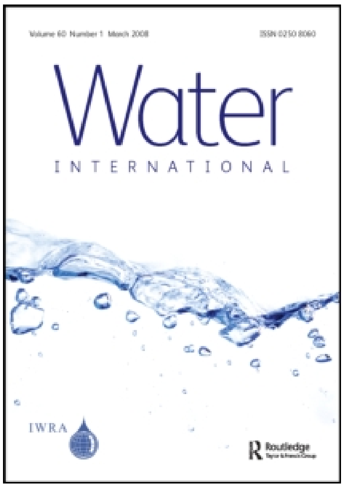

## Water International
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t792815876

# Yellow River basin: living with scarcity

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Online publication date: 05 November 2010



**To link to this Article: DOI:** 10.1080/02508060.2010.509857
**URL:** http://dx.doi.org/10.1080/02508060.2010.509857

*Water International*
Vol. 35, No. 5, September 2010, 681–701

# Yellow River basin: living with scarcity

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The Yellow River basin is a key food production centre of global importance facing rapidly growing water scarcity. Water availability for agriculture in the basin is threatened by rapid growth in the demand for industrial and urban water, the need to flush sediment from the river's lower reaches, environmental demands and growing water pollution. Climate change is already evident in the basin with long-term declines in river runoff, higher temperatures, and increasing frequency and intensity of drought. The Chinese government has exhausted most options for improving water supply. The challenge will be to switch to improved water demand management, which is hampered by existing governance structures, and lack of integrated agriculture and water resource policies.

**Keywords:** Yellow River basin; water scarcity; climate change; water trading

## Introduction

China is facing growing water scarcity in many river basins due to its rapid economic development, an expanding population, growing urbanization and limited scope to develop new supplies. Water overdrafts, both from surface and sub-surface sources, are causing serious environmental problems ranging from the degradation of ecosystems in the deltas of major rivers to aquifer depletion in northern China. The Yellow River basin (YRB) is symptomatic of the challenges facing China's water economy. The YRB, which is the second largest basin in China, is a key agricultural and industrial region in the country and also considered the "cradle of Chinese civilization". However, the basin faces severe water shortages. The particular climatological and hydrologic conditions together with very rapid industrial and urban development are making sustainable water supply for all users and uses a complex and difficult task. Given the extreme water shortages in the basin, how can water resources be managed to continue to support agricultural and economic development while also improving outcomes for the environment?

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ISSN 0250-8060 print/ISSN 1941-1707 online

DOI: 10.1080/02508060.2010.509857
http://www.informaworld.com

In this paper we report results of a two-year study on biophysical and socioeconomic aspects of the water and related resources in the YRB; the relation of water development and agricultural and economic growth; and options for enhancing water availability and access for sustained agricultural and economic development, while maintaining environmental sustainability.

## Background on the Yellow River basin

### *Water resources in the Yellow River basin*

The Yellow River (or "Huanghe" in Chinese) is the second longest river in China. It rises in the Bayangela Mountains in western China, dropping a total of 4500 m as it loops north into the Gobi Desert before turning south through the Loess Plateau and then east to its mouth in the Bohai Sea (Figure 1). The river flows 5464 km and passes through nine provinces and autonomous regions, with a basin area of 795,000 km$^2$, which includes 42,000 km$^2$ of inland river catchments in the northwest of the basin. Rainfall averages 450 mm and annual average natural runoff is 53.5 km$^3$, which is less than runoff estimates of 58 km$^3$ during the 1960s to the 1980s. Total annual water resources, including groundwater, are 64.7 km$^3$ (YRCC 2006).

The basin faces severe pressures on available water resources. With an estimated 150 million people benefiting from Yellow River water resources, both inside and outside the basin area, per capita water availability today is already only 430 m$^3$, less than half the 1000 m$^3$ threshold for chronic water scarcity (Falkenmark and Widstrand 1992). Other



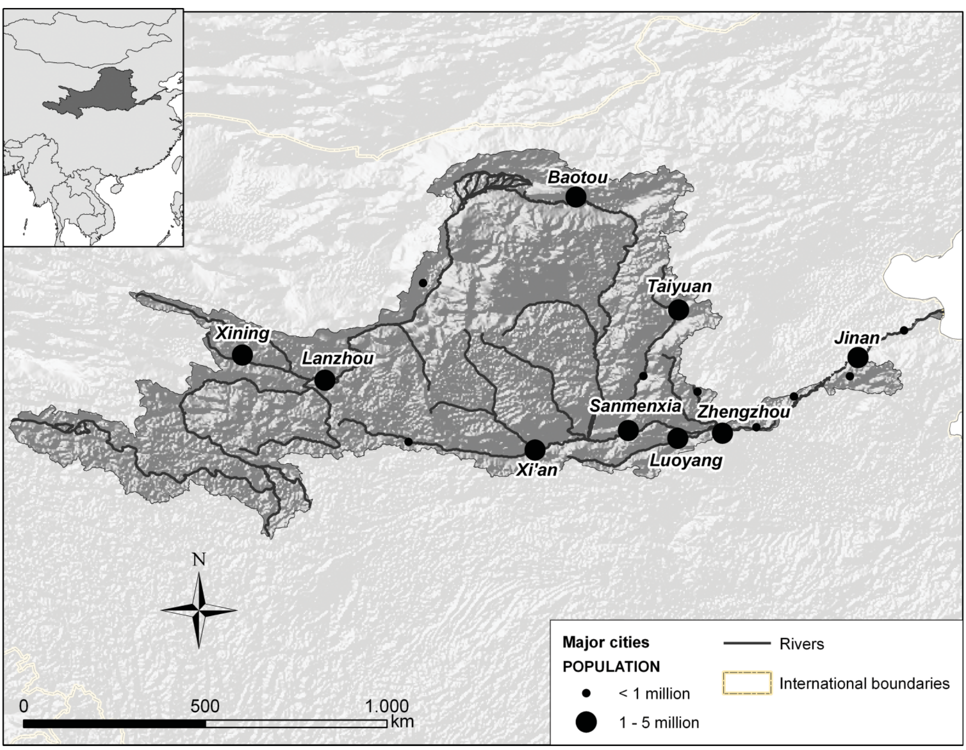


Figure 1. Map of the Yellow River basin.

indicators of water scarcity include the ratio of annual water withdrawal to renewable water resources, which exceeds 75% in the basin (Ministry of Water Resources 2001), and the high fraction of consumptive water use (ratio of consumption to withdrawal), estimated to be 75%, which is far higher than the global average of 43%. This is due to the comparatively high share of water use by agriculture, almost full use of return flow in downstream irrigation districts through conjunctive use of canals and wells, as well as considerable non-beneficial water losses (Rosegrant and Cai 2003, Cai and Rosegrant 2004).

In 2000, the basin produced 14% of Chinese grain harvest and 14% of the country's GDP using only 2% of national water resources. Total agricultural area is approximately 13 million ha of which 7 million ha are irrigated. To address past flooding problems and support agricultural and economic development, the Yellow River has been heavily engineered, with 15 large reservoirs that store 566 $km^3$ with an installed hydropower capacity of 10,380 MW.

The basin is typically divided into an upstream, midstream and downstream area. The mountainous upstream area generates most of the river flow, has a relatively low population density, limited agricultural and industrial development, and concentrates most of the poverty in the basin. The midstream area includes both the fragile Loess Plateau and semiarid and arid agricultural areas that heavily depend on irrigation. Over the last decade, there has been important industrial development in several of the mid-stream provinces, competing with irrigation for limited water resources. The downstream area contains most of the urban-industrial development, a combination of ground- and surface-water irrigation, and fragile wetland ecosystems at the river mouth.



### *Key challenges for YRB water and food security*

In addition to the low per capita water availability, other unique challenges of water availability and access in the YRB include the world's highest sediment loads, which require large flushing flows; the important role of multipurpose reservoirs for hydropower and flood control; large flooding events, and, more recently, significant droughts; rapid increases in water demand from industries, cities and the environment; high levels of degradation of water quality in the middle and downstream main channel and tributaries; large potential impact of climate change and variability; and continued poor management of the water resource. These developments have led to sharp competition between upstream and downstream users, between irrigators and industry in the midstream area and rapidly growing water degradation.

The Yellow River has the highest sediment concentration in the world, at 37.6 $kg/m^3$ (Shi and Shao 2000, Xue *et al.* 2010). Therefore, since 2002 the YRB annually flushes sediments that accumulate in the lower reaches of the river through targeted reservoir releases, using an estimated 15 $km^3$ of water resources during the rainy season. While the policy was successful at removing sediment, several irrigation intakes are now too high above the water level in the river to access water.

Both floods and droughts damage the YRB economy. For example, from 1950 to 1990, the total direct damage of floods and droughts was estimated at 116.4 billion RMB (1 RMB = US$0.146), with floods accounting for 45% of total damage (Ma 1996).

Agriculture, which is the major water user in the basin, faces increasing competition for water resources as a result of rapid urban and industrial development. In 50 years, the irrigated area in the YRB increased more than 350% and agricultural water use by more than 250% (YRCC 2006). Water demand from industry and domestic use increased even more steeply, but from a very low base. The largest adverse impacts on the availability of

Table 1. Water Allocation Agreement of 1987 and actual withdrawals, 1998 and 2008 (km$^3$).

| | | 2008 | | | 1998 | | |
|---|---|---|---|---|---|---|---|
| | UWFR | Total withdrawals | Surface water | Ground Water | Total withdrawals | Surface water | Ground water |
| Qinghai | 1.41 | 1.86 | 1.47 | 0.39 | 1.92 | 1.63 | 0.29 |
| Sichuan | 0.04 | 0.03 | 0.03 | – | 0.02 | 0.01 | 0.01 |
| Gansu | 3.04 | 4.44 | 3.80 | 0.64 | 4.15 | 3.53 | 0.62 |
| Ningxia | 4.00 | 7.63 | 7.12 | 0.51 | 9.68 | 9.14 | 0.54 |
| Inner Mongolia | 5.86 | 9.37 | 6.97 | 2.40 | 9.26 | 7.30 | 1.96 |
| Shaanxi | 3.8 | 6.27 | 3.22 | 3.05 | 5.51 | 2.42 | 3.09 |
| Shanxi | 4.31 | 4.14 | 1.70 | 2.44 | 3.64 | 1.18 | 2.46 |
| Henan | 5.54 | 6.63 | 4.20 | 2.43 | 5.77 | 3.34 | 2.43 |
| Shandong | 7.00 | 7.99 | 7.07 | 0.92 | 9.77 | 8.46 | 1.32 |
| Heibei/Tianjin | 2.00 | 0.73 | 0.73 | n/a | n/a | n/a | n/a |
| Total | **37.00** | **49.10** | **36.31** | **12.78** | **49.71** | **37.00** | **12.71** |

Note: UWFR = Unified Water Flow Regulation (enforced since 1999).
Source: YRCC (2005).



irrigation water came in 1998 from the decision by the government of China to stop the increasing flow cutoff periods to the downstream river reaches, which had attracted international attention. Flow stoppages in the YRB were the most striking evidence of excess water withdrawal and consumption in the basin with increasing cutoff periods from 1972–98. In 1997, there was no discharge from the basin to the sea for 226 days, and the river dried up to Kaifeng, 600 km inland from its mouth (Cai and Rosegrant 2004, Ke and Zhou 2007). Flow cutoffs were eliminated through unified water flow regulation (UWFR), which was implemented by the YRCC in 1999 as enforcement of the 1987 cross-provincial water allocation agreement (Table 1). Implementation of the UWFR contributed to a decline in total irrigation water use in the mid- and downstream areas by 4.8 km$^3$ from 1988–92 to 2002–2004 (Chen 2002, YRCC 1998–2006), while urban-industrial uses continued to grow (Table 2). The enforcement of the UWFR has not led to any compensation of irrigation water users. Moreover, declines in surface-water use for irrigation directly contributed to increased groundwater withdrawals, particularly in the downstream areas. Despite the maintenance of year-round flows since 1999, flows remain insufficient to prevent seawater intrusion and wetland recession.

Water quality problems have grown in the YRB, both as a result of the reduced capacity of the river to dilute waste and growing domestic, industrial and agricultural effluents. Their combined effect has reduced the Yellow River's service functions for decades to come. According to Li *et al*. (2003), in 1998 water pollution cost the YRB a total of 14.97 billion RMB or 2.6% of its GDP. In early 2010, the government of China, for the first time, released national-level estimates of pollution that also included agriculture. According to the study, agriculture is responsible for 43.7% of the nation's chemical oxygen demand (the main measure of organic compounds in water), 67% of phosphorus and 57% of nitrogen discharges (*The Guardian*, 9 February 2010). This is not surprising as the country consumes more than 30% of the world's nitrogen fertilizer, which is applied to only 7% of the world's land area. While no basin-level figures are available, the data are likely representative for water quality in the YRB. This first official recognition by the government of serious agricultural pollution will likely support a review and revision of the incentives and subsidies provided for agricultural inputs, particularly fertilizer.

Table 2. Irrigation water use, YRB, 1988–92 and 2002–2004 ($km^3$).

| Years | Reach | Total | Agricultural | Industrial | Domestic |
|---|---|---|---|---|---|
| 1988–92[a] | Upper | 13.11 | 12.38 | 0.51 | 0.22 |
| | Middle | 5.44 | 4.77 | 0.38 | 0.28 |
| | Lower | 12.18 | 11.24 | 0.55 | 0.38 |
| | Basin | 30.72 | 28.39 | 1.45 | 0.89 |
| 2002–2004[b] | Upper | 17.54 | 15.71 | 1.42 | 0.41 |
| | Middle | 5.71 | 4.16 | 0.97 | 0.58 |
| | Lower | 8.44 | 7.04 | 0.82 | 0.58 |
| | Basin | 31.69 | 26.91 | 3.21 | 1.57 |
| Difference | Upper | 34% | 27% | 179% | 84% |
| | Middle | 5% | −13% | 155% | 108% |
| | Lower | −31% | −37% | 49% | 54% |
| | Basin | 3% | −5% | 121% | 77% |

Sources: [a]Chen (2002); [b]YRCC (2002–2004), as used in Cai (2006).



To investigate the impact of climate change on future stream flows in the Yellow River, we applied the predictions of the HadCM3 global circulation model using the SRES B2 scenario.[1] We applied the statistical downscaling model to the Yellow River's headwater catchment areas using the SWAT-BNU (Soil and Water Assessment Tool developed at Beijing National university) model. According to the downscaled values, maximum air temperatures are predicted to increase by 1.3°C by the 2020s, 2.6°C by the 2050s, and up to 3.9°C by the 2080s in the basin; minimum temperatures are expected to increase by 0.9°C, 1.5°C and 2.3°C, for the same periods. Annual precipitation volumes under this scenario would be 3.5% higher in the 2020s, 6.4% higher in the 2050s, and 8.7% higher in the 2080s. The combined impact from higher temperatures and slightly higher precipitation levels on Yellow streamflows would be declines of 88 $m^3/s$, 117 $m^3/s$ and 152 $m^3/s$, for the three periods, respectively. Thus, even the relatively moderate and precipitation-abundant HadCM3 SRES B2 scenario would severely affect future regional water supply and water security in the basin, putting further pressure on food security in the country (Xu *et al.* 2009).

When linking the SWAT-BNU model results with the water simulation model of the YRCC river basin authority, we find that under climate change the annual water budget deficit would rise to 4.2 $km^3$. The situation would be even worse in dry years: in one out of four years the water shortage would reach 15.1 $km^3$ and in one out of 20 years, the shortage would reach 21.0 $km^3$ resulting in basin water deficit ratios of 28% and 37%, respectively.

### *Food and water in the Yellow River basin*

Most of the irrigation water in the YRB, and in China in general, is used for the production of basic staple crops. In 2005, production of irrigated cereals accounted for 85% of total national production, on 82% of the harvested area for cereals, up from 74% of total production on 70% of area in 1995. In comparison, worldwide, irrigated cereal production accounted for 52% of total production on only 38% of the global area harvested for cereals. The YRB accounted for 14% of irrigated harvested cereal area and production in China. While agricultural area in China is expected to continue to contract and irrigated area to barely increase over the next decades, the national share of irrigated area of the YRB is expected to increase up to 18% due to more rapid declines in irrigated rice area in other Chinese river basins (International Food Policy Research Institute [IFPRI] 2009).

Total demand for cereals in China in 1995 was estimated at 375 million metric tons: 69% for direct human consumption, and most of the reminder for animal feed. Ten years later, demand had increased to 400 million metric tons and is projected to further increase to 492 million metric tons by 2050. By then, only 44% will be destined for direct human consumption, given the large increase in the use of maize for animal feed (IFPRI 2009). In 2005, China already accounted for a quarter of the world's total livestock production (FAOSTAT 2010).

In 2007 China was the third largest bioethanol producer in the world after the United States and Brazil with an annual production of 1.35 million tons. As a result of growing concerns for food security at the national level, the government has since prohibited bioethanol production using maize and wheat as feedstocks, except for four plants that were allowed to maintain their output but not expand (Qiu *et al*. 2010).

Concerns about food security have been at the heart of much of the policy on agricultural development in China for decades. China's medium- to long-term policy for grain security 2009–20 sets a target of 95% self-sufficiency in grain production, slightly less than the 98% for the preceding period. To achieve these levels of production, the government focuses chiefly on investments in science and technology, combined with direct support to farmers. Key farm support measures include the abolition of the agricultural land tax in 2006 and continued support and subsidies for crop inputs, particularly fertilizers, fuel and water, many of which have been gradually decoupled and converted to direct transfer payments to farmers.

Similar to other parts of Asia, overall farm support measures have been growing as a result of the food price crisis, which peaked in 2007/08. By 2008, Chinese farmers received US$34.4 per acre, comparable to the per-acre level of subsidy (but not per-household support) in the United States (Huang and Rozelle 2009, Rosegrant *et al*. 2009a, Huang *et al*. 2010). Despite the government's strong efforts to achieve close to food self-sufficiency in key crops, it is likely that net food imports will increase from approximately 18 Mt to 50 Mt by 2050 given the growing land and water shortages (IFPRI 2009, Rosegrant *et al*. 2009a).

The government's goals and supporting policies on food self-sufficiency have had direct negative impacts on water availability and use in the YRB. For example, the abolition of the agricultural land tax, which traditionally was collected together with service fees for irrigation water, has increased the relative cost and difficulty of collecting the latter because the collection costs are now spread over a smaller fee base. Moreover, rates of collection have fallen because some farmers believe that following the demise of the land tax, they should also not have to pay irrigation service charges. Another example is the government support for nitrogen fertilizer, which has contributed to their over-use, resulting in heavy non-point source pollution in the YRB and elsewhere in China.

At the same time, policies in the water sector have harmed agriculture, such as the silt-flushing policy and flow-cutoff implementation discussed above. Various policies implemented to conserve irrigation water have had other adverse effects, such as reduced maintenance of the irrigation systems and reduced salaries of irrigation system managers, who are paid according to volume of water delivered, measured at the off-take level, and not volume of water conserved.

### *Water legislation and administration*

#### *Water legislation*

In 2002, the government of China passed a new water law. Key elements include the emphasis on river basin management; a strong focus on water savings and improved water-use efficiency; the implementation of water-use quotas, permits and fees for large withdrawals; and the recognition of water for ecological uses as equal in importance to water used for industry and agriculture. Given the limited water resources of the country, the government has also widened and deepened legislation on water pricing over the last ten years (Ministry of Water Resources 2003, 2005, Wang 2007, Fu *et al.* 2008). Several regulations released since 2004 support a water rights system as well as water rights transfers, particularly for the YRB. These include the *Guidance on water rights transfer demonstration works in Inner Mongolia and Ningxia,* the *Management and implementation measures on water rights transfer in the Yellow River basin,* and *Management regulation on water-saving engineering*. These regulations have provided the legal foundation for water right transfers in the YRB.

However, regulations to implement the national laws and national-level regulations in many cases are still lacking at the provincial level. The slow pace of promulgation of implementing regulations at the provincial level is likely due to provincial officials not seeing the legislation as a priority; a sheer lack of capacity and understanding by provincial officials, and a lack of financial resources to support implementation at lower administrative levels in the provinces (Wang and Zhang 2009).



### *Water administration in the YRB*

In China, water resources are administered through a nested hierarchical administrative system (Wang *et al.* 2007). The Ministry of Water Resources (MWR) is at the highest central level directly under the State Council, with Water Resource Bureaus at the provincial, prefecture and county levels, and water management stations in townships at the lowest level of administration. Water Resource Bureaus at the provincial, prefecture and county levels are controlled jointly by the respective government at the same level and the MWR. Irrigation districts administer water resources that span lower-level administrative boundaries. This system of water administration is supplemented by seven river commissions, including the YRCC, which are administered by the MWR. However, many other agencies have retained direct or indirect responsibilities for water management such as bureaus or agencies of construction, land resources, environmental protection, energy resources, meteorology and finance, key among which are the State Environmental Protection Agency and the Ministry of Energy Resources.

In this environment, local governments tend to focus on maximizing local revenues and economic growth subject to given requirements for grain self-sufficiency, rather than focusing on conserving scarce water resources. Thus, water administration and management generally see their priorities to achieve these local goals. The often contradictory objectives of the various water, agriculture and energy agencies continue to hamper integrated water resources management in China and the YRB. For example, while the YRCC is authorized by the State Council of China to control Yellow River water resources, some provinces have continued to withdraw water in excess of agreed-upon quotas without penalties. The recent Yellow River Water Regulation Act (2006) allows for punishment of those provinces that exceed their water quota, but provides no implementation mechanisms. Furthermore, the YRCC has focused on integrated surface water management on the mainstream, while most tributaries and groundwater remain without integrated management. Since 2006, YRCC has assumed some control over two key tributaries, the Weihe and Qinhe.

A cross-provincial water allocation agreement was developed in 1987 and has been enforced by YRCC since 1999 to counteract the downstream flow cutoffs in the basin as discussed earlier (see Table 1). The Agreement distributes a total of 37 km$^3$ across the riparian provinces, including 2 km$^3$ to downstream urban-industrial centres outside the basin area.

## What is the role of water development in the YRB for poverty reduction and agricultural and economic development?

To assess the role of water development for poverty alleviation and agricultural development in the YRB, we used income data from the 2001 household income and expenditure survey conducted by the National Bureau of Statistics of China. No later data were available. Because we used the international purchasing power parity (PPP) exchange rate with 2005 as the base year, we adjusted per capita income data from the 2001 survey for inflation using the consumer price index for China, with the base year 2005 = 100. The data set used for the analyses represents the rural communities and households in the YRB and included 5085 households in nine basin provinces (Ahmed *et al.* 2009).

Based on the PPP US$1.25 a day poverty line and current per capita levels of income, 30.5% of the population in the rural regions of the YRB were living in poverty in 2001. The poverty rate was highest in the mountainous areas far from the mainstream and lowest on the plains. The poverty rate in the upstream area (47.5%) is nearly five times higher than that in the downstream area (only 9.9%), while the rate in the midstream area (29.6%) is three times higher. The headcount poverty rate ranged from a high of 52.2% in the upstream province of Gansu in western China to a low of only 3.1% in the downstream province of Shandong.

There is a direct empirical link between irrigation development and poverty reduction and agricultural and economic development in the basin. The US$1.25 a day headcount poverty rate was significantly lower in irrigated areas than in non-irrigated areas of the YRB region: while 19.4% of all households living in irrigated villages are poor, the rate was more than double (41.4%) in villages without irrigation. Figure 2 shows the concentration of non-poor in irrigated villages, such as Shandong, Inner Mongolia and Henan provinces, whereas Gansu and Qinghai are provinces with the lowest share of population in irrigated villages and also the highest levels of poverty among the nine provinces sharing the YRB.

The percentage of households using electric tubewells for irrigation increases considerably from upstream to midstream areas, and increases dramatically from midstream to downstream areas. However, village-level coverage of surface irrigation reveals a rather different pattern with the largest share of cultivated land being irrigated in the midstream area. The patterns of surface irrigation and tubewells suggests that households living in the downstream area rely on groundwater for irrigating their crops, as a result of increased flexibility and reliability of the resource, particularly following the implementation of the UWFR.

A further indicator of the role of water development for agricultural and rural economic growth is the school enrolment rate. The gap in enrolment between the poor and the non-poor is smaller in irrigated villages than in non-irrigated villages. This indicates that the availability of irrigation at the community level is not only associated with increased school enrolment in the community, but the improvement also seems to benefit the poor more than the non-poor.

Irrigation also contributes to improved access to safe drinking water in the YRB. In irrigated villages 78% of households have access to safe water compared to only 47% in non-irrigated communities. While the difference in access to safe water between poor and non-poor is 16 percentage points in non-irrigated villages, it is only three percentage points in irrigated villages. These findings have important policy implications, as access to safe water is critical for improved health and nutrition, particularly for children.

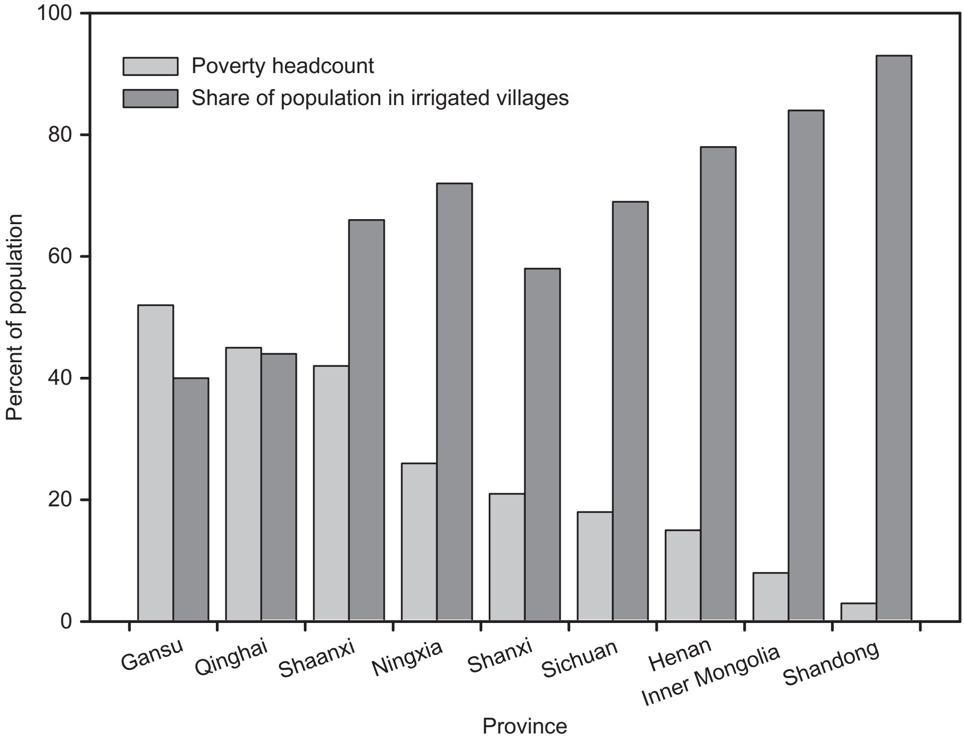


Figure 2. Headcount poverty and share of population living in irrigated villages.
Source: The authors.



The relationship between irrigation coverage and agricultural productivity is direct and very strong. Higher irrigation coverage of cultivated land at the village level is associated with greater crop productivity. Yields of various crops grown in the YRB are substantially higher in irrigated villages than in non-irrigated villages, particularly for rice (although rice only accounts for 2% of total crop area). Yield of rice in irrigated villages reached 7.2 tons/ha compared to 3.3 tons/ha in non-irrigated villages. Furthermore, the shares of land under high-yielding varieties (HYVs) of wheat and maize, the two main crops grown in the YRB, increase considerably with higher coverage of irrigated land. Cultivation of HYVs of crops is more capital-intensive than traditional varieties, but irrigation takes much of the risk out of crop production as the dependence on rainfall is reduced and encourages farmers to invest more in seed and other agricultural inputs.

Coverage of surface water for irrigation is a statistically significant determinant of per capita household income. Results suggest that a 10% increase in village-level coverage of surface irrigation increases the per capita income of households living in that village by 1.7%, on average. Furthermore, increasing irrigation coverage by 10% reduces the incidence of poverty by 5.1%. As expected, irrigation gives a higher marginal return in communities where rainfall is relatively low.

While expanding irrigation has a large impact on reducing poverty, we also found large and positive effects caused by increasing the opportunities to earn off-farm income in the rural YRB. Our econometric analyses show that the headcount poverty rate declines by 4.5% if the share of non-farm income in total per capita household income increases by 10%.

**Addressing water scarcity in the YRB: options and investment needs**

Improved water use efficiency, particularly in irrigated agriculture, but also for domestic and industrial uses, is key to meeting future growth in the demand for water for sustained agricultural and economic development. Water-use efficiency can be increased through engineering, agronomic, institutional and economic measures. More recently, economic and institutional means have become more important. When implemented appropriately, economic incentives for water management (prices, taxes, subsidies, quotas and use or ownership rights) can affect the decisions made by water users and motivate them to conserve and use water more efficiently. Efficiency pricing works well in the domestic and industrial sectors, but it is much more challenging for irrigation as price increases are often punitive to farmers because water is a large input to generally low-value production. This is particularly so in China where much of the irrigated area produces basic grains.

In the past, increasing the supply of water through new water development has been a common strategy to address water shortages. However, in maturing water economies, which are characterized both by increasing scarcity of water (Randall 1981), and by increasing transfers of water both in scale and amount, managing the demand for water becomes more important. The task of demand management is to generate both physical savings of water and economic savings by increasing the output per unit of evaporative loss of water, by reducing water pollution, and reducing non-beneficial water uses. This can be supported through a variety of policy measures, including economic incentives to conserve water, for example, through pricing reform and reduced subsidies. Other demand-side measures include regulations on the rights to use water, education campaigns, leak detection, retrofitting, recycling and other technical improvements, enhanced pollution monitoring, and quota and licence systems. While many measures of demand management have targeted irrigation as the largest water user, municipal and industrial water use cannot be allowed to grow unchecked. Regulation and economic incentives are needed to reduce the negative ecological, economic, and social impacts of these uses, especially on water quality.

Given the size of the YRB, no single intervention could possibly do justice to the extreme diversity of water-related challenges found in the basin, which ranges from the upstream mountainous areas dominated by livestock herders, to the hilly/mountainous Loess Plateau with severe erosion challenges, the semi-arid to arid irrigated plains in Inner Mongolia/Ningxia with rapidly growing industries, to the key urban-industrial centres interspersed with highly productive irrigation downstream.

Many interventions have been implemented in the past to increase water supply and enhance flood control. Key among these are the construction of the Xiaolangdi reservoir, completed in 1999, which has increased the designed flood-control period from 60 years to over 1000 years (Cai and Rosegrant 2004); the construction of several thousand silt-trap dams across the Loess Plateau (Brismar 1999); and two large watershed rehabilitation projects implemented by the government of China and the World Bank (World Bank 2003, 2007).

Additional interventions in recent years to address growing water shortages and the need for food include the conversion of hillside production into terraces (this was also done as part of the watershed rehabilitation project); rainwater harvesting schemes in the western upland areas; the use of plastic sheeting to contain soil moisture and reduce evaporation in the arid parts of Inner Mongolia and Ningxia; and the resettlement of people out of extremely dry areas.

***Technical solutions: role of engineering measures and enhanced water productivity***

The south-to-north water transfer (SNWT) project, if fully implemented, would be the largest engineering feat to date to address water challenges in northern China and the YRB. The SNWT was planned in the 1950s and officially launched in 2002. Once completed, it could transfer up to 50 km$^3$ (comparable to total Yellow River runoff) a distance of more than 1000 km, from the Yangtze River in southern China, to the North China Plain. A western, middle and eastern route have been planned and work is progressing on the technically and economically more feasible middle and eastern routes.

The general objective of the project is to sustain economic growth in northern China (Yang and Zehnder 2005, Pietz and Giordano 2009). The objective of the middle and eastern routes is to provide water for water-short regions in the Haihe and Huaihe River basins, particularly Beijing, Tianjin, Hebei, Henan and Shandong, with limited impact or benefit for the YRB. Due to the high (and increasing) construction cost, the price of water delivered through the SNWT could easily surpass the estimated "affordable" price of US\$0.70/m$^3$. The western route, on the other hand, could transfer 20 km$^3$ to irrigate an additional 1.3 million ha and provide water for economic development in Qinghai, Gansu, Shanxi and Shanxi provinces, as well as Ningxia and Inner Mongolia, all in the YRB. However, economic, engineering and ecological side effects prevent this route from development in the foreseeable future.

Even without the SNWT, engineers at YRCC still see some potential for water savings in the basin, amounting to 5.7 km$^3$ by 2020 and 7.6 km$^3$ by 2030, mostly in the agriculture sector. According to their calculations, water savings in agriculture of 4.0 km$^3$ by 2020 and 5.4 km$^3$ by 2030 can be achieved through adjustments in planting dates and crop species, crop yield improvements and lining of canals. These calculations take into account continued agricultural and economic growth and allow for small increases in irrigated area. Furthermore, the industrial sector is expected to reduce its water use by 1.5 km$^3$ by 2020 and by 2.1 km$^3$ by 2030 through increased water reuse and recycling. In the domestic sector, potential water savings have been estimated at 0.12 km$^3$ by 2020 and 0.17 km$^3$ by 2030 for the YRB, chiefly through increased leak detection and other efficiency-enhancing programmes and disconnection of illegal users.

As the simulations for climate change presented earlier show, these savings will not be sufficient to turn around trends of growing water deficits in the basin, particularly in dry years. Thus, even more investment in agricultural research and development will be needed to achieve even more rapid improvements in crop yields without use of more irrigation water; this is the current focus of the Chinese government as we discussed above.

To assess water productivity (WP) further across the YRB for key rainfed (WPR) and irrigated (WPI) crops, we used data from 60 counties from the upstream, midstream and downstream basin areas (including downstream areas irrigated outside the hydrologic boundaries), and extrapolated the results to the entire basin. We then assessed the spatial variability of water productivity as well as associated water and energy factors with regard to climate, land cover and agricultural practices (Cai *et al.* 2010).

All crops of rice and wheat receive some form of irrigation in the YRB.[2] Wheat grows during the winter–spring season, during which precipitation is less than 30% of the crop water requirement. In contrast, about 11% of maize and 17% of soybean area are rainfed. Table 3 presents average values of irrigated and rainfed area and yield by basin area. While irrigated maize yields are, on average, 77% higher than rainfed yields, basin-wide average soybean yields are similar for both rainfed and irrigated areas.

Table 3. Irrigated and rainfed area and yield of key crops by sub-basin in the YRB.

| | Crops | Basinwide | Midstream | Downstream |
|---|---|---|---|---|
| Irrigated area (000 ha) | Rice | 25.3 | 13.0 | 12.3 |
| | Maize | 540.2 | 254.3 | 284.9 |
| | Wheat | 1141.0 | 536.4 | 597.7 |
| | Soybean | 149.6 | 80.6 | 69.0 |
| Rainfed area (000 ha) | Rice | 0.0 | 0.0 | 0.0 |
| | Maize | 68.8 | 30.3 | 37.9 |
| | Wheat | 0.0 | 0.0 | 0.0 |
| | Soybean | 30.1 | 14.3 | 15.8 |
| Irrigated yields (ton/ha) | Rice | 5.4 | 5.5 | 5.3 |
| | Maize | 5.3 | 5.0 | 5.7 |
| | Wheat | 3.7 | 2.8 | 4.4 |
| | Soybean | 1.4 | 1.2 | 1.7 |
| Rainfed yields (ton/ha) | Rice | n/a | n/a | n/a |
| | Maize | 3.0 | 1.9 | 4.0 |
| | Wheat | n/a | n/a | n/a |
| | Soybean | 1.4 | 1.0 | 1.9 |

Source: Authors.

Table 4. Area-weighted WPI and WPR for different regions in YRB.

| | WPI (kg/m$^3$) | | | | WPR (kg/m$^3$) | | | |
|---|---|---|---|---|---|---|---|---|
| Region/Crops | Rice | Maize | Wheat | Soybean | Rice | Maize | Wheat | Soybean |
| Basin-wide average | 0.50 | 0.97 | 1.39 | 0.26 | – | 1.09 | – | 0.41 |
| Standard deviation | 0.25 | 0.32 | 0.51 | 0.13 | – | 0.36 | – | 0.16 |
| Midstream | 0.49 | 0.94 | 1.16 | 0.26 | – | 0.68 | – | 0.28 |
| Standard deviation | 0.22 | 0.33 | 0.49 | 0.13 | – | 0.35 | – | 0.15 |
| Downstream | 0.51 | 0.99 | 1.57 | 0.27 | – | 1.41 | – | 0.52 |
| Standard deviation | 0.26 | 0.30 | 0.34 | 0.12 | – | 0.33 | – | 0.12 |

Source: Authors.



Using the cropped area as a weighting factor, we interpolated irrigated and rainfed water productivity to the entire YRB. Table 4 presents the results for upstream, midstream and downstream areas. Results fit the range of values previously published by Zwart and Bastiaanssen (2004), who reported water productivity values of 0.6–1.6 kg/m$^3$ for rice, 1.1–2.7 kg/m$^3$ for maize, and 0.6–1.7 kg/m$^3$ for wheat. While values of water productivity for rainfed and irrigated crops are quite different in the midstream basin, they are similarly high in the downstream area.

It is interesting to note that WPR for maize and soybean is slightly higher than WPI in the downstream area and also for soybean in the midstream basin. This implies that in parts of the basin, irrigated maize and soybean may not be as water-efficient as rainfed crops. This is likely a result of inefficient water use (i.e. the divisor in the equation is higher than it should be). The standard deviation of the WPR data is higher than that of the WPI data. Thus, irrigation stabilizes crop yield and production, which is important under increasing climate variability and climate change.

While there is still scope for increased water-use efficiency in irrigated agriculture in the YRB (National Bureau of Statistics of China 2003, Yang *et al.* 2003), the scope is limited and further declines in allocation of water to irrigation will eventually result in reduced

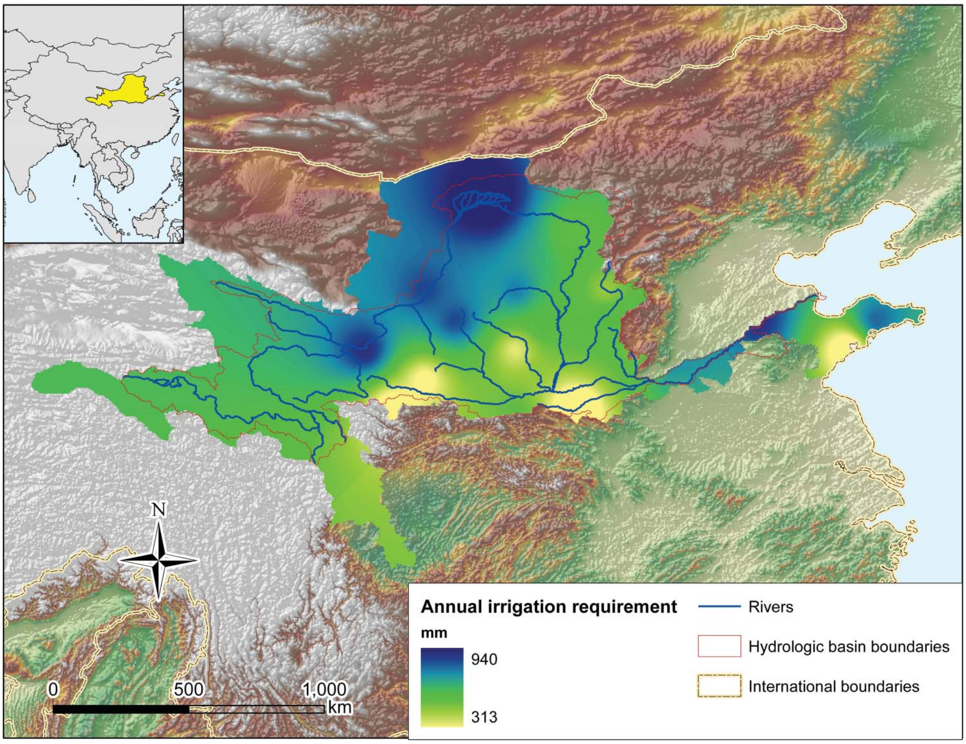


Figure 3. Irrigation requirement in the Yellow River basin.
Source: The authors.

food production with serious implications for local food security and farmer incomes, as well as potential impacts on global food prices and trade.

Figure 3 is a map of annual requirements for irrigation water for the YRB, computed as reference evapotranspiration minus precipitation, summed over the crop season. The spatial pattern of irrigation water requirements mirrors the location of irrigated areas in the basin. The highest requirement for irrigation water in the northwestern part of the midstream basin is close to one metre. The map clearly demonstrates that irrigation is and will continue to remain a major factor for agricultural production if the goals of food production are to be achieved.

### *Institutional solutions: irrigation management reform*

Despite high levels of water scarcity in the country and in the YRB, integrated water management in China remains elusive as a result of fragmented management and conflicts among water users at the national, provincial and local levels. Key challenges in Chinese water legislation and administration relate to the lack of regulations supporting implementation of the 2002 water law, and poor incentives for water conservation at the level of the irrigation system. To address growing water scarcity, in addition to water supply/engineering measures, the government has started to support reform of irrigation management.

At the level of the irrigation system, reform since the early 1990s has successively established water-user associations (WUAs) and contractors (hired technical experts) in place of collective management (water allocation through village leadership) to enhance irrigation management. A survey of irrigation districts in Ningxia and Henan provinces in 2001 and 2005 showed that by 2004, 30% of villages managed their water under contract and 21% through WUAs. However, 85% of WUAs still used the village leadership as governing board, at least in their initial set-up.

The key difference for water conservation outcomes was not the type of administration but the type of incentives. Our econometric analysis showed that regardless of the water management institution, managers who faced positive incentives – typically receiving direct compensation for reducing water applications below estimated targets – were able to reduce water use per hectare of wheat by nearly 1,000 m$^3$, or 20%, in the sampled irrigation districts, but wheat yields also declined by approximately 4%. Results were statistically inconclusive for maize and rice. While changes in institutions and incentives have successfully reduced water applications in the YRB, the sustainability of these measures remains doubtful. This is because the savings provide limited benefits to local governments and farmers when the water is transferred to other provinces without compensation. One way to address compensation is through a system of transfer of water rights as discussed below (Wang and Zhang 2009).



### ***Economic solutions: role of water pricing and water markets***

#### *Water pricing*

China has gradually moved toward efficiency-oriented policies of water pricing as a method to help rationalize water allocation and alleviate water scarcity for both the urban and irrigation sectors. Generally, water pricing is instituted to (1) create incentives for efficient water use; (2) recover costs of water service provision; and (3) ensure financial sustainability for water supply systems and irrigation, including the ability to raise capital for expansion of services to meet future demand. In water-scarce economies, such as the YRB, the efficient allocation of water across sectors is also an important consideration.

Although water prices have been steadily raised over the past several decades in China, and particularly since the latest round of water-pricing reforms started in 1997, agricultural water is still thought to be much under-priced. As a result, water charges remain a limited instrument to increase water use efficiency and productivity further (Wang and Zhang 2009). Moreover, given the growing rural–urban income divide, it is unlikely that the government will raise irrigation fees to levels high enough to reduce irrigation water use seriously (Rosegrant and Cai 2003). Furthermore, in the YRB, the UWFR has led to income shortfalls of districts in parts of the basin where irrigation water supplies were cut considerably, particularly in midstream provinces. To make up for water shortfalls, these provinces were allowed to increase irrigation service fees. For example, Ningxia doubled the price of the service charge for irrigation to 0.012 RMB/m$^3$ (US\$0.002/m$^3$) in 2000 (Wang *et al.* 2003). Downstream provinces, on the other hand, have generally maintained lower and simpler area-based fee structures.

#### *Water rights, markets and transfers*

Clearly defined and legally enforceable water rights and responsibilities for water operators and users in an irrigation system are the foundation underlying the incentives for conserving water and improving irrigation efficiency (Bruns and Meinzen-Dick 2000, Yang *et al.* 2003). The establishment of systems of water-use rights could empower water users in all sectors, as it establishes both rights and responsibilities to specified water use. If water is allocated to other sectors, typically urban and industrial, irrigators and other users would need to be compensated. Moreover, establishing water rights can serve as an incentive to invest in productive water uses, as they convey security to use water for a prolonged period. Furthermore, water-use rights provide incentives for all sectors to invest in water-saving technologies, as water outside of the existing water use right would have to be bought and paid for (Rosegrant and Binswanger 1994, Rosegrant *et al.* 2009b).

China does not currently have formal water markets that are supported by transparent and universal water property rights. There are, however, non-market mechanisms for assigning water-use rights and allocating water in China. Usufructuary rights to water use have evolved either explicitly through laws and regulations or implicitly through conventions (Ma *et al.* 2007). These rights are generally assigned based on one of three systems: first-come first-served allocation (prior appropriation rights); allocation based on proximity to water bodies ("riparian" rights); and public allocation (Heaney *et al.* 2006). Moreover, as discussed above, the government of China has released several regulations supporting water trading.



Since 2000, YRCC has promoted the establishment of water-right systems by conducting demonstration projects aimed at reducing water competition among sectors. The purpose of these demonstration sites is to reallocate water from agriculture to industry through increasing irrigation efficiency, generally through engineering measures, such as canal lining (Wang *et al.* 2006, Chen *et al.* 2007, Li 2007, Liu *et al.* 2007, Wang 2007). One transfer pilot project operates in Ningxia Province and 16 projects signed transfer contracts in Inner Mongolia, with a value of US$100 million. Under these projects, irrigation districts transfer part of their water use rights to industrial enterprises for a period of 25 years. However, analyses showed that water users in the irrigation districts are generally not aware of the water rights transfer; transfers are determined by the administration, not markets, and there are no adjustments based on market signals or economic measures. Thus, major challenges remain until a true market for water rights can be established.

The intra-provincial irrigation-to-agriculture transfers in the YRB provide important inputs for the potential development of inter-provincial water trading, which has been discussed by both policy makers and water allocation managers at the MWR and YRCC for several years. Such a reallocation could increase the water allocation efficiency of the 1987 cross-provincial water allocation agreement. Upstream provinces have a strong interest in maintaining the *status quo* in water allocation, however, and thus avoid the political costs of changing the current allocation. Moreover, given the large share of return flows in the YRB, changes in provincial permits from upstream to downstream might be inconsequential. It is therefore important to assess the full costs and benefits of changing the current system of water quotas.

Heaney *et al.* (2006) assess the benefits of water reallocation across YRB water resource regions using a production-function approach without accounting for the river hydrology (flow routing or return flows). They estimate economic benefits through increased value of agricultural production at 1 billion RMB per year, with reallocation chiefly occurring from the midstream to the downstream area. The authors caution, however, that for the benefits to be reaped, in addition to administrative challenges, new agricultural areas and labour would need to be made available downstream.

The most successful administrative water transfer to date in the YRB was the enforcement of the UWFR that ensured that flow to the Yellow River mouth was not cut off after 1999. This policy was in line with the refocus, over the last decade, on sustainable water use and keeping the Yellow River "healthy" promoted by the government of China. However, as we pointed out above, no compensation was paid to those provinces and water users that had to give up water as a result of the enforcement of the 1987 agreement.

Given the key importance of compensating irrigators for giving up water for both flows at the river mouth and rapid urban–industrial development downstream, we analyse the potential impact on basin GDP of water rights trading using a multi-agent system (MAS) modelling framework developed for the YRB (Yang *et al.* 2009). The model is populated with aggregated data from the YRCC water simulation model. A total of 52 water-use agents are defined, nine for the provinces sharing Yellow River flows, three to reflect downstream ecological needs, five to represent key reservoirs, and the reminder to represent key tributaries and inflows. The model is calibrated to 2000 data. Using the MAS model, we compared two scenarios to evaluate the consequences of changes from the current scheme of water allocation (business-as-usual of the current UWFR based on the 1987 allocation agreement): (1) water allocation across provinces without quotas; and (2) a market-based approach of water allocation for irrigation.

Under the UWFR, YRCC determines targets of monthly water releases for each of the major reservoirs on the main channel, based on the current reservoir storage, the future weather forecast, and the downstream water demand. The scenario without regulation assumes no administrative allocation mechanisms; agents are free to maximize water use subject to available resources. Thus, upstream water users will maximize off-takes, leaving less water available for downstream users; similarly, reservoir agents will maximize hydropower generation. The water rights trading scenario uses the UWFR as an initial water entitlement, based on which water can be traded among agents. To avoid adverse impacts on the downstream ecosystem, minimum downstream flows achieved under the UWFR scenario are set as constraints.

Figure 4 compares business-as-usual with the second scenario without any allocation rules for both water consumption and gross domestic product (GDP). Overall annual water consumption under the scenario without regulation is 38.3 km$^3$, 11% higher than the 34.5 km$^3$ under the UWFR scenario. The system-wide GDP is 1123.26 billion RMB under the scenario without regulation, 10% less than the 1246.68 billion RMB from the UWFR scenario. As expected, impacts on downstream ecosystem agents from unmanaged flows are considerable. For the most downstream ecosystem agent, flow stoppages start in February and continue through December, reflecting reality from 1972 to 1998 before the UWFR was enforced (Zhao *et al.* 2009). On the other hand, water consumption declines and GDP increases under the UWFR. For example, upstream GDP declines by 2.5 billion RMB annually, without compensation.

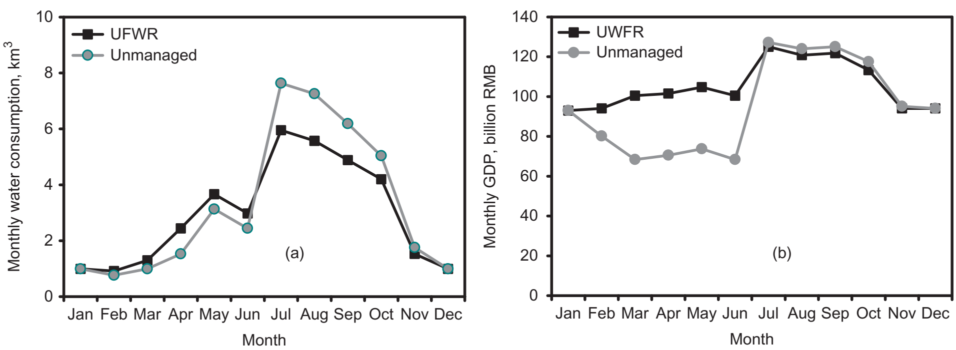


Figure 4. System-wide comparisons between UWFR scenario (baseline) and unmanaged scenario in (a) monthly water consumption; (b) monthly GDP.
Source: The authors.

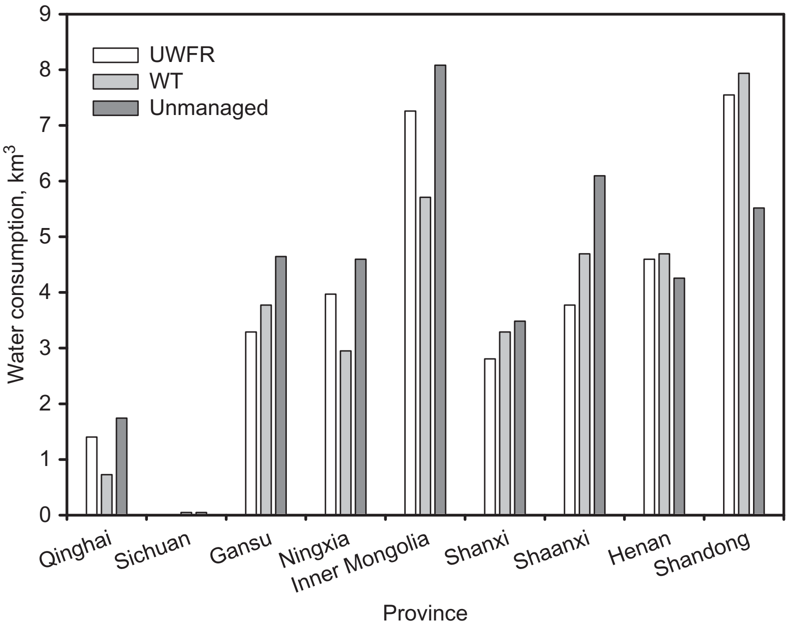


Figure 5. Water consumption in the YRB under alternative allocation scenarios.
Note: Provinces are shown from upstream to downstream.
Source: The authors.

The water trading scenario allocates priority for water use to the manufacturing and industrial (M&I) sector, after which trading can occur among irrigation sites across provinces. To ensure that the UWFR allocation to the downstream ecosystem is maintained, minimum downstream flows are included as hard constraints. Figure 5 presents total water consumption across provinces for the UWFR baseline as well as for the unmanaged and the water trading scenarios. Compared to the UWFR, water depletion increases upstream under the unmanaged scenario that basically supports maximization of withdrawals upstream. Under UWFR, on the other hand, water flows toward the downstream areas increase significantly, supporting much higher withdrawals in Shandong province, for example. Thus, the water-trading scenario follows prescribed withdrawals downstream to support the ecosystem agents, but also reallocates water from Inner Mongolia and Ningxia to Shanxi, Shaanxi and Gansu provinces.

Generally, water-trading prices are higher in low-flow months and highest in tributaries, as water transactions from the mainstream into tributaries is not feasible. Furthermore, the monthly water consumption with agents under the water price scenario is lower than that under UWFR, saving a total of 0.73 km$^3$. The annual GDP from the trading scenario is 1270.1 billion RMB, compared to 1246.7 billion RMB under UWFR, an increase by 23.5 billion RMB. GDP for individual agents is either the same or higher than that under UWFR. The GDP increase is 5.64 billion RMB for upstream agents and 17.8 billion RMB for midstream and downstream agents. Overall more water is sold than is bought in all months. Water without an agent buyer is purchased by the government to support ecosystem flow requirements. The annual total transaction costs (the sum of the water price multiplied by the amount of actual water transactions) is 2.95 billion RMB. This amount could be interpreted as a maintenance cost that the government has to pay to prevent flow stoppages otherwise occurring at the river mouth.

In summary, compared to the baseline scenario with UWFR, the scenario without regulation results in higher water consumption and lower GDP, and significant flow cutoffs at the river mouth. The water-trading scenario, on the other hand, results in a small decline in water consumption, combined with a significant increase in GDP. GDP, basically for agriculture, increases by 1.9%, which compares well with results of Heaney *et al.* (2006), even though they did not model the basin hydrology. GDP increases would be much higher if M&I would not receive first priority and thus would become an active water-trading sector.

## Conclusions

The government of China has recognized the severe water constraints in the YRB. To address growing water scarcity, the government has started to change its approaches from management of water supply toward improved management of water demand. Signs of the new approaches are the 2002 water law, the increased number of regulations on water prices and a series of water trading pilots implemented in the YRB. However, most organizations concerned with water management are still headed and staffed by engineers, and traditional water-engineering measures, as exemplified by the SNWT, still dominate interventions in terms of funding.

There is no panacea for addressing the severe water scarcity challenges in the YRB. Based on an assessment of options available, we believe that the government should continue to reform the institutions responsible for irrigation management and water pricing across all water-using sectors, but current users need to be compensated for ceding water resources to users with higher-valued uses. Projects that transfer enhanced water rights that follow market mechanisms, and include the establishment of water rights and related responsibilities would be a first step in that direction. Reform is also required at all the administrative levels from the central to the local government to support fully integrated land and water management at the basin level and to avoid large inefficiencies caused by conflicting objectives of the various agencies involved in water supply and food production in the YRB.

Expanding irrigation in the YRB will help boost crop yields, which in turn will increase incomes of the poor and reduce poverty. However, the potential for expanding irrigation is limited, and labour productivity is known to be lowest in agriculture. Therefore, accelerating a shift of the rural labour force out of agriculture by creating off-farm employment opportunities in higher-productivity sectors in rural areas is arguably even more important for future rural economic development.

Other ancillary measures that need to be continued include further adoption of water-saving technologies, and continued support to agricultural research and development to increase crop productivity for both irrigated and rainfed crops. Continued productive investment is needed, rather than subsidies, in the rural non-farm sector to ensure that the urban-rural poverty gap does not widen even further. There is still scope for savings of agricultural water through improved water productivity. But continued transfers of water out of agriculture will eventually result in declining production, with implications for national food production as well as global food prices and trade.

## Acknowledgement

This study forms part of the Consultative Group on International Agricultural Research Challenge Program on Water and Food.

## Notes

1. HadCM3 stands for United Kingdom Meteorological Office Hadley Centre's Coupled Model, version 3. The B2 storyline and scenario family characterizes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with slowly increasing population and intermediate economic development. It is considered a very moderate scenario.
2. While in government statistics some wheat areas are shown as rainfed, these areas generally have access to water harvesting facilities, ponds or groundwater. Based on our methodology, we classified them as irrigated.



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