	Year	Water Availability*	High Growth		Moderate Growth		Low Growth	
			Demands	Shortage	Demands	Shortage	Demands	Shortage
Huang	2030	44.3	57.1	12.8	53.5	9.2	52.3	8
	2050	44.8	60.5	15.7	54.5	9.7	53	8.2
Huai	2030	73.5	85.3	11.8	81.5	8	79.9	6.4
	2050	76.4	89.7	13.3	83.9	7.5	81.6	5.2
Hai&Luan	2030	40.6	56.1	15.5	53.9	13.3	52.7	12.1
	2050	41.8	58.7	16.9	55.6	13.8	53.7	11.9
Total	2030	158.4	198.6	40.2	188.9	30.5	184.9	26.5
	2050	163	208.9	45.9	194	31	188.2	25.2

* including current water transfer capacity

The water supply under the current scheme will not be able to meet the future demands, thus inter-basin water transfers for a large scale have been considered and approved. Water transfers from Yangtze River to North China are collectively known as the South-North Water Transfer Scheme. This scheme has mixed impacts on natural environment: it on one hand can provide a stable source of water for receiving basins and on the other hand has negative environmental impacts. The general layout of the scheme has been worked out as three water transfer projects, namely Western Route Project (WRP), Middle Route Project (MRP), and Eastern Route Project (ERP), which will divert water from upper, middle, and lower reaches of Yangtze River respectively, to meet the developing requirements of Northwest and North China [14]. The preliminary estimate of the total capital investment is about 500 billion RMB (about \$60 billion). The total transfer capacity of the West Route, Middle Route and East Route Project is estimated to be about 44.8 km^3/yr by 2050 [16].

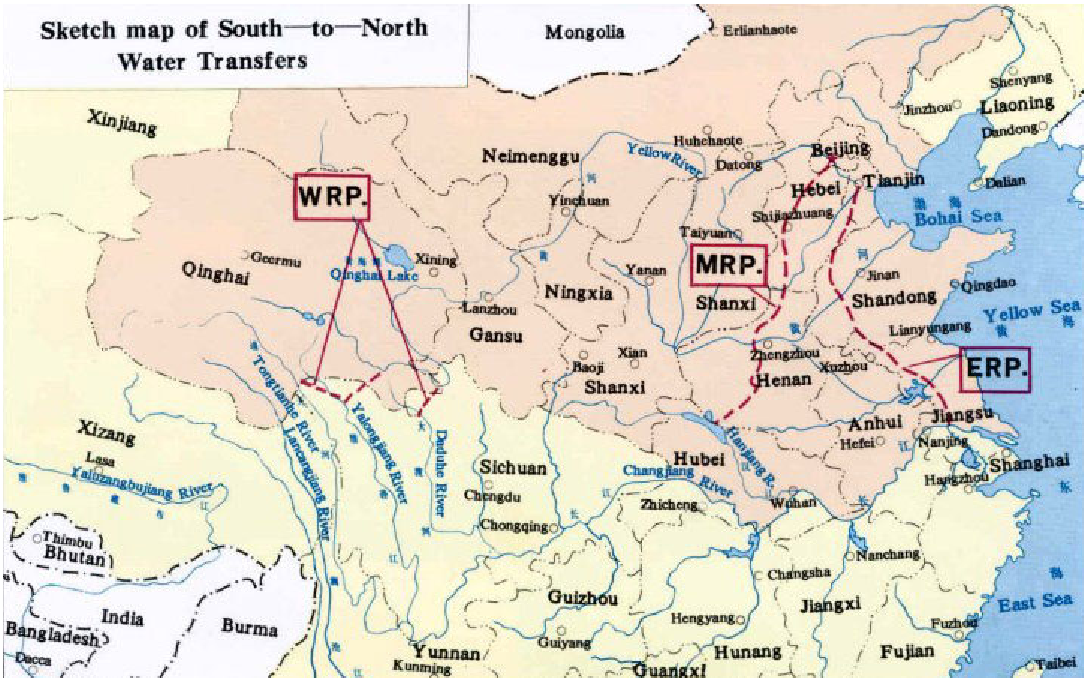


Fig. 9 sketch map of the South-North water transfer scheme

The ERP will divert water from the lower reach of Yangtze River north to supply water for the eastern Huang-Huai-Hai Plain with the termination in Tianjin City by raising water in stages through Beijing-Hangzhou Grand Canal. The Ministry of Water Resources estimates that the first round expansion of the route can complete in 3 years, and the second phase could be completed by 2010, with another round of expansion considered for after 2010. The MRP will divert water from Danjiangkou Reservoir on the Haijiang, a tributary of Yangtze River, to Beijing City through Canals to be built along Funiu and Taihang Mountains. The advantages of this project lie mainly in good quality of the water to be diverted, greater availability of water supply, and in that water can be conveyed by gravity. The project will be an important and basic facility for mitigating the existing crisis of water resources in North China. The first round of channel construction has been launched and will be completed by 2010. The WRP will divert water from the upper reach of Yangtze River into Huang River. Following the economic and technical feasibility studies, this route is expected to be constructed only sometime after 2010 [16].

If the South-North Water Transfer Scheme is successfully implemented and the total capacity fully realized as planned, the situation will be fairly positive (Table 4). Water shortage will be 10 km^3/yr by 2030 and only 0.5 km^3/yr by 2050.

Table 4
Water shortage estimation with full water transfer capacity (km^3/yr) [11]

River	Year	Water Availability*	Water transfer**	Moderate Growth	
				Demands	Shortage
Huang	2030	44.3	8.5	53.5	0.7
	2050	44.8	9.5	54.5	0.2
Huai	2030	73.5	3.9	81.5	4.1
	2050	76.4	7.4	83.9	0.1
Hai&Luan	2030	40.6	8.1	53.9	5.2
	2050	41.8	13.6	55.6	0.2
Total	2030	158.4	20.5	188.9	10
	2050	163	30.5	194	0.5

* including current water transfer capacity ** future water transfer

However, the real situation is hard to anticipate. The water transfer scheme might not be as effective as foreseen and possible negative effects on the whole ecosystem may counteract the benefits associated with. In general, the reliability of the scheme is associated with high uncertainty. For that reason, within this study, only half of the full water transfer capacity is taken to estimate the future water shortage whilst all other variables are constant as Table 3 without future water transfer. With half capacity, water shortage will be 20 km^3/yr by 2030 and 16 km^3/yr by 2050 (Table 5), which is high. This implies that the water transfer scheme may not solve the whole water problem and there might still be water shortage in North China.

Table 5
Sensitivity of water shortages with half water transfer capacity (km^3/yr)

River	Year	Water availability*	Water transfer**	Moderate Growth	
				Demands	Shortage
Huang	2030	44.3	4.3	53.5	5.0
	2050	44.8	4.8	54.5	5.0
Huai	2030	73.5	2.0	81.5	6.1
	2050	76.4	3.7	83.9	3.8
Hai&Luan	2030	40.6	4.1	53.9	9.3
	2050	41.8	6.8	55.6	7.0
Total	2030	158.4	10.3	188.9	20.3
	2050	163	15.3	194.0	15.8

* including current water transfer capacity ** future water transfer

4.3 Potential application of desalination in China

Seawater desalination has been studied in many institutes and universities in China since the 1960's, particularly membrane science and technology [17]. Besides, Chinese scientists have recently developed atomic reactors to provide heating to desalinate seawater, by burning used fuel from nuclear power stations under normal pressure. The breakthrough would be an active factor to facilitate developing of seawater desalination especially for cities with severe water shortage. A pilot project using deep-water reactor under normal pressure of 200 megawatts will be established in the coastal city of Yingkou, in which the daily capacity is expected to amount to 80,000 m^3/d [17]. However, the application of desalination in China to date is still limited. The total capacity of seawater desalination so far is about 18000 m^3/d [2]. The biggest plant is located in Dalian city with a capacity of 10000 m^3/d. More desalination plants have been built to treat brackish-, river- and wastewater, often using RO processes. Given the growing stress of water shortage, desalination becomes important to provide additional clean water from brackish water or seawater. For inland water shortage cities, such as those in Hebei and Shandong provinces, wastewater treatment has double benefits: that of reducing the discharge of waste directly into river, as well as providing more water supplies for the cities. In 1999, there was a total wastewater discharge of about 60 billion m^3/yr including industrial and municipal use. Among them, industry accounts for 67% and municipal use 33% [11]. The ratio of treatment of wastewater was only about 14% in 1997 in China [11]. Water shortage is even more serious in the coastal areas with water resources in some industrial cities averaging only 500 m^3 per person. Therefore, there is much space to develop wastewater desalination in order to utilize the water. As about two thirds of the water is used for industry in southeast coastal cities, seawater desalination, where applicable, should be considered as an alternative to provide water supply.

To evaluate the feasibility of seawater desalination, it is crucial to look at the costs and consumers' affordability. As we analyzed before, increasing desalination plants is a potential solution to solve or at least ease water scarcity in China. However, in a market economy, economical feasibility of building a desalination plant is one of the primary questions that should be answered during the feasibility surveys of investing in such a manufacture. Table 6 lists current water prices of consumption for some water shortage cities in China.

Table 6
Current water prices in water shortage cities ($/$m^3$)

City	Domestic use	Industrial use	Commercial use
Beijing	0.349	0.386	0.386
Tianjin	0.313	0.458	0.602
Shanghai	0.205	0.157	0.181
Shi Jiazhuang	0.133	0.241	0.265
Taiyuan	0.163	0.205	0.301
Datong	0.145	0.193	0.265
Huhehaote	0.133	0.157	0.301
Shenyang	0.169	0.193	0.289
Dalian	0.277	0.386	0.602
Changchun	0.301	0.554	0.554
Ha'erbin	0.217	0.289	0.482
Nanjing	0.229	0.277	0.337
Zhengzhou	0.193	0.217	0.301
Jinan	0.211	0.253	0.361

Yantai	0.181	0.187	0.301
Qingdao	0.157	0.163	0.163
Xi'an	0.181	0.224	0.301
Lanzhou	0.084	0.120	0.139
Average	0.202	0.259	0.341

From http://www.waterchina.com (03/2003)

At present, the major obstacle in applying seawater desalination in China is its price. The table above shows that the current average water price is about 0.20 \$/m^3 for domestic use, 0.26 \$/m^3 for industrial use and 0.34 \$/m^3 for commercial use. Water charges have been kept low for a long time due to the governmental policy. Water is not fully charged based on the actual cost occurred but subsidized by the government. Water prices do not reflect the true value of water in China. Nevertheless, the price of water has increased during these few years. Rising urban incomes and growing public awareness have paved the way for increases in urban water prices and increasing the reuse rate.

Today households pay very little for water compared to their income. For example, in Beijing households paid 250 RMB (\$30) for water in 2002, which accounts for only 2% of the total annual income of 12000 RMB (about \$1446). The prevailing assumption is that households are willing to pay about 3 to 5 percent of their income for access to clean water [18]. Obviously, based on this criterion, the affordability of urban residence in China is still high. People have the ability to pay more for water. The State Council recently reported that the price of urban water supply in Beijing would be increased to 6.0 RMB/m^3 (0.72 \$/m^3) by 2005, which reaches the current cost of desalted brackish water. For other water shortage cities in the north, it will take some time for water prices to increase to the level of desalination costs. The South-North Water Transfer Scheme will somehow alleviate water shortage, but will also increase water prices dramatically due to the huge investment capital, by at least 0.1\$/m^3. The transferred water will be as expensive as desalted water in the next 15 years. In reality, the problem of water shortage will not be worked out if water is still considered as only a government good. Instead it should also be treated as an economic good. In a transition economy as in China, the government will realize that subsidy to water sector will not be highly beneficial to the nation in the long run. Water is often wasted or used inefficiently due to the low prices and lack of awareness. Instead it should be put into a market where prices are determined by the principle of market economy. The governmental policy is indeed necessary to lead this pricing inform successfully step by step. As water prices increase and desalination costs continue the trend of decline, it will create a higher favorable condition to apply desalination in China in the future.

5. Conclusions

Desalination is becoming a solution for water scarcity in a number of arid countries. For the potential application of desalination in China, the following conclusions can be drawn from this study:

1. Improved desalination technologies and accumulated management experiences have been playing important roles to reduce the unit cost of water noticeably over time. To date, the unit cost of desalted water using MSF process has been reduced ten times since the 1960s. The average present unit cost is about 0.9 \$/m^3. RO technology has developed rapidly in recent decades, which makes the costs lower than MSF process for a moderate capacity. Based on this study, the average unit cost of RO process has declined to around 0.7 \$/m^3, which is very competitive for traditional water resources. The technological innovation will still bring down the cost in the future.
2. Based on the reduction trend of the desalination costs in the world, the unit cost of 1.0 \$/m^3 for seawater desalination using MSF process is suggested for potential applications in China. In

addition, a unit cost of 0.6 $/m^3 for brackish and wastewater using RO process and 1.0 $/m^3 for seawater would be appropriate. As the technology develops, RO process would be a favorable choice for both seawater and brackish water desalination in the country.

3. Water demand and supply projections indicate that water shortage will become ever severe within the next 50 years in China. Especially in North China, although taking into account water to be transferred under the scheme, water deficiency is estimated to be 16 km^3/yr in 2050. This amount of water can be potentially provided by application of brackish-, waste- and seawater desalination. Particularly for coastal cities, desalination can provide water for industries that do not have a high requirement of water quality. Desalination is therefore suggested to be a strong potential for eliminating water shortages in the future.

4. To apply desalination in China, the water price is the major obstacle. Current average water price is still lower compared to the costs of desalination. In the country, water is not charged based on the principle of market economy, rather heavily subsided by the government. To eliminate water shortage in the future, water pricing will be an effective economic instrument to conserve water and raise awareness. Governmental policy should facilitate the pricing reforms and step by step fill the gaps between costs of desalted water and actual water prices. In conclusion, desalination can provide reliable water supply and will be ultimately economically feasible, therefore it is requested to invest in and undertake consistently research on selecting planting sites and brine disposal in the near future. However, one thing should be noticed is that the costs presented here are resulted from simplified models. Thus planning an actual plant under a specific circumstance needs to conduct the final assessment of costs accurately that are based on more substantive information and specific data.

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Appendix
Sample sheet of calculation of unit costs for RO desalting plants

Country	Total capacity (m^3/d)	Process	Water quality	Contract year	Investment costs ($m)	Amortized capital costs ($/$m^3$)	O&M costs ($/$m^3$)	Total cost ($/$m^3$)	Conversion rate	1995 unit cost ($/$m^3$)	Total installed capacity (m3/d)
USA US	1249	RO	BRACK	1996	1.25	0.257	0.385	0.642	1.03	0.623	6796731
USA US	927	RO	BRACK	1996	0.94	0.260	0.390	0.651	1.03	0.632	6796731
USA US	4360	RO	BRACK	1996	4.24	0.250	0.374	0.624	1.03	0.606	6796731
USA US	4600	RO	PURE	1996	2.95	0.165	0.247	0.411	1.03	0.399	6796731
USA US	872	RO	RIVER	1996	0.71	0.209	0.313	0.522	1.03	0.507	6796731
USA US	3840	RO	WASTE	1996	5.05	0.338	0.506	0.844	1.03	0.819	6796731
Virgin Isl. VI	1022	RO	SEA	1996	2.66	0.668	1.002	1.670	1.03	1.621	6796731
Antilles AN	17000	RO	SEA	1997	39.7	0.599	0.899	1.498	1.053	1.423	7560204
Australia AU	600	RO	BRACK	1997	0.62	0.265	0.398	0.663	1.053	0.630	7560204
Austria AT	5280	RO	BRACK	1997	4.64	0.226	0.338	0.564	1.053	0.535	7560204
Bahamas BS	600	RO	SEA	1997	1.59	0.680	1.020	1.700	1.053	1.615	7560204
Brazil BR	2400	RO	BRACK	1997	2.41	0.258	0.387	0.644	1.053	0.612	7560204
Canada CA	11000	RO	BRACK	1997	9.6	0.224	0.336	0.560	1.053	0.532	7560204
Cayman Isl. KY	1135	RO	SEA	1997	2.94	0.665	0.997	1.662	1.053	1.578	7560204
Cayman Isl. KY	1600	RO	SEA	1997	1.8	0.289	0.433	0.722	1.053	0.686	7560204
Chile CL	18000	RO	BRACK	1997	16.22	0.231	0.347	0.578	1.053	0.549	7560204
Chile CL	684	RO	SEA	1997	1.8	0.675	1.013	1.689	1.053	1.604	7560204
China CN	5700	RO	PURE	1997	4.11	0.185	0.278	0.463	1.053	0.439	7560204
China CN	5700	RO	PURE	1997	4.11	0.185	0.278	0.463	1.053	0.439	7560204
China CN	10950	RO	PURE	1997	7.9	0.185	0.278	0.463	1.053	0.440	7560204
China CN	15000	RO	RIVER	1997	10.64	0.182	0.273	0.455	1.053	0.432	7560204
China CN	1000	RO	RIVER	1997	0.81	0.208	0.312	0.520	1.053	0.494	7560204
China CN	3600	RO	BRACK	1997	3.62	0.258	0.387	0.645	1.053	0.613	7560204
Colombia CO	1600	RO	BRACK	1997	1.59	0.255	0.383	0.638	1.053	0.606	7560204
Cyprus CY	40000	RO	SEA	1997	91.21	0.585	0.878	1.463	1.053	1.389	7560204
Egypt EG	3600	RO	SEA	1997	9.31	0.664	0.996	1.659	1.053	1.576	7560204
Egypt EG	2500	RO	WASTE	1997	3.44	0.353	0.530	0.883	1.053	0.838	7560204
Egypt EG	4000	RO	WASTE	1997	5.23	0.336	0.503	0.839	1.053	0.797	7560204

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