The Development, Challenges and Management of Groundwater in Rural China

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The history of groundwater in China is one of extremes, or apparent extremes. Before the 1960s, the story was one of neglect; only a small fraction of China's water supply came from groundwater (Nickum, 1988). Almost none of the Ministry of Water Resource's investment funds were allocated to the groundwater sector until the late 1960s. Certainly, to the extent that underground water resources were valuable, China was ignoring a valuable resource.

Since the mid 1970s, however, the prominence of the groundwater sector has risen dramatically. Over the past thirty years, agricultural producers, factory managers and city officials – far from ignoring groundwater resources – have entered an era of exploitation (Brown and Halweil, 1998; Smil, 1993). Arguably, there have been more tubewells sunk in China over the last quarter century than anywhere else in the world. As a share of total water supply, groundwater has risen from negligible across most of China to being a primary source of water for agriculture, industry and domestic use in many of the nation's most productive regions. Unfortunately, the resulting fall in groundwater tables has been called one of China's most serious environmental problems (World Bank, 1997).

Despite the rise in importance of the sector, and the threats to its continuation, relatively little systematic information is available about many key aspects of China's groundwater economy in rural areas. That is not to say that there is a shortage of scientific research studies that document some of China's groundwater related problems, for example, land subsidence, salt water intrusion and overdrafts (Chen et.al., 2003; Sakura et.al., 2003). Moreover, there is recent work on groundwater usage and quality in China's cities (Tang, 1999). However, with the exception of a number of general summary pieces that are based primarily on anecdotes and secondary citations (e.g., Nickum, 1998; 1988; Lohmar et al., 2003) and papers that look at groundwater use in relatively isolated agricultural areas (e.g., Wang et al., 2005a; Wang et al., 2005b; Kendy et al., 2004), there is little work based on original data that is sufficiently broad in scope to give the reader a general overview of the groundwater economy and its challenges and management, especially in rural areas.

The primary goal of this chapter is to overcome the absence of research on China's groundwater economy. To do so, we will pursue three specific objectives. First, we will characterize China's groundwater resources, briefly reviewing the main physical and geographic properties of northern China's groundwater resource development, describing the role of groundwater in the economy and examining the technology that producers are using to extract and utilize the resource. Second, we will examine the main problems that the sector is facing, including falling groundwater levels and deteriorating water quality. Finally, we will document responses of the major water stakeholders in China's agricultural sector—the government and agricultural producers—focusing primarily on the emergence of institutions as a response to some of these problems. Our findings draw primarily on two data sets that we collected ourselves, covering near 450 communities in northern China.

Due to the broad nature of the questions being asked in this chapter, we narrow the scope of our analysis in several ways. First we limit our examination to northern China, the region that uses the majority of China's groundwater.. In our study, northern China can be thought to include the following regions: North China (*huabei*), Northeast China (*dongbei*) and Northwest China (*xibei*). Our sample communities also represent all or part of four major river basins: the Hai River Basin, the lower and middle reaches of the Yellow River Basin, the northern bank of the Huai River Basin and the Songliao River Basin in the Northeast. Although we use our data to extrapolate to the entire northern China region (12 provinces and 2 municipalities), in fact, most of our data comes from six provinces—Liaoning, Hebei, Henan, Shanxi, Inner Mongolia and Shaanxi.[1] In addition, since agriculture is the main water using sector (68% in 2001, MWR 2002), our data set was collected from rural communities, and we will focus on the use of water for agriculture. [2] We also explicitly exclude all wells in our sample villages that were being used solely for drinking water.

Data

In addition to national statistics, our analysis is based on data that we collected as part of two recent surveys specifically designed to address irrigation practices and agricultural water management. The first recent survey, the China Water Institutions and Management survey (CWIM) was collected in September 2004 (Figure 1). Enumerators conducted surveys of community leaders, groundwater managers, surface water irrigation managers and households in 48 villages in Hebei and Henan provinces. The villages were chosen according to geographic properties. In Hebei, villages were chosen from counties near the coast, near the mountains and in the central region between the mountains and the coast. In Henan, villages were chosen from counties bordering the Yellow River and from counties in irrigation districts varying distances from the Yellow River. The 2004 CWIM survey is the second round of a panel survey, the first phase of which was conducted in 2001.

[1] The 12 provinces include: Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Shandong, Shanxi, Henan, Shaanxi, Qinghai, Ningxia and Gansu. The two municipalities are Beijing and Tianjin. Note, in this analysis because of the lack of information on provinces in the extreme western areas of China, we do not include Tibet or Xinjiang in northern China.

[2] Groundwater is also very important in urban water supply in northern China.

We conducted a second survey, the North China Water Resource Survey (NCWRS), in December 2004 and January 2005 (Figure 2). This survey of village leaders from 400 villages in Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi and Shanxi provinces used an extended version of the community level village instrument of the CWIM survey. Using a stratified random sampling strategy for the purpose of generating a sample representative of northern China, we first sorted counties in each of our regionally representative sample provinces into one of four water scarcity categories: very scarce, somewhat scarce, normal and absolutely scarce (mountain/desert).[3] We randomly selected two townships within each county and four villages within each township. In total, combining the CWIM and NCWRS surveys, we visited approximately 6 provinces, 60 counties, 126 townships and 448 villages.

The scope of the surveys was quite broad. Each of the survey questionnaires included more than 10 sections. Among the sections, there were those that focused on the nature of China's rural water resources, the common types of well and pumping technology. There also were several sections that examined the most important water problems, government water policies and regulations and a number of institutional responses (e.g., tubewell privatization). Although sections of the survey asked about both surface and groundwater resources, we will focus mostly on those villages that have groundwater resources (in some cases, whether they were using them or not). The survey collected data on many variables for two years, 2004 and 1995, i.e. asking about conditions back in time. By weighting our descriptive and multivariate

3 In Hebei province, where county level groundwater overdraft statistics are available, the scarcity categories were defined according to a Ministry of Water Resource publication that categorized provinces by scarcity (which almost certainly is related to the degree of annual overdraft). In the remaining provinces, all four scarcity indices were defined according to the percentage of irrigated area as follows: very scarce (between 21 and 40%), somewhat scarce (between 41 and 60%), normal (more than 61%), and mountain and desert (less than 20%). Within each of the scarcity strata, we sampled 2 or 3 counties; of all of the counties in the mountainous and desert counties, we chose one county.

analysis with a set of population weights, we are able to generate point estimates for all of northern China.[4]

China's Groundwater Resources

While China's water resources are substantial compared with those of many other countries, its population is even larger, comparatively, and its water resources are not evenly distributed across the country or across important agricultural regions. China ranks fifth in total water resources among the countries in the world. On a per capita basis, however, its water resource availability is among the lowest. Moreover, the nation's water resources are overwhelmingly concentrated in southern China; northern China has only approximately one quarter of the water endowment of the South and ten percent of the world average (Ministry of Water Resources, 2000). The lower levels of rainfall in northern China also are much more seasonal than in the South, with more than 70 percent of the rain falling between June and September. Northern China, however, remains an important agricultural region and the site for much of China's industrial production. Although it has only 24 percent of the nation's water resources, northern China contains more than 65 percent of China's cultivated land and produces roughly half of its grain (and nearly all of China's wheat and maize) and more than 45 percent of the nation's gross domestic product (Ministry of Water Resources, 2000; China National Statistical Bureau, 2000).

[4] The information that we collected comes from estimates provided to enumerators from village leaders based on their experience during the survey. For some technical data (such as data on water levels, water quality, soil salinity, etc.), although the village leaders do not have access to scientific-based measurements, they are readily able to state their perceptions on these issues. We believe in many cases, the information is fairly accurate. Even in the cases when information on the *level* of a variable for a given year may not be absolutely accurate (e.g., the salinity level of the water), due to the fact that they have been living and working in the village for many years, we believe that they are able to provide accurate estimates on the *trends* of these variables. Because these are based on the experience of village leaders, their response rates were high. In fact, for most variables the response rate was 100 percent, meaning our data are not subject to dropout bias.

Groundwater resources in China also are both unevenly distributed and unevenly used across regions. According to the latest estimates generated by the Ministry of Land Resources, the annual natural recharge of fresh groundwater resources in China is 884 billion cubic meters, about one third of the nation's total water resources (Ministry of Land Resources, 2005). Of this, about 70 percent of groundwater resources are in southern China. Only about 30 percent of the groundwater resources are in northern China. However, the intensity of groundwater use occurs in a much different pattern. Of all of the known groundwater resources, rural and urban users are using more than 70 percent of them in northern China. In contrast, less than 30 percent of the known groundwater resources in southern China are being used.

Despite the fact that most groundwater resources are located in southern China, it is fortunate that groundwater resources exist across wide expanses of northern China's river basins and that these resources are relatively abundant and accessible. Alluvial deposits consisting primarily of sand, loess silt and clay extend to a depth of more than five hundred meters below the surface in some areas (Kendy et al., 2003). These deposits comprise the aquifers that supply groundwater to regions in all major river basins in the North China Plain. The aquifers, however, vary greatly across northern China. For example, in the North China Plain, unlike the South, where villages in mountainous areas can tap groundwater resources, mountainous areas in northern China are often groundwater deficient.[5] In the flat plains, the aquifers are multilayered. The multilayered aquifers in the Hai River Basin (NCP) typically have two to five layers; the first and third layers are the most water abundant . The first layer is typically an unconfined aquifer made up of large grained homogeneous sand and gravel. The other layers are typically confined aquifers. In some areas, especially in the eastern parts of the Hai River Basin, there is a

[5]In north China, almost all provinces have both mountainous areas and flat plains; it is hard to describe which regions are mountainous and which are flat.

naturally occurring saline layer. Created during a previous Ice Age, saline water often is found in the second layer, is confined and has a salt content high enough that it is typically unusable for agriculture without treatment.

Groundwater Resources from the Farmer's Perspective

To obtain an understanding of how farmers view their water resources, we asked village leader respondents to describe the nature of the aquifers that are under their villages. Because most village leaders have not been a part of any hydro-geological surveys of their villages, they often were not able to answer questions concerning the existence, size or other geological properties of the aquifers under their villages. Instead, village leaders know more precisely how many shallow or deep wells are in their village and the depths of the wells. Although there is not a complete correlation between the depth of the wells and the nature of the aquifer, in many cases, the existence of shallow or deep well coincides with that of shallow or deep layers of a village's aquifers. Regardless of their exact hydro-geological properties, according to our data (and the perception of village leaders), "deep wells" are almost always wells that have a depth of at least 60 meters. If a village needs to drill through an aquitard (a clay layer in most cases) to sink a well, the well is always defined as a "deep well." Shallow wells, in contrast, are mostly less than 60 meters and do not penetrate an aquitard.

Whether deep or shallow, groundwater resources are extensive across regions of Northern China. We asked village leaders, if there are groundwater resources in the village. Most village leaders responded that there are groundwater resources; and the share of villages having groundwater resources was almost 95 percent in 2004. However, not all villages having groundwater use this resource for irrigation. In 2004, more than 15 percent of irrigated villages with groundwater did not use it to irrigate. We further explore the reason behind this.

According to the answers of village leader-respondents, there are two major reasons that they cannot use it. Research results show that in 2004, the most important reason is that there are cheap and sufficient surface water resources (51 percent of villages). The second important reason is that there is no money to dig tubewells (37 percent of villages)._ Such findings suggests that there still may be potential to use even greater volumes of groundwater resources in the future. With increasing water scarcity and rising water demands, more villages have begun to use their community's groundwater. For example, from 1995 to 2004, the share of villages using groundwater resources *for the first time* has increased by almost 12 percent.

Relying on the observations of our NCWRS respondents, one of our most prominent findings is the great diversity of aquifer development in northern China. Of the 238 sample villages that used groundwater for irrigation in 2004, 33 percent told us that they extract groundwater only from shallow aquifers, and 42 percent only from deep aquifers and the remainder (25 percent) from both. Our data show that in some villages in northern China, the groundwater supply from shallow aquifers is sufficient to support current local water demand for irrigation. In other villages, maybe due to exhausted or unusable shallow aquifers, farmers extract groundwater only from deep aquifers.[6] In some villages (25 percent), both shallow and deep aquifers are being used. The groundwater supply from shallow unconfined aquifers is highly dependent upon precipitation, which supplies ground-water recharge. When rainfall is above average, as it was in 2004, water levels increase in shallow aquifers due to above average recharge. This may be the reason that we observe more villages extract groundwater from shallow aquifers in 2004 than in 1995.[7]

[6] Although we have not asked the reason that why farmers only extract groundwater from deep aquifers, based on our experience in the field, it should be due to exhausted or unusable shallow aquifers.
[7] We need more investigation to explore the reason in the future.

According to our respondents, the depth to water also varied across northern China. Although the average depth to water in 2004 was 26 meters, it varied sharply across our sample villages (Figure 3). In fact, in most villages depth to water was fairly shallow. In 2004, the average depth to water for the villages from the shallowest quartile of villages was only 4 meters and that for the second quartile was only 9 meters. Villages in the third quartile were pumping from an average depth to water of more than 30 meters. In only four percent of groundwater villages were villagers pumping from more than 100 meters.

The Contribution of China's Groundwater

After the emergence of tubewell and diesel and electric pumping technology, the role of groundwater rapidly grew in importance for all uses (Wang et al., 2005). In total, the use of groundwater rose from almost zero in the 1950s to 57 billion cubic meters annually in the 1970s. After the rural economic reforms in the late 1970s and early 1980s (which, among other things shifted income and control rights from the collective to the individual household) groundwater use continued to rise, reaching 75 billion cubic meters in the 1980s and more than 100 billion cubic meters after 2000 (Ministry of Land Resources, 2005).[8] As the use of groundwater rose nationally, its share in the nation's water supply also rose (from almost nothing in the 1950s to a major fraction in the 2000s). Across China, groundwater currently supplies about 20 percent of China's water. However, this amount is unevenly distributed. In southern China, groundwater comprises approximately 14 percent of water supply; in northern China it supplies 49 percent.

[8] One of important characteristics of the rural economic reforms in China is that land was distributed evenly to individual farm households. After the rural reforms, although land ownership was still collective, land use and income rights were transferred to individual farm households. Before the rural reforms, communes and brigade/teams (that is, village collectives) financed most tubewells. After reform, the fiscal revenue position of many villages declined. More importantly, after the early 1980s the policy constraints that originally limited the scope of private activities gradually have been relaxed and this has resulted in development of private tubewells.

From this point of view, the rise of the accesibility of groundwater has certainly played an important role in the emergence of northern China's regional economy.

Although the importance of groundwater has risen for all uses, it is likely that, as with water resources in general, groundwater resources are being increasingly allocated for non-agricultural uses.[9] Unfortunately, China does not collect systematically data on water allocation to economic uses by type of water resource. As a consequence all we know are the shares of total water resources that are going for domestic, industrial and agricultural uses. Since much of the increase in water use over the past 20 years has come from groundwater, we believe it is safe to assume that the share of groundwater being allocated to domestic and industrial uses follows somewhat of a similar pattern as followed by water resource use in general. Whereas in 1978, only 1 percent of China's water use was allocated for domestic use, by 2002 about 11 percent of water went for domestic users (Table 1). The use of water for industry also rose from 14 percent in 1978 to more than 21 percent in 2002. Although the share of water used in agriculture has fallen (from 85 percent in 1978 to 68 percent in 2002), it is still the largest water user.

Irrigation and the Role of Groundwater

Our data also demonstrate the importance of groundwater in supplying irrigation to northern China's agricultural sector. According to the respondents, nearly half (49 percent) of China's cultivated area is irrigated (slightly higher than the figure contained in China National Statistical Bureau, 2004—42 percent). However, with our data we can understand the water economy more fully, since our survey covers more than what is available in official sources. For example, since national statistics do not collect irrigation data by type of irrigation water, we asked village leaders to carefully document the source of their irrigated area: either surface,

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[9] Compared with the allocation of total water use to non-agricultural sectors, groundwater allocation to non-agricultural sectors appears to have increased more quickly. In 1997, non-agricultural sectors used 46 percent of total groundwater resources; while only used 31 percent of total water resources. See Table 1, row 4.

groundwater or conjunctive use of both. Based on their responses, in 1995, of all of the cultivated land that is irrigated, only 40 percent came from surface water diversions (or was lifted from canals by pumps onto the fields). The remaining 60 percent came from groundwater sources. Between 1995 and 2004 the importance of groundwater has continued to grow. In 2004 68 percent of irrigation in northern China was from groundwater.

Crop-Specific Incidences of Irrigated Area.

Our data can also produce estimates of crop-specific sown area statistics by irrigated and non-irrigated area. For example, major food grains in Northern China are mostly irrigated (Table 2). Approximately 96% of rice and 80% of wheat are irrigated, levels that are above the national average (column1, rows 1 and 2). Hence, our data support the findings of Huang et al. (2005) that investments in irrigation have been central for China to maintain food security. Although it is well known that China's food crops are heavily irrigated and that this is an important factor in China being able to produce a large fraction of its own food, these crop-specific estimates are important because China's own statistical bureau does not report sown area by irrigated and non-irrigated area.

In contrast to the case of food grains, a majority of feed grains and lower-valued staple crop area is not irrigated (Table 2, column 1, rows 3, 5 and 6). For example, despite its growing importance in China's agricultural economy, only 49% of China's maize is irrigated.[10] An even lower proportion of coarse grains and potatoes (including white and sweet potatoes) are irrigated. Although the proportion of irrigated area in cash crops also varies by crop, much of the area of China's main cash crops is irrigated (e.g., 58 percent of cotton area, 47 *(from Table 2)* percent of oil crop area and 66% of field vegetable area—rows 4, 6 and 7).

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[10] Although maize is grown during the rainy season and so the crop generally does not require as much irrigation as wheat (which is grown mostly during the dry season), irrigation still can play an important role in increasing maize productivity (Huang et al., 2005). In north China, irrigation is supplementary.

Perhaps more importantly, in northern China irrigation for most crops mainly depends on groundwater resources (Table 2, column 3). For grains and other staple crops, except for rice, at least 70 percent of the producers in irrigated areas use groundwater resources (72 percent for wheat; 70 percent for maize; 73 percent for potatoes). For cash crops, groundwater also is the major source of water for irrigation. For example, groundwater irrigates 70 percent of cotton area, 62 percent of oil crop area and 67 percent of field vegetable area.

Developing China's Groundwater

While the development of China's surface water resources has a long history and has played an important role in China's development as a state, the development of most groundwater resources has been compressed into less than fifty years. In this section, we briefly examine the way in which China has developed its groundwater resources by first describing the trends over the past fifty years in the installation of tubewells and pumps, focusing on the path of this development over time and across space. Because we have more detailed data from the past decade, much of the discussion will focus on the recent period. The second part of this section briefly introduces the technology that is being used.

The Rise of Tubewells

According to national statistics, the installation of tubewells began in the late 1950s and, although the number of wells has grown continuously, the pace of increase has varied from decade to decade (Ministry of Water Resources and Nanjing Water Institute, 2004). During the 1950s, the first pumps were introduced to China's agricultural sector. Although still fairly limited, the growth rate was fast. During the time period of the Great Leap Forward (the late 1950s and early 1960s), however, statistical reporting was suspicious and many irrigation projects that were started during the period were badly engineered and often abandoned. After the recovery from the Great Leap Forward and the famine that followed, statistical agencies recovered and statistical series since the mid-1960s are relatively consistent.

Since the mid 1960s, the installation and expansion of tubewells across China has been nothing less than phenomenal. In 1965 it is reported that there were only 150 thousand tubewells in all of China (Shi, 2000). Since then, the number has grown steadily. By the late 1970s, there were more than 2.3 million tubewells. After stagnating during the early 1980s, a period of time when irrigated area, especially that serviced by surface water, fell, the number of tubewells continued to rise. By 1997, there were more than 3.5 million tubewells; by 2003, the number rose to 4.7 million.

The path of tubewell expansion shown in the official data is largely supported by the information we have from the NCWRS. During the survey we asked the village leader to tell us about the initial year in which someone (either the village leadership or an individual farmer) in his/her village sank a tubewell (Figure 4). According to the data, we find that by 1960, less than 6 percent of villages had sunk their first tube well. Over the next twenty years, between the early 1960s and the onset of reform, the percent of villages with tubewells rose to more than 50 percent. During the next ten years, between 1982 and 1992, the number of villages with tubewells rose by only 7 percent. After the early 1990s, however, the pace of the expansion of groundwater accelerated, and by 2004, almost 75 percent of villages had wells and thus access to groundwater.

While the growth of tubewells reported by the official statistical system is impressive, we have reason to believe the numbers are far understated. According to the NCWRS, on average, each village in northern China contained 35 wells in 1995. When extrapolated regionally, , this means that there were more than 3.5 million tubewells in the 14 provinces in northern China by 1995. As important, according to our data, the growth of wells has grown fast.[11] . By 2004, the average village in northern China contained 70 wells, suggesting that the rise in tubewell constructionsince the mid 1990s has risen even faster than indicated by official statistics. By 2004, we estimate that there were more than 7.6 million tubewells in northern China. At least in our sample villages, the number of tubewells has grown by more than 12 percent annually between 1995 and 2004.

The Technology that Pumps China's Water

As China's groundwater usage has expanded, the characteristics of pumps used for shallow and deep wells have also evolved. In 1995, the average size of the pump used on a shallow well was 3 inches, drawing 6.9 KW of power with a lift of 28 meters. The average shallow well pump discharged about 32 cubic meters per hour. By 2004, the average size pump increased marginally in size (to 3.1 inches), power (to 7.2 KW), lift (31 meters) and discharge (to 37.5 cubic meters per hour).

The rate of change of deep well pumps was greater than the rate of change of shallow well ones. In 1995 the average deep water pump was 3.9 inches in diameter, drew 13.5 KW of power, had a lift of 53 meters and discharged 61.2 cubic meters per hour. By 2004, both power and lift have increased (to 14.1 and 58 respectively). Both diameter and discharge, however, decreased slightly (to 3.7 and 60.9 respectively).[12]

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[11] As we show in Wang et al. (2005b), the expansion of tubewells does not necessarily mean that there is an expansion in water consumption. However, according to our data (which is used in that paper, also), a significant share of the new wells are being located in areas that are allowing for the expansion of cropping area, increased intensity of cropping and rising yields. Hence, while not all of the rise in wells will result in increased consumption of water, a part of the rise will.

[12] This indicates that due to the decline in groundwater table, it requires more power to extract water.

The evolution of pump technology was mostly being driven by new technologies that were coming on the market and demand for more powerful pumps. When we asked villages if they had changed the pumping technology type between 1995 and 2004, more than one quarter of villages using groundwater in 2004 responded that they had. Most interestingly although pumps are generally getting bigger and more powerful, they are not necessarily increasing in price. In fact, there is evidence that the price of pumps in China is falling. While we cannot pinpoint the reason why, it likely is due to an increase in economy of scale over the past decade. Our data shows a general trend in purchasing location from government (state-owned) to private pump dealers.

Groundwater Problems and Challenges

As with most periods of rapid economic growth and intensive resource use, many problems arise. In the case of water in the northern China, however, because of the importance of water, much attention has been focused on the sector's problems (Brown and Halweil, 1998; Smil, 1993; Ministry of Water Resources and Nanjing Water Institute, 2004). In fact, we believe there are many misperceptions about the nature of China's water problems—especially as they relate to the rural economy. In many cases, problems, although serious regionally, are not national in scope. Other problems often are confined to urban areas or rural areas, but not both. Of course, most of the misperceptions are not intentional, but a result of poor information. The goal of this section is to try to provide a brief assessment of the main problems facing China's groundwater economy. Given the fact that most of the work in the past has had an urban focus, our work centers on those problems affecting the rural sector.

Overdrafting China's Groundwater Resources

According to a comprehensive survey completed by the Ministry of Water Resource in 1996, the overdraft of groundwater was one of China's most serious resource problems (Ministry of Water Resources and Nanjing Water Institute, 2004). Although we do not know the exact way in which the survey was conducted, the results of the survey provide evidence that groundwater overdraft is a widespread problem and may be getting worse. According to the report, overdraft is occurring in more than 164 locations and affects more than 180 thousand square kilometers. The areas of overdraft range from ten to twenty square kilometers to more than ten thousand square kilometers and are in 24 of China's 31 provinces. Groundwater overdraft is affecting all types of aquifers: the shallow groundwater table (87 thousand square kilometers), the deep groundwater table (74 thousand square kilometers) and the aquifers that have two layers, both the shallow and deep layers (13 thousand square kilometers).[13] Since the 1980s, the annual overdraft of groundwater has averaged about 7.1 billion cubic meters. In the late 1990s, the annual rate of overdraft exceeded nine billion cubic meters. More than one third of the volume of overdraft is from deep wells, many of which may be nonrenewable on a short time scale.

While the problem of overdraft is usually discussed in general, in fact, the problem appears to be particularly acute in cities. The Ministry of Land Resources recently has finished an evaluation of groundwater resources in China (Ministry of Land Resources, 2005). According to the final report, groundwater resources in most large and middle cities in northern China are either in overdraft (extractions exceed recharge) or in serious overdraft conditions (the

[13] There are also several other minor types of aquifers which were being overdrafted. These minor types of aquifers that are being overdraft account for about 7 thousand square kilometers.

fall of the groundwater table exceeds 1.5 meters per year).[14] For example, in many cities the volume of water extracted from the aquifer is nearly double the volume of average annual recharge.[15]

Such dramatic numbers for all of China, and especially those for urban areas are the cause of the concern that has appeared in the literature. However, when analyzing the effect on rural areas, at least according to our NCWRS data, a somewhat different picture arises. According to our data, there was no fall in the groundwater table in 25 to 33 percent of villages in northern China using groundwater in both 1995 and 2004.[16] In 8.5 to 16 percent of villages (between one third to one half of villages that reported no fall in the groundwater table) respondents told the enumerators that the groundwater was actually higher in 2004 than in 1995. In another 10 to 17 percent of villages, the average annual fall in the groundwater table was less than one quarter meter per year. In other words, in over one third to one half of China's villages using groundwater over the past decade groundwater resources have shown little or no decline since the mid 1990s. Although, based on our data, most villages are in, or are nearly in, balance, we are not arguing that groundwater problems do not exist. In fact, there are still a large number of villages in which the water table is falling. Before classifying these villages as being irrational groundwater resource exploiters (although some of them may be), it is important to

[14] The definition of overdraft here is from MWR in China (citation). It is important to note, however, that there are other definitions. For example, Kendy points out that the MWR's definition is not an accurate way to define "overdraft." In a sustainable system, ground-water recharge should equal discharge over time. Extractions (ground-water pumping) are only a small part of total discharge from an aquifer. Other parts include natural discharge to rivers (which explains why rivers flow even long after rain and snow stop falling), and natural discharge to wetlands, lakes, and plants. If extraction (ground-water pumping) exceeds recharge, then all those other components of ground-water discharge would cease. Overdraft is better defined by long-term water-level declines.

[15] According to a comprehensive survey completed by the Ministry of Water Resource in 1996, groundwater overdrafting is a widespread problem and may be getting worse. Overdrafting is occurring in more than 164 locations and affects more than 180 thousand square kilometers. The areas of overdraft range from 10 to 20 square kilometers to more than 10 thousand square kilometers and are in 24 of China's 31 provinces.

[16] In our survey we asked village leaders about the average level of groundwater depth during the year and the "static" level of the groundwater. Before responding, we told village leaders that the static level of the water table is the level that exist at a time immediately prior to the irrigation season (e.g., in the North China Plain this would be around the month of March). According to our respondents, there were differences in the statistics on the changes in the groundwater table when using average or static groundwater levels. According to our data, the static level produced numbers that suggested there were fewer villages in which the groundwater table was falling.

remember that a village's water resources may not be overexploited, even if the water table is falling. Given the fact that many of China's aquifers are fossil, by definition, any meaningful extraction will result in declining water levels. Hence, even under the most rationally planned groundwater utilization strategy, there will be a share of villages in the China in which we should expect the water table to be falling. In addition, if we follow the MWR's definition of seriously overdraft, only 10 percent of villages using groundwater in the past decade have water tables that are falling at a rate greater than 1.5 meters per year. Of course, such decline rate is not only serious, but also a crisis!

In summary, then, the point we want to make is that in many places—indeed, in most places in northern China, it is possible that water resources are not being misused. However, we do not want to minimize the problems that are occurring in some places. There are a large number of rural areas in which the water table appears to be falling at a dangerously fast pace. Where the resource is being misused, steps will be required to protect the long run value and use of the resource. However, it is important to realize that many of the required measures (discussed in the next section) will have associated costs—to obtain adoption, productivity and avoid reduced income. Because measures to counter overdraft are not needed in all villages, leaders should not take a "one-size-fits-all" approach; to avoid inflicting unnecessary costs on producers in communities where overdraft conditions do not exist.

Subsequent Effects of Overdraft

As the groundwater table falls, producers face a number of impacts. Above all, of course, the cost of pumping rises. According to our data, for every meter by which the groundwater table falls, pump costs rise by 0.005 yuan per cubic meter (or about 2 percent of the mean level of pumping costs in 2004). In addition, wells may have to be replaced and the costs of investment expanded, although in many cases new wells have been sunk for reasons other than the falling water table. The average cost of drilling a deep tubewell (90 meters) was more than five times the cost of drilling a shallow tubewell (37 meters). According to our data (as seen in the previous section), well owners in China have sunk an enormous number of new wells in the past decade. On average, from 2002 to 2004, the typical groundwater using village sank about 22 new wells, 5 deep wells and 17 shallow wells. Although a percentage of new wells (6 of the 22) were being installed due to the fact that olds wells were abandoned, it should be noted that, according to the opinions of our respondents, only two of the six wells that were abandoned were abandoned because of the falling water table. In many cases, wells were replaced for other reasons (such as, when a well structure collapsed).

Beyond the increases in pumping costs and well installation, there are also a number of other potential consequences of overdraft (Ministry of Water Resources and Nanjing Water Institute, 2004). One of the most commonly cited consequences of overdraft is land subsidence. For example, in Hebei province alone, by 1995 more than five thousand square kilometers had subsided more than six hundred millimeters. In Tianjin Municipality, the total exceeded seven thousand square kilometers. [17] Groundwater overdraft may also lead to the intrusion of seawater into fresh water aquifers (Ministry of Water Resources and Nanjing Water Institute, 2004). By the mid 1990s overdrafting allowed seawater to intrude and contaminate aquifers under more than one thousand five hundred square kilometers of land, especially in the coastal provinces of northern China, such as Liaoning, Hebei and Shandong provinces. The MWR has also been concerned about the impact of groundwater overdraft on desertification and the depletion of streamflow that was previously supplied by natural ground-water discharge.

[17] Land subsidence mainly occurs in urban areas.

Although the consequences of overdraft are widely discussed in the literature and equated with China's water problems in general, interestingly none of these problems appears to be in anyway associated with rural areas. According to our survey of more than 400 villages, no village leader ever reported that there was any land subsidence problem. Likewise, in no case did a village leader report that his/her village's groundwater was contaminated by seawater intrusion. Finally, there also was no evidence that villages that were using groundwater—either those that were drawing down their water table or not—experienced a fall in cultivated area due to desertification. Clearly, although the attention that these problems get in the literature means that they are serious and require addressing, these appear to be no rural area problems.

Other Problems with Groundwater

Groundwater Pollution

Both the literature on groundwater and our survey also report a number of other problems that are not directly related to groundwater overdraft. For example, it has been widely reported in the press and in academic journals (e.g., Kendy et al., 2003) that pollution from municipal sewage has contaminated the groundwater of many villages in China. Part of the problem is created when farmers pump from effluent canals, using sewage-laced water on their fields. The recharge from irrigation with such water can affect the entire aquifer. Even when villages do not use the water for irrigation purposes, recharge from stream and riverbeds can contribute to groundwater pollution. According the Ministry of Water Resources and Nanjing Water Resources Institute (2004), the groundwater resources of more than 60 percent of the 118 largest cities in China have contaminated groundwater.

Drawing on our survey (in which we ask leaders about their perception of pollution), we find the scope of the problem is somewhat less and the main source of pollution different than those reported in other sources, interviews with leaders in communities suffering from contaminated groundwater demonstrate that pollution is still a serious problem. According to our sample communities, the groundwater is polluted in 5.40 percent of the villages. However, unlike the villages around cities, which are mainly being affected by municipal sewage waste, respondents identified industrial pollution and runoff from mining operations as the most common source of pollution. In fact, of all of the villages that reported contaminated groundwater, 95 percent (5.15 percent of all villages) said that the main source of pollution was from industrial and mining wastewater. Only 0.25 percent of all villages (or less than 5 percent of villages that report contamination) said that their groundwater was polluted by agricultural chemicals; none said it was due to urban sewage.

While the extent of the perception of rural groundwater pollution problem appears to be less serious than the urban/suburban problem, it is still serious. Extrapolating our results to all of northern China, we can estimate that more than 20 million rural residents living in 20 thousand rural villages are using groundwater that has been contaminated by industrial runoff. Moreover, unlike their urban and suburban counterparts, most villages in China lack any type of drinking water processing facilities. In most cases, the pollution causing the problems in one rural community was being created by the actions of industrial and mining facilities that belonged to some other community or economic agent. There is no clear advocate to force upstream communities either to stop polluting or to compensate downstream communities for the damage. There also is little funding for rural groundwater pollution abatement. In short, there is no incentive or means to address and/or curtail the activities that are polluting the groundwater of millions of rural communities.

Soil Salinization

Across China, the appearance of salinized soil has been a widespread problem, but, according to a number of sources, this problem has been improving in recent years, unlike many others. According to the Ministry of Water Resources and Nanjing Water Resources Institute (2004) , more than one million square kilometers of China's land has become salinized over the past several decades. The majority of the most serious problems have occurred in the Northeast, the Northwest and in some places on the North China Plain. Despite the widespread nature of the problem, in recent years, the area affected by salinization has fallen Ironically, it may be that the same forces diverting surface water away from agriculture and forcing producers to rely increasingly on groundwater may be the primary cause of such improvements. Without access to cheap and abundant surface water, which led to the salinized soil problem, the problem has gradually disappeared as farmers have turned to groundwater and the water table has fallen (Nickum, 1988). [18]

In our sample of villages, we find that the salinization of the soil is one of the most commonly reported problems, although, consistent with national statistics, it is improving over time. According to our respondents, in 2004 16 percent of village reported having some salinized soils. Since the process that caused the soil salinization does not affect all cultivated area in a village, only 3.4 percent of cultivated area was reported to be affected. Moreover, the scope of soil salinization is improving over time. In 1995, 20 percent of villages reported salinized soils and 4.4 percent of cultivated area was affected. Hence, between 1995 and 2004, there was nearly a 25 percent reduction in the severity of the nation's soil salinization problem.

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[18] *Salinization is caused by different factors – and responds to different solutions -- in different settings. Over time, continued ground-water use is likely to increase soil and water salinization. Each time ground water is "recycled" through the pumping and re-infiltration process, it becomes more saline.*

Managing China's Groundwater

In this section we first examine the response—or more accurately, the lack of response—of the government to groundwater problems. We then track the response of producers—those at the community and individual household level. As we will see, in contrast to officials, producers have responded sharply in many different ways.

Regulating (or Not) China's Groundwater: The Role of the Government

Over the past fifty years, China has constructed a vast and complex bureaucracy to manage its water resources. To understand the functioning of this system, it is important to first understand that, until recently, neither groundwater use nor water conservation have ever been of major concern to policymakers. Instead, the system was designed to construct and manage surface water to prevent floods, which have historically devastated the areas surrounding major rivers, and to effectively divert and exploit water resources for agricultural and industrial development. Historically, when attention was paid to water conservation, the emphasis was on surface water canal networks. Therefore, many of the most severe groundwater problems have not been directly addressed.

Laws and Measures

Water policy is ultimately created and theoretically executed by the Ministry of Water Resources. The MWR has run most aspects of water management since China's first comprehensive Water Law was enacted in 1988, taking over the duties from its predecessor, the Ministry of Water Resources and Electrical Power. The policy role of the MWR is to create and implement national price and allocation policy, and to oversee water conservancy investments by providing technical guidance and issuing laws and regulations to the subnational agencies (Lohmar et al., 2003).

In fact, officials in the MWR and officials in other ministries have spent time and effort in passing laws and regulations concerning groundwater management in rural areas. For example, according to the China's national 1988 Water Law, the property rights of all underground water resources belong to the state. This means that the rights to use, sell and/or charge for water ultimately rest with the government. The law does not allow extraction if the pumping of groundwater is harmful to the long run sustainability of the use of the resource.

Beyond formal laws, there have also been many policy measures set up in part to rationally manage use of the nation's resources. In most provinces, prefectures and counties there are formal regulations controlling the right to drill tubewells, the spacing of wells, and the price of water when sold. The national government has also set up the necessary regulatory apparatus to allow for the charging of a water extraction fee (surface water and groundwater in urban areas).

Despite the plethora of laws and policy measures that have been created by officials, there has not been an equal effort put out in implementing them. Certainly, part of the problem is one of historic neglect. In fact, the delegation of groundwater management at the ministerial level is still relatively small. There are far fewer officials working on this division than in other divisions, such as flood control, managing surface water systems and water transfer. Moreover, unlike the case of surface water management (Lohmar et al., 2003), there has been no effort to bring management of aquifers that span jurisdictional boundaries under the ultimate control of an authority that can control the government and private entities that use water extracted from different parts of the aquifer. According to Negri (1989), when there is not a single body controlling the entire resource, it becomes difficult to implement policies that attempt to manage the resource in a long term, sustainable, more optimal manner.

Whether for lack of personnel or other difficulties in implementing the measures, inside China's villages few regulations have had any affect. For example, despite the nearly universal regulation that requires the use of a permit for drilling a well, less than 10 percent of the well owners surveyed obtained one before drilling. Only 5 percent of villages surveyed believed their drilling decisions needed to consider spacing decisions. Although price bureaus in every county were supposed to regulate the price for which groundwater was sold from one farmer to another, in only 8 percent of villages did this occur. Even more tellingly, water extraction charges were not charged in any village; there were no physical limits put on well owners. In fact, it is safe to say that in most villages in China, groundwater resources are almost completely unregulated.

Producer Response

Although China's central and regional governments currently have little control over groundwater in most parts of northern China, groundwater governance is not stagnant. In fact, when assessing the way groundwater is managed, the way farmers gain access to water and the way technology is being used to conserve the resource, the sector can be considered to be extremely dynamic. In this section, we examine three sets of issues: the privatization of tubewells, the emergence of groundwater markets and the adoption of new, water saving technologies.

Privatization

Among any single individual feature of northern China's groundwater economy, the privatization of tubewells is perhaps most prominent. Before the rural reforms in the 1960s and 1970s, township governments and village leadership councils financed, owned and managed most tubewells. In most villages individual farmers at most contributed their labor for tubewell construction. Financed primarily by collective retained earnings, commune, brigade and team cadres were largely responsible for arranging for the water resource bureau-run well drilling companies to sink tubewells. Pumps in the pre-reform era all came from either the water resource bureau pump supply company or the state-run local agricultural inputs corporation.

Soon after the general economic reforms began in the early 1980s, however, the ownership of China's tubewell began to shift sharply. According to our survey in Hebei Province in the late 1990s, in the early 1980s collective ownership accounted for 93 percent of all tubewells. Throughout the late 1980s and 1990s, however, the collective ownership of tubewells diminished. During this period the share of private tubewells increased from 7 to 64 percent. Data from the NCWRS largely support these findings. Tubewell ownership in our study area, representing all of northern China, has also shifted sharply from collective to private (Table 3). In 1995, collective ownership accounted for 58 percent of tubewells in the average groundwater using village. From 1995 to 2004, however, the collective ownership of tubewells diminished and accounted for only 30 percent of wells in 2004. In contrast, during the same period the average share of private tubewells increased from 42 to 70 percent.

Our interviews also revealed that the rise of privately financed investment means that the shift of tubewell ownership is the result of the establishment of new tubewells rather than ownership transfers of collective tubewells. Due to the fall of the groundwater table and lack of maintenance on pumps and engines, a number of collective tubewells became inoperable during the past two decades and the absolute number of collective tubewells fell. During this time, the number of private wells has increased rapidly.

Groundwater Markets

As tubewells and the accompanying pumping equipment have come under the control of private individuals, access to groundwater for those farmers who do not own and operate their own wells has become a new issue. In fact, these markets have not always existed. In the 1970s and 1980s, when most wells were owned and operated by the collective, in almost all villages simple rules governed water allocations; most of the rules were based on a system in which all individuals were provided with water in an equitable way . In some villages, the collective provided water free or at a subsidized rate. In the early period after reform, however, for a number of reasons the traditional institutions began to breakdown (see for example, Wang et al., 2005a). In today's world in which most wells are owned by some, but not all, farmers there must be some way to transfer water from those with wells to those without.

In response to the demand for water in an environment increasingly dominated by private and privatized wells, following a pattern similar to that observed in South Asia (Shah, 1993), groundwater markets have begun to emerge in recent years as a way for many producers in rural China to gain access to groundwater.[19] In the 1980s, groundwater markets were almost nonexistent. Indeed, according to the NCWRS, only 21 percent of villages had groundwater markets in 1995. By 2004, however, tubewell operators in 44 percent of villages were selling water. Across all villages about 15 percent of private tubewell owners sold water. Although groundwater markets exist in less than half of northern China's villages, the numbers are still significant: farmers in more than 100,000 villages are accessing water through groundwater markets. Moreover, in villages that have groundwater markets, these markets play an important role in transferring large volumes of water among a large share of households.[20]

[19] Groundwater markets in our paper are defined as localized, village level arrangements through which owners of tubewells sell pump irrigation services to other farmers of the village (in other words, they sell water to other farmers from their wells for use on crops). In our paper, we are only going to examine "private" water markets. In other words, we examine the nature of groundwater markets that are being driven by individuals and groups of individuals that sink wells. In making such a definition, we are assuming that when village leaders (the collective) provide water to villagers, this is being done under non-market conditions.

[20] Groundwater markets in northern China are not necessarily "competitive" markets and may be more accurately characterized by captive selling. When farmers buy water through groundwater markets, they not only pay for operating costs, but also pay a little service cost that contributes to profit for the operator/owners.

Household and Village Adoption of Water Saving Technology

Another possible response to perceived water shortage is the adoption of new cultivation techniques and technologies. Our survey covered three sets of technologies: traditional technologies (agronomic-based, highly divisible;[21] generally practiced by farmers in pre-People's Republic of China), household-based technologies (highly divisible; low fixed cost; requiring little collective action) and community-based technologies (requiring collective action for adoption and maintenance; high fixed costs). The adoption paths of these three different water saving technology types trace three distinct sets of contours. Moreover, the general path of each technology within each major category—traditional, household-based and community-based—tends to follow the trajectory of the other similar technologies within its category. In this section, we track adoption with one set of measures—a village-based set of measures in which a village is considered to have adopted a technology if at least one plot or farmer in the village uses the technology. In other work (Blanke et al., 2005), we also examine a measure of area of adoption (which gives largely the same pattern of results).

As the name implies, according to our data, traditional water saving technologies have been used for many years (Figure 5, top set of lines). The strongest distinguishing characteristic of traditional water saving technologies is that, even as of the early 1950s, they were being used in a relatively large share of China's villages. For example, in 1949 farmers in 55 percent of northern China villages were already leveling their land. During the reform period, the adoption of traditional technologies grew slowly, in part because traditional technology adoption rates were already high in the pre-reform and early reform era.

In contrast, household-based technologies have taken a different technological adoption path over the past half-century (Figure 3, middle set of lines). Although it is difficult to

[21] "highly divisible" means that individual farmers can adopt the technology by themselves.

distinguish exact levels of adoption from Figure 2 (the paths are too tightly bunched), household-based water saving technology adoption rates were all low in 1949, ranging from 1 percent (surface pipe) to 10 percent (retain stubble / low till). Unsurprisingly, due to the relative abundance of water and the nature of farming at the time (collective-based with few incentives to maximize profits), household-based technology adoption rates at the village level remained low over the next thirty to forty years. It was not until the early 1990s that their adoption rates soared. By 2004, farmers in at least 45 percent of villages were using each type of household-based water saving technology mentioned in Appendix A.

Finally, although the basic pattern of community-based technology adoption follows the same fundamental trend as household-level technologies, these paths start lower and rise at a slower rate (Figure 3, lowest set of lines). Between the 1950s and 1980s, like household-level technologies, adoption rates are low. By the beginning of the reforms in the mid 1980s, the highest village-level adoption rate of a community technology (lined canals) was only 10 percent; on average the level of adoption of community technologies during the mid-1980s was around 5 percent. By the 2004, like the case of household-based technologies, the rate of adoption rose sharply relative to previous years. Because community technologies were starting from a lower level and rose less by 2004 the village-based measures still show that, on average, only about 20 percent of communities had adopted community technologies.

While, based on these descriptive contours, it is unclear what is driving the adoption path of community-based technologies, it is likely that there are two sets of forces that are at once encouraging and holding back adoption. On the one hand, rising scarcity of water resources is almost certainly pushing up demand for community-based technologies. On the other hand, the predominance of household farming in China (Rozelle and Swinnen, 2004) and the weakening of the collective's financial resources and management authority (Lin, 1991) has made it more difficult to gather the resources and coordinate the effort needed to adopt technologies that have high fixed costs and involve many households in the community. In contrast, household-based technologies may be more widely adopted due to relatively low fixed costs, divisibility, and minimal coordination requirements.

Conclusions

The primary goal of this chapter was to sketch a picture of China's groundwater water economy, with focus on rural areas. Indeed, in our efforts to do so, we have generated a number of empirical-based findings that, at the very least, may help to clarify a number of misperceptions on which past discussions of China's water resources were sometimes based. China has some of the most abundant groundwater resources in the world. Over the past two to three decades in a large portion of China's localities, these resources have begun to be tapped. According to our results, however, there are still a significant number of areas that have undeveloped groundwater resources, even in the North-eastern areas, commonly believed to be generally over-exploited.

In areas that have begun to use their groundwater resources, we have been able to paint a somewhat unorthodox picture. While there are serious groundwater problems (in around 10 percent of villages, the groundwater table fell by more than 1.5 meters per year), including groundwater overdraft in some areas of northern China, in many other areas—indeed in more than one third to one half of China's villages using groundwater in northern China, groundwater resources have not diminished at all levels or are declining less than 0.25 meters per year over the past decade. In other words, the groundwater economy is heterogeneous, and as such, in dealing with policy in the future, considering the differences is important.

We also believe we have been able to lay out a clear pattern of actual responses by major actors that helps to clarify the challenges for managing groundwater in the coming years. In short, government officials have done little to control the extraction of groundwater in rural China. Producers—especially individual farmers, on the other hand, have been responsive. Farmers have taken over control of most of the well and pump assets; farmers are increasingly taking on responsibility of transferring water from those that have wells to those that demand water. Farmers also are increasingly figuring out ways to conserve the scarce resource.[22] Hence, the policy implication of all of these results is clear. There needs to be a multi-step response by officials. First, they need to determine where serious overdraft is occurring and where it is not. Attention then needs to be paid to the areas in which there is a problem. In these areas, policy must recognize that, with proper incentives, farmers will respond by saving water and transferring the resources from those that have it to those that need it.[23] Hence, if formulas can be designed to implement price-based policies or some other set of policies that make the scarcity of water more evident, farmers will respond. Such policies will not be easy to implement as they require a lot of information on the nature of the resource. In order to avoid negative income effects on those farmers who would have to pay more for water, it may also require complex transfer schemes in which farmers that are being charged for water and are being forced to cut back at the same time can be compensated in some way to try to minimize or offset the higher water fees. The transaction costs in such a system must also be considered. In

[22] Some researchers (Kendy, et.al., 2004) argue that farmers are figuring out ways to reduce pumping without reducing crop production. Thus, they are conserving electricity, but not water.
[23] Some researchers (Kendy et.al., 2004) argue that policies must ensure that water is actually saved (i.e., irrigated area decreases). So long as crop production stays the same, no water will be saved and any “transfers” will only exacerbate the problem.

some areas, it is possible that quantity controls could work more efficiently than price-based controls.

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Table 1 Uses of water resources in China, 1978 to 2002

	Domestic(%)	Industrial(%)	Agriculture(%)
Total water resources			
1978	1	14	85
1997	10	21	69
2002	11	21	68
Groundwater resources			
1997	26	20	54

Data source: Ministry of Water Resources, 2002.

Table 2 Share of irrigated sown area by crop type the North China

Crop	Percent of cropland that is irrigated	Percent of irrigated sown area	
		Surface water	Groundwater
Rice	96	76	24
Wheat	80	28	72
Maize	49	30	70
Cotton	58	30	70
Potato	22	27	73
Soybean	24	32	67
Oil crops	47	38	62
Field vegetables	66	33	67

Data sources: Authors' survey in 2004.

Table 3 Changes of well ownership from 1995 to 2004

	All wells		Private wells	
	Collective	Private	Shareholding	Individual
Share of wells (%)				
1995	58	42	53	47
2004	30	70	38	62

Data source: Authors' survey in 2004.

Figure 1 14 counties surveyed in China in September 2004,
Water Institutions and Management survey (CWIM)

Figure 2 50 counties surveyed in December 2004 and January 2005,
the North China Water Resource Survey (NCWRS)

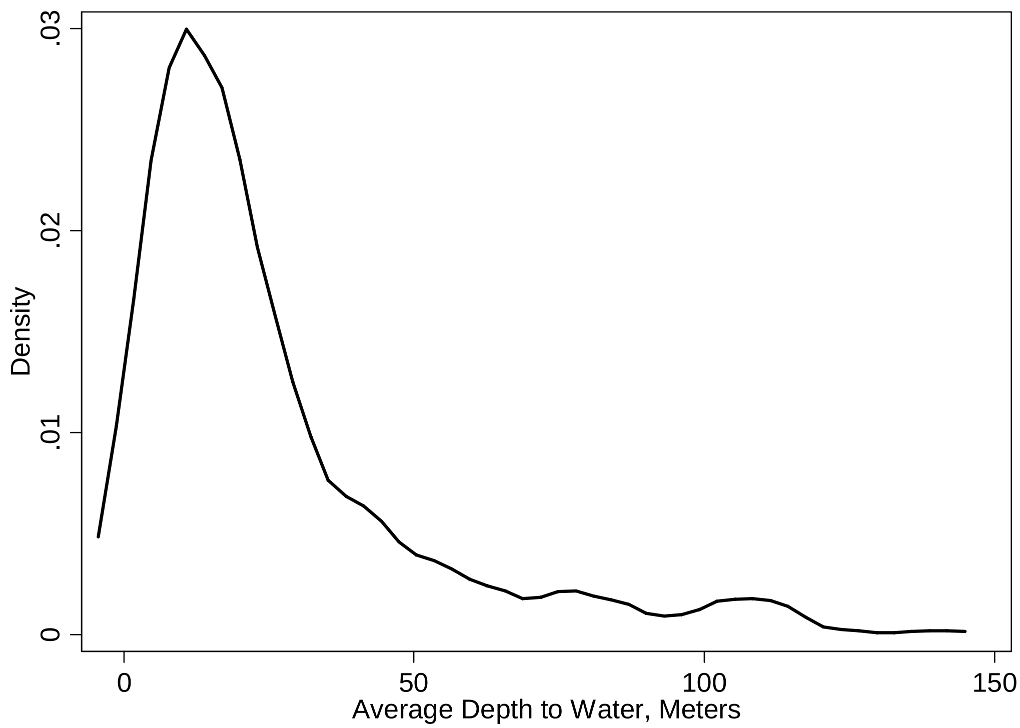

Figure 3 Average depth to water in 2004

Data source: Authors' survey in 2004.

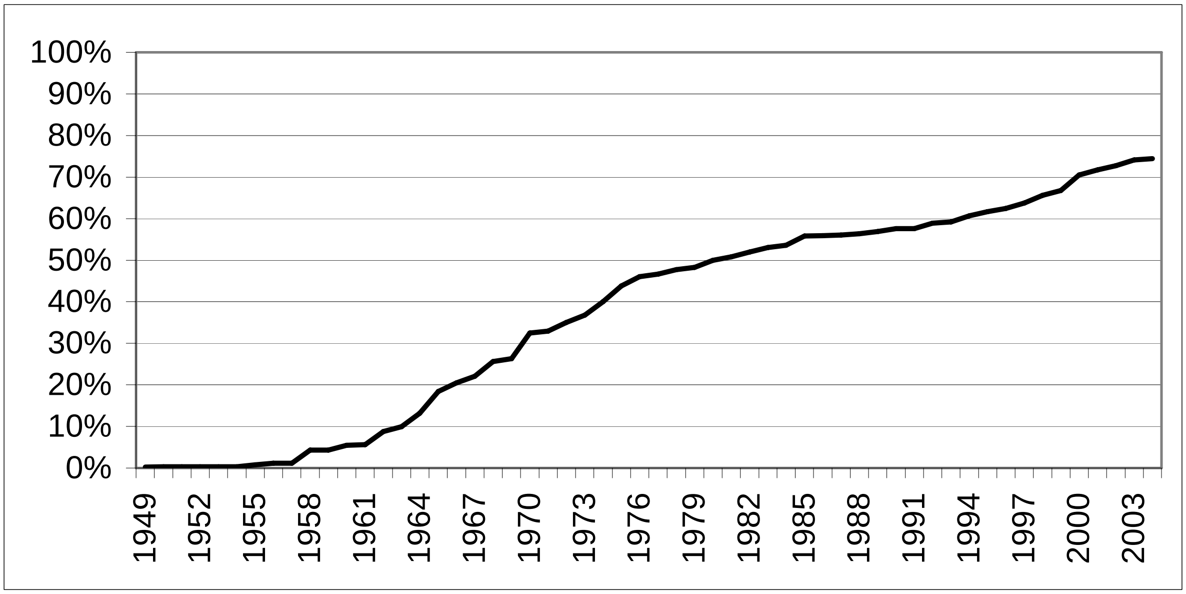

Figure 4 Share of villages with wells over time

Data sources: Authors' survey in 2004.

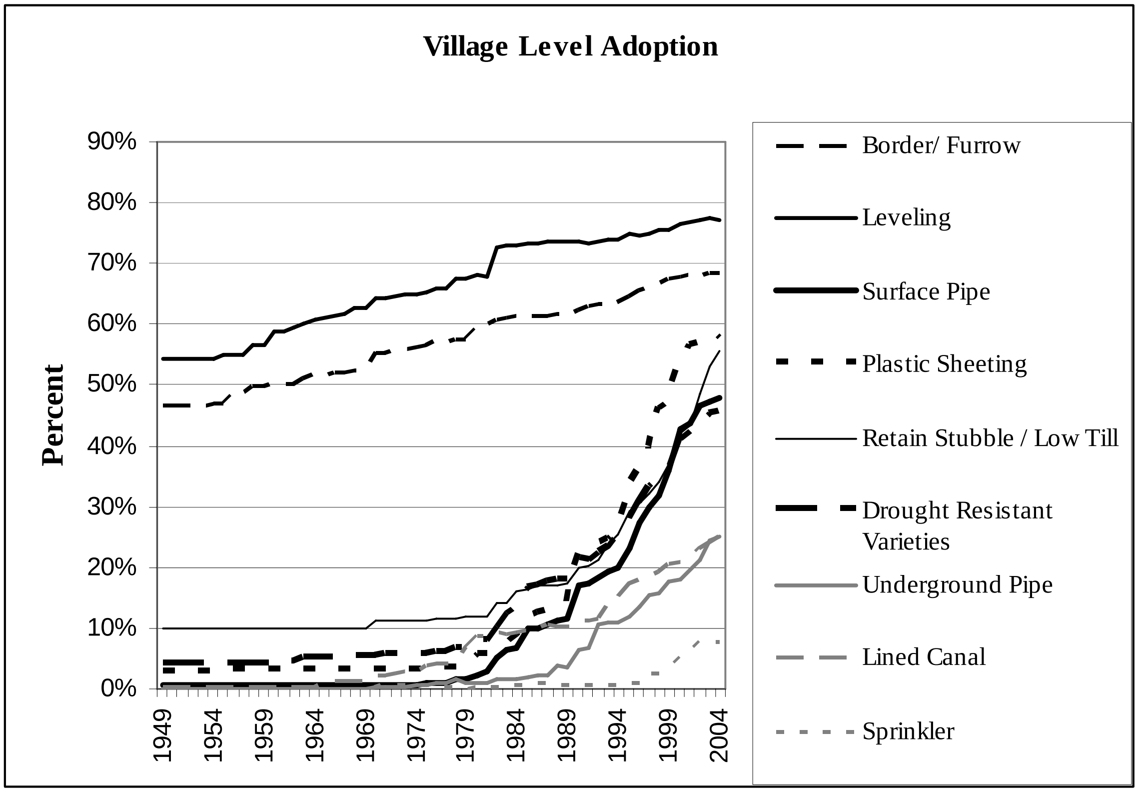

Figure 5 Share of villages adopting water saving technologies over time

Note: Village level adoption means that at least one household (or plot) in the village is using the technology. The aggregated border and furrow irrigation adoption rates are estimated taking the covariance of adoption into account – only 34.6 percent of furrow adopters were not also adopters of border irrigation.

Data sources: Authors' survey in 2004.

Appendix A

Types of Water Saving Technologies

During our survey of leaders and water managers in more than 400 villages, we discovered that there are many types of water savings technologies being used in northern China. For the purposes of this paper, the term water saving technology encompasses a wide variety of irrigation techniques and agricultural production practices. For analytical convenience, we have divided the list of technologies into three groups: traditional, household-based and community-based. In the rest of the paper, we are excluding any discussion of a series of novel water saving technologies (such as drip, intermittent irrigation, and chemicals and drugs) because across our sample, they had very low levels of adoption (that is, nearly zero).

Our use of the term water saving is limited to perceived field level applied irrigation savings. We understand that in the case of many technologies that we are considering, their adoption may not save water when net water use is measured on a basin scale. The real, or basin-wide, water saving properties of each technology depend not only on the technical features of the technology, but also on the hydrology of the system and the economic adjustments to production that are associated with adoption of the technology.

Traditional technologies include border and furrow irrigation and field leveling. We have grouped these technologies because they are widely adopted and because village leaders in a majority of villages report adopting these techniques well before the beginning of agricultural reform in the early 1980s. These irrigation methods have relatively low fixed costs and are separable in the sense that one farm household can adopt the practice independent of the action of its neighbors.

Household-based technologies include plastic sheeting, drought resistant varieties, retain stubble/low till and surface level plastic irrigation pipe. We have grouped these technologies because they are adopted by households (rather than villages or groups of households), have relatively low fixed costs and are highly divisible. Typically, adoption of these technologies is more recent than adoption of the traditional technologies.

Community-based technologies include underground pipe systems, lined canals and sprinkler systems. We have grouped these technologies because they tend to be adopted by communities or groups of households rather than by individual households. In most applications, they have large fixed costs and often require collective action or ongoing coordination of multiple households.