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China's Agricultural Water Policy Reforms

Increasing Investment, Resolving Conflicts, and Revising Incentives

Bryan Lohmar
Jinxia Wang
Scott Rozelle
Jikun Huang
David Dawe

China's Agricultural Water Policy Reforms: Increasing Investment, Resolving Conflicts, and Revising Incentives. By Bryan Lohmar, Jinxia Wang, Scott Rozelle, Jikun Huang, and David Dawe, Market and Trade Economics Division, Economic Research Service, U.S. Department of Agriculture. Agriculture Information Bulletin Number 782.

Abstract

Water shortages in important grain-producing regions of China may significantly affect China's agricultural production potential and international markets. Falling ground-water tables and disruption of surface-water deliveries to important industrial and agricultural regions have provoked concern that a more dramatic crisis is looming unless effective water conservation policies can be put into place rapidly. While China's water use is unsustainable in some areas, there is substantial capacity to adapt and avert a more serious crisis. Recent changes in water management policies may serve to bring about more effective water conservation. This report provides an overview of these changes and some analysis of their effectiveness. Wheat is the most likely crop to show a fall in production due to water shortages, but cotton, corn, and rice may also be affected.

Keywords: China, irrigation, policy, reform, agricultural production and trade.

About the Authors

Bryan Lohmar is an economist at the Economic Research Service, United States Department of Agriculture, Washington, DC, USA; Jinxia Wang is a postdoctoral scientist at the International Water Management Institute, Sri Lanka, and an associate professor at the Center for Chinese Agricultural Policy, Chinese Academy of Sciences; Jikun Huang is the director and a professor at the Center for Chinese Agricultural Policy, Chinese Academy of Sciences; Scott Rozelle is an associate professor, University of California, Davis, CA, USA; and David Dawe is an economist at the International Rice Research Institute, Los Baños, Philippines.

Please contact Bryan Lohmar with questions or comments at blohmar@ers.usda.gov.

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Contents

Summary

Water shortages in important grain-producing regions of China may significantly affect China's agricultural production potential and international markets. Falling ground-water tables and disruption of surface-water deliveries to important industrial and agricultural regions have provoked concern that a more dramatic crisis is looming unless effective water conservation policies can be put into place rapidly. Opinion over how these problems will affect agricultural production varies. As the world's largest agricultural producing country and the largest producer of major commodities that rely heavily on irrigation (wheat and cotton, for instance), China's success or failure to address water problems effectively could have major impacts on international trade of agricultural commodities. Recent changes in water management policies may serve to bring about more effective water conservation.

Whether China's water problems will affect agricultural production will depend on whether China's water management and policy institutions can respond effectively. While some observers argue that China's current water exploitation portends a serious crisis that will disrupt agricultural and industrial production, many argue that China has a large capacity to adapt and avoid such a future water crisis. To do so, however, China must establish water management practices that encourage water conservation. Changes are underway at all levels of China's water management system, but a variety of issues may limit the effectiveness of current water policies and reform efforts.

This report provides an overview of the water problems facing agriculture in China and China's overall water management system.

Current water use is unsustainable in some areas. China has a large water resource endowment on an absolute level, but it is small on a per capita basis (about one-fourth the world average) and geographically dispersed. In areas of northern China, where per capita water availability is one-tenth the world average, water use exceeds supply and there are ample signs of diminishing water resources such as falling water tables and receding surface-water supplies. These problems are most acute in three north-central river basins: the Hai, the Huai, and the Huang (Yellow) River Basins.

China's water management system is a complex arrangement of bureaucracies that sometimes have divergent interests. To manage national water supplies, China has charged several different agencies with duties that sometimes overlap. For example, urban water deliveries are managed mostly by Urban Construction Bureaus, while agricultural water deliveries are managed by local Water Resource Bureaus (under the Ministry of Water Resources) even if the water is from the same source. This institutional arrangement hinders the rapid establishment of policies to promote water conservation. Current reforms seek to centralize China's water management system in order to more effectively address water conservation.

The report also describes recent institutional and policy changes in China's water management regime, such as renewed investment in water storage and delivery infrastructure, reform of water management bureaucracies to resolve conflicts, and establishment of better incentives for farmers and local water managers to conserve water.

Recent investment changes in irrigation systems will help restore surface-water systems and encourage better water management. Falling investment in surface-water infrastructure in the late 1970s and early 1980s is partly responsible for the decline in irrigated area (in the 1980s), poor surface-water management, and growing reliance on and competition for ground water. Recent policy changes increase investment in irriga-

tion systems, target these investments more toward maintenance rather than new construction, and establish better management practices to encourage financial self-sufficiency.

Private entrepreneurs and other non-collective interests are establishing ground-water delivery systems and changing the water management system economy in important grain-growing areas. In the Hai River Basin, where farmers depend on ground water more than elsewhere in China, non-collective interests are establishing wells and delivery systems. The growth in private investment is partly in response to the falling fiscal capacity of village collectives, as well as the better service provided by privately-owned systems. Non-collective well ownership has been linked with falling ground-water tables, but the nature and cause of the link is unclear. The falling water tables could be due to private interests exploiting a free resource for their own gain; an alternative explanation might be that falling ground-water tables provide an opportunity for private investors to sink deeper wells in order to restore irrigation.

A variety of policy changes are being introduced to address inter-regional conflicts. Inter-regional conflicts are often behind declining downstream surface-water deliveries. To enforce upstream withdrawal limits, reforms that strengthen the authority of agencies overseeing larger water systems that cross administrative boundaries are being established. These reforms are happening at all jurisdictional levels, from the national level with the National River Basin Commissions, down to more local levels such as within prefectures and counties.

China is experimenting with reforms to resolve conflicts between agricultural and industrial users. Since two-thirds of China's water goes to irrigation rather than to industrial or domestic use, water deliveries to agriculture limit the amount available for other uses when water becomes scarce. Industrial and domestic use can also affect agriculture: the discharge of untreated wastewater into surface-water systems can decrease the quality of water used in irrigation. To resolve these and other disputes, policy reforms to unify water management institutions around urban areas are being promoted. These changes, however, are difficult to implement since they take important decisionmaking roles away from established interest groups.

Water price increases may have only a minor role in agricultural water use. China has been increasing water prices to encourage water saving, but prices are still low for agricultural water users. Raising water prices further, however, will have adverse effects on farmers' already low incomes and directly counter an equally important policy goal—raising farm incomes. It is also unclear whether higher prices will have much direct impact on water conservation. While China does charge for water on a volumetric basis, these charges are paid by townships, villages, and irrigation groups, not farmers. Since the administrative entities that pay volumetric prices can be quite large, there may often be free-rider problems that mute the incentives for irrigation groups and farmers to implement water-saving technologies.

Water-saving irrigation practices and technology are not widely used. Farmers have only begun to adopt water-saving practices. Low levels of adoption may be because the incentives are not in place for farmers to benefit directly by saving water. In addition, the current extension system charged with promoting the adoption of water-saving technologies or practices itself faces poor incentives and low budgets to carry out this job. The system tends to promote technological solutions developed in the agricultural university system rather than technologies and simple practices appropriate for low-income farmers.

Reform of irrigation district management may be key to future water conservation. Irrigation districts are establishing a variety of management reforms to provide better service and to promote water conservation. The two most common reforms are the establishment of Water User Associations and contracting the management of lateral canals to individuals. Both these reforms seek to improve management by providing incentives for users and managers to conserve water and improve fee collection to increase irrigation district revenues. The effectiveness of these reforms varies, however, as they take different forms and are established in different ways from place to place in China.

Cropping patterns will likely adjust in response to new water management policies and more limited water deliveries, even if irrigated acreage is maintained. How farmers will adjust to the new environment depends on many factors, and a quantitative estimate of the changes to come is well beyond the scope of this report. It is clear, however, that yields and farmers' crop choices may be affected, particularly for wheat, rice, and in some cases, cotton—relatively low-value field crops that rely on irrigation in China. High-value cash crops may expand acreage in the face of water shortages since these are often more suited to water-saving irrigation practices, bring a higher return to water used in agriculture, and, since their production is usually more labor-intensive, use more of China's most abundant resource.

China's Agricultural Water Policy Reforms

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Introduction

Rapidly growing industry, increasingly productive farmers, and a large population with rising incomes all compete for China's water resources. The sustained high industrial growth rate over the last 20 years has caused a significantly higher proportion of China's water to be allocated to industrial production. The proportion of water allocated to residential users is also increasing, particularly as the number of urban residents and incomes grow. In addition to the growing nonagricultural demand for water, China continues to expand irrigated area. These trends have resulted in higher demand for water in agriculture, which is still by far China's largest user of water, despite the growing demand for water in other sectors.

Do the rapid increases in demand and competition for China's limited water resources add up to a pending water crisis in China? Some observers hold out dire predictions of China's future water problems (Brown and Halweil 1998). Other observers make more moderate predictions regarding the effects on China's agricultural production but still suggest that many agricultural producers may have to forgo irrigation (Crook and Diao 2000). Still others suggest that China's current water problems are only marginally serious and will likely be solved just as China has solved other "crises" in the past (Nickum 1998a). According to some observers, there is significant scope for "real water saving" in China, but this may not be true in some important agricultural regions such as the North China Plain (Molden and Sakthivadivel 1999).

All observers of China's current water situation agree, however, that the "crisis" has not yet manifested itself in a substantial loss of irrigated area or industrial production. Even the most pessimistic observers characterize the "crisis" as a rapid decline in water availability that, if left unchecked, will lead to a decrease in food production in the coming 20 years. Economically, to argue that a true water crisis exists in China, one must show that water deliveries have been disrupted or prices have risen to an extent that actually threatens economic activity. Disruptions of water deliveries have occurred in some areas but so far are not severe enough to affect aggregate production, either in industry or in agriculture.[1] Overall, irrigated area has expanded in recent years, and China plans to continue expanding this area. Industrial production has also grown rapidly in the past several years, even in the regions where water is relatively scarce. In addition, water prices, while higher than in other parts of Asia (Valencia et al. 2001), are still well below the marginal value of water use in each sector and the percentage of wastewater treated after use, while increasing, is not large. Thus, there would appear to be ample room to further increase water productivity and avert a more drastic crisis in the future.

Given the public-good nature of water and the role that the state will play in managing water, the real debate over the future severity of China's water problem comes down to a question of how well policymakers can respond to the various water-related issues confronting them. On the one hand, a review of the past trends of water demand and supply, and extrapolations into the future, may lead to pessimism. A linear extrapolation from the record of the annual decline in ground water from 1980 to 1996 suggests that groundwater resources on the North China Plain will be depleted by 2030 (Goodwin 1999). Even worse, since the rate of ground-water depletion increased over this period, depletion could come much earlier than a linear trend would predict if policies do not change. On the other hand, the experiences of other water-short societies provide optimism since, as water scarcities grow, users and policymakers adjust (Nickum 1998b).

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[1] But where water delivery disruptions have occurred, they have affected farmers, industry, and residential users.

The overall goal of this report is to provide a timely analysis of how China has managed water in the past, the challenges that the nation is currently facing, and the measures that have been implemented or are at its disposal to combat water shortages in the face of future rapid economic growth and rising demand for food. To meet this goal, we have three specific objectives. First, we briefly review the state of China's water resources and water policy in the early reform period. Next, we examine some of the main problems that are facing water policymakers in China, such as (1) the allocation and management of investments in water control infrastructure and maintenance, (2) the emergence of interregional and intersectoral water conflicts, and (3) the provision of incentives for producers and water users to adopt water conservation practices. Finally, for each set of problems, we track both how the actions of policymakers and users have led to these problems and how they have responded to them. In an attempt to solve water allocation problems, policymakers have reformed formal institutions, and water users have established informal institutions that provide better incentives to use water efficiently. In addition, we provide some insight into other measures that can be used to overcome water shortages and how they may affect agriculture.

China is big, and water policy is complex, so it is impractical to cover all water-related topics in one report. Most of this report focuses on a subset of problems and only one part of the country. We concentrate our efforts on the water-short north, which includes the three most water-stressed river basins– the Hai, Huai, and Huang (Yellow) Rivers (figure 1). In addition, we focus on problems that affect water availability for irrigation in agriculture. Agriculture uses twice as much water as all other uses combined, yet the value of water used in agriculture is lower than in the other sectors, so water availability for agriculture is closely tied to industrial and domestic water demand. The infrastructure that delivers water for irrigation, however, is usually also used for flood control, so this aspect of water management cannot be fully ignored in a discussion of irrigation policy. While we acknowledge these clear interrelationships, we do not provide a detailed description and analysis of flood control problems and industrial and domestic water demand. In addition, plans are underway to transfer water from the relatively water-abundant Yangze Basin to the water-poor Hai River Basin, but these plans still have several obstacles to work out such as pollution and inter-provincial water allocations from the project. Because of this, the projects may well take over a decade to complete and the water deliveries will be too expensive for use in agriculture. We therefore do not consider these transfers in this report.

Figure 1

Water-short river basins in northern China

Water Scarcity in China

China is not particularly well endowed with water, yet water has been used as a cheap resource to expand agricultural and industrial production. While China's water resources are substantial compared with those of other countries, its population is comparatively larger and its water is not evenly distributed across the country or across important agricultural regions. China ranks fifth in total water resources among the countries in the world, but, on a per capita basis, it is among the lowest. The nation's water resources are overwhelmingly concentrated in southern China, while northern China, the area north of the Yangtze River Basin, has one-fourth the per capita water endowment of the South and one-tenth of the world average (Ministry of Water Resources 2000). The lower levels of rainfall in north China are also much more seasonal than in the South, with more than 70 percent of the rain falling between June and September. Northern China, however, remains an important agricultural region and the site for much of China's industrial production. Although it has only 24 percent of the nation's water resources, northern China contains more than 65 percent of China's cultivated land. This region produces roughly half of China's grain (and nearly all of China's wheat and maize) and more than 45 percent of the nation's gross domestic product (GDP) (Ministry of Water Resources 2000, SSB 2000).

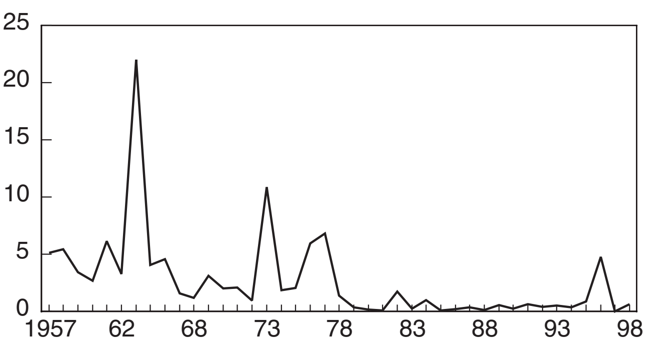
Increasing industrial output, expanding agricultural production, and rising domestic incomes have all contributed to the depletion of water resources in China. From 1949 to 1998, per capita use increased 130 percent, and total water use in China increased 430 percent (Wang 2000). Industrial use has increased at a much faster rate than agricultural use. The average annual growth in industrial water consumption was 8.6 percent over the period, compared with 2.7 percent for agriculture. Hence, from 1949 to 1998, the share of China's water resources consumed by agricultural producers fell from 97 percent to 69 percent. Industry's share rose from 2 percent to 21 percent, and domestic and other consumption rose from 1 percent to around 10 percent. Despite a slower growth rate, the absolute amount of the increase in agricultural water use is far greater than in industry over this period because industry started from a much lower base.

The rapidly rising nonagricultural demand for water is not the only problem facing agricultural water users in northern China. Water deliveries to agriculture are also threatened by deteriorating surface-water delivery infrastructure and by excessive withdrawals upstream. Large portions of China's physical water storage and transfer infrastructure, much of which was poorly built during the period of collective agriculture (1950s to late 1970s), are deteriorating rapidly. The availability of investment funds has lagged and has been generally geared toward new projects rather than maintenance of older projects. The river systems that supply water to many irrigation districts sometimes do not provide sufficient water because upstream users withdraw more water than they are allocated by law. Because of excessive withdrawals, the Yellow River has run dry before reaching the ocean for at least some period during most years since the mid-1970s. Withdrawals from the Fuyang River, in the upper part of the Hai River Basin, have severely depleted the main river. In 16 of the last 20 years, almost no flow was recorded at the Aixingzhuang hydrological monitoring station, near the middle of the river basin (figure 2). Cangzhou Prefecture, which is downstream from the Fuyang River, now receives only 10 percent of the surface-water that it received in the 1970s.

For many areas in northern China, increased agricultural water use and the related production increases have been partly due to easily exploitable ground water that has allowed farmers to irrigate a winter wheat crop in addition to another crop in the later summer season, usually corn, which relies mostly on the summer season's rainfall. By 1995, nearly 40 percent of water used in irrigation in the water-short areas of northern China came from ground water (figure 3). In important downstream provinces such as Hebei, Shanxi, Henan and Shandong, where much of China's wheat is produced, the share of ground water in irrigation use is even higher (68 percent in Hebei Province).

Figure 2

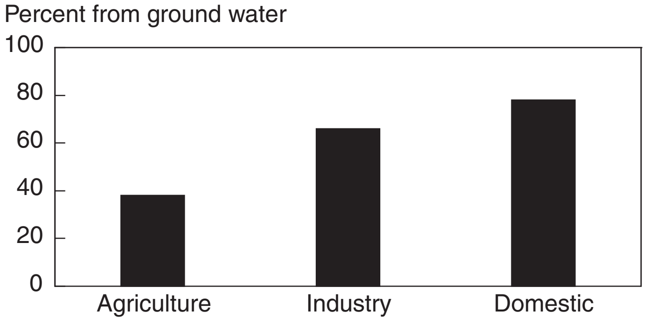
Fuyang River, volume of water flow measured at the Aixingzhuang hydrological monitoring station



Source: Wang and Huang, 2002b.

Figure 3

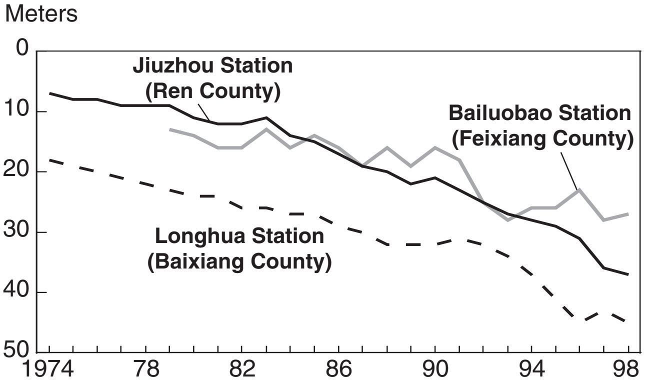
Reliance on ground water for water-scarce regions in northern China*



*Provinces in this category include Ningxia, Qinghai, Gansu, Inner Mongolia, Shanxi, Shaanxi, Shandong, Hebei, Henan, Beijing and Tianjin.
Source: Ministry of Water Resources, 1996.

Figure 4

Water table depth measured at three stations in the Fuyang River Basin, Hebei Province



Source: Wang and Huang, 2002b.

Ground water is also the primary source of water used in industry and for domestic consumption in many regions (Ministry of Water Resources 1995). In 1995, the share of industrial water deliveries that came from ground-water sources was above 60 percent in water-scarce areas of northern China, and was above 80 percent for some provinces (figure 3). China's water-scarce provinces also receive nearly 80 percent of their domestic water deliveries from ground-water sources.

Increasing demand, limited surface-water availability and reliability, and rising reliance on ground-water extraction have led to falling water tables and several other problems in northern China. For example, in several parts of the Fuyang River Basin, in Hebei Province, the shallow-water table fell at an accelerating rate over the past 20 years (figure 4). The deep-water table is declining at an even faster rate in some areas. The excessive rates of ground-water withdrawal have generated large cones of depression under urban areas in six Hebei Province prefectures: Handan, Shijiazhuang, Xingtai, Hengshui, Cangzhou, and Baoding municipalities.[2] Excessive water withdrawals and falling water tables have also caused land subsidence in some predominantly rural counties such as Henshui, Ren, and Quzhou (Hebei Hydrological Bureau and Water Environmental Monitor Center 1999).

Large extractions of ground water and the subsequent fall in the water table are also affecting the quality of ground water, particularly through the intrusion of seawater. A survey carried out in the coastal provinces of northern China in the early 1990s found that more than 2,000 km^2 of formerly fresh-water table had fallen below sea level (Nickum 1998a). Farmers, industrialists, and city water managers abandoned more than 8,000 tube wells, and irrigated area declined by 40,000 ha. While these losses represent only a small part of overall agricultural production in northern China, they do significantly affect local residents and some observers predict that, unless ground-water sources are allowed to replenish, the problems will increase at an accelerating rate.

China is starting to see the long-term effects of excessive water exploitation and is facing water-scarcity problems that might become a serious crisis in the near future unless policies are adopted and institutions emerge to avert such an event. Although water scarcity in northern China has been building for decades, it has only recently begun to affect the livelihoods of people and threaten the profitability of economic activity. In response, China has begun to address these problems at nearly all levels, from the national down to the village and farm levels. In some cases, progress is difficult to detect, but, given the length of time it took to create these problems, it is reasonable to assume that the solutions will also be difficult to implement and progress will be slow. To understand the actions taken by the government, local leaders, and individuals, we next examine the complex arrangements that govern how China recovers, stores, allocates, and manages its water resources.

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[2] A cone of depression is a natural occurrence that forms around a tube well when ground water is pumped to the surface. It refers to an area where the water forms an upside-down cone shape because the replenishing rate from the surrounding water table is slower than the withdrawal rate. In areas with heavy ground-water withdrawals, such as urban areas on the North China Plain, large cones can form under entire cities, not just around individual wells. In severe cases, these cones can result in land subsidence causing damage to urban buildings and infrastructure as well as reducing ground-water storage capacity.

China's Water Management Policies and Institutions

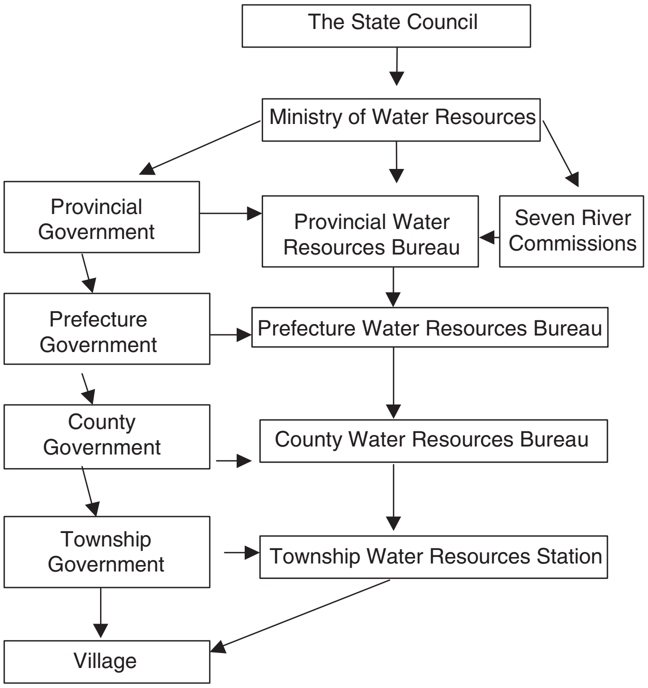
Over the past 50 years, China has constructed a vast and complex bureaucracy to manage its water resources (table 1). To understand the functioning of this system, it is important to first understand that, until recently, water saving has never been a major concern to policymakers. Instead, the system was designed to (1) construct and manage systems to prevent floods that have historically devastated the areas surrounding the major rivers, and (2) effectively divert and exploit water resources for agricultural and industrial development. Indeed, China's success in accomplishing this latter goal is largely why the nation faces water-shortage problems today.

Water policy is created and executed primarily by the Ministry of Water Resources (MWR). The MWR has run most aspects of water management since China's first comprehensive Water Law was enacted in 1988, taking over the duties from its predecessor, the Ministry of Water Resources and Electrical Power. The policy role of the MWR is to create and implement national price and allocation policy, and oversee water conservancy investments by providing technical guidance and issuing laws and regulations to the subnational agencies (figure 5). The national government invests in developing the water resources from all large rivers and lakes and projects that cover more than one province. Local governments are in charge of projects that are within their administrative districts. Historically, investment from national funding sources has been heavily biased toward new investments, while local governments have been responsible for maintenance funds.

Although much of China's water is still used by farmers in agriculture, the nation's water policy is becoming increasingly biased toward industry. Acting at the direction of the Water Law, the MWR gives priority to domestic, primarily urban, users (over agriculture and industry) in the allocation of all water. Provincial governments also have the power to allocate water based on their local priorities, a provision that has led many provinces to give industry a particularly high priority at the expense of agriculture. These policy biases apply mostly to new sources of water; water is actually taken away from agriculture only in isolated cases.[3]

Figure 5

The vertical and horizontal structure of the Ministry of Water Resources



Under the 1988 Water Law, the MWR is not solely responsible for all water-related policies; other ministries in China also influence water policy for both rural and urban areas. The diverse uses of water and diverse objectives and interests of water management agencies often result in conflicts and inefficient water use. In the use of agricultural water, the MWR shares its duties with the Ministry of Agriculture (MOA), particularly in developing local delivery plans and extending water-saving technology. In urban areas, Urban Construction Commissions (or Bureaus) are charged with managing the delivery of water to urban industrial and domestic users. Urban Construction Commissions also have taken responsibility for managing groundwater resources that lie beneath municipalities' land area. Ground-water levels, both urban and rural, are monitored jointly by the Ministry of Geology and Mining (MGM) and its local associates. In theory, the MGM's information about the ground-water level is used when deciding whether to grant ground-water pumping permits, though local water bureaus do not always use the information. China's State Environmental Protection Agency (SEPA) has the responsibility for managing industrial wastewater and municipal sewage treatment. Last, in the area of price-setting, the MWR, in conjunction with the State Price Bureau and acting with the approval of the State Council, sets

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[3] Although in some upstream regions that draw more than their allocated amount of water, enforcing the legal allocations results in agricultural users "losing" water.

Table 1—The administration of China’s water management

National Level

The State Council (SC)

The State Council is similar to the Cabinet in the United States. It oversees all national ministries and initiates laws and policy to be carried out by the various ministries. Ministries directly involved in water management, such as the MWR, SEPA, and the MGM, as well as those less directly involved such as MOA and the Ministry of Forestry, are all under the control of the SC.

Ministry of Water Resources (MWR)

The MWR implements most components of water policy since the 1988 Water Law. It is responsible for planning, constructing, and managing all water-related projects including those for flood control, power generation, water transportation, domestic water treatment, and industrial water use in addition to irrigation.

State Environmental Protection Administration (SEPA)

China’s SEPA is charged with enforcing environmental laws and the maintenance of water resources. It is in charge of wastewater treatment and enforcement of laws regarding industrial and urban water pollution. The SEPA has local-level offices similar to the MWR.

Ministry of Geology and Mining (MGM)

The MGM is charged with managing ground-water resources, primarily monitoring ground-water levels and understanding ground-water flows. The MGM also has local-level offices.

State Price Bureau (SPB)

The SPB administers the pricing of state-owned resources such as water. The national bureau sets guidelines for provincial-level bureaus to use in setting prices that take local supply and demand into account.

Ministry of Agriculture (MOA)

The MOA is charged with developing and implementing policies to guide water use once it is delivered to the field, such as the extension of water-saving irrigation practices, and has local-level offices as well.

Subnational Level

Water Resources Bureaus and Offices (WRB)

WRBs exist at all levels of the formal administrative bureaucracy in China (see figure 5). They are charged with carrying out plans initiated from levels above them, and administer irrigation districts and water resource systems that are entirely within their administrative district.

Urban Construction Commissions (UCC)

The UCCs are in charge of accessing and delivering water to urban users including industry, urban domestic use, and agriculture in areas within urban districts. The UCCs issue well-drilling and ground-water withdrawal permits for industrial users and also have their own wells and water delivery infrastructure. The UCCs also collect urban water fees.

Village Water Officers

Villages often interact with local bureaus or irrigation districts through village water officers or irrigation officers, who manage irrigation in the village. Their duty is primarily to inform farmers when the irrigation deliveries arrive, to manage allocations among the village households, and to collect water fees. Not all villages have such positions.

Cross-Administrative Institutions

National River Basin Commissions (NRBC)

A NRBC exists for each of China’s major river basins. The NRBCs are charged with implementing policies that cross provincial boundaries, primarily approving and enforcing provincial water withdrawal plans.

Irrigation Districts (ID)

Publicly run IDs manage delivery of irrigation water for all surface systems and some ground-water systems. IDs report directly to the WRB associated with the smallest administrative unit that encompasses their entire command area. Large IDs may report to the provincial WRB, while the smallest ones may report to the township-level WRB.

guidelines at the provincial level. Subnational Water Resources Bureaus and Price Bureaus (at the direction of the leaders in the localities) set the final price levels according to local supply and demand as well as other economic and political factors.

Outside of the central government, many subnational water management institutions also influence water policy. Provincial, prefectural, and county governments all have Water Resources Bureaus (WRBs, sometimes called stations at county and township levels) linked vertically to the MWR in Beijing (figure 5). Formally, the subnational offices are charged with implementing the rules and policies advanced by the national authorities. In reality, however, the heads of local WRBs are appointed by, and report to, leaders of their own jurisdictions (such as provincial governors or county magistrates). These horizontal ties frequently dominate the vertical ones. As a consequence, WRBs also create and execute water policy and regulations based on the needs of their own jurisdiction, causing a considerable degree of heterogeneity in water policies across regions. Most county offices have established water resource stations in each township, which in turn interact with local villages. Traditionally, in most villages, the village leader, or a water officer on the village committee, takes charge of the village's water management system and assesses water fees.

Since rivers, lakes, and aquifers do not always follow administrative boundaries, there are institutions that manage water across administrative boundaries. Each of China's seven major river basins has a National River Basin Commission (NRBC) to manage the basin's water resources. The NRBCs are directly under the MWR, and when they were set up, they were given the authority (at the direction of the MWR leadership) to approve or reject the provincial Water Resource Bureau's plans to withdraw water from the main stream of the river basin under their charge. Importantly, the NRBCs do not regulate water withdrawals from the tributaries of the main river under their charge—these are regulated by the local WRBs. Moreover, some observers believe that the commissions were not very effective in the immediate years after they were set up (Nickum 1998a). Provinces were able to implement their own plans, often to the detriment of other provinces and against the plans of the National Commissions, which lacked adequate enforcement power.

Below the national level, irrigation districts (IDs) were developed to administer water resources that span lower level administrative boundaries. Any given ID always reports to the officials in the WRB that encompasses the district's entire command area. For example, if an ID includes two or more prefectures, it is under the provincial WRB, but if it lies in two or more counties, all within the same prefecture, it is under the control of the prefecture's WRB.

Responsibilities of China's Local Water Management Institutions

The ultimate duty of Water Resource Bureaus has always been to create and manage water allocation plans, to conserve limited water supplies in deficit areas, and to administer water infrastructure investment. In the early years of the People's Republic of China, the WRBs were mainly in charge of surface-water development and management, working through a system of regional and local IDs. The primary task of local water policy managers is to transform investment dollars into infrastructure, maintain the system once it is in place, and manage the water flows within and among IDs.

More recently, WRBs in most regions of northern China have been spending more of their time assisting with the development of and attempting to control ground-water resources, though control of these resources has been difficult. One approach has been to control the number and location of wells. Through the late 1980s, the monopolization of well-drilling activity gave local authorities fairly comprehensive control over access to ground water since most deep wells (and many shallow wells) were sunk by well-drilling enterprises owned and operated by the WRB.[4] In recent years, however, the rise of private well-drilling companies and competition among local collectively owned (by either a township or a village) well-drilling companies has reduced this avenue of control. In this new environment, local WRBs are still charged with controlling ground-water extraction by using their authority to issue all well-drilling permits for water extraction and management (Wang 2000).[5] There are, however, many exceptions to this process. For example, Urban Construction Bureaus are notoriously inde-

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[4] Until recently, although wells were drilled chiefly by enterprises set up and controlled by the local WRB, the wells themselves were often managed on a day-to-day basis by the collective, enterprise, or some other agency.

[5] Control over water permits in urban areas by local WRBs was institutionalized in 1998 by a State Council directive, although it has not been effectively implemented in all areas (Wang and Huang 2002b).

pendent, and in many cases urban units operate on their own, without the oversight of the WRBs.

The WRBs are also charged with overseeing a system of permit rights to draw ground water in addition to well-drilling rights. This system is intended to allow them to operate a de facto ground-water allocation plan, but it has not always worked in practice. Because of the problems in monitoring ground-water extraction, there is little control over the quantity of ground water extracted once the wells are in operation. Often ground-water extraction fees from large government-owned wells are not charged by volume, but rather are based on a fixed negotiated amount per year. In general, except in cases where ground-water tables have fallen so much that they are causing an acute crisis, urban and rural localities are in charge of their own ground-water resources and little action is taken to restrict ground-water pumping.

Wastewater treatment is the responsibility of the local Environmental Protection Bureau (EPB). Because end-of-pipe monitoring technology is still underdeveloped, monitoring of wastewater flows is not a very effective strategy. Instead, China mostly relies on two measures to enforce clean water standards: regulating enterprises at the investment stage—making initial operational approval subject to the adoption of clean water technologies as part of the firm's production process (Warren 1996)—and through a system of water discharge fees and discharge allocations, which are enforced by a schedule of penalties should the firm be caught exceeding its initial pollution allotment. Even this system, however, is subject to interference by local government officials who are in charge of both production and cleanup and clearly have great incentives to expand production (Ma 1997). Given the share of wastewater that is actually treated (less than 50 percent in many places), for some firms, the benefits of treating wastewater do not justify the costs. In addition, since the EPBs earn money from fines when water is not treated, their incentive is to not encourage wastewater treatment (Sinkule and Ortolano 1995).

Financing Water Management at the Subprovincial Level

The financing of local Water Resource Bureau (WRB) activities and the fiscal crisis facing many local water agencies have played a role in shaping the way that WRBs have developed and how they have set their priorities. Operations and investments of local water bureaus are financed by fees for water deliveries, water extraction, and well-drilling permits and by transfers from the administrative hierarchy above the local bureau. Limits on the pricing of water, however, frequently keep system officials from charging enough to cover their operation and maintenance costs (Nyberg and Rozelle 1999). In addition, targeted budgetary allocations from upper-level governments often never arrive in full or are diverted for other matters (Park et al. 1996). The fiscal stress has led to distortions in the way investment funds are allocated among new and existing structures.

Shortages of current operating funds have also led to innovative, although sometimes distracting, ways of meeting fiscal deficits. To make up the deficit between revenues and expenditures, local water agencies fulfill their financial obligations through a variety of means. Irrigation officials may tap funds intended for investment in infrastructure or hold back payroll expenditures to meet immediate operating expenses. Local bureaus also sometimes encourage employees to set up businesses around the use of water, such as fish farms or tourism assets in reservoirs, with the profits from the enterprise used to supplement the revenue side of the agency's balance sheet and provide wage payments, making it easier to meet payroll expenditures. A system that relies on individuals to use earnings from a quasi-private business to subsidize a difficult-to-monitor policy task, such as the efficient delivery of water to farmers, is less likely to meet policy goals than a fully funded system.

Because of the recent signs of an impending water crisis, water management policies and institutions have changed at all levels. Nationally, China's leaders have increased investment in water delivery infrastructure and passed a reformed Water Law in 2002 that explicitly addressed the need to reign in inefficient water use and poor water management. Provincial, prefectural, and municipal governments have begun policy reform to better manage water as well. In addition, farmers and local water managers are creating new institutions that improve the reliability of water delivery and are beginning to adopt water-saving irrigation practices and technology.

Increasing Investment and Reversing Infrastructure Deterioration

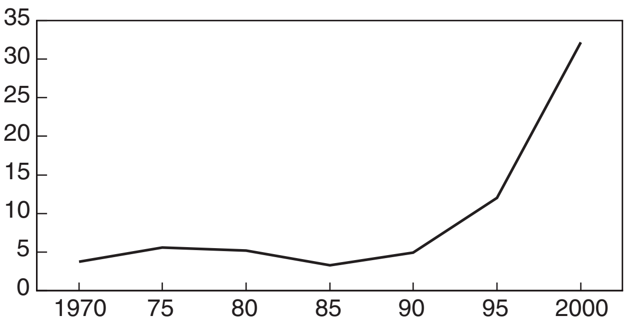
An important determinant of China's overall water management capacity is the state of the water recovery, storage, and delivery infrastructure. While de-collectivization in the late 1970s and early 1980s led to jumps in agricultural productivity and production, these same reforms led to ambiguous property rights over many local water delivery systems built during the collective period (1959-79) and a decline in local governments' ability to invest in large infrastructure projects. The ambiguity over ownership of these systems produced weak incentives to invest in and maintain them. Moreover, transfers of investment funds from the national to local governments fell, further decreasing the local governments' ability to invest in maintaining water storage and delivery infrastructure. The lack of strong incentives to invest in surface-water delivery infrastructure and fiscal constraints are largely responsible for the decline in the effectiveness of China's surface-water systems. The decline of these systems contributed to the stagnation in China's grain production and the rise in food prices in the mid-1980s to mid-1990s.

Infrastructure Investment

During the reform era (1979 to present), agricultural policymakers have not always given high priority to agricultural investment, and the neglect has slowed output growth and productivity growth and contributed to current water problems. Investment for irrigation declined in the late 1970s because of both an emphasis on delivering water for industrial users and a decrease in local sources of investment. Total national investment in water conservancy infrastructure rose from 0.8 to 5.6 billion (constant 1990) Renminbi (RMB) from 1955 to 1975, then fell over the next 10 years to 3.3 billion RMB in 1985 (figure 6). During the 30 years from 1955 to 1985, the share of irrigation in the total national investment budget rose from 2.3 percent to 6.4 percent from 1955 to 1975, before falling to less than 2 percent in 1985.

Figure 6

Investment in water conservancy infrastructure, 1970-2000



National investment statistics do not tell the whole story, however. Investments by local governments in many Irrigation Districts also fell significantly, especially in the early years of reform. The share of local government expenditures used for irrigation infrastructure fell more than any other component of public agricultural investment in the 1980s and early 1990s. From 1975 to 1985, when national investments in irrigation infrastructure fell, investment by the local governments declined even more. In addition, IDs were constrained from raising revenues themselves because of limits placed on the price of water for irrigation. Some of the actions to correct this problem, such as the encouragement of the commercialization of IDs and other water control projects, may well have made matters worse for agriculture since the commercial operations set up to increase revenues sometimes conflicted with the needs of irrigators.

An early indicator of the government's waning commitment to water control was the downward trend in irrigated area in the early 1980s. Irrigated area fell from 45.57 million ha in 1980 to 44.58 million ha in 1985, a fall of almost 1 million ha, and the figure stayed under 45 million ha until 1989 (World Bank Development Indicators).[6] Much of the fall was due to retirement of unprofitable irrigation schemes created during the collective period (Stone 1993). The fall in irrigated area was a primary reason behind the passage of China's first national Water Law in 1988.

Also during the 1980s, concern grew about the deterioration of the systems that remained in operation (Nickum 1998a). Not only had total investment in irrigation infrastructure been declining over these years, but much of the limited investment was being targeted to new construction rather than to maintenance of aging infrastructure. The history of many IDs reveals the problems encountered by the lack of maintenance funds. For example, an ID in Baoding Prefecture, Hebei Province, reached a peak of 20,000 ha irrigated by the

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[6] This figure is effective irrigated area, which may be significantly greater than the area actually irrigated.

surface-water system in 1973, but by 1986 the irrigated area served by the same system had declined to 4,000 ha. Most of the decline in area occurred either because the faltering infrastructure was unusable in some areas or deteriorating infrastructure in other areas resulted in such poor delivery service that farmers switched to more reliable ground-water sources. The artificially low water prices and poor fee collection produced funds insufficient even to meet payroll obligations, much less invest in infrastructure improvement.

The deteriorating surface irrigation systems in some places have caused many agricultural water users in northern China to become reliant on ground water. Water tables in areas with inoperable or inefficient surface-water systems have been documented to be lower than in areas with operable surface-water delivery systems (Wang 2000). It is unclear, however, whether system degradation led to overexploitation of ground water, or whether exploitation of ground water led to falling surface-water revenue and resulted in system degradation.

Serious attention was finally given to the problem of waning irrigation investment in the late 1980s after several successive years of poor harvests. Post-reform grain production peaked in 1985, then stagnated in the late 1980s. Some people blamed low investment in agriculture for this decline (Wen 1993). Estimates of the impact of irrigation investment on total factor productivity show that China's irrigation system was losing its ability to increase output and productivity (Huang et al. 2000).

Renewed Commitment to Investment

Declining irrigated area and rising food prices led to a consensus that more attention needed to be given to agriculture and a consequent rebound in investment occurred in the late 1980s. After the 1988 Water Law, investment increased from 4.9 billion RMB in 1990 to 12 billion RMB in 1995 (figure 6). Agricultural investment rose by 8.6 percent per annum in the late 1980s and by 19.7 percent in the 1990s. In the Ninth Five-Year Plan (which took effect in 1996), officials increased investment from 8 billion RMB in 1996 to over 30 billion RMB in 2000 (in real 1990 prices, Ministry of Water Resources 1999); the plan is to increase investment even more in the first decade of the 21st century.[7] This investment boom was triggered in part by the need to restore and maintain water infrastructure, but also by a renewed national commitment to all infrastructure investment. The share of national investment that goes to water-related infrastructure has not increased dramatically.

China is also beginning to shift its investment priorities from new projects to renovations and maintenance of existing systems (Nyberg and Rozelle 1999). Although it is too early to tell the depth of commitment to this new direction of investment spending, there are signs that the investments are effectively targeted at repairing IDs in decay. For example, the ID in Baoding Prefecture where the ID's command area had fallen by 80 percent over the last 20 years (referenced above) was recently granted funding to completely renovate its rapidly deteriorating canal system. Many farmers had found the system so unreliable that they had switched to ground water. Irrigation officials said that the new grant, the first funding they had received from Beijing for system repairs, would allow the system to deliver water to fully restore its former command area and to reduce conveyance losses to negligible levels.

More recently, an effort has begun to establish unambiguous property rights to many smaller systems. These smaller systems generally were built during the period of collective agriculture, and formal ownership rights were never transferred to administrative units established after decollectivization (townships and villages). Often, the new administrative units did not want to take formal ownership of the assets because many of these systems needed maintenance requiring investment in labor and capital. The new organization of agriculture under the reformed economy made it more difficult for the townships and villages to organize labor resources and many had little capital to work with. Therefore, they did not want to take ownership of assets that would draw resources away from the collective coffers. Establishing ownership is seen as an important first step in improving many of the smaller surface-water storage and delivery systems.

While the effects were not immediate, the rise in investment has reversed the trend in irrigated area. Since the early 1990s, irrigated area rose steadily from 45.35 million ha in 1989 to 53.7 million ha in 1999. The share of land irrigated rose from less than 34.6 percent in 1985 to 39.7 percent in 1999.[8] Crop-

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[7] These figures exclude spending on the massive Three Gorges Dam water project.

[8] Based on World Bank estimates of China's sown area and irrigated area. China's pre-1996 official sown area estimates are widely believed to underreport actual sown area by up to 40 percent.

ping intensity rose from 1.55 in 1990 to 1.65 in 1999, an increase likely caused by improved irrigation facilities.[9]

Emergence of Privately Owned Wells

As public investment in surface-water systems waned and deliveries became more unreliable, farmers in northern China began to rely more on small irrigation systems fed by ground water. The increased number of wells created during the 1980s and early 1990s drove the growth of agriculture in northern China (Stone 1993). Farmers in China generally prefer ground water, even in areas where surface water is inexpensive and villages are integrated into its canal network. They will take delivery of surface water when it is available, but often complain that surface water is unreliable, and therefore maintain access to ground water as well.

Despite the demand for ground-water deliveries, not all localities have the ability to provide such services. Changes brought on by the reforms in the late 1970s and early 1980s undermined the ability of village governments to invest by leaving them fiscally more independent and without the support of the larger commune or the ability to augment investment by allocating large amounts of labor, as was done under the prereform communes. Many villages, particularly those without lucrative nonagricultural enterprises, eventually faced serious fiscal shortfalls and were unable to continue using collective funds to invest in agriculture in the late 1980s and ‘90s. Therefore, many villages were unable to continue sinking wells, especially in areas where the ground-water table had fallen significantly. In some areas that depended on ground water for irrigation, the water table fell below the reach of the village wells, and access to irrigation water ceased.

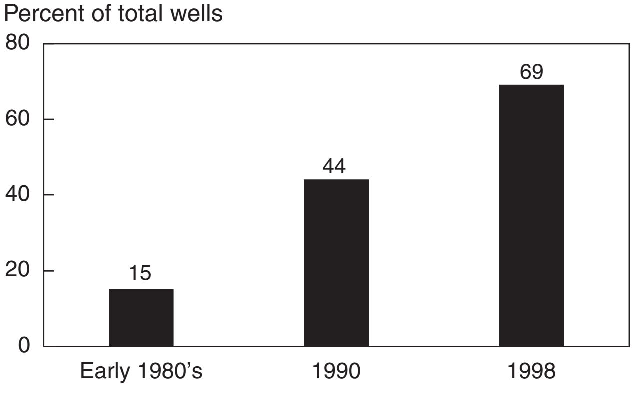
As the collective’s ability to invest declined, other investors began to take its place. Individual entrepreneurs began investing in wells and delivery systems in the early 1990s and selling the water to farmers (Wang, Huang, and Rozelle 2000). The lack of attention to this phenomenon by the national statistical service makes it impossible to observe what happened at the national level, but a survey of three Hebei counties shows the speed at which private well use has expanded. From 1983 to 1998, privately owned and operated wells, and corresponding water delivery systems, in three Hebei counties rose from 15 percent of the total wells to 69 percent (figure 7). Across some parts of China, and particularly in the Hai River Basin, private entrepreneurs have raised the capital needed to sink deeper wells and to install underground, low-pressure piping networks to deliver water to farmers’ fields. After making the investments, the entrepreneurs sell the water to local farmers.

The emergence of private entrepreneurs as water suppliers has allowed many regions to maintain irrigated agricultural production as ground-water levels declined. In one village visited by the authors in Shijiazhuang Prefecture, Hebei Province, in the summer of 2000, farmers had to forgo irrigation in the early 1990s when the ground-water table fell below the level of the village-operated wells. Many farmers switched out of wheat and into more dryland-tolerant crops such as millet and sweet potato. Irrigation was ultimately restored after several entrepreneurs and the village government together set up a water supply company that invested in deeper wells and more powerful pumping systems.

In addition to the better service often provided by private well operators, the emergence of private wells may also lead to more efficient water deliveries for onfarm water use for the individual farmer. Econometric inquiries into the determinants of water supply suggest that the privately run systems deliver water in a more timely and less costly manner and that this water is used more efficiently on the farm (Wang and Huang

Figure 7

Rise of privately owned wells in the Hai River Basin, 1980s and 1990s



Source: Wang, 2000

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[9] Cropping intensity reflects the percent of land that is double-cropped and is defined as sown area divided by arable land. A cropping intensity of 1 indicates that all arable land is sown to a crop only once per year, a cropping intensity above 1 indicates some land is double-cropped (or triple-cropped). Since the predominant wheat-corn rotation in north China depends on irrigation, it is likely that increased irrigation capacity allowed more farmers to double-crop, increasing the cropping intensity.

2002a). These results may arise because private enterprises have better incentives to lower costs, because volumetric pricing (more common with private irrigation districts) gives farmers more incentive to use water efficiently, or because the more timely deliveries that come with the small, private ground-water districts allow farmers to use less water. The more reliable and timely deliveries provided by private ground-water irrigation districts have also been linked to the cultivation of higher valued crops such as fruits and vegetables (Xiang and Huang 2000).

The increased number of private wells, however, does not necessarily mean that China will be able to avert a more drastic water crisis in the future. Recent findings show that as the share of noncollective property rights in water delivery systems in three Hebei counties increased over time, the level of the ground-water table fell (Wang 2000). This relationship may be because the private wells are being established in areas where the water table is falling below collective wells. Alternatively, the falling water tables may be evidence of the tragedy of the commons: private entrepreneurs competing over a free, but limited, resource. Thus, although the establishment of private wells has allowed many regions to maintain irrigated agriculture in the face of falling water tables, the proliferation of private wells may also hasten the coming of the time when pumping from the water table is no longer profitable.

Remaining Challenges

Although increasing investment in water recovery, storage, and delivery infrastructure will improve the water-use efficiency of these systems, these investments may not generate much real water savings or improve water productivity. For example, by reducing conveyance loss, investment in infrastructure will also reduce ground-water recharge from the conveyance of surface irrigation. These conveyance losses are not real water losses because the surface water is recovered later as ground water. There may be benefits to infrastructure improvements, however, if the water can be delivered to farmers at a cheaper price or in a more timely and reliable manner. For example, when water deliveries to farmers are measured and priced volumetrically at the juncture of a main canal with a lateral canal, conveyance loss within the lateral canal translates into a higher price per cubic meter of water delivered to the farmer's field. In addition, when infrastructure investment increases the timeliness of water delivery, the value of water in agriculture can increase substantially, particularly when farmers can influence delivery schedules. Increasing the reliability of water deliveries can also facilitate investment in water-saving irrigation technology (Caswell 1991).

Solving Water Disputes Among Regions and Users

Because of the nature of water and the externalities that arise when water use by one area imposes costs on or reduces benefits to another area, conflicts among users frequently arise. The conflicts are sharpest within a given basin and in a water-constrained region. In this section, we review several of the problems that stem from conflicts among different users. In particular, we will examine two separate sets of conflicts: those between upstream and downstream users in different geographical parts of a water basin and those between industry and agriculture.[10]

Interregional Conflicts

In China, as in the rest of the world, some of the most serious water conflicts stem from problems that arise when trying to allocate water among regions. The most common example occurs when excessive upstream water use deprives downstream users of their share of surface-water resources. It is also a problem when common-property water resources, such as a lake or a bay, are adjacent to two jurisdictional units.

The most high-profile conflicts have arisen on the Yellow (Huang) River, a river that begins in Qinghai Province and traverses Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong Provinces before reaching the sea. For most of the last 30 years, the Yellow River ran dry for at least some period before it reached the ocean (Wang 1999). The problem was becoming increasingly worse, in terms of both the duration and the area affected by the river's drying up. The flow interruption left users in Shandong and Henan Provinces without their traditional sources of surface water. Upstream urban growth and newly constructed irrigation projects in Ningxia, Gansu, Shaanxi, and Inner Mongolia relied on increasingly larger uptakes to meet the needs of their industrial and agricultural users (even though these withdrawals were frequently beyond the allocations set by the Yellow River Basin Commission). In response, downstream agricultural and industrial users either switched to ground water or went without.

This problem is not limited to the Yellow River Basin. During several trips taken by the authors to Hebei Province in the Hai River Basin over the period 1998-2001, upstream-downstream conflicts were apparent in almost every area visited. Two upstream counties in Shijiazhuang Prefecture had monopolized an entire reservoir system's capacity, and downstream counties in Cangzhou Prefecture had to rely on ground water despite a clearly unsustainable rate of extraction and deteriorating water quality. Officials in Cangzhou Prefecture reported that they received only 10 percent of the surface water that they received in the 1970s. Similarly, in the early 1990s, lakes were drying up in Baoding Prefecture. Irrigation-intensive cropping systems were being developed in the counties in the Taihang Mountains upstream from Baoding. As a result, Baoding's municipality wells were pumping so much, and recharge was so limited, that the ground was in danger of slumping and damaging parts of the city and its infrastructure.

Agriculture-Industry Conflicts

Similar problems arise when trying to allocate water between industry and agriculture. Although agriculture is the largest user of water, local authorities generally give priority to the industrial sector, which is the fastest growing sector, for use at the margin. Water used in industry has a much higher economic value, and in addition, China's leaders want to facilitate growth in industrial production more than agriculture. Hence, when there is a decision to be made whether water should be sent to an industrial facility or kept for agriculture, industry often wins out.

Giving China's rapidly growing industrial users priority over water supplies has led to declining water supplies to agriculture in many areas. For example, Hong et al. (2001) describe a large irrigation district in Hubei where there has been substantial reallocation of water from agriculture to hydropower generation and industrial and domestic uses over the past several decades, especially during the 1990s. From 1985 to 1990, agriculture received 64 percent of the water from the reservoir, but this share fell to 35 percent from 1993 to 2001. Between these two periods, total water supplies available for agriculture (including from sources other than the reservoir) declined by more than half. This sharp decline in water supplies led to a 31-percent decline in irrigated rice area, and a nearly commensurate fall in rice production (since farmers do not grow rice without irrigation).

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[10] One could also examine conflicts between rural and urban users, but, because domestic water use is relatively small, we focus on the above-mentioned two sets of conflicts. Urban-rural conflict could potentially be more serious in the future.

On the North China Plain, prolonged extraction of ground water for industry has greatly lowered the water table under many urban districts, and this, too, has implications for agriculture. In some places, the over extraction has become such a serious problem that it allowed for intrusion of contaminated water and may be causing subsidence. Farmers in and around these urban regions must draw their water from deeper and deeper wells. Faced with crippling shortages, industrial water managers have attempted to purchase agricultural water supplies, but have not always been successful. Upstream agricultural counties that have built their own reservoirs and canal systems have little incentive to provide water to industrial centers, since their own agricultural activities would be adversely affected.

Sometimes industry is denied access to agricultural water despite the fact that industry is generally a higher valuing use. These conflicts usually represent the divergent goals and interests of the Urban Construction Commissions versus the local Water Resource Bureaus and Agriculture Bureaus. For example, even though several major cities in Henan Province have so little water that some industries have had to be shut down, agricultural officials who control the water from new reservoirs have expanded rice production and have plans to develop water-intensive horticulture cultivation. Industries in one Hebei Province city, which the authors visited in 2000, had to shut down production in many of their factories and could barely operate their power generation plant during the peak irrigation season because agricultural officials drew almost all surface water. In both these circumstances, agricultural users could feasibly ship water to the cities for other uses. It is even likely that farmers could earn more money by selling water to industrial users than by using the water for agriculture.

The actions of industrial water users can also lower the amount of water available for agriculture by increasing the unusable proportion of available water supplies. A serious problem in China is the release of polluting effluents into the river systems (World Bank 1997). Although industrial wastewater treatment capacity has grown tremendously in the past several years, in most cities a large portion of industrial effluents are still discharged directly into rivers. Pollution in many areas is often so bad that surface-water cannot be used for irrigation, or, if used, it leads to soil contamination (Smil 1993). In many cases, releases from factories have harmed a region's aquaculture industry (World Bank 1997). Local officials often sidestep legislation and regulations designed to curb such pollution in order to keep local industries profitable.

Resolving Interregional Conflicts

Officials and policymakers at all levels are developing ways to manage and resolve problems generated by interregional conflicts over water. The most common solution is to increase the authority of higher level administrative units so that the unit of decisionmaking is broad enough to internalize the conflict. More recently, a system of water rights is being considered as a potentially more effective means to solve these conflicts, particularly inter-provincial conflicts along a river system.

An example of how China has moved to resolve interregional conflicts is the recent move by the State Council through the MWR to increase the authority exercised by the National River Basin Commissions (NRBCs), particularly the Yellow River Basin Commission. In response to the decreased flow to downstream provinces, the Yellow River Basin Commission in 1998 was given more personnel, a higher budget, and, along with the other NRBCs, more power to resolve conflicts among the provinces that use the water in the river basin. By 1999, the newly empowered commission restricted the upstream provinces' access to water and increased deliveries to downstream ones. During 2000, despite a drought, the water in the Yellow River flowed all the way to the ocean for the whole year.

In some cases, upper level jurisdictions have redrawn boundaries of water districts or taken control of reservoirs to make what they believe is a more rational allocation of water. For example, in Hebei Province, Shijiazhuang Prefecture had built a reservoir that served several counties under its jurisdiction. When a downstream prefecture, Cangzhou, began to suffer serious ground-water shortages because of falling water tables, the province took control of the reservoir, lined an irrigation canal that went to the downstream county, and allocated water away from Shijiazhuang to Cangzhou.

Ultimately, a system of water rights may be implemented to better manage conflicts between regions. The efficacy and feasibility of such a system are presently being debated within the relevant departments in China's Government as well as at international development agencies (such as the World Bank, the Asian Development Bank, and United Nations

Food and Agriulture Organization (FAO). The obvious political costs and difficulties in establishing such a system will likely serve to put actual implementation of a system of water rights off for some time. But the fact that such a system has been proposed and is being seriously considered portends well for progress that will help solve future water allocation problems in China.

Resolving Agriculture-Industry Conflicts

Policymakers are also responding to rationalize the allocation of water between industry and agriculture. Most regions have attempted to deal with emerging problems by defining more clearly the priorities of different users. Generally, throughout China, both industry and agriculture are encouraged to save water, but industry will get priority over new supplies and agriculture will have to make do with its existing allocation, or less.

When water shortages become serious and chronic, stronger and more permanent solutions to conflicts are necessary. To resolve problems with officials from competing ministries working to divert as much of the scarce resource for their constituents as possible, many provinces and municipalities are promoting reforms to merge the functions of different water management units into a single authority. Although such units have different names in different places, most commonly they are called the Water Affairs Bureau (WAB). The WABs, at the extreme, merge the personnel, resources, and duties of the local Water Resource Bureau (WRB), the Urban Construction Commission (UCC), and the water protection division of the local Environmental Protection Bureau (EPB) into a single unit (Ministry of Water Resources 1999).

Often cited as an example of the establishment of an effective WAB, Shenzhen Municipality was one of the first prefectures to create a unified water authority. Although water pollution and other environmental considerations instigated the reform (and not water shortage per se), Shenzhen's mayor created the WAB after the municipality's rapid growth during the 1980s and early 1990s. Industrial and urban building expansion created a serious shortage of potable water in the city, shortages that threatened to slow down Shenzhen's economic activity. A series of subsequent floods exacerbated the problems and were, in part, connected to the hasty construction of canals and wastewater treatment plants that were built without coordination with other parts of the water system.

Responding to these events, the local government passed an emergency water regulation and created the municipality's WAB. The bureau immediately took charge of all construction of water-related projects, including clean drinking-water plants, wastewater and sewage treatment plants, dikes for flood control, and other infrastructure projects. The bureau also took responsibility for creating and executing all of Shenzhen's water-related activities including those for industrial supply, wastewater cleanup, and agricultural use.[11] Deliveries to agriculture, industry, and urban residents were all under the control of a single entity. By all accounts, shortly after the creation of the bureau, Shenzhen's water supply and flood prevention improved dramatically.

Since the success of the establishment of the WAB in Shenzhen, the MWR has encouraged the plan throughout China (Ministry of Water Resources 1999). Through mid-1999, 160 counties had established WABs, although the extent of the authority and success that has been realized varies. One problem is that this reform can be very difficult to implement in practice. For example, officials affiliated with the divisions created from the former Water Resource Bureau (WRB) are often concerned that the new unit would take too much water from agriculture, while those from the former Urban Construction Commission (UCC) may view the new system as designed to remove lucrative water revenues from their control. These types of conflicts may prevent the development of well-functioning WABs. City officials in Zhengzhou, Henan Province, introduced reforms based on the Shenzhen model in 1994, just after the successful adoption of this system in Shenzhen, but as of October 2000, the reform had yet to be completed because of numerous unresolved bureaucratic problems.

Although unifying urban and rural water management is difficult, the benefits of the system can be significant. In Baoding Prefecture, where such a reform had already occurred in 1997, the WAB had built a 30-km 1.5-m pipeline from a former WRB reservoir to the UCC's clean water plant. In this case, the reform created a win-win situation. The city received much-needed high-quality water. The irrigation district, which had trouble using all of its water for agriculture

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[11] Urban jurisdictions in China usually include surrounding agricultural land.

Table 2—Responses to water conflicts in China

Conflicts over water	Problems	Policy responses
Inter-regional conflicts within a river basin	Upstream provinces allocate water away from downstream users	Increase the authority of the National River Basin Commissions (NRBCs) to enforce withdrawal limits. Ultimately, a system of water rights may be established so that provinces can trade water rights.
Inter-regional conflicts within a province	Upstream irrigation districts allocate water away from downstream districts	Increase the level of authority over water decision-making to include both up- and downstream areas and enforce upstream withdrawal limits.
Agriculture-industry conflicts	Agriculture loses significant water to the growing industrial sector or, alternatively, industrial production is adversely affected by water withdrawals for agriculture. Industrial pollution also affects agricultural water.	Combine water policymaking in extended urban areas under one bureau to coordinate agricultural and industrial water needs.

due to a decaying delivery system, was happy to have the new investment and a new cash-paying customer. Farmers, who sometimes had been implored to take water deliveries from the irrigation district, focused their attention on ground-water sources, which in this particular area were relatively abundant.

Broadening the authority of a single regional water authority also has helped address certain environmental problems. Drawdown by upstream irrigation districts and increased industrial waste ended up affecting the ecological balance of Hebei's largest lake, Baiyang Dian. In the early 1990s, the lake was severely polluted, unable to support either large-scale aquaculture or tourism. Counties below the lake were also reluctant to use irrigation water during certain seasons because of high concentrations of toxic chemicals. In response, the provincial WRB took administrative control of the lake and intervened in the water allocation plans of three prefectures that affected or were affected by the lake. A new canal was constructed leading from one of the large reservoirs, which actually had seen its service area shrink over the years. With access to new flows of water, the province greatly improved water quality in the lake, and the fishing and tourism industries rebounded. Provincial officials claim that, although only a small part of the newly raised revenues from the lake were used to pay for the additional water flows, the irrigation district was revitalized by the payments.

Options for Future Reform

While reforms that unify water management authority have helped to allocate water more rationally among users, the formal extension of water rights may provide for even more effective water allocation. A workable system of water rights, however, also requires sound legal institutions to enforce contracts and resolve conflicts. Presently, the transfer of water licenses or water-use rights is technically prohibited in China because all water is state-owned property (although water transfers do happen under certain circumstances, as indicated in the examples above). With rising water shortages and the need to allocate water more rationally, the MWR is considering modifications to the law that will formally permit transfers of water rights. Following through with reforms that establish more secure rights, and making these rights tradable, will further increase the flexibility and rationality of water allocation in China, and may even increase rural incomes and hasten the development of rural areas (Rosegrant and Binswanger 1994). The efficacy of water markets and a system of water rights, however, will depend heavily on establishing a transparent and independent legal system to enforce contracts and resolve disputes. In addition, maintaining effective infrastructure, via significant and well-targeted investment, will also improve the functioning of water markets (Michelsen 1994).

Farmers' Incentives To Reduce Water Consumption

Despite the improving water management environment in China, the fact remains that in many parts of northern China ground- and surface-water sources are being depleted and current water-use levels are not sustainable with the current water supply system. As noted earlier, agricultural users will not be given priority for any additional sources of water that become available. Indeed, while it is the stated goal of China's leaders to increase irrigated area, they also explicitly acknowledge that this expansion will occur without any additional water allocations to agricultural users. Thus, using water more efficiently is the only method to increase irrigated area and effectiveness without increasing total agricultural water demand in northern China.

Even with what seems to be an impending water crisis, farmers have hardly begun to adopt water-saving technologies or practices. The reasons for this are found in the nature of the incentives faced by China's farming community (and those in other sectors). Until the 1970s, water was considered abundant in most parts of China and was not even priced for agricultural users so there was no incentive for users to save water.[12] Collectives had de facto rights over the water in their communities—whether that water was underground or in nearby lakes, rivers, or canals. Facing low or free water prices, farmers naturally used as much water as they wanted. Even today, most farmers "save" water only when their deliveries are curtailed, not because the price is too high or because they are given other incentives.

Water Pricing in China

Shortly after the agricultural reforms that began in 1978, the central government encouraged the adoption of a system of volumetric surface-water pricing. While the prices were set by the Price Bureau in Beijing and modified by provincial price bureaus, adoption of prices did not begin all at once in all locations, but instead was allowed to diffuse gradually as experience was gathered. Hence, the current price structure exhibits substantial variation across the country, and takes into account both scarcity and the ability to pay. Typically, for a specific end-use (agriculture, industry, domestic) in a specific province, prices are uniform, although there is flexibility for local exceptions. In terms of ability to pay, agricultural users pay lower prices than domestic users, who in turn pay less than industrial users. For example, in Hubei Province, the price for agricultural users is 0.04 RMB per cubic meter, while domestic and industrial users pay 0.08 and 0.12 RMB per cubic meter, respectively. In terms of scarcity, different prices prevail in different provinces, with prices increasing substantially as water scarcity becomes more severe (generally, as one moves from south to north). For example, in the late 1990s, agricultural surface water was priced at about 0.01 RMB per cubic meter in the southern province of Guangdong, 0.04 RMB per cubic meter in the central provinces of Hubei and Henan, and 0.075 to 0.10 RMB per cubic meter in the northern province of Hebei, where water shortages are most acute (Water Resources Bureau 1998).

Despite increasing water prices, current pricing policies do not effectively encourage water saving and in fact contribute to China's water problems in other ways. Since China's farmers each farm several small plots, charging each farmer according to how much water they use (volumetric pricing) is very costly and difficult to monitor. Some observers argue that water prices are so low that demand is relatively inelastic, thus raising water prices would only raise revenues and not decrease the demand for water by a significant amount. Raising revenues, however, would still be good since the low prices fixed by the provincial price bureaus are often insufficient for irrigation districts to cover their operating costs.

Debate over Water Price

China currently is embarking on water price reform to better match water prices with the benefits of using the water, but the focus is on the domestic and industrial users; whether water prices will be raised for agricultural users is hotly debated. There is widespread agreement that water prices are too low in China, and well below the marginal benefit of water in all sectors including agriculture. Water prices will certainly increase for domestic and industrial users, but may not for agricultural users. Many policymakers believe that raising water prices for agricultural users is the only effective way to get farmers to implement sound water-saving measures. Others claim, however, that raising water prices for farmers will only further bur-

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[12] Farmers generally had to volunteer labor, however, to construct and maintain water storage and delivery infrastructure during this period.

den poor farmers facing low grain prices and, in many cases, high local taxes. This extra burden would directly counter another important policy goal in China: raising rural incomes and reversing a rising rural-urban income gap.

Currently, it is common to measure water for volumetric pricing at some point above the household, or even the village, level. Usually this is either at the main canal level or at the level of an irrigation group. Irrigation groups can be as small as 30 households but others are as large as a whole township. Water fees charged to individual households are usually a prorated amount of the total fee paid at the point of delivery (plus additional costs to cover the collection effort of the water officers and other water managers). The prorated amount is generally based on the size of the household's irrigated land endowment.[13]

Under this surface-water pricing system, farmers have little incentive to reduce their water use since they will be charged for it anyway. Indeed, there is an incentive to use more than one's share of the water, the classic free-rider problem, especially in large irrigation groups that are more difficult to monitor. Upstream users have more opportunities to "free-ride," using more water than they pay for, to the detriment of downstream users. When this happens, downstream users who pay the same water fee per hectare as upstream users actually pay more per unit of water because their deliveries fall as the upstream farmers apply more than their share. Interviews produced repeated stories of how upstream users, after opening channels to deliver water to their fields, have no incentive to close them. In extreme cases, users at the end of the lateral canals do not get any water and refuse to pay water fees.

Not only is most surface-water priced in a way that does not take volume into account, but price collection practices are such that most farmers in China currently do not know exactly how much or when they are paying for water. Many IDs use a system that in essence bills the village for the amount of water they provide to the village. This fee is often transferred to the ID through the administrative bureaucracy (e.g., the township and/or the county). In turn, the village accountant undertakes separate transactions with the townships (or sometimes the ID directly) to make payment for the water, and with the farmers to collect the water fees. Since the accountant must also settle accounts with farmers on several other transactions, including local taxes, education fees, and collectively provided services (such as running water and agricultural services such as plowing or spraying), water fees frequently are lumped together in a single bill for all services and taxes. The clearing of accounts is often done only once or twice a year. In many cases, the water that a farmer pays for had actually been applied as many as 9 to 10 months earlier. In a recent survey of more than 1,200 farmers across China (conducted by two of the authors), fewer than 20 percent of the farmers could tell enumerators the price they paid, either per hectare of land or per cubic meter, for water.

The fragmented and small-scale nature of China's farms will pose a significant problem if the government becomes committed to raising prices and charging for water on a per unit basis to encourage water savings in agriculture. In the absence of transaction costs, a system of volumetric pricing for individual farms would be preferable to the current system. The high transaction costs of measuring water intake at hundreds of millions of small parcels throughout China and collecting fees on a farm-by-farm basis, however, would probably not be the most cost-effective solution. Moreover, joint accounting practices instituted to minimize the transaction costs involved in fee collection have further divorced the farmers' production decisions from the value and amount of water that they apply. Research to understand how large these problems are, and what the optimal group size might be, is important for water prices to effectively encourage water savings at the farm level.

Although farmers do not always know the exact fees they pay for water, in cases that we have observed in which water prices are high and water shortages serious, farmers do have a qualitative understanding that the more water their irrigation group uses, the higher its fees will be. In some areas, water fees clearly are not trivial for farmers. A survey of farmers conducted in two villages in Hubei Province concludes that irrigation fees (for surface water and ground water, including pumping costs) account for about 10 percent of the farmers' total production costs and 18 percent of cash outlays. And these fees are in a central province that is water abundant relative to the more northern provinces.

Given that pricing policy does not currently provide a direct incentive to save water (a situation that will

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[13] There is some true volumetric pricing for individual farmers, but this is relatively rare in surface systems and is restricted to farmers near the head of main canals who have intake pipes directly from the main canal into their fields (ground-water deliveries, however, are often priced volumetrically).

probably not change in the near future), another approach to reduce water use in agriculture could be outright restrictions on water deliveries. When water deliveries to agriculture are cut, farmers do tend to use the remaining water more efficiently. For example, in the irrigation district described by Hong et al. (2001) where agricultural water supplies fell by more than half from 1985 to 1990 (see page 13), water use declined much more than did irrigated area or production, which both fell roughly 30 percent (since farmers do not grow rice without irrigation). Thus, when faced with diminished supplies, farmers found ways to increase water productivity so that irrigated area and production did not fall so much. The rise in productivity is probably due to improved water management at both the farm and system level. It is important to note that these improvements were not nearly enough to stem the drop in production, but this is an example of a significant decline in deliveries in just a few years. Over time, and with better management of agricultural water use, agricultural production could be maintained.

Promotion of Water-Saving Irrigation Technology

In addition to providing farmers with an incentive to save water or to use it more effectively, policymakers could also provide farmers with irrigation technology alternatives and education on water-saving practices. This component of the larger policy effort to reduce agricultural water use is being pursued in China, but hurdles remain. Even when farmers face a strong incentive to save water, they may be unaware of their options to do so. In addition, several of the options available to farmers, such as drip or sprinkler irrigation, are expensive and may not be suitable to the cultivation of some grains.

The extension system for encouraging adoption of water-saving irrigation technology also does not effectively reach many farmers for a variety of reasons. Just as it is difficult to devise a method for pricing water by volume, the millions of farm households with small landholdings in China also make it difficult to design an effective extension system. The primary means to promote the adoption of water-saving irrigation technology is to set up model villages with water-saving irrigation technology and have farmers come to see how the technology works and how effectively it reduces water use or increases yields. These demonstration projects are usually funded by grants, at least part of which come from central and regional governments, but are also often heavily subsidized by the village itself, rather than the farm households. During a survey in June 2000, the authors visited a village that provided an example of how the central government promotes the adoption of water-saving irrigation technology, in this case a package of subsidies for investment in sprinkler technology. The central, provincial, and county governments each contributed 450 RMB per ha (a total of 1,350 RMB per ha) to help defray the investment in sprinklers of 3,000 RMB per ha (meaning the producer had to invest 1,650 RMB per ha). But, the county's water bureau could not find individual farmers willing to make such an investment. Instead, they found some villages (such as the one we visited) willing to collectively invest in the sprinklers for the entire village and manage the entire purchase and installation of the sprinkler system.

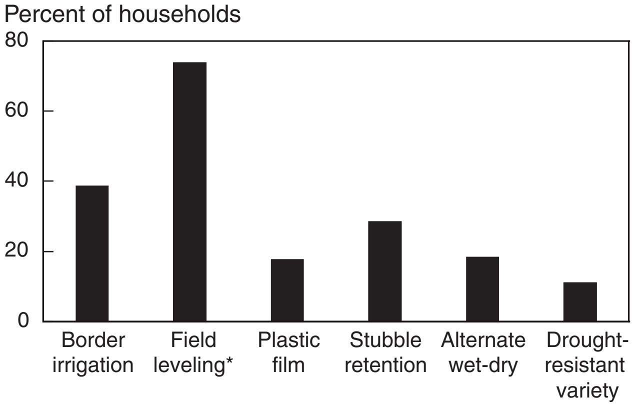
Although effective in getting technology into the field, there are several problems with this approach for promoting widespread adoption. One problem is that there is little village-to-village interaction, and the mechanisms for getting farmers or village leaders from other areas to visit the village and see the technology demonstrated are not clear. Another problem is that the villages that adopt are often so unusual (e.g., the village we visited had more than 3 million RMB - $360,000 - per year in total village revenues) that there is little basis for assessing the potential of the technology for further adoption. Moreover, the extension system has little connection with the needs of farmers. Instead, it tends to develop and promote technologies that are instigated at research institutes, rather than responding to the concerns of farmers who will actually use them. Perhaps because of this disconnect, extension services tend to promote water-saving technologies rather than teaching farmers and village leaders water-saving practices, such as careful timing of water application and monitoring of soil moisture, requiring little or no investment at all.

While farmers have yet to adopt many water-saving practices in China, there are some exceptions. One strategy to save water (or increase the value of water in agriculture) is the widespread establishment of greenhouse production over the last several years. Greenhouses are established primarily to grow vegetables in the winter when the price is as much as 10 times the summer price. But greenhouses are efficient water users and effectively raise the value of water delivered to agriculture. The greenhouses are covered with plastic to prevent evaporation and utilize other water-saving technologies, such as drip irrigation or micro-sprinkler systems. Although national statistics do not cover the rise of greenhouse agriculture, it is clear that greenhouses have become a common feature in rural China, particularly in areas near urban markets.

Farmers in rural China are beginning to adopt other water-saving technologies and practices (figure 8). Plastic sheeting to cover crops after watering is much more commonly practiced than it was 10 years ago, and there is potential for further adoption. Plastic sheeting not only prevents evaporation but also raises soil temperature, promoting plant development at early growth stages. Field leveling is a longstanding practice in rural China, but the practice is expanding and increasingly combined with border irrigation.[14] These practices ensure that water delivered to the field is evenly distributed, rather than leaving some areas dry and others with excess water. In many rice-growing regions, alternating wet and dry (AWD) irrigation is practiced. Alternating wet and dry irrigation is an example of a water-saving practice that is based on timing and takes little capital investment. Usually, an entire village will adopt this practice and farmers simply accept the alternating irrigation deliveries.

Figure 8

Use of water-saving irrigation practices in northern China



*Traditional field leveling, not laser-leveling.

Source: Lohmar et al. 2002.

Irrigation District Management Reform

The timing and reliability of surface-water deliveries greatly affect agricultural production. Often, untimely deliveries or the risk of no delivery are due to deteriorating surface-water infrastructure, or poor incentives facing water managers. But these problems are exacerbated when communication is poor between irrigation district managers and farmers or when water managers lack an incentive to make deliveries more timely. Water that is delivered at times when the crop does not particularly need it is more or less wasted, whereas well-timed water delivery can greatly increase agricultural production and has a much higher value.

To improve water delivery services, fee collection services, and communication with farmers, many irrigation districts have developed more flexible and responsive ways to deliver water. Although the institutional response varies from village to village, there are many examples of how irrigation district managers have begun to try to win back the confidence of farmers and more effectively deliver surface water. In one Henan village, the irrigation district hired teams of three people to be the liaison between the irrigation district and the farmers. Called an "irrigation association," each team serves to provide better information to the irrigation district, so deliveries can be more timely and farmers do not switch to ground water. In these villages, the increasing use of ground water has led to competition in the delivery of the village's water, forcing the surface system to improve its water delivery services.

More formal institutions are currently being promoted to encourage water conservation and improve water delivery service. To improve water delivery management within irrigation districts, many areas are either establishing water user associations (WUAs) along lateral canals or contracting the management of lateral canals to individuals. WUAs are groups of farmers along a lateral canal that select a leadership and a set of rules to manage water deliveries that they purchase directly from the ID on a per unit basis. Similarly, individuals may be selected to take over the management of lateral canals and be provided with incentives to deliver water more efficiently (water they also purchase directly from the ID). Both of these reforms take the management of irrigation deliveries away from the village collective and are intended to bypass the traditional village-township-county route of fee payment to the ID, thus saving money by reducing fees that accrue to these levels of the administrative bureaucracy. In general, they are geared toward improving the management of irrigation deliveries to farmers and improving fee collection to bolster the irrigation district's fiscal situation.

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[14] The percent of households using field leveling in figure 8 refers to traditional methods of field leveling, not laser leveling. Laser leveling would likely lead to much higher water-use efficiency than traditional leveling methods (Nyberg and Rozelle 1999).

An example of a successful WUA is the Hong Miao WUA in Hubei Province, organized in 1995 as a response to poor irrigation service and frequent conflicts between upstream and downstream users. Predictably, the downstream users were sometimes unable to irrigate their crop. Since the formation of the WUA, however, conflicts have lessened, irrigation services have improved, and irrigated area has increased from 200 to 325 hectares. Because of better coordination among the water users, the entire area can now be irrigated in 4 days (compared with two weeks before), thus reducing uncertainty to farmers regarding the timeliness of water deliveries.

Significant variation exists in how these reforms are implemented in practice. The way the WUA leadership or the granting of the canal contract is decided varies as do the rules under which these institutions operate. While initial evidence suggests that these reforms help deliver water in a more timely manner, prevent water waste, ensure that downstream users receive their water allocation, increase fee collection and, most importantly, use water more efficiently, the actual workings of these institutional reforms and the incentives they provide is an area that should be further explored. The extent to which they reduce the control of local village, township, and county officials over irrigation policy and fee collection also is unclear and likely varies.

Irrigation management reforms can also facilitate the promotion of water-saving irrigation technology and practices. Irrigation district management reforms being tried in rural China generally separate water fees from other local fees. Under such a system, farmers are more aware of their water costs than under the system in which water fees are collected along with other village fees and taxes. Moreover, the groups and WUAs can ensure that the gains from aggregate savings are passed on to member farmers. Meetings of user groups can also be used to introduce water-saving irrigation technology or teach water-saving irrigation practices such as measuring soil moisture and timing irrigation.

Options for Future Reform

There are several ways that China could provide more rational incentives for farmers to save water without adversely affecting rural incomes. One option is to give farmers salable rights to the water. Under these circumstances, farmers can establish ways to use less water and sell the surplus water to nonagricultural users to earn money. The money earned could be used to establish more sophisticated water delivery systems that increase the value of water in agriculture. Increasing the supply to nonagricultural users would bring the value of water down in the nonagricultural sectors and the smaller water supplies to agriculture would bring the value of water up. This could be a win-win scenario, an overall economic gain where the losing side (the farmers because of decreased production) could obtain some of the gains to industry because they sell the water that allows for increased industrial production. Both sides would be better off. The efficacy of such a system, as stated previously in this report, would depend on a transparent and independent legal system to enforce contracts and resolve disputes and a well-maintained delivery system.

Effects of Water Scarcity on Agricultural Production

Water is a critical factor for agricultural production in China. Without the expansion of irrigated agriculture in the North China Plain made possible by easily exploitable water resources in that region, China could not meet its grain self-sufficiency goals.[15] The changes China's leaders, water managers, and farmers need to make to maintain sufficient water resources for agriculture and increase the productivity of water use in the sector will change the way water is allocated to agriculture in many ways. Delivering water to farmers in a more reliable and timely manner and implementing water price reforms so that water use in agriculture more closely reflects its opportunity costs will enable China to adjust to limited water resources available for agriculture. This will greatly enhance the value of water to agricultural users, but, in return, agricultural users will likely have to either pay more for the water or accept cutbacks in their overall water allocations.

Adapting to higher priced water or smaller allocations of water (or both), farmers will probably shift production patterns. One of the most likely shifts in production that higher water prices and smaller deliveries might encourage is in the common practice of wheat-corn double-cropping in northern China. Currently, farmers first plant winter wheat in November and harvest it in June, then plant corn in June and harvest it in September or October. During the corn-growing season, rainfall is sufficient and irrigation is not usually needed (but is sometimes used to supplement rainfall and increase yields). During the winter wheat season, however, rainfall is scarce and the crops rely heavily on irrigation from surface-water and ground-water systems. Thus, if water prices increase or deliveries are reduced, many farmers may move out of irrigated wheat production, decreasing yields substantially.

As China's farmers move out of irrigated wheat production, production of other crops will probably increase. However, predicting which crops will increase in production as water becomes more expensive and limited is difficult because many factors are involved. First, farmers may choose to maintain wheat-sown area but forgo irrigation. This would result in lower wheat yields but not much change in other crop yields. Alternatively, farmers may switch to other crops. In the past, farmers switched to water-saving crops, such as millet, as water became scarcer.[16] On the aggregate level, however, such changes will be limited by the demand for such alternative crops. Farmers could also abandon irrigated wheat production and concentrate on a single crop of corn, which, with a longer growing season, could show significantly higher yields.

Water can become much more productive in agriculture and the price of water less of a concern if farmers adopt better water conservation practices and can take full advantage of increased timeliness and reliability of water deliveries. A variety of practices and technologies could be used to save water in wheat production, but because wheat is so land-intensive it is not particularly suitable to many of the most effective water-saving technologies, such as drip irrigation, micro-sprinkler technology, or greenhouse production. Other crops, such as the fruits and vegetables being grown in the greenhouses that are increasingly common in China's countryside, are better suited to take advantage of modern water-saving irrigation technologies. These crops also tend to be labor-intensive rather than land-intensive and therefore better match China's comparative advantage. Farmers will increasingly turn to these crops anyway as China opens its agricultural sector to international competition.

It is somewhat counterintuitive to think that water scarcity will ultimately encourage the production of relatively water-intensive crops such as fruits and vegetables, but there are a variety of forces at play in this decision and several preconditions must be met for this to happen. First, the water delivery system would have the investment and institutional reform necessary to ensure timely and reliable deliveries of water to agricultural users. If a high level of uncertainty remains in the water delivery system, farmers will not invest in the water-saving irrigation technologies necessary to produce high-value crops. Econometric evidence supports the idea that the reliability of water delivery encourages the cultivation of high-value crops in China (Xiang and Huang 2000). Second, China

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[15] China is committed to maintaining 95 percent grain self-sufficiency. Among the three major grain crops, rice, wheat, and maize, only wheat has fallen under this number (in the mid-1990s). Wheat production, more than any other crop, depends on irrigated agriculture in the water-stressed regions of North China.

[16] On a trip in June 2000, the authors visited a village where the wells dried up and irrigation was lost in the early 1990s. Some farmers in this village switched to millet and sweet potato rather than wheat because of the loss of irrigation water. Ultimately, a consortium of private investors and the village collective invested in a water supply company that sank a powerful pump 165 m down to supply water for irrigation; and wheat production was restored.

would relax its grain self-sufficiency policy so that farmers and local leaders are not under pressure to produce grain. Local leaders are often encouraged to promote grain production in rural China, and this may cause them to resist movements away from grain and into other crops. Third, farmers would have access to inexpensive and appropriate water-saving irrigation technology. Last, high-value crops would fetch prices making them truly more profitable. It is assumed, because of their labor-intensive nature, that increasing exposure to international markets will cause the relative prices of grain over high-value crops to change so that high-value crops become more profitable than grains.

Conclusions and Future Research

China has successfully harnessed its limited water resources to achieve remarkable gains in agricultural and industrial production, but in important agricultural areas of northern China, the exploitation of existing water resources has gone beyond sustainable levels. Policymakers in China, however, are responding to this situation to avert a more serious water crisis in the future. At all levels of the water management system, policies and institutions to encourage better water management and water conservation are being established. These trends are encouraging, yet it is still unclear whether China can adapt to a world where water is relatively scarce, while maintaining levels of agricultural production and increasing industrial production. More thorough and rigorous research is needed to answer some of the salient questions regarding these policy changes, the potential they hold for inducing water conservation, and the effects they will have on China's agricultural production.

Improving the storage and delivery capacity of irrigation systems will improve the performance of these systems and could affect agricultural production in several ways. As part of a national campaign to increase infrastructure investment overall, China has dramatically increased national investment in water conservancy in the past few years and plans to continue such levels of investment. To ascertain how these improvements will affect agriculture, however, depends on several unknown relationships. Among the most important is to better understand how effective the increased investment dollars have been at improving surface-water storage and conveyance infrastructure and the extent to which these investments improve the reliability of surface-water deliveries, especially at the ends of the water delivery systems. Researchable questions include: How are these investments allocated? Do they go to the most water-stressed or least efficient systems? Another important relationship to understand is how more reliable surface-water systems will help reduce farmers' reliance on ground water and decrease their ground-water withdrawals, and also the extent to which increased reliability encourages adoption of water-saving irrigation practices or other water conservation efforts. In addition, understanding how these changes in upstream irrigation districts affect downstream users will also be critical to understanding the overall effect these investments will have on the hydrological system and China's economy.

China has also established a variety of institutional responses intended to solve the problem of conflicts between users. Generally these responses seek to increase the power of a higher level of the bureaucracy, so as to "internalize" the conflict. Most of these responses, however, are new, experimental, difficult to actually implement, and therefore still have much to prove before offering solutions to water problems in China. Better understanding how such responses are adopted and implemented, and how both the losers and the winners of these changes are affected, will further our capacity to determine their ultimate success and how they will affect economic activity. A system of water rights along river basins is also being considered by water policymakers in China as a means to resolve conflicts between users. Understanding what preconditions are needed to implement a system of water rights, and how a system of water rights will affect water allocation and agricultural production will assist policymakers in their decisions over whether and how to establish a system of water rights in China.

The incentives faced by farmers and local water managers to conserve water and how they go about adopting water conservation practices will be a fruitful area for further research. A wide variety of institutional responses have been established to encourage farmers and local leaders to adopt water-saving practices including reforming irrigation management, raising water prices and reforming water fee collection, and investing in water-saving irrigation technology. Understanding how these institutions work, which type are more effective, what the determinants of adopting such measures are, and how they affect agricultural production are important questions that call for more rigorous research. The role of water prices, the adoption of water-saving irrigation practices and how these affect crop choice and yields will also play an important role in understanding how China's agricultural production will change as it adapts to more limited water resources.

To determine the impact of the above policy changes on agricultural production, it will be necessary to empirically estimate a number of relationships. An important researchable component of the problem is the extent to which farmers' water use decisions affect the production of important crops. Such decisions not only include the volume of water applied to crops, but also the timing of water allocation decisions and the role of different irrigation technologies and practices. Estimating the parameters underlying these relationships will help to determine how smaller water deliveries or higher water prices will affect yields and crop-choice decisions. How the incentives faced by local water managers induce different water allocation policies within the management districts is another area of empirical research that can help to determine how policy changes affect water deliveries, and thus, agricultural production.

A better understanding of water flows in China will help clarify how water allocation policies will affect aggregate agricultural production. The extent to which current water "losses" find their way back into the water table determines whether current water losses are "real" or not. Ground-water recharge rates, and the sources of these recharges, will help identify areas where water tables are particularly threatened and the interaction between surface-water use and falling ground-water tables. Finally, understanding the hydrology of river basins will help determine how policies to encourage water saving upstream will affect downstream users.

Overall, assessing how water policy changes underway in China will affect agricultural production in the future will require complex and ambitious research. The benefits to this research, however, could be substantial, not only in helping China maintain a viable agricultural sector, but also in determining future trade patterns emanating from the world's largest and most populated agricultural producer. China maintained near grain self-sufficiency as its population grew to nearly 1.3 billion largely through expanding irrigated acreage. The threat of losing irrigation in important temperate regions in northern China could cause China to import a much larger share of its grain needs than it has in the past. In addition, the need to make more economical use of water could also facilitate movement into high-value cash crops using sophisticated water-saving irrigation technologies. High-value crop production is also often labor intensive and this matches China's comparative advantage on international markets since China is far more labor abundant relative to land vis-à-vis its major trading partners. Thus, the need to increase the value of water used in agriculture may also induce a more general structural change in China's agriculture that many observers foresee as China's likely role in international markets: an importer of land-intensive grains and an exporter of high-value and labor-intensive crops.

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