Climate Change Adaptation through Groundwater Management of Shanxi Province, People’s Republic of China

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Management Office of ADB Loan Project ‘Shanxi Integrated Agricultural Development Project’
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Climate Change Adaptation Through Groundwater Management of Shanxi Province, People’s Republic of China

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Shanxi Province, as well as other parts of Northern People’s Republic of China (PRC), is faced with a huge dual challenge: groundwater is overused in the economically most vital parts of the Province and, on top of that, the impact of climate change is making itself increasingly felt. There is less rainfall, more variation in annual precipitation and temperatures have increased steadily, particularly in the last decade. Groundwater should serve as the buffer that would absorb these shocks, but is under stress itself. Apart from being overused it also faces the risk of pollution. Apart from being overused it also faces the risk of pollution. There is a need for a drastic change in the way groundwater is used and managed. The management of groundwater should be placed within the current policy of developing a Green PRC and developing a circular economy. Instead of the previous linear production system of ‘turning resources into products and discharging all by-products,’ we need to move to close production chains and come to the maximum re-use of rest-products, including process water. We also need to balance water consumption with its availability and where possible make a maximum effort to augment the supplies of water.

This report is prepared as a contribution to the management of groundwater in Shanxi. The report draws from experience of 0188-PRC Project Climate Change Adaptation through Groundwater Management, which has been supported by the Government of Shanxi and the Asian Development Bank (ADB). Management of groundwater is a high priority for long-term social and economic development in times of uncertainty, caused by climate change.

In Shanxi, there are over 100,000 groundwater abstraction points, with 96% of these operational. In 1984, the amount of groundwater resources extracted in the province was 2.483 billion cubic meters ($m^3$). This figure went up to 3.873 billion $m^3$ in 2000. The average annual rate of growth in groundwater abstraction was 3.5%. In recent years several measures have been taken to reverse these trends. At the same time, the overexploited area in the main plain areas is still estimated to be up to 25.4% of that area and in several basins the trend of groundwater decline continues. Moreover, shallow groundwater in for instance Taiyuan, Datong, Changzhi, Yangquan, Yuncheng, and other regions suffers from different degrees of pollution, reducing its availability for different uses.

Groundwater is not as visible as surface water is but plays a larger role than often realized in irrigation and urban and rural water supplies and in sustaining ecological service, including the base flows of rivers. Globally groundwater accounts for 43% of the water used for irrigation (Siebert et al 2010). 40% of the total industrial water withdrawals and 50% of the total municipal water withdrawal globally is estimated to come from groundwater (Zekster and Everett, 2004). Base flows of rivers and important wetlands are dependent on sub surface flows.
The intense use of groundwater is becoming a source of concern. The largest groundwater consumers globally, India, PRC, and the United States of America (USA) in that order, are faced with over extraction. High concentrations of nitrate—well above the 45 to 50 milligrams per liter (mg/L) limit for drinking water—can be found in many agricultural areas, including in Europe, and is ruling out the use of these sources for drinking water, a specter that may hold true for PRC as well.

There are a number of developments and trends which are likely to further increase groundwater use in PRC and elsewhere. Globally food production is expected to increase by 60% in 2050 (base year 2010), whereas the demand for cotton for instance is to set to increase with 81% in the same period. The major increase in food production (89%) has to come from intensification on existing land, including more double cropping (9%) (FAO 2010). Intensification and double cropping is often sustained by irrigation. Demand for horticultural crops will grow faster—which will also increase the demand for groundwater.

In 2050, urban population is expected to have reached 6.3 billion people. In a business of usual scenario urban lifestyles and contamination loads will exert huge pressure on the aquifer systems near metropolitan areas.

The ‘eye’ is very much on Shanxi and the North China Plains as the declining groundwater threaten to undermine one of the world’s most important grain baskets, potentially setting off world food prices (Evans et al., 2002; Qiu, 2010). The northern plains of PRC produce half of the country’s wheat and one-third of its corn. They do so by using groundwater at a rate that largely exceeds the way at which it is replenished. One estimate is that not less than 130 million people in PRC depend for their staple food on the unsustainable use of groundwater, as the contribution of non-renewable groundwater abstraction for irrigation accounts for 20 \( \text{km}^3 \text{yr}^{-1} \) (Wada et al., 2012). To this, the increasing demands from industries and domestic use should be added. So reversing this threat is not only of local but of global significance.

As mentioned the aim of this report is to make a contribution to improved groundwater management in Shanxi. The report first describes the current water resources situation in Shanxi and the challenges that are faced, including the nature of climate change (Chapter 1). The report subsequently describes the management of groundwater, based on current experiences in Shanxi and other parts of the world (Chapter 2). Several scalable pilots were undertaken by the 0188-PRC Project to promote precision irrigation and better groundwater use, which are documented in Chapter 3. Both Chapters 2 and 3 suggest that much is possible still to improve groundwater management and address climate change – in stronger regulation, in better engagement of stakeholders and in applying new technologies, some tested in other parts of the world and some innovative in nature. Chapter 4 suggests future directions and makes a series of policy recommendations.
Chapter 1 Introduction to Shanxi Province

Shanxi Province has a long history of agricultural and industrial development, closely related to the intense use of its scarce water resources. In this chapter the main characteristics of the Province are described. The first section introduces the geography and economic activities in the Province (section 1.1). Subsequently the climate of Shanxi is discussed as well as the climate changes (section 1.2). Section 1.3 is a bird’s eye of the groundwater resources and the degree of utilization. In the last section of this chapter, the main challenges in groundwater management are summarized, setting the stage for the subsequent chapters of this book that discuss the steps to be taken towards balanced groundwater management.

1.1 Geography, Economy and Social Development

1.1.1 Geographic location

Shanxi Province is located in the western half of North China and on the eastern side of the Loess Plateau. Located east of Shanxi are Hebei and Henan Provinces, with Taihang Mountain forming the borderline. To its west and south, are Shaanxi and Henan Provinces, separated through the Yellow River. In the North of Shanxi lies Inner Mongolia, with the Great Wall as the borderline. Surrounded almost on all sides by either rivers or mountains, Shanxi is a plateau area, situated in between the middle reach of the Yellow River and Taihang Mountain. Shanxi Province stretches over 680 kilometers (km) from north to south and over 380 km from west to east. It covers an area of 156,271 square kilometers (km²), which equals 1.6% of PRC’s total territory. Within Shanxi 59,133 km² forms part of the Haihe river basin, whereas 97,138 km² drains to the Yellow River. (See Figure 1.1)

1.1.2 Topography

Mountains and valleys

Topographically, Shanxi Province can be divided into three parts, i.e., the mountain ridges in the east, the plateau area in the west, and the fertile plain area in the center.

The distinguishing feature of the mountain area in the east of the Province is the Taihang Mountain, which separates Shanxi from Hebei and Henan provinces. Apart from the Taihang Mountain, the eastern mountain range consists of Hengshan Mountain, Wutai Mountain, Xizhou Mountain, Taiyuan Mountain, Zhongtiao Mountain, and the Southeast Jin (short for Shanxi) Plateau as well as the intermountain basins in Guanglin, Linqui, Yangquan, Shouyang, Changzhi, Jincheng, Yangcheng and Yuanqu. The Yedou Peak of Wutan Mountain is 3,058 meters above sea level and is one of the commanding peaks in North China. The lowest point is Yuanqu County Yellow River valley in the southwest of the area, at 245 meters above sea level.

The highland plateau, in the west is dominated by Lvliang Mountain. 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. Based on its topographic features in the
north and south, the Loess Plateau can be further categorized into three landscapes: Loess Hills, Loess Gullies, and Broken Loess Gullies.

The basin area in the middle spreads all over the Province from northeast to southwest Shanxi and comprises a series of graben-type technical fault subsidence basins: Datong, Xizhou, Taiyuan, Linfen 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.

1.1.3 Rivers

Rivers in Shanxi Province belong to either one of two basins: the Yellow River Basin or the Haihe River Basin. There are all together 1,000 rivers, big or small, in Shanxi. With the exception of a few rivers in the Yuncheng Basin, all streams are shared with other Provinces.

The number of the rivers with a watershed area of above 1,000 km$^2$ is 44; and that of the rivers with a watershed area of above 4,000 km$^2$ and longer than 150 km adds up to 8 (excluding the Yellow River). Of the main rivers the Fenhe, Qinhe, Suhe, Xinhe and Sanchuanhe Rivers in the southwest belong to the Yellow River Basin, whereas Sangganhe, Hutuohe, Zhanghe rivers in the east and north are part of the Haihe River Basin. The catchments of Yellow River and that of Haihe River account respectively for 62% and 38% of the total area of Shanxi Province (LI Yingming et al. 2003).

The single-largest river in Shanxi is Fenhe River, which runs through middle of the Province. Fenhe's total length is 694 km and its watershed area 39,471 km$^2$, equivalent to 25.3% of the Province. Second only to the Weihe River in Shanxi Province, Fenhe is the one of the main branches of the Yellow River. Particular along the middle and lower reaches of Fenhe River, terraces have developed alongside the river banks. Here the terrain is flat and groundwater is abundant. In this fertile area much infrastructure developed over the centuries, forming a strong base for the economy and culture of Shanxi. The pollution of the surface water has however also affected the groundwater quality adjacent to the Fenhe. (See Fig 1.2)

1.1.4 Economic and Social Development

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 person/ km$^2$.

Shanxi abounds in mineral resources. There are over 66 types of minerals with proven reserves. Shanxi's reserves of minerals as coal, bauxite, fire clay, laterite, zeolite, limestone (used for house building), sandstone (used for making glasses) ranks first in the PRC; the reserves of iron ore, magnesia salt, potassium-bearing rock and pearlite stand second and that of mirabilite third.
Shanxi is coal country. The coal reserves of Shanxi Province amount to 256 billion tons. This is close to one third of PRC’s total. In 2011, Shanxi produced 870 million tons of raw coal, of which 580 million were shipped out of the Province. In recent years, Shanxi has put in a great deal of effort in coal conversion and deep-processing. Its strategy is to change Shanxi’s role: from a main coal supplier into a coal and electricity supplier and producer of coal-based products. The annual power generation in 2011 amounts to 234 billion kilowatt per hour (kWh), with supplies to other provinces set to increase.

Shanxi has now 568.98 million mu of arable land. The area equipped for irrigation is 188.89 million mu and the actual irrigated area is 161.09 million mu. Forest cover is sporadic. In 2011, the total afforested area in Shanxi reached 2.10 million mu and the plantation area 4.20 million mu. Forests are mainly spread in eight areas—i.e., Guancen Mountain, Guandi Mountain, Taiyuan Mountain, Zhongtiao Mountain, Wutai Mountain, Heicha Mountain, Lvlian Mountain and Taihang Mountain, in the middle and south of Shanxi. Grasslands are seen mainly in Yebei Dry Steppe and Northwest Jin Shrub Grassland. They harbor species such as thyme, crested wheatgrass, rosebush, Bunge needle grass, Lespedeza davurica and horsetail beefwood.

The arable land of Shanxi consists mainly of basins, valleys and loess hills. Cereals, in particular wheat, millet, maize, sorghum, oat, broom corn, millet and buckwheat, besides potatoes, are the main crops. Yuncheng and Linfen, the two big basins, are the largest wheat producing regions in Shanxi. Maize and millet are the main crops for the southeast regions, whereas sorghum is the major produce for Xinding and Taiyuan basins in the center of the Province. Oat, potato and buckwheat are planted in Yebei region in the north. The cash crops of Shanxi include cotton, rape, mulberry, flax and beet. Yuncheng and Linfen are big producers of cotton, sourcing not only Shanxi Province but also the whole PRC.

Orchards are commonly seen in Shanxi, bearing a variety of temperate fruits such as apple, pear, grape, walnut, date and persimmon. Of all the regions keeping orchards, Xiaoyi and Fenyang are famous for their walnuts; Jishan and Liulin for their red dates and Qixu having its grapes. The year 2011 witnessed a bumper harvest of all crops for Shanxi, with grain yield amounting to 11.93 million tons, cotton 63,000 tons and oil-bearing crops 187,000 tons.

From 1949 up to 2011, Shanxi’s economy had developed in a fast speed, with its agriculture diversifying and industry advancing robustly. In 2011, the Gross Domestic Product of Shanxi amounted to 1.11 trillion Yuan. Gross domestic product (GDP) per capita reached 30,974 Yuan. There is a very large contrast with the rural areas, where particularly in the mountain regions GDP per capita is generally much less than 10,000 Yuan.
Figure 1.1. Administrative Map of Shanxi Province

(Source: Li Yingming et al., 2003)
Figure 1.2. Map of Water Resources Distribution in Shanxi Province

(Source: Li Yingming et al., 2003)
1.2 Climate Change: Shanxi

Climate change is affecting the global hydrological cycle. A reallocation of water resources is occurring in space-time and also the total amount of water is changing. Climate change affects rainfall, evaporation, runoff, soil moisture and temperature.

The effect of climate change on water resources occurs in three main directions: (1) The water cycle is changed and the intensity and duration of rainfalls are not the same as they were before. The runoff scale changed. Floods and droughts become more frequent and severe. (2) This impacts the management of water resources—some new challenges are rising sea levels, saline water intrusion, imbalanced water supply and demand, insufficient hydropower generation as a result of the changes. (3) Higher temperatures increased water evaporation. It decreases soil moisture and affects the eco-environment for farming, forests, grasslands and wetlands. It also pushes up the geographical boundaries where farming is possible.

All this requires a different type of water management. We need in particular better buffers, i.e. storages that can absorb peak flows in one period and release them in dry periods. Groundwater is the ultimate water buffer. Making better use of groundwater through recharge, retention and reuse can reduce the impact of climate change. The challenge is that in Shanxi at the same time groundwater is heavily used, reducing its capacity to act as a water buffer and mitigate the impact of droughts and high temperatures.

1.2.1 Temperature

A number of statistics make it possible to trace changes in average temperature in Shanxi Province in the last four decades of the 20th century. The trend is for Shanxi to get warmer, with a sharp surge in average temperatures in the last decade.

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<td>Average Temperature (°C)</td>
<td>8.27</td>
<td>8.41</td>
<td>8.46</td>
<td>9.14</td>
<td>8.57</td>
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(Source: Zhang Wenzhong 2013)

Through the comparative study of the average temperatures of Shanxi Province in the last four decades, it is found that the average temperature for the first decade (1960-1970) is lower than the average temperature for the four decades as a whole. The trend has been a small gradual temperature rise from 1970 to 1990, with an abrupt increase in 1990-2000 going up with 0.87°C compared with that of 1960's. The future is likely to be hotter still. The projections of the NCC (National Climate Centre, PRC Meteorological Administration) and the IAP (Institute of Atmospheric
Physics, Chinese Academy of Sciences), as well as international models, foresee a significant warming in PRC in the 21st century, with the largest warming set to occur in winter months and in northern PRC (Ding et al 2007).

Similar in Shanxi, the most notable warming occurs in the northern part. As a whole, the province is experiencing a warming trend, except for a few small parts scattered across the province (Fan and Wang 2011). Among all the measured temperatures of Shanxi Province in the last four decades from 1961-2000, the highest were registered in the year 1999, with annual average temperature being 10.3°C, and the lowest in 1967, when the annual average temperature stood at 7.6°C. The recent climate tendency rate of Shanxi Province is an increase of 0.276°C every 10 years, which is about 7 times more than average in PRC (0.04°C /10 years).

Seasonally, temperature rises are seen in spring, autumn, and winter. The most significant, increases are found for the winter (0.44°C/10 years) and spring (0.32°C/10 years) with a more moderate trend for autumn (0.17°C/10 years). Summer temperatures have been basically stable. What this means that in general the growing season is getting extended. At the same time what is observed is that temperature drops are becoming more pronounced. These sudden low temperatures are harmful for farming.

![Figure 1.3. Annual Mean Air Temperature Trend in Shanxi (1959-2008)](Source: Fan and Wang 2011)

1.2.2 Precipitation

The average annual precipitation for most regions of Shanxi Province is between 400 to 600 millimeters (mm) (Figure 1.4). Local precipitation is affected by factors such as climate, topography and latitude. Due to a combination of these factors there is a variety of high and low precipitation centers. Alpine regions thus are high precipitation zones, whereas the leeward side of a mountain and basins has less precipitation.
The orientation of the mountain ranges in Shanxi is either north-eastern or north-north-eastern. Moist air flowing from the south and southeast is impeded by these ranges and precipitation drops sharply along its way from the southeast to the north and northwest. As a result, the precipitation lines—i.e., 650 mm, 600 mm, 550 mm, 500 mm, and 450 mm—have developed either in east-northern or west-southern direction.

1.2.2.1 Precipitation inter-annual variation

Shanxi has a history of droughts. The coefficient of variation ($C_v$) of the annual precipitation per station for most regions of Shanxi Province is between 0.25–0.35. The rule that the variation decreases with the increase of precipitation is evident in Shanxi too: the variation is higher in the dryer North. Differences can in fact be high, for the periods in which meteorological records have been kept, the minimum and maximum annual precipitation for a single station varies with a factor 2.5 to 3.5, in some cases the difference is even more than 4 times.

1.2.2.2 Precipitation annual distribution

The seasonal distribution of precipitation within the year is uneven in Shanxi Province. In general, the winters are dry with little rainfall but summers have ample rain. Autumn has more rainfall than spring.

In winter, under influence of the continental arctic air mass, Shanxi has only a small amount of rainfall events. The south of Shanxi has more rainfall than the north, and mountainous areas are more humid than valleys and basin floors. In spring, when winter wind gusts weaken and summer wind becomes more prominent, there is significantly more rainfall than in winter. Even so, the total amount of precipitation in spring for most regions is not very large: generally less than 20% of the total annual precipitation. Summer is the season when rainfall is quite abundant for Shanxi. Influenced by monsoons, rainfall events are frequent, with the total amount of precipitation in the summer adding up to 60%. Of the yearly total autumn is the season when the summer wind gives way to the winter wind. Rainfalls in autumn become much less than in summer. They are
distributed in a different way. Precipitation increases as we go from the north to the south and from mountainous areas to basin floors.

Following the monthly and yearly precipitation averages that have been measured and calculated for many years, we can see that the precipitation annual distribution follows a uni-modal curve, with the maximum precipitation appearing all in four consecutive months from June to September.

The amount of precipitation in the flood season is typically about 60%-80% of that of the yearly total for most parts of Shanxi. As a general trend, precipitation increases gradually from south to north. Figure 1.6 shows the rainfall distribution for three areas in above and below average years.

From December up to March next year, only a little rainfall is witnessed in Shanxi. The amount of precipitation for these four months as a whole is usually only about 5% of that of year. According to several analyses the reduction in rainfall of the last decade is associated with a change in the rainfall distribution over the year. The rainfall reduction is mainly caused by precipitation decline during rainy season (June–September), although precipitation in post-rainy season (October–November) also shows a decrease. Decrease in precipitation is highest in central Shanxi and in the area along the west fringe between Sanchuan River and Fenhe River in western Shanxi (Fan and Wang 2011). These are also the areas where most economic activities are concentrated and where most groundwater is abstracted.

If the climate trends during the last half century for Shanxi continue in the future, from south to north the gradient in dryness may increase while the temperature gradient may decrease.

Figure 1.5. Seasonal Precipitation Trends over Shanxi (1959-2008)

(Source: Fan and Wang 2011)
Figure 1.6. Monthly Precipitation Distribution Charts in a Typical Year

(Source: Fan Duixiang et al. 2005)
1.2.3 Water surface evaporation and drought index

The water surface evaporation rate is an index which shows the evaporative volume of a region. It refers to the amount of water evaporated from a ground surface that is sufficiently supplied with water. The amount of water evaporated from a water surface depends on the temperature of the water and the air, as well as the humidity and velocity of the air above the surface. The higher the temperature and velocity of the air, the more water will evaporate; and vice versa. The highest evaporation in Shanxi is in the spring (35%) and in the flood season (45%). It is particularly in these seasons that moisture conservation to reduce evaporation is important.

The drought index is the ratio between the evaporative power and precipitation. The drought index indicates whether the climate is dry or wet. A 2.5-drought index contour line starts from the northern foot of Hengshan Mountain and the north of the Great Wall, spreads over Heituoshan Mountain, then stretches further northwestern, passes through the Great Wall, then reaches West Jin Plateau, crosses the Yellow River at southwest Linxian County, and finally enters Shaanxi province. For North Jin and Northwest Jin, which are located to the north of the contour line, the drought index is above 2.5 and they are hence categorized as semiarid zones.

For most regions in the south and southeast, including Zhanghe and Qindanhe river valleys and Zhongtiaooshan district, the drought index is between 1.5–2.0. They therefore belong to sub-humid zones. The drought index for mountainous areas is small, but that for basin areas high. The drought indexes for Datong Basin and the upper reaches of Sanggan River are all above 3.0. For Taiyuan Basin, Yuncheng Basin and most parts of Northwest Jin, their drought indexes vary from 2.5 to 3.0.

1.3 Groundwater Resources of Shanxi Province

Groundwater use has a very long history in PRC and in Shanxi. Wells were developed more than 2,000-3,000 years ago, and the Chinese well development technology was ahead of all other parts of the world. Well development accelerated since the 1960's—making up more than half of the present water used and causing the use of ever deeper aquifer systems.

1.3.1 Geology

An almost complete set of geological strata is encountered in Shanxi Province. They are, from old to new: the Archean Group (Fuping Gr. and Wutai Gr.), the Proterozoic Group (Hutuo Gr.), the Sinian Suberathem (Sinian System), Paleozoic erathem (the Cambrian System, the Ordovician System, the Carboniferous System and the Permian system), Mesozoic Erathem (Triassic, Jurassic System and Cretaceous System) and Cenozoic Erathem (the tertiary system and the Quaternary System). Geological formations such as the Silurian System, the Devonian System, the Lower Carboniferous System and the Upper Ordovician are not found in Shanxi.

Shanxi sits on top of an active block, called the “Shanxi Continental Block”, which is located to the south of Yinshan Mountain latitudinal tectonic belt and to the north of Qinling Mountains fold zone, and between the Hedong (‘East of the Yellow River’) and
Shijiazhuang–Anyang meridional tectonic belts.

Taihang Mountain is an uplift belt of the Neocathaysian structural system. Qilv Arcuate Tectonic Belt spreads obliquely on Shanxi Continental Block. Within its reach the main peaks are Lvliang Mountain and Hengshan Mountain. Latitudinal tectonic structures are seen mainly at the north and south ends of Shanxi Continental Block, whereas meridional tectonic structures are not so visible inside the Block. Therefore, Shanxi is mainly controlled geologically by the Neocathaysian structural system as well as the Qilv Arcuate Tectonic Belt. Topographically, it rises up gradually from the west to the east, with an occasional subsidence at some regions.

To sum up, there are altogether five main tectonic structures in Shanxi Continental Block:

- Hedong meridional flexure,
- Lvling-Hengshang fold belt,
- Hutuo – Fenhe synclise,
- East Jin Concavity and
- Taihang antecline.

1.3.2 Hydrogeology

Judging by the properties of water-bearing strata and groundwater occurrence, there are three main categories of aquifer systems in Shanxi:

- alluvial-lacustrine aquifers,
- carbonate rock karst fissures, and
- Metamorphic and clastic rock fissures.

Alluvial-lacustrine water bearing strata are the richest aquifers. They are mainly encountered in the five ‘graben’ basins in the central area of Shanxi, which currently forms the economic heartland of the Province. The water-bearing layers are made up of various fluvial-lacustrine loose sediments and alluvial and diluvial formations of the Quaternary System. The groundwater of this category is recharged mainly from rain and snow. It also obtains some lateral recharge from neighboring mountains and carbonate rock karst water from karst water discharge areas.

Carbonate or ‘karst’ rocks—the second main category of aquifers—occur mainly in Taihang, Lvliang and Taiyuan Mountains and Northwest Jin regions. The karst system has developed concealed ground fractures, typical for large areas in North PRC. Affected by different climate regimes, the dissolution of the rock becomes more pronounced from Northwest Jin to Southeast Jin. Typically in a single karst spring area, as water flows from the recharge area in the upper reaches to the discharge area in the lower reaches, the runoff increases and the corrosive force becomes stronger and as a result, more carbonate rocks are decomposed in the lower reaches. The Lower Paleozoic carbonate rocks are the main karst water-bearing formation in Shanxi. Large springs such as Niangziguan, Shentou and Jinci were all developed in the Middle Ordovician System. For exposed limestone areas, groundwater recharge comes directly from the infiltration of precipitation. For rivers in limestone areas, especial those on the crosscut river beds of tectonic fracture zone, a large amount of surface water leaks along the way, which then becomes an important source of recharge for karst water.

Finally, the exposed area of the metamorphic and clastic rock formations—the third type of aquifers system—in Shanxi is about 80,000 km². Groundwater is
contained in weathering cracks and tectonic fissures. The aquifers are generally shallow and discharged as mountainous base flows through isolated springs. With a short runoff and poor self-adjustability, these springs yield only small amount of waters and their discharge is not stable.

1.3.3 Groundwater resources and exploitable yield

According to Second Assessment of the Water Resources of Shanxi Province, the annually available water resources in a normal year, calculated over the period 1956-2000 is 12.38 billion m$^3$ in Shanxi Province. Of this volume the amount of surface water (river runoff) is 8.7 billion m$^3$; that of groundwater (estimated on the basis of infiltrated precipitation) is 8.4 billion m$^3$. The river base flow (the amount that has been calculated in both categories—i.e., groundwater and surface water) is 4.7 billion m$^3$. If we divide the annual volume by the size of population and the amount of arable land of Shanxi Province in 2010, we find that the amount of water resources per capita is 369 m$^3$ in the Province. This is only 16.6% of that of the PRC as a whole (2,221 m$^3$) and far below 1,000 m$^3$, the internationally acknowledged serious water shortage standard, i.e., the so-called Falkenmark indicator.

The volume of water resources per mu is 189 m$^3$. This is only 9.4% of the national average. Clearly Shanxi is water-stressed. Moreover, the amount of groundwater fluctuates from year to year, depending on replenishment and groundwater usage.

The exploitable yield of groundwater is the maximum amount of groundwater that can be obtained from the aquifer with the existing economically feasible technology and on the condition that there is no environmental or geological problems caused by exploitation (such as a decline of the groundwater table, deteriorating water quality and ground surface subsidence or adverse effects are brought about to the eco-environment). The exploitable yield can be assessed for each of the three types of aquifer systems: the alluvial-lacustrine formations, the karst systems and the metamorphic rocks.

The exploitable yield of the groundwater in Shanxi is 5.1 billion cubic meters per annum (m$^3$/a). The larger portion is from the alluvial-lacustrine formation in the plains of the Province (2.5 billion m$^3$/a). The long term annual average in the karst water is 2.108 billion m$^3$/a and whereas the exploitable yield of the metamorphic formations is 578 million m$^3$/a.

1.3.4 History of groundwater exploitation

Shanxi Province has a long history of exploiting groundwater. The practice of making dugwells can be traced back to Tang Dynasty or even earlier in history. The majority of vegetable gardens on the outskirts of a city for instance were irrigated with well water. Before PRC’s liberation, however, groundwater was not used intensively. This changed with the liberation, and the development of agriculture and industry. Since then the exploitation of groundwater increased and groundwater became the main source of water for agriculture, industry and domestic use in Shanxi Province.

The history of water exploitation in Shanxi can be roughly divided into four stages:
First stage: prior to the mid 1960's

In this period, economic development was only modest. Groundwater was not much exploited: only the Quaternary alluvial aquifers and the karst fissures in the Carboniferous System formations were exploited. Most wells developed at this time were shallow or often shaped as “a cauldron.” Water was typically lifted with buckets. At this stage, large-scale exploitation of karst springs started. In 1957, Lanchun Water Plant, which had Lancun Spring as its water source, was formally put into production, supplying drinking water to Taiyuan City. Between 1957 and 1960, the average amount diverted was 40,000 m³/day annually. In 1958, the Canal ‘Qiyi’ was being built in Guozhuang to divert water from Guozhuang Spring to irrigate fields. By the mid 1960's, the flows from the karst spring flow declined, yet this was still seen as not a major problem.

Second stage: from the mid 1960's to the early 1980's

With the socio-economic development during this period, water demand by the urban population and industries increased sharply. The whole Province was experienced a boom in groundwater development and well-digging techniques and water lifting equipment modernized. The amount of water used in 1979 had reached a historical high, with the amount of groundwater exploited amounting to 2.63 billion m³. The largest amount of groundwater was exploited for irrigation. Nearly 10,000 wells were dug and the effective irrigation area reached 17.36 million mu. In 1979, the amount of water used for irrigation was 5 billion m³, 78.6% of the total water use in the Province. Out of this quantity, the proportion of groundwater for irrigation was substantial and reached 1.67 billion m³.

With the sharp increase in water use for agriculture, exploitation of groundwater no longer focused on the shallow strata but instead move to the middle and deep geological layers. Virtually all types of groundwater were tapped and efforts were made to even explore and use deep karst water. There was no standardized planning and management at the time, and the exploitation of groundwater was disorderly. Exploitation was done through well-digging in high potential spring areas and by intense exploitation of springs. For example, in 1970’s, in the karst area of Jinci, the number of wells dug for agriculture and industry reached 44 and the flow of spring water reduced to 0.66m³/s. The Shengmu and Shanli Springs even dried up. After the Niangziguan Power Plant was put into operation, a large amount of water was required – causing the yield of the Niangziguan Spring to increase sharply to about 4.5 m³/second. In 1972, after Huozhou Power Plant was built and put into operation, 37 wells were dug at the spring area, causing the water table to declined steadily. Taiyuan City expanded rapidly in this period and Lancun Water Plant had to continuously increase its production: its exploitation in 1970’s reached 149,000 m³/d and in 1980's 260,000 m³/d. As a result, the flow of Lancun Spring fell dramatically to 0.21 m³/second. To sum up, at this stage, with the massive exploitation of groundwater, the groundwater tables in many regions declined; water in a large number of shallow wells decreased and even dried up; the flow of the springs reduced and in some cases even ceased altogether (Pan Junfeng et al. 2008).
Third stage: from 1980’s to the early 1990’s

In 1980’s, with the rapid economic development brought about by the introduction of reform and opening-up policy in the PRC, the demand for water from all sectors grew dramatically, and exploitation of groundwater followed suit. The amount of groundwater exploited in the whole province reached 2.48 billion m$^3$ in 1984 and 3.87 billion m$^3$ in 2000. This amounted to an average annual growth rate of 3.5%. The volume of groundwater exploited for industry reached 586 million m$^3$ in 1984 and 932 million m$^3$ in 2000, with an average annual growth rate of 3.7%. The groundwater tapped for urban domestic use reached 195 million m$^3$ in 1984 and 398 million m$^3$ in 2000 (excluding the amount of water used for urban gardening), with an average annual growth rate of 6.5%. Furthermore, as one of the most important coal suppliers in the PRC, Shanxi coal mining expanded without due consideration for the aquifer systems. Consequently, groundwater resources were greatly disturbed and large amounts of groundwater at shallow and middle strata were discharged. Exploitation of groundwater was excessive and by 2005, the total area with non-sustainable groundwater exploitation had reached 11,137 km$^2$. The amount of overuse tipped 688 million m$^3$.

Fourth stage: from 1990’s up to now

In this stage, steps have been taken to bring the exploitation of groundwater under control. There is no further rise in the amount of groundwater used, which has been arrested in 2010 at 3.55 billion m$^3$. However, in some areas, such as Datong and other part of the central lowlands in Shanxi, overuse continues and groundwater tables are still in decline.

The breakdown of the groundwater usage in Shanxi Province, according to the Statistics on Water Use (2010) still sees agriculture as the largest user.

Figure 1.7. Shanxi Province Water Resources Structure

(Source: Zhang Wenzhong, 2013)
Groundwater used for agriculture amounted to 1.738 billion m$^3$ (1.579 billion m$^3$ for irrigation and 159 million m$^3$ for forestry and animal husbandry), in other words 48.9% of the provincial total. Industry is the second largest user. Industry used 970 million m$^3$ or 27.3% of the provincial total; construction 32 million m$^3$, 0.9% of the provincial total; and tertiary industry 125 million m$^3$ or 3.5% of the provincial total.

The amount for domestic use is 619 million m$^3$ (356 million m$^3$ for urban areas and 263 million m$^3$ for rural areas), equivalent to 17.4% of the provincial total. Then also a small part of groundwater was used for eco-protection (off-stream water use): 70 million m$^3$, or 2.0% of the provincial total.

Figure 1.8 and Table 1.2 give the breakdown for the different sectors and municipalities, respectively (Water Resources Management Commission Office of Shanxi Province, 2008).

Following the central government’s requirement to strengthen the management of water resources and positioning groundwater as a strategic resource, Shanxi has planned measures to ‘close up wells and reduce exploitation’, ultimately limiting the amount of groundwater used to below 2 billion m$^3$ per annum.

At present, the protection of groundwater resources is a priority for governments at all levels in Shanxi. Water resources management bodies have been set up respectively at provincial, municipal, and county levels and a series of water resources management related regulations and policies have also been formulated. The exploitation of groundwater has been made subject to standard procedures for approval and management, in a clear departure from the chaos that characterized the earlier stage. Special institutions have been established to manage and protect the karst spring areas.

Figure 1.8. The Percentage of Groundwater Exploited by Different Sectors in Shanxi Province

(Source: Zhang Wenzhong, 2013)
### Table 1.2 Proportion of Groundwater Exploited (in 10,000 m³)

<table>
<thead>
<tr>
<th>Administrative Regions</th>
<th>Domestic use</th>
<th>Primary Industry (Agriculture)</th>
<th>Secondary Industry</th>
<th>Tertiary Industry</th>
<th>Eco-protection (Off-stream)</th>
<th>Total</th>
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<td><strong>173791</strong></td>
<td><strong>100315</strong></td>
<td><strong>12550</strong></td>
<td><strong>7004</strong></td>
<td><strong>355537</strong></td>
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</tbody>
</table>

(Source: Shanxi Province Water Resources Bulletin, 2013)

1.4 Groundwater Challenges

With a history of intensive development behind it, groundwater in Shanxi is faced with a number of large challenges:

- Formation of large cones of depression due to excessive extraction;
- Impacts of climate change;
- Land subsidence;
- Flow of karst springs decreased or ceased altogether;
- Groundwater pollution;
- Aquifer disturbance by mining.

1.4.1 Formation of large-scale groundwater cones of depression

Starting from the 1970’s, due to a lack of systematic planning, well development was chaotic and unevenly spaced. Particularly in the basin areas in central Shanxi groundwater was excessively tapped. In 2010, the area where groundwater was excessively exploited stood at 6,903 km² in the basin regions of Shanxi, or 25.4% of the total.

In Taiyuan, Jinzhong and Yuncheng cities, the overexploited area amounted to 40% of the total: in Taiyuan it even reached 79.8%. The excessively exploited areas lie mostly in the alluvial-diluvial formation near the mountain fans or in the center of a basin. In these areas aquifers are high yielding, and the development of groundwater resources is comparatively easy.

These are the areas where urban development, agriculture and industry are concentrated. The intensive use of
groundwater resulted in the alteration of groundwater natural flow and the formation of large cones of depression at various places, as can be seen from the cross-sections of the main cities in Shanxi (see illustrations below).

**Figure 1.9. Cone of Depression in Taiyuan City and Its Suburbs**

![Figure 1.9. Cone of Depression in Taiyuan City and Its Suburbs](Source: Shanxi Province Water Resources Administrative Commission Office, 2008)

**Figure 1.10. Cone of Depression in Datong City and Its Suburbs**

![Figure 1.10. Cone of Depression in Datong City and Its Suburbs](Source: Shanxi Province Water Resources Administrative Commission Office, 2008)
1.4.2 The impact of climate change on groundwater

Groundwater is more adaptable to a variable and changing climate than surface water. In contrast to surface water, aquifers can store large volumes of water and are naturally buffered against seasonal changes in temperature and rainfall. Therefore, groundwater plays a critical role in adapting to hydrologic variability and climate change. However, groundwater itself is also vulnerable to climate change and alterations in the hydrologic cycle. Climate effects for groundwater include a change in groundwater recharge and a change in water demand.

Groundwater recharge is the main factor for the sustainable use of groundwater (Döll and Florke 2005). Precipitation is the core component of groundwater recharge and changing rainfall patterns will affect recharge. Temperature and CO$_2$ concentrations are also important because they affect evapotranspiration and determine the amount of precipitation that percolates to aquifers. During high intensity rainfall events the infiltration capacity of soils can be surpassed quickly, leading to an increased runoff and stream flow with less rain infiltrating to groundwater. Different soils react differently to high intensity rainfall; for some thin soils, the high impact even causes more water to directly infiltrate in the underlying geological layers. Repeated and longer droughts may lead to soil crusting and hydrophobic soils, causing an increased runoff during precipitation events and a decrease in groundwater recharge.

On the other hand, in areas where groundwater is recharged from surface water bodies or via pathways such as macropores and joints, intense rainfall will probably lead to more groundwater recharge (Döll and Florke, 2005). Seasonal variability is also important for groundwater recharge, as more frequent droughts or reduced rainfall during summer months can result in greater soil moisture deficits, shortening recharge periods (Döll and Florke, 2005).

The Second Assessment of the Water Resources of Shanxi Province established

![Figure 1.11. Cone of Depression in Yuncheng City Sushui Basin](source: Shanxi Province Water Resources Administrative Commission Office, 2008)
that the average annual recharge to groundwater in the basins of Shanxi Province comes primarily from precipitation, (48.8% of the total recharge); secondly from piedmont lateral recharge (28.3%) and thirdly from surface water leakage (17.7%).

The comprehensive First Assessment of the Water Resources of Shanxi Province covered the period between 1956 and 1979. In this period the average annual amount of precipitation was 534 mm and the total amount of water in Shanxi 14.2 billion m$^3$. For the Second Assessment, the period between 1979 and 2000 was taken: the average annual amount of precipitation was established at 508.8mm and the total amount of water in Shanxi 12.38 billion m$^3$. Comparing the two long-term assessments are compared, the amount of precipitation has decreased by 5.3% and the total amount of water by 12.8%.

The effects of climate change on groundwater in Shanxi hence may be summarized as:

- The reduced precipitation translating in reduced recharge. To this is added the effect of temperature increase over the recent decades. The increased temperature leads to higher evaporation and further reduces recharge.

- Decreased rainfall and increased temperature will also increase water demand. This triggers a more intense application of groundwater. Higher temperatures (especially in autumn, winter and spring) and a lesser number days of frost will also extend the cultivation season in the colder parts of Shanxi Province, resulting in more demand for water in agriculture.

- As rainfall patterns change the recharge patterns change as well. The rainfall reduction under climate change mainly affects the summer rainfall. Rainfall is slightly more smoothened out over the year and this has slightly positive effect. The more gentle rains are likely to translate into more infiltration from rainfall and less direct run-off. This may further be promoted by appropriate groundwater recharge and peak water spreading measures (see also next sections)

1.4.3 Land subsidence

Excessive exploitation of groundwater reduced the buoyancy force of water in the aquifer and affected the bearing capacity of the soil strata, especially of the alluvial formations. As a result, clay and sandy clay formations are compressed under their own weight. At the same time, the natural flow direction, speed and hydraulic gradient of groundwater is changed as well. Subsurface erosion increases, and as the soil mass contracts, land starts to subside. Due to uneven nature of the subsidence, ground fissures develop. In Shanxi, this phenomenon has been prevalent particularly in cities which depend on groundwater as their prime water source, such as Taiyuan, Datong, Yuncheng Sushui Basin, Jinzhong, Yuci and Jiexiu.

According to the result of measurements by the Taiyuan Urban Construction Department using more than 10:00 bench marks, the land of Taiyuan City as a whole was
subsiding like a slanting funnel, which extends from Yinxing Street in the north to Jinyang Lake in the south, and from Provincial Committee Party School in the east to Jinsheng Village in the west, with the north-south length being about 15 km and the west-east width about 8 km.

The average annual subsidence between 1985 and 1989 was between 37 mm and 114 mm. In the big depression cone, there are three small subsidence centers, namely Wujiaobao (which is the center of the cone of depression), Hexi Middle School in Xiaoyuan and Yinxing Commercial Complex. The land subsidence has resulted in cracks developing in buildings (for instance in Dama Village, Wujiaobao), water logging and most probably underground pipe fracture.

In Datong, land started to subside in the late 1970's. In 1988 systematic monitoring of land subsidence started. According to the monitoring data for the period from 1988 to 1993, there are two subsidence centers in Datong municipality. They lie in the areas around Shizhuang – Xihanlin and Liqun Pharmaceutical Plant respectively. Here, the maximum total subsidence is 124 mm and the average contraction was 25 mm per year.

The accumulated subsidence in Datong is between 40 mm and 50 mm and the average subsiding speed 8 mm to 10 mm per annum which is faster than the 3 mm per annum subsidence for Datong Basin as a whole. The first ground fissure was found in 1983. At the time, a 1.3 km long ground fissure was seen in the residential quarter of Datong Locomotive Works. By 1993, the number of ground fissures had reached 7, with their total length extending to 21 km. The temporal-spatial distribution of the land subsidence areas corresponds quite well to that of the cones of groundwater depression in Datong. This confirms that the excessive exploitation of groundwater is a main cause of land subsidence.

In Yuanwo, Yuci of Jinzhong district and Yitang and Yi’an of Jiexiu Municipality, water tables declined drastically. Again, land subsided and fissures appeared at several locations. For example, Xiaohe Dam, a water conservancy project nearby Yuanwo water source, subsided mainly because the water level in the alluvial formations of the river bed dropped.

In 1978, it dropped below the water level of Xiaohe River and, after 1988; it further dropped below the 46.6 meter water level of Wenhe River. In 1983, the 12th Engineering Bureau of Ministry of Railways conducted a leveling survey in Yitang and Yi’an of Jiexiu Municipality. It found that the bench marks at three locations had sunk over 100 mm. Since 1985, there has been a phenomenon called “well-lifting”. At some pumping wells the pumping pipe had to be “lifted up” to meet the water table. Cracks also developed at the pump houses and store houses.

Finally, in Yuncheng Sushui Basin, groundwater table declined continually with the excessive exploitation of groundwater. Large fissures and landslides appeared in the peripheries of the basin.
1.4.4 Large karst spring flows decreased - even ceased all together

Karst springs usually have a continuous water flow and the quality of their water is superior. For these reasons, they have been important as sources of water supply for urban consumers and industries in Shanxi. Before 1970's, the exploitation of karst spring water was not significant, but afterwards, with the rapid agricultural, industrial and urban development, exploitation increased considerably. Not only did the number of wells increase, but also wells were developed directly in the recharge zone. Furthermore, dry spells and a reduction in rain and snowfall in the karst spring areas with 3% to 10% impacted the recharge negatively. As a consequence karst water resources went on decline.

Actual measurement of the flow of 16 of the largest karst springs indicated that the flow of these springs decreased by 30% compared with 1980's. Among these 16 springs, Lancun Spring and Gudui Spring completely ceased and Guozhuang Spring and Hongshan Spring are on the verge of drying up. The decrease in the flow of karst spring water imperils agricultural and industrial production and urban life and measures have to be taken to protect karst water resources.

Figure 1.12 Flow of 16 Large Karst Springs Compared with Rainfall

(Source: Zhang Wenzhong, 2013)
Jinci Spring in 1986 (on the left) and in 2005 (the water flow shown on the middle and right pictures is an artificially pumped water cycling).
(Source: Pan Junfeng et al., 2008)

Lancun Spring, in 1986, was on the verge of drying up (on the left), and, in 2005, has completely dried up (on the right)
(Source: Pan Junfeng et al., 2008)

Water is being pumped out from a well at Guduiquan spring in 2005.
(Source: Pan Junfeng et al., 2008)
1.4.5 Groundwater pollution

Groundwater pollution is a source of large concern in Shanxi. Groundwater pollution comes primarily from two main sources. There is the point pollution from waste water discharged by cities, mines and industry and the non-point pollution from chemical fertilizers and pesticides. Statistics show since the 1980’s, the amount of waste water discharged by industries and domestic users in Shanxi has increased steadily: 550 million m³ for 1980; 690 million m³ for 1984, 945 million m³ for 2000, and closing in on 1 billion m³.

Approximately 95% of the waste water is still discharged directly to rivers and fields. It has been allowed to flow into reservoirs or infiltrate into the soil without a single treatment. Relevant studies show that the shallow groundwater in regions such as Taiyuan, Datong, Yangquan, Changzhi, Yuncheng and Yongji is polluted in different degrees. Furthermore, in areas where cones of depression developed, wells go deeper and deeper because the water table declines continually. There are several wells whose upper interior walls are either not carefully sealed or not sealed at all; and others that actually draw mixed water. Such wells become conduits, through which polluted shallow groundwater flows to middle and deep strata. As a consequence, water in the deeper strata is also contaminated.

In recent years, karst water has been massively exploited; and urban waste water is discharged to the karst river valleys, which then infiltrates in the groundwater systems through the river beds. In coal-mining areas, coal pit waste water is discharged through shafts, creating further degradation of the karst water resources.

With the emerging of township enterprises, the exploitation of groundwater became even more disorderly. Consequently, the area with polluted groundwater has extended from the previous urban industrial zones to a longer list of regions and ground strata. Worsening groundwater pollution multiplies the problems caused by the water shortage.

Pollution from fertilizers and pesticides is also a matter of serious concern in Shanxi and in other parts of the PRC. Heavy use of nitrogen fertilizer has also caused widespread acidification of soils in the PRC. Comparing two soil surveys—from 1980’s and 2000’s in the PRC, Ghuo et al. (2010) found that in many areas soils have become too acid for the cultivation of certain crops. The intense use of fertilizer is the reason of nitrogen leaching to the groundwater, making groundwater unfit for human consumption and difficult to treat. In general soils in the main agricultural areas are depleted of organic material. Rather than a continued reliance on chemical fertilizer, the use of bio-fertilizer or bio-char or soil additives such as zeolite would restore long term soil quality and reduce the dependency on agro-chemicals.

1.4.6 Impact of coal mining on groundwater

Shanxi 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. From the north to the south, there are six large coal fields, namely Datong, Ningwu, Hedong, Xishan, Huoxi and Qinshui and several coal...
districts, such as Hunyuan, Wutai, Pinglu and Yuanqu. Of the 118 counties in Shanxi, 94 have coal fields. As far as the proven reserves or the production volume is concerned, Shanxi ranks the first in the PRC, and it produces a significant portion of the coal traded in the PRC and even internationally.

As coal and groundwater coexist in the same geological formation, coal mining will inevitably disturb geological formations and damage aquifers. Firstly, it may change the natural circulation of groundwater from the previous horizontal movement to vertical movement. Aquifers will dry up and groundwater recharges be cut off. As a result, the groundwater table will decline; springs are affected and land subsidence may be triggered. According to the Impact of Coalmining on Water Resources in Shanxi Province, a research report for the 2nd 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 waste water will pollute surface and ground water and cause other environmental problems as well. In many localities the liquid that drains from coal stocks, coal handling facilities, coal washers, and even coal waste tips is highly acidic, in particular in formations with an abundance of sulfide minerals. When the pH of acid mine drainage is raised past 3, either through contact with fresh water or neutralizing minerals, previously soluble iron(III) ions precipitate as iron(III) hydroxide, a yellow-orange solid colloquially known as yellow boy. Acid mine drainage also contains large quantities of trace minerals and heavy metals.

This is the entrance to a coalmine pit.
(Source: Zhang Wenzhong, 2008)

Wastewater discharge is coming out from the coalmine pit
(Source: Zhang Wenzhong, 2008)
Cracks developed in houses and on grounds due to coal mining activity.
(Source: Zhang Wenzhong, 2008)

Land fissures and subsidence have occurred as a result of coal mining
(Source: Zhang Wenzhong, 2008)
Chapter 2 Promoting Effective Groundwater Management

2.1 Introduction

The challenges to groundwater management are set out in the previous chapter. They concern the intensive use of groundwater, which though no longer increasing is still out of balance in several parts of the central basin area and in the mountainous karst spring areas; land subsidence, the disturbance by coal mining; and the pollution by industry and agriculture. The threats to the vital groundwater resources are amplified by climate change. This brings lesser rainfall and higher temperature to Shanxi. On the one hand this increases the demand for water and increases the area that can be cultivated in the colder regions, on the other hand the lesser rainfall means lesser recharge of groundwater: so groundwater availability is challenged from two sides. In principle, groundwater should serve as a buffer against variability in climate, but in Shanxi groundwater—particularly in the economically important central basin is under pressure from overuse and degradation.

There is an urgent need to rebalance groundwater use in Shanxi and protect its quality. This chapter sets forth the different measures to promote effective groundwater management—that can address the challenges both of intense groundwater use and the mitigation of the effect of climate change in Shanxi. The policy target in Shanxi is to reduce groundwater use from 3.5 B m$^3$ to 2 B m$^3$ per year (see Chapter 1). The challenge is to this whilst maintaining productivity and supporting the social and economic growth of the Province. Obviously a wide range of measures in an integrated approach will be required to achieve this very large challenge – based on a strong legal and institutional framework. In addition to reduce water consumption and achieving higher water productivity, all measures to replenish groundwater though a large range of recharge measures should be applied and alternative non-conventional water resources should be mobilized.

The chapter draws on ongoing initiatives in Shanxi province and on international experiences. It first discusses the legal and institutional basis for groundwater management in Shanxi and measures to further reinforce it (section 2.2). It then discusses the measures to reduce water consumption in agriculture and industry—respectively in section 2.3 and 2.4. Section 2.5 discusses the augmentation of water supplies—through systematic recharge, larger use of surface water and use of non-conventional water resources. Section 2.6 is devoted to the steps to be taken to safeguard groundwater quality. The chapter concludes with a discussion on moving to ‘water saving society’ in 2020 – setting an example for other parts of the world with similar challenges (section 2.7).

2.2 Laws, Institutions and Regulatory Measures

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 will be required so as to not just regulate but also to manage the demand for groundwater and to augment its supply.

Groundwater management in Shanxi has evolved over the years and is now supported by a range of national, provincial
and local regulations. Before 1980’s, a state of anarchy in groundwater exploitation prevailed. There was no clear understanding of groundwater availability and the limits to its usage were not understood. Essentially at that time groundwater was seen as infinite and ‘a gift from the God for people to survive.

Because at that time the techniques to develop wells were not advanced, the amount of exploited groundwater, however, was not large. As explained in Chapter 1, the situation changed dramatically after 1980, when a large number of new wells were developed. Soon after this the first laws, regulations and standards on groundwater management were announced.

Shanxi was a front runner in this field in the 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 municipal and county levels. The chief responsibilities of the new institutions were to coordinate and resolve conflicts between different departments or units on water resource development, mediate in water related disputes and to plan the managed exploitation, use, saving and protection of water resources and to formulate guidelines and policies. With the announcement of new regulation, groundwater management became gradually more systematic.

In this period, Shanxi Province promulgated the following regulations:
- Shanxi Provincial Regulation on the Administration of Water Resources;
- Shanxi Provincial Interim Measures for the Administration of Groundwater Resources;
- Shanxi Provincial Interim Measures for the Administration of Spring Areas;
- Shanxi Provincial Regulations on Water Saving for Urban Life, Factories and Mines;
- Shanxi Provincial Interim Measures for the Levy of Water Resource Fees; and

This was complemented by regulations at local level. In 1988, Taiyuan City promulgated Taiyuan City Measures for the Administration of Water Resources. In 1990, Datong City promulgated 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, also 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 onwards, strict control of water resources became the norm. Following the Central Government’s requirements on tightening the control of water resources, the Shanxi Provincial Government drew three “red lines” as the focus of its policy on groundwater management. These three red lines concerned:

1. the exploitation and use of water resources;
2. the control of pollution in water supply areas; and
3. the monitoring of efficiency in water use.

This section discusses the most important laws, administrative arrangements and regulatory measures that exist in Shanxi to manage groundwater (section 2.2.1 to 2.2.3), as well as proposed additional regulatory measures to take groundwater management to a next high level by dovetailing economic and land use planning with water availability and introducing a more encompassing quota system (section 2.2.4 and 2.2.5).

2.2.1 Prevailing laws

A number of National and Provincial laws at present create the basis for sustainable groundwater management in Shanxi. Below is an introduction to the main regulatory instruments.
(1) Water Law of the People’s Republic of China

The Water Law of the People’s Republic of China was adopted in the 24th Meeting of the Standing Committee of the 6th National People’s Congress on January 21st, 1988, and came into force on July 1st of the same year. In 2001, the Water Law was amended. This amended Law was adopted and promulgated in the 29th Meeting of the Standing Committee of the 9th National People’s Congress on August 29th, 2002 and came into force on October 1st, 2002. The Law contains eight chapters. The promulgation and enforcement of the amended Water Law marks 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.

(2) Regulation on the Administration of the License for Water Withdrawal and the Levy of Water Resource Fees

The Regulation on the Administration of the License for Water Withdrawal and the Levy of Water Resource Fees was promulgated with the Order No. 460 of the State Council of People’s Republic of China. The Regulation was adopted at the 123rd executive meeting of the State Council on January 24, 2006, and came into force on April 15, 2006.

(3) Shanxi Provincial Regulation on the Administration of Water Resources

The Shanxi Province Regulation on Control of Water Resources was approved in the 17th meeting of the Standing Committee of the 5th Shanxi Province People’s Congress on October 29, 1982. The Regulation was amended as per 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 September 29, 1994. The Regulation was revised at the 34th meeting of the Standing Committee of the 8th Shanxi Province People’s Congress on December 20, 2007.

(4) Shanxi Provincial Regulation on the Protection of the Water Resources in Spring Areas

The Shanxi Province Regulation on the Protection of the Water Resources of Spring Areas was adopted at the 30th meeting of the Standing Committee of the 8th Shanxi Province People’s Congress on September 28, 1997 and came into force on January 1, 1998. The Regulation was amended as per the Decision on Amending Several Local Regulations during the 20th meeting of the Standing Committee of the 11th Shanxi Province People’s Congress on November 26, 2010.

(5) Measures for the Administration of Water Withdrawal Licenses

The measures are part of the No. 34 Order by the Ministry of Water Resources and was adopted at a ministerial conference of the Ministry of Water Resources on March 13, 2008.

(6) Measures for the Administration of the Water Resources Assessment of Construction Projects

These measures came in force with the No.15 Order by the Ministry of Water Resources and the State Planning Commission and became effective on May 1, 2001.

2.2.2 Administrative responsibilities

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

The legal framework is set by the regulations mentioned above, including the Water Law of the People’s Republic of China, the Water Pollution Prevention and
Control Law, the Environmental Protection Law, Shanxi Province Regulation on the Administration of Water Resources, Shanxi Province Regulation on the Protection of the Water Resources of Spring Areas, and Shanxi Province Interim Administrative Measures for Groundwater Management.

The role of the Ministry of Water Resources has four main aspects:

- First, to formulate general policies, laws and regulations for water conservation so that there are laws to go by for the water sector and all activities are administered by law;
- Secondly, to draw up an integrated development plan for the water conservation industry as a whole and ensure coordination within the water sector;
- Thirdly, to formulate general technical specifications, standards and quotas, which will then be binding for water users;
- Fourthly, to make some 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 water audits (Jia Zemin et al. 1990).

In spite of the above at present, management of groundwater resources in Shanxi Province is in practice dealt with by a large number of administrative departments including the Department of Water Resources, Department of Urban Construction, Department of Land and Resources and Department of Environmental Protection. With so many government organs administering water together, problems occur such as overlapping investment of manpower and material resources, unclear responsibilities especially when problems arise, and in general lack of coordination, with each organization setting its own policies and building up its own information system.

Some examples illustrate the still fragmented responsibilities. 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 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 the license to draw water by the Department of Water Resources. The Department of Land and Resources is partly involved in groundwater investigation and monitoring. At last, the Department of Environmental Protection is mainly in charge of the protection of water source areas.

What is important to achieve is coordination between the various stakeholder organizations, between organizations at the different levels and between the plans and activities in different sectors (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 management and supply management (groundwater recharge and retention) measures. The plan and activities are preferably done at scale and density so that activities show real impact and create a system change in an area. In other countries such coordinated measures are undertaken too. Table 2.1 gives some examples.

It is also important to engage and involve the main water consumers, so that they will implement their own measures for better groundwater management. This is the lesson from Indonesia, India, Mexico and Spain for instance. Water saving in the end is in everybody’s interest—not just of the government. In some countries even special aquifer user management organizations were set up. Often, as is also explained in Chapter 3 with the examples of the 0188-PRC Grant Project, strong local economies
can be built on water saving production systems, because using water in a more precise and controlled manner saves costs and can also improve the quality of the product or the yields.

Box 2.1 in the above gives an example on how farmers were very much involved in the management of groundwater in India. This program was popular as through farmer water schools farmers also realized that water saving paid off in terms of a more profitable farming. It also helped to make the laws and regulations that were in place widely understood and to be used for general benefit.

2.2.3 Regulatory instruments

A number of important regulatory measures have been developed for groundwater management in Shanxi. These need to be systematically implemented and complemented by joint planning and follow activities.

Five of the main regulatory measures in place in Shanxi are:

- Regulating the total amount of groundwater abstracted from source areas;
- Compulsory water resource assessments for investment projects;
- Licensing of well drillers;
- Administration of water withdrawal; and
- Payment for the use of groundwater resources.

2.2.3.1 Regulating the total amount of groundwater abstracted

The first of the three “red lines” drawn by Ministry of Water Resources, mentioned above, 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 different cities of Shanxi Province, efforts should be made to quantify the amount of groundwater permitted to exploit for each city.

At present, this work is in progress. To better undertake this task, the economic interests of different cities should be taken into consideration and be well coordinated. Up to now, 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 has come into force. As an example, for Niangziguan Spring which services Yangquan and Jinzhong cities, the control index on the exploitation of karst water for Jinzhong City from Niangziguan Spring is 16 million cubic meters per annum (m$^3$/a), with the remainder reserved for Yangquan City (the spring headstream). As for Guozhuang Spring which covers Lvliang, Jinzhong and Linfen, the quota for the exploitation of karst water for Lvliang City Guozhuang Spring is 37.4 million m$^3$/a; that for Jinzhong City Guozhuang Spring 18 million m$^3$/a; and the balance is for Linfen City (the spring headstream). (Pan Junfeng et al. 2008).

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.

2.2.3.2 Water Resources Assessment of Construction Projects

Following Order No. 15 by 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 Water Resources. Basically 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. Firstly, 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.

Secondly, 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 waste water or processed mining pit waste water are used. In this way, water of different qualities is used for different purposes; the exploitation of groundwater can be controlled and efficiency in water use improved.

Thirdly, judicious 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, the discharge and the impacts on its surroundings, the discharge of waste water will be reduced to the minimum level; and groundwater and its environment will be protected.

2.2.3.3 Licensing of well development

For the control of groundwater exploitation it is critical to manage the well development industry. To manage the exploitation, use and protection of groundwater, Departments of Water Resources at all levels should work on the orderly exploitation of groundwater and the efficient use of the limited groundwater resources. The he following activities in regulating well development have been carried out by Municipalities.

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

- Capacity building for teams of well-digging technicians has been organized. Trainings have been conducted to improve well-development team leaders' awareness of rules and regulations on well-digging and the necessity to abide by them. Meanwhile, technical trainings were given to well-digging technicians to improve their well-drilling skills. The ultimate goal is to ensure an orderly exploitation of groundwater resources.

- Qualifications of well-digging teams have been strictly examined. All well-digging teams need to acquire a well-digging permit before they can actually engage in well-digging activities. To acquire the well-digging permit, they will have to go through procedures like trainings, tests, evaluation and approval.

- Application procedures for gaining approval for well-digging have been standardized and announced 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 withdrawal was initiated in 1993. On August 1, 1993, the measures for the Issuing of the License for Water Withdrawal were put in place with the No.119 Order of the State Council, which came into force on September 1, 1993.
Figure 2.1 Areas of Excessive Groundwater Exploitation in Shanxi Province (in red)

(Source: Shanxi Province Water Resources Administrative Commission Office, 2008)
<table>
<thead>
<tr>
<th>Area/Country</th>
<th>Main challenge</th>
<th>Main features in groundwater management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barcelona, Spain</td>
<td>Threatened aquifer systems</td>
<td>Participatory aquifer management, introduction of water policy, norm on groundwater use and setting hydrogeological planning boundaries, groundwater users association</td>
</tr>
<tr>
<td>Amman, Jordan</td>
<td>Lowered groundwater table, conflict between users</td>
<td>Water public transformed into public property and transferred to government control. All wells having separate files and strong well monitoring in place. Users are notified of violation of rules, which may result in confiscation of rigs and crews being arrested</td>
</tr>
<tr>
<td>Bangkok, Thailand</td>
<td>Water quality deterioration and land subsidence due to over-pumping</td>
<td>Control on industrial well drilling and fees on abstraction. Fees are put in water fund used for monitoring, action research and capacity building regulatory measures (licensing and charging); successful targeting of groundwater management measures in objectively-defined priority areas; central groundwater ‘apex’ agency working i with provincial government offices to manage a diffuse groundwater resource; recycling of groundwater conservation fee into a ‘groundwater fund’ to finance monitoring and research activities; groundwater pollution control in the more vulnerable aquifer recharge areas</td>
</tr>
<tr>
<td>Bishkek, Kyrgyzstan</td>
<td>Overuse</td>
<td>Groundwater plans, bans on pumping from fossil aquifers</td>
</tr>
<tr>
<td>Mendoza, Argentina</td>
<td>Overuse subsidence</td>
<td>Development of user quota, automatic recorders on all wells, exchange of excess quota</td>
</tr>
<tr>
<td>Santa Fe, Argentina</td>
<td>Deteriorated water quality and loss of recharge</td>
<td>Monitoring; pollution risk management; delineation of protection zones; recharge quantification</td>
</tr>
<tr>
<td>Jakarta, Indonesia</td>
<td>Sea water intrusion</td>
<td>Phasing out individual pumping; increasing groundwater price four fold; 10% of water prices shared with surrounding communities</td>
</tr>
</tbody>
</table>

(Source: www.groundwatergovernance.org)
Box 2.1 Organizing and Involving Farmers: Experiences from Andhra Pradesh (India)

It is important to engage farmers in the management of groundwater as well – so that they share the responsibility and come up with good solutions of their own. In many states in India – such as Andhra Pradesh with a population of 90 million – groundwater use has increased enormously over the last twenty years. According to the best estimates there are more than 1.2 Million borewells in this state alone. Groundwater tables have fallen in large areas.

In response to this groundwater crisis the APFAMGS project introduced a number of activities to make farmers share the responsibility for groundwater managed:

- It encouraged farmers to be directly involved in the monitoring of water tables and collecting meteorological data.
- It organized farmers in entire sub-catchment to discuss the crop planning against the availability of water by jointly preparing water balances.
- It organized ‘farmers water schools’ to give training and discuss water saving but high crop yielding measures.

In all areas where there had been overexploitation the trend reversed as a result of these activities. This was achieved by a conversion of high water demand crops (especially rice) to medium and low water demand crops and the accelerated adaptation of water saving measures and efficient irrigation systems.

Farmer ‘water schools’ in India explaining water balance over the years
(Source: Frank van Steenbergen, 2013)
2.2.3.4 Administration of water withdrawals

Administration of water withdrawal is a major element in allocating rights to the use of water resources. When granting permission to applicants to use groundwater, the government should formulate an integrated plan in order to efficiently assign water to stakeholders. While assuring that domestic water supply for urban and rural citizens is 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, even banned altogether. Under decision by the Shanxi Provincial Government, 22 areas have been earmarked in Shanxi 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 those 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.

2.2.3.5 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. Following the decree issued by the Provincial Government, the levying of water resources fees started in Shanxi in 1982. The rates for the different groups of water users are decided together by Provincial Finance Department, Provincial Pricing Bureau and Farmers’ Burden Supervision and Administration Office). As of today, Shanxi Province already has a history of 30 years levying water resources fees and witnessed three adjustments to the tariff standard: increasing the charge from 0.1 Yuan/m$^3$, the initial rate, to 2 Yuan/m$^3$, the present rate whereas the charge for areas with excessive groundwater exploitation is 3 Yuan/m$^3$. Table 2.2 is a detailed overview on the tariffs for the different categories of payers.

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 PRC have promulgated their own provincial regulations on the administration of the levy of water resources fees and started to levy water resources fees as well, though with different tariffs. Up to now, 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 has contributed to a significant reduction in groundwater use and changed a situation of overuse to one of sustainable consumption. This good example is discussed in the next section.
2.2.4 A good practice: integrated groundwater management system in Qingxu

Qinxu is an agricultural county. The total population of Qingxu County is 340,000, and the agricultural population 250,000. The County has arable lands of 436,000 mu. The irrigated areas amount to 368,000 mu, among which 170,000 mu is irrigated with groundwater (Niu Bandong 2013). The economic and agricultural development of the area has led to an annual water shortage of 57.27 million m$^3$. This was compounded by the decline in rainfall in Qinxu (Figure 2.2), as elsewhere in the Province, and the reduced water inflows from the Fenhe River and the Xiahe River, the latter having dropped to 25% of its discharge in 1950.

![Figure 2.2 Annual Rainfall Decline in Quinxu (1951-2011)](https://example.com/figure2.2)

Until 2005, the groundwater level declined by 1.6 meters per year (Li Futian 2011; Niu Bandong 2013). Due to the importance of groundwater for the county’s economy and the urgent need to avoid groundwater over-exploitation, Qinxu County established an integrated mechanism for water resource allocation, management, evaluation and monitoring of groundwater (Li He 2011).

The Qinxu Groundwater System was put in place in 2007. It 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 or industrial user will operate with his swipe card. The amount of water that can be used is based on quotas that are 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. The quota are determined first per sector (industry, agriculture, domestic and environmental) and 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, and the number of family members and the livestock owned. If water is used within the quota the price is ¥ 0.41 (Euro 0.05) per unit. If it exceeds it is ¥ 0.55. 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 to 5,000 liters.
Water fees are used to pay the electricity fee for pumping the water, the costs of irrigation management and for maintenance of the irrigation facilities. The over quota water fees are used to pay any leftover debt in electricity charges or salary and then allocated for 50% of repair costs. The balance of the funds is for developing new water resources (Li He 2011).

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 ¥ 73 (water consumption = 240 m³). According to the national statistics, in 2008, the cost of planting wheat is ¥ 274/mu, and the net income only ¥ 296 /mu; the cost of planting corn is ¥ 232 /mu, and the net income is ¥ 423/mu (Li He 2011).

Quotas are also 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. In general, however allocation of the quota is quite tight for irrigators. According to the quota regulations, any left over water can also be kept for the next year. Even though a farmer does not use up the water quota, he generally prefers to keep it for next year. This reflects that farmers do care about the quota and the price ladder.

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

The results are remarkable. In spite of the tight restriction, 70% of farmers rated the new system as good; the majority in fact as very good. As the swipe cards have to be pre-loaded, cost recovery is 100%. What is even more significant is the effect on the groundwater. Whereas prior to the system being developed (at a cost of ¥ 30 Million (Euro 3.75 Million or USD 326 per hectare) groundwater levels were in heavy decline, this has been turned around and groundwater levels have been increasing with 1.6 to 4.8 meters a year. Also, the volume of groundwater consumed was decreased steadily: from 59 million m³ in 2004 to 35 million m³ five years later—a drop of 30% in a time when the demand for industrial and agricultural water is increasing.
The regulated system encouraged farmers to adjust farming practices (Li He 2011): better field preparation (81%), use of plastic mulch (61%), and change of varieties (49%). Awareness on pollution risk from fertilizers and pesticides has also been built from 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 increasing contradiction between the supply and demand of water resources has been alleviated. This was also achieved by complementary investments in water buffering in the catchment, the phasing out of water-in efficient industrial technology, leakage control, the promotion of water saving devices. In industry, for instance, the amount of water required to produce an added value of ¥10,000 declined from 56 m$^3$ to 18 m$^3$. The groundwater environment has recovered from continuous worsening (Li Futian 2011).

The Qinxu system through tiered pricing system, high tariffs and highly efficient ‘swipe card- based regulation also created the incentives for ‘a water saving society’. The Qinxu model set the stage for farmers to invest in efficient water management, resulting in a considerable water savings in staple crop areas for an entire district which is nothing short of impressive. Interventions at this scale are also highly necessary and worthy of more support. As the system is large and requires upfront investment in time (intensive discussion with all stakeholders) and money (the investment in the new infrastructure), there is a strong case for governments and international financial institutions to invest in such scaled up models. Regulation such as Qinxu is moreover necessary—without it the introduction of efficient irrigation runs the risk of encouraging an expansion of irrigated area; and with it an increase in water usage.

2.2.5 Expanding and improving the total quantity water control system

Shanxi Province has adopted the total quantity control system of water consumed for managing its water resources (section 2.2.3.1). The system is already in place in specific areas, such as in Qinxu, described above, and in Taiyuan. Based on these good experiences in Shanxi, the quota systems needs to be expanded and improved. The experience from Australia can serve as an example too (Box 2.2).
Box 2.2 Water Allocation System in Australia

The water allocation system in Australia has the following main elements:

(i) Nationally compatible water access entitlements—water licences and allocations;
(ii) Transparent water planning;
(iii) Water plans with provisions for environmental water needs;
(iv) Over-allocated resources returned to sustainable extraction;
(v) Removal of barriers to trade in groundwater licences and allocations;
(vi) Water accounting—by metering and remote sensing;
(vii) National Water Commission overviews implementation of actions over 10 years.

(Source: www.groundwatergovernance.org)

Box 2.3 Relocating Industries in Taiyuan

To enhance the environment of Taiyuan City, several factories were moved out of Taiyuan City in 2011 under the directives of the Taiyuan Municipal Government.

One example was the Taiyuan Fertilizer Plant, built as one of the 156 key projects shortly after the liberation of the People’s Republic of China (PRC) in 1949 with the assistance of the former Soviet Union. The medium-sized nitrogen fertilizer plant was capable of producing 240,000 tons per annum of ammonia and 320,000 tons per annum of ammonium nitrate. The main equipment of the plant, however, was heavily outdated and the plant became one of the largest water users and polluters in Taiyuan. For these reasons, Taiyuan Fertilizer Plant was shut down and moved out of Taiyuan City in May, 2011 in order to ameliorate the environment of Taiyuan City and redress the imbalance between water supply and demand.
Figure 2.4 Total Quantity Control of Water Resources (Quota System)

(Source: Zhang Wenzhong, 2013)

Figure 2.5 Quinxu County Water Resources Quota System

(Source: Li Futian, 2013)
What needs to be done as a matter of priority in Shanxi is to improve the system by precisely establishing – in addition to groundwater - the amount of surface water and water diverted from river inflows (Yellow River Diversion) available for each region. Once this is determined, quota for surface water, groundwater and diverted river inflow can be decided for different districts (municipalities and counties).

A system should be built that combines total quota for the planning period and for each year. Meanwhile, it is also important to have in place mechanisms that encourage and guide water saving practices, and the development and utilization of unconventional water resources (reclaimed water, mine water), as discussed in the other section of this chapter. The total water quality control will consist of four levels:

- **Water quota by different sectors:** This refers to the allocated quotas of surface water, groundwater and water diverted from exterior rivers (in particular the Yellow River) for each sector. Quotas are allocated to various sectors in accordance with different periods of time and the availability of local water sources. At present, the water allocation for Shanxi Province is 7.64 billion m$^3$ by 2015, 9.3 billion m$^3$ by 2020, and 9.9 billion m$^3$ by 2030.

- **Water quota for different regions:** Water quotas are determined for each municipality and county in accordance with the availability of the water resources and the level of their social and economic development. This may take into account the proposed geographical restructuring of the Province with more economic activities re-allocated to water-rich mountain areas. The water quotas will guide the management of water resources by each region.

- **Water quota for different villages:** Water rights are basically allocated in accordance with the amount of controllable water resources after a comprehensive analysis and assessment of the quantity, type and distribution in time and space of controllable water resources in the county.

- **Water quota for individual users within the village,** be they industries, farms, domestic consumption or ecological services.

In other words, a four-layer allocation mechanism should come in place following the Qinxu model (see Figure 2.5). This quota system needs to be complemented by a water market mechanism, whereby there excess water quota are traded. This will be to encourage the use for high efficiency purposes. The Qinxu system has been a pioneer of applying this total water quality control in Shanxi and in the PRC. It combines the application of water quota, the use of automated well operation systems and swipe cards and the possibility of water trading.

### 2.2.6 Next challenge: regulation through economic and land use planning

Beyond the regulation that is now in place, there is a need in the future to make a strong connection to the planning of economic activities in Shanxi and the presence and availability of groundwater, especially in areas where groundwater is scarce and overused as in Shanxi. Ultimately, high water consuming or polluting activities needs to be phased out and reallocated to areas with higher water potential. Moreover, the economic base may be restructured towards a more diversified and circular, low carbon economy.

#### 2.2.6.1 Economic land use planning

The first element is to create a better balance with respect to the location of the main economic activities. An overall plan should be made for allocating water to various sectors of the national economy and to base the location of the economic activities on the availability of these resources. The social and economic development of a region should not exceed the carrying capacity of its (ground) water resources. At regions or valleys where water resources are scarce and water supply falls far behind demand, input and output efficiency benchmarks should be used to
decide whether or how to exploit and utilize water resources. Any construction project that demand a high consumption of energy but yields a low output or produces heavy pollutions should be prohibited. An optimized plan should be made to integrate water resources of all kinds: groundwater, surface water as well as unconventional water sources.

Shanxi Province is short of water and the distribution of water resources is uneven in the Province. On the other hand, most social and economic activities of Shanxi are concentrated at the central basin areas, which are the areas with the largest cone of depression (see also Figure 1.9, 1.10 and 1.11).

A geographical transformation of economic activities is required in the mid to long term. It is imperative to control the scale of development of the central basin areas and to curb any newly built industries and enterprises at the areas. It is suggested that urban and industrial activities should be spread out along the two mountainous areas in the east and west of Shanxi. Only in this way the imbalance between water supply and demand at the central basin areas can tackled. Also by so doing, we can tap the full potential of the comparatively rich storage of water resources at the two mountainous areas, and narrow the gap between the sub-developed mountainous areas and the developed central areas of Shanxi.

The 0188-Project, described in Chapter 3 gives a number of examples of introducing efficient and high yielding economic activities in these now poverty-stricken areas.

**2.2.6.2 Economic restructuring**

The second element is the restructuring of the economic base. Shanxi Province’s economic base is dominated by coal, metallurgy, electrical power and chemical industry. The four industries account for over 70% of Shanxi’s Gross National Income and are responsible for more than 80% of the total industrial water consumption of the Province. The current on-going economic transformation in the country provides opportunities to diversify and come to a cleaner industrial base with a much higher productivity per unit of water and lower pollution loads.

Shanxi Province should build on its competitive position in coal production, but broaden its services and outputs including the development of equipment manufacturing and coal chemical industry. Efforts should be made in developing coal mining machinery, railway equipment, heavy machinery, textile machinery, hydraulic component parts, automobiles and automobile parts, new energy equipment and energy saving devices. Relying on its rich storage of coal and coal bed methane, Shanxi can and should develop new coal-based chemical industries, for example, making oil, olefin, natural gas, or glycol with coal.

In this transformation, the concept of low-carbon economy should be embraced in traditional industries as coal production, coking industry, metallurgy and electrical power and a low-carbon industrial energy base should be built. Coal mining and industrial wastes like gangue, fly ash, smelting slag, waste water, and waste gas should be fully re-utilized. Gangue, for example, can be used for power generation and making new construction materials. Similarly, fly ash and smelting slags can also be used to make new types of construction materials. Efforts should be devoted to develop a circular economy, to promote energy conservation and waste discharge reduction and to develop low-carbon and clean energy sources. Enterprises should be encouraged to build circular production to combine circulating industries. In particular, coke oven gas, coal bed methane, blast furnace gas, biogas and urban waste should be utilized comprehensively. The potential of gangue, reclaimed water, and coal mine water should be fully tapped. It is suggested that circular industry parks be built in Shanxi so as to promote circular economic development in an integrated way. Industrial policies should be linked with environmental ones so that industrial development can go hand in hand with environmental protection.
### Table 2.2 Shanxi Province Standard for the Levy of Water Resources Fees

<table>
<thead>
<tr>
<th>Water Source</th>
<th>Water Types</th>
<th>Purposes of Water Use</th>
<th>Rate (Yuan/m³)</th>
<th>Non-excessive Exploitation Area</th>
<th>Excessive Exploitation Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water use within quota</td>
<td>Water use exceeding quota</td>
<td>Water use within quota</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Below 20%</td>
<td>20% or Above but below 40%</td>
<td>40% or Above but below 60%</td>
</tr>
<tr>
<td>Ground Water</td>
<td>Self-provided water source</td>
<td>Water for special uses</td>
<td>10.00</td>
<td>20.00</td>
<td>30.00</td>
</tr>
<tr>
<td></td>
<td>Urban public water supply &amp; Water conservation water supply</td>
<td>Water for special uses</td>
<td>4.00</td>
<td>8.00</td>
<td>12.00</td>
</tr>
<tr>
<td></td>
<td>Water use for industries, businesses, commercial service industries</td>
<td>Water for special uses</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>Water use for administrative and public departments</td>
<td>Water for special uses</td>
<td>0.50</td>
<td>1.00</td>
<td>1.50</td>
</tr>
<tr>
<td>Mining waste water</td>
<td>Mining (the amount of discharged water)</td>
<td>Water for special uses</td>
<td>1.20 (3.00, a temporary rate as per the No. 200 Shanxi Pricing Decree in 2009)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Surface Water</th>
<th>Self-provided water source</th>
<th>Water for special uses</th>
<th>Water use exceeding quota</th>
<th>Water use within quota</th>
<th>Water use exceeding quota</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Urban public water supply &amp; Water conservation water supply</td>
<td>2.00</td>
<td>4.00</td>
<td>6.00</td>
<td>8.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Water use for special uses, businesses, commercial service industries</td>
<td>0.50</td>
<td>1.00</td>
<td>1.50</td>
<td>2.00</td>
<td>2.50</td>
</tr>
<tr>
<td>Water use for administrative organs</td>
<td>0.25</td>
<td>0.50</td>
<td>0.75</td>
<td>1.00</td>
<td>1.25</td>
</tr>
<tr>
<td>Cross-flow cooling water use in coal-fired power generation (Yuan/kwh)</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water use in hydropower generation (Yuan/kwh)</td>
<td>0.005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2.6.3 Agricultural restructuring

Agriculture is the largest water user in Shanxi Province and agricultural water use takes 65% of the total water consumed in the whole Province. The amount of groundwater used for agriculture accounts for 49% of the total amount of groundwater exploited in the whole province. The promotion of efficient water saving agriculture can maximize the use of rainwater for irrigation and is an effective way to adjust agricultural structure and to control the amount of water consumed.

- Phase out crops that have low economic output per unit of water and specialize more in high value crops and market chains that create additional value.

- Advanced water-saving irrigation methods that suit local conditions should be promoted, such as pipe irrigation, sprinkler irrigation, drip irrigation, micro irrigation and root irrigation. Proper management and maintenance of water-saving irrigation facilities should be ensured, as discussed in section 2.4.

- Drought-resistant crop varieties should be promoted in order to save water. High water-consuming crops like paddies should be avoided in water-scarce areas.

2.3 Controlling the demand of water in agriculture

The quota system and the other regulatory measures give a strong incentive to reduce the demand for water in agriculture in Shanxi, particularly in the central basin area, that where the cones of depression have developed. The need to control and reduce water in agriculture is obvious: irrigation remains the largest consumer of water—in Shanxi as in most other parts of the world. Agricultural water use accounted for 67.4% of water consumption in Shanxi. Advanced irrigation technologies are being introduced but their coverage is still below expectation. At present, more than 95% of the irrigated
areas in Shanxi Province still use the traditional inefficient border irrigation systems. In managing groundwater demand in Shanxi addressing water productivity in agriculture is a main task.

Efficient and water-saving agriculture make maximum effective use of natural precipitation and irrigation water. Through a range of measures, in (i) engineering, (ii) crop agronomy, (iii) field water management including soil management, one cannot only reduce water losses, but also increase the output and value of unit water consumption. Better water management not only reduces water use but also makes it possible to get a higher yield and a better quality of crop. In this section the most important ways to reduce water and get higher water productivity are discussed.

### Table 2.3 Methods for Achieving Higher Efficiency in Agricultural Water Management

<table>
<thead>
<tr>
<th>Engineering measures</th>
<th>Agronomic measures</th>
<th>Management techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprinkler irrigation</td>
<td>Tillage techniques</td>
<td>Irrigation scheduling</td>
</tr>
<tr>
<td>Micro-irrigation</td>
<td>Mulching</td>
<td>Soil moisture forecasting</td>
</tr>
<tr>
<td>Conveyance pipes</td>
<td>Soil conditioners</td>
<td>Irrigation monitoring</td>
</tr>
<tr>
<td>Plastic mulch</td>
<td>Balanced fertilizer and IPM</td>
<td></td>
</tr>
<tr>
<td>Canal lining</td>
<td>Drought resistant varieties</td>
<td></td>
</tr>
<tr>
<td>Improved field irrigation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### 2.3.1 Engineering measures for efficient agricultural water use

There are several engineering solutions that can make a major contribution to higher water productivity. Such hydraulic engineering solutions include sprinkler systems, micro-irrigation and conveyance pipes that are particularly useful in groundwater irrigation, often in combination with plastic mulch. In surface water irrigation, canal lining and improved field irrigation (including the use of plastic mulch) are important ways forward.

(1) **Sprinkler irrigation**

Sprinkler irrigation delivers pressurized irrigation supply. They sprinkle water in the air and irrigate as if through rainfall. Its outstanding advantage is the strong adaptability to topography, ability to automation, the high irrigation equitability and the possibility to regulate air humidity and temperature. Sprinkler systems are especially suitable for permeable soils and sloping land.

Comparing sprinkler irrigation with traditional field irrigation, sprinkler irrigation can save 30%–50% water and increase production by 10%–30%. It is important, particularly in sprinkler systems, to understand that there is a difference between gross and net water losses: some of the water saved by sprinkler systems is not really lost otherwise, as it could also be recouped as it would have recharged the groundwater. In sprinkler systems, there is less recharge and in fact most of the water that is lost in sprinkler systems is irretrievable, because it is lost to the atmosphere.
A main gain in sprinkler irrigation is that they increase crop yields as they reduce the incidence of pests and diseases. Therefore, sprinkler irrigation has become the main technique for higher water productivity. The technique is already mature. However, in the future more improvement can be expected, in development of low cost of sprinkler irrigation equipment as well as the use of micro-sprinklers. In Shanxi province, sprinkler irrigation systems should be given priority in high economic value crops.

(2) Micro-irrigation

Micro-irrigation includes several techniques: drip irrigation technique, micro jet irrigation and bubbler irrigation. Compared with traditional field irrigation technique, micro irrigation may save up to 60% water, though again there is difference between gross and net gains, as with the sprinklers. Of all the irrigation techniques, water utilization is highest in the different micro irrigation systems.

*Drip irrigation:* Drip irrigation delivers water to the roots of crop directly through a set of plastic tubes. Through drippers, water is emitted on the surfaces close to the roots. It then infiltrates the soil, soaking the most developed root area of the crop root. In some countries, such as Tunesia, the drip is located inside the soil, directly feeding the roots. The outstanding advantage of drip irrigation is its high efficiency, possibility of automatic operation and ability to manage optimal soil humidity.

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% (for some crops it can reach even 85%). Compared with sprinkler irrigation, drip irrigation can save 15%~25%. Drip irrigation can be combined with fertigation: dissolving fertilizer and other agro-chemicals with the irrigation water ensuring maximum efficiency in supplying nutrient and reduce pollution. Importantly this saves costs, but also labor inputs and time. As drip irrigation provides ‘just enough’ moisture for crop, it is difficult for weeds to grow, which reduces the labor to do the weeding. The disadvantage is 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 zone.
The drip irrigation system that is used in the pilot project: the left picture is a panoramic view of the greenhouse with drip irrigation system and the right picture is a section of the system
(Source: ADB Grant Project 0188 – PRC Qi County Pilot Project, 2012)

*Micro-spray or micro-sprinkler:* In micro-spray irrigation water is sprayed on the soil surface with small suspended sprinklers (micro sprinklers). The working pressure of nozzle in these systems is almost the same of the drippers. Because the wet area of micro sprinkler is bigger than the dripper irrigation, the flow can be larger. The spray orifice can be larger, and the flow velocity is much larger too so in compared to drip irrigation the possibility of blockage is reduced.

Micro-sprinklers have large potential for the high economic value crops, particularly where there is lack of water resources.

The suspended micro-sprinkler system is used in a mesh tent.
(Source: ADB Grant Project 0188 – PRC Pingshun County Pilot Project, 2012)
**Bubbler Irrigation:** Bubbler irrigation or ‘spring’ irrigation is an advanced water-saving irrigation technology. 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 wetted. The larger opening emitter 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 are equipped with a filter to assure water quality and also 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 their cost.

(3) **Low pressure conveyance pipes**

Low-pressure conveyance pipes, either PVC or galvanized iron, have been a breakthrough in groundwater irrigation. They have improved irrigation water use efficiency and have also made it possible to reach land that was otherwise difficult to bring water to. Low pressure pipes have had wide application in the north of PRC. Though the technology has been more mature, there are some issues yet to be studied such as the pipe material, the connecting parts and ancillary equipment, the industrialization of product.
(4) Plastic mulch

Drip irrigation, as described above, can be combined with the use of plastic mulch. This sees the drip lines covered by the 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, raises and controls soil temperature making it possible to cultivate earlier and later. The warmer temperature and moist conditions stimulate also the natural nitrogen-fixation in the soil and reduce the need for fertilizer. In the particular case of drip systems combined with plastic mulch the advantage is that the drip systems do not easily age. An area for further development is to improve the bio-degradability of the plastic mulch and even to add plant nutrients.

Compared with surface irrigation, yields can increase by more than 20% and water-saving can be 40%-50%. The utilization rate of chemical fertilizer can be improved 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. The Ministry of Water Resources has recently planned to promote in Shanxi 200,000 ha of the efficient drip irrigation under film in the northern part of the Province.

The plastic film mulching that is used in a pilot project.
(Source: Shanxi Province Shouyang Plastic Mulching Demonstration Project, 2007)

(5) Canal lining

Whereas the previous engineering solutions are very appropriate for groundwater based systems, there is also much to gain in more efficient use of surface water. Canal lining is one of the effective measures to reduce water losses in surface irrigation. This can be done through a variety of types of materials: from geo-textiles to concrete lining. The high cost of the seepage control, management difficulties and freeze-thaw damage are main restricting factors for promoting canal seepage prevention measures. The use of lower cost impermeable material, the adequate maintenance, the protection of freeze-thaw damage and the economic viability of seepage control measures need to be further studied and resolved.

The canal seepage prevention system of Fenhe River Irrigation Administration
(Source: Shanxi Province Fenhe River Irrigation Administration, 2011)
(6) Improved field irrigation
At present field flood irrigation techniques still dominate in the Shanxi Province. Loss of irrigation water occurs in two ways, in the water distribution system and in the field irrigation network. Over the past decade, under the leadership of the Ministry of Water Resources, much investment has taken place in large and medium-sized irrigation districts, mainly through the upgrading of the main canals and branch canals. Reducing field water losses in the irrigation system becomes the next important task for water saving in the PRC.

According to surveys, the effective utilization coefficient of irrigation water for field gravity irrigation district network in Shanxi ranges between 60-70%, or even lower. This has considerable lower than the 90% specification common in irrigation and drainage engineering design. It is clear that the focus of agricultural irrigation water-saving is at field level. Changes here, moreover, are relatively low cost.

The most promising developments in efficient surface irrigation technology include: development and application of laser graded land leveling; improved furrow and ditch specifications, and optimized field irrigation methods such as flat furrow irrigation; alternate furrow system brake-pipe irrigation and other advanced field irrigation systems.

2.3.2 Agronomic measures for efficient agricultural water management

The second major category of measures that can reduce water consumption in agriculture, without effecting yields are agronomic improvements. In fact agronomic and engineering water-saving technologies are complementary.

Engineering measures, as mentioned earlier, reduce the leakage and seepage loss in the conveyance and irrigation system. Most of this leakage and seepage loss, however, is also reused: hence they do not constitute a full real loss. Agronomic water-saving technologies, on the other hand, can reduce the soil moisture transpiration, evaporation loss and improve crop yields, so agronomic water conservation is conservation of water resources in the true sense of the savings.

Two typical agronomic measures: one land leveling and the other mechanized agronomy
(Source: Shanxi Province Xiaohe River Irrigation Area, 2011)

Agronomic water-saving technologies include the adjustment of crop planting systems, selection of drought-tolerant and high-yielding varieties, uses of mulching, including the plastic films, controlled fertilizer application and chemical control. All these measures reduce the field water consumption and increase the crop yields: these two factors combined increases water productivity considerably. The combination
of agricultural water-saving technologies with engineering water-saving technologies can improve the efficiency of water use even more. The most common agronomic water-saving technologies currently used are:

- Improved tillage
- Mulching
- Using soil conditioners
- Drought resistant crops

(1) Tillage-based soil moisture conservation techniques

By deep plowing to mix soil moisture, by applying organic fertilizer—including bio-fertilizer (see Box 2.4)—the soil structure is improved: the active soil layer is increased, rainwater infiltration velocity and infiltration volume is enhanced and runoff losses reduced. If soil mulching through planking is introduced, then capillaries are closed off, which reduce soil moisture evaporation and preserves soil moisture.

In rain-dependent crops, important gains in preserving moisture through improved tillage have been achieved too (see Box 2.5).

(2) Mulching (including plastic mulching)

Covering the surface of cultivated land with plastic film, straw and other materials will inhibit the evaporation of soil moisture. It reduces the surface rainfall runoff, which improves the utilization rate of water. In addition, mulching is increasing soil temperature, soil fertility and is, improving the soil physical shape.

(3) Soil conditioners

Water retention agents, plant transpiration agent and soil conditioners form a third category of agronomic water saving measures. With the help of these measures the drought-resistant ability of soils can be enhanced for the purpose of water saving and increasing yield. A water retention agent is a macromolecular compound attracting 400 to 1000 times its own weight in water.

More than 85% moisture is free water available by plants. The use of those soils conditioner can increase crop yield by 8% to 20%. Using the methods can improve soil water retention capacity, and reduce crop transpiration losses.

A particularly promising product in Shanxi is the use of zeolite. Zeolite is volcanic clay, which occurs in large areas in the Province (see also section 2.5.4).
Box 2.4 Bio-fertilizer

Bio-fertilizer is made by digesting organic waste material, wood ash/ charcoal, sugars catalyzed with enzymes. Fresh unpolluted and untreated water has to be used (like rainwater). If rock dust it is added the weathering process is accelerated and the bio-fertilizer will be rich in minerals. The important advantage of bio-fertilizer is that it builds up better soils rather than just adding short term nutrient to it. Cost wise it compares with regular fertilizer and it can also help to convert a waste product in a useful input. In Shanxi Kaisheng Industries is a pioneer in bio-fertilizer as well as other bio-remedians.

Shown in the picture is the fungi fermentation plant of Shanxi Kaisheng Fertilizer Plant.
(Source: Shanxi Kaisheng Fertilizer Plant)
Box 2.5 Moisture Conservation through Improved Mechanized Tillage

Path breaking research has been done by the Dry Land Farming Centre of the Shanxi Agricultural Academy in China. The main contention is that much of the measures to maximize the use of soil moisture in dry land farming are time-consuming and laborious. Traditional methods such as mulching, leveling and harrowing are very important to get more out of ‘green water’ – but they demand much labor too and this with an aging rural population becomes a constraint. There are moreover improved methods to increase the water productivity of dry land farming beyond what is traditionally done by hand.

Take for instance the cultivation of wheat – to make maximum use of the water availability a ridge of 12-14 centimeter height and 30 centimeter wide is proposed with four dense planting lines of wheat (see picture). The dense planting ensures a dense canopy of leaves and reduces soil evaporation. The ridge covered with plastic mulch ensures in-field water harvesting and also reduces moisture loss. Yield increases with 15% over the practice of two wheat row wedged between strips of plastic mulch and even more over more traditional methods.

To achieve the improved methods requires a level of intense labor and precision that is difficult to achieve without the help of tractor with special mounted equipment.

Another example is a multi-functional corn seeder, capable of supplementing water, ridging, mulching, applying fertilizers, and sowing precisely. In the process of sowing, the tractor-mounted seeder achieves several agronomic drought-resistant and yield-increasing measures at one go:

- Supplementing water during sowing from a water container that is part of the corn seeder
- Mulching and moisture retention
- Plastic ridge mulching, ditch planting – leading to in field water collection
- Deep sowing and fertilizer application, boosting plant production
- Dense planting for high yield technique.

Shown in picture is a special agronomic way to plant wheat with four rows of dense wheat and a row of plastic mulch in between to better keep the soil moisture.
(Source: the Dry Land Farming Centre of the Shanxi Agricultural Academy in China, 2013)
(4) Balanced water-fertilization use or integrated nutrient management

Water-fertilizer coupling is an integrated nutrient management system, based on the content of soil nutrients and nutrition, the supply rate, the demand volume and uptake of crop nutrients. It is combined with efficient irrigation methods and will help reduce pollution. In terms of nutrient composition and water-fertilizer coupling techniques, there are a number of technical issues that need to be addressed.

The left picture shows a sign board detailing a formula to combine the use of different fertilizers; and the right picture also a sign board announcing an experiment to protect dry-land farming with both agronomic measures and fertilization methods.

(Source: Shouyang Experimental Field of Shanx Province Institute of Agricultural Sciences, 2005)

(5) Using drought-resistant varieties

Cultivation of the water-saving and high-yielding varieties is an important way to improve crop yields. Cultivating drought-resistant and high-yielding varieties is a new direction of crop breeding.

It is an essential measure of improving the agricultural water productivity. The main challenge in plant breeding at the moment is combing high yields with drought resistance. In addition to breeding for drought resistance, more work is needed on breeding for other factors, such as salinity tolerance.

2.3.3 Water-saving through better water management

Next to water saving by engineering and agronomic measures, there is a considerable scope for improvement through better water management. Better water management combined with other measures can multiply the impact on water saving and we can get twice the effect with half the effort. Some main management water-saving technologies are in the following areas:
(1) Better irrigation scheduling

Better irrigation scheduling holds an important key to higher water productivity. In order to obtain maximum yield, we have to promote and control crop growth and development according to physiological characteristics of crops, and through irrigation and agronomic measures regulate soil moisture. Crops differ in their demand for water at different developmental stages and it is possible to optimize here. For example, wheat used to be irrigated 5-7 times every year in the past, but now this is reduced to only 2–3 times; yet, production increased significantly. Also spectacular improvements have been achieved with other crops, such as rice (see Box 2.6).

Box 2.6  Improved Irrigation Agronomy: System of Rice Intensification (SRI)

In recent years, rice cultivation in different parts of the world has achieved higher yield with less water use by applying “alternate wetting and drying” methods—following a global movement called System of Rice Intensification (SRI). By early transplanting and not inundating the rice fields constantly, the root systems of the rice develop better. With this, rice can do with less water and yields can go up.

Regulated deficit irrigation is a new irrigation method which is based on traditional irrigation principles and methods. It was proposed in the mid-1970s. It is based on the genetic and biological characteristics of the crop. At some stages of the growth period, crop is imposed a certain degree of water stress (deficit) artificially, which causes it to adjust its photosynthetic processes and develop more vigorous growth.

Shown in the picture is a comparison between the roots of the rice planted with traditional method and that with “alternate wetting and drying” method

(Source: Frank van Steenbergen, 2013)
(2) Soil moisture monitoring and irrigation forecasting

With the aid of the weather forecast and advanced scientific and technological means, the optimum irrigation time and irrigation amount can be forecasted, which makes irrigation more timely and applied at the right amount. Soil moisture content can be controlled effectively to achieve the goals of water-saving and increase production. The technology is still in the research and pilot phase.

![Soil moisture monitoring and irrigation forecasting](image)

The irrigation forecasting system of Shanxi Province Central Irrigation Experiment Station (left picture) and that of Loufan Hydrological Station (right picture)
(Source: Shanxi Province Central Irrigation Experiment Station, 2007 and Shanxi Province Loufan Hydrological Station, 2011)

(3) Measuring and distribution of the water consumption in irrigation areas

To realize efficient water use, optimum water distribution and reasonable scheduling, water regime can be improved and mastered by the managers in irrigation areas in a timely and accurate manner, which is the basis of technology engineering for the implementation of water-saving irrigation. The technology still needs to be studied in equipment, data acquisition, computer processing, and automation.

![Measuring and distribution of the water consumption in irrigation areas](image)

Shown in the left picture is the controller of well water use of the smart water management system and in right picture a system schematic diagram.
(Source: Qingxu County, Shanxi Province, 2007 and Shanxi Province Wenyu River Irrigation Area, 2011)
(4) Promotion of efficient water use integrated technology

Currently, it may not be ideal to rely on single water-saving technology. If the engineering water-saving technology, agronomic water-saving technology and management water-saving technology are integrated into some complete sets of water saving technology, it can obtain maximum and co-optimized effect. Efficient water-use technologies—which are suitable for different regions, different natural conditions and social economic conditions—should be researched, integrated and shared with large groups of agricultural water users. The introduction of these measures is very much related to effective regulation and management of groundwater resources in a region. Local groundwater governance is important to promote the rational development, utilization, conservation, configuration and protection of water resources. Local governments coordinate the water use of the various departments. In addition, economic incentives should be activated (see also section 2.7). The adaptation of agricultural water-saving measures will strongly benefit from the application of water-use quota, the introduction of pricing, the enforcement of water-use permits, and the trade in it through water markets.

Water-saving in agriculture relies on a set of interlocking measures—on the policy and regulation side and on the use of a series of promising techniques. In addition it requires the close engagement of the person that is directly in charge of water use in agriculture, i.e., the farmers. It is important to closely engage through education and awareness, and encourage through the right set of incentives and availability of high quality solution. Chapter 3 of this report is an example of how this was achieved under the 0188-PRC Grant project.

Figure 2.7 The Schematic Diagram of Policies and Regulations

(Source: Qingxu County, Shanxi Province, 2006)
2.4 Water saving in industry

Being the second largest water user, water saving in industries is an important part of groundwater management in Shanxi Province. The compulsory water demand assessment of infrastructure investments—under Order No. 15/2002 by the Ministry of Water Resources and the State Planning Commission—is an important instrument in this respect. In general, all over the world, there is the understanding that we should not just prevent negative environmental impact but be more pro-active and emphasize positive contribution of industries to water management in water saving and water treatment (see Box 2.7).

There is often much scope to turn a waste product into a productive asset, which is also the central thinking in the circular economy.

2.4.1 General policy directions

Some of the most important policy directions for water saving in industry are:

- High water-consuming techniques, equipment and products should be eliminated as soon as possible.
- Enterprises that cannot meet mandatory requirements for water withdrawal should also either be eliminated or upgrade their outdated technology.
- Water-saving techniques and equipment should be widely promoted, such as re-use for industries, efficient water-cooling technologies, effective water saving for thermo systems and technical process flows, water saving for washing, industrial water supply and waste water treatment, and the use of unconventional water resources.
- Water withdrawal quotas allocated to major industries should be closely supervised. The State and Shanxi Province Water Withdrawal Quotas Standards should be strictly enforced and enterprises which exceed their quotas be ordered to correct their practice within prescribed timeframe.
- Strict control should be imposed on the launching of new highly water-consuming industrial projects. Especially for the central basin areas where water supply is inadequate and falls far behind demand, regional industrial structure and layout should be adjusted in accordance with its water resources conditions (see also section 2.2.5).
Shown in the picture are some industrial water-saving facilities  
(Source: Zhang Wenzhong, 2013)

Box 2.7  Examples of Saving Water through Public-Private Partnerships

The town of Terneuzen, located on the southwest tip of the Netherlands, is home of a special public-private partnerships in the area of water management. Working together with a local water company, The Dow Chemical Company consumes 7,500 cubic meters of treated wastewater from the Terneuzen community every day. In the past, the Dow facility used desalinated water for its steam generation and industrial processes. Meanwhile, the municipal effluence was treated and released to a nearby estuary. Currently, the municipal waste – which is less expensive and requires 65 percent less energy to demineralize than saltwater by Dow – is treated using reverse osmosis and sent directly to the Dow plant. Everyone benefits from this partnership. The town gets its water treated and the company has a less expensive source of industrial water. In addition, Dow has reduced its wastewater per unit of product by 35%.

Another example comes from South Africa. This public-private partnership project that was jointly carried out by Anglo American, BHP Billiton Energy Coal South Africa (BECSA) and the eMalahleni Local Municipality, and has been described as a “world class initiative and an exemplary model for development”. Anglo American and BHP Billiton worked together to commission the eMalahleni Water Reclamation Plant (EWRP) in 2007. The plant was established to treat the water from three Anglo American Thermal Coal operations, and BHP Billiton obtained a “right-of-use” of the EWRP to treat water from its South Witbank Colliery on the basis of shared operating costs. In addition, Anglo American has put in place infrastructure and agreements with the city of eMalahleni to deliver treated water from the plant into the local municipality’s drinking water system. The plant operates at a 99% water recovery rate and the ultimate goal is for it to be a zero waste facility through the 100% utilisation of its by-product. The EWRP currently treats around 30 Million litres of water a day, providing a safe and secure water source. Some of this treated water is used directly in Anglo American mining operations, but the majority is for social use and meets 12% of eMalahleni’s daily water needs. By the end of 2011, the plant had treated 30 billion litres of contaminated mine water and supplied 22 billion litres to eMalahleni Local Municipality.
Good practices—such as water recycling and reuse, and treatment of industrial waste water for reuse—should be advocated for enterprises. As for water treatment, it is critical to adopt efficient, safe and reliable technologies. Efforts should be made to improve the utilization rate of recycling water and to reduce the amount of water needed for the production of every single product. A spectacular improvement was achieved in this respect by Taiyuan Iron and Steel Group Co., Ltd. (TISCO) Steel Plant in Taiyuan: water consumption per unit output was reduced to less than 5% (see Box 2.8).

Also, waste water should be adequately treated and possibly turned into a usable resource, and the amount of waste water discharged from water recycling systems be controlled. In particular, professional operations and management approaches such as centralized water supply and waste water treatment should be introduced to Industrial Parks and Development Zones, so as to realize an optimized sequential ‘cascade’ utilization of water resources.

The use of unconventional water resources as mine pit wastewater, rain water, resurgence water, brackish water and so on should be encouraged. It is quite common now for large industries in different parts of the world to secure part of their own water supply by developing water-harvesting systems around their plant and become ‘water neutral’.

**Box 2.8 Closing the Water Loop in Industries**

To save water, Taiyuan Iron and Steel Group Co., Ltd. (TISCO) has upgraded all its production techniques and technologies and made great efforts in recycling and reusing waste water. TISCO has built four waste water treatment projects: Reverse osmosis treatment, dual water supply & drainage pipe network, municipal wastewater recycle and reuse, advanced reclaimed water treatment. As a result, TISCO’s water consumption per ton of steel has reduced from 21.05 m$^3$ to 1.28 m$^3$ and its industrial water reuse rate reached 97.96%. TISCO has not only improved its water use efficiency but blazed a trail in waste water treatment; conversion of waste into resources; matching different water supplies for different purposes; water saving and pollution reduction.

*Shown in the picture is TISCO’s waste water treatment system.*
(Source: Taiyuan Iron and Steel Group Co. Ltd. 2013)
Waste water treatment is a major part of industrial and urban life cycle water saving. Following the principle that ‘high-quality water is used for high purposes’, we should utilize all types of water resources—allocating water of different qualities for different purposes. This is especially important for cities where groundwater has been excessively exploited. Surface water (including water diverted from the Yellow River) should be used mainly for industrial productions, whereas superior quality groundwater is reserved for urban drinking water. Waste water—having been treated and meeting the required standard of quality—can be reused for industrial production, urban landscape greenery, as well as agricultural irrigation.

Water prices, effluent charges and fiscal incentives are effective demand management tools for improving water quality and managing the use of the total water resources in the industrial sector elsewhere in the world. They can provide several benefits to industries, the society and the environment. First, conservation may reduce costs to society where the marginal cost of water supply is rising. Second, conservation and recycling may result in savings of up to 80 percent of intake water in industries. Lastly, conservation and recycling may reduce the amount of liquid effluent discharged and may improve water quality in rivers and streams. (Bathia et al. 1994)

Some international good practices maybe considered systematically:

1. Conduct regular audits to quantify water use in industries;
2. Compare water use to industry benchmarks, if available, and publish these;
3. Learn from water-saving success stories of industry peers (see Table 2.4);
4. Systematically investigate the feasibility of the following options in operations:
   - Reduce the flow of water
   - Modify the equipment or install water-saving devices
   - Replace existing equipment with more water-efficient equipment
   - Water treatment, recycling and reuse
   - Change to waterless process
5. Educate employees about the importance of using less water;
6. Use non-potable water for industrial processes.

In industry, water-saving measures can have multiple benefits, including reducing water and wastewater costs, reducing pre-treatment costs, reducing energy costs, reducing chemical cost, increasing chemical and metals recovery rates, and reducing pollution emissions. Below are some examples of multi-functional water-using measures in some selected industries.

Shown in the picture are industrial water metering devices.
(Source: Zhang Wenzhong, 2013)
Table 2.4 Water-Saving Options for Different Business Types: Some Successful Practices

<table>
<thead>
<tr>
<th>Office buildings</th>
<th>Metal industry</th>
<th>Beverage industries</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Use high-efficiency water systems, including toilets</strong></td>
<td>Plumb facilities for counter current rinsing</td>
<td>Provide adequate metering for process control</td>
</tr>
<tr>
<td><strong>Avoid automatically timed flushing systems</strong></td>
<td>Use conductivity controllers for rinse tanks</td>
<td>Design the facility for ease of cleaning</td>
</tr>
<tr>
<td><strong>Use self-closing faucets for hand washing</strong></td>
<td>Install automatic shutoff valves on all hoses</td>
<td>Take advantage of dry methods for clean-up and transport</td>
</tr>
<tr>
<td><strong>Use energy-efficient cooling systems</strong></td>
<td>Re-circulate water and/or use waste streams as make-up water for fume scrubbers</td>
<td>Use product and by-product recovery systems</td>
</tr>
<tr>
<td><strong>Use closed-loop heating systems</strong></td>
<td>Employ good tank design</td>
<td>Consider all possible opportunities for water recovery and reuse and for alternative water supplies</td>
</tr>
<tr>
<td><strong>Install ice-making machines that are air-cooled.</strong></td>
<td>Mix or air-agitate tank contents</td>
<td>Design for minimal or no water use</td>
</tr>
<tr>
<td><strong>Use water treatment only when necessary</strong></td>
<td>Use multiple drag-out reduction methods</td>
<td>Provide adequate metering for process control</td>
</tr>
<tr>
<td><strong>Installing automatic-shutoff and solenoid valves</strong></td>
<td>Use filtration and water-treatment equipment where applicable</td>
<td></td>
</tr>
<tr>
<td><strong>Installing faucets on set tubs and janitorial sinks</strong></td>
<td>Employ reactive rinsing</td>
<td></td>
</tr>
<tr>
<td><strong>Install low-flow, high-pressure nozzles on hoses</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Separate metering of individual units.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Use high-efficiency water systems, including toilets</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.4.2 Water saving in mining

An area of special attention in Shanxi is the water management around mines and using the opportunities for treating and reducing mine process water. A good understanding of mine water management issues related to underground and open pit mines depends on collecting a comprehensive hydro-geological data set. With this information, a conceptual model can be constructed and later converted into a 3-dimensional numerical model to simulate and assess the mine development.

In mine industries, it is recommended to use exploration and geotechnical boreholes for hydro-geological monitoring purposes. Exploration holes can be used for hydro-geological and environmental data collection, producing large savings in cost and time. A properly structured and managed procedure to borehole development can result in an efficient, environmentally-sound and cost-effective hydro-geological data collection program. For instance, at one of the largest gold mine projects (Koza Gold) located in Western Turkey, geotechnical drills with depths ranging from 200-400 meters were used. Important features were tested and holes were converted to piezometers to monitor phreatic levels or groundwater response during pumping tests.

One novel development that is worth considering for Shanxi is the reuse of mine shaft and mine pits for groundwater storage. Such ‘man-made aquifers’ are now being piloted in South Africa. The main philosophy
is not to see mining as a finite extractive industry, but to plan the reuse of the shaft and pits for water storage in due time—if necessary back-filled with the mine excavation material. This requires systematic investigation of the water quality effects from the excavated layers and the mine operations. Water saving can be done in a range of mining operations, not only in the direct extractive activities but also in site management (as box 2.9 shows).

**Box 2.9 Dust Suppression and Water Saving**

Newmont Mining Corporation in the United States, one of the oldest and largest gold mining companies in the world, was facing challenges in its operations due to high dust levels. Severe dust levels on the mine roads were causing respiratory issues, reduced visibility, and concerns on the pollution from the water runoff. The dust on the roads was being controlled with a magnesium chloride solution that required roads to be treated by water trucks up to 18 times per day, amounting to more than 380,000 cubic meters of water used in the process during a seven-month period. In partnership with Newmont, General Electric Company developed a long-term dust suppression strategy based on an organic binding agent. The binding agent is applied to harden the road surfaces and make them dust-free. By reducing the frequency of road treatments, the dust suppression strategy helped Newmont reduce its water usage by 90 percent and decrease fuel consumption by 182,000 liters per year—saving $378,000 in operating costs annually.

**2.5 Developing alternative water resources and promoting to recharge of groundwater**

A target to reduce annual use of groundwater from 3.5 billion cubic meters (m3) to 2 billion m3 annually has been set. To relieve the pressure on groundwater use, alternative sources of water need to be developed - either from surface water sources or from reuse. These options are discussed in section 2.5.1 and 2.5.2. Another important avenue is to more systematically recharge groundwater from both rainwater, floodwater and peak flows as well as soil and water conservation in the mountain. This is discussed in sections 2.5.3 and 2.5.4.

**2.5.1 Increasing use of existing surface water sources**

According to the 2nd Assessment of the Water Resources of Shanxi Province, the utilization rate of surface water in Shanxi is 38.83%, which places Shanxi in the category of middle-level utilization Provinces in the PRC. Of all the surface water resources, the utilization rate of rivers like Qinhe, Daqinghe, Hutuohe, Zhanghe, and the rivers alongside the Yellow River is very low.

The utilization rate of Qinhe is only 4.95%, with a particularly large potential for exploitation. Over a long period of time (1956-2000), the average annual amount of water flowing out of Shanxi is 7.327 billion m3, 84.4% of the total runoff for the same period (Fan Duixiang et al. 2005). The reason most part of the surface water cannot be efficiently utilized is that there are no water conservation works on major rivers. As a result, a conjunctive water supply system, where surface water use from large-scale conservation works serves as the backbone and groundwater as its supplementary resource and buffer, has not come into being.

To meet the ever increasing demand of water and reduce pressure on ground water, more investment in water conservation works, especially works for surface water, is required. The development of Pingshun Reservoir and Wujiazhuang Reservoir in particular has to be expedited. In addition, since the founding of the People’s Republic of China, several Yellow River Irrigation...
Projects like Yumenkou, Zuncun and the Wanjiazhai Yellow River Diversion Project have been built along the Yellow River in Shanxi. The average annual amount of the Yellow River water utilized by these projects, however, is only one-fifth of the allocated quota to Shanxi, and a large part of the quota has not yet been exploited. The Yellow River should be a more important water source for Shanxi Province in the years to come and the existing Yellow River Irrigation Projects should be used more efficiently. The Wanjiazhai Yellow River Diversion Project and Central Area Yellow River Diversion Project should be promoted as the major ways to ease the water shortage in Shanxi.

2.5.2 Using non-conventional water resources

Treated and reused urban waste water and recycled coal mine pit water are also important substitutes for groundwater. The amount of waste water discharged in Shanxi Province reached 1 billion cubic meters per annum (m$^3$/a), but only less than 60% was treated and of this amount less than 10% is reused. Therefore, strict measures such as the promulgation of laws, regulations, policies or economic sanctions should be adopted to provide the framework for increased waste water reuse.

By the end of 2010, the municipalities and counties of Shanxi Province had all built their own waste water treatment plants. The capacity of all these water treatment plants have combined amounts of up to 2.48 million cubic meters per day (m$^3$/d), with the active capacity being 1.54 million m$^3$/d.

At present, waste water recycling and reuse projects have been implemented only in five waste water treatment plants in five cities of Shanxi: Taiyuan, Datong, Yangquan, Xinzhou and Linfen. The total capacity of the waste water recycling and reuse however is only 62,000 m$^3$/d. This reclaimed water is mainly used for industrial purposes and the reuse rate of the recycled water is very low. Dividing the amount of waste water treated each day, i.e. 1.1738 million m$^3$/d, by the reuse rate, the amount of reused water adds up to only 5.3% of the total discharged water and the rest of the recycled water is simply discharged into rivers. There still remains a great potential for further development. (Shanxi Province Development and Reform Commission, 2010)

Treated waste water from the dual water system in the TISCO factory (Taiyuan) is being used in some of the industrial processes.
(Source: Zhang Wenzhong, 2013)
2.5.3 Storage and use of rain and flood water

Better storage of rainwater and flood water can ‘add water’ and make a considerable contribution in alleviating scarcity. There are many ways to store rain and flood water—i.e., in storage tanks and ponds, in lakes, in irrigation canals, or in the soil and landscape. Table 2.5 gives an extensive overview. A few of these techniques are highlighted below:

- **Rooftop rainwater collection and storage system.** This system is mainly used by households, public utilities and industries. The reclaimed water is used mainly for non-drinking water purposes, such as irrigation, toilet flushing, laundry, and cooling cycle, etc. Rooftop rainwater collection can bring about multiple benefits—for example: saving fresh water, reducing urban waste water discharge and treatment, lowering the amount of pollutants discharged, and improving eco-environment, etc.

- **Community and park rainwater collection and storage system.** In newly built urban communities, parks or other places with similar environment, rainwater runoff can be collected and stored from rooftops, at green areas and alongside roads. This can greatly decrease the amount of storm water runoff and non-point source pollutants discharged in cities, optimize community water supply, reduce water logging, and improve environment. As these landscape systems are huge and cover a wide area, it is important to make sure that rainwater is properly intercepted and cleansed in the beginning, that the green areas and roads have proper height, and that both the indoor and outdoor rainwater storage and discharge systems are properly designed.

- **Groundwater recharge with increased rainwater infiltration.** Through various rain infiltration set-ups, rainwater infiltrates the ground to recharge and retain groundwater resources. This is an indirect way to utilize rainwater and can help alleviate land subsidence. There are two major technological approaches: (i) the decentralized infiltration technique; and (ii) the centralized recharge technique. The decentralized infiltration technique can be applied to various places, such as urban areas, residential quarters, parks, roads, and factories, etc. Depending on the specific local conditions, the scale of infiltration can be large or small. With a simple set-up, this technique does not require much investment in building rainwater collection and conveyance systems. With this technique, groundwater can be recharged and furthermore, runoff pollutants are effectively prevented from moving into groundwater with the filtering function of the surface vegetation and soil. The infiltrating speed is generally slow, however. The decentralized infiltration technique is very much constrained at places where groundwater table is high, soil infiltration capacity poor and/or rainwater heavily polluted. With the centralized recharge technique, groundwater is recharged with stored water in trenches, wells, ponds, blocked canals, weirs and lakes.

In Shanxi Province, precipitation is distributed quite unevenly and the inter-annual variation of floods is even more dramatic. Furthermore, most rivers in the Shanxi have short flow paths and steep slopes, with high sediment concentration and large sediment discharge. With the abrupt rises and falls of floods, it is hard to develop and store the flood water resources in reservoirs. From 1956 to 2000, the average annual runoff flowed out of Shanxi Province reached 7.33 billion m$^3$ (Fan Duixiang 2005), taking 84.4% of the total amount of surface water for the same period. In 2010, the amount of runoff flowed out of Shanxi reached 3.06 billion m$^3$ (Shanxi Province Department of Water Resources 2010), most of which are floods.
in the rainy season of the year. There are a number of ways to make better use of the flood water:

- **Fully utilizing flood resources through integrated scheduling of various water conservancy projects.** As precipitation in Shanxi distributes quite unevenly in time and space, engineering measures should be adopted to fully utilize flood resources. Through these engineering measures, a network of rivers is built which breaks various watershed boundaries and transfers water between different river basins. Subsequently, the amount of water abandoned at flood seasons can be reduced to the minimum and the amount of usable water resources for the whole Province increases. By so doing, we can store up excess water in fat years to make up for lean ones and better cope with droughts and floods.

- **Phased water level control and scientific scheduling of water storage.** On the premise that floods are safely controlled, phased flood water level control with information acquired through monitoring and forecast, can be adopted to scientifically schedule water storage at various dams.

- **Cascade development and utilization of mountainous flood resources.** Riverbed floods are intercepted and stored at water storage project facilities such as small reservoirs, embankments etc. in order to better regulate the time and space of water supply and to increase the amount of usable water.

- **Promoting spate irrigation to increase groundwater recharge.** During flood season, efforts should be made to fully utilize flood resources, like spate irrigation, flood warping land, etc.

Recharge is therefore an important element in groundwater management—where and where not to have rainfall infiltrate, and how to optimize this recharge process. Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate is the rate at which soil is able to absorb rainfall or irrigation. It is measured in millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, run-off will usually occur unless there is some physical barrier. Some water that infiltrates will remain in the shallow soil layer, as so-called ‘green water’ and some will gradually move vertically and horizontally through the soil and subsurface material. Eventually it may enter a river stream by seepage into the stream bank. Some of the water may infiltrate deeper, recharging groundwater aquifers. If the aquifers are porous enough to allow water to move freely through it, people can drill wells into the aquifer and use the water for their purposes.

Recharge can come from the interception of rain and run-off water or peak flows in rivers (natural recharge), from increased infiltration of natural processes by manmade interventions (managed aquifer recharge) or can be a by-product of some other factor (i.e., irrigation). Recharge at scale, therefore, requires managing natural recharge, applying artificial recharge, and controlling incidental recharge.

There are many techniques to improve recharge—some ancient and time-tested, some very innovative. They range from individual rooftop rainwater harvesting systems, small storage solutions and recharge wells to water harvesting at catchment level, as in spate irrigation. Small-scale water recharge works best if it addresses local household or community needs. Many systems are suitable for installation and management at household level, community level or by catchment managers or private or government water utilities. Table 2.5 gives an overview of different techniques for water buffering, used in different part of the world. They come in different categories: soil moisture storage (A); shallow groundwater recharge (B); surface water storage and beneficial use of floods (C); and general landscape measures to retain water in an area (D).
Table 2.5 Overview of Different Techniques for Water Buffering

<table>
<thead>
<tr>
<th>#</th>
<th>Main category</th>
<th>Slope</th>
<th>Rainfall</th>
<th>Locational features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Contour soil bunds</td>
<td>3-15%</td>
<td>A-SA-SH</td>
<td>Along the ridge area. Not on black cotton soil and preferably on well drained soils. Built staggered along contour lines. On steeper slopes trenches must be preferred. Higher density of bunds on agricultural land than on grazing land. Smaller distance between bunds on steeper slopes, less permeable soils, and higher rainfall areas.</td>
</tr>
<tr>
<td>2</td>
<td>Grass strips</td>
<td>&lt;8%</td>
<td>SA-SH-H</td>
<td>All soils. Often integrated with bunds especially on slopes up to 15%. The grass strip may provide fodder and host beneficiary insects for integrated pest management. Less suitable for mechanized agriculture.</td>
</tr>
<tr>
<td>3</td>
<td>Gully plugging</td>
<td>&lt;10%</td>
<td>All</td>
<td>All soils – in rills and gullies. Most effective with re-vegetation and when applied in series along the whole length of the gully. In moist areas live checkdams can be used. In moist areas is important to safely dispose excess water. Construction material according to local availability.</td>
</tr>
<tr>
<td>4</td>
<td>Terraces</td>
<td>15-55%</td>
<td>All</td>
<td>Deep soils. Various shapes according to use and agroclimate. In wetter areas a lateral gradient is needed to dispose excess runoff. In dry areas the spacing can be augmented to collect extra water for cultivation on the bench. In the first years after construction grazing should be supervised and/or avoided to avoid breakage.</td>
</tr>
<tr>
<td>5</td>
<td>Stone bunds</td>
<td>&lt;35%</td>
<td>A-SA</td>
<td>All soils where stones are available. It helps the farmer in getting rid of stones from the field. More stable than soil bunds. It needs less space than soil bunds and terraces. Discourage free grazing or provide passageways for animals movement.</td>
</tr>
<tr>
<td>No.</td>
<td>ADB Code</td>
<td>Measure</td>
<td>Slope (%)</td>
<td>Suitability</td>
</tr>
<tr>
<td>-----</td>
<td>----------</td>
<td>-----------------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>6</td>
<td>A</td>
<td>Trapezoidal bunds</td>
<td>0-2%</td>
<td>A-SA</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
<td>Tied ridges</td>
<td>1-5%</td>
<td>A-SA-SH</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>Demi lunes</td>
<td>&lt;5%</td>
<td>A-SA</td>
</tr>
<tr>
<td>9</td>
<td>A</td>
<td>Tal ya trays</td>
<td>Gentle</td>
<td>A-SA</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>Swales</td>
<td>&lt;15%</td>
<td>SH-H</td>
</tr>
<tr>
<td>11</td>
<td>A</td>
<td>Composting</td>
<td>-</td>
<td>All</td>
</tr>
<tr>
<td>12</td>
<td>A</td>
<td>Bio-char</td>
<td>-</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>---</td>
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<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>A</td>
<td>Organic mulching</td>
<td>20</td>
<td>SA-M</td>
</tr>
<tr>
<td></td>
<td>All soils – in too arid areas it attracts termites and in moist areas might host pests. A copious amount of biomass is needed. Often applied localized around high value crops such as banana and coffee.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>A</td>
<td>Plastic mulching</td>
<td>-</td>
<td>A-SA-M</td>
</tr>
<tr>
<td></td>
<td>All soils – and mostly used for high value cash crops. Colour of the plastic material changes according to the local agro-climate.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>A</td>
<td>Making use of invertebrates</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Specific agro-ecology can particular improve poor sandy soils. In moist areas practice that favour the presence of earthworms are suggested. In Dry areas sawbugs favour infiltration and recharge of the aquifer. Vermiculture is a way to produce high quality compost in a short time.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>A</td>
<td>Planting pits</td>
<td>2-8%</td>
<td>A-SA</td>
</tr>
<tr>
<td></td>
<td>On gentle slopes were surface runoff is evenly spread due to topography or thanks to stone lines. Common in sandy, sandy loamy soils that tend to develop a superficial crust. For trees and crops such as sorghum and maize.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>B</td>
<td>Contour trenches</td>
<td>&lt;30%</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>On pervious soils – really effective runoff control especially when in staggered lines. The steeper the slope the closer the lines need to be.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>B</td>
<td>Tube recharge</td>
<td>&lt;10%</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Where shallow groundwater is at reach and natural infiltration in the soil is slow. Preferably in natural depression close to a well that runs dry for part of the year. All soils - &gt;5-10 m from abstraction point</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>B</td>
<td>Subsurface dams</td>
<td>&lt;5%</td>
<td>A-SA</td>
</tr>
<tr>
<td></td>
<td>Dry river bed (&lt;30 mtr width) with underlying impermeable bedrock and a considerable amount of sand able to hold water. Often preferred to sand dams when the banks of the river are far apart, and or unstable, and/or low. Location to be chosen according to community needs and were less earthwork is needed for maximum amount of storage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>B</td>
<td>Sand dams</td>
<td>&lt;5%</td>
<td>A-SA</td>
</tr>
<tr>
<td></td>
<td>Dry river bed (&lt;30 m width) with impermeable bedrock, high and stable river banks. Stones and sand need to be in the immediate proximity of the sand dam location in order to keep costs acceptable. Location to be chosen according to community needs and were less earthwork is needed for maximum amount of storage</td>
<td></td>
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</tr>
<tr>
<td>No.</td>
<td>Category</td>
<td>Description</td>
<td>Remarks</td>
<td></td>
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<td>-------------</td>
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<td></td>
</tr>
<tr>
<td>21</td>
<td>Infiltration ponds</td>
<td>Pervious soil/sub-soil, where enough runoff can be collected using local slopes and depressions. Can be used at the foothill to collect and infiltrate excess runoff from the upper slopes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Harvesting water from roads</td>
<td>In Proximity to asphalt and/or dirt roads. The runoff can be collected from culverts or by diverting the flow from side drains. The water can be stored in simple ponds built on clay soils, or used on adjacent fields.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Small hill-side storages</td>
<td>Built in small valleys and depressions on the hillsides where enough runoff can be collected from the upper catchment area. On impermeable clay otherwise lining is required</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Water harvesting ponds</td>
<td>Impermeable clay otherwise lining is required. In a position where enough water can be collected from slopes, roads and channels.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Harvesting water from rock outcrops</td>
<td>A rocky and sloping surface such as rock outcrops or rocky hillsides. The shape of the rock formation must allow the water to flow to one side where storage must be put in place. Gutters can be used to maximize water collection.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Harvesting water from roofs</td>
<td>Topography independent. Suitable on any kind of roof that have a smooth lining. Most common on institutional building, schools and health centers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Spate irrigation</td>
<td>Water is diverted from seasonal stream floods over large areas for agricultural and other productive uses. The intake from the river must be on the flatter portion of the river to avoid rushing water damages.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Cisterns</td>
<td>All soils – above or underground.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Category</td>
<td>Description</td>
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<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td></td>
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</tr>
<tr>
<td>29</td>
<td>Controlled sand and gravel mining</td>
<td>Where policies and local bylaws allow formal/informal agreement for the limitation/ban of sand harvesting. Sustainable sand mining in specifically designed areas.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Protection of springs and recharge zones</td>
<td>The recharging area upstream of the spring eye is protected with fences and/agreement to impede polluting activities and constrain access.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Protection of footpaths</td>
<td>Especially on erosion prone soils and on sloping paths used by livestock for daily movements.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>River bank plantation</td>
<td>On weak banks and/or where sediments/nutrients pollution of the water bodies is a threat.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Protecting wetlands</td>
<td>Seasonal or permanently flooded wetlands that are threatened by encroaching human activities.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Intensive controlled grazing</td>
<td>Crusted clay - all soils. Possible where there are extensive grazing areas in dry savannah environment.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Farm forestry and wind-breaks</td>
<td>All soils – around homesteads and on farm boundaries. Trees can also coexist with annual crops.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>Conservation agriculture</td>
<td>On farmland. Particularly important on erosion prone soils and to favor an optimal use of water.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.5.4 Soil and moisture conservation

Shanxi Province is located at the eastern flank of the loess plateau. Soil erosion has dissected the ground surface, with steep slopes and deep gullies. The ground is mostly covered with loosely structured loess, which erodes easily under the influence of gravity, water and wind. Vegetation is sparse. Natural secondary forests and natural grasslands are distributed mainly in forests areas, mountainous areas, and upland steppes. The annual precipitation in Shanxi is limited and concentrated, with a large evaporation rate. As a result, the area is dry and prone to droughts. Though in the loess plateau substantial work has been to preserve soil and water, a large part of the area still needs to be treated. There are a number of priorities in soil and moisture conservation.

- Water conservation forests should be planted on the barren hills and slopes around major water conservation parks at mountainous or hilly areas. The sparse woodlands and shrubs should be fenced off for afforestation. The low-quality young and middle-aged plants at the existing water conservation forests should be given proper care, and the rest of the plants should be fenced off for afforestation. Special soil conditioners maybe used to improve moisture availability for the young planting during the critical first years.

- Building up sediment storage and water conservation projects by implementing warp land dams. The warp land dam is a type of water and soil conservation project commonly seen in areas where soil erosion is serious. It is built at gullies of various heights to impede floods and store sediments for building farmlands. With warp land dams, more farmlands with better water and fertility conditions are created. In the past, farmers worked on a large area of farmlands but harvested little, but with the level fertile soils created behind the warp dams they need only to work on a few newly created fertile farmlands but harvested quite fruitfully. With this optimized utilization of farmlands, farmlands on steep slopes can be converted back to forest and grass lands, large areas of vegetation can be restored and natural environment ameliorated. With the construction of warp dams, conflicts on land use between forestry and animal husbandry are settled. In the past, fierce competition for land use existed between farming, forestry and animal husbandry, but now the three complement each other. Warp land dams also impede and store surface flood water. As a result, the flood velocity is slowed down and more water infiltrates the ground to recharge groundwater. It is estimated that a warp land dam of one mu can help convert 6–10 mu of slope farmlands back to forest and grass lands. As an example, at Wangmaozhuang Small Valley in Suide County of Shaanxi Province, thanks to the widely built warp land dams, the total grain output has increased steadily with the rising local population and the shrinking grain planting area. Furthermore, with the conversion of large areas of slope farmlands back to forest and grass lands, the share of arable lands has reduced from 57% to 28% of the total land area; and on the contrary, the share of forests has risen from 3% to 45%, and that of grasslands from 3% to 7%. Currently, the per capita forest land is 2.4 hectare, the per capita grassland 0.3 hectare and the grain yield per mu over 500 kilograms (kg).

Apart from better recharge of water, it is also important to retain water in the areas by improving the quality of the soil to absorb and retain water. There are several ways to improve soil conditions in this respect that are important to consider for Shanxi Province. A well-known technique to increase soil moisture holding capacity is using natural rocks in agriculture. These can
also improve the long term fertility of soils and, hence, reduce the dependence on chemical fertilizer. There are several forms of rock dust that improve soil fertility and water holding capacity on a long-term basis. These rock dusts (stone meals) can be collected or produced on small and large scale. One of the most promising rock dusts in Shanxi is zeolite, which is already mined in the Province but not used very much in agriculture.

Another promising ‘natural’ technique is the use of bio-fertilizer combined with rock dust. Rock dust (from mines and quarries) contains the nutrients that help develop and restore soil productivity on a long-term basis. If mixed with bio-fertilizer, using natural enzymes, sugars and manure, the biodiigesting place will accelerate their uptake.

Box 2.10 Zeolites

Zeolites are hydrated aluminosilicate minerals. They have a negatively charged micro-porous structure and, hence, eminently tie water as well as plant nutrients such as Kalium or Phosphate. In nature, there are over 40 varieties determining their suitability to bind cations. The mineral has an open micro-pore structure which helps to store and retain water. Zeolite also improves aeration, breaks down clay clumping, improves root development, and promotes germination and the sustained growth of grasses and grains. Zeolite decreases water runoff and ponding, reduces the occurrence of localized dry spots, and increases amount of water available to plants. It helps microbiological activity and, hence, natural soil fertility.

Shown in the picture is the zeolite structure.
(Source: Wikipedia)
2.6 Groundwater quality protection and remediation

Worldwide, aquifers have suffered heavily from pollution caused by urbanization, industrial development, agricultural activities, and mining enterprises. Shanxi Province unfortunately is not an exception. Pollution of aquifers occurs where the subsurface contaminant load generated by manmade discharges and leachates (from urban, industrial, agricultural, and mining activities) is inadequately controlled. Much of the contamination of aquifers is irreversible and persistent and will deny future generations the safe use of groundwater, unless costly remediation is undertaken. Table 2.6 gives an overview of some of the most common sources of groundwater pollution (World Bank 2002). In Shanxi, the pollution from coal mining is a particular problem.

To protect aquifers against pollution it is necessary (i) to control both existing and future land use, (ii) to control effluent discharge and waste disposal from the main sources of pollutions, such as coal mines and agriculture; and, ultimately, (iii) to treat contaminated aquifer systems. These activities are discussed respectively in section 2.6.1 to 2.6.4

2.6.1 Controlling land use

Whereas earlier the reallocation of economic activities was discussed to relieve pressure on groundwater scarcity (section 2.2.6), similarly, a comprehensive land use planning approach is required to protect groundwater quality. Based on international experiences, there are a number of steps to reduce the risk of groundwater pollution:

- Mapping aquifer vulnerability;
- Inventory of contaminant load;
- Aquifer groundwater level and quality monitoring; and
- Assessment and control of pollution hazards.

(1) Mapping aquifer vulnerability

The mapping of groundwater pollution vulnerability is the first step in groundwater quality protection, particularly when initiated at municipal or provincial scale. Aquifer pollution vulnerability needs to be assessed, looking at the sensitivity of different aquifer system to being negatively affected by an imposed contaminant load. The sensitivity will relate to the importance of the aquifer system for domestic use or economic activities and the risk of contamination. Aquifer pollution vulnerability maps are a valuable tool to prevent groundwater pollution hazards.

(2) Inventory of subsurface contaminant load

This step concerns the systematic identification, siting, and characterization of pollution sources, including information on their historical evolution. This will lead to prioritizing groundwater pollution control measures in areas with potentially polluting activities.

(3) Aquifer groundwater level and quality monitoring

Aquifer water level and quality monitoring is needed to understand the baseline natural quality of the groundwater system; to collect new data on the aquifer system; to improve its conceptual and numerical modeling; and to provide verification of groundwater pollution hazard assessments.
Table 2.6 Common Groundwater Contaminants and Associated Pollution Sources

<table>
<thead>
<tr>
<th>Common groundwater contaminants and associated pollution sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural activity</td>
</tr>
<tr>
<td>In-situ sanitation</td>
</tr>
<tr>
<td>Gas stations and garages</td>
</tr>
<tr>
<td>Solid waste disposal</td>
</tr>
<tr>
<td>Metal industries</td>
</tr>
<tr>
<td>Metalliferous and coal mining</td>
</tr>
<tr>
<td>Pesticide manufacture</td>
</tr>
<tr>
<td>Oil and gas exploration /extraction</td>
</tr>
</tbody>
</table>

Figure 2.8 Aquifer Vulnerability Maps Published on the Internet (Netherlands)

(Source: Provincie Gelderland of the Netherland – Water Atlas)

(4) Assessment and control of groundwater pollution hazards

It is crucial to prioritize groundwater pollution control measures in areas where a range of potentially polluting activities already exists. Both in urban and rural settings, it will first be necessary to establish which among these activities pose the more serious hazard to groundwater quality and which one needs to be phased out or regulated. A plan of implementations needs to be drawn up, combining strict and clear targets as well as the cooperation of the main organizations involved (see Box 2.11)
2.6.2 Controlling pollution from coal mining

Among all the 119 counties, cities and districts in Shanxi Province, there are 94 with coal resources. The coal-bearing places in Shanxi Province cover an area of 62,000 square kilometers (km²), equal to 40% of the total land area. The identified coal resource reserves are 265.2 billion tons, which represents 26% of coal resources of the nation. The waste water from mining and other industries seriously pollutes the surface water body, causing river pollution on more than 3,753 km river length (Hong et al. 2011).

Coal seams and mudstones contain pyrite (ferrous sulphide), which is subject to oxidation by air as the water table is lowered. This process is accelerated by sulphur-oxidizing bacteria. As a result, water draining from coal mines becomes very acidic (AMD – Acid Mine Drainage), with pH values of up to 2 to 3, due to sulphuric acid, and high concentrations of dissolved sulphate and iron, as well as other metals.

Once the mine is closed the acid water can contaminate groundwater resources. One of the key AMD treatment solutions is underground mine sealing: an air-with-water replacement of sealing mine openings with impermeable grouting material—for example, flue gas desulphurization (FGD), which is a by-product from coal-fired power plants) to prevent oxidation reaction. In addition, depending on mining wastewater quality over 90% can be reused by applying advanced treatment technologies, such as reverse osmosis and microfiltration. Water reuse, combined with proper water management procedures, enables the mining industry to save up to 40% of its daily freshwater intake (Szyplinska, 2011).

Box 2.11 Promote Cleaning Technology through Industry Associations (An Example from Pakistan)

Groundwater pollution from the leather industry, especially by chromium, has been a major problem in several parts of Pakistan, and its control is a priority in the protection of groundwater quality. In the 1990s, the Pakistan Tanners Association initiated the Korangi Environmental Management Programme (KEMP). The main objective of the programme was to reduce pollution from untreated effluents so as to comply with international European Union regulations. The programme initially targeted owners of tanneries in the Korangi area, near Karachi.

Under the programme, cleaner production methods and technologies were introduced, including laboratory improvements; conservation measures; physical improvements in drainage and chemical storage; and operational health and safety systems. Cleaner technologies include chemical recovery plants, primary treatment plants, and mechanized solutions, such as salt dedusters.

Under the project, ‘free’ technical advice was given, with the consultants team being paid, once a tannery accepted the clean technology package. Following the KEMP’s success, a similar programme was started in Pakistan’s textile industry, in which 100 progressive textile mills are participating.
Shown in the picture is the secondary water treatment in a leather factory in Pakistan
(Source: Frank Van Steenbergen, 2013)

A more conventional approach to contain groundwater pollution from mining is in-situ remediation. Passive in-situ groundwater remediation using permeable reactive barriers (PRBs) represent a practical solution to aquifer pollution from industrial and mining activities.

Permeable reactive barriers (PRBs) are subsurface constructions situated across the flow paths of contaminant plumes. They are installed either as permanent, semi-permanent, or replaceable units. The contaminants are removed from the groundwater flow by geochemical processes taking place in the reactive material of the barrier filling. The choice of reactive materials and retention mechanisms are dependent on the type of contamination to be treated by the barrier system. Suitable materials are elemental iron, activated carbon, zeolites, iron oxides/ox hydrates, phosphates and clay minerals. This method has a high potential to reduce the remediation costs of contaminated shallow aquifers significantly and therefore contribute to the preservation of groundwater resources (Prokop et al. 2003).

Figure 2.9 Permeable Reactive Barriers
(Source: Wikipedia)


2.6.3 Controlling pollution from agriculture

As mentioned in Chapter 1, pollution from agro-chemicals constitutes a second major problem in Shanxi. The recommended practice to reduce this pollution is a reorientation of farming practices, focusing more on integrated pest management and integrated nutrient management. Integrated pest management (IPM) aims to control pests and crop diseases by using natural and safe methods. Integrated pest management minimizes economic as well as environmental risks. It helps to prevent groundwater contamination from pesticides and herbicides.

To prevent pest infestation, it is recommended to rotate between different crops, select pest-resistant varieties, and plant pest-free rootstock. These control methods can be very effective and cost-efficient and present little to no risk to people or the environment. Effective, less risky pest controls are chosen first, including highly targeted chemicals such as pheromones, to disrupt pest mating, or mechanical control such as light trapping or weeding. Through further monitoring, identifications and action thresholds indicate that less risky controls are not working, then additional pest control methods would be deployed, such as targeted spraying by pesticides (Chevalking et al. 2008).

Similarly, the use of fertilizer can be reduced by Integrated Nutrient Management. Studies have estimated that up to 45% of fertilizer use can be reduced by more precise application (in time, quantity, and type) and by applying alternatives. In rice systems, for instance, on average about 65% of the applied nitrogen is lost in the environment (Pathak et al. 2011).

Moreover, it has been demonstrated that increases in nitrogen and phosphorus application correspond to decreasing returns suggesting that further applications are not as effective at increasing yields. Greater returns are achieved at first with increments in added nitrogen, but, at higher application, the curve turns negative (Tilman et al. 2002). In many instances, Integrated Nutrient Management (INM) is a viable way forward. INM uses complementary measures: both natural and man-made sources of soil nutrients and mechanical measures and considerable attention to timing, crop requirements, and agro-climatic considerations (Gruhn et al. 2000).

Real-time crop sensors for site-specific application of nitrogen are a breakthrough in precision agriculture (Singh et al. 2006), and allow for significant improvements in nitrogen use efficiency. The combination of mineral and organic fertilizers has a better ability to sustain yields in the longer run rather than just mineral fertilization (Gruhn et al. 2000), besides increasing crop production per unit of synthetic fertilizer applied (Tilman et al. 2002). Prasad et al. (2002), for instance, found increased yields in a rice-groundnut cropping when green manure was combined with inorganic fertilizers. There are several other breakthroughs, such as the use of enzymes, to promote the uptake of phosphorus and, hence, to reduce the actual fertilizer applications. Another recommended practice is the larger use of zeolite (see above) in farming so to increase long-term fertilizer availability.

2.7 The ultimate goal: building a water-saving society

The ultimate goal in Shanxi will be to build a strong water-saving society. Water shortage is a fundamental reality for Shanxi Province. This is not something new: droughts have been common throughout the history of Shanxi. As Chapter 1 explained, Shanxi is an area with low rainfall and substantial differences from one year to another. All this is exacerbated by the changes in climate in the last three decades. It should be a long-term and basic policy for Shanxi’s social and economic development to save water on the
one hand and to improve the utilization efficiency of water resources on the other. Experience from the pilot projects undertaken under the 0188-Grant Project also suggest that it is possible to build strong local economies on water saving agriculture. The ultimate objective of building a water-saving society is that by 2020, a modern water-saving society is in place in the whole province that accords with the water resources situation in Shanxi, aligns with Shanxi’s economic and cultural features and sets the base for a moderately prosperous society.

A water-saving society comprises five elements—i.e., (i) water-saving agriculture; (ii) water-saving industry; (iii) water-saving domestic urban and rural consumption; (iv) water-saving eco-environment; and (v) water resources protection. Each district in Shanxi should formulate its own economic development plans in accordance with the availability of its water resources. The preceding sections of this chapter gave suggestions as to what can be done in water conservation and water resource protection.

The building of a water-saving society requires the creation of a water resources management system, based on water rights and water markets. Economic incentives are important element in a water saving society, besides the strong regulation by government and the engagement of large groups of stakeholders and water users. A first requirement is that water rights are allocated to different areas. Subsequently, rational amounts of water rights should be determined for users of all kinds and at all levels. This quota system is already in place in some parts of Shanxi and is described in section 2.2.4 and 2.2.5. Besides, water consumption quotas should be developed to curb increases in water use and to improve water utilization efficiency and save water, as was for instance already done for industries in Taiyuan.

Secondly, markets for water rights trading will be established to facilitate the transfer of water rights. Trading of water rights can be an effective incentive scheme for water saving: water users are paid back for their water saving efforts. As a result, the utilization efficiency and benefit of water resources are improved, and water resources can be reallocated. To support the development of a society and an economy that is built on the basis of efficient use of water, two complementary activities need to be considered:

1. A dynamic groundwater monitoring framework; and
2. Awareness activities to engage a large number of people in groundwater management.

2.7.1 Establishing a dynamic groundwater monitoring network

The dynamic real-time monitoring of groundwater is an important part of the groundwater management and protection. It is also essential for the implementation of a water withdrawal licensing mechanism. Only through the monitoring of the groundwater table, the volume of water abstracted, water quality and changes in the surroundings (like precipitation, river runoffs) can we understand groundwater conditions and make adjustments to our exploitation plan or take measures to control groundwater exploitation.

This monitoring can also be used to engage a large number of persons in groundwater management by sharing the outcomes with them. This can be through reports or through open access information placed on website, but it can also be done through special awareness events, discussion and public displays (such as the groundwater monitoring information photo below).
2.7.2 Engaging a large audience: awareness raising on groundwater

There is growing recognition of the importance of social norms and attitudes in the management of groundwater: it ensures that water users change their own behavior and also that they will correct the behavior of others. All over the world, new initiatives have been launched in the last decade by large international agencies, governments, local citizens’ group and nongovernmental organizations (NGOs). In Shanxi creating more awareness among water users, the general public but also young children will help to create a ‘water saving society’.

Awareness campaigns are a widely used policy tool. In awareness campaigns, policy makers and other interested groups aim for behavioral changes based on new social norms and attitudes towards water use. There is a widespread recognition of the need for community involvement in public and private programs. Awareness-raising should be seen as an interactive movement in which different parties are engaged to make their voices heard, change their own behavior, and create social pressure. For this purpose, an optimal combination between different communication channels is required.

In designing groundwater activities, it is important to (i) make clear choices on the mode of campaigning and (ii) systematically develop and implement the groundwater awareness campaign.

There are several ways to campaign for better groundwater management. The campaign-planning model presented here focuses on finding optimal combinations of different methodologies to awareness raising. Examples of such methodologies are public relations, advocacy, interpersonal communication or educational programs in schools. The choice for a given methodology is based on (i) the planned outreach of the campaign, (ii) the complexity or simplicity of the content, (iii) the extent to which the public is directly involved in the activities, and (iv) the amount of influence the "target audience" has on the campaign content.

Following these criteria, there are 3 basic modes of campaigning for awareness:

1. **Market mode**: this aims at a large outreach with simple content and a low level of active public engagement. It mainly aims to ‘give the idea’.
2. **Educational mode**: this has a medium-sized content and the content of is more complex. The engagement of the public is low to medium—changing behavior in the long run.
3. **Social and local mode**: here the
outreach is low. A smaller number of people is reached but those that are reached are actively involved and the aim is to directly influence their behavior.

Every campaign methodology can fit into one of these modes as illustrated in Figure 2.10. The approaches in the center of a mode are most characteristic of this mode, for example, “participatory tools,” found in the middle of the social/local mode. Comparing this to “advocacy” shows that the latter has elements of both a social/local mode and a supra local/market mode. A characteristic of a good campaign is an optimal combination of elements from the different modes.

To engage more people in groundwater management groundwater level recorders were placed in several locations in the Netherlands. These recorders displayed the changes in water levels and had explanations on the critical nature of groundwater.

Creating awareness (market mode) through billboard message has been employed by the Linfen City and Houma City Water Resources Management Commission. (Source: Zhang Wenzhong, 2013)
2.7.3 Groundwater education in schools

Education methodologies have become popular in many campaign approaches: in water conservation projects, in hygiene campaigns and in environmental awareness initiatives. Involving the educational sector provides great opportunities, because it is an existing system already focused on learning. Training teachers in water issues and incorporating water issues in regular curricula may be very effective and sustainable ways to raise awareness.
Figure 2.11 Examples of Awareness-Raising Activities

(1) Jointly making a resource map with water users (social mode); (2) organizing a youth event such as a groundwater congress (social mode); (3) using games (educational mode); (4) using a water droplet as an icon.

Box 2.12 Integrating Water Issues in Regular School Curricula

Water-saving education for children can be included in regular subjects taught at school under the following topics:

Water and Legislation
- Prepare a summary of the local water rules and laws.
- Who is responsible for the legislation?

Water and Geography
- Map your watershed. What are the boundaries of the watershed? How are they defined?

Water and History
- Identify historical/present groundwater uses.

Water and Chemistry
- How is the health of a groundwater body determined?
- What environmental problems do watersheds face?

Water and Mathematics
- Compare pollutants in a groundwater body over time.
- Graph population growth along the waterway.

Other examples of activities could include the following: to interview a professional from the water sector; conduct community interviews on water related topics; and invite a government representative to explain water laws.
Chapter 3 Experiences of multiple benefit pilots

The Asian Development Bank (ADB) approved in 2009 the Shanxi Integrated Agricultural Development Project to strengthen agricultural production in 26 counties in the Shanxi Province with a specific focus on alleviating poverty of small farmers. Complementing the project was a USD500,000 grant from the ADB Water Financing Partnership Facility to support climate change adaptation through groundwater management and efficient agriculture. Under this, 0188-PRC Grant Climate Change Adaptation through Groundwater Management pilot/demonstration activities were undertaken in four counties in Shanxi Province.

Greenhouses in Qixian County demonstrate efficient agriculture. (Source: ADB Grant Project 0188 – PRC Qi County Pilot Project, 2012)

The counties were selected after a careful scrutiny of a long-list of eight counties. The long list was based on a number of criteria: use of groundwater, part of the larger ADB Poverty Alleviation Loan Project, and accessibility. For all these counties, basic data were collected and assessed. Field surveys were organized, including interviews with farmers, and experts were consulted. In the end, Qixian, Xi, Pingshun, and Lishi counties were selected (see table 3.1) after a competitive selection process among local governments and farmers. The pilot counties were chosen for their representativeness of different areas of Shanxi Province and the interests by local government and farmers. The pilots were introduced after considerable discussion with these stakeholders. This chapter discusses these four innovative pilots, respectively, in sections 3.1 to 3.4. Considerable research was undertaken in support of the cold weather irrigation pilot in Lishi County (this research is discussed separately in section 3.5).

1 The long list of eight counties consisted of Yuci District, Qixian and Taigu County (Jinzhong Municipality), Lishi District (Luliang City), Xixian County and Yaodu Development Zone (Linfen Municipality), Liyi County (Yuncheng Municipality) and Pingshun County (Changzhi Municipality).
Figure 3.1 Location Map of the Demonstration Project Counties

(Source: Frank van Steenbergen, 2013)
Table 3.1 Pilots Undertaken under the 0188-PRC Grant

<table>
<thead>
<tr>
<th>County</th>
<th>Village</th>
<th>Pilot system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qixian</td>
<td>Xiliuzhi</td>
<td>Drip irrigation in greenhouses, including electricity saving frequency converter</td>
</tr>
<tr>
<td>Xixian</td>
<td>Quyan</td>
<td>Spring (large diameter micro-irrigation) for orchards in loess plateau</td>
</tr>
<tr>
<td>Pingshun</td>
<td>Wanli</td>
<td>Micro-sprinkler in mesh tents for prickly ash shoot cultivation</td>
</tr>
<tr>
<td></td>
<td>Wangqu</td>
<td></td>
</tr>
<tr>
<td>Lishi</td>
<td>Xiaoshentou</td>
<td>Drip/micro sprinkler irrigation in greenhouses combined with warming ponds</td>
</tr>
</tbody>
</table>

The grant was intended to support farmers in introducing innovative water use practices and increase climate change resilience to arrest 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 highly relevant. The pilot activities promoted efficient use of water in irrigation, creating multiple benefits and helped build up local economies based on the efficient use of water. In the next part of this chapter, the pilot activities are described. They serve as examples that can be up-scaled in other parts of Shanxi, provided that attention is given to detail and quality.

Another important challenge is to work on the long-term sustainability of micro-irrigation. This means making sure that farmer are able to replace the equipment and that a service sector to support this is available. The pilots, however, are testimony to the fact that there are still many unused opportunities to restore balance in groundwater use and to create stronger buffers in times of climate change.

3.1 Qixian - efficient greenhouse irrigation in the plains

Intensive farming activities in the lowland areas of the Shanxi province have created a situation of unsustainable groundwater use in a water scarce area. The large cones of depression and continued falling water table in some areas pose a threat to the economic development of this agricultural heartland, as described in the previous chapters.

Qixian County is typical for the central farm belt of Shanxi, the main grain basket and source of vegetables and livestock products. Farm incomes are relatively high in Qixian. They stand at 14,704 Yuan per farm family member. The lack of an industrial base in Qixian is compensated by intensive farming activities that include poultry and cattle fattening.

The agricultural prosperity in Qixian County, however, is built on a foundation of unsustainable groundwater use. The area is clearly water scarce: it has an overall annual per capita availability of 263 m³ and a useable availability of 163 m³, all clearly below the so-called ‘Falkenmark Indicator’ for water scarce areas (1,000 m³ per capita). As surface water is limited and polluted, the larger part of water use is from groundwater. 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 0.76 meter 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 pilot installation of Xiliuzhi Village is at 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, reaching much higher water productivity than hitherto achieved and reducing pressure on the use of groundwater. In the village at present 15 hectares is covered by greenhouses—supplied by wells set at 150 meters depth. Greenhouses in Xiliuzhi come in two varieties. First are semi-arched traditional structures that have a three-meter thick mud wall on one side. Thick straw blankets are positioned on top of these—rolled down and insulating the greenhouse at night. These greenhouses come at a cost of 56,000 Yuan per standard unit (667m² or 11.1 mu). The second type of greenhouse is lower in cost. These greenhouses consist of (removable) arched plastic sheds and are installed at a much lower price of 10,000 Yuan. These plastic sheds are only used in the warm season as it is not possible to shelter them from the cold with straw blankets as in the semi-arched structures.

Prior to the installation of the micro-irrigation systems under the pilot, flood irrigation was common in the greenhouses. Water was distributed from a small canal running across the length of the greenhouse. In the pilot, these flooding systems were replaced with state of the art drip irrigation systems. These consisted of (i) 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 five years the use of frequency converters in industries has become widespread, in irrigation its application is very 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 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 set at 0.6Y/m³. From the central control unit, the water is led through buried pipelines to 39 traditional greenhouses and 20 arched structures under the pilot. Water supply in each greenhouse is independent with their 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 and 70 centimeters (cm) to allow the cultivation of vegetables. On the control houses next to every greenhouse unit, the main messages on water and fertilizer applications in different parts of the season are painted. Prior to the operation, training was provided to the farmers on the use of the drip systems. The cost of this installation amounted to USD45,600 (under the ADB grant) with supplementary funding of 210,000 Yuan by 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 saving in water and fertilizer usage. Water supply for the traditional greenhouses is set at 11 m$^3$/hour; for the arched greenhouses at 8.5 m$^3$/hour. The water saving amounts to an estimated 40%-60% or 200 m$^3$ for the semi-arched greenhouses and 150 m$^3$ for the plastic sheds. Fertilizer consumption is reduced with 35%-40%. Moreover, the more accurate applications translate into an increased crop yield of 25%-40%. Water productivity (the ‘crop per drop’) improves with 90%. Some crops such as zucchini are particular sensitive to this type of precision farming: they would do not do well without these improved systems. These estimates are based on limited farmer interviews, but would need to be confirmed in more detailed monitoring.

In money terms, the estimated benefit is an additional profit of 10,000 Yuan per year per traditional greenhouse. This compares favorably to the investment per hectare of 4,000 Yuan per greenhouse or 6,000 Yuan, if all investments are included. For semi-arched structures, the benefits are less as they are not suitable for winter cropping as they cannot be insulated—gross benefit is 5,000 Yuan and net benefit 2,000 Yuan. Very important are also 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 has already started the development of a second system that is a copy of the pilot installation. The new system is funded entirely by farmer members and is even more sophisticated. It is three times larger than the pilot with 102 traditional greenhouses and 57 arched greenhouses having subscribed to it. It also includes a system of sensors in all connected greenhouses that will indicate when crops are moisture-stressed, so that irrigation can start. There has been much interest in farmers of other areas visiting the system and the plan is to fully cover the area with improved drip systems by 2013. The systems are well

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2 It should be noted that this is the gross saving or the reduced seepage. In other more wasteful irrigation systems, not all water unused is lost, because of part of the seepage adds to the groundwater and can hence be reused.
designed and carefully implemented—unlike in some other parts of the Province—which is a pre-condition for success.

3.2 Xixian – developing horticulture in the loess plateau

The hilly rural tracts of Shanxi are mostly poor. Meanwhile, there is still potential to expand farming and other economic activities as comparing with the lowlands, water resources are not overused. It is important is to introduce systems with high water productivity, that expand the range of crop options in these areas and take into account the aged composition of the rural population by reducing the requirements for hard physical labor.

Xi County ranks among the 35 poorest counties in the PRC. The population counts 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 2,496 Yuan, close to the poverty line of PRC. About 53,000 persons in Xi County, in fact, are living below the poverty line.

The county is part of the large Loess Plateau and is highly accidental consisting of eight separate plateau areas. Since 1979, considerable work has been done on the rehabilitation of the vulnerable catchments—with 1 million mu treated and a similar area still to do. The cost of this is approximately 5,500 Yuan/mu, but varies widely: on the flat plateau areas, it is 1,500 Yuan/mu; but on the sloping areas, it is considerably higher though cost has been reduced with the increased use of bulldozers. In areas with a slope in excess of 25 degrees, only reforestation is undertaken. Though many areas still need to be treated, the impact of the loess plateau treatment is already very positive. Compared to 1979 when the program started:

- Soil erosion reduced with 1,320 ton per square kilometer per year;
- Retention of surface water increased with 26% (from 14% to 40%);
- Interception of sediment increased with 32.5% (from 17.5% to 50%);
- Forest cover increased with 32.8%.

Spring irrigation is employed in apple orchards in Xixian County. (Source: ADB Grant Project 0188 – PRC Qi County Pilot Project, 2012)

Xi County has a climate that is suitable for high value fruits, in particular pears, apples and apricots. The ‘Golden Pear’ from Xi 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 degrees), the large variation between night and day temperature (causing sugar levels to increase) and the
excellent thick loamy soils (with good aeration) and the presence of large number of varieties (close to 100 varieties of pear for instance) explain the comparative advantage of Xi county in fruit production. The area under fruit trees is heavily promoted: the target is 350,000 mu of which 310,000 mu is reached. Xi County’s economic strategy is very much based on ‘specialty’ agriculture; it has no industrial or mining base, but has 430,000 mu of arable land. Rainfall is 570 mm a year but variable and there are 150-170 days without frost.

Promotion consists of the following:
- Promoting new plantations and better water resource development;
- Introducing better agronomy, including better fertilizer usage and grafting;
- Promoting intercropping by crops that are low in height such as chrysanthemum and beans;
- Improved marketing both by better storage at farmers’ levels and developing new marketing canals.

Production is, however, held back because of the dependence on variable rainfall. Irrigation is limited—not more than 4,400 mu and in several cases suffering from insufficient performance and management. Farmers often resort to irrigation by bucket from local water points, but also given the relatively old age of farmers, there is not much that can be achieved with such methods. The pilot under 0188-PRC was developed in Quyan village—close to the Wulu Mountain range. Quyan—that counts 120 households and 514 people. The arable area belonging to the village is 2,800 mu used for corn/ millet/ sorghum/beans and potatoes and cash crops—in particular, pears, herbs and oilseeds. Under the demonstration project 250.5 mu (serving 52 farm households) was developed on a comparatively level area, though still with a height difference still of 20 meters. Such slopes made furrow irrigation—apart from its inefficiency—impossible.

Under the project instead a so-called ‘spring system’ were developed—with 0.8 mm diameter supply pipes making clogging unlikely. Each spring pipe outlet is feeding a circular pit excavated around a single fruit tree.

The spring pipes are supplied by 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 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. Earlier, this was 90 mm but then there was insufficient pressure in the system. Two thirds of the pipeline has been replaced. The water comes from the spare capacity of the village water supply system that besides the agricultural areas is feeding six small village clusters.

The source of the system is a spring located at lower alleviation with water being pumped up through a largely buried pipeline to a central tank. Part of the pipeline is exposed though and drainage wells are there to empty the main supply line and avoid it bursts in heavy frost. For the micro-irrigation system, a small central unit is in place besides the central tank to regulate pressure. It is equipped with a centrifugal filter to clean the water. There is also the option at this 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 pilot in Quyan village has received a very enthusiastic reception by local farmers. The piped micro-irrigation ‘spring’ system makes it possible for the mainly aged farm labor to grow irrigated orchards. Earlier this was done by hand-carried cans, but obviously there is only so much a farmer can do. The expectation is that, with the spring system, a yield of 1,500 kg/mu can be reached with a sales price for apples/pears of 5 Yuan/kg—creating a production value of 7,500 Yuan/mu. Without irrigation, yields are closer to 600 kg
per mu. The cost of the pilot amounted to 335,000 Yuan, coming to a very favorable unit cost of 1,350 Yuan/mu. The payback period, hence, is short. The pilot 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 into. The plans at county level are eventually to have 160,000 mu under improved irrigation system, but this will require a careful planning and development of local water resources as well.

### 3.3 Pingshun – creating a controlled environment for specialty crops

Pingshun is a mountainous county located in the southeast of Shanxi. It has population of 164,000—the majority of which depends on agriculture (135,000). Most of the 12,920 of arable land is rain-fed with irrigated land amounting to 10%. Groundwater resources are as yet not much used. The county has several mineral resources (silica, aluminium, commercial clays) and plans for sustainable energy (wind, solar) as well as tourism potential. The main economic base, however, for the time being 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 7,658 Yuan but farmer incomes are substantially lower at 2,720 Yuan per capita.

Efficient pressurized irrigation systems are often promoted to save water but their largest benefit, in fact, may lie in the higher production they make possible. While this is not new (for instance, the international so-called Comprehensive Assessment on Water Resources estimated already that micro-irrigation systems achieve 5%-56% higher yields), it often goes unnoticed.

A very good example of the multiple added value of pressurized irrigation system is the micro-sprinkler system introduced under the ADB 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, 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 a main impetus from a local enterprise that processes the crops and is providing farmers the required upfront investment in the seedlings and equipment. Prickly ash got a major boost in Pingshun six years ago when the local government introduced the use of mesh tents. This helped to largely control the problem of aphids (lice) and reduced the use of pesticide and improved the quality of the product.

A further improvement in the cultivation of prickly ash shoots, introduced under the Grant Project is the use of micro-sprinklers suspended in the mesh tents. This was experimented in three areas: Wangli (31 farms/40 mu), Wangqu (38 farms/ 50 mu), and Henantan (100 farms/ 130 mu). Under the new irrigation system, the suspended micro-sprinklers not only irrigate but also wash down the remaining aphids. The micro-sprinklers can be also 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 avoids that soils get too wet. As a result less fertilizer, pesticide and water (estimated at 40%) is used and a higher yield with a cleaner product is achieved (estimated 20% more). The strength of the system is not water saving as such, but also energy saving (less fertilizer and pumping) and creating a controlled micro-environment that allows a higher production.

To source water to the prickly ash shoot farm areas two water source systems were developed pumping water in one case from an improved well near the river and in the other case (feeding the two smaller areas) directly from the river. Two storage tanks were built on the nearby mountain slopes, one measuring 380 m$^3$ and one 250 m$^3$.---
served in total by 4,000 meter of pipeline. All these costs were taken care of by the local government contribution.

It turned 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 micro-sprinkler was laid out. The distribution well is equipped with the water meter and a mixing point for fertilizer and pesticide. The total investment was 1.07 million Yuan, hence, close to 5,000 Yuan/mu. Of this, the ADB grant was used for the field pipelines and micro-sprinklers within the farm area. This amounted to 247,000 Yuan or 1,150 Yuan/mu.

The expected income increase is 15%-20%, which will be achieved at a much reduced labor input. The micro-sprinkler will also bring a much better quality green leave product as many aphids are washed out and pesticide use can be very much reduced. The local government is keen to expand the micro-sprinkler system on all prickly ash shoots 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 in its usage.

An important success factor in the development of the local economy is the local food-processing plant that has specialized in making prickly ash pickles and markets this product in a large part of the PRC. The factory was set up by a local entrepreneur and has been a major force in the promotion of the crop. Farmers enter into a contract with the enterprise, whereby their price is guaranteed and they receive credit in the farm of seedlings and equipment. The deal has worked very well, as there is much interest to expand the area under cultivation and the factory has opened a new production line recently whereby it can process three times more than what is currently produced in Pinghsun county.

3.4 Lishi - developing cold weather irrigation

With demand for fruit and vegetables increasing all over the PRC, greenhouses have also made an appearance in more unlikely cold weather areas such as Lishi County in the Lvliang Mountains. Lishi has a continental monsoon climate with very cool winters and in some years not more than 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 GDP of the county but the proportion is increasing, largely due to the energetic 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 standing at 3 billion Yuan for instance).

The rural area is poor with farm incomes at 1,106 Yuan—far below PRC’s poverty line of 2,293 Yuan. Water availability per capita is limited at 324 m$^3$ per year. Still only a relatively small part of the water resources are used in Lishi County. The area is very accidental with only 5% of the land being arable—with flat areas and valley bottoms used for the cultivation of maize and vegetables and the keeping of livestock. In the hilly area replanting is taken up among others with walnut trees. The greenhouses in Lishi resemble the semi-arched structures common in other parts of the Province - but several modifications are made to deal with the cold winter weather. The loess mud walls are thicker (4 meters instead of 3 meter) than usual. At night, many of the greenhouses are insulated with thick cotton blankets that are skillfully moved over the semi-arched plastic roofs. The area under such cold weather greenhouses has expanded rapidly to 500 hectares in the last five years in Lishi, and the target is to triple this.

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

A team from the Taiyuan University of Technology, described in section 3.5, spent a winter season taking measurements to assess the best option for cold weather irrigation.

As an outcome, a warming system for the greenhouse area of Xiaoshentou (altitude 975 meters) was developed. 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 is still around 5 degrees 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. Water is distributed at a control station and is also filtered there. From here, the water is distributed to separate greenhouses.
In each greenhouse, a small plastered brick masonry pool is constructed measuring 2.75 by 1.75 meter and a depth of 1.20 meter. If water is kept here 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 micro-sprinklers (for oyster mushrooms).

The pond is built at ground level with a small rim of 25 cm to avoid dirt 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 the concrete structure, geo membrane is used to avoid leakage. The dimensions were chosen to as not to take 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 degrees so that it can feed the greenhouse irrigation system with the help of a small submersible pump.

The underground tanks and micro-irrigation system make it possible to grow a third crop in the greenhouses with at an extra annual turn-over of 5,500 Yuan/mu, already more than the cost of the greenhouse installation. In addition, the more precise irrigation and controlled environment that the drip and micro-sprinklers provide are—as in the other pilots—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 authoritative statements for the installations in Xiaoshentou; but farmers predictions is that crop yields may increase with at least 10%, and fertilizer and pesticide consumption be reduced with 20%. Labor inputs would drop even more.

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The consultant expert is measuring temperature in greenhouse walls. 
(Source: Lishi District County Pilot Project, Low Temperature Measurement, 2012)
Whereas the project installed the warming ponds 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: this system is more costly and take more (shadow) space. All in all, under the 0188-PRC grant, drip systems were installed in 29 greenhouses (standard size 1.1 mu) and micro-sprinklers in 17 greenhouses (total 1.93 ha). The cost of this (including the control station) was 245,000 Yuan, or around 5,000 Yuan/mu. In addition from the local government funding, 3 million Yuan was spent on the main water supply systems—that however serves the entire greenhouse area (3.3 ha).

In spite of the high cost, the scaling up potential is high in Lishi, as there are ambitious plans to develop irrigation sources and construct more cold weather greenhouses. It is conceivable for Lishi to develop into a center of excellence on cold weather systems, developing the techniques but also for instance developing seeds and other varieties that are particularly cold-resistant.

One area of concern in Lishi, 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, in the different parts of the year, needs to be carefully observed and assessed, also with the changing rainfall patterns in Shanxi.

3.5 Special topic: research into cold area irrigation

Cold areas are common in Shanxi Province, but also elsewhere throughout North China and elsewhere in other parts of the world, such as Central Asia. The work done in Lishi County, therefore, has a relevance that goes beyond the pilot area only.

Only in Shanxi for instance approximately 40% of the provincial area can be defined as being low-temperature. Winter air temperatures are below zero for extended periods, the more so in the mountain regions and the more so towards the northern of the Province.

Agriculture is however expanding in these areas, and particular greenhouses are increasingly being used in the high altitude and latitude areas. Obviously, however, the low temperature of irrigation water in the winter is a constraint to cultivation. Springs, shallow groundwater, phreatic water or local rivers are preferred as the source of irrigation water, but all these shallow sources carry water that is relatively cold in the winter. The cost for developing deep wells that would yield warmer water is, if at all possible, prohibitive in these mountain regions.

In Xiaoshentou village Xinyi town in Lishi district water temperature in the winter varies between -3°C and 3°C in the river. It is not more than 5°C in the collector wells or storage ponds from which water is delivered to greenhouse area. All of this is below the 8°C to 10°C of water temperature that is the required minimum for the vegetable cultivation, such as cucumber, tomatoes, green beans, melons, eggplants and beans, due to the effect on planting and soil temperature. Raising irrigation water temperature in greenhouses therefore is a crucial issue for vegetable cultivation at high altitude and low temperature areas.

Under the PRC-0188 Grant Climate Change Adaptation through Groundwater Management, systematic research was undertaken into the design and use of warming ponds. The challenge was to develop warming ponds that within a relatively short time period would raise water temperature to the required 8°C. The pond had to be economical in size and not take up too much space in the green house.

To develop the warming pond, research was undertaken over the winter period November 2011 to April 2012. The tests were undertaken on the spot, i.e., in the
greenhouses in Xiaoshentou village Xinyi town LiShi. The research looked at several parameters: the river water temperature at source; the water temperature distribution within the collecting wells as well as in the interstitial flow wells; water temperature distribution in different models of warming ponds; the temperature distribution near the warming ponds; the soil temperature at different depths outside the greenhouse; the distribution of air temperature inside and outside the greenhouse; the temperature distribution within the insulating greenhouse walls and the material composition of these walls and the air humidity inside and outside the greenhouse.

The test data were updated in every 7 to 10 days, with the frequency of observation increasing during periods with snow or rain, when temperature falls sharply. The aim was to build up a complete set of data at different temperature and sunlight conditions. During each test, continuous observation were made required for the whole day at 0:00, 4:00, 7:00, 9:00, 11:00, 13:00, 15:00, 17:00, 19:00. More observation was needed around noon for its wider temperature variations.

Two specific designs for a sunken warming pond were tested. The first was a rectangular sunken pond with an elevated rim of 10 centimeter (cm); the second design was a square sunken pond with a rim of 65 cm above the surface. The warming ponds are built with bricks and provided with a cover of geomembrane to control seepage. Water in the pond is stored up to the level of the ground surface. These two test designs are shown in figure 3.14-3.15.

Nine continuous observations were conducted from November 2011 to April 2012, assessing temperature change in the two experimental warming ponds. The challenge was for the water in the entire pond to heat up to the desired minimum temperature within a reasonable period and at the same time have enough water storage space to irrigate the greenhouse vegetables.

Table 3.2 and Table 3.3 show how surface temperature in the ponds fluctuates during the course of the day. The critical parameter however is the water temperature at depth of 80 cm or 120 cm because this determines whether the entire pond can be used for irrigation. The question is, therefore, which pond design is most conducive for developing transmitting temperature from the surface of the water to the lower layers.
The rectangular pond makes it possible to warm up water to above 8°C in the course of the day under most circumstances. After water fills, the water temperature in the pond rises slowly but gradually, with surface water warming obviously rising faster than the water in the bottom of the pond.

The air temperature in the greenhouse is highest between 12:00 to 20:00. The warming up occurs very much during these hours, the lesser rise in temperature is from 20:00 to 8:00 the next day. In addition, water temperature changes with the depth of water in the pond; the change of surface water is more than that of deep water. The temperature response of surface water is more obvious.

In comparison the warming up time in the square pond with the higher rim is considerably longer. The explanation is the better contact between heated indoor air and the irrigation water in the low-rim rectangular pond. The period that water temperature takes to increase from 6.5°C at water inlet to irrigable 8°C is about 23 hours (maximum 31 hours) in rectangular warming pond, but up to 96 hours in square warming pond.

Total water demand for each irrigation in the greenhouse is estimated at 9.2 m³ during a period of 7 days. The storage capacity of the rectangle water heating pool is about 5.4 m³, so with two irrigation events in a week the greenhouse can be served. The relatively short warming time makes it possible to replenish the water in the pond in time.

Due to the relatively low 10 cm rim from the top to the ground, there is still the risk that dirt may fall in the water, which would affect the functioning of the drip irrigation systems or micro-sprinklers. Hence, 150 mm mesh wool fabric net is suggested to cover the pool to prevent debris falling into the water. In order to clean the pond, the water inlet and outlet should be set above the water level.

From 24-hour observations of soil temperature, it appeared that soil temperature in the top 15 cm can rise to more than 20°C between 14:00-15:00. The drip irrigation system can make full advantage of these favorable conditions by irrigating crops at noon time, when soil and air temperature are at the highest, which further help increase water temperature.
<table>
<thead>
<tr>
<th>Date</th>
<th>Weather</th>
<th>Outdoor temperature (℃)</th>
<th>The daily average temperature of river water (℃)</th>
<th>The water inlet temperature of warming pond (℃)</th>
<th>Time of warming up to 8 ℃ (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011.11.26-2011.11.29</td>
<td>Cloudy to shade</td>
<td>10</td>
<td>-3</td>
<td>2.9</td>
<td>5.5</td>
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<tr>
<td>2011.12.19-2011.12.21</td>
<td>Clear to cloudy</td>
<td>1.8</td>
<td>-14.5</td>
<td>-5.6</td>
<td>-2</td>
</tr>
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<td>-14.2</td>
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<td>-8.2</td>
<td>-2.3</td>
</tr>
<tr>
<td>2012.1.29-2012.1.31</td>
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<td>-15.5</td>
<td>-7.7</td>
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<td>2012.2.16-2012.2.18</td>
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<td>-11</td>
<td>-5.8</td>
<td>2.7</td>
</tr>
<tr>
<td>2012.3.10-2012.3.12</td>
<td>Cloudy to clear</td>
<td>3.5</td>
<td>-4.5</td>
<td>0.1</td>
<td>4.5</td>
</tr>
</tbody>
</table>
Table 3.3 Warming Result of Square High Rim Warming Ponds

<table>
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<tr>
<th>Date</th>
<th>Weather</th>
<th>Outdoor temperature (℃)</th>
<th>The daily average temperature of river water (℃)</th>
<th>The water inlet temperature of heating pool (℃)</th>
<th>Time of warming up to 8 ℃ (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Daily highest</td>
<td>Daily lowest</td>
<td>Daily average</td>
<td></td>
</tr>
<tr>
<td>2011.11.26 - 2011.11.29</td>
<td>Cloudy to sleet</td>
<td>10</td>
<td>-3</td>
<td>2.9</td>
<td>2</td>
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<tr>
<td>2011.12.19 - 2011.12.21</td>
<td>Clear to cloudy</td>
<td>1.8</td>
<td>-14.5</td>
<td>-5.6</td>
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<td>2012.1.2-2012.1.5</td>
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<tr>
<td>2012.1.13-2012.1.16</td>
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<td>2012.2.16-2012.2.18</td>
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<tr>
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<td>3.5</td>
<td>-4.5</td>
<td>0.1</td>
<td>4.5</td>
</tr>
</tbody>
</table>

(Source: Research under 0188-Grant)
3.6 Observations from the pilots

Most of the pilot irrigation systems became operational in the course of 2012 (Lishi, Qixian, Xi and Pinghsun) and what is documented here are first experiences. Given the significant challenges on the North China plain the pilots are promising, however, to say the least.

The modernized efficient irrigation systems in Qixian, Xi, Pinghsun and Lishi achieved a more judicious use of water but equally important they helped to increase yields by creating a controlled micro-environment. These demonstrations made a quantum leap in water productivity possible.

The effect was double edged: the new system reduced water use and increased yields at the same time. The improved systems in Xi, Pinghsun and Lishi 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 economized on the use of agrochemicals and labor. This fits in well with the increasing demand for quality food in PRC as well as the aging agricultural labor force. The success of the pilots is also apparent from them being reproduced. With short payback periods and additional benefits, these innovations are set to travel easily, especially in horticulture for which they are very best suited.

To introduce them more widely there are four priorities:
Further popularize the precision irrigation systems, especially the need for quality installations;

- Create more example systems both in greenhouse areas as well as in open field systems, in the latter case make use of other technologies such as conveyance pipes and sprinkler systems, as well as a range of soil improvement measures;
- Make sure a service system is in place and farmers are enabled to replace the systems, when they need replacement and buy them in new areas – considering a certain amount of subsidy to accelerate demand;
- Introduce quality standards for the micro-irrigation systems, avoiding that below quality installation spoil the interest in the precision irrigation systems.

The larger picture is that the pilots have been able to create local economies based on water efficient agriculture. They have enabled the cultivation of high quality crops, some specialty delicacies (such as prickly ash shoots or the Xi golden pear) that could not be 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/ sauce entrepreneur, or the farmers union in Qixian or Lishi or golden pear marketing industry in Xixian. The pilots can also make a significant indent in water consumption in agriculture, still the largest groundwater user in Shanxi. In addition, more measures and a comprehensive plan in line with the movement towards total water control are necessary to bring groundwater use back in balance and bring the resource economy back from the brink.

A skilled technician is demonstrating the importance of precise installation
(Source: ADB Grant Project 0188 – PRC Lishi District County Pilot Project, Warming Pond Design and Experiment, 2012)

An officer explains the importance of the value chain in water efficient economy (left). Packaging of a sauce made from prickly ash shoots shown on the right.
(Source: ADB Grant Project 0188 – PRC Pingshun Pilot)
Chapter 4 Messages and recommendations

4.1 Messages

Groundwater has historically been essential for agriculture and for urban development in Shanxi. As described in Chapter 1, in the last three decades overuse, pollution and also geological disturbance due to mining operations have put this critical asset in danger, however.

Some of these threats may degrade the aquifer system irretrievably: the water storage capacity may be affected and groundwater pollution may put groundwater systems out of use for many centuries to come. At the same time with the economy further developing, the demand for good quality, reliable water supplies increases. Climate change is another very large challenge. The reduced rainfall means less recharge of groundwater and at the same time a larger demand for irrigation. The higher temperature means that farming may expand in the colder areas of the Province in particular, but also that evaporation will be higher. Against all these pressures groundwater is also seen to serve as a buffer against climate change.

To manage groundwater hence should be a highest priority for the Government of Shanxi. There are a number of examples now—from Shanxi Province and PRC, but also from outside the country—that can serve as a source of inspiration, described in Chapters 2 and 3. Better management and use of groundwater will preserve the future but may support economic development as well. A number of policy changes are urgently required. These are described below.

4.2 Policy recommendations

This report would like to propose the following complementary policy recommendations:

- Strengthening the management of groundwater resources;
- Improving the total quantity control (quota) system of water consumed;
- Accelerating the development of a water-saving society;
- Increasing the amount of water available by better recharge and retention and developing non-conventional water resources;
- Strengthening the protection of groundwater resources;
- Continuing innovation in water efficiency measures and techniques.

The following discusses these policy recommendations in detail.

4.2.1 Strengthening the management of groundwater resources

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

Firstly, the availability of groundwater needs to be taken into account in spatial planning and in restructuring economic activities. The availability of groundwater resource 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. To ensure 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, 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 produces heavy pollutions should be prohibited. In time adjustment of economic layout and structure should be developed in accordance with the availability of water resources. In Shanxi future urban and industrial development should consider the mountain areas where water resources are still relatively abundant.

Secondly, a unified and strong water resources management administrative system should be established. The unified management of water resources should be developed further. At present the Ministry of Water Resources is present at various levels, setting the framework for water resource 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, inter-industrial, trans-regional, inter-departmental administrative system, which covers both surface water and groundwater, should be established instead under state ownership of water resources. At the same time the relations and responsibilities between different administrative level and also with watershed management, waste water 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: whoever consumes water pays for it; whoever pollutes water pays for it and whoever causes damage to the eco-environment pays for it. Together with the three compensation mechanisms, we should also put in place three restoration mechanisms: ensuring the balance between water supply and demand, ensuring that water quality reaches the required standard and ensuring that water environment and ecology are satisfactory.

Thirdly, 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.

4.2.2 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. What needs to be done is to improve the system 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 quota 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 (section 4.2.3) and the development of unconventional water resources, such as reclaimed water, mine water and recharge from floods and high water flows (section 4.2.4).
4.2.3 Accelerate the building a water-saving society in Shanxi Province

It is a basic national policy for 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 into a role model for the water stressed areas in PRC.

First of all, efforts should be made in starting intense awareness activities to engage all water users and key stakeholders and emphasize the importance of water resources and its 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 whilst 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 are 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 agricultural sector, we need to first of all build an integrated groundwater management system, as has been piloted in Qinxu. The amount of water used and the share of quota 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 Qingxu County is a successful and time-tested case in point. This system can and should be promoted and replicated in other counties or municipalities of Shanxi. 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.

Fourthly, efficient water-saving irrigation techniques, as implemented in the 0188 ADB Grant Project, should be promoted throughout the whole Province. This promotion of precision irrigation should actively engage local enterprises and farmers’ cooperatives. It is important that the introduction and scaling-up of these new techniques is 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. Below-standard introduction of water efficiency measures should be avoided at any cost, because this will not serve the purpose and will create disappointment instead.

4.2.4 Increasing the amount of water available by better recharge and retention and developing non-conventional water resources

The total amount of water resources is now 12.3 billion m³ per annum for Shanxi province, of which surface water and groundwater each take half. In the past, groundwater has been excessively exploited in Shanxi province and as a result, the groundwater table in the important central plains of Shanxi has dropped. To relief 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:

Firstly, 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 river beds will slow down the speed 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 the areas with beneficial effect on groundwater recharge, soil moisture and micro-climates. More investment is also required, under adequate engineering, in flood storage reservoirs of different sizes.

Secondly, in the plain areas more flood water 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 flood water spreading should be introduced systematically throughout the lowlands of Shanxi Province.

Thirdly, efforts should be put in to vigorously promote the reuse of water, in particular:

1) Reuse of urban waste water. For this, we need to make a plan on urban wastewater reclamation and reuse and then invest in additional wastewater recycling facilities. It is also important to encourage enterprises to use wastewater with economic policy incentives.

2) Grey water techniques should be promoted. There should be grey water reclamation and reuse pilots first at the residential quarters where buildings conglomerate and then to be promoted and replicated at other areas.

3) In general is essential to accelerate the paces of water-saving technological development. Advanced technologies should be adopted on water recycling and reuse, on cooling water and on water treatment. Finally we should also increase the reuse rate of water used for industrial activities and of mine drainage.

4.2.5 Strengthening the protection of groundwater resources

Strengthening the protection of groundwater resources, turning waste water into usable resources, and preventing and treating water sources pollution are essential measures to achieve the sustainable development and utilization of water resources. This requires:

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

Secondly, combining decentralized and centralized pollution treatment methods and activating large, medium and small-sized treatment plants simultaneously. We should also tighten our control of industrial and mining pollution sources and strictly limit the amount of wastewater they discharge. 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, tightening the control of the mining sector in order to protect groundwater resources. Coal mining has increased manifold from 2000 to 2012 and production in Shanxi now touches 1 billion ton of coal a year. In the past several years, many smaller mines have closed down or been merged with
larger mines in Shanxi, so the coal mining sector now consists of a small number of large companies. This makes it easier to regulate the coal mining sector. Coal mining has an enormous impact on the long term sustainable availability of groundwater and its impact needs to be regulated with high urgency.

Here three safeguards are required:
(1) all new coal mines should have a clearance of the water bureau with respect to their mining operations to ensure that aquifer systems are not perched because of mining operations;
(2) all existing and new coal mines should have a compulsory environmental management plans that describes the remedial actions and investments in (a) reduce waste water quality and prevents pollution (b) avoid leakage from coal waste through safe linings and other measures; and
(3) Damage from older coal mines, including closed mines and empty seams, should be controlled. Here three actions are recommended: (i) the pollution from old mine tailing 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; (ii) the risk of acid mine water should be mapped and where it causes major threats to population and eco-systems corrective measures should be taken; and (iii) the reuse of coal seams should be considered: they may be refilled with the crushed stone and in critical areas man-made aquifers may thus be created.

4.2.6 Continuing innovation and make Shanxi a leading center in water efficiency

In certain areas, there has been considerable innovation in new water using techniques. The 0188 PRC grant introduced efficient 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 and will lead to sustainable development. It is recommended that the Government of Shanxi with local research organizations develops 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 area for innovation that is particularly promising and important for Shanxi by way of example is the use of soil improvement methods, in particular the application of zeolite and bio-fertilizer. Zeolite is a mineral that occurs abundantly in Shanxi, but is not systematically used in agriculture. Zeolite can however at low cost can ensure the more efficient uptake of fertilizer (reducing the risk of nitrogen pollution) and significantly improve the moisture holding capacity of the soil, reducing the need for irrigation.

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

A third area where there is much scope for innovation is water treatment methods especially from mining. This can be active water treatment, including the use of bio-reactors, passive water treatment with constructed wetlands, and the controlled storage and release of acid mine waste.
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Project Research Results

