AGRICULTURAL PRODUCTION AND GROUNDWATER CONSERVATION

Examples of Good Practices in Shanxi Province, People's Republic of China

Frank van Steenbergen, Frank Radstake, Fan Guisheng, and Zhang Wenzhong

ASIAN DEVELOPMENT BANK

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FOREWORD

Water security is one of the key global challenges for the 21st century. *The Global Risks Report 2016* prepared for the World Economic Forum highlights the water crisis, along with the failure of climate change mitigation and adaptation measures (and weapons of mass destruction), as among the topmost impactful risks for the years to come.[1] The 2016 report also focuses on the climate–water nexus and associated food security risk in the context of climate change. The report describes how changing climate and weather patterns can jeopardize food security and agricultural production across geographies. The countries most vulnerable to climate often heavily depend on agricultural productivity to sustain economic growth and development.

In Asia and the Pacific, agriculture is the biggest consumer of water—on average, 70% of water resources are used for irrigated agriculture. Yet, the use of water in the agriculture sector remains inefficient and results in low productivity. At the same time, cities are growing at a phenomenal rate—by 2050, about 64% of Asia's population will be urban. A growing population requires more food, energy, and domestic water. Asia has the fastest-growing economy—predicted to contribute up to 52% of the global gross domestic product by 2050. Moreover, considering the impacts from a changing climate, ensuring water security for all is essential for continued inclusive growth.[2]

The Asian Development Bank (ADB) is working with member countries and other development partners to strengthen water management by implementing its Water Operational Plan, recognizing the increasing demand for water and its impacts on food production.[3] As part of the needed integrated approach, the sustainable use of groundwater is emerging as a key to ensuring water security. Groundwater is often locally available, and, if managed well, it can supply good quality water all year round, including during drought seasons.

In line with ADB's Operational Plan for Agriculture and Natural Resources, ADB aims to promote inclusive growth and improved rural livelihoods by increasing agricultural productivity. The focus includes the water, food, and energy nexus to guarantee consistency across decision making and to create the best mix of solutions for each member country.[4]

In 2009, ADB approved the Shanxi Integrated Agricultural Development Project to strengthen agricultural production in 26 counties in Shanxi Province. Complementing the project is a $0.5 million grant from the Water Financing Partnership Facility to support climate change adaptation through groundwater management. The grant was given to Lishi, Pingshun, Qi Xian, and Xi Xian counties after a competitive selection process among local governments and farmers. The objective of the grant was to support farmers introducing innovative water use practices and to increase climate change resilience to arrest declining groundwater levels. Declining groundwater tables lead to higher pumping costs and lower water security.

This report presents the experiences in Shanxi Province, which provide excellent examples of interventions that can be taken by local stakeholders to contribute to securing their livelihood. The experiences show the multiple benefits realized by farmers as the pilots began operating. The support for the four pilot sites resulted in savings in water, energy, fertilizers, and pesticides. The new practices also required less labor, which benefited many farmers in Shanxi Province, a significant number of whom are women and elderly.

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1 World Economic Forum. 2016. *The Global Risks Report 2016, 11th Edition.* Geneva. http://www3.weforum.org/docs/Media/TheGlobalRisksReport2016.pdf

2 In 2013, the Asian Development Bank (ADB) published its *Asian Water Development Outlook 2013*, which outlines a water security framework that assessed water security in five key dimensions: household water security, economic water security, urban water security, environmental water security, and resilience to water-related disasters. This approach for water security is designed to represent the multiple dimensions of water in people's lives and livelihoods, with poverty reduction and governance as crosscutting perspectives in each of the five dimensions. In 2016, the *Asian Water Development Outlook 2016* was published to refine indicators for each key dimension, provide updated data and more detailed levels of spatial aggregation, and track progress in water security in Asia and the Pacific for the period 2011–2015.

3 ADB. 2011. *Water Operational Plan, 2011–2020.* Manila.

4 ADB. 2015. *Operational Plan for Agriculture and Natural Resources: Promoting Sustainable Food Security in Asia and the Pacific in 2015–2020.* Manila.

For example, in Lishi County, Xiaoshentou's warming ponds make it possible to grow a third greenhouse crop. The drip sprinkler irrigation system is designed to give farmers a 10% increase in crop yields with lower labor inputs. Fertilizer and pesticide consumption is likewise expected to decrease by 20%. In Pingshun County, the average income increase is about 15%–20%, achieved with less labor. The microsprinkler also promises to bring better-quality leafy produce, as aphids are washed out and pesticide use is reduced. In Qi Xian County, the drip systems combined with inexpensive plastic mulch led to 40%–60% water savings and 35%–40% fertilizer savings. Simultaneously, the new systems translated into a 25%–40% increase in crop yield. Lastly, in Xi Xian County, the system is poised to produce a yield of 1,500 kilograms of apples per *mu*,[5] compared with 600 kilograms per *mu* without the system.

Gradual replication in various stages is currently under way in Shanxi and other provinces in the People's Republic of China (PRC), often financed by counterpart funds from the local governments. It is a clear indication that, despite climate change's adverse impact on water resources and food production, there are opportunities for traditional farmers in Shanxi Province to adapt to these changes and make agricultural production more sustainable.

ADB envisages that the examples can provide practical guidance for the PRC and other developing member countries to introduce and implement new agricultural practices and improve the sustainable use of groundwater resources. We, therefore, hope that this report will be read widely outside the PRC.

Ayumi Konishi
Director General
East Asia Department
Asian Development Bank

5 A *mu* is a Chinese unit of measurement corresponding to 0.067 hectares.

ACKNOWLEDGMENTS

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We highly value the excellent leadership and inspiration of the Shanxi Provincial Government for initiating the process of exploring and implementing new approaches to groundwater management for agricultural usage. Their vision and efforts have made a significant contribution to the rural population of the northwestern PRC. We would also like to thank all the members of the project management office of the Shanxi Poverty Alleviation Office, who worked effortlessly to prepare and implement the day-to-day tasks that were necessary for the successful completion of the grant project.

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Finally, we like to thank the Water Financing Partnership Facility Secretariat, particularly Gil-Hong Kim, Vijay Padmanabhan, Yasmin Siddiqi, Pia Corrina Reyes, and Ellen Pascua, who provided strong commitment and financial and technical support to facilitate the preparation and implementation of the grant project.

ABBREVIATIONS

ADB	Asian Development Bank
GDP	gross domestic product
NCP	North China Plain
PRC	People's Republic of China

WEIGHTS AND MEASURES

cm	centimeter
ha	hectare
kg	kilogram
m^3	cubic meter
mm	millimeter
1 *mu*	0.067 ha

CURRENCY EQUIVALENTS

(as of 15 September 2016)

Currency Unit	–	yuan (CNY)
CNY1.00	=	$0.15
$1.00	=	CNY6.67

EXECUTIVE SUMMARY

Similar to many areas in the People's Republic of China (PRC), Shanxi Province is experiencing reduced water security for the agriculture sector. Changing climate conditions, including reduced rainfall, are increasing reliance on groundwater resources in the province. Unsustainable groundwater use for food production intensifies the impacts of climate change, and cost-effective adaptation responses are needed to better equip vulnerable agricultural regions. Groundwater is the main source of water supply for many local farmers in Shanxi Province. Water is often used with inefficient and outdated irrigation techniques. However, most traditional farmers are eager to improve and modernize their crop production and adopt more sustainable agricultural methods. Following increasing agricultural and industrial water use, Shanxi Province's groundwater tables have been declining since 1956, a problem compounded by the impacts of climate change. Currently, roughly a quarter of the province's land area—especially the fertile valleys—is experiencing falling groundwater tables. An estimated decrease in rainfall of 12% since 1960 and a rise in average temperature of 1.2°C over the same period have added to the pressure on groundwater availability.

The Asian Development Bank (ADB) in 2009 approved the Shanxi Integrated Agricultural Development Project to strengthen agricultural production in 26 counties in Shanxi Province. Complementing the project is a $500,000 grant from the Multi-Donor Trust Fund under the Water Financing Partnership Facility to support climate change adaptation through groundwater management. The grant supported farmers introducing water conservation and energy-efficient water use practices and increasing climate change resilience to halt declining groundwater levels. Declining groundwater tables lead to higher pumping costs and lower water security, making support for farmers to adopt such sustainable practices in selected pilot sites in Shanxi Province highly relevant. The grant was given to Lishi, Pingshun, Qi Xian, and Xi Xian counties after a competitive selection process among local governments and farmers. About 600 farmers in these four counties were introduced to modern and efficient horticultural irrigation systems.

Groundwater-saving technologies and practices are needed in the lowland areas where overuse is most prevalent and groundwater levels have dropped significantly. Farmers in Xiliuzhi Village, Qi Xian County changed irrigation practices from flood to drip irrigation in their greenhouses. The new system has pressure meters, dual distribution lines, a centrifugal filter to remove impurities from water, and a frequency converter, the last being an innovation that reduced energy consumption by 40%. As a comparison of the progressive approach that the Shanxi Provincial Government is taking, the experiences in Qinxu County are summarized, where the provincial government, independent from the ADB grant, already implemented a tradable quota system, tiered pricing, swipe cards, automatic water-level recorders, and a data control center.

In the upland areas, groundwater overuse is not yet a problem, but agricultural expansion is needed to keep up with the increased demand for (high-quality) food. In Xi Xian County, the innovative use of large diameter, 0.8 millimeters (mm) micro-irrigation pipes that do not clog easily was introduced in Quyan Village. The water supply comes from a natural spring feeding the main pipe 110 mm in diameter, which was itself enlarged from its previous 90 mm diameter to increase pressure on the supply pipes. In Pingshun County, the villages of Henantan, Wangqu, and Wanli got a boost in the cultivation and production of prickly ash shoots, a local delicacy, with the introduction of microsprinklers suspended in mesh tents. In addition to irrigating, this system washes down remaining aphids and avoids the soil getting too wet. Farmers in Xiaoshentou Village, Lishi County, who battle the cold temperature of the irrigation water, were introduced to a drip sprinkler irrigation combined with warming ponds in greenhouses.

The demonstration sites began with soil surveys and discussions with farmers. In some cases, it took time to convince farmers of the benefits of pressurized irrigation systems due to their novelty. Intense dialogue with the farmers, coupled with training courses on the use of the technology, helped farmers understand and finally accept the new systems. Eventually, the irrigation systems were designed and became operational in 2012, and farmers saw firsthand the effects of improved groundwater management. Today, water associations promote the irrigation systems in tandem with county authorities.

As the demonstration sites began operating, the farmers experienced multiple benefits. In several cases, this encouraged others to replicate the systems practiced. In Lishi County, Xiaoshentou's warming ponds make it possible to grow a third greenhouse crop. The drip sprinkler irrigation system is designed to give farmers a 10% increase in crop yields with lower labor inputs. Fertilizer and pesticide consumption is likewise expected to decrease by 20%. In Pingshun County, the average income increase is about 15%–20%, achieved with less labor. The microsprinkler also promises to bring better-quality leafy produce as aphids are washed out and pesticide use is reduced. In Qi Xian County, the drip systems combined with inexpensive plastic mulch led to 40%–60% water savings and 35%–40% fertilizer savings. Simultaneously, the new systems translated into a 25%–40% crop yield increase. In Xi Xian County, the system is poised to produce a yield of 1,500 kilograms (kg) of apples per *mu*, compared with 600 kg per *mu* without the system.

ADB's support for agricultural modernization resulted in savings in water, energy, fertilizers, and pesticides. Agricultural modernization also required less labor, which benefited many farmers in Shanxi Province, a significant number of whom are elderly. Gradual replication of the project in various stages is currently under way, financed by counterpart funds from the provincial government. This clearly indicates that despite climate change's adverse impact on water resources and food production, there are opportunities for traditional farmers in Shanxi Province to adapt to these changes and make agricultural production more sustainable.

The demonstration activities show that further control of groundwater use is possible without jeopardizing development. Based on the demonstration activities implemented in Shanxi Province, and recognizing future challenges to sustain or increase agricultural production in more uncertain climatic conditions, a number of key recommendations for strengthening groundwater management were formulated by various stakeholders in Shanxi Province:

1. **Establishing the strictest water resources management systems.** Such systems include levying groundwater resource taxes and promoting water-saving behavior with a charging mechanism; water quotas and rights trading market; and irrigation water fees in the whole province according to the amount of water used for each *mu*. The ultimate goal is to promote water-saving irrigation practices among farmers.

2. **Planning water use.** The construction of a modern water supply network and a water ecoculture should be expedited.

3. **Promoting demonstration projects.** More efforts should be spent in building demonstrations for various water-saving projects and in ensuring their outreach.

4. **Adopting innovative water-saving technologies and practices.** Different water-saving irrigation techniques should be selected for different natural conditions, and a multiple range of water-saving solutions that suit the specific conditions of a region should be implemented. New water-saving techniques should be promoted and supported, with various water-saving irrigation techniques and equipment disseminated to more farmers. The government should provide funds to purchase and install irrigation equipment, whereas grant or loan projects or farmers themselves provide the counterpart funds. It is also possible to rely on companies of scale or farmers' cooperatives for investment.

5. **Conducting water-saving technical training.** These training sessions should be given priority so that efficient irrigation technologies can be readily mastered by trainees, and the existing water-saving facilities can run normally and be serviced and maintained properly.

6. **Adjusting the current farming structure, especially large-scale cultivation.** High water-consuming varieties should be eliminated, while more agronomic water-saving techniques are promoted.

Manager of the wells and water systems in Pingshun County

PHOTO CREDIT: FRANK RADSTAKE

Greenhouse farmer in Lishi County

PHOTO CREDIT: FRANK RADSTAKE

1 AGRICULTURAL PRODUCTION AND GROUNDWATER USAGE

The Bigger Picture: Water and Agriculture in Northern People's Republic of China

Many areas in the People's Republic of China (PRC) are under close observation as groundwater tables are in decline due to overpumping and lack of quality protection, which poses serious concerns for sustainable economic development. In particular, in the North China Plain (NCP) region, comprising the deposits of the Yellow River and forming the largest alluvial plain of eastern Asia, tube well irrigation has helped maintain high agricultural and industrial growth rates.[1] Decreasing groundwater resources in the NCP threaten to undermine one of the world's most important grain baskets.[2] These dry northern plains produce half of the country's wheat and one-third of its corn. They do so by overdrafting, i.e., using groundwater at a rate that largely exceeds the way at which aquifers are replenished or recharged. Decreasing water quality, increasing pumping depth, and, consequently, escalating pumping cost necessitate the imposition of limits on groundwater extraction of aquifers in many areas.

This illustrates the fragile footing on which agriculture in northern PRC is based. One estimate is that not fewer than 130 million people in the PRC depend on the unsustainable use of groundwater for their staple food, as the contribution of nonrenewable groundwater abstraction for irrigation accounts for 20 billion cubic meters per year.[3] The ramifications are quite substantial—once the PRC starts running out of exploitable groundwater, the country will have to increasingly resort to the world market for its grains, and food prices would increase all over the globe. The PRC's wheat imports already increased and are a factor in the higher global grain prices of the last 5 years. This trend is expected to continue in the coming years.[4]

Development in Shanxi Province

Shanxi Province has a long history of agricultural and industrial development, closely related to the intense use of its scarce water resources. The province is located in the western half of northern PRC and on the eastern side of the Loess Plateau. Located east of Shanxi Province are Hebei and Henan provinces, with Taihang Mountain forming the borderline. To its west is Shaanxi Province and to its south Henan Province, separated by the Yellow River. In the north of Shanxi Province is the Inner Mongolia Autonomous Region, with the Great Wall as the borderline. Surrounded almost on all sides by either rivers or mountains, Shanxi Province is a plateau area, situated between the middle reach of the Yellow River and Taihang Mountain. Shanxi Province stretches over 680 kilometers from north to south and over 380 kilometers from west to east. It covers an area of 156,271 square kilometers, which equals 1.6% of the PRC's total territory.

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1 T. Shah, A. D. Roy, A. S. Qureshi, and J. Wang. 2003. Sustaining Asia's Groundwater Boom: An Overview of Issues and Evidence. *Natural Resources Forum.* 27 (2). pp. 130–141.

2 R. Evans, S. Foster, and H. Garduño. 2002. Achieving Groundwater Use Efficiency in Northern China. Paper presented at the Third Rosenberg International Forum on Water Policy. Canberra, Australia. 9 October; J. Qiu. 2010. China Faces Up to Groundwater Crisis. *Nature.* 466 (7304). p. 308.

3 Y. Wada, L. P. H. van Beek, and M. F. P. Bierkens. 2012. Nonsustainable Groundwater Sustaining Irrigation: A Global Assessment. *Water Resources Research.* 48 (6). W00L06.

4 Organisation for Economic Co-operation and Development (OECD) and Food and Agriculture Organization of the United Nations (FAO). 2011. *OECD–FAO Agricultural Outlook 2011–2020.* Paris: OECD Publishing. www.agri-outlook.org

In 2011, the total population of Shanxi Province stood at 35.93 million, of which 17.85 million was urban. The average population density is 229 persons per square kilometer. The province abounds in mineral resources. There are over 66 types of minerals with proven reserves, the most predominant of which is coal. The coal reserves of the province amount to 256 billion tons, or close to one-third of the PRC's total. In 2011, Shanxi Province produced 870 million tons of raw coal, of which 580 million were shipped out of the province. In recent years, the province has put in a great deal of effort in coal conversion and deep-processing. Its strategy is to change the province's role from a main coal supplier into a coal and electricity supplier and producer of coal-based products.

Shanxi Province has now 568.98 million *mu*, equivalent to 37.93 million hectares (ha), of arable land.[5] The area equipped for irrigation is 188.89 million *mu* (12.59 million ha) and the actual irrigated area is 161.09 million *mu* (10.74 million ha). Forest cover is sporadic. In 2011, the total afforested area in the province reached 2.10 million *mu* (0.14 million ha) and the plantation area 4.20 million *mu* (0.28 million ha). The arable land of Shanxi Province consists mainly of basins, valleys, and loess hills. Cereals—in particular wheat, millet, corn, sorghum, oat, broom corn, millet, and buckwheat—and potatoes are the main crops. Shanxi Province's cash crops include cotton, rape, mulberry, flax, and beet. Orchards are commonly seen bearing a variety of temperate fruits such as apple, pear, grape, walnut, date, and persimmon.

From 1949 to 2011, the province's economy developed rapidly, with its agriculture diversifying and industry advancing robustly. In 2011, the gross domestic product (GDP) of Shanxi Province amounted to CNY1.11 trillion ($166.5 billion) and GDP per capita reached CNY30,974 ($4,646). This is in very large contrast with the rural areas, where, particularly, in the mountain regions, GDP per capita is generally much less than CNY10,000 ($1,500).

Groundwater: Key to Sustainable Agricultural Production

In Shanxi Province, bordering the NCP, water demand has increased significantly with the development of its industrial base, mining sector, and agricultural production. In 1984, the amount of groundwater resources extracted in the province was 2.483 billion cubic meters, and this figure went up to 3.873 billion cubic meters in 2000, accounting for 67.6% of the water supply for the whole province. By 2009, there were 103,949 groundwater abstraction points, 96% of which are operational. After increasing by 3.5% per year for several decades, the growth in groundwater abstraction has come to a standstill in the last decade, but areas of high vulnerability persist.

This intense groundwater exploitation formed large regional cones of depression, causing environmental problems such as aquifer depletion, land subsidence, and spring exhaustion.[6] Groundwater systems in Shanxi Province have become under pressure, limiting their ability to serve as a buffer for dealing with the increased variation in water availability that comes with climate change.

The reason behind this overdrafting in Shanxi Province is the lack of coordinated planning and management of water resources that were the order of the day until 2000. Since 2000, groundwater administration and regulation in Shanxi Province has been strengthened (Appendix 1). The increase in groundwater use has been brought to a halt, but areas where usage exceeds recharging still persist. In 2005, the overexploited area was estimated to be up to 6,903 square kilometers, mainly in the productive valley bottom in the center of Shanxi Province. The overexploited area covers 40% of the economically important basin area in Jinzhong, Taiyuan, and Yuncheng. In the cities where groundwater is the major source of water (such as Datong, Jinzhong, Jiexiu, and Taiyuan) and land subsidence and fissure development have been observed (particularly in Taiyuan), drastic measures (including well closure) have been taken to overcome the problems.

[5] A *mu* is a Chinese unit of land measurement (1 *mu* = 0.067 hectares; 1 hectare = 15 *mu*).

[6] Evans, Foster, and Garduño 2002 (footnote 2).

Overdrafting is not the only issue. The shallow groundwater in Changzhi, Datong, Taiyuan, Yangquan, Yuncheng, and other regions suffers from different degrees of pollution. Groundwater pollution comes primarily from two main sources: (i) point pollution from wastewater discharged by cities, mines, and industry; and (ii) nonpoint pollution from chemical fertilizers and pesticides. In recent years, the large quantities of groundwater being extracted together with sewage discharge, activities of coal mines, and the influence of human activities are worsening the groundwater quality. This situation is also aggravated by natural fluoride and arsenic concentrations in the groundwater.

Shanxi Province, in fact, is famous for its coal deposits. The area with coal-bearing strata covers 40% of the provincial territory, with the total amount of coal reserves (within 2,000 meters in depth) reaching 640 billion tons. As coal and groundwater coexist in the same geological formation, coal mining often disturbs geological formations and damages aquifers. It may change the natural circulation of groundwater from the previous horizontal movement to vertical movement. Aquifers will dry up and groundwater recharges will be cut off. As a result, the groundwater table will decline, springs are affected, and land subsidence may be triggered. According to a research report on the impact of coal mining on water resources in Shanxi Province, prepared for the Second Assessment of the Water Resources of Shanxi Province, a single ton of coal produced can damage 2.54 tons of water. In addition, the discharge of large amounts of pit wastewater will pollute surface water and groundwater as well as cause other environmental problems.

A New Challenge: Adapting to a Changing Climate

A changing climate resulting in a decrease in rainfall and a rise in temperature adds to the concerns on falling groundwater tables. In Shanxi Province, the reported average rainfall decline since 1960 has amounted to 99 millimeters (mm), equal to about 12%. The decrease is mainly caused by precipitation decline during the rainy season (June to September), although precipitation in the post-rainy season (October to November) also shows a decrease. Decrease in precipitation is highest in central Shanxi Province and in the area along the west fringe between the Sanchuan and Fen rivers in western Shanxi Province.[7]

Precipitation is the core component of groundwater recharge and changing rainfall patterns will affect recharge. Reduced precipitation translates into reduced recharge. The Second Assessment of the Water Resources of Shanxi Province established that the average annual recharge to groundwater in the basins of Shanxi Province comes primarily from precipitation (48.8% of the total recharge); second, from piedmont lateral recharge (28.3%); and third, from surface water leakage (17.7%).

Temperature and carbon dioxide concentrations are also important because they affect evapotranspiration and determine the amount of precipitation that infiltrates the aquifers. Temperatures have increased about 1.2°C since 1960. A temperature increase leads to higher evaporation and further reduces recharge. Recent climate trend projections of Shanxi Province report an increase in average air temperature of 0.276°C every 10 years, which is about seven times more than the average in the PRC (0.04°C every 10 years) (footnote 7). In all seasons, air temperatures increased, but winter, spring, and autumn experienced the most pronounced increase in air temperature.[8]

Higher temperatures decrease soil moisture and affect the eco-environment for farming, forests, grasslands, and wetlands. While this creates new farming opportunities, it also calls for higher water consumption, triggering a more intense application of groundwater. Higher temperatures and fewer number of frost days also push up the geographical boundaries where farming is possible, extending the cultivation season in the colder parts of Shanxi Province.

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7 X. Fan and M. Wang. 2011. Change trends of air temperature and precipitation over Shanxi Province, China. *Theoretical and Applied Climatology.* 103 (3). pp. 519–531.

8 For winter, the increase was 0.44°C every 10 years, for spring 0.32°C every 10 years, and for autumn 0.17°C every 10 years. No significant trend was detected for summer.

Demonstrating More Sustainable Groundwater Usage

The Asian Development Bank (ADB) in 2009 approved the Shanxi Integrated Agricultural Development Project with the objective of strengthening agricultural production in 26 counties in Shanxi Province. Complementing the project is a $500,000 grant from the Multi-Donor Trust Fund under the Water Financing Partnership Facility to support climate change adaptation through groundwater management.[9] Groundwater management practices in Shanxi Province were reviewed, and the local governments of Lishi, Pingshun, Qi Xian, and Xi Xian counties initiated a number of demonstration activities to promote the efficient use of water in irrigation as well as to manage groundwater.[10] The counties were selected after careful scrutiny of a long list of eight relatively poor candidate counties of the 26 covered in the ADB-supported Shanxi Integrated Agricultural Development Project (Map shows the location of areas covered by this project, including the demonstration sites). The long list was based on a number of criteria: (i) use of groundwater, (ii) participation in the Shanxi Integrated Agricultural Development Project, and (iii) accessibility. For all these counties, basic data were collected and assessed. Field surveys, including interviews with farmers, were organized, as were expert consultation sessions. Lishi, Pingshun, Qi Xian, and Xi Xian counties were selected after a competitive selection process among local governments and farmers. The four demonstration sites were chosen for their representativeness of different areas of Shanxi Province and the interest by local government and farmers. The pilot activities were introduced after considerable discussions with these stakeholders.

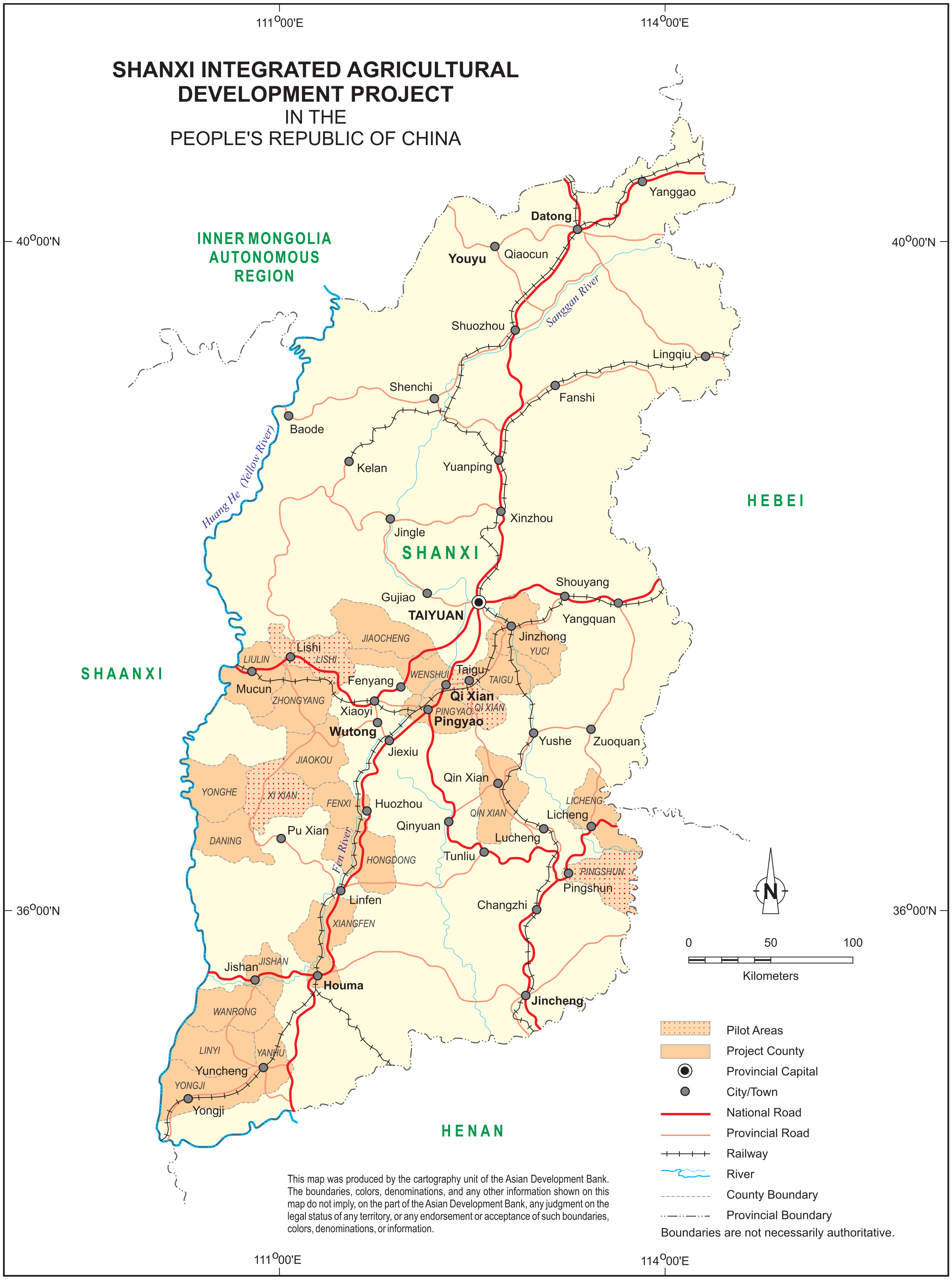
A fifth demonstration activity in Qinxu County discussed in this report was developed and entirely funded by the Shanxi Provincial Government. A description of the activities in Qinxu County is provided because of the relevance for Shanxi Province and groundwater management in general.

This report describes selected innovative and practical measures being taken to balance groundwater use in Shanxi Province, particularly the different pilots to control agricultural water use while maintaining or increasing productivity. In terms of groundwater use, Shanxi Province may be categorized into two areas: (i) the intensively used lowland areas; and (ii) the relatively "untouched" upland areas, where groundwater use has not progressed as far and poverty is more widespread. Section 2 focuses on demonstration site activities in efficient irrigation and groundwater use in the lowland parts of Shanxi Province, where overuse is most prevalent. Section 3 covers the higher and hillier areas, where overuse is not yet a problem but where agricultural expansion is needed to keep up with the increased demand for (high-quality) food. Section 4 summarizes the outcomes of the different demonstration sites and elaborates on policy lessons for groundwater management in Shanxi Province. It also emphasizes the need for sharing experiences in groundwater management and describes actions to share and duplicate demonstration activities throughout the NCP.

9 Contributors to the Multi-Donor Trust Fund under the Water Financing Partnership Facility include the governments of Australia, Austria, Norway, Spain, and Switzerland.

10 F. Guisheng, F. van Steenbergen, and Z. Wenzhong. 2013. *Climate Change Adaptation through Groundwater Management in Shanxi Province.* Consultants' final report. Manila: ADB (G0188-PRC).

MAP Location of Demonstration Sites in Shanxi Province



Groundwater monitoring is key to sustainable agricultural development

PHOTO CREDIT: FRANK VAN STEENBERGEN

2 CONSERVING GROUNDWATER IN THE LOWLAND AREAS

Background and Rationale

The lowland areas of Shanxi Province are its fertile plain and basin areas, located in the center and spreading all over the province from the northeast to southwest. The lowlands comprise a series of graben-type technical fault subsidence basins: Datong, Linfen, Taiyuan, Xinzhou, and Yuncheng. The altitude of the area drops gradually from north to south, with Datong Basin being 1,050 meters, then Taiyuan Basin at 750 meters, and, in the far south, Yuncheng Basin at 400 meters. All basins are covered with loess and with alluvial and diluvial deposits. With its flat terrain and rich soil, this basin area is the heartland of the province, sustaining extensive agriculture and industry and accommodating the main population centers of the province. It is also the area of most intensive use of groundwater.

The current groundwater problem spots in Shanxi Province are, therefore, its lowland areas. Intensive farming activities in the lowland areas of the province (including grains and vegetable production, livestock raising, and cattle fattening) have created a situation of unsustainable groundwater use in a water-scarce area. As earlier described, such overexploitation of groundwater resources is manifested in the large cones of depressions causing, among others, land subsidence and aquifer depletion. This poses a threat to the economic development of the area.

New approaches to reverse groundwater overuse but maintain a vibrant rural economy have been developed in Qi Xian and Qinxu counties. In Qi Xian County (Xiliuzhi Village), drip irrigation in greenhouses, including an energy-saving frequency converter, was established by the project. As a comparison of the progressive approach that the Shanxi Provincial Government is taking, this section also summarizes the experiences in Qinxu County, where the provincial government, independent from the ADB grant, already implemented a tradable quota system, tiered pricing, swipe cards, automatic water level recorders, and a data control center.

Qi Xian County: Efficient Greenhouse Irrigation in the Plains

Qi Xian County is typical for the central farm belt of Shanxi Province, the main grain basket and source of vegetables and livestock products. Farm incomes are relatively high in the county. They stand at CNY14,704 ($2,205) per farm family member. The lack of an industrial base in Qi Xian County is compensated by intensive farming activities that include poultry and cattle fattening.

The agricultural prosperity in Qi Xian County, however, is built on a foundation of unsustainable groundwater use. The area is clearly water scarce: it has an overall per capita water availability of 263 cubic meters (m^3) and a usable availability of 163 m^3—all clearly below the so-called Falkenmark indicator for water-stressed areas. The Falkenmark indicator or water stress index is one of the most commonly used measures of water scarcity. It calculates water scarcity as the amount of renewable freshwater that is available for each person per year. A country's Falkenmark indicator below 1,700 m^3 per capita per year suggests that the country is experiencing water stress; water scarcity and absolute water scarcity refer to conditions with indicators below 1,000 m^3 and 500 m^3 per capita per year, respectively.[11]

[11] M. Falkenmark, J. Lundquist, and C. Widstrand. 1989. Macro-scale Water Scarcity Requires Micro-scale Approaches: Aspects of Vulnerability in Semi-arid Development. *Natural Resources Forum.* 13 (4). pp. 258–267.

Lowland greenhouse area in Qi Xian County

PHOTO CREDIT: FRANK VAN STEENBERGEN

As surface water is limited and polluted, groundwater has, for the most part, been substantially used. Yet, groundwater has been overused for a long time at a ratio of 173% of the recharge in 2010. The inevitable drop in groundwater levels is about 0.76 meters in an average year. The need for more efficient irrigation and higher productivity within a framework of regulating and reduced groundwater consumption is obvious.

The demonstration installation of Xiliuzhi Village is a short distance from the county capital. It introduced efficient greenhouse irrigation that can serve as an example for a larger area in the central plains in Shanxi Province, reaching much higher water productivity than hitherto achieved and reducing pressure on the use of groundwater. In the village, at present, 15 ha are covered by greenhouses supplied by wells set at depth of 150 meters. Greenhouses in Xiliuzhi Village come in two varieties: the first variety is a semiarched traditional structure, with a 3-meter mud wall on one side. Thick straw blankets are positioned on top of these structures, rolled down to insulate the greenhouses at night. These greenhouses come at a cost of CNY56,000 ($8,400) per *mu*. The second type of greenhouses consists of (removable) arched plastic sheds and is installed at a much lower price of CNY10,000 ($1,500). These plastic sheds are only used in the warm season, as it is not possible to shelter them from the cold using straw blankets, as in the case of the semiarched structures.

Prior to the installation of the micro-irrigation systems in the demonstration sites, flood irrigation was common in the greenhouses. Water was distributed from a small canal running across the length of the greenhouse. In the demonstration sites, these flooding systems were replaced with state-of-the-art drip irrigation systems. These consisted of (i) a central control unit, (ii) buried pipeline connection, and (iii) drip systems within the greenhouses. The central control unit was equipped with pressure meters, double distribution lines, a centrifugal filter to remove impurities from the water, and a frequency converter. The frequency converter is an innovation within the greenhouse systems. The converter adjusts the current to the demand of the system. In this way, an energy saving of 40% over conventional power systems is realized. Whereas, in the last 5 years, the use of frequency converters in industries has become widespread, its application in irrigation is quite new.

The control unit is operated on the basis of voluntary self-management by the water and electricity service association that operates under the guidance of the village administration. Apart from operating the equipment,

Drip system in semiarched greenhouse in Qi Xian County

PHOTO CREDIT: FRANK VAN STEENBERGEN

the service association takes care of the irrigation scheduling as no more than four greenhouses can be provided water at the same time. Farmers pay for water and electricity—the cost of the former is set at CNY0.6 ($0.09) per cubic meter. From the central control unit, the water is led through buried pipelines to 39 traditional greenhouses and 20 arched structures under the demonstration activities. Water supply in each greenhouse is independent, having its own water meter, electricity meter, additional second filter system, and connection for a fertilizer and pesticide mixing unit. The emitters are regularly spaced at 50 centimeters (cm) and 70 cm to allow the cultivation of vegetables. Recommended water and fertilizer applications in different parts of the season are painted on the control houses next to every greenhouse unit. Prior to the operation, training was provided to the farmers on the use of the drip systems. The cost of this installation amounted to $45,600 (under the ADB grant), with supplementary funds of CNY210,000 ($31,500) through local government funding from improvements to the main water source. The expected life span is 8 years.

The drip systems are used in combination with inexpensive plastic mulch. The main benefits are the savings in water and fertilizer usage. Water supply for the traditional greenhouses is set at 11 m^3 per hour and for the arched greenhouses at 8.5 m^3 per hour. According to farmer interviews, the water savings amount to an estimated 40%–60%, or equivalent to 200 m^3 for the semiarched greenhouses and 150 m^3 for the plastic sheds. Fertilizer consumption is reduced by 35%–40%. Moreover, the more accurate applications translate into an increased crop yield of 25%–40%. Water productivity (the “crop per drop”) improves by 90%. Some crops, such as zucchini, are particularly sensitive to this type of precision farming—they would not do well without these improved systems.

Proud owner of a modern drip system in a semiarched winter-proof greenhouse in Qi Xian County

In monetary terms, the estimated benefit is an additional profit of CNY10,000 ($1,500) per year per traditional greenhouse. This compares favorably to the investment per hectare of CNY4,000 ($600) per greenhouse or CNY6,000 ($900) if all investments are included. For semiarched structures, there is less benefit as they are not suitable for winter cropping because they cannot be insulated.

The gross benefit is CNY5,000 ($750) and net benefit is CNY2,000 ($300). Also important are the labor savings, estimated at 80% as the drip systems made it possible to do away with the time-consuming flood irrigation.

The Farmers Union in Xiliuzhi Village has already developed a second system that is a replica, albeit with further sophistication, of the demonstration installation. The new system is funded entirely by farmer members. The system under construction will cover an area three times larger than the demonstration sites, with 102 traditional greenhouses and 57 arched greenhouses subscribed to it. It also includes a sensor system that makes it possible for the irrigation delivery to automatically respond to soil moisture stress. There has been much interest among farmers of other areas visiting the system and the plan is to fully cover the area with improved drip systems. A shortage of investment capital—not enthusiasm—is the main bottleneck. The system in Qi Xian County is also far more robust than similar drip systems installed under other programs: the filter systems, for instance, ensure the constant running of the micro-irrigation systems and explain part of the large enthusiasm by farmers from the area.

Qinxu County: Regulating Groundwater Use

Qinxu County has traditionally been an agricultural county, administered under Taiyuan City. The total population of Qinxu County is 340,000, of which the agricultural population is 250,000. The county has 436,000 *mu* (29,067 ha) of arable land and the irrigated areas cover 368,000 *mu* (24,533 ha), of which 170,000 *mu* (11,333 ha) is irrigated with groundwater. The economic and agricultural development of the area has led to an annual water shortage of 57 million cubic meters. This was compounded by the decline in rainfall in Qinxu County, as elsewhere in the province, and the reduced water inflows from the Fen and Xiahe rivers, the latter having dropped to 25% of its discharge in 1950.

Until 2005, the groundwater level declined at about 1.6 meter per year.[12] Due to the importance of groundwater for the county's economy and the urgent need to avoid groundwater overexploitation, Qinxu County established a sound mechanism for water resource allocation, management, evaluation, and monitoring of groundwater.[13] The Qinxu Groundwater Management System, put in place in 2007, has equipped all 1,298 agricultural wells in the county (responsible for 80% of the water use) with an automatic operating system that a farmer will operate with his swipe card. The amount of water that can be used is based on a quota that is given out annually. The same is done for 379 small industrial users; whereas for 59 larger companies, water usage is even recorded by remote metering and monitoring. In the PRC, direct groundwater regulation can more easily be implemented since water-related institutional structures reach to the farm level.[14]

The quota is determined first by sector (industry, agriculture, domestic, and environment), then for each of the 197 villages within the county, and finally for each farmer within the village. The quota varies from area to area and depends on the groundwater resources sustainably available. The quota for individual families is based on the land owned, the number of family members, and the livestock owned. If water is used within the quota, the price is CNY0.41 ($0.06) per unit. If it exceeds the quota, it is CNY0.55 ($0.08). The unit relates to the electricity units consumed. As some wells are very shallow and others are deep, the volume of water against a unit may vary from 500 liters to 5,000 liters.

Water fees are used to pay the electricity fee for pumping the water, the salary of irrigation management, and for the maintenance of the irrigation facilities. The over-quota water fees are used to pay any leftover debt of the electricity fee or the salary, and then allocated for 50% of repair costs. The balance of the funds is for developing new water resources (footnote 13).

The water price is quite expensive when compared with the cost of planting and the potential profit. This ensures the price signals are effective. In Xihuaiyuan Village, the water fee per *mu* comes down to CNY73 ($11) (water consumption = 240 m^3). According to the national statistics, in 2008, the cost of planting wheat was CNY274 ($41) per *mu* and the net income only CNY296 ($44) per *mu*; the cost of planting corn CNY232 ($35) per *mu* and the net income CNY423 ($63) per *mu* (footnote 13).

The quota, in principle, can also be traded between villages and between farmers. There is an upper limit to the price (twice the basic amount) which cannot be exceeded. Among farmers, it is more common to share "excess water" with family members and neighbors than to trade. As in other cases, in the absence of groundwater markets, growing water scarcity has not led to monopolization of the resource (footnote 14). In general, however, the allocation of the quota is quite tight for irrigators. According to the quota regulations, any leftover water can also be carried over to the subsequent year. If a farmer has not used up the water quota, he or she may prefer to carry it over to the subsequent year. This reflects that farmers do care about the quota and the price ladder.

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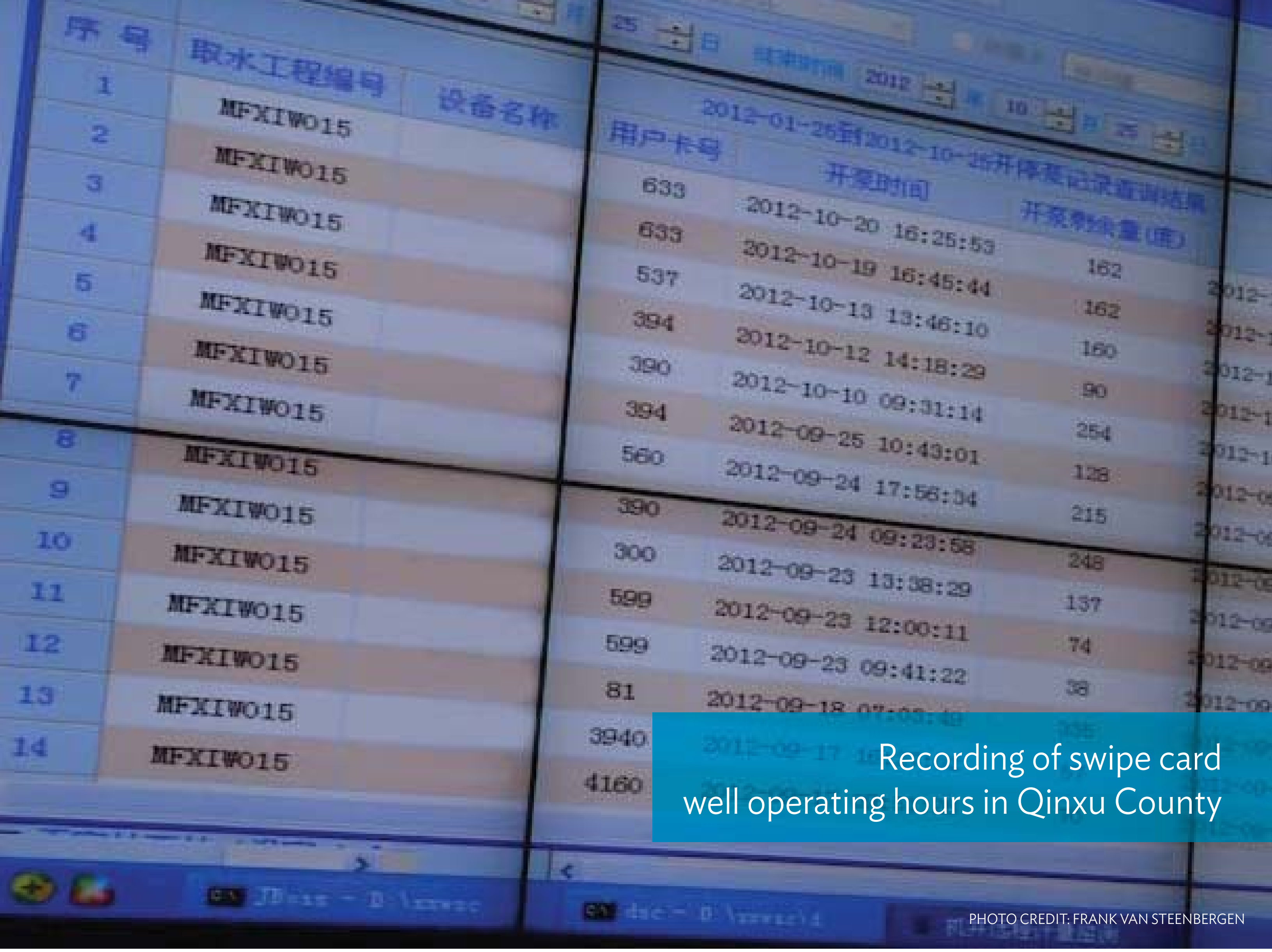

Recording of swipe card well operating hours in Qinxu County

PHOTO CREDIT: FRANK VAN STEENBERGEN

The swipe card transactions are transmitted through the internet to the Digital Water Resource Information Centre in the Water Resources Bureau of Qinxu County. This center meticulously records the number of units consumed by each farmer based on his or her swipe card transactions. A farmer may use water from more than one neighboring well. If a card is lost, it can easily be replaced as the information center keeps the records for several years. The information center is also connected to 60 solar-powered observation wells that transmit data on groundwater levels on a continuous basis.

The results are remarkable. In spite of the tight restrictions, 70% of farmers rated the new system *good*—the majority, in fact, *very good*. As the swipe cards have to be preloaded, cost recovery is 100%. Although no analytical modeling work has been carried out, the presumed contribution to groundwater conservation is significant. Whereas prior to the system being developed, at a cost of CNY30 million ($4.5 million) per hectare, groundwater levels were in heavy decline, this has been turned around and groundwater levels have been increasing between approximately 1.6 meters and 4.8 meters a year. While the new systems may not have been the only reasons, the volume of groundwater consumed was lowered steadily: from 59 million cubic meters in 2004 to 30 million cubic meters in 2009—a drop of 40%. The regulated system encouraged farmers to adjust farming practices: better field preparation (81%), use of plastic mulch (61%), and change of crop varieties (49%) (footnote 13).

Awareness of the pollution risk from fertilizers and pesticides has also been promoted through government communication campaigns. Finally, the implementation of the project enhances the efficiency of water use and its benefits, and promotes the sustainable utilization of water resources. The gap between supply and demand of water resources has gradually been reduced. The groundwater environment has recovered from continuous worsening (footnote 12).

3 INCREASING WATER PRODUCTIVITY IN THE UPLAND AREAS

Background and Rationale

Topographically, the upland areas of Shanxi Province can be divided into two parts: the mountain ridges in the east and the plateau area in the west. The distinguishing feature of the mountain area in the eastern part of the province is Taihang Mountain, which separates Shanxi from Hebei and Henan provinces. Apart from Taihang Mountain, the eastern mountain range consists of Hengshan Mountain, Wutai Mountain, Xinzhou Mountain, Taiyuan Mountain, Zhongtiao Mountain, and the Southeast Jin (short for Shanxi) Plateau. The Yedou Peak of Wutai Mountain is 3,058 meters above sea level and is one of the commanding peaks in northern PRC. The highland plateau in the west is dominated by Lüliang Mountains. It further consists of Luya Mountain, Yuzhong Mountain, and the West Jin Loess Plateau. The highest peak is Guandi Mountain, which is 2,830 meters above sea level. Economic development in the uplands has lagged behind development in the lowlands as the former's economy is primarily based on agriculture. There is a limited industrial and mining base in the uplands. These sectors usually compete with households and the agriculture sector for groundwater consumption.

Overuse of groundwater resources is not yet a problem in the upland areas, because agricultural production is primarily based on specialty agriculture (high-value fruit trees and cash crops), unlike in the lowlands where intensive farming activities are practiced. However, agricultural expansion is needed to keep up with the increased demand for higher quality food. In contrast to the lowlands, there is still potential to expand upland production to other crop options, but since agricultural production is dependent on variable rainfall (i.e., it is mostly rainfed as irrigation is limited), there is need to introduce systems with high water productivity (i.e., higher monetary output per unit of water). More efficient irrigation would not only help increase yields and decrease water usage but would also promote labor savings which is beneficial for the aging rural population.

Under the ADB grant, three demonstration projects were funded aiming at high-value water-saving agriculture. In Xi Xian County (Quyan Village), a spring system with large diameter micro-irrigation was piloted for orchards in the Loess Plateau. In Pingshun County (Henantan, Wangqu, and Wanli villages), a microsprinkler in mesh tents for prickly ash shoot cultivation was introduced. In Lishi County (Xiaoshentou Village), where cold weather is a major constraint, drip and microsprinkler irrigation systems were established in greenhouses in combination with warming ponds.

Xi Xian County: Developing Horticulture in the Loess Plateau

Xi Xian County ranks among the 35 poorest counties in the PRC. The population is 107,000, spread over 8 townships and 97 villages. The rural nature is obvious: 80,000 of the residents are farmers. The average per capita farmer income is CNY2,496 ($374)—close to the level of the poverty line of the PRC. About 53,000 persons in Xi Xian County, in fact, are living below the poverty line.

The county is part of the large Loess Plateau and is highly undulated, consisting of eight separate plateau areas. Since 1979, considerable work has been done on the rehabilitation of the vulnerable catchment, with 1 million *mu* (0.067 million ha) treated and a similar area still needing to undergo rehabilitation. Rehabilitation costs are approximately CNY5,500 ($825) per *mu* but vary widely: on the flat plateau areas, the cost is CNY1,500 ($225) per *mu*, but on the sloping areas, it is considerably higher, though costs have been reduced with the increased use of bulldozers. In areas with a slope in excess of 25 degrees, only reforestation activities are undertaken.

Loess Plateau in Xi Xian County

PHOTO CREDIT: FRANK VAN STEENBERGEN

The impact of the Loess Plateau treatment has been very positive. Compared to 1979 when the program started, (i) soil erosion was reduced by 1,320 tons per square kilometer per year, (ii) retention of surface water increased by 26.8% (from 14.0% to 40.0%), (iii) interception of sediment increased by 32.5% (from 17.5% to 50.0%), and (iv) forest cover increased by 32.8%.

Xi Xian County has a climate that is suitable for high-value fruits, particularly pears, apples, and apricots. The “Golden Pear” from Xi Xian County enjoys national fame and was already served in the royal courts of the Ming and Qing dynasties. It was also selected as one of the specialty fruits for the 2008 Olympics. The climate (average 8.9°C), the large variation between night and day temperatures (causing the fruit’s sugar levels to increase), the excellent thick loamy soils (with good aeration), and the presence of a large number of varieties (e.g., close to 100 varieties of pear) explain the comparative advantage of the county. The areas under fruit trees are heavily supported by (i) developing new plantation and promoting better water resource development; (ii) introducing better agronomy, including better fertilizer usage and grafting; (iii) promoting intercropping by crops that are low in height, such as chrysanthemum and beans; and (iv) improving marketing both for better storage at farmers’ levels and developing new marketing canals. The target area for development is 350,000 *mu* (23,333 ha), of which 310,000 *mu* (20,667 ha) has been reached. Xi Xian County’s economic strategy is primarily based on “specialty” agriculture—it has no industrial or mining base, but has 430,000 *mu* (28,667 ha) of arable land. Rainfall is 570 mm a year, but variable, and there are only 150–170 days without frost.

Layout of spring system in Xi Xian County

PHOTO CREDIT: FRANK VAN STEENBERGEN

Production, however, has been held back because of the dependence on variable rainfall. Irrigation is limited—not more than 4,400 *mu* (293 ha) and, in several cases, suffering from insufficient performance and management. Farmers often resort to irrigation by bucket from local water points. Yet, given the relatively old age of farmers, there is not much that can be achieved with such methods.

The demonstration site under the ADB grant was developed in Quyan Village, close to the Wulu Mountain range, which counts 120 households and 514 inhabitants. The arable area belonging to the village is 2,800 *mu* (187 ha), which is used for corn, millet, sorghum, beans, potatoes, and cash crops, in particular, pears, herbs, and oilseeds. Under the demonstration project, 250.5 *mu* (16.7 ha) serving 52 farm households were developed on a comparatively level area, yet with a height difference still of 20 meters. Such slopes made furrow irrigation, apart from its inefficiency, impossible.

Under the project, a so-called spring system was developed, with 0.8 mm diameter supply pipes making clogging unlikely. Each spring pipe outlet feeds a circular pit excavated around a single fruit tree.

The spring pipes are supplied by polyvinyl chloride (PVC) hoses laid out over the orchard area. These flexible lines in themselves are connected to outlets on the main pipeline feeding the area. The length of this main pipeline is 2,320 meters running along the entire length of the 250.5 *mu* (16.7 ha) area. There are 58 wells on the pipelines to serve the water lines to the orchards. The diameter for the main pipeline is 110 mm. Previously, this was 90 mm, but there was insufficient pressure in the system. Two-thirds of the pipeline was replaced.

Buried water supply system in Xi Xian County

PHOTO CREDIT: FRANK RADSTAKE

Water comes from the spare capacity of the village water supply system that, in addition to the agricultural areas, is feeding six small village clusters. The source of the system is a spring located at a lower elevation with water being pumped up through a largely buried pipeline to a central tank. Part of the pipeline is exposed, though with drainage wells to empty the main supply line, especially during heavy frost, to prevent the pipe from bursting. For the micro-irrigation system, a small central unit is in place, beside the central tank, to regulate pressure. It is also equipped with a centrifugal filter to clean the water. There is the option at the central unit to add fertilizer or pesticide to the irrigation water. The main water supply system is operated by the county water resources bureau, whereas the village committee takes care of the irrigation system. Training was provided on two occasions.

The demonstration site in Quyan Village has received a very enthusiastic reception by local farmers. The piped micro-irrigation spring system has facilitated the cultivation of irrigated orchards, primarily by an aging farm labor force. Earlier, this was done with hand-carried cans. The expectation is that, with the spring system, a yield of 1,500 kilogram (kg) per *mu* can be reached with a sales price for apples or pears of CNY5 ($0.75) per kilogram, thus creating a production value of CNY7,500 ($1,125) per *mu*; without irrigation, yields are closer to 600 kg per *mu*. The cost of the demonstration activities amounted to CNY335,000 ($50,250), exceeding the grant amount of CNY238,000 ($35,700), yet very favorable at CNY1,350 ($202) per *mu*. Hence, the payback period, which could be less than a year, is short. The demonstration activity fits well into the plan of the local government to expand the area under (irrigated) high-value niche horticulture, provided small local water resources can be developed and tapped. The plans at the county level are eventually to have 160,000 *mu* (10,667 ha) under the improved irrigation system, but this will require careful planning and development of local water resources.

Farmer in Xi Xian County

PHOTO CREDIT: FRANK RADSTAKE

Pingshun County: Creating a Controlled Environment for Specialty Crops

Pingshun County, a second area selected for an improved groundwater pilot in the uplands under the ADB grant, is a mountainous county located in the southeast of Shanxi Province. It has a population of 164,000, the majority of which (135,000) depends on agriculture. Most of the 12,920 *mu* (861 ha) of arable land is rainfed, with irrigated land amounting to 10%. Groundwater resources are, as of yet, not heavily utilized. The county has several mineral resources (silica, aluminum, and commercial clays), plans for sustainable energy (wind and solar), as well as potential for tourism. For the time being, however, the main economic base is agriculture—the main crops being commercial trees (walnut and prickly ash) and annual crops (such as rice, wheat, and legumes). The area is also classified as a poverty county. Its annual GDP per capita is CNY7,658 ($1,149), but farmers' incomes are substantially lower at CNY2,720 ($408) per capita.

Efficient pressurized irrigation systems are often promoted to save water, but their largest benefit, in fact, lies in the higher production they make possible. While this is not new—for instance, the international comprehensive assessment of water resources already estimated that micro-irrigation systems achieve 5%–56% higher yields—this yield effect of pressurized irrigation often goes unnoticed.

A very good example of the multiple added value of pressurized irrigation systems is the microsprinkler system introduced under the grant project on farms of prickly ash (*Zanthoxylum*). This thorny scrub is usually grown for the typical peppers it produces that are the main ingredient in the famously hot Sichuan dishes. In Pingshun County, however, prickly ash is grown not for its pepper but for its young tender leaves. This is a relatively new niche product, sold as pickles and also as a fresh delicacy in the growing urban markets. The cultivation of prickly ash shoots received its main impetus from a local enterprise that processes the crops and is providing farmers the required up-front investment in seedlings and equipment. Prickly ash got a major boost in Pingshun County 6 years ago when the local government introduced the use of mesh tents. This helped to largely control the problem of aphids (lice), reduce the use of pesticide, and improve the quality of the product.

A further improvement in the cultivation of prickly ash shoots, introduced under the grant, is the use of microsprinklers suspended in the mesh tents. This was experimented in three sites: (i) Henantan, 100 farms per 130 *mu* (8.67 ha); (ii) Wangqu, 38 farms per 50 *mu* (3.33 ha); and (iii) Wanli, 31 farms per 40 *mu* (2.67 ha). Under the new irrigation system, the suspended microsprinklers not only irrigate but also wash down the remaining aphids. The microsprinklers can also be connected to small mixing tanks within the mesh tent that make it possible to add small doses of fertilizer or pesticide. The controlled system also prevents the soils from getting too wet. As a result, lower amounts of fertilizer, pesticide, and water (estimated at 40%) are used, yet a higher yield with a cleaner product is achieved (estimated 20% more). The main advantage of the system is not water savings as such, but also energy savings (less fertilizer and pumping). It also created a controlled microenvironment that allows for a higher production.

To supply water to the prickly ash shoot farm areas, two water source systems were developed: pumping water from an improved well near the river, and (feeding the two smaller areas) pumping water directly from the river. Two storage tanks were built on the nearby mountain slopes, one measuring 380 m^3 and the other 250 m^3—served by a total of 4,000 meters of pipeline. The local government contribution covered all these costs. It was also necessary to include a gravity hammer in the system. This was provided under the grant project. Within the irrigated area, a distribution network was laid serving distribution wells (169) in each of the prickly ash tents. Within the mesh tents, a network of suspended lines with microsprinkler was laid out. The distribution well is equipped with a water meter and a mixing point for fertilizer and pesticide. The total investment was CNY1.07 million ($160,500), i.e., close to CNY5,000 ($750) per *mu*. Of this, CNY247,000 ($37,050) or CNY1,150 ($172) per *mu* of the ADB grant was used for the field pipelines and microsprinklers within the farm area.

The expected increase in income is 15%–20%, which will be achieved at a much reduced labor input. The microsprinkler will also bring a considerably better-quality green leaf product as many aphids are washed out and pesticide use can be greatly reduced. The local government is keen to expand the microsprinkler system on all prickly ash shoot farms in the area and also experiment with other vegetable crops. One lesson was the need for intense communication and discussion with farmers, as the system is very new and requires convincing and good understanding of its usage.

Local enterprise expanding its capacity for prickly ash processing in Pingshun County

PHOTO CREDIT: FRANK RADSTAKE

Lishi County: Developing Cold-Weather Irrigation

With demand for fruits and vegetables increasing all over the PRC, greenhouses have also made an appearance in more areas with very cold weather, such as Lishi County in the Lüliang Mountains. Lishi County has a continental monsoon climate with very cold winters and, in some years, only 130 days without frost. A large part of the rural population depends on (temporary) jobs in industry or mining. Agriculture makes up 3% of the county's GDP, but the proportion is increasing due largely to the active development of cold-weather greenhouses and the recession affecting the other sectors. The main economic base, however, is in coal extraction and in industry (industrial turnover stands at CNY3 billion, or $450 million).

The rural area is poor, with farm incomes at CNY1,106 ($166)—far below the PRC's poverty line of CNY2,293 ($344). Water availability per capita is limited at 324 m^3 per year. Still only a relatively small part of the water resources is used in Lishi County. The area has a very hilly (uneven surface) topography with only 5% of the land being arable—with flat areas and valleys used for the cultivation of corn and vegetables and the raising of livestock. In the hilly areas, replanting of walnut trees, among others, is undertaken.

The greenhouses in Lishi County resemble the semiarched structures common in other parts of the province, but several modifications have been made to deal with the cold winter weather. The loess mud walls are thicker (4 meters instead of 3 meters) than usual. At night, many of the greenhouses are insulated with thick cotton blankets that are skillfully moved over the semiarched plastic roofs. The area in Lishi County under such cold-weather greenhouses has expanded rapidly to 500 ha in the last 5 years, and the target is to triple this coverage.

Cold area greenhouses in Lishi County

PHOTO CREDIT: FRANK VAN STEENBERGEN

The challenge is not only the air temperature but also the temperature of the irrigation water. As a rule of thumb, if irrigation water is colder than 10°C, plants will not do well. The reason is that the root hairs of the crops do not develop and many of the microbiota activity in the soil stops functioning. This is particularly fatal for young seedlings. In Lishi County, the river water, for a large part of winter, is close to or even below 0°C.

Following a winter season of a team from the Taiyuan University of Technology taking measurements, the ADB grant project developed a warming system for the greenhouse area of Xiaoshentou (altitude 975 meters). This warming system in cold area greenhouses can serve as an example for many cold-weather regions of the world. First, water is used from a relatively warm source—in this case, an underground spring along the Dongchuan River—stored in a 200 m^3 reservoir. The advantage of the spring water is that it is still around 5°C at the coldest time of the year. The spring water is then conveyed through a buried pipe to the horticultural area where it is collected in a closed storage pond. The water is distributed at a control station and is also filtered there. From there, the water is distributed to separate greenhouses. In each greenhouse, a small plastered brick masonry pool is constructed measuring 2.75 meters by 1.75 meters and a depth of 1.20 meters. If water is kept in this pond for 48 hours, it will have warmed up enough to irrigate the greenhouse area measuring 1,600 m^3 through a system of regularly placed drips under plastic mulch (for vegetables) or through suspended microsprinklers (for oyster mushrooms). The pond is built at ground level with a small rim of 25 cm to avoid dirt from falling in. It is covered with a mesh for the same purpose and also to avoid the growth of algae in warmer periods of the year. Underneath, a concrete structure geo-membrane is used to avoid leakage. The dimensions were chosen so as not to take up too much space and, at the same time, maximize exposure to sunlight and earth warmth. The dimensions ensure that the water temperature near the bottom of the pond is in excess of 10°C so that it can feed the greenhouse irrigation system with the help of a small submersible pump. Two other designs were considered: one option was a deep cistern, but this would not warm up the water sufficiently; the other was a raised tank, but this would be costlier and would not make use of the insulating effect of the ground.

The underground tanks and micro-irrigation system make it possible to grow a third crop in the greenhouses with an extra annual turnover of CNY5,500 ($825) per *mu*, already more than the cost of the greenhouse installation. In addition, the more precise irrigation and controlled environment that the drip and microsprinklers provide are, as in the other demonstration site, expected to reduce the costs of agricultural inputs and the amount of labor, whereas the crop yields are expected to increase. Because the system became operational very recently, it is too early to make a precise statement about the results of the installations in Xiaoshentou. However, farmers' predictions are that crop yields may increase by at least 10%, and fertilizer and pesticide consumption may be reduced by 20%. Labor inputs would drop even more.

Whereas the project developed the cold-weather installations in Xiaoshentou, improved systems have also been constructed in the other greenhouses in the area. These, however, use an older version of the warming pond consisting of a small elevated tank within the greenhouse. All in all, under the ADB grant, drip systems were installed in 29 greenhouses—standard size 1.1 *mu* (0.073 ha)—and microsprinklers in 17 greenhouses (total 1.93 ha). The cost of these installations (including the control station) was CNY245,000 ($36,750) or around CNY5,000 ($750) per *mu*. In addition, CNY3 million ($450,000) from local government funding was spent on the main water supply system that serves the entire greenhouse area (3.3 ha).

In spite of the high cost, the scaling-up potential is significant in Lishi County, as there are ambitious plans to develop irrigation sources and construct more cold-weather greenhouses. One area of concern in Lishi County, as in all mountain areas, is to have a good understanding of the fragmented water resources in the tracts. The availability of adequate amounts of water during the different parts of the year needs to be carefully observed and assessed, together with the changing rainfall patterns in Shanxi Province.

Warming pond in Lishi County

PHOTO CREDIT: FRANK VAN STEENBERGEN

4 KEY FINDINGS AND RECOMMENDATIONS

Opportunities for Improvement

Support for introducing good agricultural practices to promote groundwater conservation should be of highest priority. Groundwater has historically been essential for agriculture and for urban development in Shanxi Province. However, in the last 3 decades, overuse, pollution, and geological disturbance due to mining operations have put this critical asset in danger. At the same time, with the economy further developing, the demand for good-quality, reliable groundwater supplies will increase.

Climate change is an additional challenge that will only highlight the need to better manage and ensure reliable groundwater sources. Changing rainfall patterns, specifically reduced rainfall, increase reliance on groundwater resources, which, in turn, increases pressure on groundwater availability due to reduced recharge. In the agriculture sector, decreasing rainfall means a larger demand for irrigation. The higher temperature means that farming may expand in the colder areas of the province and that evaporation will be higher as well. Better management and use of groundwater will not only facilitate preservation but also ensure that groundwater reserves are used as a buffer against climate change.

The presented demonstration activities show that conserving groundwater use is possible without jeopardizing development. In the more progressive lowland areas, the unsustainable use of groundwater has been reversed within a framework of regulating groundwater consumption that encouraged farmers to adjust their farming practices. One of the main messages is that regulated systems translate into economic benefits. In the upland areas, more efficient irrigation systems translate into higher agricultural yields but lower costs of agricultural inputs (labor, fertilizer, and pesticides).

The larger picture is that the demonstration activities have been able to create local economies based on water-efficient agriculture. They have enabled the cultivation of high-quality crops and some specialty delicacies (such as prickly ash shoots or the Xi golden pear), which could not have been grown in the same manner without the water-efficient systems. The local value chain has been a very important factor of success: the prickly ash pickle and sauce entrepreneur, or the farmers' union in Qi Xian or Lishi counties, or the golden pear marketing industry in Xi Xian County.

All these innovations can make a significant contribution to reducing water consumption in agriculture, which is still the largest groundwater user in Shanxi Province. In addition, more measures and a comprehensive plan are necessary to balance out groundwater use and bring the resource economy back from the brink. The effect is, in fact, the opposite—more efficient and better regulated groundwater systems yield economic benefits, which are quite substantial—as the different experiences show. There is, hence, an economic case for investing in regulation and efficiency that is on a par with investing in infrastructure.

Technical Innovation: A Continuous Learning and Assessment Process

The modernized efficient irrigation systems in Lishi, Pingshun, Qi Xian, and Xi Xian counties achieved a more judicious use of water, but, equally important, they helped to increase yields by creating a controlled microenvironment. These demonstrations made possible a quantum leap in water productivity. The effect was double-edged: the new system reduced water use and increased yields at the same time. The improved systems in Lishi, Pingshun, and Xi Xian counties also introduced and facilitated high-value farming in relatively difficult but water-rich areas—without these innovations, such farming systems would have been difficult. Furthermore, the demonstration activities greatly saved on the use of agrochemicals and labor, thus capitalizing on the demand for food quality and also fitting in with the aging nature of the PRC's agriculture labor force. Their success was also apparent by their replication in other areas. With short payback periods and additional benefits, these innovations are set to spread easily, especially in horticulture for which they are very best suited.

PHOTO CREDIT: FRANK RADSTAKE

It noted that most of the systems in Lishi, Pingshun, Qi Xian, and Xi Xian counties became operational in the course of 2012. Monitoring and evaluation of the sustainability of these systems will be key to the opportunities of applying them at larger scales in other areas in the PRC. Given the significant challenges in the NCP, the demonstration activities are promising, to say the least.

To successfully replicate or introduce more widely the pilot activities, the following priority measures are recommended:

- Further popularize the precision irrigation systems, especially the need for quality installations.
- Create more sample model systems both for greenhouse areas and for open fields (in the latter case, for example, make use of other technologies such as conveyance pipes and sprinkler systems, as well as a range of soil improvement measures).
- Make sure a support service system is in place, where farmers are able to replace systems, if need be, or buy them for new areas (giving some form of subsidy would help accelerate demand).
- Introduce quality standards for the micro-irrigation systems, since substandard installation would spoil interest in precision irrigation systems.

In addition, the Qinxu systems, through a tiered pricing system and highly efficient swipe card-based regulation, also created the incentive for a water conservation society. The Qinxu model set the stage for farmers to invest in efficient water management, resulting in considerable water savings in staple crop areas for an entire district, which is nothing short of impressive for interventions at this scale and also highly necessary and worthy of more support. As the system is large and requires up-front investment in both time (intensive discussion with all stakeholders) and money (outlay for the new

Centrifugal filter and frequency converter in Qi Xian County

PHOTO CREDIT: FRANK VAN STEENBERGEN

infrastructure), there is a strong case for governments and international financial institutions to invest in such scaled-up models. Regulations such as those in Qinxu County are, moreover, necessary, as without them the introduction of efficient irrigation runs the risk of encouraging an expansion of irrigated area and, with it, an increase in water usage.

Sharing and Upscaling of Experiences

The challenges in Shanxi Province are not unique, but instead apply also to a large part of the NCP. To share and discuss the Shanxi experiences in improving groundwater management and technological innovation, the provincial government regularly organizes specific consultation and workshop events—and likewise to learn from other provinces. Although Shanxi Province has made significant progress in promoting innovative technologies and strengthening groundwater management, it is recognized that there are still many problems to be tackled (Appendix 2). For example, the participants of a 2013 groundwater forum proposed the following recommendations for climate change adaptation through groundwater management:[15]

15 In 2013, the Shanxi Provincial Government organized a national forum in Taiyuan City on Groundwater Resources Management and Climate Change Adaptation. The forum was attended by 90 participants, ranging from representatives from national government agencies to local governments, water users, and ADB. Through technical presentations and discussions, site visits to Qinxu County's digital water conservancy information system and Qi County's greenhouses with efficient water-saving techniques, as well as scaled-down demonstrations of water-saving technologies, the participants gained a deeper understanding of the importance and urgency of mitigating climate change impacts with groundwater management and learned about the major tasks for groundwater management in Shanxi Province.

(i) The strictest water resources management systems should be established, including, among others, levying groundwater resources taxes and promoting water-saving behavior with such a charging mechanism, water quotas and a rights trading market, and levying irrigation water fees in the whole province according to the amount of water used for each *mu*. The ultimate goal is to promote water-saving irrigation practices among farmers.

(ii) Water use should be well planned. Construction of a modern water supply network and a water ecoculture should be expedited.

(iii) More efforts should be spent in building demonstrations for various water-saving projects and in ensuring their outreach.

(iv) Different water-saving irrigation techniques should be selected for different natural conditions, and a multiple range of water-saving solutions that suit the specific conditions of a region should be adopted (Appendix 3). Special effort should be exerted in promoting new water-saving techniques and in sharing various water-saving irrigation techniques and equipment with more farmers. The government should provide funds to purchase and install irrigation equipment, whereas grant or loan projects or farmers themselves provide the counterpart funds. It is also possible to tap companies of scale or farmers' cooperatives for investment.

(v) Water-saving technical training should be given a priority so that efficient irrigation technologies can be readily mastered by trainees, and the existing water-saving facilities could run normally and be serviced and maintained properly.

(vi) The current farming structure, especially large-scale cultivation, should be adjusted. High water-consuming varieties should be eliminated, while more agronomic water-saving techniques are promoted.

Demonstrating water-saving technologies at the Shanxi Groundwater Forum

PHOTO CREDIT: FRANK VAN STEENBERGEN

Groundwater monitoring and public awareness in Jinan, Shandong Province

PHOTO CREDIT: FRANK RADSTAKE

Another important aspect that is regularly discussed is the process of upscaling from pilot to larger-scale implementation. An example in the PRC where the Shanxi pilots have been adopted in other areas is the NCP, where ADB is supporting the Shandong Provincial Government and preparing for the Shandong Groundwater Protection Project. The project will explore and implement restoration approaches for overexploited groundwater resources in Weifang and Zibo cities in Shandong Province. Experiences from Shanxi Province have been incorporated into the design of the investment project in Shandong Province.[16] The Weifang–Zibo area is the largest overexploited aquifer in Shandong Province, and the second largest in the PRC.[17] The project area, part of the NCP, is a primary vegetable producer for Beijing and has a high concentration of greenhouses. In some downstream areas, agricultural production has already stopped due to lack of suitable water sources.

16 For more information on the project, see http://www.adb.org/projects/47047-002/main

17 The overexploited area of the Weifang–Zibo aquifer covers approximately 5,422 square kilometers.

APPENDIX 1 Groundwater Administration and Regulation in Shanxi Province

BACKGROUND

To manage groundwater and protect its quality, a solid legal and institutional framework is essential to control the main processes in groundwater development and, as much as possible, integrate groundwater management with land development and land use planning, as well as economic development in general. The legal and institutional framework provides the basis for sustainable groundwater management, whereas special activities and investments are required so as not just to regulate but also to manage the demand for groundwater and augment its supply.

Groundwater management in Shanxi Province has evolved over the years and is now supported by a range of national, provincial, and local regulations. Before the 1980s, a state of anarchy in groundwater exploitation prevailed. There was no clear understanding of groundwater availability and the limits to its usage. Essentially, groundwater was seen as infinite and a free gift for people to survive.

At the time, though, the techniques of constructing wells were not advanced; hence, the amount of exploited groundwater was relatively modest. This situation changed dramatically after 1980, when a large number of new wells were developed. Soon after, the first laws, regulations, and standards on groundwater management were announced.

Shanxi Province, in fact, was a front-runner in this field in the People's Republic of China (PRC). In July 1982, the Shanxi Provincial Government set up a Water Resources Administration Commission and, in the same year, corresponding administrative organs of water resources were established at the municipal and county levels. The chief responsibilities of the new institutions were to coordinate and resolve conflicts between different departments or units on water resources development; mediate in water-related disputes; plan the managed exploitation, use, saving, and protection of water resources; and formulate corresponding guidelines and policies. With the announcement of new regulations, groundwater management became gradually more systematic.

During this period, Shanxi Province promulgated the following regulations: (i) Shanxi Provincial Regulation on the Administration of Water Resources; (ii) Shanxi Provincial Interim Measures for the Administration of Groundwater Resources; (iii) Shanxi Provincial Interim Measures for the Administration of Spring Areas; (iv) Shanxi Provincial Regulations on Water Saving for Urban Life, Factories and Mines; (v) Shanxi Provincial Interim Measures for the Levy of Water Resource Fees; and (vi) Circular of the People's Government of Shanxi Province on the Strict Control of the Drilling of Deep Wells.

Provincial regulations were complemented by regulations at the local levels. In 1988, Taiyuan City promulgated the Taiyuan City Measures for the Administration of Water Resources. In 1990, Datong City promulgated the Datong City Measures for the Administration of Water Resources. In 1991, Taiyuan City promulgated Taiyuan City Regulation on the Administration of Jinci Spring Area and Taiyuan City Regulation on the Administration of Lancun Spring Area. In 1997, the provincial regulations were updated with the announcement of the Shanxi Provincial Regulation on the Protection of the Water Resources of Spring Areas.

From 2000 onward, strict control of water resources became the norm. Following the central government's requirements on tightening the control of water resources, the provincial government in Shanxi Province drew the three "red lines" as the focus of its policy on groundwater management. These three red lines involved the (i) exploitation and use of water resources, (ii) control of pollution in water supply areas, and (iii) monitoring of efficiency in water use.

ADMINISTRATION AND COORDINATION

Within Shanxi Province, the Ministry of Water Resources is in charge of water resources management as well as the promotion of the national water conservation industry. The ministry is an administrative department of the State Council. Correspondingly, the departments of water resources at all administrative levels are in charge of water resources in their own area of jurisdiction.

The role of the Ministry of Water Resources includes four key aspects: (i) to formulate general policies, laws, and regulations for water conservation so that the water sector and all its activities are administered by law; (ii) to draw up an integrated development plan for the water conservation industry as a whole and ensure coordination within the water sector; (iii) to formulate general technical specifications, standards, and quotas, which will then be binding for water users; and (iv) to make general administrative rules and regulations for the water sector, for example, the administrative examination and approval procedures of water conservation projects, regulations on the administration of the license for water withdrawal, the implementation of water resources assessments, and undertaking of water audits.[1]

Nevertheless, in practice, groundwater resources in Shanxi Province are managed by a large number of administrative departments, including the (i) Department of Water Resources, (ii) Department of Urban Construction, (iii) Department of Land and Resources, and (iv) Environmental Protection Department. With so many government agencies administering water together, problems occur, such as overlapping investment of staff and material resources, unclear responsibilities especially when problems arise, and general lack of coordination with each organization setting its own policies and building up its own information system.

For example, the Department of Urban Construction is mainly responsible for urban water supply, including piped water supply and water saving. As the source of supply for most cities in Shanxi Province is groundwater, the Department of Urban Construction manages groundwater primarily through its control over city water supply companies (including the latter's planning as well as zoning of water source areas). The department also undertakes awareness activities and tries to encourage individual water users to save water. Water supply companies, however, have to apply for a license to draw water from the Department of Water Resources. The Department of Land and Resources is partly involved in groundwater investigation and monitoring. Lastly, the Environmental Protection Department is mainly in charge of the protection of water source areas.

It is important to achieve coordination among the various stakeholder organizations, between organizations at the different levels, and between plans and activities of different sectors (i.e., province, municipality, and county). The preparation of integrated plans is a powerful instrument to achieve such coordination, especially when combined with follow-up action to introduce both demand and supply management (groundwater recharge and retention) measures. The plan and activities are preferably conducted at a scale and density that activities show real impact and create a system change in an area.

It is also important to engage and involve the main water users and consumers in the coordination process so that they will understand and implement their own measures for better groundwater management. Water saving in the end is in everybody's interest—not just that of the government.

EXISTING REGULATORY FRAMEWORK

The legal framework is set by the regulations mentioned earlier, including the (i) Water Law of the PRC, (ii) Water Pollution Prevention and Control Law, (iii) Environmental Protection Law, (iv) Shanxi Province Regulation on the Administration of Water Resources, (v) Shanxi Province Regulation on the Protection of the Water Resources of Spring Areas, and (vi) Shanxi Province Interim Administrative Measures for Groundwater Management. Table A1.1 provides an overview of the main regulatory instruments.

[1] J. Zheming, D. Gulin, and L. Guichun. 1990. *Introduction to Water Resources Management.* Taiyuan City, People's Republic of China: Shanxi People's Press.

Table A1.1: National and Provincial Regulations Forming the Basis for Sustainable Groundwater Management in Shanxi Province

Water Law of the PRC	This law was adopted at the 24th Meeting of the Standing Committee of the 6th National People's Congress on 21 January 1988 and came into force on 1 July 1988. In 2001, the Water Law was amended. This amended law was adopted and promulgated at the 29th Meeting of the Standing Committee of the 9th National People's Congress on 29 August 2002 and came into force on 1 October 2002. The law contains eight chapters. The promulgation and enforcement of the amended Water Law marks the PRC's transition from traditional water conservation to modern and sustainable water management. The emphasis in the amended law is the building of a water-saving and pollution-curbing society.
Regulation on the Administration of the License for Water Withdrawal and the Levy of Water Resource Fees	This regulation was promulgated by Order No. 460 of the State Council of the PRC. The regulation was adopted at the 123rd executive meeting of the State Council on 24 January 2006 and came into force on 15 April 2006.
Shanxi Provincial Regulation on the Administration of Water Resources	This provincial regulation was approved at the 17th Meeting of the Standing Committee of the 5th Shanxi Province People's Congress on 29 October 1982. The regulation was amended by the Decision on Amending the 1st Clause of the 19th Article of Shanxi Province Regulation on Water Resources, which was adopted at the 11th meeting of the Standing Committee of the 8th Shanxi Province People's Congress on 29 September 1994. The regulation was revised at the 34th meeting of the Standing Committee of the 8th Shanxi Province People's Congress on 20 December 2007.
Shanxi Provincial Regulation on the Protection of the Water Resources in Spring Areas	This provincial regulation was adopted at the 30th meeting of the Standing Committee of the 8th Shanxi Province People's Congress on 28 September 1997 and came into force on 1 January 1998. The regulation was amended by the Decision on Amending Several Local Regulations during the 20th meeting of the Standing Committee of the 11th Shanxi Province People's Congress on 26 November 2010.
Measures for the Administration of Water Withdrawal Licenses	These measures are part of Order No. 34 of the Ministry of Water Resources, adopted at a ministerial conference of the Ministry of Water Resources on 13 March 2008.
Measures for the Administration of the Water Resources Assessment of Construction Projects	These measures came into force by Order No. 15 of the Ministry of Water Resources and the State Planning Commission and became effective on 1 May 2001.

PRC = People's Republic of China.

Source: Shanxi Provincial Government.

IMPLEMENTATION MEASURES

A number of important implementation measures have been developed for groundwater management in Shanxi Province. Five of the main regulatory measures in place are (i) regulating the total amount of groundwater abstracted from source areas, (ii) compulsory water resources assessments for investment projects, (iii) licensing of well drillers, (iv) administration of water withdrawals, and (v) payment for the use of groundwater resources.

Regulating the total amount of groundwater abstracted. The first of the three "red lines" drawn by the Ministry of Water Resources, mentioned earlier, on the strict control of water is the control of the total amount of water resources abstracted. In compliance with the results of the second survey and assessment of water resources in the different cities of Shanxi Province, efforts should be made to quantify the amount of groundwater permitted to be exploited for each city.

At present, this work is in progress. To better undertake this task, the economic interests of the different cities should be taken into consideration and well coordinated. Up to now, the quota (as per 90% of the guaranteed groundwater yield rate) on the exploitation of karst water at all large karst springs has been specified and come into force. For example, for Niangziguan Spring, which services Yangquan and Jinzhong cities, the control index on the exploitation of karst water for Jinzhong City is 16 meters per year, with the remainder reserved for Yangquan City. As for Guozhuang Spring, which covers Lüliang, Jinzhong, and Linfen, the quota for the exploitation of karst water for Lüliang and Jinzhong cities is 37.4 million cubic meters and 18 million cubic meters per year, respectively. The balance is for Linfen City (the spring headstream).[2]

[2] P. Junfeng, Z. Jingting, and L. Yongping. 2008. *Protection of Karstic Spring in Shanxi Province.* Beijing: China Water and Hydropower Press.

It may also become necessary to impose total bans on groundwater abstraction for certain areas and even close wells, as happened in Taiyuan City when groundwater was substituted for surface water.

Water resources assessment of construction projects. Following Order No. 15 of the Ministry of Water Resources and the State Planning Commission on Measures for the Administration of the Water Resources Assessment of Construction Projects in 2002, Shanxi Province has made water resources assessment of construction projects mandatory. It promulgated the Shanxi Province Measures for the Administration of Construction Projects of Water Resources. Under this regulation, a thorough technical examination of the water resources aspects of all newly built and expanded large-scale construction projects has to be conducted in order to ensure safe and wise water use in the new developments.

The compulsory water resources assessment for main investments has a number of benefits. First, enterprises are compelled to try new ways to save water. Following the assessment, a construction company has to adopt advanced techniques and technologies to improve its water use efficiency and save water so as to make the most of the limited water resources. To save water, all the newly built power plants, for instance, adopted air cooling turbo-generators, with which their water use has been greatly reduced.

Second, industries and cities are also encouraged to look at additional new sources of water. In areas where water supply is not sufficient, unconventional water resources such as recycled wastewater or processed mining pit wastewater are used. In this way, water of different qualities is used for different purposes; consequently, the exploitation of groundwater can be controlled and efficiency in water use improved.

Third, well-evaluated water use for new investment projects is ensured. With the careful examination of all water-related aspects of an investment project—such as the condition of its water resources, the water use during construction, and the discharge and the impacts on its surroundings—the discharge of wastewater will be minimized, and groundwater and its environment will be protected.

Licensing of well development. It is critical to manage the well development industry to control groundwater exploitation. The water resources departments at all levels should work on the orderly exploitation of groundwater and the efficient use of the limited groundwater resources to manage the exploitation, use, and protection of regional groundwater resources. The following highlights a number of activities in regulating well development that have been carried out by municipalities in Shanxi Province.

Local administrative measures have been introduced to serve as guidelines for well development. For instance, Lüliang and Jinzhong cities promulgated the Lüliang District Measures for the Administration of Groundwater Prospection and Well-Drilling and Jinzhong District Interim Measures for the Administration of Well-Drilling in 1999 and 2000, respectively. Yanhu District of Yuncheng City promulgated the Yuncheng City Yanhu District Measures for the Administration of Well-digging in 2000.

Qualifications of well-digging teams have been strictly examined. All well-digging teams must acquire a well-digging permit before they can engage in well-digging activities. To acquire the permit, they will have to go through procedures such as training, tests, evaluation, and approval. Training sessions have been conducted to improve the awareness of well-development team leaders of the rules and regulations on well-digging and the necessity to abide by them. Meanwhile, technical training sessions were held for well-digging technicians to improve their well-drilling skills. The ultimate goal is to ensure an orderly exploitation of groundwater resources.

Application procedures for gaining approval for well-digging have been standardized and announced to the public. The Regulation on Approval Procedures for Water Withdrawal Applications serves as the hallmark. No individual or company is permitted to dig a well before acquiring a water withdrawal permit. Meanwhile, limits are imposed on an authority's power to approve in accordance with the depth of a well under application.

Administration of water withdrawals. The administration of water withdrawal is a major element in allocating rights to the use of water resources. This was initiated in 1993, with the measures for the Issuing of the License for Water Withdrawal put in place on 1 August 1993 with Order No. 119 of the State Council, which came into force on 1 September 1993.

When granting permission to applicants to use groundwater, the government should formulate an integrated plan to efficiently assign water to stakeholders. While assuring that domestic water supply for urban and rural citizens is the first priority, it should also take into account agricultural and industrial water use as well as water use for other purposes. In critical areas, the withdrawal of water may be very strictly regulated or even banned altogether.

Under decision by the provincial government, 22 areas in Shanxi Province have been identified as areas with either excessive or severely excessive groundwater exploitation, and 31 areas have been earmarked as spring protection areas. Strict measures are adopted to control the exploitation of water in these areas. The amount of water that a permit holder is allowed to withdraw has been restricted so as to redress the excessive exploitation of groundwater.

Payment for use of water resources. The introduction of payment for the use of water resources has eased the shortage of water resources in Shanxi Province. Following the decree issued by the provincial government, the levying of water resources fees in the province started in 1982. The rates for the different groups of water users are decided together by the provincial finance department, provincial pricing bureau, and Farmers' Burden Supervision and Administration Office. Shanxi Province already has a history of 30 years of levying water resources fees and witnessed three adjustments to the tariff standard: increasing the charge from (i) CNY0.1 ($0.015) per cubic meter ($m^3$), the initial rate, to (ii) CNY2.0 ($0.30) per m^3, the present rate; whereas, the typical charge for areas with excessive groundwater exploitation is (iii) CNY3.0 ($0.45) per m^3. Fees also vary among different uses. Moreover, where quotas are set, markups are in place when user quotas are exceeded. Table A1.2 provides a detailed overview of the tariffs for the different categories of payers as of 2013.

Levying of water resources fees has contributed to the control of groundwater exploitation. It has promoted water saving and encouraged the measuring and monitoring of water resources. With Shanxi Province taking the lead, other provinces, cities, and regions in the PRC have promulgated their own provincial regulations on the administration of levying water resources fees and started to levy water resources fees as well, though with different tariffs. Up to now, about 25 provinces (autonomous regions or municipalities) in the PRC have promulgated provincial-level regulations on the payment of water resources fees.

The charging regulations and the water quota system are also at the heart of the successful groundwater management system of Qinxu County, where farmers apply swipe cards to operate wells, with water usage recorded against the quota for each user. The Qinxu system, described in section 4, has contributed to a significant reduction in groundwater use and changed a situation of overuse to one of sustainable consumption.

Table A1.2: Shanxi Province Standard for the Levy of Water Resources Fees, 2013

Water Source	Water Type	Purpose of Water Use	Rate (CNY per m^3)									
			Non-excessive Exploitation Area					Excessive Exploitation Areas				
				Water use exceeding quota					Water use exceeding quota			
			Water use within quota	Below 20%	20% or above but below 40%	40% or above but below 60%	60% or above	Water use within quota	Below 20%	20% or above but below 40%	40% or above but below 60%	60% or above
Groundwater	Self-provided water source	Water for special uses	10.00	20.00	30.00	40.00	50.00	15.00	30.00	45.00	60.00	75.00
		Water for common uses	2.00	4.00	6.00	8.00	10.00	3.00	6.00	9.00	12.00	15.00
	Urban public water supply and water conservation water supply	Water for special uses	4.00	8.00	12.00	16.00	20.00	6.00	12.00	18.00	24.00	30.00
		Water use for industries, businesses, commercial service industries	1.00	2.00	3.00	4.00	5.00	1.50	3.00	4.50	6.00	7.50
		Water use for administrative and public departments	0.50	1.00	1.50	2.00	2.50	0.75	1.50	2.25	3.00	3.75
	Mining pit wastewater	Mining (the amount of discharged water)	1.20 (3.00, temporary rate per No. 200 Shanxi Pricing Decree in 2009)									
Surface Water	Self-provided water source		1.00	2.00	3.00	4.00	5.00	–				
	Urban public water supply and water conservation water supply	Water for special uses	2.00	4.00	6.00	8.00	10.00	–				
		Water use for industries, businesses, and commercial service industries	0.50	1.00	1.50	2.00	2.50	–				
		Water use for administrative organs	0.25	0.50	0.75	1.00	1.25	–				
	Cross-flow cooling water use in coal-fired power generation (CNY per kWh)		0.002									
	Water use in hydropower generation (CNY per kWh)		0.005									

CNY = yuan, kWh = kilowatt-hour, m^3 = cubic meter.

Source: Shanxi Provincial Government.

APPENDIX 2

Strengthening the Management of Groundwater Resources in Shanxi Province

The sustainable utilization of groundwater resources is of strategic importance to social and economic development in Shanxi Province. To ensure the sustainable utilization of water resources is fundamental to the long-term development of agriculture, industry, national economy, and society as a whole. To strengthen the management of groundwater, the following are important actions to consider.

First, the availability of groundwater needs to be taken into account in spatial planning and in restructuring economic activities. The availability of groundwater resources should be accommodated in social and economic development when deciding on where to locate new urban areas or industrial development. An overall plan should be made for allocating water to various sectors of the economy, including ecological functions. Ensuring a safe environment should be the prerequisite for the exploitation of groundwater resources. The social and economic development of a region should conform to the long-term availability of its water resources. At regions or valleys where water resources are scarce and water supply falls far behind demand, as in the central basins in Shanxi Province, the input and output efficiency of the various activities should be the benchmark to decide whether or how to exploit and utilize water resources. Any construction projects that demand a high consumption of energy but yield a low output and produce heavy pollution should be prohibited. In time, adjustment of economic layout and structure should be developed in accordance with the availability of water resources. In Shanxi Province, future urban and industrial development should consider the mountain areas where water resources are still relatively abundant.

Second, a unified and improved water resources management administrative system should be established. The unified management of water resources should be developed further. Currently, the Ministry of Water Resources is present at various levels, setting the framework for water resources development. More aligned planning, scheduling, allocation, and management are critical to the management of water resources. At the same time, the powers to manage water resources in a centralized manner should be fully implemented. A situation where different industries, departments, and regions have their own different water resources management priorities should be avoided. A consolidated, unified, interindustrial, transregional, and interdepartmental administrative system, which covers both surface water and groundwater, should be established instead under state ownership of water resources. In strengthening unified management, the relations and responsibilities between different administrative levels and also with watershed management, wastewater management, irrigation system management, and others should be clarified. At the same time, the incentive and penalty systems should be strengthened. Three compensation mechanisms should be further strengthened: (i) whoever consumes water pays for it, (ii) whoever pollutes water pays for it, and (iii) whoever causes damage to the eco-environment pays for it. Together with the three compensation mechanisms, three restoration mechanisms should also be put in place: (i) ensuring balance between water supply and demand, (ii) ensuring that water quality reaches the required standard, and (iii) ensuring that the water environment and ecology are safeguarded.

Third, water resources-related policies and regulations should be improved. Sustainable utilization of water resources should be incorporated into national and local legislation. Regulations and code of ethics on the sustainable utilization of water resources should be formulated. In particular, efforts should be made in tightening rules and regulations on water rights allocation and water resources allocation and in ameliorating the legal system for water resources. This should be combined with strengthening water law enforcement and guaranteeing that water administration is open, fair, and standardized.

Improving the total quantity control (quota) system of water consumption. Shanxi Province has already adopted the total quantity control system of water consumed for managing its water resources. This needs to be consolidated. The system should also be improved by establishing not only the amount of groundwater but also surface water, including the water diverted from the Yellow River that is available for each region. Subsequently, binding annual and medium-term quotas for surface water, groundwater, and diverted river inflow can be decided for different areas (municipalities and counties). This should be complemented by mechanisms that encourage water-saving practices and the development of unconventional water resources, such as reclaimed water, mine water, and recharge from floods and high water flows.

Accelerating the building of a water-saving society in Shanxi Province. It is a basic national policy of the People's Republic of China (PRC) to save water and, hence, secure the sustainable utilization of water in the medium term. This is captured under the goal of "building a water-saving society" by 2020. There are a number of activities that could change Shanxi Province into a role model for the water-stressed areas in the PRC:

First of all, efforts should be made in starting intense awareness activities to engage all water users and key stakeholders and to emphasize the importance of water resources and their relevance to social and economic development. Everyone should be concerned about water and protect it voluntarily.

A second activity is improving the water-use efficiency of products and processes. Water-saving norms should be set for various products (such as sanitary wares) and production processes in different large industries. Water-use norms for various products can be lowered while their corresponding production techniques are improved. Consumers will come to know the importance of water saving through these legal norms and may save water voluntarily as they become aware of the economic implications otherwise.

Third, irrigation for agriculture accounts for almost 50% of the total water use in Shanxi Province. The largest potential for water saving is in this area. To save water in the agriculture sector, an integrated groundwater management system needs to first be built, as has been piloted in Qinxu County. The amount of water used and the quota share consumed can be recorded with the use of swipe cards, and charges for water use are also accurately calculated. The integrated groundwater management system of Qinxu County is successful and, by now, a time-tested case. This system can and should be promoted and replicated in other counties or municipalities of Shanxi Province. Before adopting the system, the local governments, farmers, and other water users of these counties should, however, gain a thorough understanding of the system through discussions or brainstorming.

Fourth, efficient water-saving irrigation techniques, as implemented in the Asian Development Bank's grant project, should be promoted throughout the whole province. This use of precision irrigation should actively engage local enterprises and farmers' cooperatives. It is important that the introduction and scaling up of these new techniques are done in a proper way with ample time for training of farmers. Guidelines on the standards of such installations should be followed, and adequate training given to the local experts installing the systems. Substandard introduction of water-efficiency measures should be avoided at any cost, because this will not serve the purpose and will instead create disappointment.

Increasing the amount of water available by better recharge and retention and developing nonconventional water resources. The total amount of water resources is now estimated at 12.3 billion cubic meters per year for Shanxi Province, of which surface water and groundwater each take half. In the past, groundwater has been excessively exploited in the province and, as a result, the groundwater table in the province's important central plains has dropped. To relieve the pressure on groundwater, there is a need to accelerate the development of storage reservoirs and river diversions. Furthermore, surface water, particularly floods and peak flow discharges, has not been fully controlled and utilized, and there is scope for more systematic reuse of water. Given this situation, the following are proposed:

First, in the mountain areas, groundwater should be better recharged and retained using techniques that so far are not widely used in the province. The use of series of check dams in dry riverbeds will slow down the speed of floods and cause more water to infiltrate and replenish groundwater. The use of subsurface dams will retain subsurface flows in riverbeds in mountain catchments. Investment in water recharge and retention in the mountain areas needs to intensify, and more technical options should be used. If this is done in an intensive manner, water will be better buffered in areas with beneficial effects on groundwater recharge, soil moisture, and microclimates. More investment is also required, under adequate engineering, in flood storage reservoirs of different sizes.

Second, in the plain areas, more floodwater should be allowed to infiltrate and recharge the aquifers. This can be done by routing peak flows in the rainy season to irrigated areas with relatively coarse soils, allowing water to infiltrate from the fields. Especially where corn, sorghum, or millets are grown, this will not affect production. Controlled floodwater spreading should be introduced systematically throughout the lowlands of Shanxi Province.

Third, efforts should vigorously promote the reuse of water, in particular the following:

(i) *Reuse of urban wastewater.* For this, a plan needs to be compiled on urban wastewater reclamation and reuse, followed by investment in additional wastewater recycling facilities.

(ii) *Promotion of gray water techniques.* It is important to encourage enterprises to use wastewater with economic policy incentives. There should be pilots of gray water reclamation and reuse, first in the residential quarters where buildings conglomerate, and then promoted and replicated in other areas.

(iii) *Acceleration of the pace of water-saving technological development.* Advanced technologies should be adopted on water recycling and reuse, on cooling water, and on water treatment. Finally, the reuse rate of water used for industrial activities and of mine drainage should be increased.

Strengthening the protection of groundwater resources. Essential measures to achieve the sustainable development and utilization of water resources include strengthening the protection of groundwater resources, turning wastewater into usable resources, and preventing and treating water pollution sources:

First, major pollution control endeavors should be combined with comprehensive urban pollution treatment. In the urban and mining areas where wastewater discharges are intensive, wastewater treatment plants should be built systematically to “digest” the discharged wastewater locally. It should be strongly prohibited to discharge wastewater directly into the underground through sewage pits or abandoned wells and contaminate groundwater. Similarly, discharging wastewater and polluted water directly into riverbeds should be forbidden.

Second, decentralized and centralized pollution treatment methods should be combined, and large, medium-sized, and small treatment plants simultaneously activated. Control of industrial and mining pollution sources should be tightened and the amount of wastewater they discharge strictly limited. Industries and mines are strongly advised to constantly update their technologies and promote clean production methods. They should also build their own wastewater treatment facilities and increase the amount of reused wastewater.

Finally, there is a need to tighten the control of the mining sector to protect groundwater resources. Coal mining has increased manifold from 2000 to 2012, and production in Shanxi Province has now reached 1 billion tons of coal annually. In recent years, many smaller mines have closed down or been merged with larger mines in the province, so the coal mining sector now consists of a small number of large companies. This makes the coal mining sector easier to regulate. Coal mining has an enormous impact on the long-term sustainable availability of groundwater, and its impact needs to be regulated with utmost urgency.

Three safeguards are required:

(i) All new coal mines should obtain clearance from the water bureau with respect to their mining operations to ensure that aquifer systems are not harmed because of mining operations.

(ii) All existing and new coal mines should have a compulsory environmental management plan that describes the remedial actions and investments in (a) preventing pollution and reducing wastewater quality, and (b) avoiding leakage from coal waste through safe linings and other measures.

(iii) Damage from older coal mines, including closed mines and empty seams, should be controlled: (a) the pollution from old mine tailings should be minimized—in some cases, the mining waste can be reused or, through a series of measures, precious elements can be recouped from the mine seams; (b) the risk of acid mine water should be mapped and, where it causes major threats to population and ecosystems, corrective measures should be taken; and (c) the reuse of coal seams should be considered—they may be refilled with crushed stones and, in critical areas, artificial aquifers may thus be created.

Continuing innovation and making Shanxi Province a leading center in water efficiency. In certain areas, there has been considerable innovation in new water-using techniques. The ADB grant project introduced efficiently controlled irrigation, which has provided the basis for vibrant local water-efficient economies.

More innovation is required as this will strengthen the economy of Shanxi Province and will lead to sustainable development. It is recommended that the provincial government, with local research organizations, develop a center of excellence for applied water-efficient methods. This should cover the entire spectrum of opportunities to reduce water consumption but, at the same time, maintain or even improve productivity.

There are many areas for innovation. One that is particularly promising and important for Shanxi Province by way of example is the use of soil improvement methods, in particular the application of zeolite and biofertilizer. Zeolite is a mineral that occurs abundantly in the province but is not systematically used in agriculture. Zeolite can, however, at low cost, ensure the more efficient uptake of fertilizer (reducing the risk of nitrogen pollution) and significantly improve the moisture-holding capacity of the soil, thereby reducing the need for irrigation.

A second promising introduction is the use of biofertilizer, which also brings with it the long-term improvement of soil structure and moisture-holding capacity. Biofertilizer uses digesting processes with catalyst enzymes, excess manure, rock dust minerals, and sugar (or organic waste products). In comparison with conventional chemical fertilizer, it improves the quality of soil by replenishing organic material and minerals. As such, it can remediate soil quality and improve the water-holding capacity.

A third area with much scope for innovation is water-treatment methods, especially from mining. This can either be active water treatment (including the use of bioreactors), or passive water treatment with constructed wetlands, or even the controlled storage and release of acid mine wastes.

APPENDIX 3

Selected Water-Saving Technologies and Practices Useful in Groundwater Irrigation

There are several hydraulic engineering solutions that can contribute to higher water productivity, such as sprinkler systems, micro-irrigation, and conveyance pipes, which can be particularly useful in groundwater irrigation, sometimes in combination with plastic mulch.[1] Many of these solutions reduce total water consumption. However, the net benefits of the system largely depend on the local conditions. Water savings also reduce groundwater recharge. Furthermore, reduced water usage can decrease the incidence of pests and diseases, and hence increase irrigation productivity. Finally, the presented water-saving systems can likewise reduce the need for fertilizers, pesticides, and labor.

SPRINKLER IRRIGATION

Sprinkler irrigation delivers a pressurized irrigation supply.[2] It sprinkle water in the air as if irrigating through rainfall. Among its outstanding features are its strong adaptability to topography, ability for automation, high irrigation equitability, and possibility to regulate air humidity and temperature. Sprinkler systems are especially suitable for permeable soils and sloping land.

Compared with traditional field irrigation, sprinkler irrigation can save 30%–50% of water and increase production by 10%–30%. Sprinkler irrigation systems facilitate such increases in crop yields while reducing the incidence of pests and disease. Therefore, sprinkler irrigation has become the main practice for higher water productivity. Though the technique is already mature, more improvement can be expected in the development of low-cost sprinkler irrigation equipment as well as the use of microsprinklers. In Shanxi Province, sprinkler irrigation systems should be given priority for high economic value crops.

MICRO-IRRIGATION

Micro-irrigation includes several techniques: (i) drip irrigation technique, (ii) microspray irrigation, and (iii) bubbler irrigation. Compared with traditional field irrigation techniques, micro-irrigation may save up to 60% of water. Of all the irrigation techniques, water utilization is highest in the different micro-irrigation systems:

- **Drip irrigation.** Drip irrigation delivers water directly to the roots of crops through a set of plastic tubes called drippers.[3] These drippers emit water on the surfaces close to the roots, thus infiltrating the soil and soaking the crops' most developed root area. In some countries, such as Tunisia, the drip is located inside the soil, directly feeding the roots. The main advantages of drip irrigation are its high efficiency, possibility of automatic operation, and ability to manage optimal soil humidity.

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1 For sprinkler and micro-irrigation system designs, visit the web page of the Natural Resources Conservation Service of the United States Department of Agriculture at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_017641.pdf

2 For more detailed description of sprinkler irrigation system design, visit the web page of the Food and Agriculture Organization of the United Nations at http://www.fao.org/docrep/s8684e/s8684e06.htm or of Harmony Farm at http://www.harmonyfarm.com/sprinkler-irrigation-design/

3 For drip irrigation design guidelines, visit the web page of Irrigation Tutorials at http://www.irrigationtutorials.com/drip-irrigation-design-guidelines-basics-of-measurements-parts-and-more/

Drip irrigation can deliver water accurately according to the demand of farm crop and, therefore, reduces losses of water to a minimum. Typically, compared with traditional field ground irrigation, drip irrigation can save 35%-55% of water (for some crops, it can reach to 85%). Compared with sprinkler irrigation, drip irrigation can save 15%–25% of water. Drip irrigation can be combined with fertigation—dissolving fertilizer and other agrochemicals with the irrigation water ensuring maximum efficiency in supplying nutrients and reducing pollution. Importantly, this saves costs as well as labor inputs and time. As drip irrigation provides "just enough" moisture for crops, it is difficult for weeds to grow, which reduces the labor for weeding. The disadvantages are the costs and the problem of the drippers clogging easily. In Shanxi Province, however, drip irrigation should be vigorously promoted and applied in the vegetable and fruit zones.

- **Microspray or microsprinkler irrigation.** In microspray irrigation, water is sprayed on the soil surface with small suspended sprinklers (microsprinklers). The working pressure of the nozzle in this system is almost the same as the drippers. Because the wet area of the microsprinkler is bigger than in dripper irrigation, the spray orifice and, hence, flow velocity can be larger. Thus, compared to drip irrigation, the possibility of blockage is reduced. Microsprinklers have great potential for high economic value crops, particularly where there is lack of water resources.

- **Bubbler irrigation.** Bubbler irrigation or "spring" irrigation is an advanced water-saving irrigation technology.[4] It uses emitters with a much larger diameter than the drippers in drip irrigation systems. The water coming out of the bubblers is collected in small basins around a fruit tree from which the soil is dampened. The larger opening of the emitters reduces the risk of clogging. This makes bubbler irrigation suitable for lower-quality water. It is relatively low cost and is particularly suitable for fruit-growing areas.

In general, micro-irrigation system costs are high. It is recommended that they be equipped with a filter to assure water quality and that fertilizer mixing units are added. The high cost of the micro-irrigation systems limits, at present, their use to high-value horticulture. There are several areas for research and development in micro-irrigation: developing technology for sloping areas, the standardization of production, and the reduction of cost.

Low-pressure conveyance pipes. A breakthrough in groundwater irrigation are low-pressure conveyance pipes, made of either polyvinyl chloride (PVC) or galvanized iron. They have improved the water-use efficiency of irrigation systems and have also made it possible to reach land to which it was otherwise difficult to bring water. Low-pressure pipes have had wide application in the northern regions of the People's Republic of China. Though the technology is more mature, there are some issues yet to be studied, such as the pipe material, the connecting parts and ancillary equipment, and the industrialization of the product.

Plastic mulch. Drip irrigation, as described earlier, can be combined with the use of plastic mulch, i.e., the drip lines are covered by plastic film. Plastic mulch can also be used without drip systems. In general, the use of plastic mulch has important advantages: it reduces soil evaporation, represses weeds, and raises and controls soil temperature making it possible to cultivate earlier and later. The warmer temperature and moist conditions also stimulate the natural nitrogen-fixation in the soil and reduce the need for fertilizer. An area for further development is to improve the biodegradability of the plastic mulch and even to add plant nutrients. Compared with surface irrigation, yields can increase by more than 20% and water savings can be up to 40%–50%. The utilization rate of chemical fertilizer can be improved by 20%, whereas the land utilization rate can increase by 8%. The use of low-cost plastic mulch has completely changed the traditional way of agricultural water use.

Polymers. Polymers are an industrial by-product that absorb moisture and, thus, add to the water-holding capacity of the soils. This secures water availability in the root zone and makes the farming system less vulnerable to droughts. In greenhouses, moreover, polymers help the top soil from getting moist at night, thereby reducing the incidence of certain pests. An important innovation is the "Waterpad," where polymers are glued in between jute and brown paper. This keeps the polymers in place and helps extend the polymers' effective life to 5 years.

4 For bubbler irrigation design, visit the University of Arizona web page at http://ag.arizona.edu/research/dirt/Bubbler%20irrigation%20design.pdf

Agricultural Production and Groundwater Conservation

Examples of Good Practices in Shanxi Province, People's Republic of China

Climate change and declining water resources threaten food production systems worldwide, increasing the need for efficient agricultural processes. The Shanxi Province of the People's Republic of China has been experiencing declining groundwater tables since 1956. This publication provides examples of how the Asian Development Bank's development support met the rising challenges in water security, food production, and climate change faced by communities in the Shanxi Province. It describes initiatives in four counties in the Shanxi Province selected as pilot areas, where traditional farmers learned modern methods of groundwater use and management. As a result, options for more sustainable use of groundwater were introduced, while farm labor was reduced, crop yields increased, and water was used more efficiently.

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