WATER MANAGEMENT

Water Sustainability for China and Beyond

Despite investments in water infrastructure, China must address complex human-nature interactions to ensure supply and quality.

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A water crisis has prompted the Chinese government to develop an ambitious water conservancy plan. However, the plan may not achieve water sustainability and may cause unintended environmental and socioeconomic consequences, unless it accounts for complex human-nature interactions (*1*). Water shortages, for example, force people to find alternatives, such as treatment facilities, whose land and energy requirements aggravate food and energy production, which need large amounts of water. Other nations face similar challenges and share real water from China along international rivers and/or virtual water through trade. Water problems are particularly challenging in China, which has the largest population, fastest-growing economy, rising water demand, relatively scarce water, dated infrastructure, and inadequate governance. We highlight China's water crisis and plan, and then offer recommendations.

Water Crisis and Grand Investment

Two-thirds of China's 669 cities have water shortages, more than 40% of its rivers are severely polluted, 80% of its lakes suffer from eutrophication, and about 300 million rural residents lack access to safe drinking water (*2*). China's per capita availability of renewable water resources is about a quarter of the world average, but water consumption per unit of Gross Domestic Product is three times the world average because of water-intensive industrial structure, outdated technologies, low reuse rate, and wastefulness (*2*). Uneven natural water distribution aggravates the crisis. Influenced by a monsoonal climate, precipitation generally declines from the southeast to the northwest and varies greatly from year to year and season to season (*2*). Water-related disasters such as 1998 floods and 2010 droughts saw large losses of life and property, as well as damage to human well-being and the environment.

In January 2011, the government's annual "No. 1 Document," which reflects its top priorities, outlined a plan to expedite water conservancy development and reform and to achieve sustainable use and management of water resources within this decade (see the supplementary materials). The plan is to quadruple total investment in solving water problems to four trillion yuan (U.S. $635 billion) in the next 10 years compared with the investment in the past decade (see the graph).

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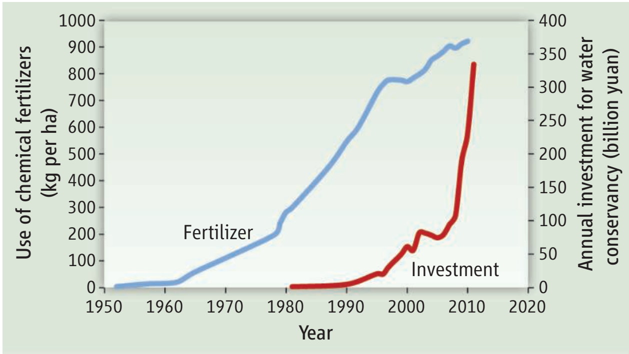

China's investment in water conservancy (*19–21*) and use of chemical fertilizers (*22*).

More than 46,000 of the 87,000 dams and reservoirs built since the 1950s have surpassed their life spans, or will within 10 years, which will increase the risk of structural failure (*3*). The central government plans to repair and reinforce them by the end of 2015 (*3*) and also build new dams, reservoirs, and canals. Since the 1950s, China has constructed 12 major projects that annually divert more than 9 billion m^3 of water; many more such projects are being constructed or planned (table S1), including the South-North Water Transfer Scheme—the world's longest and largest water diversion project with a planned investment of 486 billion yuan (U.S. $77 billion) and 45 billion m^3 of annual water transfer.

The plan focuses largely on engineering measures related to water quantity. Except for water-related targets in the 12th Five-Year Plan, the water plan does not set quantitative targets for water quality, which is low in China and severely affects human and ecosystem health [e.g., increased cancer mortality is attributed to water pollution (*4*)].

Policy Recommendations

This planned investment is laudable, but not sufficient. Thus, we offer the following.

Coordination. Many agencies are involved in water governance (table S2) but lack coordination. At the central government level, the Ministry of Water Resources (MWR) leads design and implementation of the new water plan. The Ministry of Environmental Protection (MEP) is supposed to be in charge of water pollution prevention and control, but lacks adequate resources and jurisdiction. Many water projects (e.g., Jinsha River hydropower) were rushed without following the national law of environmental impact assessments and have caused enormous environmental and socioeconomic impacts (*5*). New laws are needed regarding development (e.g., hydropower) of rivers and river basins (*5*). To implement laws, relevant sectors and agencies (e.g., water resources, environmental protection, shipping, and agriculture) must coordinate and punish law-breaking behaviors.

Coordination must cross organizational levels and sectors. Many water-related laws and policies are not implemented because central and local governments' efforts are not coordinated. In 2004, the central government promulgated a policy to stop construction of golf courses, which consume and pollute much water. Yet over 400 golf courses have since been built (*6*). The government encourages urbanization, but water protection does not receive as much attention as energy (e.g., green building codes tend to focus more on energy and less on water). The number of households has been growing more rapidly than population due partly to increased divorce and shrinking of multigenerational families (*7*). Rapid housing and land development consumes much water, generates wastewater, and expands impermeable surfaces that increase runoff (*8*).

China has achieved remarkable food production, in part through expansion of irrigation and use of pesticides and chemical fertilizers (see the graph), which has escalated water pollution and depleted surface- and groundwater. More water will be needed by mines as China expands coal production (*9*). Water diversion projects may encourage consumption and increase demand. The Luanhe-to-Tianjin project annually diverted roughly one billion m^3 of water into Tianjin (table S1), but Tianjin's water-fueled growth now demands even more from the South-North Water Transfer Scheme. China's plan aims to reduce water use in irrigated agriculture (61% of total water use in 2010) largely by constructing efficient farm infrastructure. This may actually increase water use and redistribute supply at a larger scale (e.g., water basin), reducing aquifer replenishment and intensifying depletion at large scales (*10*).

Although water demand is growing, supply is increasingly limited. Glaciers are retreating due to climate change (*11*), reducing water supply. Depletion of water reduces biodiversity (thus, ecosystem services such as water purification) and causes pollution such as eutrophication. Pollution and the spread of invasive species through water diversion may compromise water quality and supply.

Coordination requires continued efforts to lower population growth and slow household proliferation; clarify water rights (e.g., setting maximum water-use quotas at various levels and for all entities); reform water pricing (e.g., increasing block tariffs that discourage high usage); and eliminate inefficient practices (e.g., through rebates for water-saving equipment). More secure land rights to farmers may encourage them to sustain their lands by avoiding overuse of fertilizers and thus protect water. Incentive programs alone cannot guarantee less water use (*10*). Both "hard path" (e.g., dams) and "soft path" (e.g., public education, efficient technology, and financial incentives) approaches are needed (*12*).

Institutional innovations are indispensable. An effective entity (e.g., a sustainability coordination office) is needed directly under the State Council (the country's highest executive organ) to clarify functions and responsibilities of water management agencies (table S2), reduce institutional mismatches, identify shared interests, avoid conflicts, and bridge gaps. With the State Council's support, it would have resources and authority to work across agencies and sectors, as well as with the public and nongovernmental organizations. It also would facilitate public communication and disclosure of information to make government transparent and accountable.

Integrated monitoring and proactive measures. Current monitoring programs include indicators such as water quantity and use efficiency (by the MWR) and water quality (by the MEP). To more accurately predict changes and take proactive adaptive management measures, it is essential to monitor indicators that drive changes in water quantity and quality directly and indirectly. Ministries should expand monitoring, particularly in areas with severe water shortages, to indicators in human dimensions (e.g., values and attitudes toward water, land use, and development).

To minimize negative legacy effects and avoid irreversible impacts, China can learn from other countries (e.g., the U.S. Clean Water Act). China should take proactive measures (e.g., solicit public opinions before implementation) for major projects; track government officials' responsibilities and performance related to water; and expand the major evaluation and promotion criteria of short-term economic performance.

Integrating social sciences. China has been vigorously promoting natural sciences and technology but lags behind in integrating them with social sciences, development of which was constrained for decades by government's political ideology (*13*). Incorporating social sciences is not a panacea, but can help, e.g., by predicting water demand and long-term effects of China's water plan, and could lead to positive changes in human behaviors. Efficiency of the plan can be enhanced through changing people's values, attitudes, and behaviors toward water. Changing consumption is crucial for water sustainability, because engineering measures (e.g., long-distance water transfer) have caused serious socioeconomic and environmental costs, despite enormous benefits (*12*).

Enhancing international cooperation. China's water plan does not consider virtual water in trade or real water in international rivers. China's trade during 1996–2005 caused a net loss of 23.5 billion m^3 of virtual water (*14*). Although virtual water is but one consideration in trade, and there may be other benefits and costs, it is important for achieving water sustainability. Use of real water in international rivers also has broad implications. Headwaters of 12 major international rivers are in China (*15*), and conflicts have increased over their use in recent years (*16*).

It is important for China to take a more active role to reduce its water footprint and to cooperate on the use of international rivers. For example, although the Mekong River Commission (MRC) has been operating since 1995, its effectiveness may be improved by including China. China has been uninterested because joining MRC would compromise sovereign control and limit unilateral action. Thailand was reluctant to admit China because it did not want MRC to be dominated by communist countries (China, Lao PDR, and Vietnam) (*17*). Lessons can be learned from other international cooperative efforts (e.g., the Nile Basin Initiative).

Conclusion

Policies for water and other issues should be jointly designed, implemented, monitored, and evaluated. Integrated Water Resource Management (IWRM) may be a useful approach. China has begun to adopt IWRM concepts, although it is not easy (*18*). But China now has financial resources and motivations to address the water crisis and to generate lessons for achieving sustainability in China and the rest of the world.

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Supplementary Text
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Full References

Supplementary Text

Section 1. China's grand water conservancy plan

Since the water conservancy plan (*23*) is written in Chinese, here we translated and highlight the overarching goal and main objectives of the plan. Although the plan provides a comprehensive list of many items, it focuses largely on engineering measures (Objectives #1 and #2) for water quantity but minimally on water quality. The distribution of investment for China's 12th Five-Year Plan (2011–2015) also reflects such a focus [i.e., 93% for engineering projects and only 7% for conserving soil and ecological construction (*24*)]. Except for the water-related targets in the 12th Five-Year Plan and 10% revenue from land sales for farmland water conservancy construction, the plan does not set any quantitative targets under Objectives #3 and #4.

Overarching goal:

The overarching goal is to fundamentally reverse the backward situation of China's water conservancy development by 2020.

Main objectives:

(1) Establish a flood and drought control and relief system

- Dramatically improve the capacity of flood and drought control in key cities and flood protection areas
- Rehabilitate major sections of over 5,000 (*25*) small- and medium-sized rivers by 2015
- Complete the reinforcement of over 46,000 (*25*) dilapidated small reservoirs and establish the forecasting and warning system in flood-prone areas by 2015

(2) Establish a reasonable water resources allocation and highly efficient water-use system

- Enhance the capacity for water resources allocation and supply through water transfer projects and connecting different rivers, lakes and reservoirs
- Set peak annual water exploitation and consumption (670 billion m^3)
- Improve water conservancy infrastructure for farmland and increase effective irrigation area by 2.67 million ha
- Improve water-use efficiency: reduce water use per unit GDP and increase the utilization coefficient of irrigation water by at least 22% (to 0.55 or higher)

(3) Establish a system for protecting water resources and securing the health of aquatic ecosystems

- Promote protection and treatment of aquatic ecosystems, and improve living environment for humans
- Effectively control soil erosion in key areas
- Basically control over-extraction of groundwater
- Other water related targets in the national 12th Five-Year Plan (2011–2015) (*26*): reduce chemical oxygen demand (COD), total nitrogen discharge, and water use per unit industrial added value by 8%, 10%, and 30%, respectively, compared with those of 2010; increase urban sewage treatment rate to 85%; reduce the discharge of heavy-metal pollutants in key areas by 15% compared with that of 2007; complete safe drinking water projects in rural areas and ensure safe water supply in all urban areas

(4) Establish a system and mechanism that facilitates the development of water conservancy

- Double the average annual investment compared with 2010
- Allocate 10% revenue from land sales for farmland water conservancy construction
- Expedite the reform of the water conservancy system (clarify water rights, promote water price reform, incorporate incentive mechanisms, and promote the legislative system)
- Implement the most strict water resources management system (control water use, improve water use efficiency, and restrict pollution discharge in water function zones)
- Promote water conservancy science and technology innovations and applications

Section 2. Virtual water flows within China and across the world

From 1996 to 2005, China imported 119.2 billion m^3 of virtual water, of which 91.9, 15.7, and 11.6 billion m^3 were related to crop, animal, and industrial products, respectively. At the same time, it exported 142.7 billion m^3 of virtual water, of which 89.3, 23.4, and 51.0 billion m^3 were related to crop, animal, and industrial products, respectively (*14*).

For details of real and virtual water transfers within China, please refer to (*29*, *30*). For detailed comparisons of virtual water flows among different countries, including China, please refer to (*14*, *31*, *32*).

Table S1. China's major water transfer projects. SNWTS, South-North Water Transfer Scheme; NA, not available. Data are compiled from multiple sources, primarily (*33–42*).

Location/Project	From	To	Date of construction	Date of completion	Total investment (billion yuan)	Volume diverted (billion m^3/year)	Maximum diversion discharge (m^3/s)	Length of transfer (km)	Irrigated area (million ha)
Yunnan Province	Yi'nihe River	Jinshajiang River	1958	1972	0.43	NA	33	NA	0.01
Jiangsu Province	Yangtze River	Huaihe River	1961	1977	0.18	2.40	470	400	2.80
Guangdong Province	Dongjiang River	Hong Kong	1963	1965	NA	0.62	NA	83	0.17
Gansu Province	Datonghe River	Yongdeng County	1976	1995	2.95	0.44	36	70	0.06
North China Region	Luanhe River	Tianjin City	1982	1983	1.13	0.70	100	234	NA
Liaoning Province	Biliuhe Reservoir	Dalian City	1982	1986	NA	0.13	15	150	NA
Shandong Province	Yellow River	Tsingdao City	1986	1989	0.95	0.64	75	262	0.09
Yunnan Province	Erhai Lake	Binchuan County	1987	1994	0.07	0.05	10	41	0.06
Hebei Province	Qinglong River	Qinhuangdao City	1989	1991	0.24	0.17	14	63	0.43
Hebei Province	Yellow River	Baiyangdian Lake	1989	1994	NA	1.25	320	779	NA
Jilin Province	Western Songhuajiang River	Changchun City	1993	2000	2.68	0.33	11	55	NA
Shanxi Province	Yellow River	Shanxi	1993	2011	17.34	1.20	48	452	NA

Location/Project	From	To	Date of construction	Date of completion	Total investment (billion yuan)	Volume diverted (billion m^3/year)	Maximum diversion discharge (m^3/s)	Length of transfer (km)	Irrigated area (million ha)
		Province							
Northeastern China	Songhua River	Liaohe River	2008	NA	NA	4.40	500	656	2.85
Eastern Route of SNWTS	Yangtze River	Yellow River	2002	2020*		148	1000	1150	2.26
Middle Route of SNWTS	Yangtze River	Huaihe and Haihe Rivers	2003	2030*	486	130	800	1240	2.32
Western Route of SNWTS	Yangtze River	Yellow River	Planned	2050		170	NA	700	2.33
Guangdong Province	Xijiang River	Eastern Zhujiang River Delta	Planned	NA	23.60	2.07	NA	95	NA
Anhui Province	Yangtze River	Chaohu Lake, Huaihe River	Planning	NA	28	0.80	300	269	0.97
Yunnan Province	Jinshajiang River	Lijiang River, and Dali, Kunming, Yuxi Cities etc.	Planning	NA	62.90	3.40	NA	900	NA
Zhejiang Province	Qiandao Lake	Hangzhou City	Planning	NA	20	1.69	NA	271	NA

*The first phases of the Eastern and Middle Routes are scheduled to complete in 2013 and 2014, respectively.

Table S2. China's central water-related agencies and their main functions. Notes: MWR, Ministry of Water Resources; MEP, Ministry of Environmental Protection; MOHURD, Ministry of Housing and Urban-Rural Development; MOA, Ministry of Agriculture; SFA, State Forestry Administration; NDRC, National Development and Reform Commission; MOC, Ministry of Communications; SOA, State Oceanic Administration; MOH, Ministry of Health. [Source: Adapted from (*2*), page 252]

Agency	Main water-related functions
MWR	Water resources management and supervision; water and soil protection; hydrological management; flood control and drought relief; management of water infrastructure and engineering projects; water-saving management; management of water withdrawal permits; charge water resources fees; planning of water function zones; coordinate and arbitrate water disputes; review and verify the capacity of pollutant load of water bodies; make proposals on the limit of total wastewater discharge; water resources conservation planning
MEP	Water pollution prevention and control; collaborate with relevant agencies to draft water conservation plans, policies, laws, regulations and standards; water quality and pollution monitoring; charge wastewater discharge fees; review environmental impacts assessment reports of water engineering projects
MOHURD	Urban and industrial water-saving management; urban water supply, drainage and planning, construction, and management of wastewater treatment projects
MOA	Non-point source pollution control; conserve fishery waters, fish, wildlife, plants, and aquatic environment and habitats
SFA	Ecological management of watersheds; protection and management of water conservation forests; wetlands management
NDRC	Participate in water resources development and ecological construction plans; balance development planning and policy among agriculture, forestry, and water resources
MOC	Inland navigation; control of pollutants discharged from ships
SOA	Coastal water use, monitoring, and management
MOH	Supervision and management standards for drinking water sources

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