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A Scenario Analysis

Klaus Hubacek and Laixiang Sun

Keywords

input-output analysis (IO)
lifestyle changes
ecological-economic modeling
natural resources
regional disparity
development strategy

Summary

China's development over the last few decades has been characterized by high rates of economic growth, large-scale migration from rural areas to the fast-growing cities accompanied by changes in lifestyles, and steady population growth. These developments have left deep marks on resource availability and quality. In this article we conduct a scenario analysis of how lifestyle changes and other major developments might affect water resources.

China has the longest tradition in river and water resource management in the world. Its civilization has sought to control the effects of floods and drought for thousands of years and has utilized water flows for irrigation and navigation. In the last century, competing uses such as domestic, municipal, and industrial water consumption have also become reasons for the regulation of and large-scale abstraction of water.

To investigate the major changes in economy and society and their effects on the water situation in China, a set of scenarios is developed and analyzed within a structural economics framework. A hydrological model that represents water flows in the major watersheds is linked to a regional input-output model that represents socioeconomic activities in the major economic-administrative regions of China. The regional analysis shows that the North and Northwest regions are water-scarce and that lifestyle changes and technical shifts are the most important factors driving future water consumption.

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Major Challenges in Water Management

Chinese society has confronted the challenge of complex river and water resource management for thousands of years. In recent decades, China's impressive economic and social development has placed an additional heavy burden on the water sector. Increasingly, China faces severe water problems. During the 1990s, an average of 26.6 million hectares of land experienced drought each year. The water shortage was 30 billion cubic meters (m^3) in irrigation areas[1] and 6 billion m^3 in the cities. China is a relatively water-scarce nation with per capita water resource availability only about one quarter of the world average. This scarcity problem is further worsened by uneven spatial distribution of water resources with surpluses and deficits. Generally speaking, the South is rich in water, whereas the North is short in supply. Furthermore, water resources are subject to seasonal variations and interannual disparities with frequent flood and drought disasters. Human settlement patterns adapt to water availability and thus—in the case of China—to these greatly varying precipitation levels. As a consequence, more people in China are affected by flooding than by droughts (The conservation and protection of water resource 2000; Heilig et al. 2000; Ministry of Water Resources 1992).

Agriculture has been the largest sector of water use in China, consuming almost 80% of the total in the 1990s. But the increase in agricultural water consumption over recent years has been low. The Nanjing Institute of Hydrology and Water Resources estimated that between 1980 and 1993 the cumulative increase in agricultural water consumption was about 3.6%. The amount of water used for irrigation even declined by over 4%. In contrast, water use in industry increased by 94% and the urban water supply grew by 256% (Heilig 1999; United Nations 1997).

This increase in water use is compounded by a decrease in water quality. Water is contaminated by untreated residential and industrial waste, leakages from outdated waste-treatment systems, and due to increasing uses of agricultural fertilizers and pesticides. About 80% of the wastewater is untreated. The concentrations of water pollutants are among the highest in the world, causing damage to human health and loss of agricultural productivity (Asian Development Bank and Chinese Ministry of Water Resources 1999). Studies show that one-third of the rivers in the country and over 90% of the rivers flowing through cities are polluted. Some major lakes are in various phases of eutrophication,[2] and coastal areas are hit by seawater intrusion. The water sources of more than 50% of China's major towns are not suitable for drinking. In southern cities, pollution causes 60 to 70% of the total water shortage (China's Agenda 21 no date; Ministry of Water Resources 1998).

In addition, global climatic changes may have a lasting impact on China's water resources, as has been suggested by a high frequency of droughts and floods all over the country. The rising sea level leads to increased seawater intrusion in coastal areas and has ecological and economic effects on low-lying or coastal areas (China's Agenda 21 no date). Based on the results of the majority of Global Circulation Modeling (GCM) scenarios, climate variability is expected to increase, which implies an increasing frequency of extreme events (Fischer and Wiberg 2001).

Ongoing inefficiency of water use reflects not only the backwardness of production technology in China, but also the inadequacy of water management and its institutional arrangements. For industrial production, China is using some 10-20 times more water than advanced nations to produce the same amount of value added. The situation in agriculture is similar: about 60% of irrigation water is lost by canal seepage at different levels. Inefficient irrigation causes water loss, raises the water table and with it the ineffective evaporation of the ground water, and leads to soil salinization and waterlogging, both of which can lead to decreases in agricultural productivity. In terms of institutional arrangements, adequate pricing mechanisms have been lacking and political and institutional friction across various administrative levels is frequent. As reported by the World Bank (2001), the fragmented nature of the mandates of the ministries and the uncertain relations between provincial governments and the central government do not permit a coherent integrated approach to solving urgent and complex problems of water management.

Flood damage, polluted rivers, droughts, soil degradation, and rivers and estuaries with high levels of sedimentation not only might bring about considerable long-term environmental effects but also might have disastrous implications for the social and economic fabric of the nation, with severe ripple effects beyond its boundaries. Water shortages have an especially profound effect on irrigation in North China, on industrial use of the water supply for the energy base in Shanxi, and on mid-South Lianning and the Shandong Peninsula (World Bank 2001).

These challenges have attracted considerable public attention and research interest. Research and policy discussions have focused on how to increase (nonconventional) sources of water supply, such as water-loss reduction, reuse or recycling of water, interbasin transfers, and desalination of seawater and groundwater, rather than on the politically difficult decision of reallocating agricultural water use to sectors with higher value added. Allocating water among many conflicting potential uses presents governmental agencies with a major dilemma. Government must achieve a consensus on policy among the multiple sectoral interests by introducing appropriate incentives and institutional arrangements. The prospect of water scarcity and increasing environmental, social, economic, and financial pressures calls for coordinated decision making, beyond optimization of water resources in sectoral isolation and through fragmented institutional control (Bouhia 2001). Water must be considered as an integral part of a larger system in terms of its functions in the context of interactions between the various economic sectors, residential water use, the environment, public health, and other national priorities. Thus lifestyle changes cannot be discussed and modeled in isolation.

In recognition of the desire for a more integrated quantitative analysis, we develop a set of economic and social development scenarios based on a structural economics framework. We establish a link between a hydrological model that represents water flows in the major watershed and a regional input-output model that represents socioeconomic activities in the major economic-administrative regions of China. Then we compare the resultant water demand in the year 2025 with the available regional water supply.

Input-Output Modeling and Sectoral Water Consumption

Economic Models and Water Resources

A number of economic models have been developed to model the interaction between economic sectors and water resources. Since input-output (IO) modeling has the most prominent tradition within economic water models we focus our attention mainly on IO models but will also report on other modeling efforts as they relate to China.

Application of IO techniques to the study of resource and environmental issues began in the late 1960s and early 1970s (Cumberland 1966; Leontief 1970). Early comprehensive ecology-economy models tried to depict a comprehensive set of interactions, including water flows, between the two systems (see for example Daly 1968; Isard 1972). Later models were less ambitious and added water to a standard regional or national IO table. For example, Carter and Ireri (1970) developed an interregional IO model extended by water-use coefficients to calculate water embodied in product flows between California and Arizona. Duchin and colleagues used water-use coefficients for Indonesia (1993) and on a global level (Duchin and Lange 1994). Lange (1997), in her work on Namibia, shows how natural resource accounts (NRAs) comprising six categories of water supply and its uses can be used for economic analysis. Lange (1998), in her study on Indonesia, shows how NRAs together with input-output modeling can be used to evaluate different policies such as food self-sufficiency, given changes in the economy and society and given a certain resource endowment. Bouhia (2001) developed a hydro-economic model by combining a water resource-allocation model, based on a linear programming model, with a static IO model. Water is represented in monetary and physical terms balanced in material balance accounts. Bouhia developed a set of water multipliers allowing her to assess the effects of different development scenarios of water demand. A couple of authors also focused on water quality, or the emissions side. For example, Thoss (1983) developed a generalized IO model for residuals management, which was applied to water pollution in the Ruhr (Thoss and Wiik

1974). A macroeconomic model accounting for water pollution at a national level, in Norway, was developed by Førsund and Strøm (1985).

A number of modeling efforts have also been carried out specifically for China. Xie and colleagues (1991) applied IO modeling to the Beijing urban water systems. Chen (1990, 1992) proposed an input-occupancy-output model and used the model for agriculture and energy in China. The occupancy section of their table represents stock indicators for natural resources, labor force, fixed assets, and circulating funds. Chen (2000) also constructed a water resource input-occupancy-output model and studied the economic value of water for Shanxi province. The IO table was enlarged to include a set of water input coefficients and wastewater emission coefficients.

A few studies also looked at the long-term effects of economic and social trends on water use in China. Yang and Zehnder (2001, p. 86) based their water demand projections for 2010 and 2020 on extrapolations of trends between 1980 and 1998. The effect of urbanization is not included. Irrigated areas are assumed to remain the same as in the 1998 figure. Water uses for environmental purposes (such as in-stream water flow, water for pollutant dilution, salt leaching, silt flush, and wildlife) are not taken into consideration.

None of the studies discussed here satisfactorily solves the problem of modeling the water situation on a national level without using average coefficients and therefore disguising important regional differences. The present article is one of the very first papers that address long-range water questions on the national as well as the regional level. The combination of regional IO tables and very detailed biophysical information in a geographic information system allows us to especially address regional disparities of water availability and needs, based on changing demographic, economic, and lifestyle conditions.

The core of our structural economics approach is an input-output model, expanded by water-use coefficients and oriented to a static comparison across a base year case and pathways of future scenarios. The basic purpose of an input-output model is to predict levels of output, value added, and employment, given a certain increase in final demand (representing various socioeconomic scenarios). The integration of regional input-output (IO) tables, very detailed biophysical information in a geographic information system (GIS), and consumption data for rural and urban populations allows us to address the regional disparities of water availability and the needs generated by the dynamics of demographic, economic, and lifestyle factors.

Specification of the Input-Output Model

To combine value and physical data within a consistent methodological framework, we extend the IO tables by a set of natural-resource parameters that represent consumption patterns of water for each economic sector.

The enlarged IO table (see table 1) provides an accounting scheme for economic activities

Table 1 A schematic presentation of an extended input-output table[a]

	Grain, other crops, livestock, etc.	Rural, urban, etc.	Total output	Water
Grain, other crops, livestock, etc.	Interindustrial flows (z_{ij})	Final deliveries (u_{is})	Goods and services deliveries (X_j)	Depreciation and degradation (d_{ir})
Capital, labor, etc.	Factor inputs (value added) (v_{kj})			
Total input	Goods, services, and factor inputs (X_i)			
Water[b]	Natural resource inputs (L_{rj})	Natural resource uses (L_{rs})		

Source: Modified, based on Fischer and Sun (Fischer and Sun 2001).
[a] The inner parts of this table are in monetary units and the outer parts in physical units (cubic meters).
[b] Due to a lack of data we did not include any information about different types of water quality.

(z_{ij}, and v_{kj}), household and other categories of final consumption (u_{is}), environmental inputs (L_{rj} and L_{rs}), and effects on the environment (d_{ir}). The inner parts of table 1 are in monetary units and the outer parts are in physical units (in cubic meters).

As a next step we transform the (z_{ij}) matrix to a coefficient matrix (A-matrix). To achieve this we divide the input flows to the jth economic sector, z_{ij}, by the total input to the sector, X_i. The coefficient matrix gives an empirical measurement of the relationships among the various sectors of the economy. Similarly, to get input coefficients of natural resources, we divide the natural resource inputs to the jth economic sector L_{rj} by the total input to the sector X_j. These coefficients represent the direct or first-round effects of the sectoral interaction in the economy. The matrix $(I - A)^{-1}$ gives the so-called Leontief multiplier matrix. The multiplier accounts for the total cumulative effect on sectoral output and resource consumption of the intersectoral production chain actions initiated by the changes in final demand.

Changes in final demand drive water consumption in an input-output framework via direct and indirect water consumption by economic sectors and via direct water consumption by households.

Representation of the Economy and Its Water Use at the National and Regional Levels

In our analysis we use the regional and national input-output tables for 1992, which were compiled by the State Statistical Bureau of China (State Statistical Bureau of China 1996, 1997). The national table includes 118 sectors; 6 of these are in agriculture, 84 in industry, 1 in construction, 6 in transport and communication, and 21 in service sectors. The regional tables exist only in a more aggregate form, distinguishing only one agricultural sector. The "value-added" categories at both the national and regional levels include the following: capital depreciation, labor compensation, taxes, and profits. "Final use" at the national level comprises six categories: peasant, nonpeasant, and government consumption, fixed investment, inventory changes, and net exports. The regional table gives only three final-use categories: total consumption, total investment, and net exports.

For the purpose of analyzing water consumption at the regional level, we disaggregate the aggregate agricultural sector into six subsectors, divide total consumption into peasant, nonpeasant, and government consumption, and separate fixed investment from changes in inventory. We further assume that peasant consumption is similar to rural consumption and that nonpeasant consumption resembles the consumption pattern of urban populations. Unfortunately, the State Statistical Bureau classification system for urban, rural, and city populations contains obvious inconsistencies, because the system mixes territorial and functional definitions.

As mentioned earlier, in 1992 about 78% of the total water use in China, or 406 billion m^3 of water, was used in the agricultural sector—mainly for production of grain and other crops. Other important water-use sectors include energy, with a consumption level of about 51 billion cubic meters (10%), and manufacturing, with a level of 41 billion cubic meters (8%) (United Nations 1997). In our IO model we distinguish energy and fertilizer production sectors from other industries. We also distinguish the transportation sector from services (United Nations 1997). No statistical data on water use are available at the required sectoral level of this study. We use the disaggregation of government statistics provided by Strzepek and colleagues (1998). These accounting exercises give sectoral water requirements at base-year efficiency level for the base year 1992.

Our final demand categories include consumption by rural and urban households and government, investment, inventory changes, and net exports. Value-added categories include capital and labor compensation, taxes, and profits.

In our IO model, China is divided into eight regions based on geographic, agroclimatic, and demographic characteristics and economic development levels. This regionalization is consolidated with provincial-level administrative boundaries for the sake of data availability and consistency.

A basic problem in modeling water use within an economic framework arises from the discrepancy between economic regions and watershed

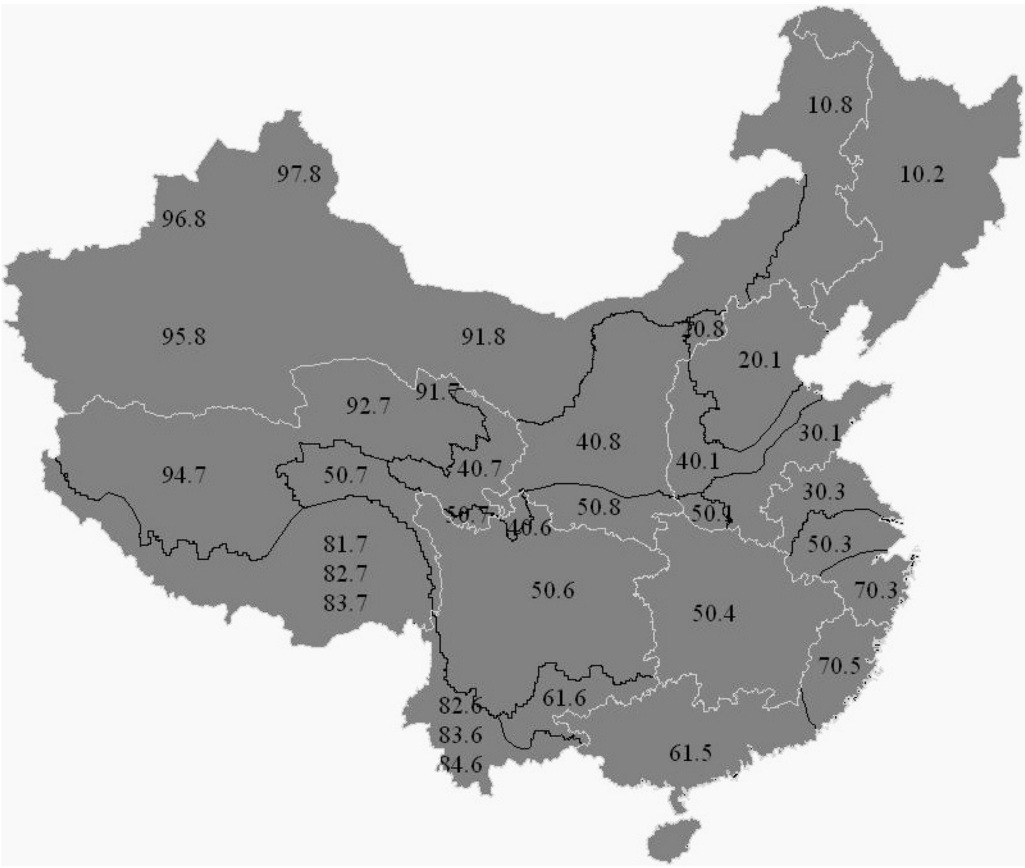

Figure 1 Hydroeconomic regions in China. The overlay of the economic and watershed (hydrologic) regions results in hydroeconomic regions. Water not used in one hydroeconomic region flows downstream to the next, which could bring it to a different economic region. The first number in the hydroeconomic region code represents the hydrologic region and the last number represents the economic region. The white lines indicate boundaries in economic regions and the black lines indicate boundaries in hydrologic regions. *Source:* CHINAGRO Project, LUC Group, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

regions. Demand figures for water use are based on economic boundaries as derived from the input-output framework. Water supply figures, however, must be based on hydrological conditions. In order to assign water supply quantities to our economic regions, we use the hydrologic model *Climate and Human Activities—Sensitive Runoff Model* (CHARM) developed by Wiberg and Strzepek (Wiberg 2002b; Wiberg and Strzepek 2000). The model is applied to the nine major water resource regions of China in order to estimate the available natural water supply in each of the economic regions. CHARM has been developed to use climate databases to produce daily runoff amounts calibrated to the annual averages. CHARM models surface runoff, evapotranspiration, and subsurface runoff for individual cells. The output of this grid-cell level approach can then be aggregated to form our economic units.

CHARM first calculates direct surface runoff, dependent on different land-cover types. Evapotranspiration and subsurface runoff remove water from the soil. After saturation of the soil, any additional water runs off over the surface. Changing land use and cover can be accounted for by changing the volume of water that runs off as direct surface runoff. Water not used in one hydroeconomic region flows naturally downstream to the next region. Figure 1 shows the hydroeconomic regions designed to fit our regional input-output tables.

Regional differences do exist in water consumption by households and industrial and service sectors. These are due to the adaptation of households or companies to the availability of water resources, and therefore the development of technologies or the formation of habits in dealing with an abundant or scarce resource. These regional differences in the base year 1992 are captured by regional specific residential water requirement coefficients and sectoral water requirement (and productivity) coefficients.

Structural Change in Production and Consumption

The impact of changes in the economy and society on water consumption are dictated by future patterns of both consumption and production. This section assesses these patterns and establishes widely accepted scenarios for these major driving forces.[3]

Economic Growth and the Consequent Per Capita Income Growth

Since 1978, China's gross domestic product (GDP) has expanded at an average rate of nearly 10% and its total exports have expanded at 17% per year. The Fifteen-Year Perspective Plan (1995–2010) identifies two fundamental transitions to sustain future growth: (1) from a traditional planned economy to a socialist market economy; and (2) from the extensive growth path, based on increases in inputs, to an intensive growth mode, driven by improvements in efficiency (World Bank 1997). Assuming the continuance of high rates of saving (which support high investment rates), of market-oriented reforms, and of high factor productivity growth, the World Bank projected an average GDP growth rate of 6.6% annually until 2020 (World Bank 1997). It is assumed that the pace of GDP growth will be slowing down over time, from some 8% today to 5% in 2020—due to a then stagnating labor force, diminishing marginal returns, and lower gains from structural change.

These aggregate growth trends mask diverging paths for different parts of China. A large body of literature deals with regional disparities in China (Liu et al. 1999). It is generally acknowledged that three regions with discrete development paths have emerged in the past two or more decades: (1) the leading coastal areas, characterized by high income levels and a high growth rate; (2) the catching-up central regions, with average income levels but rapid structural changes from agriculture to industry and services; and 3) the backward regions of the west, with a much lower growth rate, and with a small share of the population dominated by national minorities. Another significant disparity exists between rural and urban areas. The per capita income level of urban residents has been 2.5 times higher than that of their rural counterparts over the past two decades (Heilig 1999).

The GDP growth rate is a comprehensive indicator that is not independent of population growth (implying labor force growth) and technological progress. To make the income growth rate independent of other driving forces, we subtract out the predicted growth rate of the population as well as the portion corresponding to technological progress (about 35% of GDP growth) from the predicted national GDP growth rate (World Bank 1992, 1997). As a result, we obtain a net per capita income growth rate. For simplicity, we call it the per capita income growth rate. To accommodate the regional and rural versus urban differences discussed above, we distinguish growth rates for urban and rural areas and for two large development zones.

Population Dynamics and Urbanization

In 1949, China had a population of 540 million; three decades later its population was more than 800 million; and currently China's population has approached 1.3 billion. Today's high share of young Chinese people at reproductive age has created a strong population momentum that is now driving China's population growth despite already low levels of fertility. China is confronted with two counteracting trends: whereas economic growth, urbanization, and the associated lifestyle changes may lead to lower fertility rates, modernization and the opening up of society may lead to opposition to the government's strict one-child policy in family planning. In its most recent (medium variant) projection, the United Nations Population Division estimates that China's population will increase to 1.49 billion in 2025 and then slightly decline to 1.488 billion in 2050 (Heilig 1999; United Nations Population Division 1998).

This increase in China's population is complicated by certain population dynamics across regions. On one hand, migration from western and central China to the eastern regions, especially the coastal areas, adds percentage points to population shares of the eastern regions. On the other hand, the fact that fertility rates are higher in the western regions than in the eastern regions has basically counterbalanced, if not exceeded, the impact of migration (Jiang and Zhang 1998). In addition, one has to consider the movement of traditional industries, particularly heavy industry, from the eastern regions inward to the western regions, and the new strategic movement of the Chinese government to reduce regional disparity. As a comprehensive result of these three trends, the cumulative impact of migration on regional population distribution up to 2025 may not be very significant.

Despite the fact that the urban population is constantly increasing, China can still be considered a predominantly rural society. In 1997, after rapid increase of the officially defined urban population for more than a decade, only some 30% of the population lived in urban areas (Heilig 1999). The rather recent increase in urban population is mainly due to the promotion of towns into cities, thus increasing the number of cities altogether. Another reason for the increase of urban population has been the loosening of strictly controlled internal migration to meet the labor demand of the growing cities and towns as well as a wave of temporary "illegal" rural-urban labor migration. The United Nations Population Division (1998) estimates that by 2025 about 50% of the Chinese population will live in urban areas.

Change in Diet

With respect to changes in consumption patterns, changes in diet structure are the most relevant for agricultural water use. Traditionally, cereal products have been of overriding importance for China; other food products such as meat, fishery products, vegetables, and fruit played only a secondary role (Heilig 1999). This pattern has been changing due to recent social and economic developments. Urban residents typically prefer a more diverse diet and eat more processed foods. Today's Chinese eat more meat and dairy products, which has boosted livestock production. China's population has enormously increased its meat consumption and also eats more fruits and vegetables, whereas direct consumption of grain has leveled off or even declined (Wu and Findlay 1997). Despite these developments, China's average food calorie supply per person per day is still below the average level of developed countries (FAOSTAT 1998). Therefore, an increase in per capita calorie consumption can be expected in the future.

To calculate aggregate final demand from households for the products of each production sector, we multiply average expenditures of urban and rural residents, respectively, by the total numbers of urban and rural residents in each region. To obtain total final demand corresponding to each production sector, we link other final demand components to household consumption according to their current ratio to the level of aggregate household consumption.

Technical Change

In the 1960s, the first long-range forecasts of water consumption made in the United States predicted an increase in annual freshwater consumption by 2–2.5 times from 1970 to 2000, mainly due to increases in water use in industry and heat power generation. In the 1970s and 1980s, a transition from extensive water resource consumption to intensive and multipurpose water resource utilization brought about a stabilization of water consumption. Similar trends were observable in northern and western European countries (Shiklomanov 1994, p. 266).

In China important steps have also been made toward saving water. Recently six ministries, including the State Economic and Trade Commission, the Ministry of Water Resources, and the Ministry of Construction, jointly confirmed a ten-year goal for saving water in industrial companies. The rate of recycled water is targeted to increase from its present 50% to 60% in 2005 and 65% in 2010 (Shanghai will reach 80% 2001; The ten-year goal 2000).

For the scenario of a water-recycling rate beyond 2020, Chen (2003) assumes recycling rates between 25% and 90% depending on the regions. Our estimates for the industrial sector follow the projected trend of the official water savings efforts of the relevant ministries in China, assuming a recycle rate of 85% (Thomas et al. 1997).

For the service sector we can observe two opposing trends: inefficient water use and increasing water demand based on higher expectations for health and hygienic standards. Unfortunately, statistical data on water use in the service sector are hard to find. In Chinese statistics, water use in the service sector is subsumed under urban water use. We therefore use the regional variability of urban water consumption in our water use scenario for the service sector in 2025. In terms of technical change we use the improvement in labor productivity because water use in the service sector is derived from worker-output ratios (Strzepek et al. 1998). During 1985–2000, the labor productivity of the service sector increased by 3.12% per annum. We assume a gradual slowdown of this growth rate in the future, to 2.5% annually on average (State Statistical Bureau 2001, 2002).

The agricultural sector has much room for improvement. Unfortunately, field data on the effectiveness of water savings technology are not readily available because over the last 20–30 years, the emphasis has been on water supply rather than water conservation (World Bank, 2001, p. 73). Efficiency of irrigation networks is only about 40–50%. In the North China Plain areas, the efficiency is around 55–65% (Liu and He 1996; Ministry of Water Resources 1998). There seems to be potential for water savings through better management and infrastructure. But part of the water lost upstream through percolation and seepage returns to the hydrologic system and is available to downstream users. Real savings could only be made from reductions in evapotranspiration and flow to the ocean through measures such as, for example, improved crop genetics, plastic and organic mulching, irrigation scheduling, and best farm management practices (Liu and He 1996; Ministry of Water Resources 1998; World Bank 1999,[12pc] 2001).

Table 2 Renewable water supply and water demand in China for 2025 (in million cubic meters [10^6 m^3])

Region	Water supply (10^6 m^3)	Water demand (10^6 m^3)
North	**95.76**	**151.95**
Northeast	125.15	51.99
East	256.19	126.68
Central	507.89	75.41
South	600.89	122.55
Southwest	694.11	68.52
Northwest	**155.47**	**209.07**
China	2,435.46	806.18

Note: The Plateau is missing in our scenario analysis due to lack of data. Water supply is based on Wiberg (2002a; 2003); water demand is generated by the IO model. The lines in bold face refer to regions that will become net water importers, that is, water demand is larger than water supply.

In order to facilitate these changes, the Chinese government is promoting water-saving irrigation; the State Council has approved the establishment of water-saving/yield-increasing counties as well as water-saving well irrigation districts across the nation.

To establish scenarios for future production functions of the economic sector, we use a mixed approach of applying case studies and the RAS methods.[4] We use the case studies to project key cells in the A-matrix. Then we estimate the remaining cells based on future sectoral structure and by using the RAS method.

Results and Implications

In this section we compare the resultant water demand from IO modeling with the available regional water supply for the year 2025 estimated by the CHARM model.

Table 2 compares water supply with water demand and also shows the per capita water availability for each of the economic regions. In the Northwest and North the demand for water exceeds its potential supply. The North, which includes the capital, Beijing, can also be considered severely water-scarce with only 226 m^3 of water per capita. Anything below 1,000 m^3 per capita is generally considered water-scarce.

Table 2 shows the advantage of a regional analysis over a national one. If we were to compare water supply at the national level, we would not be able to see the water shortages at the regional level and might conclude that the availability of water is not a problem in China. This advantage is achieved at the expense of further sectoral detail. This is caused by the general problem that economic regions and their associated IO tables do not match the relevant mapping for a certain pollutant or resource (in this case the watershed).

China needs to make an adjustment in the allocation of its scarce water resources in a way more compatible with economic efficiency. The value added by each unit of water is much lower in agricultural sectors than in nonagricultural sectors. This difference may necessitate a policy shift away from the constraining goal of food self-sufficiency and toward a more flexible notion of food security. It is necessary to expand the food market beyond national borders to allow flexibility in cropping decisions on the farm level, to encourage production and export of the crops China grows best, and to allow imports to cover the remaining demand. "Virtual water import" in the form of grain imports should be incorporated into current regional and national agricultural development strategies (Yang and Zehnder 2001). On the other hand, we should highlight that a radical shift in water allocation policy is politically infeasible and dangerous because of the simple fact that currently about 50% of the Chinese labor force works in agriculture.

The same logic applies to the industrial sector. It might be necessary to relocate parts of water-intensive industries to water-rich areas. Currently the heavy water-consuming industries such as power, petrochemicals, coal, and metallurgy are mainly located in the North, which has a shortage of water resources.

Table 3 Water multipliers of selected regions in China for 2025 (in m^3/1000 yuan)

Sectors of the economy	North	Central	South	Northwest
Grains	750	842	1,344	2,139
Horticulture	269	316	241	630
Forestry	73	11	6	650
Livestock	130	76	133	362
Energy	27	34	52	30
Industry	20	14	17	43
Services	9	7	9	13

Note: Water multipliers for 2025 are calibrated based on simple assumptions on water-savings rates across industries and on 1992 sectoral multipliers. As a consequence, they reflect regional differences of the base year.

Comparative water-use efficiency across industries and regions can also be indicated by water multipliers, as reported in table 3.

A water multiplier expresses the direct and indirect amount of water use necessary to meet the water requirements for an additional unit of final demand in a given sector. Table 3 shows how the necessary amount of water induced by final demand differs between the economic regions. For the agricultural sector, the regional differences are dependent on agroclimatic conditions and variations in crops and water-use habits based on availability. The differences for the other sectors reflect differences in habits, prices, and the state of water-use technologies in different regions.

The current modeling framework also allows evaluation of the step-by-step additional effects on water demand of population growth and urbanization, income growth, dietary changes, and technological changes, including water-related efficiency gains. In table 4 we report the step-by-step adding-in effects for the most water-scarce region, the North, with a scenario list of technical change (scenario B), population growth (C), urbanization (D), and income growth (E), and we compare them with the base year case (A).

Table 4 shows that technological change (scenario B) could potentially reduce total water consumption by some 49% (48.43 million m^3), all other factors being equal. The projected population growth would induce a water consumption increase of about 43% (22.37 million m^3). Urbanization—representing current lifestyle

Table 4 Water consumption patterns in different scenarios for the North of China in 2025 (in million cubic meters [10^6 m^3])

Sectors of the economy	A	B	C	D	E
Grains	50.72	29.85	39.15	35.11	64.89
Horticulture	13.07	9.11	11.98	18.09	35.63
Forestry	0.40	0.22	0.70	1.01	2.30
Livestock	0.42	0.34	0.45	0.64	1.52
Handicraft	0.04	0.01	0.02	0.03	0.07
Fishery	0.88	0.13	0.17	0.28	0.85
Energy	11.20	0.85	1.71	2.64	6.40
Fertilizer	0.46	−0.01	0.08	0.05	0.12
Industry	12.86	1.79	2.42	3.93	10.94
Construction	0.31	0.14	0.19	0.33	0.93
Transportation	0.01	0.01	0.01	0.01	0.04
Trade	0.44	0.26	0.35	0.58	1.65
Services	0.74	0.42	0.57	0.97	2.78
Urban households	4.77	4.77	9.30	5.44	5.44
Rural households	3.45	3.45	6.50	18.39	18.39
Total water consumption	99.76	51.33	73.60	87.49	151.95

Note: Main assumptions: Scenario A: base year 1992; B: A + technology of 2025; C: B + population of 1.49 billion; D: C + 52% urban population with the associated expenditure patterns; E: D + 4.2–5.7% average annual growth rate in per capita income with the associated income elasticities (thus lifestyle). In all of the scenarios, trade balances of land-intensive products are kept proportional to today's imports and exports.

differences between urban and rural areas—would further increase water consumption by 19% (13.84 million m^3). Income growth and the accompanying lifestyle changes represented by income elasticity measures would induce an additional increase in water consumption by 74% (64.46 million m^3). The overall impact on water demand is about a 52% increase in comparison with the base year case.

The above findings have a basic similarity to those of our previous work on land use (Hubacek and Sun 2000, 2001). The biggest jump in demand for additional water in this research and for significantly increased productivity of cropland and grassland in the previous research is caused by the same factor—per capita income growth with the associated lifestyle change. Nevertheless, a major difference is worth mentioning. In the case of land use, it is easier to identify the key sectoral or product-specific driving force, which is the significant increase in per capita meat consumption and consequently the high demand for feed grain and other feeds. In the case of water use, the driving forces become more dispersed. In addition to the meat-feed-driven high demand for water in the production of grain, horticulture, residential consumption, and trade and services become major driving forces as well. In comparison with the base year case, the latter three forces would drive up the demand for water three times more (table 4). The socioeconomic dynamics represented by the above driving forces include a significant increase in per capita meat and fruit consumption, a significant growth of the middle-class population with a modernized hygiene and living standard, and the resultant development in services.

Conclusions

In the literature a number of reasons for increasing water scarcity in China have been discussed. Our study in this article has identified and quantified potential regional patterns of water demand and supply for China through regional input-output modeling and the establishment of a linkage between the input-output model and a hydrological model. In this study, we have developed a set of diverse scenarios based on different combinations of the widely expected developments in population growth, changes of lifestyle, level of migration, and economic growth for a 30-yr period. Given the assumed future extent of technological progress, we show how these combinations might affect demand for water consumption in China. The increases in final consumer demands and thus sectoral outputs would drive the associated water needs to exceed projected supply in the North and Northwest. In other words, these regions in China would not be able to support the increased demand without significant improvement in water productivity, water savings measures, and/or increasing imports of water-intensive products or water. The main factors that shape the future water consumption patterns would be lifestyle changes and related factors (more water demand) and technological progress (water saving).

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Notes

1. One cubic meter (m^3, SI) = 10^3 liters (L) $\approx$ 264.2 gallons.
2. In addition, the total lakes area has decreased by more than 14% over the last 30 years.
3. For an extensive discussion of these scenarios see Hubacek and Sun (2000, 2001).
4. The term RAS refers to a mathematical procedure for adjusting, sequentially, rows and columns of a given input-output coefficient matrix, $A(0)$, in order to generate an estimate of a newer matrix, $A(1)$, when only the new structural information on sectoral output, $X(1)$, intermediate deliveries, $U(1)$, and intermediate purchases, $V(1)$, is assumed known. Once the procedure converges, the final outcome to be used is denoted as $A(1) = RA(0)S$, in which R is a diagonal matrix that is the product of a series of diagonal matrices, and so is S.

References

Asian Development Bank and Chinese Ministry of Water Resources. 1999. *Strategic options for the water sector*. T.A. 2817. Manila: Asian Development Bank and Chinese Ministry of Water Resources.

Bouhia, H. 2001. *Water in the macro economy: Integrating economics and engineering into an analytical model*. Ashgate studies in environmental and natural resources economics. Aldershot, UK: Ashgate Publishing Limited.

Carter, H. O. and D. Ireri. 1970. Linkage of California-Arizona input-output models to analyze water transfer patterns. In *Applications of input-output analysis. Proceedings of the fourth international conference on input-output techniques, Geneva, 8–12 January 1968. Published in honor of Wassily Leontief*, Vol. 2, edited by A. P. Carter and A. Brody. Amsterdam: North-Holland Publishing Company.

Chen, J. 2003. South-North water diversions. Beijing: Institute of Geographic Sciences and Natural Resources Research (IGSNRR) at the Chinese Academy of Sciences.

Chen, X. 1990. Input-occupancy-output analysis and its application in China. In *Dynamics and conflict in regional structural change*, edited by M. Chatterji and R. E. Kuenne. London: Macmillan Press, pp. 267–278.

Chen, X. 1992. Input-occupancy-output analysis of urban and rural economies of China. Beijing: Science Press.

Chen, X. 2000. Shanxi water resource input-occupancy-output table and its application in Shanxi Province of China. Paper presented at the *Thirteenth International Conference on Input-Output Techniques*, August 21–25, Macerata, Italy.

China's Agenda 21 (The Administrative Center for China's Agenda 21). No date. *White paper on China's population, environment, and development in the 21st century*. Beijing: China's Agenda 21.

Cumberland, J. H. 1966. A regional interindustry model for analysis of development objectives. *Papers and Proceedings, Regional Science Association* 17: 65–94.

Daly, H. E. 1968. On economics as a life science. *Journal of Political Economy* 76(3): 392–406.

Duchin, F., C. Hamilton, and G.-M. Lange. 1993. *Environment and development in Indonesia: An input-output analysis of natural resource issues*. Jakarta: Associates in Rural Development and Institute for Economic Analysis, New York University for USAID.

Duchin, F. and G.-M. Lange. 1994. *The future of the environment: Ecological economics and technological change*. New York: Oxford University Press.

FAOSTAT. 1998. *Food balance sheets*. Rome: Food and Agricultural Organization.

Fischer, G. and L. Sun. 2001. Model-based analysis of future land-use development in China. *Agriculture, Ecosystems and Environment* 85(1–3): 163–176.

Fischer, G. and D. A. Wiberg. 2001. Climate change impacts on water-stressed agriculture in northeast China. In *Natural environment management and applied systems analysis,* edited by M. Makowski and H. Nakayama. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Førsund, F. R. and S. Strøm. 1985. Industrial structure, growth and residual flows. In *Handbook of natural resource and energy economics*, Vol. 1, edited by A. V. Kneese and J. L. Sweeney. Amsterdam: Elsevier Science Publishers.

Heilig, G. 1999. *Can China feed itself?* Laxenburg, Austria: International Institute for Applied Systems Analysis.

Heilig, G. K., G. Fischer, and H. V. Velthuizen. 2000. Can China feed itself? An analysis of China's food prospects with special reference to water resources. *International Journal of Sustainable Development and World Ecology* 7: 153–172.

Hubacek, K. and L. Sun. 2000. *Land use change at the national and regional level in China: A scenario analysis based on input-output modeling*. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Hubacek, K. and L. Sun. 2001. A scenario analysis of China's land use change: Incorporating biophysical information into input-output modeling. *Structural Change and Economic Dynamics* 12(4): 367–397.

Isard, W. 1972. *Ecologic-economic analysis for regional development*. New York: The Free Press.

Jiang, Z. and E. Zhang, eds. 1998. *Population forecasting at the provincial level for China*. Beijing: China Population Publishing House.

Lange, G.-M. 1997. An approach to sustainable water management in southern Africa using natural resource accounts: The experience in Namibia. *Ecological Economics* 26(3): 299–311.

Lange, G.-M. 1998. Applying an integrated resource accounts and input-output model to development planning in Indonesia. *Economic Systems Research* 10(2): 113–134.

Leontief, W. 1970. Environmental repercussions and the economic system. *Review of Economics and Statistics* 52(3): 262–272.

Liu, A., S. Yao, and Z. Zhang. 1999. Economic growth and structural changes in employment and investments in China, 1985–94. *Economics of Planning* 32(3): 171–190.

Liu, C. and X. He. 1996. *Projection of water for the 21st century in China*. Beijing: Science Press.

Ministry of Water Resources. 1992. *Water resources assessment for China*. Beijing: China Water and Power Press.

Ministry of Water Resources. 1998. *China's water conservation in the turn of the century*. Beijing: China Water Resource and Hydro-power Publishing House.

Shanghai will reach 80% in repeat water usage in five years. 2001. *Science and Technology Daily* 8 May, 2001.

Shiklomanov, I. A. 1994. World water resources: Assessment and prediction. In *Innovation, resources and economic growth,* edited by A. Q. Curzio, M. Fortis, and R. Zoboli. Berlin: Springer-Verlag.

State Statistical Bureau. 2001. *China statistical yearbook 2001*. Beijing: State Statistical Publishing House.

State Statistical Bureau. 2002. *China statistical yearbook 2002*. Beijing: State Statistical Publishing House.

State Statistical Bureau of China. 1996. *1992 input-output table of China (in value)*. Beijing: China Statistical Publishing House.

State Statistical Bureau of China. 1997. *1992 regional input-output table of China (in value)*. Beijing: China Statistical Publishing House, Department of Economic Accounting.

Strzepek, K., A. Holt, and M. McCluskey. 1998. *National and regional water demands for China*. Laxenburg, Austria: International Institute for Applied Systems Analysis.

The conservation and protection of water resource is a long-term task. 2000. *China Water Resource News* 21 March.

The ten-year goal of industrial water saving is fixed. 2000. *China Metallurgical News* 15 December.

Thomas, R. P., S. H. Conrad, D. M. Jeppesen, and D. Engi. 1997. *Understanding the dynamics of water availability and use in China*. SAND97-1626 UC-602. Albuquerque, NM: Sandia National Laboratories.

Thoss, R., ed. 1983. *A generalized input-output model for residuals management*. In *Input-output modeling. Proceedings of the third task force meeting,* edited by M. Grossim and A. Smyshleyoev. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Thoss, R. and K. Wiik. 1974. A linear decision model for the management of water quality in the Ruhr. In *The management of water quality and the environment*, edited by J. Rothenberg and I. G. Heggie. London: Macmillan.

United Nations. 1997. *China: Water resources and their use*. New York: United Nations.

United Nations Population Division. 1998. *World's population prospects 1950–2050: The 1998 revision*. New York: United Nations.

Wiberg, D. A. 2002a. *Climate change scenarios and water resource availability in China*. Unpublished manuscript at the International Institute for Applied Systems Analysis.

Wiberg, D. A. 2002b. Development of regional economic supply curves for surface water resources and climate change assessments: A case study of China. Ph.D. dissertation, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, CO.

Wiberg, D. A. 2003. *Climate change scenarios and water resource availability in China*. IR-03. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Wiberg, D. A. and K. M. Strzepek. 2000. *CHARM: A hydrologic model for land use and climate change studies in China*. IR-00-072. Laxenburg, Austria: International Institute for Applied Systems Analysis.

World Bank. 1992. *World development report 1992: Development and the environment*. Washington, DC: The World Bank.

World Bank. 1997. *China 2020: Development challenges in the new century*. Washington, DC: The World Bank.

World Bank. 1999. *Accelerating China's rural transformation*. Washington, DC: The World Bank.

World Bank. 2001. *China: Air, land, and water environmental priorities for a new millennium*. Washington, DC: The World Bank.

Wu, H. X. and C. Findlay. 1997. China's grain demand and supply: Trade implications. In *Agricultural policies in China*. Paris: Organisation for Economic Co-operation and Development.

Xie, M., G. Nie, and X. Jin. 1991. Application of an input-output model to the Beijing urban water-use system. In *Chinese economic planning and input-output analysis*, edited by K. R. Polenske and X. Chen. Hong Kong: Oxford University Press, pp. 239–257.

Yang, H. and A. Zehnder. 2001. China's regional water scarcity and implications for grain supply and trade. *Environment and Planning A* 33(1): 79–95.

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