Investment, Conflicts and Incentives: The Role of Institutions and Policies in China's Agricultural Water Management on the North China Plain

Bryan Lohmar, Jinxia Wang, Scott Rozelle, Jikun Huang, and David Dawe [1]

Summary

China's water problems have become well known internationally and could have an enormous impact on crop production, quality of life, and economic development in general. Recently, rapidly falling groundwater 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 policies on water conservation are soon formulated. Opinion over how this "crisis" will affect agricultural production, however, varies substantially. Some argue that the current events portend a major crisis that will cause China to import enormous quantities of agricultural goods while others argue that the "crisis" is not too severe and that China can feasibly avoid major disruptions in production.

This paper provides a timely and comprehensive overview of China's water problems focusing on the particular problem of depleting water resources available for agriculture on the North China Plain. This Plain is a major grain producing area that relies heavily on irrigation but is also where groundwater levels have been falling at alarming rates and competition for water from nonagricultural sectors makes the opportunity cost of water delivered to agriculture higher than elsewhere in China. This Plain is a particularly important wheat producing area, and wheat production is threatened more by competition for water resources than by production of other crops because wheat is relatively low-valued and is more dependent on irrigation.

---

[1]Bryan Lohmar is an Economist at the Economic Research Service, United States Department of Agriculture, Washington, D. C. , USA; Scott Rozelle is Associate Professor, University of California, Davis, CA, USA; Jinxia Wang is Postdoctoral Scientist of IWMI and Research Fellow of the Center for Chinese Agricultural Policy (CCAP), Chinese Academy of Sciences (CAS), Beijing, China; Jikun Huang is Director and Professor of CCAP, CAS; and David Dawe is a Scientist at the International Rice Research Institute, Los Banos, Philippines. The authors would like to thank William Coyle, Noel Gollehon and Micheal Trueblood for helpful comments.

China's water policies, shortage problems and their potential solutions are complex and multifaceted. The paper thus begins with a short but thorough description of the current water situation on the North China Plain, followed by a description of the institutions and policies charged with managing China's water resources. To provide organization to the analysis of the complex issues involved, we break a more focused analysis of the problems and responses into three sections, each of which is a subset of the larger problem. One subset looks at the falling and poorly targeted investment patterns, the subsequent deterioration of surface-water storage and delivery systems, and the responses to this problem. Another section addresses the overlapping and competing interests of bureaucratic authority, how these problems contribute to unsustainable water management and recent reforms intended to rationalize the water management system. Finally, we look at the set of issues relating to farmers' incentives to learn and implement water-saving irrigation (WSI) practices and technologies. This section discusses water prices and WSI technology extension services. After the three sections, but before a general conclusion, we discuss how the changes underway may affect agricultural production on the North China Plain.

To understand how China's agricultural production may be affected by future competition for water, first, it is important to understand the current state of water depletion and the policies and institutions that govern how China's water is managed. In the first section (Water Scarcity and Water Management Policy in China) of this paper, we document how groundwater levels have been falling at an accelerating rate and how deliveries of surface water have become less reliable. In addition, we describe how the Ministry of Water Resources (MoWR), the main bureaucratic institution charged with managing China's water resources, carries out the water management policy, along with a description of subnational authorities and other government ministries that manage some aspects of water policy. Because the financing of these government offices is often a source of poor incentives to effectively manage water for agriculture, we also briefly describe how water management institutions are traditionally financed.

The overall investment into water recovery, storage and delivery infrastructure is a critical part of water resources management and is the topic of the first of the three sections that break the problem down into subsets. Much of China's water recovery, storage and delivery infrastructure was built under the People's Communes, and when these organizations collapsed in the late 1970s, many assets were left without clear ownership and mechanisms to maintain them. At the same time, national investment priorities moved away form agriculture. As a result, area irrigated fell in the early and mid-1980s, prompting stagnant grain production and higher food prices by the mid-1980s. The national government responded to these signs by increasing national investment in agricultural infrastructure, and the trend of increasing agricultural investment is expected to continue well into the twenty-first century. Private investors have also become an important part of water delivery in rural China in the last decade, especially in developing small groundwater-fed IDs in areas where surface water deliveries are problematic or the water table has fallen below the reach of collectively owned wells.

While physical infrastructure is an important component of water management, the institutions charged with water management must also be given clear responsibilities and incentives that encourage them to manage water effectively. In the section under "Solving Water Disputes among Regions and Users," we address the role of the water management institutions, and the conflicts that occur within the bureaucratic framework charged with supplying water to the various users. In China, as with many other areas managing scarce water resources, conflicts occur between regions, between different parts of the bureaucracy and between different users, notably agriculture versus industry. We look at how conflicts between regions, part of the bureaucracy and between agriculture and industry have been behind poor water management in the past and describe the steps taken to resolve these conflicts.

Finally, the delivery of water to over 100 million small farm households and the provision of incentives to them to use water efficiently and effectively constitute, perhaps, the biggest water management problem facing water policy makers and local water managers in China today and this is explored in the section under "Farmers' Incentives to Reduce Water Consumption." Pricing water volumetrically, the usual solution offered by economists, would likely generate very high transaction costs in an environment where each farm household irrigates only a fraction of a hectare of land. Instead, farmers are usually charged according to their irrigated area, regardless of how much water they use and, often, they do not know how much they pay for water, even though water fees can be a significant part of production costs. This system generates a variety of perverse incentives and does not encourage water saving. In addition, efforts to introduce WSI practices and technologies have not been entirely successful. Recent efforts to improve pricing practices and encourage more rational water use in agriculture have been established and may ultimately work to encourage the adoption of water saving agricultural practices and irrigation technology.

The effects that increasing competition for water will have on agricultural production are not clear and they depend largely on the extent to which China can avert a more widespread water crisis. Irrigated wheat production on the North China Plain is perhaps the most threatened practice, but if irrigated wheat area declines, what will farmers plant instead? Interestingly, one option that many farmers seem to be moving toward is the cultivation of relatively water-intensive cash crops using a variety of technologies that reduce water loss and improve the effectiveness of water delivery. In the section under "The Effects of Water Scarcity on Agricultural Production," we discuss the possible changes in the structure of China's agriculture that may come about due to increasing competition for water from nonagricultural sectors.

Introduction

Rapidly growing industries, 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 demand water for nonagricultural uses, China continues to expand its irrigated area. These trends have resulted in higher demand for water in agriculture that, despite the growing demand by other sectors, is still by far the largest user of water in China.

Does the rapid increase 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 but suggest that many agricultural producers may have to forgo irrigation. Still others suggest China's current water problems are only marginally serious and will likely be solved just as China has solved other "crises" in the past. According to some observers, there is significant scope for "real water saving" in China (Barker and Molden 2000; MoWR, IWR& HR 1999).[2]

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 fall 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 but so far they have been relatively rare events in relatively isolated areas and have not yet affected the aggregate production, both in industry and in agriculture.[3] In other areas, the irrigated area has actually expanded in recent years and leaders have plans to continue expanding the irrigated area. Industrial production has also grown rapidly in the past several years, even in regions where water is relatively scarce. In addition, water prices, while higher than in other parts of Asia, are still well below the marginal value of water use in each sector. Despite the dire predictions of a looming water crisis, water use in China is still relatively wasteful and inefficient, which implies that there is ample room to improve the efficiency of water use and avert a more drastic crisis in the future.

Given the public goods 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 may come down to a question of how well policy makers 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,

---

[2]"Real water saving" refers to saving non-recoverable water loss such as through evaporation or inessential transpiration, rather than saving on water loss through seepage, which can be recovered downstream in the water basin.

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

and extrapolations into the future, may lead to pessimism. If one extrapolates linearly from the record of the annual decline in groundwater from 1980 to 1996, then one could come to the conclusion that groundwater resources on the North China Plain will be depleted by 2030 (Goodwin 1999). On the other hand, the experiences of other water-short societies provide optimism since, as water scarcities grow, users and policy makers adjust to the situation (Nickum 1998b). But policy makers need to know how water users in different sectors and regions will respond as institutions and policies change.

Little work has gone into understanding how well policy has responded to changing conditions in the past, how formal and informal institutions have emerged or adjusted to deal with the current water shortages, or how producers and consumers respond when facing water shortages. For example, few papers focus specifically on the effectiveness of China's water policies, particularly at the local level, nor have researchers examined water management policies at the regional level.[4] Moreover, even less is known about how China's water managers and farmers are responding to water scarcity. Yet it is here that most decisions about water use are actually made. In the face of rising scarcity, formal water management institutions have initiated reforms, and informal institutions have emerged in the countryside to provide more secure water resources.

The overall goal of this paper 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 issues that water policy makers in China are facing. These issues include a) the allocation and management of investments in water control infrastructure and maintenance; b) the emergence of interregional and inter-sectoral water conflicts; and c) the provision of incentives for producers and water users to more effectively manage water. Finally, for each set of issues we track both how the actions of policy makers and users have created these problems and how they have responded to them. To address water allocation problems, policy makers 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 further measures at the disposal of water policy makers, managers and users to address water shortages.

In this report we emphasize the role of policies and institutions, particularly *at the regional and local levels*, and the presentation of new data drawn from several field studies and numerous interviews. We explicitly document *both formal and informal* water management institutions found in China. We also consider institutional change, not only as being created by some act of the policy-making bureaucracy, but also as being induced by factor scarcity—in this case water—and the actions of parties that benefit from, and bear the cost of, the (water) scarcities. The material that we use in the paper on the policies, the

[4]Some papers in the literature, such as Crook 1999, Diao 1999 and Crook and Diao 2000, describe the history and recent changes in policies and institutions affecting water use. The papers, however, focus primarily on national policy and none center on examining how policy changes might affect water availability and usage.

policy making processes and the institutions come primarily from our field work and analyses that have been done over the past 3 years.

China, however, is big, and water policy is complex, so it is impractical to cover all water-related issues in one report. Most of this report focuses on a subset of issues and only one part of the country. We concentrate our efforts on the water-short North and only briefly address issues of flood control and management of the abundant water resources in South China. In addition, we focus on issues that affect water availability for irrigation in agriculture. Agricultural water use is twice as large as all other uses combined, but it is also the lowest-value user, so water availability for agriculture is closely tied to industrial and domestic water demand. In addition, water recovery projects that deliver water for irrigation are 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 leave the detailed description and analysis of flood control problems and industrial and domestic water demand to others.

Water Scarcity and Water Management Policy in China

Signs of Increasing Water Scarcity

While China has large water resources compared to other countries, its population is comparatively even 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 poorest. The nation's water resources are overwhelmingly concentrated in southern China, while northern China, the area north of the Yangtse river basin, has one-fourth the per-capita water endowment of the south and one-tenth the world average (MoWR 1998).[5] The lower levels of rainfall in North China are also much more seasonal than in the South, with over 70 percent of the rain falling between the months of 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 over 65 percent of China's cultivated land, produces roughly half of its grain (and nearly all of China's wheat and corn) and over 45 percent of the nation's GDP (MoWR 1998; SSB 1999).

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 has increased 130 percent and total water use in China has increased 430 percent (Wang 2000). The industrial sector has increased at a much faster rate than the agriculture sector. The average annual growth in industrial water consumption was 8. 6 percent over the period, compared to just 2. 7 percent for agriculture. Hence, over the period

[5]Loosely speaking, northern China includes three main geographic regions according to China's own definitions: Northwest, North, and Northeast China.

1949 to 1998, the share of China's water resources consumed by agricultural producers fell from 97 percent to 69 percent. The share of industries rose from 2 to 21 percent and the share of domestic and other consumption rose from 1 to around 10 percent. Despite a faster growth rate, the amount of increase in agricultural water use is much larger than industrial water use over this period since industries started at a much smaller base.

The effects of the increase in water demand have been most acute in northern China. As demand increased in the industrial and urban sectors, shortages of water resources forced officials to cut back on deliveries of water to farmers in some provinces. In many parts of northern China (for example, in northern Anhui, northern Jiangsu, Shandong, Shanxi, Gansu, Qinghai, and Xinjiang Provinces and the Provincial-level Municipalities of Beijing and Tianjin), agricultural water consumption declined from 1994 to 1998 (MoWR 1994–1998). In other areas (e.g., Liaoning, Jilin, Heilongjiang, Hebei, Henan, Inner Mongolia and Ningxia Provinces), water demand for agriculture increased, but only modestly. In contrast, industrial water use still increased over the period, especially in the industrial centers of Beijing, Tianjin and Shenyang, and Provinces, such as Hebei and Shandong, that have high concentrations of urban and rural industries.

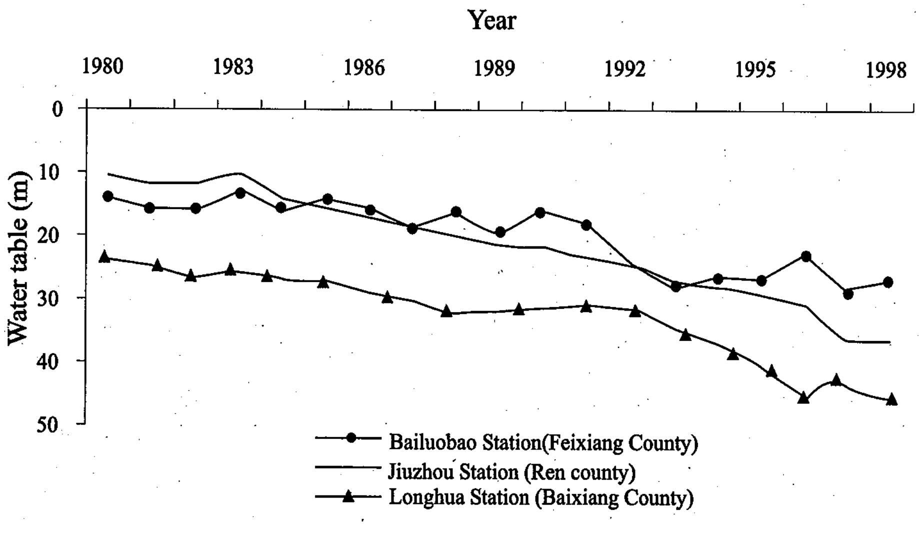
The rapidly rising nonagricultural demand for water is not the only problem facing agricultural water users in North China. Water deliveries to agriculture are also threatened by deteriorating delivery infrastructure of surface water and by excessive withdrawals upstream. Large portions of China's physical water storage and transfer infrastructure, many of which were poorly built during the period of collective agriculture (1950s to the late 1970s), are rapidly deteriorating. Availability of investment funds has lagged and is generally geared toward new projects rather than toward maintenance of older projects. The river systems that supply water to many surface systems also sometimes do not provide sufficient water because upstream users withdraw more water than are supposed to under law. Because of excessive upstream withdrawals, the Yellow river has run dry before reaching the ocean for at least some period every year since 1974 (except last year, 2000, due to new enforcement rules, described in section under "Solving Water Disputes among Regions and Users"). Withdrawals from the Fuyang river, in the upper part of the Hai river basin, almost completely depleted the main river. In 16 of the last 20 years, almost no flow was recorded at the mouth of the river, and Cangzhou Prefecture, which is at the downstream end of the basin, 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 groundwater that has allowed farmers to irrigate a winter wheat crop in addition to another crop in the later summer season, usually corn, that relies mostly on the summer season's rainfall (Stone 1993). For example, in 1995, two wheat growing provinces, Hebei and Shanxi, relied on groundwater for more than 50 percent of their total irrigation water consumption (MoWR 1995). In other important wheat- growing provinces, such as Shandong and Shaanxi, the share of groundwater in irrigation use is above 40 percent. The coastal parts of northern China (including northern Jiangsu, Shandong, Hebei and Liaoning) also have seen irrigated area from groundwater exploitation expand faster than in the inland areas where there is relatively less access to groundwater (MoWR 1998).

Groundwater is also the primary source of water used in industry and for domestic consumption in many regions (MoWR 1995). In 1995, the share of industrial water deliveries that came from groundwater sources was above 50 percent in nearly all of northern China, and was above 80 percent for some provinces, such as Hebei and Shaanxi. Most of China's northern provinces also receive most of their domestic water deliveries from groundwater sources. In two northern provinces, Ningxia and Inner Mongolia, groundwater supplied more than 90 percent of domestic water consumption.

Increasing demand, limited availability and reliability of surface water and rising reliance on groundwater extraction have led to falling water tables and a number of other problems in North China. For example, in Feixiang county, a county located in the upstream part of the Fuyang river basin in Hebei Province, the shallow groundwater table fell at 0. 6 m/yr. in the 1980s and 1. 3 m/yr. in the 1990s (figure 1). Even greater rates of decline occurred in the middle and downstream parts of the basin. In addition, the deep water table is declining at an even faster rate, currently at around 1.7 m/yr. The excessive groundwater withdrawal rates generate large cones of depression under urban areas in six Hebei Province prefectures: Handan, Shijiazhuang, Xingtai, Hengshui, Cangzhou and Baoding municipalities.[6] Land subsidence has also occurred in some predominately rural counties such as in Henshui, Ren and Quzhou counties (Smil 1993; HHB&WEMC 1999).

Figure 1. Trends of groundwater table in Bailuobao, Jiuzhou and Longhua, 1980-98.



[6]A cone of depression is a natural occurrence that forms around a tube well when groundwater is pumped to the surface and it is an area where the water forms an upside-down cone formation because the replenishing rate from the surrounding water table is slower than the withdrawal rate. In areas with heavy groundwater withdrawals, as in urban areas on the North China Plain, they can become large cones that form under entire cities, not just around individual wells.

While the long-run impact of the falling water table in North China is not clear, current rates of extraction are not sustainable given current rates of recharge. In the longer run, areas with cones of depression may even lose their capacity to hold large quantities of groundwater. In this way and others, the subsidence brought on by groundwater depletion may permanently harm the land's capacity for groundwater storage. However, if effective water-saving practices can be implemented or if new water sources can be found in the near future, the present levels of groundwater depletion do not necessarily represent permanent damage because most of northern China's groundwater can be recharged through infiltration of surface water if the withdrawals are sufficiently reduced (Nickum 1998a).

Large groundwater extractions and the subsequent fall in the water table could also affect the *quality* of water, particularly through the intrusion of seawater. A survey carried out in the coastal provinces of northern China in the early 1990s found that over 2,000 km^2 of the formally freshwater 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 hectares. While these losses represent only a small part of the overall agricultural production in North China, they do significantly impact residents in the affected regions and some observers predict that unless groundwater sources are allowed to replenish, the problems will increase at an accelerating rate.

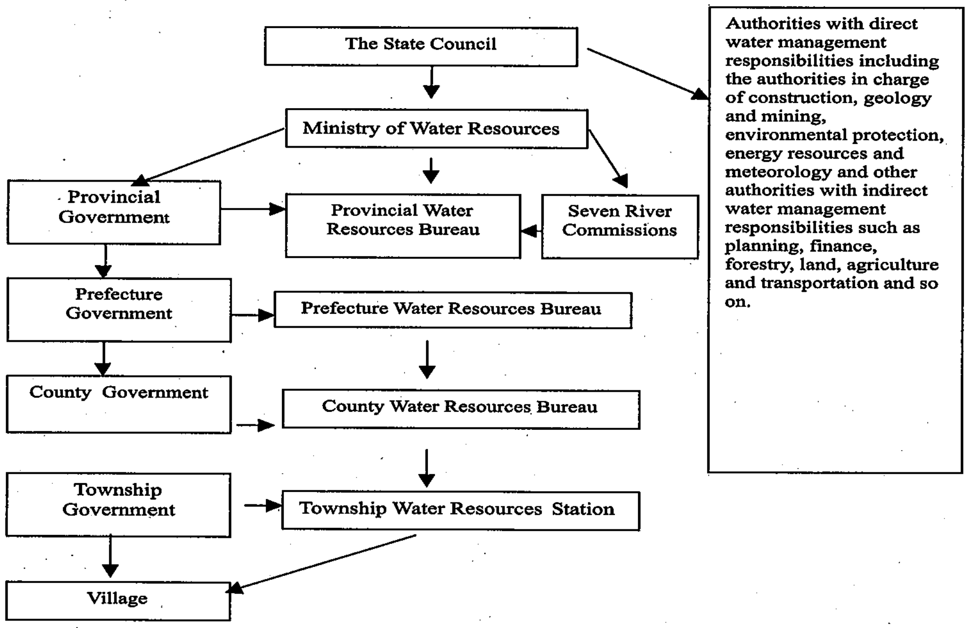
China is starting to see the long-term impacts of excessive water exploitation and is facing water-scarcity problems that might become a serious crisis in the near future, unless, of course, policies are adopted and institutions emerge to avert such an event. Although water scarcity in northern China has been building for decades, it has only recently begun to affect the livelihoods of people and threaten the profitability of economic activity. Unchecked, the problems could develop into catastrophic proportions. China, however, *has begun* to address these problems at nearly all levels, from the national level down to the village and farm levels. In some cases, the progress is difficult to detect, but given the length of time it took to generate 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 examine, in the following section, the complex arrangements that govern how China recovers, stores, allocates and manages its water resources.

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 (figure 2). To understand the functioning of this system, first, it is important to understand that, until recently, water saving has never been a major concern to policy makers. Instead, the system was designed to a) construct and manage systems to prevent floods that have historically devastated the areas surrounding the major rivers, and b) 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 ultimately created and theoretically executed by the MoWR (MoWR 2000). The MoWR 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,

Figure 2. The structure of water management institutions in China.



the Ministry of Water Resources and Electrical Power. The policy role of the MoWR is to create and implement a national price and allocation policy, and oversee water conservancy investments through the provision of technical guidance and issuance of laws and regulations to the subnational agencies. 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 towards 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 according to the direction of the Water Law, the MoWR gives priority to the domestic and industrial sectors (over agriculture) 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.

Under the 1988 Water Law, the MoWR 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 MoWR shares its duties with the Ministry of Agriculture, particularly in developing local delivery plans and extending water-saving technology. In urban areas, *chungjianwei* (Urban Construction Commissions or Bureaus) are charged with managing the delivery of water to urban, industrial and domestic users. These Commissions also have taken responsibility for managing groundwater resources that lie beneath the land area of the municipalities. Groundwater 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 groundwater level is used when deciding whether to grant groundwater pumping permits, though our field work revealed that local water bureaus do not always use this information. China's State Environmental Protection Agency (SEPA) has the responsibility for managing industrial wastewater and municipal sewage treatment. Lastly, in the area of price-setting, the MoWR, in conjunction with the State Price Bureau and acting with the approval of the State Council, sets guidelines at the provincial level. Subnational Water Resource Bureaus and Price Bureaus (at the direction of the leaders in the localities) set the final price levels according to local supply and demand conditions as well as according to other economic and political factors.

Outside of the central government, many subnational water management institutions also influence water policy. Linked vertically to the MoWR in Beijing (a tie that is mainly reinforced by the investment funds allocated by the central government), provincial, prefectural and county governments all have Water Resources Bureaus (WRBs), sometimes called Stations at county and township levels). 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, making for a considerable degree of heterogeneity in water policies across regions. Most county offices also have established water resources stations in each township that, 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 also institutions that manage water across administrative boundaries. Each of China's 7 major river basins has a National River Basin Commission (NBRC) to manage the basin's water resources. The NBRCs are directly under the MoWR, and when they were set up they were given the authority (at the direction of the MoWR leadership) to approve or reject provincial Water Resource Bureaus' plans to withdraw water from the main stream of the river basin under their charge. Importantly, the NBRCs do not regulate water withdrawals from the tributaries of the main river under their charge—these are regulated by the local WRBs. Moreover, some scholars believe that the commissions were not very effective in the years immediately after they were set up. Provinces were known to primarily implement their own plans, often to the detriment of other provinces and against the plans of the National Commissions.

Below the national level, the 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 within the same prefecture, it is under the control of the prefecture's WRB.

Responsibilities of Local Water Management Institutions

The ultimate duty of WRBs has always been to create and manage water allocation plans, conserve limited water supplies in deficit areas and administer water infrastructure investment (our interviews). In the early years of the People's Republic of China, the WRBs were mainly in charge of the development and management of surface water, working through a system of regional and local IDs. The primary task of local water-policy managers is to translate 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 spend more of their time assisting in the development of, and attempting to control, groundwater resources, though control of groundwater resources has been more difficult. One approach has been to control the number and location of wells. In the pre- and early reform years (up through the late 1980s), the monopolization of well-drilling activity gave local authorities a fairly comprehensive control over the access to groundwater since most deep wells (and many shallow wells) were sunk by well-drilling enterprises owned and operated by the WRB.[7] In recent years, however, the rise of private well-drilling companies and competition among locally state-owned (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 groundwater extraction by using their authority to issue *all* well-drilling permits for extraction and management of water.[8] We have, however, encountered many exceptions to this process. For example, Urban Construction Bureaus are notoriously independent 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 groundwater in addition to well-drilling rights. This system is intended to allow them to operate a de facto groundwater allocation plan, but it has not always worked in practice. Because of the problems in monitoring groundwater extraction there is little control over the quantity of groundwater extracted once the wells are in operation. In several areas that we visited, groundwater extraction fees from large government-owned wells are not charged by volume, but are rather based on a fixed negotiated amount per year regardless of the amount extracted. In general, except in cases where groundwater tables have fallen so much that they are causing an acute crisis, urban and rural localities are in charge of their own groundwater resources, and little action is taken to restrict groundwater pumping.

Wastewater treatment is the responsibility of the local Environmental Protection Bureau (Sinkule and Ortolano 1995). Because end-of-pipe monitoring technology is still underdeveloped, monitoring of wastewater flows is not a very effective strategy. Instead, China

---

[7]Although until recently wells were mostly drilled 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. Today, many of the wells are drilled and operated by private entrepreneurs.

[8]The control over water permits in urban areas by local WRBs was institutionalized in 1998 by a State Council directive in 1998, although it has not been effectively implemented in all areas.

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 their initial pollution allotment. Even this system, however, is subject to interference by local government officials who are in charge of both production and clean-up and clearly have great incentives to expand production (Ma 1997). Given the low share of wastewater that is actually treated, it appears that the benefits of treating wastewater to private firms 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 Sub-Provincial Level

Financing activities of local WRBs and the fiscal crisis that many local water agencies face 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. Low water-price limits, however, frequently keep system officials from charging enough to cover their operation and maintenance (O&M) costs (Nyberg and Rozelle 1999). In addition, targeted budgetary allocations from upper-level governments often never arrive in full or are diverted for other pressing matters. The fiscal stress has led to distortions in the way investment funds are allocated among new and existing structures (discussed below). Shortages of current operating funds also have 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 that we observed during several fieldwork trips. Irrigation officials frequently tapped funds intended for investment in infrastructure or held back payroll expenditures to meet immediate operating expenses. Local bureaus are also often encouraged to allow employees to set up businesses around the use of water resources, such as fish farms or tourism assets in reservoirs, to earn profits that 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 cross subsidize a difficult-to-monitor policy task, such as the efficient delivery of water to farmers, will likely fail to meet the policy goals.

Due to the recent signs of an impending water crisis, water management policies and institutions have made changes at all levels. On the national level, China's leaders have increased national investment into water delivery infrastructure and passed a reformed Water Law in 1998 that explicitly addresses the need to rein in inefficient water use and poor water management. Provincial, prefectural and municipal governments have initiated policy reform to better manage water resources as well. In addition, farmers are creating new institutions that improve the reliability of water delivery and are beginning to adopt WSI practices and technology.

Increasing Investment and Reversing Deterioration of Infrastructure

An important part of China's overall water management capacity is the state of 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 under the People's Communes and to a fall in the ability of local governments to invest in large infrastructural projects. The ambiguity over ownership of these systems generated weak incentives to invest in and maintain them. Moreover, transfers of investment funds from the national to local governments fell, further decreasing the ability of local governments to invest in maintaining water storage and delivery infrastructure. This lack of strong incentives and ability to invest in the delivery infrastructure of surface water is partly responsible for the fall in the effectiveness of surface water systems, and the decline of these systems was partly behind the stagnation in China's grain production and rising food prices from the mid-1980s to the mid-1990s.

Infrastructural Investment

During the reform era (from 1979 to date), agricultural policy makers have not always given high priority to agricultural investment, and the neglect has slowed output and productivity growth and contributed to current water problems. Investment for irrigation declined in the late 1970s due to both a changed emphasis towards industrial water delivery and the fall in local sources of investment. Although total national investment in irrigation infrastructure rose from 0. 8 to 5. 6 billion (constant 1990) *yuan* from 1955 to 1975, it fell over the next 10 years to 3. 3 billion in 1985 (table 1). During the 30-year period between 1955 and 1985, the share of irrigation in the total national investment budget rose from 2. 3 to 6. 4 percent between 1955 to 1975, before falling to less than 2 percent in 1985 (table 1).

National investment statistics do not tell the whole story, however, since investments by local governments in many smaller IDs have also fallen significantly, especially in the early years of reform. The decline in the share of local government expenditure among all the various components of public agricultural investment was highest in irrigation infrastructure. During the period between 1975 and 1985 when national investments in irrigation infrastructure fell, investment by the local governments declined even further. Some of the actions taken by leaders to correct this problem, such as the encouragement of the commercialization of IDs and other water-control projects may well have made the under-investment problem worse.

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 a pre-reform high of 44. 97 to 44. 04 million hectares between 1975 and 1985, a fall of almost a million hectares (SSB 1985). Much of the fall was due to retirement of unprofitable irrigation schemes created under the People's Communes (Stone 1993). The fall in irrigated area was a primary reason behind the passage of China's first national Water Law in 1988.

During the same period, concern also grew about the deterioration of the systems that still remained in operation (Nickum 1998a). Not only had total investment in irrigation

Table 1. National investment in infrastructure and water infrastructure, 1955–1995 (in 1990 billion yuan).

	Total National Investment in Infrastructure	Total National Investment in Water Infrastructure	Total Investment Allocated to Water Infrastructure (%)
1955	36. 8	0. 8	2.3
1960	86. 8	7. 5	8.6
1965	37. 7	2. 1	5.7
1970	67. 1	3. 7	5:5
1975	87. 6	5. 6	6.4
1980	107. 3	5. 2	4.8
1985	174. 2	3. 3	1.9
1990	170. 4	4. 9	2.9
1995	431. 6	12.0	2.8

Source: MoWR 1996.

infrastructure been declining over these years but nearly all 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 lack of maintenance funds. For example, one ID that we visited in Baoding Prefecture, Hebei Province, reached a peak of 20,000 hectares irrigated by the surface water system in 1973, but this area then declined to 4,000 hectares by 1986. According to the ID officials, most of the fall 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 groundwater sources.

The deteriorating surface irrigation systems in some places have caused many agricultural water users to become reliant on groundwater in North China. As Nickum (1998) points out, one of the key factors that held back the expansion of irrigated area and triggered the fall of groundwater levels was the degradation of the surface irrigation systems, not the urbanization of irrigated land. Water tables in areas with inoperable or inefficient surface water systems have been documented to be lower than in those areas with operable surface water delivery systems (Wang 2000).

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 (SSB 1989). 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

Falling irrigated area and rising food prices led to a consensus that more attention needed to be concentrated on agriculture and a consequent rebound in investment in the late 1980s. After the 1988 Water Law, investment increased from 4. 9 billion *yuan* in 1990 to 12 billion in 1995 (table 1). Agricultural investment rose by 8. 6 percent per annum in the late 1980s and by 19. 7 percent in the 1990s (table 2). In the Ninth Five-Year Plan (which took effect in 1996), officials increased investment from 8 billion *yuan* in 1996 to 17. 2 billion *yuan* in 1997 (in real 1990 prices, MoWR 1999), and the plan is to increase investment even more in the first decade of the twenty-first century (interviews with MoWR officials).

Table 2. Average annual increase in national infrastructure and water infrastructure investment, 1951–1997 (in 1990 yuan).

	Average Annual Increase in Total National Investment in Infrastructure	Average Annual Increase in Total National Investment in Water Infrastructure	Average Total Investment Allocated to Water Infrastructure (%)
1951-1957	28. 1	20. 1	5. 3
1957-1965	1. 5	2. 4	7. 6
1965-1975	8. 8	10. 1	7. 0
1975-1982	2. 2	-7. 6	5. 9
1982-1986	15. 2	2. 1	2. 7
1986-1990	-1. 3	8. 6	2. 2
1990-1997	17. 9	19. 7	2. 8

Source: MoWR 1996.

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 47. 4 million hectares in 1989 to 53. 2 million hectares in 1999 (SSB 2000). Using SSB cultivated area figures, the percent of land irrigated has risen from less than 50 percent in 1985 to nearly 54 percent in 1999. The multiple cropping index, one of the main ways that irrigated area affects production and productivity, rose from 1. 55 in 1990 to 1. 65 in 1999.

More importantly, the rise in food output and productivity since the late 1970s can be linked with rising public investment, including investment in irrigation. Recent work by Huang and Rozelle (2000) and Fan and Pardey (1997) show that public investment in research and development (R&D) plays an important role in increasing output, and the new seed varieties developed through R&D investment generally are sensitive to timely water deliveries (Pingali et al. 1997). Huang and Rozelle (2000) have established a direct link between new investment in water infrastructure and China's grain output.

China's officials have also announced that they are beginning to shift their 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, in our recent trip to an ID in Baoding Prefecture, managers had just been granted funding to completely renovate its rapidly deteriorating canal system. Over the previous 20 years, with no support from the fiscally constrained local government, and with artificially low water prices, the system's command area had fallen by more than 80 percent. Many farmers had found the system so unreliable that they had switched to groundwater. Irrigation officials said that the new grant, the first funding they had ever received from Beijing for system repairs, would allow the system to deliver water to nearly 8 times as many customers. Officials in the ID estimated that the conveyance losses would become negligible, down from more than 50 percent losses in the pre-renovated canal system.

More recently, an effort has been started to establish unambiguous property rights to many smaller systems. Many of these systems were built during the period of collective agriculture and formal ownership rights were never transferred to administrative units that were established after de-collectivization (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 and demanded 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.

The Emergence of Privately Owned Wells

As public investment in surface water systems waned and deliveries became more unreliable, farmers in North China began to rely more on small irrigation systems fed by groundwater. The rise of wells during the 1980s and early 1990s drove the growth of agriculture in North China (Stone 1993). In many of our interviews with farmers in areas that can be served by surface water or groundwater, farmers almost always say that, given the current environment in China, they prefer to rely on groundwater. Even in areas where surface water is inexpensive and villages are integrated into its canal network, if groundwater is available, farmers may still sink wells. When surface water is available, they take its delivery many times but almost all farmers complain that it is unreliable. Many farmers that we interviewed across the North China Plain said that they were willing to pay up to twice the cost for groundwater compared to surface water, as long as it was available when needed.

Despite the demand for groundwater deliveries, not all localities have the ability to provide such services. Changes brought on by the reforms in the late 1970 s and early 1980s not only initiated rapid economic growth but also 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 labor resources as was done under the pre-reform communes. In the 1980s, most wells were built by county well-digging teams with the support of local leaders. Maintaining and increasing agricultural production constituted an important part of a village leader's performance evaluation and this caused them to put an emphasis on these goals. It was common to use collective investment funds to expand the reach of groundwater and maintain secure water deliveries to local farmers. But many villages, particularly ones without lucrative nonagricultural enterprises, eventually faced serious fiscal shortfalls and were unable to continue sinking wells.

As the ability of the collective to invest fell, however, other investors have begun to take their place. For example, individual entrepreneurs have begun to invest in wells and delivery systems since the early 1990s, and selling the water to farmers (Wang 2000). The lack of attention by the national statistical service makes it impossible to observe what happened at the national level, but our own survey of three Hebei counties shows the speed at which private well use has expanded. Between 1983 and 1998, the share of privately owned and operated wells, and corresponding water delivery systems, in the three Hebei counties rose from 17 to 69 percent (table 3). Across some parts of China, private entrepreneurs have raised the capital needed to sink the deeper wells and install underground, low-pressure piping networks to deliver water to farmer's fields. After making the investments, the entrepreneurs sell the water to local farmers on a commercial basis.

Table 3. The relationship between the property rights structure of groundwater delivery systems, water table exploitation and reliance on surface water over time in three Hebei counties.

	Average Non-Collective Property Rights (%)	Level of the Groundwater Table (m)	Surface Water Used (%)
1983	17	37	12
1990	44	42	16
1997	68	47	2
1998	69	48	2

Source: Wang 2000.

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

In addition to the better service that farmers say are provided by private well operators, the emergence of private wells may also lead to more efficient water deliveries for on-farm water use for the individual farmer. Results from 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 2002). These results may be because a) private enterprises have better incentives to lower costs, b) the volumetric pricing practices (more common with private IDs) give farmers more incentive to use water efficiently, or c) the more timely deliveries that come with the small, private groundwater districts allow farmers to use less water. The more reliable and timely deliveries provided by private groundwater IDs have also been linked to the cultivation of higher-valued crops, such as fruits and vegetables (Xiang and Huang 2000).

The rise of private wells, however, does not necessarily mean that China will be able to avert a more drastic water crisis in the future. In fact, our data show that in areas with more private wells, the groundwater table is lower. While it could also be reverse causation (that is, it might be that private wells arise when water is relatively scarce), there are many situations in which the tragedy of the commons could occur from private entrepreneurs competing over a free, but limited resource. Thus, while the establishment of private wells has allowed many regions to maintain irrigated agriculture in the face of falling water tables, they may also hasten the coming of the time when pumping from the water table is no longer profitable.

Remaining Challenges

While increasing investment into water recovery, storage and delivery infrastructure will improve the efficiency of these systems, it is important to note that these investments may not generate much real water savings. To the extent that the investment makes water delivery more timely and reliable, they do at least increase the value of water in agriculture. By reducing conveyance loss, investment in infrastructure will also reduce groundwater recharge from the surface irrigation's conveyance. This portion of an irrigation system's inefficiency is not real water loss because it is recovered as groundwater. However, there are benefits to infrastructure improvements, especially when water can be delivered to farmers at a cheaper price or in a more timely and reliable manner. When water deliveries to farmers are measured above the village level, then conveyance loss within the village translates into a higher price per cubic meter of water delivered to farmers. 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 into WSI technology (Caswell 1991).

Clearly, China's leaders did get the message that their neglect of public investment into agriculture was catching up with them. Rising food prices in the late 1980s and a fall in irrigated area in the early and mid-1980s triggered new investment by the national government. The focus on new construction versus maintenance of older projects, has also been modified. In addition, local leaders and, more recently, private entrepreneurs are investing in small water-delivery systems that rely on groundwater to maintain production. While new investments will certainly help solve some of China's production problems in some areas, the scarcity of water in other areas means that other institutional responses are still needed to manage the inter-sectoral conflicts that will arise. Moreover, policies and regulations will also be needed to create better incentives for users to save water. These topics are addressed in the next two sections.

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 frequently arise among users. The conflicts are sharpest within a given basin and in a water-constrained region. In the following section, we review several of the issues 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. [9]

Conflicts over water arise for several reasons including the nature of the resource itself and competition for access to it. Conflicts and distortions are, often, due to the system's rigid and bureaucratic nature, which is not ideal for managing a resource where the supply can vary from year to year. The multiple layers in the existing institutions give rise to conflicts between institutions that are charged with similar or, in some cases, outright conflicting, tasks. Still others have to do with weak monitoring arrangements and poor incentive structures.

One of the main problems with China's water management stems from the overall rigidity of the allocation system. [10] Water demand and supply often follow different patterns. Systems have supplies that vary between years and within the year depending on rainfall and other climatic factors. Allocations to the various users, however, follow a different pattern and planning dictates that delivery schedules are made well ahead of the actual deliveries. When supplies are short, there may not be enough water in the system to fulfill the scheduled allocations. Local agencies must then reset the allocations, and at least one sector (usually agriculture) or region will suffer due to policy (e.g., giving priority to industrial users) or rigidities in the system. Without proper coordination, upstream users often withdraw their allocations first and leave insufficient water for downstream users, even though it might be that the most economically efficient use lies downstream.

Improving the flexibility of the surface-water delivery system, however, comes at some cost, which needs evaluation against the benefits before deciding on the preferred policy solution. For example, it is difficult and costly for surface-water systems to develop delivery regimes that match the ease with which farmers can access and apply groundwater. Finding ways to integrate delivery of the two sources of water, surface water and groundwater, often provides additional flexibility and can solve some water delivery problems. Strategies for conjunctive use of water are viable for many areas in China; Nickum (1998) reports that up to 25 percent of all of China may have access to both surface water and groundwater, and the percentage is likely higher on the North China Plain.

---

[9]One could also examine conflicts between rural and urban, 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.

[10]This problem is by no means unique to China. It is a problem in nearly all water-management systems throughout the world.

Adding groundwater to a system, however, creates its own set of problems. Water management authorities have difficulties in monitoring groundwater withdrawal and lack of monitoring can lead to overextraction. It is difficult to implement water pricing schemes formulated to correct shortages and when water fees are assessed they tend to be done in a way that does not necessarily lead to more efficient water use (for example, a per hectare charge for water could actually lead to overuse; this idea is developed more in the following chapter). Irrigation systems may require that groundwater users attach meters to their wells, but the obvious incentives to tamper with meter readings discourages most water managers from even trying this policy. Groundwater can also be monitored by limiting the number of wells sunk and the pumping capacity of each well. This practice, however, only limits the draw per hour but places no limit on the number of hours the pumps can operate. The lack of proper enforcement may also undermine this regulatory approach. In many areas, political pressure makes the granting of well permits automatic, while in others it is difficult to monitor the construction of wells. In addition, local water stations receive fees for granting permit rights, so they may have an incentive to promote, rather than restrict, the sinking of wells.

Interregional Conflicts

In China, 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 results in downstream users not getting their share of surface water resources. It is also a problem when there are common property water resources, such as a lake or a bay, that are adjacent to two jurisdictional units.

The most high-profile conflicts have arisen on the Yellow river (*Huanghe*), a river that begins in Qinghai Province and traverses Sichuan, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong Provinces before reaching the sea. During the reform era (the late 1970s to 1999) the Yellow river was running dry for at least some days of the year before it reached the ocean (Wang 1999). Over the period, the problem became increasingly worse, both in terms of the duration and the area affected by the drying up of the river. 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 limits imposed on these provinces by the Yellow River Basin Commission). In response, downstream agricultural and industrial users either switched to groundwater or went without it.

But this problem is in no way limited to the Yellow river basin. During a trip to southern Hebei, upstream-downstream conflicts were apparent in almost every area we visited. Two upstream counties in Shijiazhuang Prefecture had monopolized the entire reservoir system's capacity and downstream counties in Cangzhou Prefecture had to rely on groundwater despite a clearly unsustainable rate of extraction and deteriorating water quality. 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 of Baoding. As a result, Baoding municipality's wells were pumping so much, and recharge was so limited, that the ground was in danger of slumping and destroying a major part of the city and its infrastructure. One can see that nearly all the rivers one crosses when traveling from Beijing to Shijiazhuang by train or car are dry, even during the rainy season.

Agriculture-Industry Conflicts

Similar problems arise in trying to allocate water between industry and agriculture. Although agriculture is the largest user of water, the MoWR and its sub-provincial agencies give priority to the industrial water sector, which is the fastest growing sector, for use at the margin. as China's leaders clearly see the nation's development path as relying on industrialization and take actions that will help promote that goal. Hence, when there is a decision to be made on whether water should be sent to an industrial facility or kept for agriculture, industry generally wins out. Interviews with officials in almost every province, prefecture and county also reveal that urban residents remain privileged in their claim to water, though in areas of severe shortage they may suffer frequent shortages or water rationing as well.

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 an ID in Hubei (with a command area of about 150,000 hectares) 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 38 percent from 1993 to 1998. 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 30-percent decline in irrigated area, and a nearly commensurate fall in production.

The competition for water between agriculture and industry is acute and this competition is partly to blame for depletion of water resources. In many cities of the North China Plain we visited, prolonged extraction of groundwater for industry had greatly lowered the water table in many urban districts. In some places, the overextraction had become such a serious problem that it allowed for intrusion of contaminated water and was threatening to cause subsidence. Faced with crippling shortages, industrial water managers have attempted to purchase agricultural water supplies but they have not been always 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. In addition, the current water law technically prohibits the transfer of water rights.

Industry-agricultural conflicts can produce inefficient uses of water. 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, which could feasibly ship water to several of these cities, have expanded rice production and have plans to develop water-intensive horticultural cultivation. Industries in one city in Hebei Province that we visited in early 2000 had to shut down production in many of their factories and could not nearly operate their power generation plant during the peak irrigation season since agricultural officials drew almost all surface water, regardless of the formal water allocation plan.

The actions of industrial water users can also have serious effects on rural users. One of the most serious problems is the release of polluting effluents into the river systems (World Bank 1997). The Urban Environmental Protection Bureau officials treat only a small fraction of China's municipal sewage and industrial wastewater. And, although the capacity of industrial wastewater treatment has grown tremendously, in most cities industrial effluents are still largely discharged directly into rivers. Pollution in many areas is often so bad that surface water cannot be used for irrigation, or if used, leads to soil contamination (Smil 1993). There are many cases in which releases from factories have harmed a region's aquaculture industry (World Bank 1997). Local officials often ignore legislation and regulations designed to curb such pollution to keep local industries profitable.

Resolving Interregional Conflicts

To manage the conflicts and problems that arise from actions of IDs in upstream provinces, prefectures, and counties, China's officials are showing that they can address the allocation problems. The most common solution is to increase the authority of higher-level administrative units so that the unit of decision making 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.

The best example of China's ability to resolve interregional conflicts is the recent move by the State Council through the MoWR to increase the authority exercised by the National River Basin Commissions, particularly the Yellow River Basin Commission. In response to the decreased flow to downstream provinces, in 1998, the Yellow River Basin Commission 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 major 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 even 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, Shijiazhuang Prefecture had built a reservoir that serviced a number of counties under its jurisdiction. When a downstream prefecture, Cangzhou, began to suffer serious groundwater shortages due to falling water tables, the province took control over the reservoir, lined an irrigation canal that went to the downstream county, and allocated water away from Shijiazhuang to Cangzhou.

Resolving Agriculture-Industry Conflicts

Even more drastic moves are being taken 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. In a recent trip to five provinces around China taken by two of the authors, provincial and sub-provincial government officials told us industry had priority over agriculture.

When water shortages become serious and chronic, then 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 *shuiwuju* (Water Affairs Bureau [WAB]). At the extreme, the WABs merge the personnel, resources and duties of the local WRB, the Urban Construction Commission (UCC) and the water protection division of the local Environmental Protection Bureau (EPB) into a single unit (MoWR 1999).

Although water pollution and other environmental considerations were the trigger (and not water shortage per se), an example of the establishment of an effective WAB is found in Shenzhen Municipality, one of the first prefectures to create a unified water authority (MoWR 1999). 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 canal and wastewater treatment plants without coordination with other parts of the water system.

Responding to these events, the local government passed an emergency water law and created the municipality's WAB, which 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 infrastructural 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 MoWR has encouraged the plan throughout China (MoWR 1999). Through mid-1999, 160 counties had established WABs, although the extent of the authority and success that have been realized vary. For example, Hebei Province decided to unify the WRB and the Urban Construction Commission in 2000. The deputy provincial governor, who described his work that had created the province-wide WAB, told us that the reform was proceeding smoothly. The hope was that by controlling all water resources from a single agency, the transfer of water from agriculture to industry would be quicker, more rational and accomplished with less conflict. However, it is unclear how well this reform will work in practice. Officials affiliated with the divisions created from the former WRB were afraid that the new unit would take too much water from agriculture, while those from the former UCB believed the new system was promoted to remove water revenues from their control. These types of conflicts may prevent the development of well-functioning WABs. City officials in Zhengzhou, Henan

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

Province, introduced reforms based on the Shenzhen model in 1994, just after the successful adoption of this system in Shenzhen but, on a recent trip, officials conveyed that the reform had yet to be completed due to numerous unresolved bureaucratic issues.

While unifying urban and rural water management is difficult, the benefits of the system can be striking. In Baoding Prefecture, where such a reform had already occurred in 1997, the WAB had built a 30-kilometer 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 got the much needed, high quality water. The ID, that was having trouble using all of its water for agriculture 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 into taking water deliveries from the ID, focused their attention on groundwater 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. For years, many ID officials were unwilling to draw down their reservoirs in certain seasons, preferring to keep them full until the rains were assured. Similar actions by all IDs 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 concentration 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 command area shrink over the years (because, according to farmers, it was inefficiently operated). With access to new flows of water, the province greatly improved the quality of 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 ID was revitalized by the payments.

Options for Further Reform

While reforms that unify water management authority have helped allocate water more rationally among users, the formal extension of water rights may provide for even more effective water allocation. Presently, the transfer of water licenses or water use rights is prohibited in China. But with the rising water shortage and the need to allocate water more rationally, the MoWR is considering modifications to the law that will permit water right transfers under certain conditions. 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.

Farmers' Incentives to Reduce Water Consumption

Despite the improving water management environment in China, the fact remains that in many parts of northern China groundwater sources are being depleted and current water use levels are not sustainable with the current water supply system. As already noted in this paper, agricultural users will not be given priority to 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 North 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: water underground, in nearby lakes, rivers or in 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.

Water-Price Incentives

Shortly after the agricultural reforms that began in 1978, the central government sanctioned a system of volumetric pricing of surface water. This system did not begin all at once in all locations but instead was allowed to diffuse gradually as experience was gathered. Hence, the current structure of prices 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 or 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 *yuan* per cubic meter, while domestic and industrial users pay 0. 08 and 0. 12 *yuan* per cubic meter, respectively. In terms of scarcity, different prices prevail in different provinces, with prices increasing substantially as water scarcity becomes severer (generally, as one moves from south to north). For example, in the late 1990s agricultural surface water was priced at around 0. 01 *yuan* per cubic meter in the southern province of Guangdong, 0. 04 *yuan* per cubic meter in the central provinces of Hubei and Henan, and 0. 075 to 0. 10 *yuan* per cubic meter in the northern province of Hebei, where water shortages are most acute.

Since the onset of price reform for agricultural water, officials have raised water prices in many areas a number of times, although the rise in the *real* price for water has not increased

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

much, if at all. For example, in one county in Hebei Province, the nominal price of surface water for agriculture was 0. 02 *yuan* in 1985, 0. 045 *yuan* in 1990, and 0. 10 yuan in 1997. Taking into account the effects of inflation by dividing by the rural consumer price index shows that, in real terms, the price of water was almost exactly the same in 1997 (0. 023) as it was in 1985 (0. 02). In almost every place that the authors visited over the past few years, real prices for agricultural surface water have largely remained constant over time.

The Water-Price Debate

Currently, China's leaders are embarking on water price reforms to better match water prices with the benefits of using the water, but this focuses 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 policy makers believe that raising water prices to agricultural users is the only effective way to get farmers to implement sound water-saving measures. While in theory this may be true, in practice this will be difficult due to the logistical problems involved in volumetric pricing at the farm level. Others claim that raising water prices to farmers will only further burden 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. The fact that water costs already comprise a major share of farmers' total costs and cash outlays serves to support the argument that substantially higher water prices will adversely affect farm incomes.

Even if the government is committed to raising prices and charging for water on a per unit basis to encourage water savings, the fragmented and small-scale nature of China's farms poses a significant problem. It is common to measure water for volumetric pricing at the point of entry to an irrigation group and the size of these groups varies substantially. Some groups are as small as 30 households (such as in the Zheng He ID in Hubei Province) but others are as large as the whole township (such as at the People's Victory Irrigation Canal in Henan Province). Water fees charged to individual households are usually a prorated amount, based on the size of the household's irrigated land endowment and 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).[13]

Under this pricing system for surface water, 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-

[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 (groundwater deliveries, however, are often priced volumetrically).

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 extract more than their share. Interviews generated 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 it provides 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 ID (making payment for the water) and the farmers (collecting fees). Since the accountant must also settle accounts with farmers on a number of other transactions, including local taxes, education fees and collectively provided services (such as running water and plowing or spraying), water fees are frequently lumped together in a single bill for all services and taxes. The clearing of accounts is often done only once or twice a year, and so, in many cases, the water that a farmer pays for had actually been applied as much as 9 to 10 months earlier. In a recent survey of more than 1,200 farmers across China by one of the authors, less than 20 percent of them could tell enumerators the prices they paid for water, either per *mu* or per cubic meter.

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 likely 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 farmer's 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 saving 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 their fees will be. In some areas water fees are clearly not trivial for farmers. For example, a survey of farmers conducted in two villages in Hubei Province demonstrates that irrigation fees (for surface water and groundwater, including pumping costs) account for about 10 percent of the farmers *total* production costs and 18 percent of *cash outlays*. While these costs are significant, pricing policies are such that, often, farmers cannot reduce these costs by reducing water use and, therefore, they have no direct incentive to save water.

The cost of water to farmers, while substantial, may not be high enough for price policy to induce significant water saving. Indeed, even if water costs account for 10 percent of production costs, as reported above, if irrigation increases yields by 30–50 percent or allows for cultivation of high-valued cash crops, then these costs may be the best investment a farmer makes. Farmers may be willing to spend even more to maintain the same water deliveries. Some scholars argue that water costs are so low, due to years of using water as a subsidy to agriculture and that the price is very inelastic so increasing water prices will generate more revenues for water managers but will not generate much water savings.

Given that pricing policy does not currently provide a direct incentive to save water and this will not likely 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 ID described by Hong et al. (2001) where agricultural water supplies fell by more than half between the years 1985 and 1990 water use declined much more than did irrigated area or production, thus water productivity increased. The rise in productivity is probably due to improved water management at both farm and system levels. It is important to note that these improvements were not nearly enough to stem the fall in production, but this is an example of a significant fall in deliveries in only 5 years. Over time, and with better management of agricultural water use, agricultural production could be potentially maintained. Cuts in agricultural water deliveries would have to be carefully coordinated with improvements in water use efficiency to minimize the potential adverse impacts on farm incomes.

Promotion of WSI Technology

In addition to providing farmers with an incentive to save water or use water more effectively, policy makers 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 for doing so. In addition, several of the options made available to farmers, such as drip or sprinkler irrigation, are expensive and may not be suitable to cultivation of some grains.

The extension system for encouraging the adoption of WSI 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 WSI technology adoption is to set up model villages with WSI technology and have farmers come to see how the technology works and how effectively it reduces water use or increases yields (Diao 1999). These demonstration projects are usually funded by grants, at least part of which comes from central and regional governments, but are also often heavily subsidized by the village itself, rather than the farm households. During a field trip in June 2000 by four of us, we saw an example of how the central government promotes the adoption of WSI technology, in this case, a package of subsidies for investment into sprinkler technology. The central, provincial and county governments each contributed 30 *yuan* per *mu* (a total of 90 *yuan* per *mu*) to help defray the investment in sprinklers of 200 *yuan* per *mu* (meaning the producer had to invest 110 per mu). But the county's water bureau could not find individual farmers willing to make such an investment. Instead, they found some villages willing to collectively invest in the sprinklers for the entire village, and manage the entire purchase and installation of the sprinkler system.

While 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 *yuan* per year in total village revenues) that there is little basis for assessing the potential of the technology for further adoption (Diao 1999). 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 WSI technologies rather than teaching farmers and village leaders water saving practices, such as careful timing of water application and monitoring soil moisture, that require little or no investment at all.

While farmers have yet to adopt many water savings practices in China, there are some exceptions. One of the most obvious strategies to save water, or increase the value of water in agriculture, to anyone who has visited China's countryside over the last several years, is the widespread establishment of greenhouse production. Greenhouses are established primarily to grow vegetables in the winter when the price is as much as ten 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 other WSI technologies are usually used in them, such as drip irrigation or micro-sprinkler systems. While national statistics do not cover the rise of hothouse agriculture, it is clear from the personal observations of the authors that greenhouses have become a common feature in the Chinese countryside, particularly over the last few years.

Other WSI technologies and practices are also becoming common in rural China. Farmers have increased the use of furrows for field crops and vegetables. Furrows not only allow for more uniform water delivery in the field but also deliver water closer to the crop's root system, increasing the amount of plant water intake per unit delivered. Plastic sheeting to cover crops after watering is much more commonly practiced than it was 10 years ago. Plastic sheeting not only prevents evaporation but also raises soil temperature, which can promote plant development at early growth stages. In some rice-growing regions, alternating wet and dry farming has been adopted in many regions. Alternating wet and dry agriculture is an example of a WSI practice that is based on timing and takes little capital investment other than teaching the farmers how to carry out the technique.

Reform of ID Management

The timing and reliability of surface water deliveries greatly affects agricultural production. Often untimely deliveries or the risk of no delivery is due to deteriorating surface water infrastructure, or the poor incentives facing water managers outlined in the section under "Increasing Investment and Reversing Infrastructure Deterioration. " But these problems are exacerbated when there is poor communication between ID managers and farmers. Water that is delivered at times when the crop does not particularly need it is more or less wasted, while well- timed water can greatly increase agricultural production and has a much higher value in agriculture.

To improve water delivery services, fee collection services and communication with farmers, many IDs have developed more flexible and responsive ways to deliver water. Although the institutional response varies from village to village, we observed many examples of how ID managers have begun to try to win back the confidence of farmers and more effectively deliver surface water. In one Henan village, the ID hired teams of three people to be the liaison between the ID and the farmers. Called an "irrigation" association, they serve to provide better information to the ID, so that deliveries can be more timely and farmers do not switch to groundwater. In these villages, it is interesting to see how the increasing use of groundwater has led to competition in the delivery of the village's water, forcing the surface system to improve its water delivery services.

The Role of WUAs and WSCs

Several IDs have also established Water User Associations (WUAs) and Water Supply Corporations (WSCs) to provide more effective delivery services of surface water. WUAs are groups of farmers, with the same legal status given to individuals, organized to manage local water delivery in a unified way and to collect water fees. The WSCs are legal corporations, generally associated with a main canal in a large ID, that buy water from the ID volumetrically and sell it volumetrically to local WUAs. If the WUAs that are formed are smaller than existing irrigation groups and provide better incentives for the group to manage water efficiently, then free-rider problems are likely to decrease as farmer participation increases. If this happens, then volumetric pricing, even at the village level, will be more effective and irrigation infrastructure is more likely to be maintained. The system of WUAs and WSCs also circumvents the previous system of water-fee payments that went through the village-township-county bureaucracy before being delivered to the ID and subsequently reduces the amount taken out at the various bureaucratic levels. Thus, farmers in WUAs pay less and the IDs receive more money for water deliveries.

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 to 2 weeks earlier), thus reducing uncertainty to farmers regarding the timeliness of water deliveries.

Irrigation groups and WUAs can also facilitate the promotion of WSI technology and practices. Nearly all the ID management reforms being tried in rural China separate water fees from other local fees so that farmer associations are more aware of their water costs than under the system where water fees are collected along with other village fees and taxes. The gains from saving water, therefore, are more easily seen. Moreover, the groups and WUAs can assure that the gains from aggregate savings are passed on to member farmers. Meetings of user groups can also be used to introduce WSI technology or teach WSI practices, such as measuring soil moisture and irrigation timing techniques.

Options for Further Reform

There are several ways that China could provide more rational incentives for farmers to save water in China that will not adversely affect rural incomes. One option is to give farmers saleable rights to the water. Under these circumstances, farmers can establish ways to use less water, then sell the surplus water to nonagricultural users to earn money. The money could then 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 access some of the gains to industry because they sell the water that allows for increased industrial production. Both sides would be better off.

Another way to promote water conservation in agriculture while protecting farm incomes is to raise water prices and find other ways, rather than low-cost water, to subsidize farmers. Since water is delivered to farmers well below its value in other sectors and often below the costs of delivery, the system represents an indirect subsidy to agriculture via water. Therefore, a system where farmers receive direct subsidies and then are charged a high water price, would generate incentives to save water without hurting farm incomes. Exactly how to implement such a system without running afoul of WTO rules or inviting corruption by local officials, however, may prove difficult. One method may be to incorporate such changes into larger fiscal and tax changes being considered to lower taxes levied on farmers.

Effects of Water Scarcity on Agricultural Production

Water is a critical factor to agricultural production in China and without the easily exploitable water resources in the North China Plain and the expansion of irrigated agriculture in that region, China could not come near to meeting its grain self-sufficiency goals.[14] The changes China's leaders, water managers and farmers need to make to maintain sufficient water resources for agriculture and increase the efficiency of water use in the sector will change the way water is allocated to agriculture in many ways. To successfully adapt to limited water resources for agricultural production, not only will water prices have to increase but water will have to be delivered to farmers in a more reliable and timely manner. 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.

---

[14]China's leadership is committed to maintaining 95 percent grain self-sufficiency. Among the three major grain crops, rice, wheat and corn, only wheat has fallen under this percentage (in the mid-1990s), and wheat production, more than any other crop, depends on irrigated agriculture in the North China Plain.

Adapting to higher priced water or smaller allocations of water (or both), farmers will likely shift production patterns. One of the most likely shifts in production that higher water prices and smaller deliveries might encourage is in North China's wheat-corn rotation, the most common in the region (Huang and Rozelle 1998). Currently, farmers first plant winter wheat, which is planted in November and harvested in June, and second plant corn, which is planted in June and harvested in September or October. During the corn-growing season, rainfall is sufficient and irrigation is usually unnecessary. During the winter wheat season, however, rainfall is scarce and the crop relies heavily on irrigation from surface water and groundwater systems. Thus, if water prices increase or deliveries are reduced, farmers will likely move out of irrigated wheat production, which will decrease yields substantially. If projections that show the price of wheat falling more than corn due to trade liberalization are true, then many farmers may go out of a wheat-corn rotation to focus on a full season corn crop.

As China's farmers move out of irrigated wheat production, the production of other crops will likely increase, but predicting which crops will increase in production as water becomes more expensive and limited is difficult because it depends on many factors. First of all, farmers may choose to maintain the wheat-sown area but forgo irrigation. This would result in a lower wheat crop but not much change in other crops. Alternatively, farmers may switch into other crops. Economically, one might think that farmers will switch into water-saving crops, such as millet, as water becomes scarcer, and this has happened in the past.[15] On the aggregate level, however, these changes will be limited by the demand for such alternative crops. Farmers could also abandon wheat production and concentrate on a single crop of corn, which with the longer growing season could show significantly higher yields.

But if farmers learn to use water better and can take full advantage of increased timeliness and reliability of water deliveries, then water can become much more productive in agriculture and the price of water is less of a concern. There are a variety of practices and technologies that could be used to save water in wheat production, but since wheat is so land-intensive, it is not particularly suitable to many of the most effective WSI technologies, such as drip irrigation, micro-sprinkler technology or hothouse production. Other crops, such as the fruits and vegetables being grown in the hothouses that are increasingly common in China's countryside, are better suited to take advantage of modern WSI technologies. These crops also tend to be labor- rather than land-intensive and, therefore, better match China's comparative advantage, so 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 a number of preconditions must be met

[15]On a trip in June 2000, we visited a village where the wells had dried up and irrigation was lost in the early 1990s. Some farmers in this village switched to millet and sweet potatoes rather than wheat due to 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.

for this to happen. The first is that the water delivery system gets 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 WSI technologies necessary to produce high-valued crops. Econometric evidence supports the idea that reliability of water delivery encourages cultivation of high-valued crops in China (Xiang and Huang, 2000). The second is that China's grain self-sufficiency policy is relaxed in some way and that farmers are not under pressure to deliver a fixed grain quota to the state. Under the present system, an important part of local leaders' evaluation is the continued high level of grain production, and this may cause local leaders to resist movements away from grain into high- valued crops. The third is that farmers have access to inexpensive and appropriate WSI technology. Last is that prices must be such that high-valued crops are 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-valued crops to change so that high-valued crops are clearly more profitable than grains.

Conclusion

China's successful development of water resources to fuel increases in agricultural and industrial production is now starting to show signs of serious stress on water resources in important agricultural areas. It is fair to say that present irrigation practices are not sustainable. What is less clear is whether China can adapt to a world where water is relatively scarce and still maintain high levels of agricultural production and increase industrial production. To do so, China will have to reform its water management system at all levels, from the policies put forth by upper-level water managers in Beijing, down to the technologies and water-saving strategies used by the smallest farmers in the countryside.

In many respects, solutions to the problems outlined in each of the above four sections will not work unless progress is made in the other two areas as well. For example, increased infrastructure investment and resolution of conflicts will generate better incentives for saving water at the farm level. When water deliveries are more certain, farmers are more likely to invest in WSI technology (Caswell 1991). Alternatively, if progress is not made at the farm level, then water will still be wasted regardless of whether the infrastructure is well maintained or conflicts among users are resolved.

China has a wide variety of mechanisms that are being, or could be, established to save water in agriculture, all of which will either require, or will be made more effective through, investment. Improving the storage and delivery capacity of irrigation systems will allow for better surface water management that will, in turn, reduce the dependency on groundwater, provide incentives for WSI technology adoption and reduce the true cost of water to users at the end of the canal system. Investment at the national level will be the most important part of this effort, but it must be matched by investment at the local level as well.

Thus far, increasing investment is perhaps the most successful component of China's effort to bring about more rational water allocation policies in agriculture. Since the early 1990s, national leaders have committed to increasing investment in water management infrastructure. This commitment will increase in the first decade of the twenty-first century as well. Local-level governments are also finding ways to increase investment into water delivery infrastructure, though perhaps not as much as the national government. In addition, new investment into water management infrastructure puts more emphasis on maintenance rather than on building new projects.

But investment in physical infrastructure may be ineffective without changing the institutions that, while having served a productive purpose in the past, are now becoming part of the problem as water becomes scarcer and conflicts arise. A primary benefit of infrastructure investment is not that the newer systems "save" water, since much of the conveyance losses under the older systems return to the water table, but that water can be delivered much more economically and efficiently, greatly increasing the value of water in agriculture. But this benefit could be lost if parties mismanage or compete over water resources in ways that increase the uncertainty over future water deliveries. Thus, establishing an institutional and policy framework that reduces conflicts and brings a more rational management of water resources will be an important part of the overall effort to avert more serious water shortage in North China.

China has embarked on a series of institutional reforms intended to address the problem of conflicts between users, but most of these reforms are new, experimental, difficult to actually implement and, therefore, still have a long way to go before offering solutions to China's water problems. Since many of these reforms involve taking away authority over water deliveries, or more importantly, water fee collection, from some part of the traditional bureaucracy, they are generally resisted and are only imposed with a great deal of political effort from higher levels. But because of the severity of China's water problems in some areas, institutional and policy reform to internalize conflicts, or increase communication between users and suppliers, have taken hold in many regions, with varying degrees of success. China could be stronger, however, in promoting the importance of strong unified water authority in local areas and promoting the development of WUAs and WSCs in the countryside.

Ultimately, both increased investment and institutional reform must conspire to create an environment whereby farmers benefit from adopting WSI practices. Creating timely and reliable water delivery systems will facilitate the adoption of WSI practices, but it will not be enough. Farmers must know that they will pay less if they reduce their water demand. This implies a system by which farmers are charged for water volumetrically, or nearly volumetrically. Alternatively, farmers' water allocations could be cut, so that they have little choice but to learn to use effectively the water that is allocated to them. This will avoid the adverse effects that raising water prices will have on farm incomes. If deliveries are cut, however, farmers will likely want to purchase WSI technology, and this will be expensive. Well-functioning extension services to encourage, and in some cases perhaps subsidize, the adoption of WSI technology and practices will therefore be an important part of the policy regime to encourage WSI in agriculture.

Because of the millions of dispersed farm households cultivating small plots in China, implementing effective policies to encourage water saving at the farm level is perhaps the most difficult component of the whole policy effort to increase water saving in agriculture. The cost of pricing and extension policies that interact with individual farmers in China are likely to be too high to make them workable in reality. Instead, pricing and extension services will have to focus on the village level, or with groups of farmers at best. Without the direct interaction with water users in agriculture, second best solutions can still be achieved with effective allocation and extension policies that interact as closely with individual producers as is economically feasible.

Most important to note is that there is room for improvement in all aspects of water policy in China and that it has made a clear effort to aggressively address water shortages and develop ways to maintain, indeed increase, irrigated area without increasing the water allocated to agriculture. It will take time, however, for the policy and institutional changes to spread, develop and actually result in increased water use efficiency in agriculture in a significant way. But China has begun in the right direction and, given a history of resolving crises in the past, it is reasonable to believe that the barriers to further reform will fall as the water crises becomes more acute. If this happens, then there is a good chance that the current water crises in China will pass.

Bibliography

Barker, Randy; and David Molden. 2000. Global water shortages, Alternatives for increasing water productivity, and implications for China. Paper submitted to Water Policy Forum jointly held by the Center for Chinese Agricultural Policy of Chinese Academy of Science and the International Water Management Institution on 1 June in Beijing, China.

Brown, Lester; and Brian Halweil. 1998. China's water shortages could shake world food security. World Watch 11 (2): 10-18.

Caswell, M. 1991. Irrigation technology adoption decisions: Empirical evidence. In *The economics and management of water and drainage in agriculture*, ed. A. Dinar and D. Zilberman. Norwell: Kluwer.

Crook, F. 1999. USDA-MoA 1999 scientific exchange on water issues trip report, chapters 2 and 3.

Crook, F.; and X. Diao. 2000. Water pressure in China: Growth strains resources. *Agricultural Outlook*, 25-29. January–February. USDA: Economic Research Service.

Diao, X. 1999. USDA-MoA 1999 scientific exchange on water issues trip report, chapter 4.

Fan, S.; and P. Pardey. 1997. Research, productivity, and output growth in chinese agriculture. *Journal-of-Development-Economics* 53(1): 115-37.

Goodwin, D. 1999. USDA-MoA 1999 scientific exchange on water issues trip report, chapter 7.

HHB&WEMC (Hebei Hydrological Bureau and Water Environmental Monitor Center). 1999. *Hebei water resources assessment.* China.

Hong, Lin; Li Yuanhua; Li Deng; C. D. Chen; David Dawe; and Randy Barker. 2001. Analysis of changes in water allocations and crop production in the Zhanghe irrigation system and district, 1966-98. In *Proceedings of International Workshop on water saving irrigation for paddy rice, Wuhan, China, March 23-25, 2001.*

Huang, Jikun; and Scott Rozelle. 1996. Technological change: Rediscovery of the engine of productivity growth in China's rural economy. *Journal of Development Economics* 49: 337-369.

Huang, Jikun; and Scott Rozelle. 1998. *Wheat in China: Supply, demand, marketing, and trade in the twenty-first century.* Discussion Paper. Bozeman, Montana: Montana State University, Trade Research Center.

Huang, Jikun; and Scott Rozelle. 2000. Transition, development, and the supply of wheat in China. *The Australian Journal of Agricultural and Resource Economics* 44 (4): 543-572. (December)

Huang, Jikun; Hu Ruifa; Jin Songqing; and Scott Rozelle. 2000. *The creation and spread of technology and total factor productivity in China's agriculture.* Working Paper. Davis, California: University of California, Davis, Department of Agricultural and Resource Economics. (December).

Hydrological Bureau of Ministry of Water Resources. 1987. *Assessment of China water resources.* Beijing: Water Resources and Hydropower Publishing House.

Lin, J. Y. 1992. Rural reform and agricultural growth in China. *American Economics Review* 82(1): 34-51. (March)

Lohmar et al. 2000. USDA-MoWR 2000 scientific exchange on water issues trip report.

Ma, X. 1997. Compliance, enforcement, and urban waste water control in China. Ph.D. Diss. Department of Civil Engineering, Stanford University. Duplicated.

MoWR (Ministry of Water Resources). 1994, 1995, 1996, 1998, 1999 and 2000. *China Water Resources Bulletin.*

Ministry of Water Resources, Institute of Water Resources and Hydropower Research. 1999. *Study on real water saving.* World Bank Financed Research Project #7107256, Draft Report.

Nickum, J. 1998a. Is China living on the water margin? *The China Quarterly* 156. (December).

Nickum, J. 1998b. Water, population and environment in Asia. *Population and Development Series #22*, The Asian Population and Development Association.

Nyberg, A. and S. Rozelle. 1999. *Accelerating development in Rural China.* World Bank Monograph Series, Rural Development Division.

Pingali, P.; M. Hossain; and R. Gerpacio. 1997. *Asian rice bowls.* London, UK: CAB Press.

Rozelle, Scott; and Jikun Huang. 2000. Transition, development, and the supply of wheat in China. *Australian Journal of Agricultural and Resource Economics* 2000. (forthcoming)

Sinkule, B. ; and L. Ortolano. 1995. *Implementing environmental policy in China.* Westport, CT: Praeger Press.

Smil, V. 1993. *China's environmental crisis: An inquiry into the limits of national development.* Armonk, New York: M. E. Sharpe.

SSB (State Statistical Bureau). 1985, 1989, 1999 and 2000. *China statistical yearbook.* China Statistics Press.

Stone. 1993. Basic agricultural technology under reform. In *Economic trends in Chinese agriculture: The impact of post-Mao reform,* ed. Y. Y. Kueh and R. F. Ash, 311-359. Oxford: Clarendon Press.

Wang, Jianzhong. 1999. Situation and strategy of the Yellow river cutting off. *China Water Resources* 4: 10-11.

Wang, Jinxia; and Jikun Huang. 2002. Tubewell management and technical efficiency. *Journal of Water Resources Advances* 2.

Wang, Jinxia. 2000. Innovation of property right, technical efficiency and groundwater irrigation management. Ph.D. Diss. Chinese Academy of Agricultural Sciences

Wang, Jinxia; Jikun Huang; and S. Rozelle. 2000. Property right innovation and ground water irrigation management. *Journal of Economic Research* 4:66-74.

Warren, K. 1996. Pollution prevention and China's industrial waste problem. Ph.D. Diss. Department of Civil Engineering, Stanford University.

Wen, G. Z. 1993. Total factor productivity change in China's farming sector: 1952-1989. *Economic Development and Cultural Change* 1-41. 1993.

World Bank. 1997. *At China's table.* Monograph. Washington D. C.

Xiang, Qin; and Jikun Huang. 2000. Property right innovation of groundwater irrigation system and cropping patterns change. (in Chinese). *Management World* 5: 163-168.