CHAPTER 7

Water and Urbanization

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The geography, spatial characteristics, and pace of urbanization in China will be powerfully affected by the availability of potable water to urban residents and industry. This chapter examines the evolving water supply situation in China's urban sector; the degree to which water could constrain potential growth and urban development in parts of the country (Bao and Fang 2007); and the scope for enhancing the efficiency with which supplies are used and recycled.

The chapter is divided into six sections. The first section provides an overview of the growing scarcity of water in China. The second section describes patterns and trends of water supply. The third section describes the effect of pollution on water supply. The fourth section assesses the likely trajectory of water demand and its distribution across sectors. The fifth section draws some implications for investment. The final section provides some policy recommendations.

Low per Capita Availability of Water

China's total naturally available water flows (not stocks) from all surface and underground sources are estimated at about 2,812 billion cubic

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meters a year, placing China fifth in the world, behind Brazil, the Russian Federation, Canada, and Indonesia (FAO 2007). However, on a per capita basis, China's naturally available annual water flow of 2,114 cubic meters per person in 2003–07 is one of the lowest levels in the world for a populous country, next only to India's 1,150 cubic meters per person (FAO 2007). China's available water per person is one-third the world average (6,794 cubic meters per person), and one-quarter the average for the United States (9,446 cubic meters per person) (World Bank 2007). Thus, in a global context, China's per capita availability of water is exceedingly low, suggesting the potential for water stress as demand for usable water rises with growth in population and per capita income.

Despite the one-child policy introduced in 1979, China's population has been growing steadily, from almost 1 billion in 1980 to 1.19 billion in 1993 and 1.31 billion in 2005 (table 7.1). As a result, annual per capita water availability dropped by 25 percent between 1980 and 2005, from 2,840 to 2,147 cubic meters per person (table 7.2).

Regional Differences in Water Availability

China's low natural availability of water per person masks substantial regional disparities in water availability.[1] Demand for water is growing throughout the country, but total water availability in the north is about one-sixth that in the south (405 billion cubic meters versus 2,406 billion cubic meters (see table 7.2) and one-tenth the world average (Wang and Lall 2002). The 596 cubic meters per person in the north in 2005 qualifies the north as a whole as an area of water scarcity, a condition worse than one of water stress.[2] The north is a very large area and was home to 680 million people (more than the total population of Europe or Latin America) in 2005. Although it accounts for roughly 52 percent of China's population, it has just 14 percent of China's water resources (NBS 2006).

Water scarcity is most acute north of the Yangtze River, particularly in the catchments of the Huai, Hai, and Huang (Yellow) Rivers (the 3-H

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[1] Average annual rainfall is about nine times greater in the southeast (1,800 millimeters) than in the northwest (200 millimeters). More than 45 percent of China receives less than 400 millimeters of precipitation a year (Economy 2004).

[2] *Water scarcity* is defined as an annual supply of water less than 1,000 cubic meters per person. *Water stress* is defined as an annual supply of water of less than 2,000 cubic meters per person.

Table 7.1. Population of China, 1980–2005, by Region

	Population										
	1980		*1993*		*2002*		*2005*		*Annual growth rate (percent)*		
Region	*Billion*	*Percent*	*Billion*	*Percent*	*Billion*	*Percent*	*Billion*	*Percent*	*1980–93*	*1993–2005*	*1980–2005*
North[a]	0.52[b]	52.5	0.62	52.1	0.65	51.0	0.66	50.4	1.4[b]	0.5	1.0[c]
South[a]	0.48[b]	47.5	0.57	47.9	0.63	49.0	0.65	49.6	1.3[b]	0.1	1.2[c]
Urban	0.19	19.2	0.33	27.7	0.50	39.1	0.56	42.8	4.3	4.5	4.4
Rural	0.80	80.8	0.85	71.4	0.78	60.9	0.75	57.3	0.5	–0.01	–0.3
Total[c]	0.99	100.0	1.19	100.0	1.28	100.0	1.31	100.0	1.4	0.8	1.1

Source: NBS 1981, 1994, 2003, and 2006.

a. The north–south split is based on World Bank 2001a and IIASA 1993. North is defined as the Huai, Hai, and Huang River basin provinces (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Jiangsu, Anhui, Shandong, Henan, Shaanxi, Gansu, Qinghai, and Ningxia) and the three provinces in the northeast (Liaoning, Jilin, Heilongjiang). South is defined as the rest of China.

b. Figures are from NBS 1981 for 1981, and the population of south China does not include Hainan Province.

c. Excludes Hong Kong, Macao, and Taiwan.

Table 7.2. Gross Water Availability per Capita, in North and South, 1980–2005

	Gross water availability[a]		*Water availability per capita (cubic meters)*			
Item	*Billion cubic meters*	*Percent of total*[b]	*1980*	*1993*	*2002*	*2005*
Total	2,812	100	2,840	2,363	2,197	2,147
Surface	2,712	96 (76)				
Aquifer	829	29 (23)				
North	405	14	779	653	623	614
Surface	334	12 (10)				
Aquifer	169	6 (5)				
South	2,406	86	5,015	4,223	3,819	3,702
Surface	2,377	85 (67)				
Aquifer	678	24 (19)				

Source: IIASA 1993; table 7.1.

a. The sum of surface and aquifer water exceeds the total water resource by the amount of overlap between them.

b. The figures in parentheses are adjusted to account for the overlap.

rivers).[3] Since the 1980s, the magnitude and frequency of water shortages have been growing, generating severe economic losses.[4] Total water shortages in 2000 were calculated at 38.8 billion cubic meters; unless measures are taken to reduce demand and augment supplies, they are projected to reach 56.5 billion cubic meters by 2050. These shortages are estimated to cost the Chinese economy Y 5.0–Y8.7 billion a year (US$620 million–US$1.06 billion) (Economy 1997; Economy 2004).[5]

The problems in Beijing and the Hai River basin are well known but not unique. In the relatively dry regions in the north, northwest, and northeast, there are many large urban centers, including seven cities with populations of more than 2 million each and 81 cities with populations of 200,000–500,000 each. In many of the major cities, urban water use has increased, as mayors have embarked on beautification campaigns to

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[3] In the densely populated Hai River basin, for example, industrial output is growing rapidly, and the basin is intensively cultivated. However, water availability per capita is only 343 cubic meters a year. Residents in the Pearl River basin in the south have nine times more water available per capita.

[4] Agriculture is the most water-intensive activity, followed by food processing, paper, and textiles (Guan and Hubacek 2007). It takes 1,000 tons of water to produce 1 ton of grain. The water-scarce north exports agricultural products to other regions, using 7,340 million cubic meters of water, of which 4,284 million cubic meters is from surface water resources and the rest from rainfall. This amounts to a net export of 5 percent of water resources from the north to other regions of China. In contrast, Guangdong, relatively water-rich province, imports water-intensive goods (about 445 million cubic meters) and produces or exports electric components and various commercial and social services, which are not water intensive (Guan and Hubacek 2007).

[5] These numbers were calculated for all China as of 1997.

plant trees, shrubs, flowers, and grass along roadways and in municipal parks (USDA 2000), in part to attract new investments and skilled labor and in part to combat locally the effects of dust storms associated with the depletion of surface and aquifer water elsewhere. These large cities compete with agriculture for scarce water resources. The problems are emerging in an acute form in other metropolitan subregions experiencing very rapid growth, because the elasticity of water demand with respect to urban population growth is greater than one (Bao and Fang 2007). More than 400 of China's 600 cities are believed to be short of water, and about 100 face serious water shortage problems (Wang and Lall 2002).

To compensate for surface water scarcity, China uses a growing reliance on groundwater in the north and desalinated water in coastal areas.[6] Groundwater is being depleted at a faster rate than it is being replenished, leading to "mining" of aquifers. When aquifers are mined, they are not available as insurance in drought periods, compromising sustainable use of the resource for current as well as future generations. In 2006, 30 percent of arable land in Sichuan Province was expected to yield no output because of the drought ("Still Poor" 2006).[7] In some areas, the overuse of underground water is contributing to severe aridity and increasing migration away from fragile lands.

The extent of the mining of groundwater is severe. Sustainable groundwater flows in the Hai River basin have been estimated to be on the order of 17.3 billion cubic meters a year, while 1998 withdrawals were 26.1 billion cubic meters a year, indicating overextraction of as much as 8.8 billion cubic meters annually. As a result, groundwater

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[6] China is also investing heavily in desalination plants. The second-largest plant in the country, which can process more than 100,000 tons of water a day, will be built in Zhejiang, at a cost of Y 1.1 billion. Its production will enable it to supply industrial users and 500,000 people across the coastal Xiangshan county. More than 20 desalination plants process 120,000 cubic meters of seawater a day. By 2010 this will increase to 800,000–1 million cubic meters a day. The State Development and Reform Commission forecasts that desalinated water will account for 16–24 percent of water used in coastal areas in the future ("China Turns" 2007).

[7] Rainfall in Guangdong Province was down 40 percent in 2005 (MacBean 2007). The worst drought in 30 years hit Liaoning in 2007, drying up 88 small and medium-size reservoirs and leaving 1.2 million people short of drinking water ("Drought Leaves" 2007). Water scarcity and climate change could reduce China's agricultural output by 5–10 percent by 2030. However, China is still aiming to achieve the target of producing 95 percent of its grain consumption domestically ("China to Keep" 2007). In addition to water shortages, air pollution reduces agricultural productivity. Almost 70 percent of the crops planted in China cannot attain optimal yields, primarily because of the haze from pollution (MacBean 2007; Shalizi 2007).

tables have dropped by as much as 90 meters in the Hai plains (World Bank 2001a). The groundwater table in Beijing is estimated to have dropped 100–300 meters. Anecdotal evidence suggests that some deep wells around Beijing now have to reach 1,000 meters to tap usable quantities of water, dramatically increasing the cost of water supply and the risk of contamination from arsenic and other contaminants.

The removal of underground water domes has many adverse consequences. It has resulted in saltwater intrusion along coastal provinces in 72 locations, covering an area of 142 square kilometers, according to one estimate (World Bank 2001a). It is also leading to subsidence in coastal and noncoastal areas. The subsidence is up to several meters in cities such as Beijing, Shanghai, Shijiazhuang, Taiyuan, and Tianjin, causing damage to buildings and bridges and even leading to their collapse. Subsidence of land as water is extracted is also diminishing flood protection and exacerbating water logging in urban areas, because drainage is less effective (World Bank 2001a).[8]

Contribution of Pollution to Water Shortages

Many of China's water bodies are polluted, some heavily so. Surface and groundwater pollution now represent a major problem for both public health and the environment. Pollution-degraded water exacerbates the shortage of water resources downstream. It also makes it difficult to recycle water where it is scarce. As such, pollution represents a growing constraint on national development objectives in China.

In 2003, 38 percent of China's river waters were considered to be polluted, up from 33 percent a decade earlier. According to the 2003 annual report of the State Environmental Protection Administration (SEPA), more than 70 percent of the water in five of the seven major river systems—the Huai, Songhua, Hai, Yellow, and Liao—was grade IV or worse, meaning it could not be used for of any designated beneficial uses. In the Hai and Huai River systems, 80 percent of the water was unusable (EIA 2003; SEPA 2003). Even the majestic Yangtze River suffered a sharp decline in water quality, more than doubling the percentage of its water not suitable for human contact to 48.5 percent in 2002 (Economy 2004).

Half of all water pollution is caused by nonpoint sources in rural areas, including fertilizer runoff (which increases the flow of nitrogen

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[8] Such environmental damage can be reduced with better management of groundwater extraction. See the example in Zhengzhou (Gong, Li, and Hu 2000).

and phosphorous into water bodies [see Palmer 2001]), pesticides; and waste from intensive livestock production. These problems, especially in certain rural areas close to cities, can be expected to worsen in the near future. With growing urban demand, livestock production has increased its contribution to the gross value of agricultural output from 14 percent in 1970 to 31 percent in 1998. Horticultural production for urban centers is also rising steeply. These trends are expected to continue, as urbanization increases, disposable incomes rise, and food distribution systems in rural areas improve. Rural sources of pollution, such as livestock operations, rural industry, and towns and villages, remain essentially uncontrolled and unaccounted for by current government management programs (Wang 2004).

The remaining half of water pollution comes from industrial and municipal wastewater discharges and the leaching of pollutants from unlined solid waste sites into surface or below-ground water bodies (World Bank 2004). The rapid growth in urban populations and industrial activities is adding to the pollution of China's waterways from phosphorous, indicator bacteria, metals, and solvents. In the absence of sufficient water treatment plants, large volumes of raw sewage are dumped into local streambeds daily, and industrial water is often untreated. Only 56 percent of urban wastewater was treated in 2006. The target is to reach 70 percent for cities with populations of more than 500,000 ("Strong Growth" 2007). When upstream water is returned to the stream polluted, water quality downstream is degraded. In some cases, polluted water in the streams has seeped into the groundwater (USDA 2000). Government monitoring and enforcement programs are having only limited impact, because of selective application of the laws and low levels of fines at the provincial and central levels, combined with weak enforcement of rules at the local level, which diminish the deterrence value of regulations. Regulations are also incomplete insofar as load-based standards are absent and the standards that are set are not achievable given China's current technological capabilities. For these reasons, "more than 75 percent of the water in rivers flowing through China's urban areas is unsuitable for drinking or fishing. Only 6 of China's 27 largest cities' drinking water supply meet State standards . . . [and] many urban river sections and some large freshwater lakes are so polluted that they cannot even be used for irrigation" (Economy 2004; see also ABS Energy Research 2006).

In 2000 the major water pollutant—chemical oxygen demand (COD) discharge—was split almost evenly between industrial and municipal sources.[9] Industrial sources, mostly in urban areas, contributed about 7.40 million tons, while municipal sources, from commercial, residential, and public amenities, contributed about 7.05 million tons of COD. Municipal wastewater and COD discharge has been growing (at 3.1 percent a year in the 1990s) relative to industrial wastewater discharge; by 2000, municipal wastewater discharge (at 22.1 billion tons) was 14 percent (2.7 billion tons) more than industrial wastewater discharge (Wang 2004). The costs of benefits forgone by not treating wastewater were estimated at Y 4 billion in 2000 rising to Y 23 billion in 2050 in the Hai and Huai basins (World Bank 2001a).

Disaggregating the total industrial discharge into sectors shows that six sectors (pulp/paper, food, chemicals, textiles, tanning, and mining) account for 87 percent of total industrial COD load but only 27 percent of the value of gross industrial output. Toxic pollution loads (principally metals and solvents) are undocumented but estimated to be about 1.7 percent of total COD loads, representing a significant threat to public health and aquatic systems. High pollution loads in the water seriously affect the pollution of coastal zone waters, which do not meet coastal zone standards for marine aquatic life (Wang 2004).

Recent Trends in Water Demand

Water use in China is sometimes disaggregated into four categories. Two reflect production-related demand by farms and factories (agriculture and industry), and two reflect consumption-related demand by households (rural and urban) (table 7.3).

Production-Related Demand

Agriculture remains the largest user of water in China, accounting for about 64 percent of the total in 2005 (NBS 2006), even though annual water use for agriculture decreased by 3 percent between 1980 and 2005 (from 370 billion to 358 billion cubic meters), as industrial and urban needs preempted agricultural needs, and productivity (efficiency) of water use in agriculture increased.

Industry, which has sustained double-digit growth rates since the early 1980s, is the second-most important source of demand for water.

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[9] COD measures the oxygen needed to decompose organic matter. The United States uses the five-day biochemical oxygen demand criterion (the amount of oxygen required by bacteria to break down organic matter over five days). The modeling of water quality and the factors influencing the level of dissolved oxygen are described by Palmer (2001).

Table 7.3. Water Use, by Sector, 1980–2005

	Water use										*Annual growth rate (percent)*		
	1980		*1993*		*1997*		*2002*		*2005*				
Sector	*Volume (billion cubic meters)*	*Percent of total*	*Volume (billion cubic meters)*	*Percent of total*	*Volume (billion cubic meters)*	*Percent of total*	*Volume (billion cubic meters)*	*Percent of total*	*Volume (billion cubic meters)*	*Percent of total*	*1980–1997*	*1997–2005*	*1980–2005*
Production	416	94	471	91	504	91	488	89	487	87	1.1	–0.4	0.6
Agricultural	370	83	383	74	392	70	374	68	358	64	0.3	–1.1	–0.1
Industrial	46	10	89	17	112	20	114	21	129	23	5.4	1.8	4.2
Domestic	28	6	47	9.1	53	9	62	11	68	12	3.7	3.2	3.6
Urban	6.8	1.5	24	4.6	25	4.4	32	5.8	n.a.	n.a.	7.9	5.3[a]	7. 3[b]
Rural	21.3	4.8	23	4.4	28	5	30	5.4	n.a.	n.a.	1.6	1.4[a]	1.6[b]
Total	444	100	519	100	557	100	550	100	563	100	1.3	0.1	1.0

Source: IIASA 1999; NBS 2003, 2006.

n.a. Not available.

a. Figures are for 1997–2002.

b. Figures are for 1980–2002.

Between 1980 and 2005, water use in industry increased from 46 to 129 billion cubic meters, an increase of 280 percent. In 2005 industry accounted for 23 percent of total water consumption (NBS 2006).[10] Together, the production sectors—agricultural and industry—are responsible for 87 percent of water demand in China.

Some observers believe that water demand by industry may be decelerating, as industries are becoming more water efficient or shifting toward subsectors with lower water requirements (University of British Columbia 2004). The evidence for this, however, is still anecdotal. Even if a shift is occurring, as recently as the late 1990s, industry in China was consuming 4–10 times as much water as industry in more-industrial countries (Wang and Lall 2002). China uses six times more water per unit of GDP than the Republic of Korea and 10 times more than Japan ("Still Poor" 2006).

Consumption-Related Demand

Urban residential water demand was insignificant in 1980, at 1.5 percent of the total. By 2005, the number of residents in China's cities had more than doubled, from 191 million in 1980 to an estimated 562 million in 2005 (see tables 7.1 and 7.3), and their per capita income increased even more rapidly. As a result, between 1980 and 2002, urban residents' share of total water use quadrupled to almost 6 percent, with urban water consumption increasing from 7 billion to 32 billion cubic meters (see table 7.3). This increase reflects the rising standard of living in urban areas, which allowed urban residents to purchase washing machines and move into apartments with flush toilets and individual showers.[11] Urban areas experienced the largest increase in water use of any sector in the past two decades. The increase was accompanied by the rising discharge of black, yellow, and grey waters.

Per capita water use in cities varies greatly by region. Annual domestic demand in Beijing rose from 552 million cubic meters a year in 1993 to 829 million cubic meters in 2000. In contrast, in Tianjin, in the dry Hai River basin, residents still use only 135 liters of water a day—less than 40 percent of the 339 liters a day used by residents in the wet urban areas in the southern province of Guangdong (USDA 2000).

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[10] The growth of industrial water use in China is commensurate with its stage of development: water withdrawals for industry average 59 percent of total water use in high-income countries and just 8 percent of total water use in low-income countries (UNESCO 2003).

[11] Domestic household consumption per capita rose tenfold in the past five decades, to 240 liters a day per person in 2000 (University of British Columbia 2004).

Future Demand Projections

Agriculture remains the largest consumer of water in China, but growth in demand has been greatest in urban and industrial use. In 2005, China consumed about 563 billon cubic meters of water, of which 64 percent was used for agriculture, 23 percent for industry, and 12 percent for household purposes. Demand for water grew at an annual rate of 7.3 percent for urban households and 4.3 percent for factories between 1980 and 2002, with water demand by rural households and farms remaining almost unchanged.

In the absence of a detailed and calibrated China-wide simulation model, it is difficult to analyze the implications of different scenarios for water demand. However, some aspects of future water demand can be analyzed with the aid of a simple simulation model (Shalizi 2006). The model is used as a broad-brush illustrative exercise to understand the key drivers of water demand. It cannot be used to identify location-specific policy priorities or planning targets.

The key variables in the model are population forecasts and changes in (a) the urban–rural composition of the population; (b) per capita water demand by rural and urban households; and (c) the composition of production by primary (agriculture), secondary (manufacturing), and tertiary (services) activities. These variables can be used to project the sensitivity of the aggregate demand for water to different average GDP growth rates through 2050, assuming that water demand per yuan of output in the various subsectors does not change significantly. The projections provide a backdrop for comparing actions to aggressively increase the efficiency of water use in subsectors versus actions to aggressively increase water supplies, recognizing that the composition of the portfolio of feasable actions will vary by region, river basin, and even locality.

The projections use two scenarios for population in 2050. The first is the United Nations' medium-term projection, which assumes a growth rate of 0.2 percent a year, with the population peaking and then leveling off at 1.4 billion people by 2050. The second is the figure of 1.6 billion in 2050, which was used in the World Bank's water strategy for North China (World Bank 2001a) and implicitly assumes a 0.45 percent annual growth rate. The model assumes the same urban–rural split and GDP structure for 2050 used in the water strategy study of the World Bank. It also assumes that demand for water of rural and urban households will continue to grow at either a slow rate (similar to that during 1997–2002) or a fast rate (similar to that during 1980–97).

Using these very simple assumptions, the model projects that a doubling of the population growth rate from 0.2 to 0.45 percent a year has a negligible impact on water demand. The increase in the urban share of the population, however, is more significant, particularly if average demand for water by urban households continues to grow rapidly. These changes in demand—not excessive in their own right—will be more difficult to accommodate if there is not also a substantial deceleration, and possibly even a decline in water demand by agriculture and industry.

Even though the share of agriculture and industry in GDP is decreasing, if per unit water consumption patterns in the production sectors do not change significantly, water shortages will continue to grow, constraining the economy's ability to grow at an average rate of more than 5 percent a year over the next 50 years. Even a 4 percent annual growth rate through 2050 could generate the need to more than double water supply in many areas.

To put this required increase in water in perspective, aggregate water demand grew only 27 percent during the explosive growth period of 1980 to 2005, rising from 444 billion to 563 billion cubic meters. This increase put acute strain on supplies in the 3-H river basin. Key metropolitan regions began experiencing so much water shortage that they had to resort to diverting water from downstream rural users and estuaries and to pumping aquifers at a rate faster than replenishment, a strategy that is unsustainable.

Policy and Investment Implications

Generalizations and "one size fits all" recommendations are likely to be inappropriate in China, because of its size and complexity. But solutions tailored to location-specific problems are difficult to summarize and tedious to enumerate. Moreover, some of the information necessary to evaluate proposed solutions is not easily obtainable in public documents or consistent across sources (in part because information sources vary in their definitions and coverage and are rarely complete).[12]

Many of the problems cited in this chapter are well known to Chinese authorities, who have initiated a wide range of programs to cope with

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[12] Many instances of water scarcity are highly localized and are not reflected in national statistics. In addition, the accuracy and reliability of information vary greatly across subnational regions and categories of information, as does the year in which the information was gathered. As a result, establishing consistency between different variables within and across time periods is difficult. All data should therefore be considered as estimates.

them.[13] In addition to the comprehensive overview of China's water needs completed by the Ministry of Water Resources in 2002, the World Bank prepared a strategy document in 2002 that outlines key actions (World Bank 2002a). Neither of these documents provides a quantitative assessment of how much of the various problems will be resolved by the actions proposed, and neither fully costs or sequences the actions. The documents nevertheless provide an excellent array of actions to be implemented.

China has been very successful in investing in physical infrastructure to control flooding, restore forested watersheds, and improve water supply and wastewater treatment. It has been far less successful in managing demand through better pricing and conservation policies, or in achieving better institutional coordination of integrated water management programs at different jurisdictional levels, although there have been some successes that have not yet been generalized (as in the Tarim River basin [World Bank 2004]). Where water is not being used efficiently, expanding water supply at increasing marginal costs will only increase the drain on public resources. Such a strategy is also not sustainable.

Expanding the role of markets and market price signals as a feedback mechanism in allocating water would go a long way toward helping conserve the resource and allocate it to the highest economic use; doing so would also send signals on priority investment requirements. Expanding the role of water markets and prices is a corollary of expanding the role of markets in the production of private goods and services (Yaozhou 2000). However, the expansion of water markets and prices presupposes progress in establishing the institutional framework for water rights/entitlements, valuation, and appropriate measurement, efforts that are still incomplete.[14]

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[13] The *Water Resources Report* (MWR 2003) summarizes the implementation status of these programs.

[14] Tradable water rights are one potentially important route to improving institutions for the allocation and use of water. This calls for designing and implementing mechanisms that will facilitate the functioning of a system of tradable water rights. As noted in a recent World Bank report (2004: 3–4). "Such a system would make a major contribution to increasing the value of production per unit of water consumed in irrigated agriculture areas and to the reallocation of water from agriculture to priority uses. A significant amount of informal water trading already goes on in China. Chinese water law includes provisions for the issuing of water licenses, but the issuing and enforcing of water licenses in irrigation areas is not widespread. At each point of water measurement, a corresponding water right should be issued that includes a flow rate, a total volume of allowable annual delivery per extraction, and a total volume of allowable annual consumptive use. The sum of all of the consumptive use rights for a river basin or aquifer should not exceed the allowable total consumptive use in the basin or aquifer in order to have sustainable water resources use and management. Once the

Imposing taxes and subsidies, as well as educating farmers, firm managers, and households in water conservation options, will be required to augment the role of water pricing where market prices provides insufficient information and incentives for the correct allocation of water.

Demand-management strategies, including conservation measures, are essential not just to reduce water wastage but also to reduce the need for costly interbasin water transfers. With some important exceptions, encouraging urbanization (and new infrastructure development) in areas that are not currently water scarce or likely to become water scarce may be an efficient long-term strategy. There was a dramatic demographic shift from rural to urban areas between 1980 and 2005. Net-rural-to urban migration was about 310 million people in the 25-year period 1980 and 2005. As a result the urban share of the national population increased from 19 to 43 percent (see table 7.1).[15] This shift was associated with a quadrupling of the urban share in total water demand. However, during this 25-year period, there was a negligible net demographic shift from north to south of approximately 20 million migrants.[16] As a result, the relative shares of the two zones remained almost constant, at 52 percent for the north and 48 percent for the south, despite growing water scarcity in the north.[17] This anomaly requires further analysis, but lack of adequate price signals on the real economic costs of water could be one factor.

Allowing or encouraging continued urbanization also requires that the collateral damage associated with expanding urban water demand be

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consumptive use water rights issued equal the allowable total consumptive use rights in a basin, no further water rights should be issued. No water diversion or well drilling and pumping should be permitted without a corresponding water right. Once a complete system of water rights per measurement is operational, then a system of tradable water rights could begin to function. To ensure maintaining a water balance and no negative impacts on third parties, the consumptive use right is the right that should be traded. All water rights trades should be registered and approved by the government authorities ensuring no effect on third parties. Without a complete system of consumptive use water rights and measurement, tradable water rights will not be able to aid in the reallocation of water within a sustainable water resources management system; therefore, trading in water rights should be restricted."

[15] If the urban share of the national population had been the same in 2005 as it was in 1980, the urban population would have been 310 million less than it was.

[16] If the northern share of China's population had been the same in 2005 as it was in 1980, the population in the north would have been 22 million less than it was.

[17] One caveat is the possibility that official data underestimate the extent of migration of the population from the north to the south. This problem is analogous to the difficulty of measuring the population in urban areas, which include unregistered (non–hukou) migrants, as noted in chapter 3.

reduced. Using fresh water would be less consequential if water abstracted upstream could be returned to river flows in good condition to be used again downstream. This can be done only if water polluted through urban and industrial use is treated appropriately first, which will require significant new investments. For example, despite its 1,179 operational industrial wastewater primary treatment plants, which have the capacity to treat 1.13 billion cubic meters of industrial wastewater, Chongqing, a center for heavy industry, treats only about 57 percent of its industrial wastewater and 54 percent of its household wastewater (Okadera, Watanabe, and Xu 2006). Because Chongqing is situated upstream of the Changjiang River, the polluted water flows through the Three Gorges Dam to urban and rural areas downstream. An additional US$122 million of investment is required to fully treat the water in Chongqing (Okadera, Watanabe, and Xu 2006).

Overall, about half of China's urban wastewater is treated. Even in Beijing, only 50 percent of wastewater is treated, despite the increase in wastewater treatment capacity from 50 million tons in 1990 to 517 million tons in 2003; the goal is to treat 70 percent by 2010 (Yang and Abbaspour 2007). Some 278 cities have no treatment facilities ("Drip, Drip, Drip" 2006). Thus, in addition to higher water prices in urban areas, charges for wastewater discharges and other pollutants must rise. Better monitoring, information disclosure, and enforcement of appropriate standards are also needed.

Pollution from urban municipal sources could be managed by the use of updated municipal sewerage systems, including collecting sewers and treatment plants designed to receive industrial wastewater. This combined use would yield large savings, both to the municipality and to industries, because of economies of scale in removing degradable organics (with the provision that participating industries would first remove toxic and other harmful substances using in-plant treatment before discharging into the municipal system). To the extent practicable, the treated municipal effluent would be reused as water supply for irrigation and industry. Municipal systems would also include provisions for effective use of on-site excreta disposal units for homes and buildings not connected to municipal sewers (the same provision would apply to rural homes), so that these wastes are not left unmanaged and subject to being flushed into waterways by surface runoff.

Public disclosure of information on water quality and community consultation could improve feedback and facilitate better monitoring. Research by Jiangsu Province, SEPA, and the World Bank on pilot versions of community consultation and feedback processes, as well as public disclosure of information (Wang and others 2004), have determined that they are effective and have the potential to be scaled up (Lu and others 2003; Jiangsu Environmental Protection Bureau 2007).

Reducing the Cost of Wastewater Treatment and Improving Its Monitoring

Increasing wastewater charges (specially the rate by which charges increase) will be easier if there is better monitoring and information disclosure and if more wastewater is treated for reuse. Increasing the amount of wastewater treated for reuse requires that increases in wastewater charges be complemented by declines in the cost of investment in wastewater treatment plants.[18]

More than 1,000 wastewater plants were built between 2000 and 2006 ("Strong Growth" 2007), but the utilization rate is only 60 percent. About 50 plants in 30 cities are operating at below 30 percent capacity, and some are left idle, mainly because of inadequate wastewater collection facilities ("Strong Growth" 2007; Yang and Abbaspour 2007) and because revenues collected from customers are transferred to the general city budget and not used to ensure that treatment plants have the resources needed to operate.[19]

Operational efficiency is also low, mainly because plants carry out only primary treatment. Even in Shanghai the efficiency is only 10–30 percent (Okadera, Watanabe, and Xu 2006). Moreover, investment coordination across metropolitan regions is inadequate. There are economies of scale and optimal sizes for wastewater treatment plants. Despite this approach, many small, adjacent municipalities respond to national directives by implementing their own suboptimal wastewater treatment plants, increasing the overall national costs of wastewater treatment.

Widening the options for wastewater investment decisions can help contain costs. As noted in the *World Development Report 2003* (World Bank 2002b), New York City found it cheaper to repurchase land along part of its watershed that had been sold for development than to build

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[18] At the current low rate for wastewater collection, private sector participation is difficult to imagine. Until these rates are increased, the public sector will have to shoulder the needed investment costs associated with increasing wastewater treatment capacity to reduce water pollution in urban areas. One estimate puts the figure as US$30 billion between 2006 and 2010 (Zhong, Wang, and Chen 2006).

[19] This information is based on informal communications with the author of an ongoing "City Development Strategy" in 11 cities in China.

an expensive water treatment plant. Doing so was possible because the topography provided for a natural filtration process that was very effective. This option will not be an appropriate in all cases, but it may be in some cases. More important, widening the array of options to be reviewed and evaluated, when undertaking cost-benefit or feasibility studies, may help identify new cost-effective solutions. Restricting land development and restoring local watershed filtration capacities may reduce the amount of water requiring treatment, thereby reducing the cost of wastewater treatment in China.

Augmenting the Water Supply

Demand-management policies through market prices or new institutional arrangements may not be sufficient to deal with the full range of environmental water problems facing China. It is easier to introduce water charges when scarcity has emerged but critical thresholds have not yet been crossed. It is more difficult to introduce water pricing and wastewater charges when implicit rights to subsidized or free water resources have been acquired and critical thresholds crossed.

Two such thresholds are important in China. The first is the lack of adequate water in rivers to ensure year-round flows to flush the rivers, transport silt to the delta, and avoid ecosystem damage downstream, all of which are already occurring. The second is the need to restore some, if not all, of the groundwater that has been overpumped in the recent past. In both cases, more water flow has to be restored to the ecosystem and aquifers.[20]

It may be possible to restore water flows to natural systems by setting the price so high that existing users voluntarily renounce some of their water claims. But in the absence of water markets and well-defined water rights, it may not be possible to fully restore the minimum requisite water abstracted from rivers that now run dry. More important, ecosystem needs are public goods and by definition difficult to include in water markets (when flows in rivers are low, for example, water for environmental

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[20] In the case of aquifers, one study (Gunaratnam 2004) provides a clear set of actions to be implemented: "The key actions required by the action plan are (a) definition of groundwater management units with determination of sustainable yields; (b) preparation of groundwater management plans; (c) allocation of licensing linked to sustainable yield and undertaken by one department only; (d) licensing of well construction drillers; (e) development of a national groundwater database; and (f) preparation and implementation of a groundwater pollution control strategy, including provision in selected cities for recharging of groundwater by spreading of treated wastewater effluents or of floodwaters on permeable spreading areas, and for the injection of treated effluents to establish groundwater mounds to prevent salinity intrusion into freshwater aquifers."

needs must come from a reduction in irrigation). Ensuring that public goods, such as ecosystem water requirements, are handled appropriately will require institutional reforms, as noted earlier.

Investment in catchment reservoirs and watershed management in catchment basins through reforestation, to stabilize damaging unevenness in water flows over time, are other examples of supply-oriented interventions that need to complement demand-management policies, particularly where externalities and public goods are involved. For the future, some augmenting of existing supplies—through interbasin transfers and the reuse of wastewater, for example—will be required.[21] One such interbasin transfer is the South-to-North Water Transfer Project.[22] This scheme entails transferring 19 billion cubic meters a year initially and eventually up to 45 billion cubic meters of water a year from the Yangtze River, at a cost of US$60 billion. The crucial component of the project, including that which supplies Beijing, was completed in July 2006; the entire project will not be completed until 2050 ("China: A Five-Year Outlook" 2004; "Still Poor" 2006; Wu 2006).[23] Depreciating these costs and adding operating costs will likely require prices well in excess of those currently prevailing of less than one yuan per cubic meter. (World Bank 2001b) However, even with the south–north transfer, water use in irrigated agriculture in the 3–H basins will need to be reduced by 20–28 billion cubic meters from current levels by 2020.

Gunaratnam (2004) points out that in industrial countries, treated municipal wastewater represents a very valuable source of supplemental water for the industrial raw water supply and for irrigation of farming and urban green zones. The use of treated municipal wastewater for urban green zones may even be the preferred use, because of the lower quality requirements and relatively low infrastructure costs (Yang and Abbaspour 2007).[24] Hence, future plans for meeting urban needs should incorporate provisions for municipal sewerage systems to facilitate reuse. Using the price of fresh water in 2003 as an opportunity cost, the net economic benefit of reusing wastewater in Beijing is Y 134–Y 298 billion a year

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[21] Interest in reusing water is not new. See the case study of water reuse project in Changzi city by Peng, Stevens, and Yiang (1995).

[22] The concept of south–north water transfer was first aired by Mao Zedong, in 1952. Three channels (western, middle, and eastern routes) with a total length of 1,300 kilometers will link four major rivers of China: the Yangtze, Yellow, Huaihe, and Haihe ("China: Moving Water" 2003). See Gao and others (2006) and Wu and others (2006) for details on the western and middle routes of the South-to-North Transfer Project.

[23] Initially, the capital costs of the south–north transfer of 18 billion cubic meters was estimated to be Y 245 billion (World Bank 2001b).

[24] Wastewater can also be used to replenish the groundwater (Yang and Abbaspour 2007).

(19–43 percent of Beijing's GDP in 2005). Beijing now requires new residential buildings with construction areas larger than 30,000 square meters to have on-site wastewater reuse facilities (Yang and Abbaspour 2007).[25] Such planned reuse would have to be subject to regulatory control through permits to ensure that public health needs are protected.

Conclusions

China's rapid urbanization increases the urgency of decisively tackling the growing scarcity of water, a constraint that can only tighten as the climate warms and glaciers feeding the major river systems and aquifers disappear in the coming decades. Urban development and the geography of urbanization will need to be coordinated with policies aimed at managing demand in urban as well as rural sectors and by measures to augment or recycle the usable supply of water.

Despite growing water scarcity in the north, there has been no noticeable demographic shift from north to south. This anomaly requires further analysis; lack of adequate price signals on the real economic costs of water could be one factor. With some important exceptions, encouraging urbanization (and new infrastructure development) in areas that are not currently water scarce, or likely to become water scarce, may be an efficient long-term strategy.[26]

Among the actions discussed in this chapter, four stand out as most significant from the perspective of urban development:

- Allocate water for public uses (such as estimated ecosystem water needs) first, before allocating it to private uses (industry, residential, and agriculture as residual claimants), through either markets or administrative arrangements.[27] In either case, water use must be regulated to protect public health and the environment.
- Shift from administrative to price-based allocation of water, initially through better technocratic analysis, eventually complemented through water markets based on the fair and transparent allocation of property rights in water. Water markets cannot totally replace administrative

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[25] Onsite treatment is often economically unviable; treatment should be centralized (Yang and Abbaspour 2007).

[26] This is a broader strategy than the informally discussed possibility of moving China's capital out of Beijing to a less water-stressed area.

[27] The South African Water Act of 1997 considers its water resources as a public good, a resource for all under state control and licensed (http: www.thewaterpage.com/SolanesDublin.html). China's water laws have been revised recently to address some of the public goods issues raised above (Xiangyang 2004).

(quota) allocations of water, for reasons that are well known and implicit in the previous recommendation regarding public/private use of water. The balance between the two allocation mechanisms (administrative versus market) will be determined politically, though good technocratic analysis can inform the political debate.

- Improve the institutions involved in water management, not only at the metropolitan level but also at the river-basin level, including through better coordination of water use through invigorated river basin/watershed management commissions, and greater involvement of communities in joint monitoring and enforcement through public disclosure schemes.
- Increase urban water recycling through more reliable and cost-effective wastewater and sewerage treatment, and more appropriate sewerage and wastewater charges.

The greatest challenge is for national and local/urban governments to craft policies and rules within China's complex cultural and legal administrative system that provide incentives for users to increase efficiency of water use and for polluters to clean up the water they use and return clean water to stream flows. Using a standard public economics framework, water requirements for public goods, such as ecosystem needs, should be set aside first, before allocating property rights in water (to enable water markets to function and generate efficient allocation signals). Even then, water markets will have to be regulated to ensure that public goods, such as public health, are not compromised. Until water markets are implemented, staying the course on increasing the water and sewerage or the wastewater prices administratively and encouraging water conservation is necessary to reduce the wasting of currently scarce water resources as well as the new water supplies to be provided in the future. Investments in supplying water for rapidly growing urban areas and treating urban sewerage and wastewater will be more effective when combined with more-vigorous demand-management policies and institutional reform.

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