

Practices of groundwater over-exploitation control in Hebei Province

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Abstract

Twenty-one provinces in China have the problem of groundwater over-exploitation, and Hebei is the province with the longest-lasting and most severe groundwater over-exploitation problems. In 2014, the Chinese government initiated a pilot project of groundwater over-exploitation control in Hebei Province. Comprehensive measures have been adopted, including replacement of groundwater supply with surface water, development of a water-saving agricultural irrigation system, adjustment of agricultural planting mode, and improvement of water use right and water pricing systems. Pilot projects of groundwater over-exploitation treatment in Hebei Province can provide a good reference for other arid and semi-arid regions to implement and strengthen groundwater management strategies.

Keywords: Groundwater management; Groundwater over-exploitation control; North China; Pilot project

Introduction

Groundwater is an important water source in supporting China's economy and the development of society. From the 1970s, China, especially the north region, started to intensively pump groundwater for agricultural irrigation, industrial development, and city expansion. To meet water demand for rapid development of the economy and society, groundwater has been continuously and disorderly exploited with very large amounts for a long time in some regions in China, and severe problems of over-exploitation have occurred in many places. In recent years, some provinces and regions in China have actively carried out regulations of groundwater over-exploitation control and achieved obvious positive results, as well as plenty of beneficial experiences in groundwater over-exploitation management and control. The practices, including prohibition of groundwater pumping from deep confined aquifers in regions of Suzhou-Wuxi-Chang ([Jiangsu Provincial People's Congress \(2012\)](#)), ecological restoration in Shiyang River Basin ([Zhang & Yang, 2016](#)), prevention and control of seawater

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intrusion in Laizhou City (Cheng & Dai, 2016), and shutting down the pumping in urban areas of Liaoning City, have effectively promoted the control and management of groundwater over-exploitation in China.

Hebei, located in North China, is the province with the most severe problem of groundwater over-exploitation in China. In 2014, four ministries at the national level of China, including Ministry of Finance, Ministry of Water Resources, Ministry of Land and Resources, and Ministry of Agriculture, jointly launched a pilot project of groundwater over-exploitation control in Hebei Province. Since then, multiple measures have been applied to reduce groundwater use and increase recharge. With more than five years' efforts, obvious results have been achieved, and many good experiences have been gained.

Hebei Province is a serious water shortage region, with an average annual rainfall of 532 mm, and the total amount of water resources of 20.5 billion m^3/a , per capita water resources of 307 m^3 , which is far below the internationally recognized 500 m^3 of 'extreme water shortage standard'. The total annual water supply of Hebei Province is about 19 billion m^3 , of which, 75% is from groundwater supply. More than 70% of the total water supply is used for agriculture. Hebei Province is one of the major grain-producing provinces in China, with a total irrigation area of about 67.05 million mu (1 mu = 0.067 hm^2), of which, 63% is irrigated by groundwater, 18% by the conjunctive supply of surface and groundwater, and the remaining 19% by surface water.

According to the evaluation of groundwater over-exploitation regions carried out by China's Ministry of Water Resources, the groundwater over-exploitation plain area of Hebei Province is 67,000 km^2 , accounting for 90% of the plain area of Hebei. Before the implementation of the groundwater overdraft control pilot project, the annual average amount of groundwater over-exploitation of Hebei Province was nearly 6 billion m^3 , of which, 3 billion m^3 is deep confined groundwater which is very difficult to recharge. This means that at least 6 billion m^3 of groundwater pumping needs to be reduced to stop groundwater over-exploitation. Groundwater exploitation in Hebei Province is shown in Figures 1 and 2.

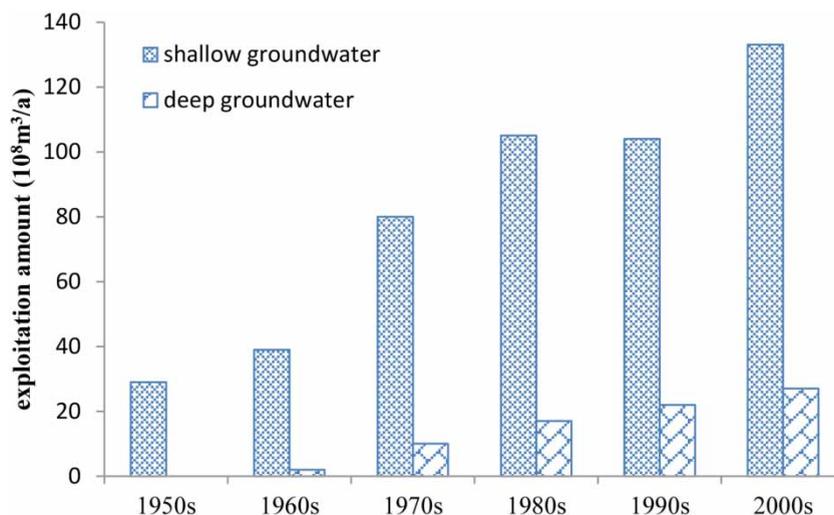


Fig. 1 Change in groundwater exploitation amount of Hebei from the 1950s to 2000s.

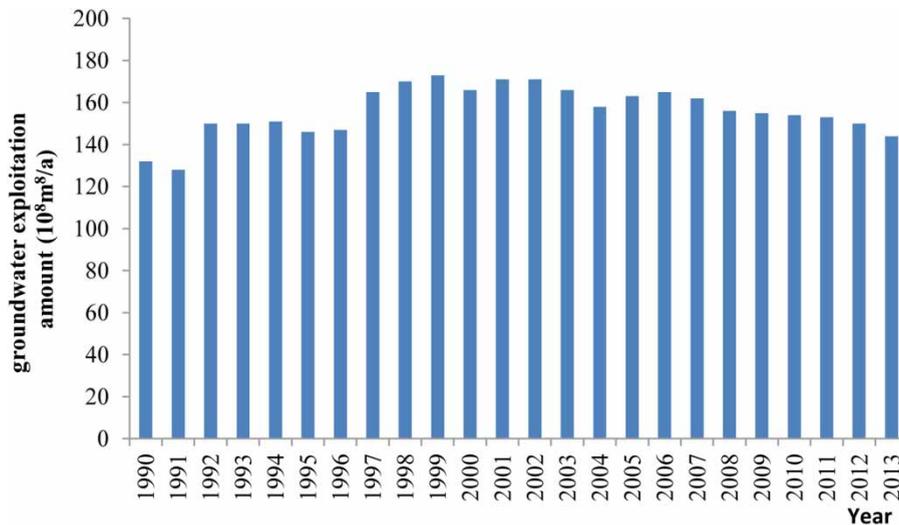


Fig. 2 Yearly groundwater exploitation amount of Hebei from 1990 to 2013.

The groundwater over-exploitation in Hebei Province has caused a series of ecological and geological problems, including aquifer depletion, land subsidence, surface cracks, and saltwater intrusion. In the early 1960s, the groundwater depth in most places in Hebei was about 3–5 m. Due to the long-term and large amount of groundwater overdraft, the groundwater level has been decreased continuously. The groundwater level in the piedmont plain area has dropped to about 30–40 m, which is lower than the depth of the bottom of the first aquifer, and the aquifer has almost dried out. Then, the groundwater in deeper aquifers has to be extracted, which also causes a large number of scrapped pumping wells, and increasing costs of agricultural irrigation.

Implementing comprehensive measures to reduce groundwater exploitation

There are two means to reduce withdrawal and to treat over-exploitation of groundwater. The first is to replace the current groundwater with more surface water, which requires surface water sources and some surface water projects; the other way is reducing groundwater supply by water conservation measures and water demand decrease. It is a complicated issue to achieve water conservation and the pilot project in Hebei Province has explored a series of measures to save water.

Replacing groundwater supply with surface water

Seven out of eleven cities in Hebei Province are in the water-taken area of the mid-line of the South-to-North Water Transfer Project and the annual average water transfer capacity is about 3.0 billion m³/a, which is mainly planned for water supply in urban region. Replacing extracted groundwater with water from the South-to-North Water Transfer Project is the main measure to control the urban groundwater over-exploitation problem in Hebei Province. Due to the limitation of water quantity, water supply cost, urban water demand, and other factors, the water supplied by the South-to-North Water Transfer Project

cannot be directly used for irrigation. The water price of the South-to-North Water Transfer Project is composed of basic water price and metering water price. The basic water price is determined by repayment on principal and interest of the loan, and appropriate compensation for basic operation and maintenance costs of the project.

The metering water price is determined by other costs and specified taxes other than the compensation of basic water price. Table 1 shows the water price of the South-to-North Water Transfer Project, indicating the water price to the diversion gates of different areas. For the water price to users, the operation costs of water supply project, water resource tax, sewage treatment fee, etc., are also considered.

In addition, due to the expansion of urban development, some of the water sources originally used for water supply for rural areas were diverted to provide water for the urban area. These water sources for the urban area can be substituted by South-to-North Water Transfer Project and again back to the rural area water supply, as one of the means of groundwater over-exploitation control in rural areas. At present, the construction of local water plants and the pipeline network of the South-to-North Water Transfer Project have not all been completed yet, thus the substitution of urban groundwater supply by South-to-North Project transferred water has not yet achieved the desired results. Furthermore, diverting and utilizing water of the Yellow River and Weihe River as agricultural irrigation water is one of the measures to reduce groundwater exploitation for irrigation. There used to be many small ponds in the rural area of Hebei, which could store surface water. However, due to continuous drought, reduction of water resources amount from the upstream, coupled with the land use tension, many rural ponds have dried up, and have been abandoned or backfilled, and even have become the sites of construction of houses and factories, which made using surface water very difficult. In the pilot project, some ponds and river canals were constructed to build water networks in the rural areas, to better store and allocate surface water.

Adjustment of agricultural planting patterns and habits

The farmers in North China have used the form of double cropping in a year, with one season of wheat in winter, and the other of corn in summer. It is known that the growth of wheat needs a great deal of irrigation water. In the pilot project, it is proposed that in regions with severe problems of deep confined groundwater over-exploited for irrigation and without surface water available for replacement, the planting area of winter wheat should be reduced. This means that the double cropping form of winter wheat and summer corn should be changed to a single cropping form of corn, or cotton, or peanut, or oil sunflower, or other crops with less need of irrigation water. In this way, 180 m³ of water can be saved per mu (1 mu = 1/15 hm²) of irrigation area per year. In order to make the farmers be supportive to change the cropping form, the government compensates the farmers 500 yuan per mu per year for stopping planting wheat.

Table 1. Engineering water prices for the middle route project of the South-to-North Water Transfer Project.

Provinces	Water price (yuan ^a)	Basic water price (yuan)	Metering water price (yuan)
Hebei Province	0.97	0.47	0.50
Tianjin Province	2.16	1.04	1.12
Beijing Province	2.33	1.12	1.21

^a1 yuan is about 0.14 USD.

So far, in Hebei Province, farmers have stopped cultivating wheat for 1 million mu of the originally wheat-planted land, and the water-saving effect is obvious. However, this approach relies on subsidies from the government, and once the subsidies stop, farmers are very likely to return to planting wheat, which in turn, will again increase irrigation water use. In addition, some farmers said that even with subsidies, they may be willing to plant wheat, because the selling price of corn is too low to make a profit in these years. In addition, because of the decreasing income caused by planting corn, some farmers are requesting that the subsidy standard is increased to 650 yuan per mu.

In addition, in order to reduce groundwater exploitation, the agricultural department in Hebei Province recommends that farmers cultivate more water-saving wheat varieties. Theoretically, water-saving wheat varieties can save about 50 m³ of water per mu per year compared to the regular varieties. However, some farmers always follow the same old habits and use the same amount of water for irrigation required by regular varieties. Therefore, the training of farmers on related planting techniques and methods should be strengthened.

Development of efficient water-saving irrigation

Influenced by the impact of small-scale family management of arable land, local farmers lack understanding of water-saving technologies; meanwhile, due to insufficient investment, efficient water-saving irrigation in Hebei Province is underdeveloped. Before the pilot project, the proportion of irrigation area with water-saving irrigation technology used in the province was less than 30%, and most farmers still use the measure of flood irrigation. It can be said that the agricultural water waste is one of the important factors which cause the contradiction between supply and demand of water resources in Hebei Province. The groundwater over-exploitation project takes efficient water-saving irrigation technology as one of the important measures to improve irrigation water efficiency, and reduce water use, mainly by using low-pressure pipes, sprinkler irrigation, micro-irrigation, and other measures, to replace the traditional flood irrigation method.

At present, the pilot area has newly developed an area of more than 6 million mu of efficient water-saving irrigation. However, the cultivated land management mode in North China is still operated on a small scale by individual farmer's families. This planting pattern has brought some difficulties in adaptation to water-saving measures. When farmers use sprinkler irrigation and other irrigation methods to water their own arable lands, it is inevitable not to affect the neighbouring farmlands, so some farmers who only have a relatively small area of farmland are not willing to adopt this approach. As well, some irrigation equipment, such as traveling irrigation machines, which are not convenient to use, are rarely accepted by the farmers in Hebei Province.

Implementation of ecological replenishment of rivers and lakes

The South-to-North Water Transfer Project, local reservoir storage, and reclaimed water are utilized to recharge some main rivers in the over-exploited area. Since Hebei's utilization amount of water transferred from the Yangze River by the South-to-North Water Transfer Project has not reached the amount allocated to the province due to the delay in construction of supporting projects, the Ministry of Water Resources proposed to put the unused water into the river to improve the ecological environment of the river and replenish the surrounding groundwater. The measures began in September 2018 and, currently, 1,320 million cubic meters of water have been replenished, including 872 million cubic meters of water

from the South-to-North Water Transfer Project, 368 million cubic meters of water from reservoirs, and 80 million cubic meters of recycled water.

Strengthening groundwater management

Groundwater is the main agricultural water supply source in North China. There are more than 900,000 groundwater intake wells in the whole of Hebei Province. These large-quantity, thoroughly distributed wells have caused great difficulties in groundwater management. For a long time, groundwater in North China has been under ‘unmanaged’ conditions. If farmers want to use groundwater, they dig a well, then pump water, without any capability restrictions. In the Hebei pilot project, the national and local water conservancy department has made great efforts to strengthen groundwater management.

Clarifying water use rights

In order to more effectively manage the use of water resources, Hebei Province has carried out work on the clarification of water resources use rights, and is trying to assign water use rights to each water user. Taking Anping County in Hebei as an example to illustrate the method of water use rights’ clarification in Hebei Province: the first step is to determine the amount of available water resources which can be allocated, including the allowable withdrawal of shallow groundwater, the local surface water, as well as the South-to-North Project transferred water and other transferred water, thus the total amount of water that can be allocated is about 50.4 million m³ in the county of Anping; the second step is to determine the water allocation to each sector according to the current status of water use. In the past three years, the urban and rural domestic water use in Anping has been 8.59 million m³, the water use of the non-agricultural sector (including water use of industrial enterprises, construction industry and mining industry) 8.56 million m³, and the ecological water consumption 0.5 million m³, thus the reserved water amount is determined to be 147,600 m³. Then, the agricultural water allocated is calculated by deducting the amount of water used for domestic, non-agricultural sector, ecological environmental, and reserved water from the total amount of water that can be allocated, which is about 33.1 million m³; the third step is to issue water right certificates. Domestic water use, non-agricultural sector water use, and the ecological environmental water use should be issued water use permits, and agricultural water users should be issued water use right certificates. The amount of water use rights of each farmer’s family is equal to the amount of agricultural water allocated per mu multiplied by area of arable land operated by the farmer’s family. The cultivated land area of Anping County is 475 thousand mu, and the agricultural water allocated per mu land is 70 m³/mu. So far, water use rights have been clarified in most regions in Hebei. At present, the right of water use regulates the amount of water available to each water user, but it is not clear whether the source is groundwater or surface water. In order to strengthen groundwater management, the next step might be further clarifying the available amount for each source.

Water pricing reform

Low water price is an important cause of waste of water resources. Hebei water prices are generally low, which do not reflect the scarcity of water resources, and the endogenous motivation for the whole

society to save water is insufficient (Ma, 2016). Thus, Hebei Province carried out a series of reform measures relevant to water price.

First, in many places, there was a problem of inadequate collection of water resources fee. To change this situation and ensure the smooth collection of the water fee, Hebei Province changed the concept of water resource fee to water resource tax and raised the collection standard of groundwater resource tax.

By increasing the groundwater tax standards, enterprises are urged to adjust water use structure, reduce groundwater use, and convert to using surface water more often. It is estimated that with the water tax reformation, the average tax per cubic meter of surface water is about 0.3 yuan; the groundwater tax is distinguished between non-overdraft area, overdraft area, and serious overdraft area. The average water taxes of groundwater resources are 1.42, 2.01, and 3.54 yuan, respectively, for non-overdraft area, overdraft area, and serious overdraft area. Then, on average, the tax of groundwater resources is 4.1 times of surface water; the tax of groundwater in serious over-exploitation area is 2.5 times of non-over-exploitation area, and 11.8 times of surface water. The big difference of water tax between groundwater resources and surface water is conducive to make enterprises adjust the water use structure in a timely fashion, and also to improve water efficiency.

Second, implement the ‘three-level ladder water pricing system’ for domestic water use. Normally, the first, second, and third levels of water price should follow the ratio of 1:1.5:3. The amount of water use with the first level of domestic water price should guarantee the basic domestic water needs for residents, and in principle, is not more than 10 m³ of each household per month. The second ladder of water use amount with the second level domestic water price should reflect the reasonable water use demand of improvement of residential living quality, and is not more than 15 m³ for each household per month. The amount of water use beyond the second ladder should be charged with the third level domestic water price.

The water use amount ladders and water prices for different levels of domestic water use in Baoding city in Hebei Province are as follows: the first ladder is 0–120 m³ with water price of 3.55 yuan/m³; the second ladder is 120–180 m³ with water price of 4.66 yuan/m³; and the third ladder is 180 m³ or more with water price of 7.99 yuan/m³ (Qi, 2015).

Third, formulate agricultural water use prices. For a long time the cost of agricultural water use in Hebei Province has only included the cost of drilling wells and electricity consumption of pumping. Farmers did not need to pay any water resources fees, which resulted in farmers paying little attention to wasting water during flooding irrigation.

This pilot project proposes to formulate and collect an agricultural water fee. The agricultural water fee should be developed based on the cost of agricultural water and the affordability for farmers. The fees to use deep groundwater and shallow groundwater for agricultural irrigation should also be different. We take Guantao County in Hebei province as an example to illustrate the formulation process of agricultural water price.

Step 1, calculating water supply costs. The cost of agricultural water supply mainly includes depreciation of fixed assets, materials and fuel costs, construction maintenance costs, management fees, and so on. After calculation, the total cost of per cubic meter water supply in Guantao County shallow-well irrigation area is about 0.52 yuan/m³ and the total in the deep-well irrigation area is about 0.91 yuan/m³. For specific calculation see data in Table 2.

Step 2, calculating the highest affordable water price for farmers. Wheat and corn are the main agricultural varieties planted in Guantao County. The average per mu production of these crops is 2,358.3 yuan/year, and cost per mu is 1,309.3 yuan/year, thereby net income per mu is 1,049 yuan/

Table 2. Water supply cost calculation of well-irrigation area in Guantao County, Hebei Province.

Type	Costs (10,000 yuan)				Total costs (10,000 yuan)	Operating costs (10,000 yuan)	Yearly water supply (100,00 m ³)	Per m ³ water supply costs (10,000 m ³)			Terminal cost water proce (yuan /m ³)
	Depreciation of fixed assets	Materials and fuel costs	Construction maintenance costs	Management and other costs				Total costs	Operating costs	Electricity fees	
Deep- well	571	333	160	29	1,093	522	1,195	0.91	0.44	0.28	0.91
Shallow- well	964	1,116	237	473	2,790	1,826	5,349	0.52	0.34	0.21	0.52
Average	1,536	1,449	397	502	3,883	2,348	6,544	0.59	0.36	0.22	0.59

year. It is appropriate that the agricultural water fee accounts for 5%–8% of per mu production and 10%–13% of per mu net income. Thus taking 13% of per mu net income, we used 0.566 yuan/m³ as the highest affordable price for farmers.

Step 3, determining actual executing water price. When the water use of shallow-well irrigating area is less than or equal to agricultural irrigation water quantity quota determined by rights (150 m³/mu), we execute the operating cost water price as 0.34 yuan/m³. If the quota is exceeded, the excess water quantity is charged as the total cost water price plus 0.1 yuan, i.e., 0.62 yuan/m³.

The water price of the deep-well irrigation area takes the maximum of the total cost of deep-well irrigation area, twice the total price of shallow-well irrigation area, and the highest affordable water price. Therefore, we take 1.04 yuan/m³ as the operating water price in the deep-well irrigation area, and an extra 0.1 yuan for quantities exceeding the quota, as 1.14 yuan/m³.

Changing water resources fees to water resources taxes has prominent effects on industrial water saving. High water consumption industries, such as the iron and steel industries, have always been pillar industries in Hebei Province. Since the implementation of water resource tax reformation, many iron and steel enterprises have actively equipped themselves with advanced sewage treatment equipment and water recycling systems, in order to reduce withdrawal of fresh water. However, on the other hand, the agricultural water price reform is relatively difficult to implement. The reasons are complex and may include agricultural water use measurement has not been fully covered, farmers have been used to free irrigation water for a long time, and also the interests of farmers should be fully guaranteed.

Discussion and conclusion

Groundwater over-exploitation control and management are very complex, and especially in China, the utilization of groundwater is widely dispersed, the over-exploitation has a very long history, and some regions rely on groundwater too much (Wang *et al.*, 2000). As well, groundwater management in China is relatively weak. Groundwater over-exploitation control should not only focus on taking engineering measures, but also improving management regulations and enhancing management capacity should be emphasized.

First, the issue of groundwater over-exploitation is related to many aspects, including water use, ecological protection, land use, food production, etc., involving functions and responsibilities of several departments. Inter-departmental cooperation and coordination mechanism must be established and enhanced. This pilot project of groundwater over-exploitation control in Hebei Province is led by the Ministry of Finance at the national level, and involves the Ministry of Water Resources being responsible for technology lead, Ministry of Land and Resources being responsible for groundwater table monitoring, and Ministry of Agriculture being responsible for agronomic water-saving measures. These departments have all closely participated in the whole process of the project, including planning and design, implementation and development, evaluation and assessment (Su & Peng, 2015).

Second, in China, the agricultural sector is the biggest consumer of groundwater, groundwater over-exploitation control and management affects numerous farmers, thus getting support from farmers is the key. First, the advocacy of groundwater resources protection should be enhanced to let farmers understand the significance and meaning of groundwater resources protection and be aware of the whole process of the implementation; second, the interests of farmers should be guaranteed. Some approaches

of controlling groundwater over-exploitation, such as adjustment of agricultural planting structure, may have a certain impact on the income of farmers, thus, there must be a corresponding compensation mechanism so that farmers would not suffer much income loss; third, the technical training of farmers is necessary and should be enhanced to assist farmers to maintain application of water-saving technologies and facilities, and also to understand the corresponding water rights, water prices, and other management measures.

Third, for the treatment of groundwater over-exploitation, the effects of surface water diversion to replenish groundwater in rivers and lakes are obvious. The diversion of the Yangtze River into several main rivers in North China through the South-to-North Water Transfer Project not only increases the recharge of groundwater, but also significantly improves the ecological environment of surface water. Around the replenished rivers, the problem of continuous decline of the groundwater level has been improved in many areas, and the previously dried-up river channels have now become beautiful areas. However, a big challenge for this method is the cost. The method is currently still in the pilot stage. Hebei Province has not yet paid for this part of water, and there is no charging mechanism yet. The notice on water supply price for the main works of the 1st Phase of the Middle Route of South-to-North Water Transfer Project issued by the NDRC in April 2019 has indicated that:

‘On the premise that the upstream water is abundant and the normal production and living water supply can be guaranteed, and on the basis of paying the basic water fee in full in the receiving area, the price of ecological water replenishment for the middle line project shall be determined by the supply and demand parties through consultation with reference to the current water supply price policy.’

If the method is taken as a long-term method, it is necessary to establish a reasonable and feasible water price mechanism.

Fourth, a groundwater monitoring and metering system is the foundation of groundwater resources management and exploitation control. Although the supply of groundwater resources accounts for more than 70% of Hebei Province’s water supply, a groundwater resources monitoring and pumping amount metering system have not be well established. The groundwater over-exploitation control pilot project in Hebei is trying numerous methods to advance a dynamic monitoring system of groundwater. Many groundwater table monitoring wells are built and a groundwater information management platform is established in the department of water resources at county, city, and province levels. It is being attempted to meter all industry and urban water use, as well as some agricultural water use. As to the 900,000 pump wells in Hebei Province, in fact, it is very difficult to meter all the wells, since this is very costly and difficult to manage. During the first year of the pilot project, we tried to install metering equipment for some irrigation wells and met some problems. Some farmers tried to abstract water using their own pumps without metering and some metering equipment was destroyed. Hence, we are trying to find other ways to determine the amount of groundwater pump use, like using the amount of electricity use to calculate the water use.

Last but not least, effective management regulation needs to be formulated. In order to control over-exploitation of groundwater and enhance the protection of the groundwater system, Hebei Province promulgated the ‘Groundwater Management Regulation of Hebei’, which defines the responsible parties and the procedure of groundwater management, and the punishment measures of unreasonable exploitation and destructive behaviors regarding groundwater. On this basis, the government also put forward

the approach and systematic requirements of water use rights and water price reform, making the management legalized and long-term effective.

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