CPWF Project Report

Yellow River Basin: Living with Scarcity

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Project Team

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Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

Yellow River Basin Focal Project (YBFP)

The Yellow River Basin (YRB) Focal Project set out to study water poverty, water availability and access, water productivity, and water and related institutions in the Yellow River basin to develop and rank a series of high-priority interventions aimed at increasing water and food security for the poor, while maintaining environmental sustainability. The YBFP identified complex relations between water and poverty in the YRB; identified streamflow declines in the basin despite predicted higher rainfall; calculated basin-water shortfalls as a result of both economic development and climate change; assessed various aspects of rainfed and irrigated crop water productivity; and identified key reforms for water-related institutions. Moreover, the YBFP empirically assessed the benefits of agricultural water rights trading applying an innovative modeling framework to the basin.

CPWF Project Report series:

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LIST OF ACRONYMS AND TECHNICAL TERMS

BFP	Basin Focal Project
BCM	Billion cubic meters
BNU	Beijing Normal University
CCAP	Center for Chinese Agricultural Policy
CCIS	Canadian Climate Impact Scenarios
CPI	Consumer Price Index
CPWF	Challenge Program on Water and Food
DEM	Digital Elevation Model
ET	Evapotranspiration
ET0	Reference Evapotranspiration
GDP	Gross Domestic Product
GME	General Maximum Entropy
HIES	Household Income and Expenditure Survey
HYV	High-Yielding Varieties
ID	Irrigation District
IFPRI	International Food Policy Research Institute
MAS	Multi Agent System
MER	Ministry of Energy Resources
NER	Nett Enrollment Rate
OLS	Ordinary Least Squares
P	Precipitation
PE	Effective Precipitation
RMB	Chinese Currency
SCS	Soil Conservation Service
SDSM	Statistical DownScaling Model
SNWT	South-to-North Water Transfer
SWAT	Soil and Water Assessment Tool
TU	Tsinghua University
UIUC	University of Illinois at Urbana-Champaign
UWFR	Unified Water Flow Regulation
WP	Water Productivity
WPI	Irrigated Water Productivity
WPR	Rainfed Water Productivity
WUA	Water User Association
YBFP	Yellow River Basin Focal Project
YRB	Yellow River Basin
YRCC	Yellow River Conservancy Commission

Unit conversion:
1 ha = 15 mu

RESEARCH HIGHLIGHTS

China is facing growing water scarcity in many river basins due to its rapid economic development, an expanding population, growing urbanization, and limited scope to develop new supplies. Water overdrafts, both from surface and sub-surface sources, are causing serious environmental problems ranging from the degradation of ecosystems in the deltas of major rivers to aquifer depletion in northern China. The Yellow River Basin (YRB) is symptomatic of the challenges facing China's water economy. The YRB, which is the second largest basin in China, is a key agricultural and industrial region in the country and also considered the "cradle of Chinese civilization". However, the basin faces severe water shortages. The particular climatological and hydrologic conditions together with very rapid industrial and urban development are making sustainable water supply for all users and uses a complex and difficult task. Given the extreme water shortages in the basin, how can water resources be managed to continue to support agricultural and economic development while also improving outcomes for the environment?

To assess this question, we asked a series of sub-questions, including: How are water and poverty related in the basin? We found that the headcount poverty ratio is significantly lower in irrigated areas than in nonirrigated areas of the YRB region. For instance, while 19.4 percent of all households living in irrigated villages are poor, the rate is more than double (41.4 percent) in nonirrigated villages. Moreover, we found that the combination of higher rainfall and the extensive use of tubewell irrigation contribute to higher crop productivity, and hence, increased income of the households living in the downstream area. As a result, the poverty rate in the upstream area (47.5 percent) is nearly five times higher than in the downstream area (only 9.9 percent), while the rate in the midstream area (29.6 percent) is three times higher. We also found important linkages of irrigation with other development indicators. For example, school enrollment rates are higher in irrigated villages than in nonirrigated villages; and irrigated villages have better access to safe drinking water in the YRB—78 percent of households in irrigated villages have access to safe water compared to only 47 percent in nonirrigated communities. Higher irrigation coverage of cultivated land at the village level is associated with greater crop productivity and greater use of HYVs of wheat and maize. Finally, increasing irrigation coverage by 10 percent reduces the incidence of poverty by 5.1 percent.

We also looked at the water supply and demand balance in the basin over time to assess implications for both food and water security. We found that socioeconomic development, along with rising concerns for public health and environmental degradation, and global climate change will drive water demand increases over the next 10–20 years. We found that based on projected changes in water supply and demand, by 2020 the YRB will face water shortages of 8 km^3 and a water deficit ratio of 14.5 percent, which would mostly affect the rural production sector, particularly irrigation. Under drier-year scenarios, water shortages would increase significantly and outflows to the Bohai Sea would drop to 15 km^3 and 9 km^3 under 75 percent exceedance frequency and 95 percent exeedance frequency, respectively. If climate change is considered as well, the water deficit ratio would increase to 23 percent under average conditions. As expected, conditions would be most dire under combined climate change and dry-year conditions, with shortages of 21 km^3 and a water deficit ratio of up to 37 percent. We evaluated a series of engineering solutions and found that none of these would be able to close the growing gap between water supply and demand.

As irrigation water supplies are increasingly squeezed by domestic, industrial, and environmental water demands, including large water needs for sediment flushing, an important question to address is the potential to enhance water productivity in the irrigation sector. We found that for all key basic food grains that we assessed in the basin that irrigated and rainfed water productivity was higher in the downstream area compared to the midstream area of the YRB. Interestingly, for both maize and soybean, rainfed water productivity—depending on precipitation only—was significantly higher compared to irrigated water productivity in the downstream basin; and for soybean rainfed productivity is also slightly higher in the midstream area of the basin. However, the standard deviation of rainfed productivity levels is considerably higher than that of irrigated productivity. This implies that from upstream to downstream regions of the YRB, irrigated maize and soybean may not be as water-efficient as rainfed crops, but irrigation stabilizes crop production per unit of water consumption, which increases in importance with increased incidence of extreme events under climate change.

Policies and institutions are considered to be key to effective water management in the YRB and elsewhere. We found that the Government of China has made significant strides in its legal framework for water management. For example, the 2002 Water Law considers increased conservation of water resources as a key objective. Moreover, the law calls for a water-allocation system based on the issuance of water-abstraction permits and water-use fees. A wealth of successive *ad hoc* regulations further support water savings by providing clarifications on water permits and rights, water pricing, and abstraction fees. Despite this, implementation has been slow, particularly at the province level, and field research on the ground has shown that irrigation districts have been implementing changes only slowly.

The Government of China has been highly successful in eliminating flow-cutoffs that had plagued the Yellow River annually for more than 2 decades (1972-1998). The Yellow River Conservancy Commission (YRCC) implemented a province-level, quota-based water allocation system (Unified Water Flow Regulation-UWFR) that had been in existence since 1987. Despite this success, the regulation is facing criticism, particularly in the upstream and poorer regions of Qinghai, Gansu, Ningxia, and Inner Mongolia. Before the regulation entered into effect, these regions had free access to water resources and enjoyed more than three times the per capita water availability of the downstream regions. The lack of compensation for the interprovincial water transfers has contributed to a decline in irrigation water use, and tension has risen as some producers in the irrigation districts have started to see negative effects.

We also found that the establishment of Water User Associations (WUAs) in China did not have the desired effect—conserving water resources—in many irrigation districts, as governance structures only changed in name, whereas economic incentives were often not provided. However, when new irrigation management entities (or existing ones) were entitled to keep as excess profit the difference between the water fee collected (which is based on an estimate of village water needs compiled before the farming year) and the total fee calculated from the actual water supplied (which can be reduced at the request of the water manager), then water user per ha declined. Preliminary survey results found that such declines did adversely affect wheat yields, whereas declines for other crops were not statistically significant. However, no clear impacts on farmer incomes could be detected suggesting the need for further analyses. To achieve water use savings without adverse impacts on crop yields or farmer incomes, it would be important to provide economic incentives directly to this user group instead of to irrigation districts.

We also assessed the possibility of trading of water rights in a market system to compensate irrigators or other water-using sectors for giving up water. From a legal perspective, laws and regulations, particularly starting with the 2002 Water Law, have established a system of water-use rights and water abstraction fees, but the law does not allow transferability of these rights. In some regions of the YRB experiments have been conducted on water-rights transfers from the agriculture to the industry sector, but these experiments were set up and run by the local government rather than resulting from trade driven by market mechanisms. The establishment of water transfers is also hindered by a still underdeveloped water-use rights system; although the system is supported by law, most provinces have yet to allocate water quotas to individual users.

We empirically implemented the potential impact of irrigation-water-rights trading across the YRB on the basin gross domestic product (GDP) using a multi-agent system (MAS) modeling framework. We compared two scenarios to evaluate the consequences of changes from the current scheme of water allocation (that is, business-as-usual under the current UWFR based on the 1987 allocation agreement): (1) water allocation across provinces without quotas, and (2) water trading among agents using irrigation water. We also studied the impact of enforcing full environmental flow requirements (as established by several Chinese studies) on the potential for water trading. As expected, under a scenario without any water quotas, annual water consumption is higher—by 11 percent (38.3 km^3 compared with 34.5 km^3 under the UWFR). At the same time, the basin-wide GDP—at 1123.26 billion RMB under the scenario without regulation—is 10 percent lower than the 1246.68 billion RMB achieved under the UWFR scenario. As a result of increased water consumption without the UWFR, flows to the downstream ecosystem are reduced and flow cutoff events occur from February to June. Flow impacts are even stronger for the delta, where cutoff periods start in February and continue through December. This scenario thus adequately mimics the 1972-1998 period before the Government enforced provincial water-use quotas.

If irrigation water trading is allowed, upstream districts tend to sell water to gain revenue, while downstream users buy water for greater water-use benefit. The GDP increase is 5.64 billion RMB for upstream agents and 17.8 billion RMB for midstream and downstream agents, with a total GDP increase of 23.45 billion RMB. Moreover, annual water consumption under the water-trading scenario is slightly lower at 33.8 km^3 than the annual water consumption under the UWFR scenario while total GDP is higher at 1270.1 billion RMB in the former scenario.

Can the YRB economy accommodate full environmental flow requirements? We find that it is physically impossible to satisfy both human and ecosystem requirements for the months of January, April, and June unless additional measures, such as reservoir re-operation or new infrastructure development, are undertaken. Thus, water trading has the potential to mitigate growing water shortages in the YRB. Ongoing intra-provincial irrigation-to-agriculture transfers provide important inputs for the potential development of inter-provincial water trading, which has been discussed for several years by both policymakers and water allocation managers at the Ministry of Water Resources and the YRCC. Such a reallocation could increase the water allocation efficiency of the 1987 cross-provincial water-allocation agreement.

EXECUTIVE SUMMARY

Background

The Yellow River Basin (YRB) is a key food production center of global importance facing rapidly growing water scarcity. Water availability is further threatened by growing water pollution, global warming, environmental water needs, and continuing industrial and municipal water demand growth. While poverty in the basin has declined rapidly over the last three decades (in line with rapid overall declines in China), pockets of poverty remain in the upstream areas. Water productivity in the basin varies by both crop and location in the basin and has improved considerably over the last several decades. While China has made significant changes in managing its water resources, current governance structures leave much to be desired for effective and efficient water allocation in the basin. To assess how water can be allocated more efficiently and effectively to ensure sustainable food production in the YRB into the future, a series of engineering, institutional, and economic measures have been assessed.

In this final report we discuss the results of a two-year study on biophysical and socioeconomic aspects of the water and related resources in the YRB; the relation of water development and agricultural and economic growth; and options for enhancing water availability and access for sustained agricultural and economic development, while maintaining environmental sustainability.

Objectives

The Yellow River Basin Focal Project studied water poverty, water availability and access, water productivity, and water and related institutions in the YRB to develop and rank a series of high-priority interventions aimed at increasing water and food security for the poor, while maintaining environmental sustainability. To achieve the expected outputs, the project implemented six distinct work packages:

WP1: Water Poverty
WP2: Water Availability and Access
WP3: Water Productivity
WP4: Institutional Analysis
WP5: High-Impact Interventions
WP6: Knowledge Base and Evaluation Platform

Research area

Research took place in the Yellow River Basin in China. The Yellow River (or "Huang He" in Chinese) is the second longest river in China. Originating in the Bayangela Mountains in western China, the river drops a total of 4,500 meters as it loops north into the Gobi Desert before turning south through the Loess Plateau and then east to its terminus in the Bohai Gulf. In total, the river flows 5,464 kilometers and passes through nine provinces and autonomous regions, with a basin area of 795,000 km^2.

Methods

We used a variety of research methods, ranging from stakeholder consultations, workshops with researchers, to descriptive qualitative analysis, and quantitative, modeling analysis. Quantitative analysis methods included a) econometric analyses to relate agricultural water with poverty outcomes and to relate water-related institutions with water savings; b) hydrologic and water supply and demand simulation modeling, including SWAT modeling to assess the impact of climate change on Yellow River Basin water resources; water supply and demand modeling (YRCC-led) to assess water availability and use in the basin; and MAS modeling to assess the impact of alternative high-impact interventions; and c) GIS-based analysis of water productivity to assess the spatial variation of water productivity across the basin.

Research findings

Our key findings include:

Water Availability

The Yellow River Basin is a highly water-scarce basin. Much of the infrastructure on this highly controlled river has been built for flood control, but climate change and droughts will bring new challenges to a basin that has only been prepared for flood management.

While the situation is already severe under average conditions, water availability is expected to worsen significantly under climate change.

The HadCM3 and SDSM used in this study project warming of 1.34^{o}C by 2020, 2.6^{o}C by 2050, and up to 3.9^{o}C by 2080 for the maximum air temperature in the study area. The values are 0.87^{o}C, 1.49^{o}C, and 2.27^{o}C for minimum air temperature. Weak changes in regional precipitation amounts are also projected. Annual precipitation is projected to increase by 3.47% by 2020, 6.42% by 2050, and 8.67% by 2080. However, streamflow for three benchmark periods will decrease by 88.61 m^3/s, 116.64 m^3/s, and 151.62 m^3/s, respectively. The decline in streamflow will affect regional water supply and security in the YRB. The scenarios presented here, and the simulated impacts on the hydrologic regime, raise questions over the availability of future water resources in the study area, particularly in terms of the magnitude of seasonal runoff.

Climate change would raise the annual water deficit by 4.21 billion cubic meters (BCM), and the discharge into the Sea would drop by 2.18 BCM. As expected, the worst water situation is achieved under combined dry-year and climate change condition: In a year with 75% and 95% exceedency frequency, respectively, the volume of water shortage would reach 15.055 BCM and 21.022 BCM, respectively, under climate change, and the water deficit ratio for the entire basin would reach 28% and 37%, respectively. A key concern regarding water shortages is not only fulfilling productive water demands, but also the large minimum flow requirement to move sediments downstream to avoid breaching the dikes, estimated at 15 BCM during the rainy season.

At the same time, the water engineers at YRCC still see some potential for total water savings in the basin, amounting to up to 5.7 BCM by 2020 and 7.6 BCM by 2030. As the dry-season, climate change calculations show, however, these savings will not be sufficient to turn around trends of growing water deficits in the basin.

Water Productivity

Irrigated yield is significantly higher than the rainfed yield for corn, and soybean in different regions of the YRB; however for soybean in downstream areas, rainfed yield is even higher than irrigated yield. WPI is slightly lower than WPR for corn and soybean, which implies that the irrigated crops may not be as efficient as rainfed crops with regard to water productivity for particular crops in the YRB.

WPI and WPR vary spatially from upstream to downstream with both changing climate and water supply conditions. The water factor is particularly sensitive to spatial scale, which reflects the impact of water regulation over space in the YRB through engineering measures. The water factor has stronger effect on both crop yield and WP than the energy factor.

Irrigation stabilizes the crop production per unit of water consumption. Croplands have higher water consumption than urban lands but lower than forest lands. Among the sub-basins, the midstream region has more important agricultural water management issues from the perspective of both crop yield and WP.

Water Institutions

Increased conservation of water resources is one of the key goals of China's 2002 Water Law. Under this law, the Ministry of Water Resources (MWR) manages all water resources through a water-allocation system based on the issuance of water-abstraction permits and water-use fees. A wealth of successive ad hoc regulations support water savings by providing clarifications on water permits and rights, water pricing, and abstraction fees. Despite the development of this legislative body, implementation of the allocation system at the provincial level has been slow due to a lack of details on how to implement the law, conflicts between water users, and financial difficulties.

Given the scarcity of water resources in the Yellow River Basin and the lack of compensation for transferring water to more well-off, downstream users, tensions and conflicts among water stakeholders have risen. Although YRCC is authorized by the State Council to control the Yellow River water resources, it has limited powers to penalize those users who consume beyond specified province-level water use limits. Only the State Council can actually enforce water use, but this power is seldom exercised in practice. Integrated management of the Yellow River water is faced with many difficulties, particularly given the fact that water control is new and no ready-made river control standard can be followed. Further, the Yellow River Water Quantity Control Management Method does not have detailed implementing regulations; and many aspects of reservoir control application regulations of hydropower stations are at odds with the Yellow River Water Quantity Control plan. Currently, the YRCC only directly allocates water from Liujiaxia Reservoir to Toudaoguai and from Sanmenxia Reservoir to Lijin gauge; other sections remain without integrated management. Since 2006, limited water allocation is also exercised by YRCC on two tributaries, the Weihe River and the Qinhe River.

A field survey across 51 villages in four irrigation districts in Ningxia and Henan found that, following the liberalization of collective water management, the share of villages with collective management of water resources declined from 91 percent in 1990 to 49 percent in 2004. By that year, 30 percent of the villages in the two provinces managed water resources through a hired manager, whereas 21 percent instituted water user associations (WUAs). The pace of reform has been significantly faster in Ningxia than in Henan; this is not unexpected in China, as local governments are often given large autonomy to decide on the form and timing of institutional changes. Analyses of field data showed, however, that hired managers or WUAs were not necessarily more effective than the past collective system. Instead, what mattered were the incentives provided by the various governance mechanisms as well as the overall implementation process. When new irrigation management entities (or existing ones) were entitled to keep as excess profit the difference between the water fee collected (which is based on an estimate of village water needs compiled before the farming year) and the total fee calculated from the actual water supplied (which can be reduced at the request of the water manager), then water user per ha declined.

Water Poverty

Using the purchasing power parity (PPP) $1.25 a day poverty line and per capita income levels, we estimated that 30.5 percent of the population in the rural YRB region were living in poverty in 2001. The poverty rate was highest in the mountain region and lowest in the plain land region.

The incidence of poverty (headcount poverty rate) varied widely in different parts of the rural YRB, ranging from a low of only 3.1 percent in the YRB part of Shandong province in the east to as high as 52.2 percent in the YRB part of Gansu province in western China. This pattern of poverty incidence corresponds quite well to that of the national level—poverty in China is mainly concentrated in the western part of the country.

The profile of poverty in the YRB focused on the empirical links between water and poverty in the basin. The PPP $1.25 a day headcount poverty rate is significantly lower in irrigated areas than in non-irrigated areas of the YRB region: while 19.4 percent of all households living in irrigated villages are poor, the rate is more than double (41.4 percent) in non-irrigated villages.

The estimated income elasticity with respect to irrigation coverage suggests that, a 10-percent increase in the village-level irrigation coverage increases per capita income of households living in that village by 1.7 percent on average. Further, poverty simulations using the estimated parameters of the income model suggest that, increasing irrigation coverage by 10 percent reduces the incidence of poverty by 5.11 percent.

While the impact of irrigation expansion on poverty reduction is large, we also find fairly large and positive effect from expanding off-farm income opportunities in rural YRB. The headcount poverty rate is expected to decline by 4.52 percent if the share of non-farm income in total per capita household income increases by 10 percent.

In sum, expanding irrigation in the YRB will help boost crop yields, which in turn will increase incomes of the poor and reduce poverty. However, there are limits to expanding irrigation coverage, and labor productivity is known to be lowest in agriculture. Therefore, accelerating a shift of rural labor force out of agriculture by creating off-farm employment opportunities in higher productivity sectors in rural areas is arguably even more important for the poor. That said, rapid agricultural growth must be pursued for poverty reduction. The World Development Report 2008 shows that growth in agriculture is two to four times more poverty alleviating than growth in other sectors. Both China and India offer concrete evidence of this finding. Therefore, faster agricultural growth accompanied by a speedy shift of rural labor force out of agriculture is key for poverty reduction in the YRB.

High-Impact Interventions

Given the size of the YRB, no single intervention could possibly do justice to the extreme diversity of water-related challenges found in the basin, which ranges from the upstream mountainous areas dominated by livestock herders, to the hilly/mountainous Loess Plateau with severe erosion challenges, the semi-arid to arid irrigated plains in Inner Mongolia/Ningxia with rapidly growing industries, to the key urban-industrial centers interspersed with highly productive irrigation downstream. Many interventions have been implemented in the past to increase water supply and enhance flood control. Key among these are the construction of the Xiaolangdi reservoir, completed in 1999, which has increased the designed flood-control period from 60 years to over 1000 years; the construction of several thousand silt-trap dams across the Loess Plateau; and two large watershed rehabilitation projects implemented by the government of China and the World Bank. Additional interventions in recent years to address growing water shortages and the need for food include the conversion of hillside production into terraces (this was also done as part of the watershed rehabilitation project); rainwater harvesting schemes in the western upland areas; the use of plastic sheeting to contain soil moisture and reduce evaporation in the arid parts of Inner Mongolia and Ningxia; and the resettlement of people out of extremely dry areas.

Based on stakeholder working groups, expert discussions among the research team, and quantitative analysis, we are suggesting the following high-impact interventions:

<u>Technical interventions:</u>

While many technical or engineering interventions have been already implemented in the basin, a series of additional measures could increase water supply or reduce demand. The possibly most important one is the south-to-north water transfer (SNWT) project. If fully implemented, it could transfer up to 50 km^3 (comparable to total Yellow River runoff) from the Yangtze River in southern China to the North China Plain. However, among the three routes (western, middle and eastern routes) only the western route would directly affect water resources in the YRB. It could transfer 20 km^3 to irrigate an additional 1.3 million ha and provide water for economic development in Qinghai, Gansu, Shanxi and Shanxi provinces, as well as Ningxia and Inner Mongolia, all in the YRB. However, economic, engineering, and ecological side effects prevent this route from development in the foreseeable future.

Even without the SNWT, engineers at YRCC still see some potential for water savings in the basin, amounting to 5.7 km^3 by 2020 and 7.6 km^3 by 2030, mostly in the agriculture sector (but allowing for continued agricultural and economic growth and small increases in irrigated area). However, these savings will not be sufficient to turn around trends of growing water deficits in the basin, particularly in dry years. Thus, even more investment in agricultural research and development will be needed to achieve even more rapid improvements in crop yields without use of more irrigation water.

An assessment of crop water productivity across the YRB showed that while there is still scope for increased water-use efficiency in irrigated agriculture in the YRB, the scope is limited and further declines in allocation of water to irrigation will eventually result in reduced food production with serious implications for local food security and farmer incomes, as well as potential impacts on global food prices and trade.

Reform of governance:

Despite high levels of water scarcity in the country and in the YRB, integrated water management in China remains elusive as a result of fragmented management and conflicts among water users at the national, provincial, and local levels. Key challenges in Chinese water legislation and administration relate to the lack of regulations supporting implementation of the 2002 water law; and poor incentives for water conservation at the level of the irrigation system. To address growing water scarcity, in addition to water supply/engineering measures, the government has started to support reform of irrigation management. Our studies found that significant scope for governance and institutional reforms remain in the following areas: 1) Reforming irrigation management institutions; 2) Reforming water pricing; 3) Implementing water rights transfer projects; and 4) Support for water reallocation across provinces.

Economic solutions: Role of water pricing and water markets

Although water prices have been steadily raised over the past several decades in China, and particularly since the latest round of water-pricing reforms started in 1997, agricultural water is still thought to be much under-priced. As a result, water charges remain a limited instrument to increase water use efficiency and productivity further. Moreover, given the growing rural-urban income divide, it is unlikely that the government will raise irrigation fees to levels high enough to reduce irrigation water use seriously. Furthermore, in the YRB, the UWFR has led to income shortfalls of districts in parts of the basin where irrigation water supplies were cut considerably, particularly in midstream provinces.

Since 2000, YRCC has promoted the establishment of water-right systems by conducting demonstration projects aimed at reducing water competition among sectors. The purpose of these demonstration sites is to reallocate water from agriculture to industry through increasing irrigation efficiency, generally through engineering measures, such as canal lining. One transfer pilot project operates in Ningxia Province and 16 projects signed transfer contracts in Inner Mongolia, with a value of US$100 million. Under these projects, irrigation districts transfer part of their water use rights to industrial enterprises for a period of 25 years. However, analyses showed that water users in the irrigation districts are generally not aware of the water rights transfer; transfers are determined by the administration, not markets; and there are no adjustments based on market signals or economic measures. Thus, major challenges remain until a true market for water rights can be established.

Importantly, the intra-provincial irrigation-to-agriculture transfers in the YRB provide important inputs for the potential development of inter-provincial water trading, which has been discussed by both policymakers and water allocation managers at the MWR and YRCC for several years. Given the key importance of compensating irrigators for giving up water for both flows at the river mouth and rapid urban-industrial development downstream, we analyzed the potential impact on basin GDP of water rights trading using a multi-agent system (MAS) modeling framework developed for the YRB.

We compared two scenarios to evaluate the consequences of changes from the current scheme of water allocation (that is, business-as-usual under the current UWFR based on the 1987 allocation agreement): (1) water allocation across provinces without quotas, and (2) water trading among agents using irrigation water. We also studied the impact of enforcing full environmental flow requirements (as established by several Chinese studies) on the potential for water trading. As expected, under a scenario without any water quotas, annual water consumption is higher—by 11 percent (38.3 km^3 compared with 34.5 km^3 under the UWFR). At the same time, the basin-wide GDP—at 1123.26 billion RMB under the scenario without regulation—is 10 percent lower than the 1246.68 billion RMB achieved under the UWFR scenario. As a result of increased water consumption without the UWFR, flows to the downstream ecosystem are reduced and flow cutoff events occur from February to June. Flow impacts are even stronger for the delta, where cutoff periods start in February and continue through December. This scenario thus adequately mimics the 1972-1998 period before the Government enforced provincial water-use quotas.

If irrigation water trading is allowed, upstream districts tend to sell water to gain revenue, while downstream users buy water for greater water-use benefit. The GDP increase is 5.64 billion RMB for upstream agents and 17.8 billion RMB for midstream and downstream agents, with a total GDP increase of 23.45 billion RMB. Moreover, annual water consumption under the water-trading scenario is slightly lower at 33.8 km^3 than the annual water consumption under the UWFR scenario while total GDP is higher at 1270.1 billion RMB in the former scenario.

<u>Conclusions</u>

The government of China has recognized the severe water constraints in the YRB. To address growing water scarcity, the government has started to change its approaches from management of water supply toward improved management of water demand. Signs of the new approaches are the 2002 water law, the increased number of regulations on water prices and a series of water trading pilots implemented in the YRB. However, most organizations concerned with water management are still headed and staffed by engineers, and traditional water-engineering measures, as exemplified by the SNWT, still dominate interventions in terms of funding.

There is no panacea for addressing the severe water scarcity challenges in the YRB. Based on an assessment of options available, we believe that the government should continue to reform the institutions responsible for irrigation management and water pricing across all water-using sectors; but current users need to be compensated for ceding water resources to users with higher-valued uses. Projects that transfer enhanced water rights that follow market mechanisms, and include the establishment of water rights and related responsibilities would be a first step in that direction. Reform is also required at all the administrative levels from the central to the local government to support fully integrated land and water management at the basin level and to avoid large inefficiencies caused by conflicting objectives of the various agencies involved in water supply and food production in the YRB.

Expanding irrigation in the YRB will help boost crop yields, which in turn will increase incomes of the poor and reduce poverty. However, the potential for expanding irrigation is limited, and labor productivity is known to be lowest in agriculture. Therefore, accelerating a shift of the rural labor force out of agriculture by creating off-farm employment opportunities in higher-productivity sectors in rural areas is arguably even more important for future rural economic development.

Other ancillary measures that need to be continued include further adoption of water-saving technologies, and continued support to agricultural research and development to increase crop productivity for both irrigated and rainfed crops. Continued productive investment is needed, rather than subsidies, in the rural non-farm sector to ensure that the urban-rural poverty gap does not widen even further. There is still scope for savings of agricultural water through improved water productivity. But continued transfers of water out of agriculture will eventually result in declining production, with implications for national food production as well as global food prices and trade.

1. INTRODUCTION

1.1 Overview

The Yellow River Basin Focal Project (YBFP) studied water poverty, water availability and access, water productivity, and water and related institutions in the Yellow River Basin to develop and rank a series of high-priority interventions aimed at increasing water and food security for the poor, while maintaining environmental sustainability. To achieve the expected outputs, the project implemented six distinct work packages (see also Figure 1.1.1):

WP1: Water Poverty
WP2: Water Availability and Access
WP3: Water Productivity
WP4: Institutional Analysis
WP5: High-Impact Interventions
WP6: Knowledge Base and Evaluation Platform

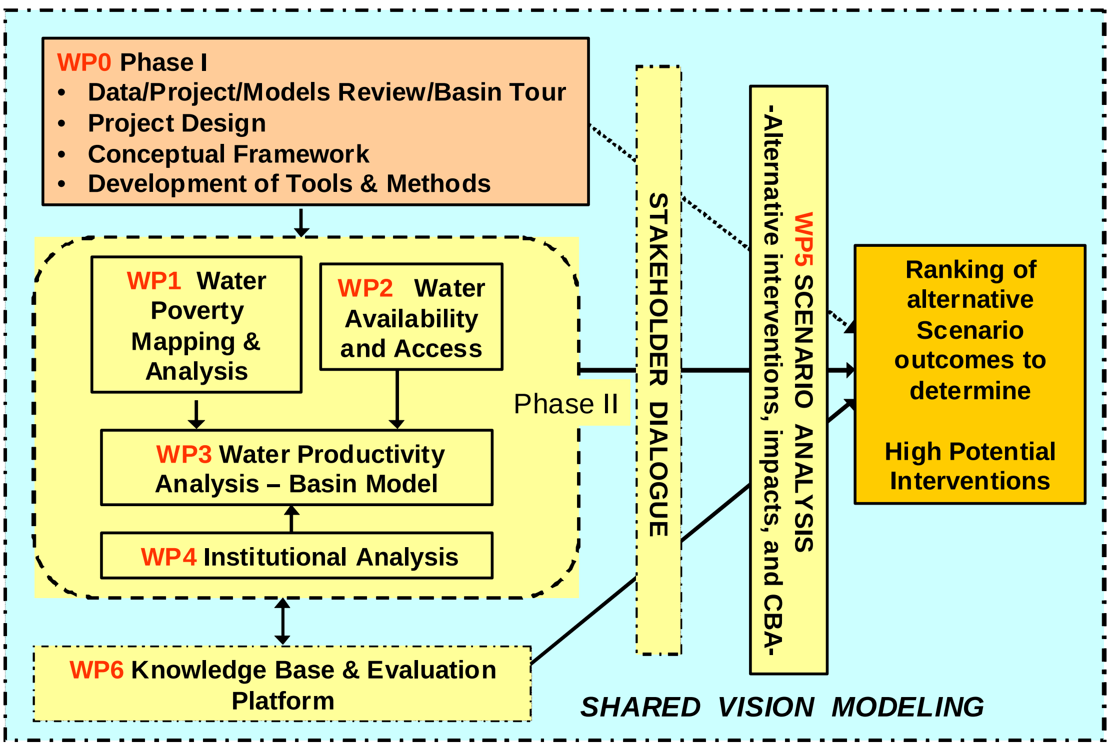

Figure 2.1.1.1: Yellow River Basin Focal Project Implementation Process

For this final report, we will report on each of these work packages, starting with 1) Water Availability and Access, 2) Water Productivity, 3) Institutional Analysis, 4) Water Poverty, 5) High-Impact Interventions, and 6) Knowledge Base and Evaluation Platform.

1.2 Introduction to Study Site

China is facing growing water scarcity in many river basins due to rapid economic development, an expanding population, growing urbanization, and limited scope to develop new supplies. Water overdrafts, both from surface and sub-surface sources, are causing serious environmental problems ranging from the degradation of deltaic ecosystems of major rivers to aquifer depletion in North China. According to an estimate by China's Ministry of Water Resources, the loss of food production due to water stress

has reached 25–30 million metric tons (mmt), and the direct economic loss to agriculture and industry was about RMB 150 billion (equivalent to US $18 billion) in 2005 (China Economic Herald, 2005). As serious as the economic costs of water scarcity are its ecological consequences. The drying of the Yellow River, the large-scale groundwater mining in the North China Plain, and rapidly growing water pollution in the basin are some of the symptoms of negative environmental impacts of water scarcity.
The Government of China has declared the lack of water resources a serious limitation to the economic and social development of the country (Premier Zhu Rongji, National People's Conference meeting, February 2000.). Several studies found limited water supplies to have direct negative impacts on food production in the country (see, for example, Brown, 1995; Brown and Halweil 1998; Rosegrant et al., 2002; Yang et al., 2003). With business-as-usual water management and agricultural development practices, these trends are set to worsen in future years given the continued rapid economic development in China combined with continued, albeit low, population growth, and rapidly changing diets, including increased consumption of meats and vegetables.

The Yellow River (or "Huanghe" in Chinese), is the second longest river in China. Originating in the Bayangela Mountains in western China, the river drops a total of 4,500 m as it loops north into the Gobi Desert before turning south through the Loess Plateau and then east to its terminus in the Bohai Gulf (Figure 1.2.1). In total, the river flows 5,464 km and passes through nine provinces and autonomous regions, with a basin area of 795,000 km^2 (including 42,000km^2 inland river catchments in the northwest of the basin) at present. The basin population is estimated at 0.11 billion and farmland area covers 0.244 billion mu (equivalent to 16.3 million ha), about 13 percent of China's total cultivated area. The annual average natural runoff amounts to 53.5 billion m^3, and total water resources amount to 64.7 billion m^3 (Yellow River Water Resources Bulletin 2006).

The Yellow River is one of the most heavily controlled rivers in the world by advanced engineering systems. Thus, spatial and temporal variability of water availability depends on both natural hydroclimatic processes and human interferences. Unique water availability and access challenges of the Yellow River Basin include low per-capita water availability, significant potential impact of climate change and variability; large spatial and temporal variation in surface runoff generation; the significant role of multipurpose reservoirs that control the whole runoff (sometimes with competing uses); important roles of flooding, drought, and the notorious large flow cutoffs of the late 1990s (which had been gradually increasing since the 1970s); large differences in access and use by water use sector and socioeconomic group; and water quality degradation in the middle and downstream main channel and tributaries. As a result of high levels of water scarcity, the basin faces competition between irrigators in the mid- and upstream areas and growing non-irrigation demands downstream, as well as rapidly growing water degradation. Water scarcity and poor quality have already contributed to economic losses in the basin as a result of both water scarcity and poor water quality and resulting environmental problems.

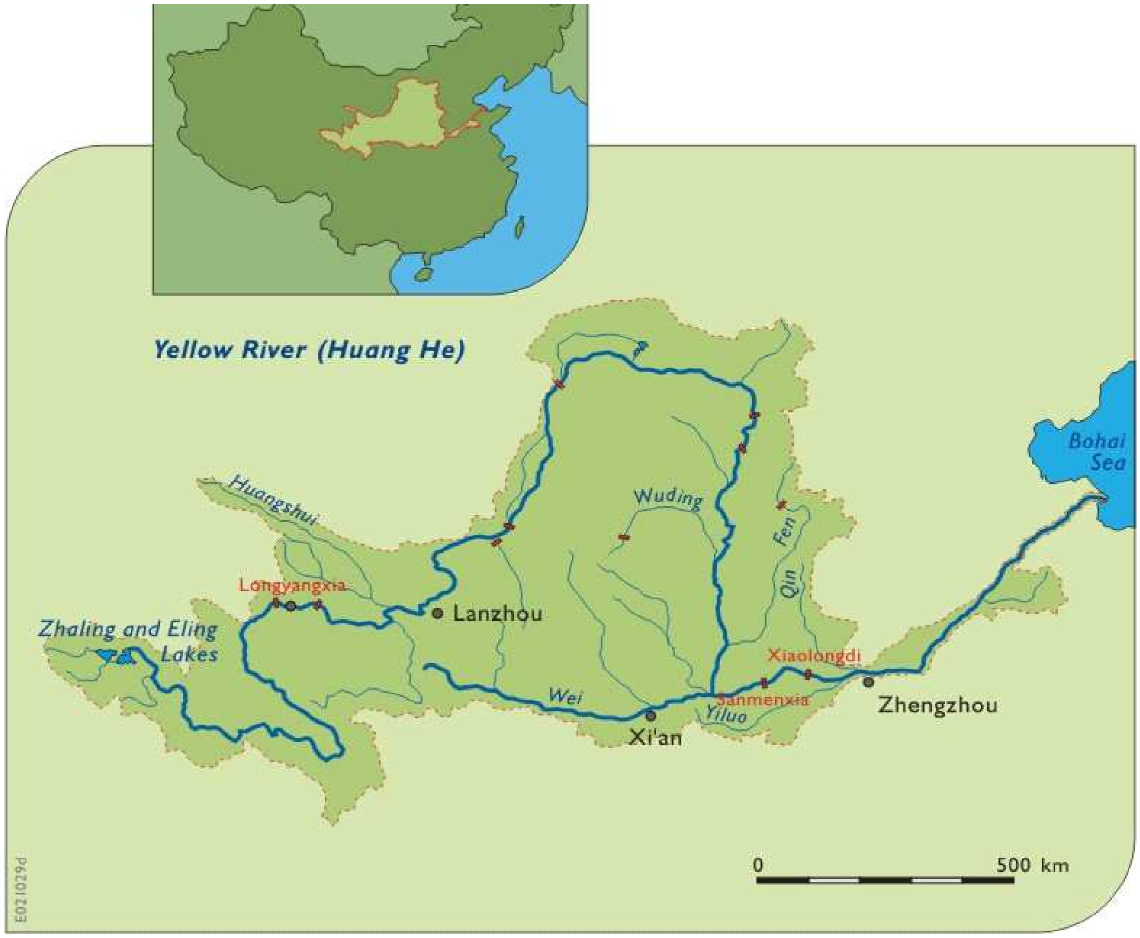

Figure 2.1.2.1: Yellow River Basin Hydrologic Boundaries

2. PROJECT OBJECTIVES

The project aimed at studying water poverty, water availability and access, water productivity, and water and related institutions in the Yellow River Basin to develop and rank a series of high-priority interventions aimed at increasing water and food security for the poor while maintaining environmental sustainability. Outcomes from the following six work packages are reported in the following:

1. Water Poverty Analysis
2. Water Availability and Access
3. Water Productivity
4. Institutional Analysis
5. High-Impact Interventions
6. Knowledge Base and Evaluation Platform

2.1Water Availability and Access (YRCC, BNU, and IFPRI)

The Yellow River is one of the most heavily controlled rivers in the world by advanced engineering systems. Spatial and temporal variability of water availability depends on both natural hydroclimatic processes and human interferences. Unique water availability and access challenges include low per-capita water availability, significant potential impact of climate change; large spatial and temporal variation in surface runoff generation; the significant role of multipurpose reservoirs that control the whole runoff (sometimes with competing uses); flooding; droughts; large differences in access and use by water use sector and socioeconomic group; and water quality degradation in the middle and downstream main channel and tributaries. Natural and human factors generate conditions of extreme water scarcity and as a result the basin faces competition between irrigators in the mid- and upstream areas and growing non-irrigation demands downstream, exacerbated by rapidly growing water degradation. Water scarcity and poor quality, and the ensuing environmental problems, have already contributed to economic losses in the basin. From 1950 to 1990, the total direct damage of floods and droughts was estimated at 116.4 billion RMB (1 RMB = US$0.146), with floods accounting for 45% percent of total damage (Ma 1996).

The following sections provide a brief description of the modeling tools used (longer descriptions can be found in Appendix B); describe the current water supply and demand situation in the river; review the impact of future supply and demand, as well as the potential impact of climate change on water resources; and concludes with a combined analysis of demand increase and climate change impact.

2.1.1 Methods

To undertake this analysis, two modeling systems were used: the YRCC water simulation model and the BNU SWAT model.

2.1.1.1 Yellow River Conservancy Commission Water Supply and Demand Model

The YRCC water simulation model is a node-link model simulating the characteristics of water use spatially and temporally based on given boundary conditions and given operating rules. The core of the model is a simulation model, which can simulate and evaluate alternative water allocation rules, as well as alternative water development plans. The YRCC supply and demand model is used to assess water shortages over space and time based on different hydrologic flow inputs.

2.1.1.2 BNU SWAT Model

SWAT, acronym for "Soil and Water Assessment Tool", is a river basin, or watershed-scale model developed by Arnold et al. (1992; 1998) for the United States Department of Agriculture-Agricultural Research Service (USDA-ARS). SWAT was developed to predict the impact of different land uses/covers and land-management practices on water resources, water flow, and sediment and agricultural chemicals transport in large complex watersheds with varying soils over long periods of time (Neitsch et al. 2005). This model has been adopted by many U.S. federal and state agencies (USDA, USEPA, etc.) and many countries (Pang et al. 2007; Cheng et al. 2009b). SWAT is employed in this study to simulate the hydrologic regime and estimate responses to the future climate change.

For the climate change analysis, the SRES B2 scenario was used in combination with the HadCM3 model. The output of the HadCM3 model was downscaled to the basin using the Statistical DownScaling Model (SDSM). The local climate change scenarios generated by the downscaling were then used to drive the SWAT model of Beijing National University. With this input, the SWAT model is able to simulate future hydrologic processes and changes in the modeled daily flow regime between current and future climate scenarios can be compared and analyzed.

2.1.2 Results

2.1.2.1 Water supply and demand in the YRB

Based on data collected from 1956 to 2000, total annual water resources in the Yellow River Basin are 64.71 BCM, including 53.48 BCM from surface water, and 11.23 BCM from net utilizable groundwater resources. The annual water quantity upstream of the town of Huayuankou is 62.08 BCM, which includes 53.28 BCM from surface water, and 8.81 BCM for net utilizable groundwater. Runoff in the Yellow River is mainly concentrated from July to October, a period that accounts for about 58 percent of annual runoff. The lowest monthly runoff occurs in January, accounting for only about 2.4 percent of annual runoff. The maximum monthly runoff typically occurs in July and August, accounting for 14~16 percent of annual runoff. The regions of upper Longyangxia, from the Longyangxia dam to the city of Lanzhou and from Long men to Sanmenxia, respectively account for 34.8 percent, 22.3 percent, and 20.3 percent of the total surface water runoff in the Yellow River Basin. In provinces and autonomous regions within the basin, the province with the largest amount of surface water resources is Qinghai province, accounting for 34.8 percent; the Gansu province follows with 20.5 percent; Ningxia is the most water-poor province receiving only 1.6 percent of surface water resources. Table 2.1.1 presents basin area, river length and number of tributaries by basin section.

Table 2.1.1. Basin area and river length in key YRB reaches

Reach	Start to end	Basin area (km^2)	River Length (km)	Numbers of tributaries
Upper reaches	River source to Hekouzhen	385,966	3471.6	43
	River source to Madou	20,930	369.7	3
	Madou to Longyangxia	110,490	1417.5	22
	Longyangxia to Xiaheyan	122,722	793.9	8
	Xiaheyan to Hekouzhen	131,824	990.5	10
Middle reaches	Hekouzhen to Taohuayu	343,751	1206.4	30
	Hekouzhen to Longmen	111,591	725.1	21
	Longmen to Sanmenxia	190,842	240.4	5
	Sanmenxia to Taohuayu	41,318	240.9	4
Lower reaches	Taohuayu to estuary	22,726	785.6	3
	Taohuayu to Gaocun	4,429	206.5	1
	Gaocun to Aishan	14,990	193.6	2
	Aishan to Lijin	2,733	281.9	0
	Lijin to estuary	574	103.6	0

The Yellow River has the highest sediment concentration in the world; it annually carries 1.6 billion tons of sediment to the sea, with an average sediment load of 37.6 kg/m^3 (Xu et al. 2002; Shi and Shao 2000). While an important research topic, we do not conduct any research on sedimentation for the YBFP.

The YRB has been heavily engineered. Currently, over 3,100 large, moderate and small reservoirs have been built in the basin with a total volume of 58 billion m3 (table 2) essentially the equivalent of total runoff; more than 4,500 water diversion projects and 29,000 water-lifting projects have been constructed.

Since the 1980s, water supply to all sectors has increased from 35 BCM to 48 BCM. Within basin boundaries, water supply for agriculture is 38.6 BCM, accounting for 80 percent of total supply. Supply for industry is 5.95 BCM, accounting for 12.4 percent of total supply. Total urban domestic water supply is 1.81 BCM, accounting for 3.8 percent of total supply. Rural domestic water supply is 1.7 BCM or 3.5 percent of total supply. An overview of annual water withdrawals by province and sector for 2008 in the YRB are shown in table 2.1.2.

The provinces of Inner Mongolia and Ningxia have become the regions with the greatest water use in YRB, with 10.64 BCM and 9.96 BCM, accounting for 22.1 percent and 20.7 percent of total withdrawals, respectively. The regions of Shaanxi, Henan, Gansu and Shanxi are following, with withdrawals of 7.04 BCM, 6.02 BCM, 4.97 BCM and 4.9 BCM, respectively, accounting for 14.7 percent, 12.5 percent, 10.3 percent and 10.2 percent of the total. The regions of Shandong and Qinghai, had withdrawals of 2.46 BCM and 2.06 BCM, respectively, accounting for 5.1 percent and 4.3 percent of the total. The lowest water use province is Sichuan, as a result of its very small share in the basin area. The province used 0.016 BCM, accounting for 0.03 percent of the total.

Table 2.1.2 Annual water withdrawals in the Yellow River Basin (BCM) in 2008

Province	Urban domestic water use	Rural domestic water use	Industrial water use	Agricultural water use	Total
Qinghai	0.08	0.12	0.28	1.58	2.06
Sichuan	0.00	0.01	0.00	0.00	0.02
Gansu	0.26	0.26	1.21	3.25	4.97
Ningxia	0.13	0.07	0.46	9.30	9.96
Inner Mongolia	0.20	0.15	0.54	9.76	10.64
Shaanxi	0.47	0.35	1.29	4.93	7.04
Shanxi	0.32	0.27	0.73	3.58	4.90
Henan	0.21	0.34	0.94	4.53	6.02
Shandong	0.15	0.13	0.50	1.69	2.46
Total	1.81	1.70	5.95	38.61	48.07

Note: Only areas within the basin are included.
Source: Yellow River Conservancy Commission (2009).

- *Irrigation*

Irrigated area inside basin boundaries increased from 8.0 BCM in 1950 to 75.3 BCM (7.5 million hectares) in 2008/9—if areas outside basin boundaries are included area increases to 12.6 million hectares. Expansion has been most rapid in the downstream reaches where area expanded from 3.0 billion m^2 in the 1950s to more than 23.3 billion m^2 (2.3 million ha) in 2008/9, and water use increased from 1.9 BCM in the 1950s to 12.2 BCM in 1990s (average water use is a very high 10,000 m^3/ha).

- *Domestic water use*

Domestic water use includes residential uses and the water used by commerce and public institutions such as schools and government offices. The YRB is responsible for the domestic water supply for more than 100 million people. However, the population is not evenly distributed in the basin. The highest population concentration is found in the area from Longmen to Sanmenxia (45.1 percent), mainly centered in the Wei River Basin, a key economic, cultural, and political center of China. The second highest area is from Huayuankou to the river mouth in Henan and Shandong provinces (13.2 percent). These are two of the most densely populated areas in China.

During the past several decades, urban growth has outpaced overall population growth in China and elsewhere. Rapid urbanization has greatly increased urban-domestic water use. Furthermore, in rural areas, rising income levels have enabled more households to turn to piped systems, and the amount of domestic water uses has also increased significantly. According to Jin and Young (2001), the total annual domestic water use in China was only 1 BCM in 1949. It then increased from 2 BCM in 1965 to 20 BCM in 1993 and to 54 BCM in 1998. In the YRB, the amounts of domestic water use in urban and rural areas (including livestock uses) in 1990 were 1.14 BCM and 1.35 BCM, respectively (inside the basin area). By 2001, water use increased to 2.27 BCM and 1.6 BCM, 37.8 percent of which was contributed by surface water and the reminder by groundwater (YRCC 2003). In other words, nearly two-thirds of the domestic water resources were supplied by groundwater. By 2008, the total surface and groundwater depletion for urban (urban public use and domestic use) was 1.64 and 1.343 BCM, respectively; and surface and groundwater contributed similar amounts.

- *Industrial Water Use*

The industrial sector in the YRB has been developing rapidly over recent decades, and the amount of water used for industrial activities has experienced a drastic increase. Between 1980 and 1993, water use in the YRB increased from 2.79 to 5.45 BCM, and then to 6.19 BCM in 2001. In 2001, surface water accounted for 45.1 percent of total industrial use, and groundwater accounted for 54.9 percent (YRCC 2003). Although the rate of groundwater use is not as high as for domestic water uses (54.9 percent versus 62.2 percent), it definitely plays a major role for the industrial sector. Most industries (including mining) are concentrated close to urban areas. According to Xi et al. (1997) five industries, including chemical engineering, electric power, metallurgy, mechanical engineering, and textile industry accounted for 67.1 percent of total industrial water use.

Similarly to domestic water use, the region from Longmen to Sanmenxia has the highest share of industrial water uses (30.4 percent); and the region from Lanzhou to Toudaoguai has the second highest share (20 percent). The general shift of economic development from the relatively rich (and high-wage) eastern to middle and western China implies that the YRB would become more critical as a source of water for growing industries in the future.

- *Environmental water use*

In the past 40 years (1960-2000), 11 large reservoirs have been built in the main channel of the Yellow River in the upper and middle reaches (Yu 2006). All of these have contributed to changes in the riverine ecosystem (Liu et al. 2008). The environment is particularly fragile in the Loess Plateau and in the arid regions of the basin. Up to now, little attention has been paid to the river's ecological health; instead, the focus was on increased withdrawals to supply a rapidly increasing population and for urban-industrial growth. Flow cutoffs in the YRB were the most striking evidence of excess water withdrawal and consumption in the basin with increasing cutoff periods from 1972-1998. In 1997, there was no discharge from the basin to the sea for 226 days, and the river dried up to Kaifeng, 600 km inland from its mouth (Ke and Zhou 2007, Cai and Rosegrant 2004).

Such occurrences impacted industrial and agricultural production in both urban and rural areas along the lower reaches, destroyed the ecosystem of the estuarial delta, and as a result damaged the livelihoods of people across the basin.

2.1.2.2 Significant water related challenges in the basin

- *Floods*

Flood damages of the Yellow River have attracted worldwide attention. During 2540 years, from 602 BC to 1938, records show 1,590 documented dike breaches, including five major changes of the downstream river course (i.e. the reaches below the Huayuankou gauge station). Five provinces in the Huang-Huai-Hai Plain have been affected by floods: Hebei, Shandong, Henan, Anhui and Jiangsu. According to instrumental records fourteen levee breaches have occurred from 1919 to 1938 (20-year period). In 1933, the flood peak flow at Huaxian Station was 22,000m3/s; more than 50 dikes breached downstream, affecting 2.73 million people in Henan, Shandong, Hebei and Jiangsu provinces. Overbank flows are frequently caused by medium and small floods in the lower Yellow River, and seriously affect people's lives and property. According to incomplete statistics, since 1949 to before the operation of the Xiaolangdi reservoir, more than 20 floods were recorded in the lower floodplains. In August 1996 the peak flow was 7,860 m^3/s at Huayuankou station. The entire floodplain was inundated, with an average water depth of about 1.6 m, and a maximum depth of 5.7 m. A total of 1,374 villages, 1.188 million people, and 247 million mu arable land were affected by the flood; 265.4 thousand houses collapsed, 409.6 thousand houses were damaged, and the direct economic loss amounted to 6.46 billion RMB.

- *Droughts*

Mainly as a result of rapid growth in both irrigation and non-irrigation water demands, and partly because of a declining trend in annual runoff over the past decades, droughts have overtaken floods as the main weather-related hazard in the YRB. The basin is among the regions of China that are most seriously affected by droughts. The northwestern Loess Plateau Region is especially drought-prone. After the foundation of People Republic of China (PRC), the Party and government focused on hydraulic engineering construction projects in the basin and developed a large number of irrigation projects to combat drought. However, for most parts of the Loess Plateau agriculture still relies heavily on rainfall. From 1950 to 1974, the Loess Plateau region was hit by seventeen drought episodes, once every 1.5 years on average. Nine of these years registered severe droughts. In 1965 droughts in northern Shaanxi caused crop failure over 1,000 mu, and in northwest Shanxi 2,600 mu were affected. During the past 20 years, severe drought occurred several times in the upper and middle reaches of the Yellow River Basin, causing significant grain yield reduction and drinking water shortages. In 1994, the drought disaster covered an area of 6,000 mu, and the reduction of agricultural production reached 6 million metric tons. From winter 2008 to spring 2009, wheat-producing provinces in northern China suffered drought stress. The area affected by drought reached 1.13 million mu (75,000 ha) in Gansu, Shaanxi, Henan, Shanxi, and Shandong provinces in the YRB.

- *Declining groundwater tables*

With the rapid increase in the amount of groundwater extraction in some areas, the groundwater level has declined rapidly. In turn, this has caused expanding land subsidence, cracks and a series of environmental geological problems. According to some statistics, the area subjected to groundwater overexploitation in the YRB covers 15,900 km2. Of these, 12,500 km2, or 78 percent of the total, are affected by severe exploitation. There are ten larger groundwater funnels, including Yinchuan, Dawukou funnel in Ningxia, Fengdong, Xinghua, Luqiao, Weibin funnel in Shaanxi Province, Songgu, Taiyuan and Yuncheng funnel in Shanxi Province, and Wu zhi ~ Wenxian ~ Mengxian funnel in Henan Province. In the last few years, groundwater tables have been generally declining north of the Yellow River, but increasing in the area south of the Yellow River (Shuming, personal communication).

- *Water pollution*

A 2007 study by the Yellow River Conservancy Committee surveyed water quality over more than 8,384 miles of the river. Based on the analysis, water in 33.8 percent of the river system was considered below level five quality. Based on UNEP guidelines, level five is unfit for drinking, for aquaculture, for industrial use and even for use in agriculture. The report stated that waste and sewage discharged into the system totaled 4.29 billion tons. Industry and manufacturing accounted for 70 percent of the discharge into the river, households accounted for 23 percent, and just over 6 percent came from other sources.

In addition, the continuous increase in wastewater discharge into the river is exacerbating the conflict between water demand and supply (Xue 2007).
The YRB is affected by many water resource problems, ranging from water scarcity, to pollution issues, to flood risk. Water authorities will face great challenges in meeting the instream flow requirements and providing more water for the growing populations, for industry and agriculture in this century.

2.1.2.3 Climate change impacts on hydrological flows (SWAT BNU)

Along with the challenges described in the previous section, water managers may have to face even worse water scarcity conditions as a result of climate change. Understanding the relationships between the hydrologic regime, climate factors, and anthropogenic effects is important for the sustainable management of water resources for the study area and for the entire YRB. Climate change impacts are assessed for two areas, the upper catchment of the Yellow River Basin, north of Lanzhou station, which accounts for 58 percent of total water supply in the YRB; and the Wei River Basin, which includes the Wei River, the Jing River and the Beiluo River and flows across Shaanxi, Gansu and Ningxia provinces and autonomous region.

Downscaling through SDSM shows that daily Tmax and Tmin have an increasing trend under the B2 emission scenario (table 2.1.3).

Table 2.1.3 Increment of daily Tmax and Tmin in future periods compared with the baseline

Parameter	**Baseline**	**Future Scenarios**		
		2020s	**2050s**	**2080s**
Daily T_{max}（℃/d）	13.5	0.4	1.9	4.0
Daily T_{min}（℃/d）	0.6	0.5	1.6	2.7
Annual precipitation（mm/yr）	451.3	-81.9	-32.2	-41.3

Figure 2.1.1 shows the spatial distribution of annual mean increment for daily T_{max} and T_{min} in different time periods compared with the baseline (1961-1990). Findings show an increase in daily minimum and maximum temperatures of up to 2°C by mid-century, and up to 4°C by 2080.The magnitude of this increasing trend is higher in the western part of the study area. Figure 2.1.2 presents changes in precipitation compared to the baseline. Generally, precipitation is expected to decline under this scenario. Average annual precipitation is projected to decline by up to 7 percent to 2050 and up to 9 percent to 2080.

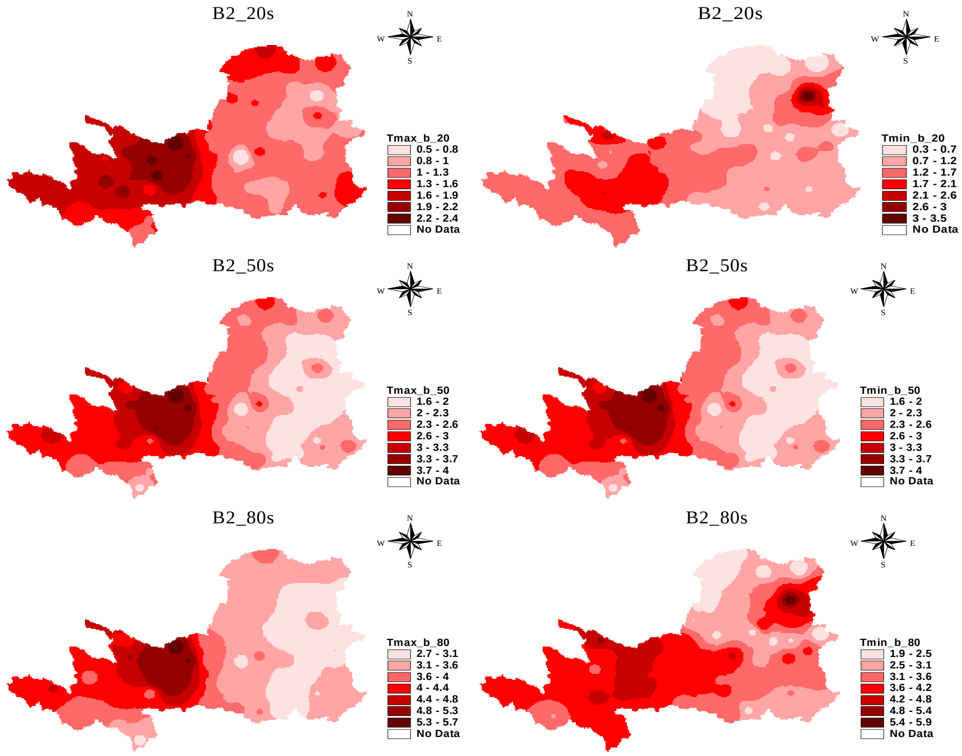

Figure 2.1.1. Spatial distributions for the increment of daily Tmax and Tmin

Note: spatial distributions for the increment of daily T_{max} and T_{min} in the future (20s, 50s and 80s describe 2020s, 2050s and 2080s respectively), T_{max} spatial distribution are shown on the left.

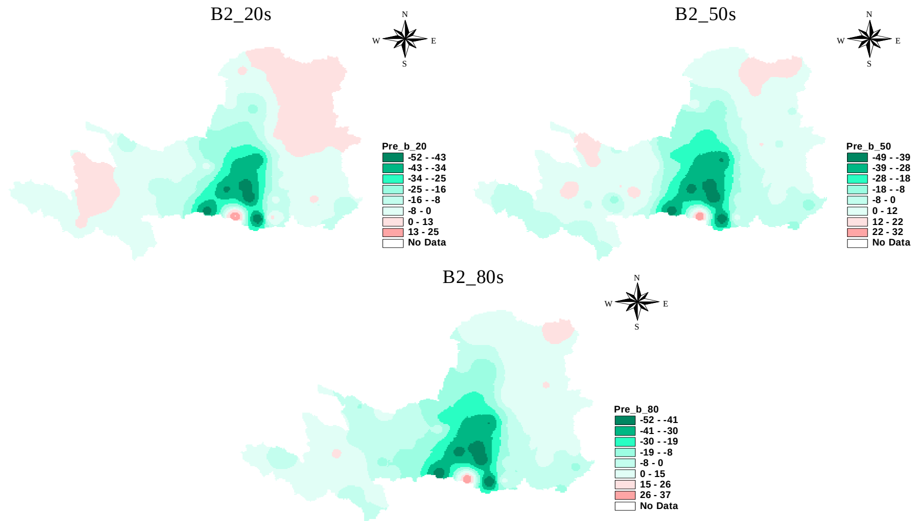

Figure 2.1.2. Spatial distribution for the increment of annual precipitation

Note: spatial distribution for the increment of annual precipitation in the 2020s, 50s and 80s.

As a result of climate change, streamflow would decline by 9-20 percent in the area north of Lanzhou, by mid-century, whereas in the Wei River Basin flows could decline by 8 percent or increase by up to 5 percent in the 2050s. The trends seem to point to an overall reduction of water availability under climate change. Without adequate adaptation strategies, climate change is likely to aggravate the competition for water across the domestic, agriculture, and industry sectors.

2.1.2.4 Water supply and demand analysis, using the YRCC model

- *Average annual water supply and demand analysis*

Without considering climate change, average annual water supply in the YRB is 44.58 BCM (1956-2000), the gap between water supply and demand is 7.53 BCM, and the water deficit ratio for the whole basin is 14.5 percent. Sectors lacking water include agriculture, forestry, animal husbandry, and irrigation. The water deficit ratio is 18.1 percent for the area from Hekouzhen to Lanzhou. Moreover, the water deficit ratio in Qinghai, Gansu, Inner Mongolia, Shaanxi, and Shandong is in excess of 15 percent. Total surface water consumption is 24.03 BCM, and the average annual water volume flowing into the sea is 18.96 BCM. Therefore, the water volume in the rainy season could not meet the water requirements for sediment transport. Considering that the water volume required for sediment transport is 15 BCM in the flood season, the volume of water shortage for meeting the water requirement for sediment transport is 1.56 BCM. Details are presented in Table 2.1.4.

Considering climate change, the natural flow of rivers is reduced in the Yellow River. The average annual water supply declines to 40.37 BCM—based on information from the SWAT BNU model. As a result, the volume of water shortage is 11.75 BCM, and the water deficit ratio reaches 22.5% in the whole basin. For the Hekouzhen to Lanzhou reach, the deficit is 29.6% and for Qinghai, Gansu, Ningxia, Inner Mongolia and Shaanxi more than 25%. The total surface water consumption is 20.53 BCM, the average annual water volume flowing into the sea is 16.78 BCM. Compared to a situation without taking into account climate change, the average annual volume of water shortage increased by 4.21 BCM, the ratio of water deficit increased by 8%, the water volume into the sea declined by 2.18 BCM, of which 1.73 BCM is reduced during the flood season. Finally, the water shortage for meeting sediment transport demands is 3.29 BCM.

- *Dry-year water supply and demand analysis*

A dry-water year results in both lower runoff and increased agricultural water demand. As a result, water shortages will increase dramatically in the YRB. Without climate change, using 75% and 95% exceedency frequency over average flows, the average annual volume of water shortage increases by 4.49 BCM and 12.21 BCM, respectively, and the water volume flowing into the sea drops by 4.09 BCM and 9.71 BCM, respectively.

Considering the impact of climate change, the runoff of the Yellow River will reduce further. At 75 percent and 95 percent exceedency frequency, the volume of water shortage will reach 15.055 BCM and 21.022 BCM, respectively, and the ratio of water deficit in the whole basin will reach 28 percent and 37 percent, respectively. Taking into account climate change, therefore, the supply and demand of water resources will be extremely serious in dry years (Table 2.1.5).

Table 2.1.4 Supply and demand analysis of water resources for the Yellow River with and without considering climate change (BCM)

The second grade District or Provinces(regions)	Water demand	The scenario without considering climatic change				The scenario considering climatic change			
		Water supply	Water shortage	Water shortage ratio（%）	Consumptive use of surface water	Water supply	Water shortage	Water shortage ratio（%）	Consumptive use of surface water
Upper	0.263	0.257	0.006	2.4	0.214	0.262	0.001	0.38	0.219
From	4.819	4.042	0.777	16.1	2.636	3.741	1.078	22.37	2.398
From Lanzhou	20.026	16.412	3.615	18.1	9.645	14.094	5.932	29.62	7.792
From	2.62	2.437	0.183	7	1.245	2.434	0.186	7.1	1.28
From	15.093	12.966	2.127	14.1	6.561	11.562	3.531	23.39	5.299
From Sanmenxia to	3.772	3.524	0.248	6.6	1.594	3.539	0.233	6.18	1.605
Underside	4.931	4.469	0.462	9.4	2.039	4.259	0.672	13.63	1.829
Inner Flow	0.588	0.475	0.113	19.2	0.102	0.476	0.112	19.05	0.111
Qinghai	2.592	2.006	0.586	22.6	1.4	1.922	0.67	25.85	1.293
Sichuan	0.031	0.031	0.001	1.8	0.025	0.031	0	0	0.025
Gansu	5.996	4.667	1.329	22.2	2.893	3.931	2.065	34.44	2.375
Ningxia	8.64	7.519	1.12	13	3.848	6.48	2.16	25	3.197
Inner	10.713	8.91	1.803	16.8	5.487	7.743	2.97	27.72	4.337
Shaanxi	9.03	7.416	1.614	17.9	3.524	6.426	2.604	28.84	2.622
Shanxi	6.585	6.206	0.379	5.8	3.275	6.238	0.347	5.27	3.346
Henan	6.065	5.801	0.264	4.4	2.938	5.581	0.484	7.98	2.721
Shandong	2.462	2.026	0.436	17.7	0.644	2.016	0.446	18.12	0.618
Total	52.113	44.581	7.532	14.5	24.034	40.367	11.745	22.54	20.533

Table 2.1.5 Water supply and demand balance under different runoff conditions (BCM)

Conditions	Scenarios	Water demand in the basin	Surface water supply in the basin	Water shortage in the basin	Water shortage ratio in the basin （%）	Surface water supply out of basin	Runoff flowing into the sea
Average annual	not considering climatic change	52.113	44.581	7.532	14.5	9.28	18.958
	considering climatic change	52.113	40.367	11.745	22.54	9.28	16.777
	difference value	0	-4.214	4.213	8.04	0	-2.181
75%	not considering climatic change	53.687	27.617	12.025	22.4	8.242	14.868
	considering climatic change	53.687	24.587	15.055	28.04	8.242	12.977
	difference value	0	-3.03	3.03	5.64	0	-1.891
95%	not considering climatic change	57.228	23.947	19.737	34.49	7	9.244
	considering climatic change	57.228	22.663	21.022	36.73	7	7.715
	difference value	0	-1.284	1.285	2.25	0	-1.529

2.1.3 Conclusion

The Yellow River Basin is a highly water-scarce basin. Much of the infrastructure on this highly controlled river has been built for flood control, but climate change and droughts will bring new challenges to a basin that has only been prepared for flood management. While the situation is already severe under average conditions, water availability is expected to worsen significantly under climate change and in dry years. Both the water and economic development scenarios and the climate change scenarios raise questions over the availability of future water resources in the study area, particularly in terms of the magnitude of seasonal runoff. Climate change would raise the annual water deficit by 4.21 BCM, and the discharge into the Sea would drop by 2.18 BCM. As expected, the worst water situation is achieved under combined dry-year and climate change condition: In a year with 75% and 95% exceedency frequency, respectively, the volume of water shortage would reach 15.055 BCM and 21.022 BCM, respectively, under climate change, and the water deficit ratio for the entire basin would reach 28% and 37%, respectively. A key concern regarding water shortages is not only fulfilling productive water demands, but also the large minimum flow requirement to move sediments downstream to avoid breaching the dikes, estimated at 15 BCM during the rainy season.

2.2Water Productivity Assessment

In this section, we use experimental data, statistical data, and empirically estimated data to analyze the water productivity (WP) of major crops (corn, wheat, rice, and soybean) in 461 counties in the YRB. WP values for rainfed crops and irrigated crops are estimated separately and maps of WP by crop are generated for the whole basin. We analyze the spatial variability of WP with regard to climate, land cover, and agricultural practices. We map WP by crop for the entire basin by interpolating from the WP assessment for the 461 counties. These maps provide information for WP spatial pattern analysis. Finally, we conduct Budyko curve analysis to assess the relationship between WP and water and energy across different spatial scales.

2.2.1 Methods

The first step for WP assessment is to collect data on the main agricultural production systems, including the water data such as precipitation, irrigation application, and crop ET; and crop data such as yield and area by crop. Challenges arise with incomplete or unknown data, particularly to split irrigated and rainfed crops. To assess WP for irrigated and rainfed crops separately, we adopt a method presented by Cai et al. (2007) to retrieve irrigated and rainfed area and yield using gross crop production data and hydrologic and agronomic inputs. Cai et al. (2007) proposed a method to split harvested area and yield for irrigated and rainfed crops in a region given gross area and yield; and climatic, agronomic, and economic data for crops. Irrigated area is defined as the physical land crop area with an irrigation system; rainfed area is defined as a cropped area that only utilizes effective rainfall, which is the portion of rainfall that is available to meet consumptive crop water requirements, excluding surface runoff and deep percolation. In contrast, irrigated areas use surface runoff by diversion (withdrawal) and/or groundwater by pumping in addition to effective rainfall. The method based on the principle of generalized maximum entropy (GME), which combines incomplete data, empirical knowledge, and a priori information. Data requirements for the GME model include:

- Crop data, including total crop area, gross crop yield, crop growth period and stages by month, crop ET coefficient (*kc*) (Doorenbos and Pruitt, 1977), crop response coefficient to water stress (k_y) (Doorenbos and Kassam, 1979), and crop value indicator (e.g., producer's crop prices, crop trade prices; FAOSTAT www.faostat.org)
- Climate data, including monthly rainfall in the study area and reference crop evapotranspiration (*ET0*) (Allen et al., 1998)
- Land and water data, including total irrigated land (*TIA*), multi-planting factor (*MP*), and monthly total irrigation water withdrawal in the study area (*TIW*).

Based on these data items, the following items are computed and used for the retrieval of the irrigated and rainfed crop area and yield:

- Monthly crop potential evapotranspiration (*ETC*) (Doorenbos and Pruitt, 1977, Allen et al., 1998)
- Monthly effective rainfall (*PE*) (USDA-SCS, 1967)
- Irrigation water withdrawal by month

It has been demonstrated that this method provides reasonable estimates of irrigated and rainfed crop area and yield under different spatial scales (as large as the entire YRB and as small as one county in Texas, USA). This model is used in this section at the county level to retrieve the crop data and to calculate the WP in the YRB.

2.2.2 Results

Sixty counties have been selected to evaluate the irrigated/rainfed area aggregation. Selection was based on the locations of the CLIMWAT stations. We established the GME model for each of the sixty counties using the crop and climate data described in the previous section. The percentages of irrigated area to the gross area in the sixty counties are 100 percent, 89 percent, 100 percent, and 83 percent for rice, corn, wheat, and soybean, respectively, and 94% for all of these crops. The average irrigated crop yield for rice, corn, wheat, and soybean are 5.4, 5.3, 3.7, and 1.4 ton/ha, respectively, compared to the average rainfed crop yield of 3.0 and 1.4 ton/ha for corn and soybean, respectively. Table 2.2.1 shows the average values of irrigated and rainfed area (AI and AR) and yield (YI and YR) by sub-basin.

Table 2.2.1: Irrigated and rainfed area and yield by sub-basin of the YRB

	Crops	Basin-wide	Middle stream	Downstream
AI (1,000 ha)	**Rice**	25.3	13.0	12.3
	Corn	540.2	254.3	284.9
	Wheat	1141.0	536.4	597.7
	Soybean	149.6	80.6	69.0
AR (1,000 ha)	**Rice**	0.0	0.0	0.0
	Corn	68.8	30.3	37.9
	Wheat	0.0	0.0	0.0
	Soybean	30.1	14.3	15.8
YI (ton/ha)	**Rice**	5.4	5.5	5.3
	Corn	5.3	5.0	5.7
	Wheat	3.7	2.8	4.4
	Soybean	1.4	1.2	1.7
YR (ton/ha)	**Rice**	0.0	0.0	0.0
	Corn	3.0	1.9	4.0
	Wheat	0.0	0.0	0.0
	Soybean	1.4	1.0	1.9

The WP values are calculated for irrigated (WPI) and rainfed (WPR) crops for the selected 60 counties. Note that the actual ET for irrigated crops include both effective rainfall and irrigation water consumption, and for rainfed crops include effective rainfall only. The mean and standard deviation of WPI and WPR for different crops are given in Table 2.2.2.

Table 2.2.2 Area-Weighted WPI and WPR for different regions in YRB

Region/Crops	**WPI (kg/m^3)**				**WPR (kg/m^3)**			
	Rice	**Corn**	**Wheat**	**Soybean**	**Rice**	**Corn**	**Wheat**	**Soybean**
Basin wide average	0.50	0.97	1.39	0.26	-	1.09	-	0.41
standard deviation	0.25	0.32	0.51	0.13	-	0.36	-	0.16
Middle stream	0.49	0.94	1.16	0.26	-	0.68	-	0.28
standard deviation	0.22	0.33	0.49	0.13	-	0.35	-	0.15
Downstream	0.51	0.99	1.57	0.27	-	1.41	-	0.52
standard deviation	0.26	0.30	0.34	0.12	-	0.33	-	0.12

The modeled results from this study mostly fit the ranges from previous studies. The average value for WP of rice from Zwart and Bastiaanssen (2004) is 0.6–1.6 kg/m^3, and the average WP for corn from Zwart and Bastiaanssen (2004) is 1.1–2.7 kg/m^3. WPI for wheat is similar to that assessed by Zwart and Bastiaanssen (2004).

It is interesting that WPR for corn and soybean are slightly higher than WPI, although the variation of the WPR (over the sixty counties) is also higher than the variation of WPI. This implies that from upstream to downstream regions of the YRB, the irrigated corn and soybean may not be as efficient as rainfed crops with regard to water productivity, but irrigation stabilizes the crop production per unit of water consumption, which is expected.

This result is related to the synchronized pattern of precipitation and solar energy in the YRB and most of the area in China (Figure 2.2.1). Reference evapotranspiration (ET0), which indicates the solar heat flux in plant growth, moves in concert with precipitation. The coincidence of water and radiation provides conditions highly favorable to crop growth. This favorable pattern also explains the fact that a large portion of irrigated crops in the YRB belongs to the category of supplementary irrigation, which only uses irrigation water as a supplement to effective rainfall for crops during dry periods.

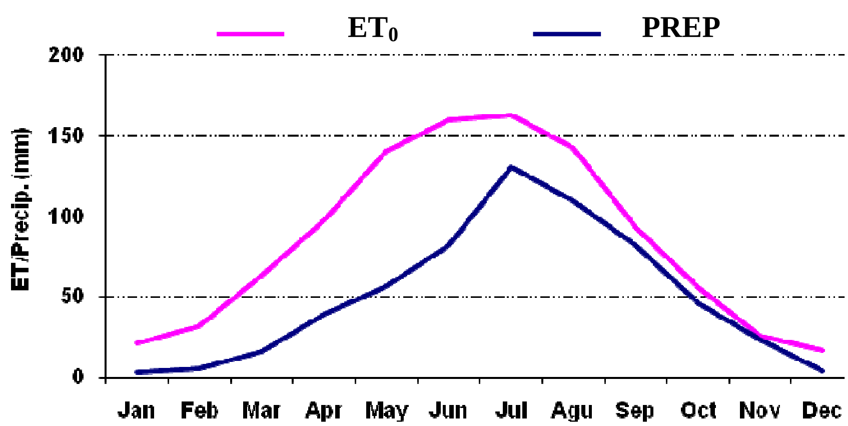

Figure 2.2.1. Monthly reference crop evapotranspiration (ET0) and precipitation (PREP) in the YRB (multiple-year average)

Using crop area as the weighting factor, the irrigated and rainfed water productivity for all crops can be calculated for the 60 selected counties (Figure 2.2.2 and Figure 2.2.3) and interpolated to the entire YRB. One can see that the spatial patterns of WPI and WPR differ in the midstream area but are similar in the downstream part of the YRB. The values of WPI range from 0.31 to 2.17 kg/m^3. The values of WPR have a wider range, from 0.0 to 1.4 kg/m^3. The counties with higher WPR are located at the southeastern part of the basin, where the rainfall is relative sufficient. The maps shown in these figures were created by interpolation of the 60-county results.

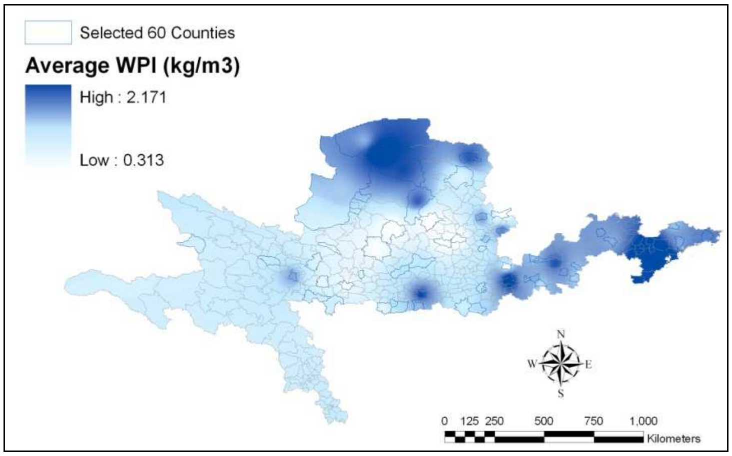

Figure 2.2.2: Basin-wide average WPI for the YRB

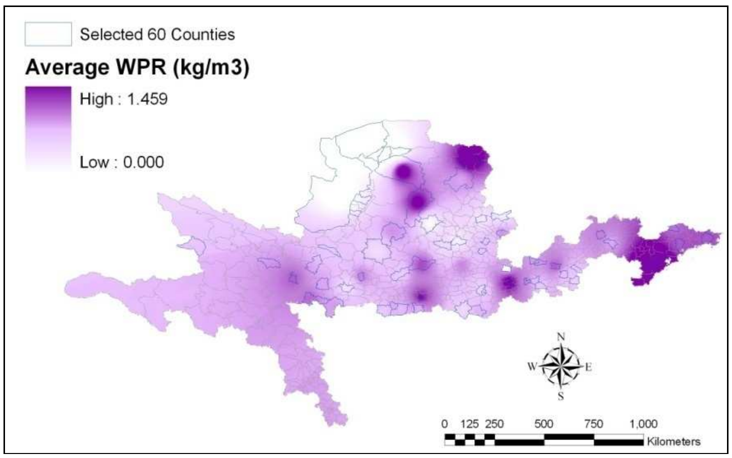

Figure 2.2.3: Basin-wide average WPR for the YRB

Figure 2.2.4 assesses the relationship between two ratios throughout the duration of the crop growing season: (1) crop water use (actual evapotranspiration, or Ea) to precipitation (P) and (2) potential evapotranspiration (Ep) to precipitation (P). Potential evapotranspiration is the amount of water that could be evaporated and transpired if there was sufficient water available. It incorporates the energy available for evaporation and the ability of the lower atmosphere to transport evaporated moisture away from the land surface. Values for Ep/P that are below one indicate humidity and limited energy to move the moisture away from the land surface; Ep/P ratios greater than one indicate relatively dry areas, where potential evapotranspiration is larger than the total rainfall.

In the YRB, about 10 percent of counties are located above the line where evapotranspiration and precipitation are equal (Ea/P = 1). In these counties, crop water use is in excess of precipitation, which implies a need for irrigation. These counties are chiefly located in the northern part of Inner Mongolia for midstream counties and in parts of Qinghai province for upstream counties. Most upstream counties in the YRB are relatively wet with relatively low potential crop evapotranspiration and are therefore located close to the Ep/P = 1 line.

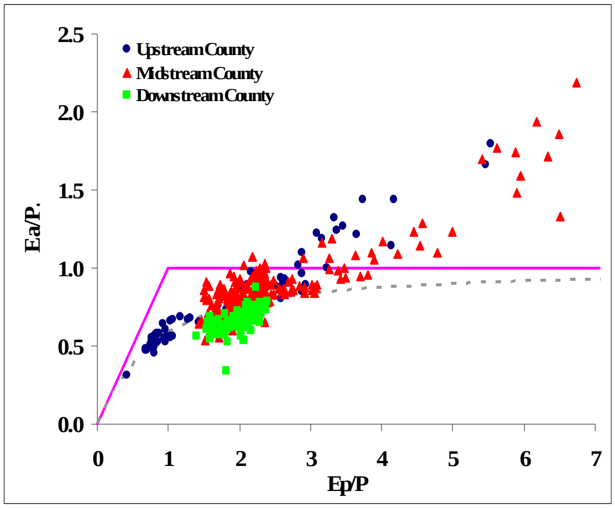

Figure 2.2.4: Relationship between potential evapotranspiration to precipitation and actual evapotranspiration to precipitation

2.2.3 Discussion

To systematically evaluate the spatial pattern of WPI and WPR in the YRB, two more maps have been generated. The AI ratio map (Figure 2.2.5) shows that the most intensive irrigated area is located in the northwestern part of the midstream basin, where several major irrigation districts are located. The irrigation water requirement is computed as ET0 discounted by PE. The annual irrigation water requirement map summed over the months in the crop growth season is shown in Figure 2.2.6, which is also created by interpolating the 60 counties' results. The spatial pattern of irrigation water requirement mostly matches with that of the irrigated area. The highest irrigation water requirement in the northwestern part of the midstream basin is close to 1 meter.

If we compare the result of WPI with these two maps, it is clear that the high WPI values have a similar spatial pattern to the AI ratio and irrigated water requirement map. This result implies that although the midstream area uses more water for irrigation due to the climate characteristics, it also has higher water productivity than the downstream area.

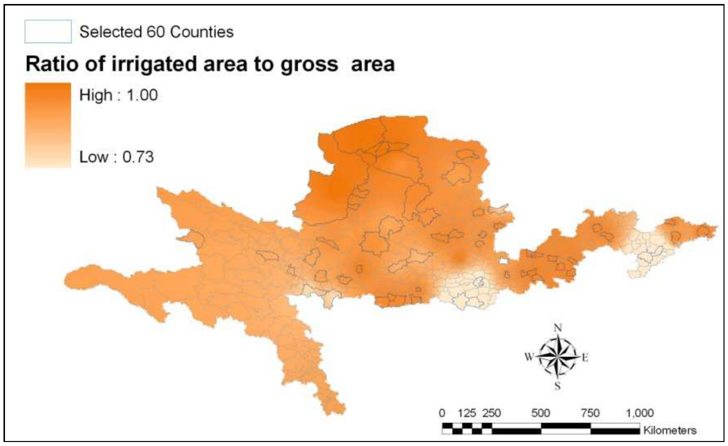

Figure 2.2.5: The distribution of the ratio of irrigated area to gross area in the YRB

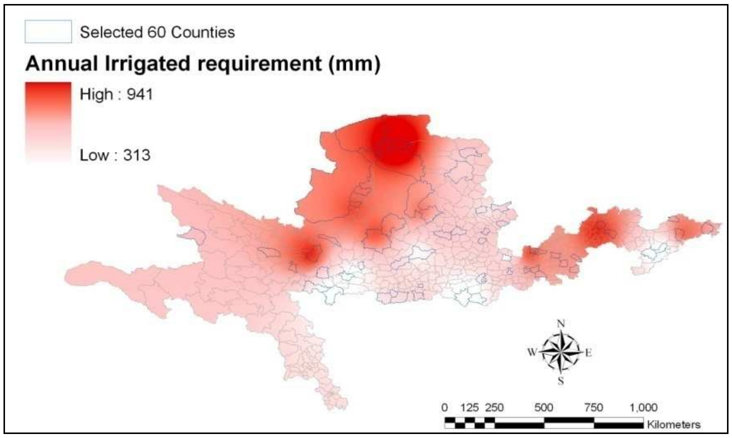

Figure 2.2.6: Irrigation requirement (mm) in the YRB

2.2.4 Conclusion

In general, irrigated yields are significantly higher than rainfed yields in the YRB, which justifies the large-scale presence of irrigation in the basin. However, rainfed water productivity is higher for both maize and soybean in the downstream part of the basin and in the midstream part of the basin for soybean as well, given that sufficient precipitation is typically available for growing these crops. Efficient water productivity is also related to the synchronized pattern of precipitation and solar energy in the YRB, supporting rainfed crop development when sufficient precipitation is available. However, the standard deviation of rainfed water productivity demonstrates that irrigation stabilizes crop production per unit of water consumption, which is valuable given the increased incidences of extreme flood and drought events.

Given the extreme water scarcity in the YRB management and technical solutions need to be found to increase water productivity. Further irrigation development is likely limited in these areas, specifically in the Loess Plateau located in the midstream region. We have also found that water productivity is most sensitive to water availability in the upper and middle regions of the basin—in particular, throughout Inner Mongolia—given the combination of low precipitation and high temperatures. Reducing irrigation in this region would save large amounts of water, but it would also demand that alternative rural development strategies be used in its place given how essential irrigation water for agricultural production in this area.

2.3 Institutional Analysis

This work package described the legal framework for water administration and management in the Yellow River Basin. Water allocation principles and mechanisms in the basin are described at the national, basin, and local levels. Given the significant correlation between access to irrigation and wealth in villages in the YRB, policies and institutions affecting irrigated agriculture are examined in detail. Given the growing scarcity of water resources in the basin, institutions and economic incentives affecting water use are also described and assessed. The research focused on the effectiveness of current institutional arrangements regarding water productivity and reducing poverty and on institutional reforms that could improve the situation.

2.3.1 Methodology

We used a variety of methodologies for this work package, including literature reviews, econometric analysis of data collected in the past, and stakeholder forums. Detailed information on econometric analyses and equations can be found in Wang and Zhang (2009). In the following, we provide a brief summary regarding the data and key equations.

The data for come from a survey that CCAP conducted in 51 villages in four irrigation districts (IDs) in Ningxia (upstream) and Henan (downstream) in 2001 and 2005. Villages were picked in the upper, middle and lower reaches of a canal. Due to different water availability in the canal, choosing villages in the upstream and downstream part of the ID means that the sample includes villages located both in relatively water-abundant and water-scarce regions. Villages were randomly chosen from a census of villages in the upper, middle and lower reaches of the canals within the IDs. In total 51 village' leaders, 56 water managers, 189 farm households and 378 plots were surveyed.

In order to explore the relationship between crop water use and irrigation management institutions, including incentives, we used the following equation:

$$w_{ijk} = \alpha + \beta I_{ijk} + \delta Z_{ijk} + D_{ijk} + \varepsilon_{ijk} \qquad (2.3.1)$$

where w_{jk} represents average water use per hectare of wheat, maize or rice from the i^{th} plot of household *j* in village *k*. The rest of the variables are those that explain water use: I_{ijk}, our variable of interest, measures the nature of the incentives faced by the water manager; Z_{jk}, a matrix of control variables, represents other village, household and plot factors that affect water use. Specifically, we included a number of variables to hold constant the nature of the village's production environment and its cropping structure. We include variables such as the source of water (either surface or ground), the degree of water scarcity, and the level of irrigation investment per hectare to measure the production environment. Besides, we included variables reflecting village socioeconomic characteristics such as cultivated land per capita, share of labor with education above middle schooling, distance to the township, households, share of labor working outside, income per capita, and share of lining canals. Household characteristics include age and education of the household head and land endowment. We also add four plot characteristics, including measures of: soil types; plot location (distance from the plot to the farmer's house); and whether the crop on the plot is planted in rotation with another crop or not (*single season* equals one, if not). Finally, our model also includes D_{ijk}, a dummy variable representing the ID that serves the household. The symbols α , β and δ are parameters to be estimated and ε_{ijk} is the error term that is assumed to be uncorrelated with the other explanatory variables in our initial equations, an assumption that we subsequently relax.

We used the following equation to examine the relationship between water productivity (production of per unit of water) and its determinants:

$$P_{ijk} = \alpha + \beta I_{ijk} + \gamma X_{ijk} + \delta Z_{ijk} + D_{ijk} + \varepsilon_{ijk} \qquad (2.3.2)$$

where P_{ijk} represents the water productivity of wheat, maize or rice from the *ith* plot of household *j* in village *k*. In equation (2.3.2), water productivity is explained by incentives, I_{ijk}, (same definition as equation (2.3.1)), X_{ijk}, which measures agricultural inputs, Z_{ijk} which holds other factors constant, including characteristics of the production environment of the village, household and plot, and the irrigation district dummy, D_{ijk}. In addition, we add a variable reflecting production shocks (measured as yield reduction on a plot due to floods, droughts or other "disasters").

In order to control for the potential endogeneity of incentives in the water use and water productivity equations, we adopt an instrumental variable approach. To do so, prior to estimating equation (2.3.1) and (2.3.2), we regressed a set of variables on the incentive indicator variable of village, I_k:

$$I_k = \alpha + \beta IV_k + \gamma Z_k + \varepsilon_k \qquad (2.3.3)$$

where the predicted value of I_k from equation (2.3.3) multiplied by the dummy variable of incentives of plot, I_{ijk}, results in the predicted value of I_{ijk}. This value would replace I_{ijk} in equation (2.3.1) and (2.3.2). Equation (2.3.3) includes $Z_{k,}$ which are measures the other village-level control variables (most of which are the same as those in equation 2.3.1—e.g., measures of the village's production environment and cropping structure).

In addition to irrigation management reform, other socioeconomic factors also influence agricultural production, income and poverty. In order to answer the question of whether irrigation management reform affects outcomes, it is necessary to control for these other factors. To do so, we specify the link between agricultural production and its determinants as

$$Q_{ijk} = \alpha + \beta W_{ijk} + \gamma X_{ijk} + \delta Z_{ijk} + D_{ijk} + \varepsilon_{ijk} \qquad (2.3.4)$$

where Qijk represents the yields of wheat, maize or rice from the i^{th} plot of household j in village k. In equation (2.3.4), yields are explained by the variable of interest, W_{ijk}, which measures water use per hectare, X_{ijk}, which measures other inputs to the production process, Z_{ijk} which holds other factors constant, including characteristics of the production environment of the village, household and plot, and the irrigation district dummy, D_{ijk}. The control variables of village production environment, household and plot characteristics are similar to those of equation (2.3.1) except for the village-level cropping structure. In addition, we add a variable reflecting production shocks (measured as yield reduction on a plot due to floods, droughts or other "disasters"). The impact of irrigation management reform is measured through the water use variable.

We also establish the following equation to examine the relationship between income and other factors:

$$y_{jk} = \alpha + M_{jk}\beta + Z_{jk}\gamma + D_{jk} + \varepsilon_{jk} \qquad (2.3.5)$$

where y_{jk} represents total income per capita for household j, and the other variables, including M_{jk}, a measure of incentives, are the same as in equation (2.3.1). In examining the effect of irrigation management reform on poverty, we proceed in largely the same way. Because we are measuring poverty in terms of income, one would use largely the same specification and expect similar results, albeit with opposite signs.

2.3.2 Results-

- *Legal framework for water management*

Due to increased water shortages and environmental problems as a result of rapid agricultural and economic growth, China has implemented a range of changes in its legal systems related to water resources starting in the 1980s (Wang and Huang, 2000). In 1988, the first comprehensive Water Law was issued, which provides the general framework and principles for water resources management in China. Three other water laws (Soil and Water Conservation Law, Water Pollution Law, Flood Control Law) were formulated or revised in the 1990s. In 2002, the 1988 Water Law was revised to implement a series of key changes in water management (Ma et al. 2007; Ministry of Water Resources 2003). First, river basin management was emphasized by explicitly including river-basin management as part of administrative regional level management (Art. 12). Second, the new Water Laws placed a strong focus on water savings and improved water-use efficiency (Arts. 8/50). In order to strengthen water management, the Law asks the central government to take full control over all water resources and to allocate quotas for different uses (Art. 47). Moreover, the Government is tasked with implementing a system based on permits and fees for water withdrawals (except domestic water use and small-scale livestock watering, ponds, and community-owned reservoirs) (Arts. 7/48). Third, in water allocation decisions, ecological water use was given high priority and equal importance with both industry and agricultural water use (Arts. 9/21). The new Water Law also suggests that in arid and semi-arid areas, linkages between available natural resources, environmental quality and economic growth are to be fully considered (Art. 21). Finally, the law provides details on planning regarding the protection of water resources, and the control of water-related conflicts.

In addition to the four water laws, several water management regulations have been issued. They mainly cover individual aspects of water management, such as water pricing, water rights, the water withdrawal permit system, water resource fees, water projects, water finance, water savings, and irrigation district management.

In order to promote the establishment of a water rights system and water rights transfer, some relevant regulations were also issued recently. For example, in 2004, the MWR issued a Guidance on Water Rights Transfer Demonstration Works in Inner Mongolia and Ningxia. In 2005, the MWR formally released some suggestions on water right transfers (Ministry of Water Resources, 2006). The MWR also issued a framework for the establishment of water right systems in 2005.

Based on the Central Government’s water law and regulations, local governments are called upon to develop plans for implementation that reflect the local socioeconomic and natural resources conditions. However, implementation has generally been slow. For example, details for the implementation of the 2002 Water Law were not issued until 2006 in most provinces of the YRB (Ministry of Water Resources 2006). The slow pace of formulation of provincial-level implementation measures indicates that regional authorities either give implementation a low priority or face difficulties to decide on how to implement the legislation. Yet another explanation could be that political infighting—particularly sharp conflicts among various stakeholders over the right to manage water resources—and other issues at the sub-provincial levels (i.e., financing difficulties) have hindered the promulgation of implementing legislation at the provincial level (Wang and Huang 2000).

It is worth noting that the Chinese legal system is mainly dominated by regulations not laws. Several of these are temporary and many lack implementing provisions; and most are very general, making implementation difficult. Furthermore, several key regulations, such as on water resource fee collection methods, have not been issued until 2006 though the State Council intended to formulate them in the 1980s.

- *Administration of water resources*

In China, water resources are administered through a nested hierarchical administrative system (Wang et al. 2007). The MWR is at the highest central level directly under the State Council, with Water Resource Bureaus (WRB) at the provincial, prefecture, and county levels. Water management stations in townships are the lowest level of state administration. Water Resource Bureaus at the provincial, prefecture and county levels are controlled jointly by the government at the same level and the MWR. Water resource bureaus at the sub-national level (including all bureaus under national levels, such as provincial, prefectural and county level bureaus).are mainly controlled by the government at the same level since it appoints the governors of water resource bureaus The MWR provides sub-national water resource bureaus with technical guidance, issues water policies, laws and regulations, and allocates some water infrastructure investments at the local level, normally a function of the local water resource bureaus.

Irrigation Districts (IDs) were developed to administer water resources that span lower-level administrative boundaries (Wang and Huang, 2000). Any given ID reports to the officials in the WRB that encompasses the district's entire command area. For example, if an ID includes two or more prefectures, it is under the provincial WRB, but if it lies in two or more counties within the same prefecture, it is under the control of the prefecture's WRB.

This system of water administration is supplemented by seven river commissions, which are administered by the MWR (Wang, et al. 2003). The YRCC and the Huai River Basin Commission are old commissions created in the 1930s while the Pearl River Basin Commission, the Hai River Basin Commission, the Songliao River Basin Commission and the Taihu Lake Commission were all created in the 1980s. They are responsible for coordinating water allocation among provinces by implementing the policies of the MWR.

In addition to the administrative system of the MWR, there are several other government authorities with direct or indirect water management responsibilities such as bureaus or agencies of construction, land resources, environmental protection, energy resources, meteorology, and finance (Ministry of Water Resources, 2006). Therefore, given the various interests of different government agencies water management in China is highly fragmented despite the presence of a specific Ministry with authority on the topic. Faced with increasing water shortages in most northern regions and even in some southern regions, integrated management of water resources has recently become an important target of central government agency reform.

The unclear division of responsibilities among various agencies has created conditions that allow management conflicts between rural and urban water uses, between managers of surface and groundwater resources, and between water quantity and water quality control; this state of things has profoundly challenged the realization of integrated water management in China and in the YRB (Wang and Huang 2000; Wang et al. 2003). For example, surface water and rural groundwater is administrated by the MWR, while urban groundwater is administrated by the Ministry of Construction and groundwater used for mining is governed by the Ministry of Land Resources (MLR). Water pollution control is the responsibility of the State Environmental Protection Agency (SEPA), including inspections and fee collection, while the Ministry of Construction inspects wastewater treatment facilities and collects wastewater disposal charges. However, the MWR is in charge of management of sewage or polluted water in rivers. Both the MWR and the SEPA monitor water pollution in surface and groundwater resources, but the MLR also takes part in groundwater monitoring. Management conflicts over hydropower between the MWR and the Ministry of Energy Resources (MER) are another example of management friction. As a result of such conflicts, the MWR and the MER have been divided and merged several times.

Water management conflicts within the vertical administrative system (from central to local governments) and across the horizontal local government system are important constraints to integrated management both at the national and YRB level (Wang et al. 2003). Maximizing local revenue and economic growth subject to a certain level of grain self-sufficiency in the region is the major objective of local governments. In another word, after ensuring a certain level of grain self-sufficiency, the major objective of local governments is to maximize local revenue and economic growth. This objective has influenced the decisions of local water resource bureaus regarding water allocation among sectors, as well as the efforts of local governments toward investments and water activities. As a result, the regional distribution allocation of water resources to industry and agriculture is often not consistent with national plans or relative profitability.

- *Institutional arrangements for water allocation in the YRB*

Water allocation across provinces
Before the implementation of the Unified Water Flow Regulation (UWFR), water users across the basin could freely draw water from this then "open-access resource" (Ma et al., 2007; Wang, 2007). Regional water use was simply determined by water withdrawal capacities. Open-access entails a high risk of resources degradation. To satisfy rapidly growing water demands, provinces along the Yellow River constructed a large number of water withdrawal facilities. From the 1950s to the 1990s, water consumption of the Yellow River increased by 150 percent. As a result of poor management and low water-use efficiency, river waters trickled to a standstill in the lower end of the basin since the early 1990s(Wang et al. 2003). Water use per capita and as a share of GDP in the four upstream provinces of Qinghai, Gansu, Ningxia and Inner Mongolia were much higher than in the downstream provinces of Shaanxi, Shanxi, Henan, and Shandong. Due to geographical constraints, it was particularly difficult to get water in Shanxi, where per capita water use and water use as a share of GDP was less than 200 cubic meters and 400 cubic meters, respectively. In Ningxia these figures were more than 1,500 cubic meters and 400 cubic meters, respectively.

Increasing depletion of Yellow River water resources, particularly, long-term flow cutoffs in the downstream reaches, had attracted serious attention from the Central Government and the State Council. In December 1998, the State Council, the State Planning Commission, and the MWR jointly issued the Annual Allocation and Main River Water Quantity Controlling Programme for the Yellow River, authorizing the YRCC to exert integrated control of Yellow River waters, through the UWFR. UWFR allocates water across provinces based on quotas that had been defined in 1987, amounting to a total of 37 BCM (Table 2.3.1). Compared to an average of 126 days in which the river flow to the Sea was cut off during 1995 to 1998, flow at Lijin Station was cut off only for 8 days between 1999 and 2000, and since 2000, river flow has not been interrupted anymore.

Table 2.3.1. Water allocation agreement of 1987 and actual withdrawals, 1998 and 2008 (BCM).

Province	UWFR *	2008			1998		
		Total withdrawals	Surface water	Ground water	Total withdrawals	Surface water	Ground water
Qinghai	1.41	1.86	1.47	0.39	1.92	1.63	0.29
Sichuan	0.04	0.03	0.03	-	0.02	0.01	0.01
Gansu	3.04	4.44	3.80	0.64	4.15	3.53	0.62
Ningxia	4.00	7.63	7.12	0.51	9.68	9.14	0.54
Inner Mongolia	5.86	9.37	6.97	2.40	9.26	7.30	1.96
Shaanxi	3.80	6.27	3.22	3.05	5.51	2.42	3.09
Shanxi	4.31	4.14	1.70	2.44	3.64	1.18	2.46
Henan	5.54	6.63	4.20	2.43	5.77	3.34	2.43
Shandong	7.00	7.99	7.07	0.92	9.77	8.46	1.32
Hebei/Tianjin	2.00	0.73	0.73	na	na	na	na
Total	37.00	49.10	36.31	12.78	49.71	37.00	12.71

* UWFR: Unified water flow regulation (enforced since 1999). Source: YRCC (2005).

However, the UWFR has received criticism. To date, the downstream regions have not had to pay compensation for the incremental units of water that they have received as a result of water cuts to upstream users. Moreover, because water sales in the upstream regions have fallen, upstream IDs are beginning to experience declines in revenues. In interviews during 2001, we were told that a significant amount of maintenance would have to be delayed or cancelled because of the revenue shortfall. If such practices continue and become more severe, the entire irrigation system could suffer serious damage.

In response, upstream water suppliers have demanded to increase prices for water to maintain revenues. Although initially there was some opposition by the central government, after the introduction of the YRB water allocation program, water prices in the upstream areas were allowed to rise. For example, Ningxia doubled the price of water in agriculture from 0.006 Yuan/m^3 (equivalent to US$0.0009/$m^3$) to 0.012 Yuan/$m^3$ (US$ 0.002/m^3) in 2000 (Wang et al. 2003). As a result of higher water fees, the water authorities have regained some of their lost revenues.

Uncompensated water transfers between poorer provinces to more well-off provinces can have important impacts on the poor (Wang et al. 2003). Re-allocations to date have occurred between the relatively worse-off upstream provinces of Ningxia and Gansu to richer provinces, such as Shandong. Most likely, the shift of water access away from upstream provinces will have a negative effect on some producers in the ID and (as discussed above) could adversely affect the operation and future effectiveness of irrigation itself. Given the scarcity of water resources in the YRB and the lack of compensation for transferring water to better-off downstream users, tensions and conflicts among water stakeholders have risen.

Although YRCC is authorized by the State Council to control the Yellow River water resources, YRCC is not a first-tier government agency. The water law does not clearly define the powers of YRCC for administrative enforcement, supervision, and punishment, and the relationship between the YRCC and local governments remains unclear. Integrated management of the Yellow River water is made more difficult by the fact that water-control policies are relatively new. Further, the *Yellow River Water Quantity Control Management Method* does not have detailed implementing regulations. In addition, the water control plan has hardly been implemented; detailed plans for implementation are therefore urgently needed. Currently, the YRCC has only conducted integrated control for two main river reaches: from Liujiaxia Reservoir to Toudaoguai and from Sanmenxia Reservoir to Lijin gauge; and since 2006 YRCC has also implemented control on two tributaries; however, other sections remain without integrated management.

Water Allocation within Provinces

Generally, the upper-level water resources bureaus, at the provincial and prefecture levels, prepare annual water allocation plans for lower-level regions and then submit them for approval to the local governments (Wang et al. 2003). Before formulating water allocation plans, water resources bureaus at upper levels will solicit opinions on water requirements from the water management agencies at the lower levels. Opinions on water allocation from lower-level water management agencies are the foundation of water allocation plans and are then adjusted and coordinated by upper-level water management agencies according to the overall water supply and demand situation. After the local government approves the water allocation plan, the allocation plan will be sent to lower-level governments to be implemented. Last year's water supply and demand situations and the current year's water demand are important parameters for the formulation of water allocation plans. Because water supply in the current year cannot be predicted with great certainty and some water use sectors will not be satisfied with the water allocation plan, conflicts among various water use departments tend to arise and plans tend to be adjusted.

While water resources bureaus at the upper level coordinate and decide on water allocation between upstream and downstream water users within their administrative boundaries, actual water allocation decisions are made by the upstream local government and downstream water users have little power to influence these allocation decisions (In China, there are both vertical and horizontal management systems, vertical relates to various levels of water resource bureaus, horizontal relates to the local management system (including water and other sector's management, in each administrative level, such as at province level, provincial water resources bureau not only need to follow the regulation of the Ministry of Water Resources, but also need to follow the management of the local provincial government that is in charge of all bureaus' management within the province). Furthermore, higher-level government agencies have limited influence on lower-level agencies in actually implementing water allocation plans, as relationships are mainly technical, not administrative. When water conflicts occur, the water resources agency at the upper level will try to mediate. If the problem still cannot be resolved, then the local government that is in charge of all bureaus' management will intervene. For serious conflicts, local or higher-level courts will be called upon.

Water Allocation within Irrigation Districts
Water allocation at the main or first-level canals and the second-level canals within a province's ID are controlled by one of the following government agencies—the provincial, prefectural or county's water resources bureau—depending on the size and reach of the ID. By regulation, the general principle for water allocation is to give the first priority to downstream users, lift irrigation (vs. gravity irrigation), the canal's high off-takes (versus the lower off-takes), agriculture (versus forestry), more vulnerable groups, and large consolidated tracts of land (versus fragmented land).

Irrigation water is allocated based on water quotas. The water quota differs by crop type, the availability of water supply, delivery efficiency of the surface water system, the location in the canal, and rainfall, climatic, soil, and other local characteristics that influence the crop water demand. The purpose of the water quota is to provide IDs with a way to allocate water and limit the over-exploitation of an area's water resources. Provincial regulations, for example, for Ningxia, stipulate that officials are supposed to send more water to downstream regions and give priority to vulnerable groups, such as the poor. The actual record shows, however, that implementation of the regulations is spotty. Officials in some areas follow the downstream first rule; while those in other areas do not. Moreover, we have found no evidence, on a district-wide scale that water officials purposely give priority to the poor.

Water Allocation within the Village Level
Water allocation at the village level has evolved as a result of a complex set of characteristics of the village, the nature of its water resources and local cropping patterns. It chiefly follows three approaches--equity, efficiency and payment capacity. Based on a survey of 51 irrigating villages in Ningxia and Henan provinces, we found that 13 percent of sample villages use the equity method, where water is first provided to the tailenders. Irrigating the nearest fields first is the physically most efficient way as it reduces delivery losses to allocate water. Interestingly, despite the emphasis of IDs on equity, a much greater number of villages (70 percent) claim they use the efficiency method of water allocation. Finally, some villages use other methods based on the payment order. A mere 2 percent of villages provide water on a first pay, first serve basis. The remainder of the villages has no established rules.

- *Irrigation Management Reform--Econometric results*

Based on our field surveys, after upper-level officials began implementing the reforms, three main management systems emerged for surface waters. If the village leadership through the village committee directly takes responsibility for water allocation, canal operation maintenance (O&M) and fee collection, the village's irrigation system is said to be run by collective management; this is the system that essentially has allocated water in most of China's villages during the People's Republic period. The alternative is a water user association (WUA). This is theoretically a farmer-based, participatory organization that is set up to manage the village's irrigation water. In WUAs a member-elected board is supposed to be assigned the control rights over the village's water. In the third system, defined as Contracting, the village leadership establishes a contract with an individual to manage the village's water.

According to our data, since the early 1990s and especially after 1995, reform has successively established WUAs and Contracting in place of collective management (Table 2.3.2). The share of collective management declined from 91 percent in 1990 to 49 percent in 2004 (column 5). Across our sample, contracting has developed more rapidly than WUAs. By 2004, 30 percent of villages managed their water under contracting and 21 percent through WUAs. Assuming the results from our sample reflect the more general trends across north China, the somewhat more rapid emergence of contracting may be due to the ease of setting the system up and the similarities of the reforms to the other reforms that have unfolded in rural China (Nyberg and Rozelle, 1999).

Table 2.3.2. Surface irrigation management in the sample villages, in the four selected irrigation districts, Ningxia and Henan Province, 1990 – 2004

	Ningxia		Henan		Total
	Weining ID	Qingtongxia ID	People's Victory ID	Liyuankou ID	
1990			(percent)		
Collective	100	81	100	100	91
WUA	0	5	0	0	3
Contracting	0	14	0	0	6
1995					
Collective	100	72	100	100	87
WUA	0	10	0	0	6
Contracting	0	18	0	0	7
2001					
collective	27	51	92	100	64
WUA	50	14	0	0	14
Contracting	23	35	8	0	22
2004					
Collective	25	29	89	100	49
WUA	38	29	0	0	21
Contracting	38	42	11	0	30

Data source: Authors' survey

The dramatic differences in type of irrigation management between Ningxia and Henan Provinces suggest that upper level government policy may be playing an important role. In 2000, in order to promote water management reform, Ningxia provincial water officials issued several documents that encouraged localities to proceed with water management reform (Wang, 2002). Regional water officials exerted considerable effort to promote water management reform in a number of experimental areas. However, while there were changes in name, in most cases (85 percent of the WUAs), the governing board of the WUA was the village leadership itself.

More importantly are the incentives provided to water managers, which are directly connected to water fee payments. Water fees collected from farmers include two parts: basic water fees per mu (0.067 ha) associated with total cropland in the village and volumetric water fees associated with the volume of water used. The basic water fee is determined by dividing the total water fee for the village by the total land area; this fee is then proportionally allocated to farmers based on their specific holdings. Prior to the farming year, ID officials determine (on the basis of historic use patterns and other criteria) a targeted amount of water that a village should use (called the target quantity). Based on a per cubic meter charge, the total value of the expected water use for the village is then divided by the village's total quantity of land and this volumetric water fee is added to the basic water fee to create the farmer's total water fee. As can be seen, the volumetric water fee also provides the farmer no incentives to save water since he pays a fixed fee for each hectare of land. The water manager in some communities, in contrast, does have an incentive. In implementing water management reform ID officials agree that the water manager only has to pay the per cubic meter charge for the water that is actually used (actual quantity). If the actual quantity of water delivered to the village (at the request of the water manager) is less than the targeted quantity, the difference between the volumetric fee that is collected from the farmers and that which he pays for the water is his excess profit. The excess profit is an amount that is earned by the manager beyond the fixed payment and is what we call the incentive. For example, in 2004, on average, leaders in only 46 percent of villages offered WUAs and contracting (or non-collective) managers with incentives that could be expected to induce managers to exert effort to save water for additional income.

We find that water use for wheat and maize is lower in the villages that have established incentives mechanisms compared to villages without incentives, but higher for rice with incentives compared to previous irrigation management (collective).

Table 2.3.3 Incentives, water use and water productivity in the sample irrigation districts, Ningxia and Henan Province

	Non-collective with incentives	Non-collective without incentives	Collective
Water use (m3/ha)			
Wheat	5484	6794	4990
Maize	6622	8006	7112
Rice	28012	32237	23378
Water Productivity (kg/m3)			
Wheat	1.00	0.80	1.50
Maize	1.36	1.05	1.33
Rice	0.30	0.31	0.50

Data source: Authors' survey

Based on multivariate econometric analysis, we find that after holding constant other factors, households that are in villages with a high share of canal lining use less water per hectare for wheat and maize. We also find that those villages with a higher share of rice use less water for wheat and maize per hectare, as most water was allocated to rice, and water productivity for other crops therefore increases (Table 2.3.4). Moreover, our results show that when officials provide water managers with incentives, without regard to whether they shifted to WUA or contract management, managers appear to reduce water deliveries for wheat in the village. In other words, without regard to the form of the water management institution, if managers face positive incentives, water use per hectare of wheat can be reduced by nearly 1,000 cubic meters, about 20 percent of their typical water use.

Table 2.3.4 Regression analysis of the determinants of crop water use at the plot level

	Water use per hectare		
		OLS	
	Wheat	Maize	Rice
Irrigation management institutions			
If non-collective with incentives	-1,186	-7376	-5,552
	(3.12)***	(1.19)	(1.17)
If non-collective without incentives	-3642	-3532	-5,463
	(1.17)	(0.70)	(1.44)
Production environment			
Share of village irrigated area serviced by surface water (%)	15.736	28.619	19.233
	(2.58)**	(1.57)	(0.24)
Village water scarcity indicator variable (1=yes; 2=no)	-424	-70	-9,606
	(1.55)	(0.15)	(3.14)***
Value per hectare of accumulated investment into village irrigation infrastructure (yuan/ha)	0.062	0.032	-1.273
	(2.39)**	(0.74)	(2.06)**
Cropping structure			
Share of sown area in rice (%)	-24.666	-38.365	27.042
	(3.48)***	(2.80)***	(0.36)
Village characteristics			
Cultivated land per capita (ha)	-795	-7,912	-52,082
	(0.26)	(1.44)	(1.79)*
Share of labor with education above middle schooling (%)	1.338	22.679	-20.421
	(0.24)	(2.34)**	(0.35)
Distance to township (km)	47.884	140.503	-445.785
	(1.40)	(2.44)**	(1.24)
Households	2.657	4.187	15.675
	(3.44)***	(2.72)***	(1.85)*
Share of labor working outside (%)	1.914	-33.737	-189.636
	(0.21)	(2.23)**	(1.93)*
Log of income per capita	223	1,549	-436
	(0.67)	(2.28)**	(0.13)
Share of lining canals (%)	-22.400	-28.080	19.445
	(4.78)***	(2.89)***	(0.47)
Household characteristics			
Age of household head	-6.224	-127.5	1,661
	(0.07)	(0.77)	(2.01)**
Age of household head, squared	-0.216	0.942	-20.336
	(0.24)	(0.55)	(2.25)**
Education of household head	-48.385	-160.581	-720
	(1.31)	(2.41)**	(1.94)*
Farm size (ha/household)	-311	967	-1,094
	(0.89)	(1.55)	(0.34)
Plot characteristics			
Loam soil (1=yes; 0=no)	169.496	-79.185	351.363
	(0.56)	(0.15)	(0.12)
Clay soil (1=yes; 0=no)	-126.425	-451.128	-204.508
	(0.47)	(0.95)	(0.07)
Distance to home (km)	-259.910	177.667	-813.347
	(1.30)	(0.43)	(0.57)
Single crop (1=yes; 0=double cropping)	1,103	442	-2,287
	(2.53)**	(0.71)	(0.20)
ID Dummy	--	--	--
Constant	3,193	-5,501	-1,137
	(1.03)	(0.84)	(0.04)
Observations	432	334	194
Adjusted R-squared	0.47	0.40	0.37

Absolute value of t-statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

The econometric analysis results also show that the water productivity of wheat will be increased if reform with incentives have been implemented (Table 2.3.6, column 1). The coefficient on the incentives indicator variable is positive and significant at the 5 percent level. This shows that after holding constant other factors, if water managers face incentives during the management reform, wheat production of per unit water can be increased by 0.25 kg. In our sample areas, the average water use per hectare is about 5,500 cubic meter. When putting the predicted value of the incentives indicator into the water use model and water productivity equation described in the methodology section our results change little and largely support the findings from the OLS model (Table 2.3.5 and 2.3.7). For example, compared with OLS estimation, the t statistic of the estimated coefficient on the incentive variable in wheat water use actually declines (row 1). However, the magnitude of the coefficient also suggests that the savings from providing incentives are large. Holding other variables constant, in the villages in which leaders offer managers positive incentives, water use declines 1122 cubic meter per hectare, even higher than the result from the OLS model (Table 2.3.5).

Table 2.3.5 Regression analysis of the determinants of crop water use at the plot level

	Water use per hectare		
		2SLS	
	Wheat	Maize	Rice
Irrigation management institutions			
If non-collective with incentives	-1,118	-29	3,068
	(2.71)***	(0.04)	(0.75)
If non-collective without incentives	119	960	1,816
	(0.25)	(1.29)	(0.40)
Production environment			
Share of village irrigated area serviced by surface water (%)	14.231	23.006	-29.618
	(2.37)**	(1.27)	(0.40)
Village water scarcity indicator variable (1=yes; 2=no)	-470	-152	-9,932
	(1.69)*	(0.32)	(3.28)***
Value per hectare of accumulated investment into village irrigation infrastructure (yuan/ha)	0.068	0.024	-1.456
	(2.52)**	(0.54)	(2.13)**
Cropping structure			
Share of sown area in rice (%)	-26.543	-43.762	19.685
	(3.78)***	(3.24)***	(0.26)
Village characteristics			
Cultivated land per capita (ha)	-606	-8,070	-74,035
	(0.19)	(1.36)	(2.27)**
Share of labor with education above middle schooling (%)	2.025	25.936	-0.741
	(0.37)	(2.69)***	(0.01)
Distance to township (km)	59.045	165.580	-644.714
	(1.64)	(2.72)***	(1.54)
Households	2.552	3.115	13.410
	(3.28)***	(1.99)**	(1.52)
Share of labor working outside (%)	2.375	-22.496	-152.650
	(0.25)	(1.39)	(1.58)
Log of income per capita	168	1,681	13.536
	(0.49)	(2.46)**	(0.00)
Share of lining canals (%)	-22.471	-23.763	41.699
	(4.78)***	(2.40)**	(0.97)
Household characteristics			
Age of household head	-7.150	-149.964	1,545
	(0.08)	(0.91)	(1.85)*
Age of household head, squared	-0.180	1.192	-19.114
	(0.20)	(0.69)	(2.10)**
Education of household head	-47.508	-160.153	-744.060
	(1.29)	(2.41)**	(2.00)**
Farm size (ha/household)	-490	827	-1,247
	(1.39)	(1.33)	(0.38)
Plot characteristics			
Loam soil (1=yes; 0=no)	187	-106	-778
	(0.62)	(0.20)	(0.25)
Clay soil (1=yes; 0=no)	-138	-547	-1,417
	(0.51)	(1.15)	(0.50)
Distance to home (km)	-244	209	-589
	(1.22)	(0.51)	(0.41)
Single crop (1=yes; 0=double cropping)	1,106	449	-2,734
	(2.53)**	(0.73)	(0.24)
ID Dummy	--	--	--
Constant	3,632	-5,776	1,670
	(1.16)	(0.88)	(0.06)
Observations	432	334	194
Adjusted R-squared	0.47	0.40	0.36

Absolute value of t-statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 2.3.6 Regression analysis of the determinants of water productivity at the plot level

	Water productivity (kg/m^3)		
		OLS	
	Wheat	Maize	Rice
Irrigation management institutions			
If non-collective with incentives	0.220	0.269	0.046
	(2.11)**	(1.36)	(0.56)
If non-collective without incentives	-0.082	-0.032	0.034
	(0.85)	(0.17)	(0.42)
Production inputs			
Log of labor use per hectare	-0.117	-0.138	0.025
	(2.29)**	(0.97)	(0.61)
Log of fertilizer use per hectare	-0.043	0.043	0.009
	(0.47)	(0.27)	(0.19)
Log of value of other inputs per hectare	0.029	-0.275	-0.063
	(0.39)	(2.07)**	(0.99)
Production environment			
Share of village irrigated area serviced by surface water (%)	-0.003	-0.001	-0.001
	(1.76)*	(0.14)	(0.72)
Village water scarcity indicator variable (1=yes; 2=no)	0.201	0.380	0.076
	(2.45)**	(2.26)**	(1.20)
Value per hectare of accumulated investment into village irrigation infrastructure (yuan/ha)	-0.000	-0.000	0.000
Household characteristics	(0.95)	(0.73)	(1.17)
Age of household head	0.003	0.087	0.009
	(0.09)	(1.32)	(0.48)
Age of household head, squared	0.000	-0.001	-0.000
	(0.36)	(1.07)	(0.43)
Education of household head	0.014	0.048	0.008
	(1.20)	(1.83)*	(1.01)
Plot characteristics			
Loam soil (1=yes; 0=no)	0.044	0.075	0.093
	(0.45)	(0.35)	(1.40)
Clay soil (1=yes; 0=no)	-0.020	-0.079	-0.017
	(0.24)	(0.42)	(0.29)
Distance to home (km)	0.082	-0.021	0.034
	(1.29)	(0.13)	(1.05)
Single crop (1=yes; 0=double cropping)	-0.294	0.486	0.832
	(2.10)**	(1.93)*	(3.15)***
Production shocks			
Yield reduction due to production shocks (%)	-0.011	-0.008	-0.001
	(3.73)***	(1.46)	(0.36)
ID Dummy	--	--	--
Constant	2.134	2.048	0.302
	(2.04)**	(0.98)	(0.45)
Observations	432	334	194
Adjusted R-squared	0.46	0.10	0.42

Absolute value of t-statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 2.3.7 Regression analysis of the determinants of water productivity at the plot level

	Water productivity (kg/m^3)		
		2SLS	
	Wheat	Maize	Rice
Irrigation management institutions			
If non-collective with incentives	0.222	0.233	0.039
	(1.97)**	(1.10)	(0.57)
If non-collective without incentives	-0.141	-0.359	0.013
	(1.04)	(1.49)	(0.14)
Production inputs			
Log of labor use per hectare	-0.121	-0.130	0.024
	(2.37)**	(0.91)	(0.60)
Log of fertilizer use per hectare	-0.058	0.066	0.007
	(0.64)	(0.42)	(0.13)
Log of value of other inputs per hectare	0.038	-0.245	-0.060
	(0.50)	(1.83)*	(0.95)
Production environment			
Share of village irrigated area serviced by surface water (%)	-0.003	-0.001	-0.001
	(1.83)*	(0.08)	(0.56)
Village water scarcity indicator variable (1=yes; 2=no)	0.203	0.377	0.081
	(2.46)**	(2.25)**	(1.32)
Value per hectare of accumulated investment into village irrigation infrastructure (yuan/ha)	-0.000	-0.000	0.000
Household characteristics	(1.03)	(0.84)	(1.04)
Age of household head	0.002	0.091	0.009
	(0.08)	(1.38)	(0.48)
Age of household head, squared	0.000	-0.001	-0.000
	(0.37)	(1.14)	(0.45)
Education of household head	0.013	0.045	0.009
	(1.08)	(1.70)*	(1.04)
Plot characteristics			
Loam soil (1=yes; 0=no)	0.031	0.075	0.093
	(0.31)	(0.35)	(1.38)
Clay soil (1=yes; 0=no)	-0.012	-0.027	-0.017
	(0.14)	(0.14)	(0.28)
Distance to home (km)	0.085	-0.030	0.030
	(1.34)	(0.19)	(0.95)
Single crop (1=yes; 0=double cropping)	-0.296	0.460	0.830
	(2.11)**	(1.82)*	(3.14)***
Production shocks			
Yield reduction due to production shocks (%)	-0.010	-0.008	-0.001
	(3.50)***	(1.43)	(0.31)
ID Dummy	--	--	--
Constant	2.205	1.540	0.306
	(2.11)**	(0.73)	(0.46)
Observations	432	334	194
Adjusted R-squared	0.45	0.10	0.42

Absolute value of t-statistics in parentheses
* significant at 10%; ** significant at 5%; *** significant at 1%

Descriptive statistics from our data show that water management reform with incentives negatively influences the yields of wheat and rice (Table 2.3.8, rows 1 and 3). Compared with villages without incentives, in the villages that provide incentives to managers to save water, wheat yields decline by nearly 11 percent. However, farmer incomes do not seem to be affected (rows 4 and 5). Part of the explanation for the difference between yields and income may be due to the fact that water fees also fall in villages that have reformed. Another explanation is that farmers are shifting to other sources of income in those villages that provide water managers with incentives.

Table 2.3.8 Incentives, production, income and poverty in the sample irrigation districts, Ningxia and Henan Province.

	Non-collective with incentives	Non-collective without incentives	Collective
Wheat yield (kg/ha)	4310	4716	4880
Maize yield (kg/ha)	6272	6064	5669
Rice yield (kg/ha)	6578	7337	6836
Income (yuan)	3403	2959	2247
Share of household below poverty line (%)	7.32	5.32	7.43

Data source: Authors' survey

Similar results also can be found in the poverty model (Table 2.3.9). We measure poverty status based on whether or not the poverty line has been crossed. Our results say that there is no effect of a village’s decision to provide water managers with incentives on a household poverty status. If universally true, such a finding would be important, since critics of water management reforms often point out that one possible adverse consequence of using incentives to induce water reform is that managers may cut back on water deliveries to marginal users, who may also be those on the poorest land. Our results here, however, should be interpreted with caution. We have not identified what may be behind this result. In many villages, leaders have specified strict rules in the agreements with water managers that they cannot exclude households from water allocation schedules. In short, while interesting, we believe our current results may be more important as raising awareness of possible associations rather than as definitive. Future research should try to pinpoint the source of this effect and use larger data sets to strengthen our understanding of these issues.

Table 2.3.9. Regression analysis of the determinants of poverty

	Dummy of poverty	
	OLS	**2SLS**
Water management institutions		
If non-collective with incentives	0.471	0.226
	(1.24)	(0.66)
Production environment		
Share of village irrigated area serviced by surface water (%)	-0.000	0.001
	(0.02)	(0.15)
Village water scarcity indicator variable	0.562	0.513
(1=yes; 2=no)	(1.90)*	(1.77)*
Value per hectare of accumulated investment into village irrigation infrastructure (Yuan/ha)	-0.000	-0.000
	(0.35)	(0.31)
Cropping structure		
Share of sown area in rice (%)	-0.005	-0.003
	(0.69)	(0.45)
Household characteristics		
Age of household head	0.075	0.061
	(0.64)	(0.53)
Age of household head, squared	-0.001	-0.001
	(0.77)	(0.67)
Education of household head	-0.064	-0.060
	(1.55)	(1.47)
Farm size (ha/household)	-1.232	-1.094
	(2.51)**	(2.35)**
Share of no-farm labor (%)	-0.017	-0.017
	(2.29)**	(2.29)**
Share of no-farm income (%)	-0.006	-0.006
	(0.95)	(1.01)
Assets used in agricultural production per capita	-0.000	-0.000
	(2.19)**	(2.11)**
Number of plots per household	0.016	0.023
	(0.54)	(0.79)
Production shocks		
Yield reduction due to production shocks (%)	0.018	0.018
	(2.40)**	(2.43)**
ID Dummy	--	--
Constant	-1.315	-1.145
	(0.51)	(0.44)
Observations	378	378
Pseudo R-squared	0.26	0.25

2.3.3 Conclusion

Given the scarcity of water resources in the Yellow River Basin and the lack of compensation for transferring water to more well-off downstream users, tensions and conflicts among water stakeholders have risen. Although YRCC is authorized by the State Council to control the Yellow River water resources, YRCC is not a first-tier government agency. The water law does not clearly define the powers of administrative enforcement, supervision, and punishment of YRCC and the relationship between the YRCC and local governments remains unclear. Integrated management of the Yellow River water is faced with many difficulties, particularly given the fact that water control is new and no ready-made river control standard can be followed. Further, the Yellow River Water Quantity Control Management Method does not have detailed implementing regulations; and many aspects of reservoir control application regulations of hydropower stations are at odds with the Yellow River Water Quantity Control plan. In addition, the water control plan has hardly been implemented; detailed plans for implementation of the Yellow River Water Quantity Control are therefore urgently needed. Currently, the YRCC has only conducted integrated control for two main river reaches: from Liujiaxia Reservoir to Toudaoguai and from Sanmenxia Reservoir to Lijin gauge; other sections remain without integrated management.

Uncompensated water transfers from poorer provinces to more well-off provinces can have important impacts on the poor. Re-allocations to date have occurred between the relatively worse-off upstream provinces of Ningxia and Gansu to richer provinces, such as Shandong. Most likely, the shift of water access away from upstream provinces will have a negative effect on some producers in the ID and (as discussed above) could adversely affect the operation and future effectiveness of the ID itself. To mitigate these negative effects, central government leaders should estimate the value of compensation to be paid and implement compensation.

Econometric research results show that since 1990, and especially after 1995, collective management has been replaced by non-collective management, including WUAs or contracting. In some regions, non-collective management forms even have become the dominant pattern. Innovation of irrigation management reflects many stakeholders' interests, such as upper and local governments, village leaders and farmers, in particular, policy makers' intervention in the reform seems to play an important role.

Designing the reform is one issue, implementing is another issue. Even though the reform has been designed well, effectively implementing the reform seems to be out of policy makers' control and should be highly emphasized. The major difference between non-collective and collective management is the incentives faced by managers. The need of effective incentives is one of our key results. Research shows that if managers are provided with positive incentives to earn money by saving water, they will try to improve irrigation management, and water delivered to farmers will be significantly reduced. More importantly, our analysis found that even if irrigation management with incentives reduces water use and increases water productivity, with negative impacts on wheat production, both income and poverty are not be negatively influenced. Although this result need to be further explored in the long term, at least in the short term, it appears that farm incomes are not affected by reduced water availability.

Overall, we propose that the Government should continue to support the irrigation management reform. However, different from the beginning stage, more emphasis should be put on the effective implementation of the reform. Although the negative impact on farmers have not been identified at this point, in the long term, the government still need to focus on this issue and take some measures to promote the healthy development of water reform.

Another important issue is to identify how much water should be saved through the irrigation management reform and how this water can be most effectively re-allocated to those uses that have the highest overall benefit to the basin economy and ecology.

2.4 Water Poverty Analysis

2.4.1 Methods

Three types of poverty estimates have been measured for the Yellow River Basin: the headcount index, or poverty incidence (P0); the poverty gap index, or poverty depth (P1); and the distribution-sensitive poverty index, or poverty severity (P2). The headcount index (P0) shows the proportion of the poor population to the total population. It is a simple poverty measure and its interpretation is straightforward. However, this measure is insensitive to the depth of poverty, which the poverty gap index (P1) takes into account. The poverty gap is an estimate of the income (or expenditure) that would be required to bring every individual up to the poverty threshold. A reduction in the income of any poor individual would increase the poverty gap (and vice versa), but the poverty head count would remain unchanged. But the poverty gap index is insensitive to the redistribution of income among the poor. As the name indicates, the distribution-sensitive poverty measure (P2) is sensitive to the reallocation of income among the poor. This poverty measure decreases if income is transferred from a poor individual to a poorer individual (and vice versa).

All three poverty measures are members of the Foster-Greer-Thorbecke (FGT) class (Foster, Greer, and Thorbecke 1984), which may be expressed as

(Eq 2.6.1)

where z denotes the poverty line, α is a measure of the sensitivity of the index to poverty, the income (or consumption expenditure) per capita for the ith person's household is x_i in a population N, and the poverty gap for individual i is $G_i = z - x_i$ (with $G_i = 0$ when $x_i > z$). The head-count index P0 is obtained when α = 0; when α = 1, the index is the poverty gap index P1, and when α is set equal to 2, P2 is the squared poverty gap or poverty severity index.

The poverty profile also provides estimates of inequality in income and land distribution in the YRB using the Gini coefficient; the most widely used single measure of inequality. It is based on the Lorenz curve, a cumulative frequency curve that compares the distribution of a specific variable (for example, income) with the uniform distribution that represents equality. For measuring the inequality in income distribution, the Gini coefficient can be estimated from the cumulative percentage of households (from poor to rich) on the horizontal (X) axis and the cumulative percentage of income on the vertical (Y) axis of the Lorenz curve. The Gini coefficient is then defined as

$$Gini = 1 - \frac{1}{N}\sum_{i=1}^{N}(x_i - x_{i-1})(y_i + y_{i-1}) \quad \text{(Eq 2.6.2)}$$

where xi is a point on the X-axis and yi is a point on the Y-axis. When there are N equal intervals on the X-axis the equation simplifies to

$$Gini = 1 - \frac{1}{N}\sum_{i=1}^{N}(y_i + y_{i-1}) \quad \text{(Eq 2.6.3)}$$

For estimating poverty in the YRB, we used the latest international poverty line of US$1.25 per day, measured at the purchasing power parity (PPP) exchange rate with 2005 as the base year. The 2005 PPP exchange for China is 3.4 yuan per US$1.00.

We used income data from the 2001 Household Income and Expenditure Survey (HIES) conducted by the National Bureau of Statistics (NBS) of China for analyzing poverty and inequality in the YRB. Because we used the PPP exchange rate with 2005 as the base year, we adjusted per capita income data from the 2001 survey for inflation using the consumer price index (CPI) for China, with the base year 2005 = 100.

The HIES data set used for the analyses represents the rural communities and households only in the YRB. This partial data set included 5,085 households in nine provinces belonging to the YRB. We also used 1951-2000 average rainfall data from 83 out of 90 counties in the YRB.

In addition to poverty measures, determinants of poverty need to be assessed. There are two main approaches to modeling the determinants of poverty in a multivariate regression framework. The first approach seeks to explain the level of household income (or consumption expenditure) per capita—the dependent variable—as a function of a variety of explanatory variables. The form of this model could be as follows:

$$\ln(y_i/z) = \alpha_0 + \sum_{k=1}^{K} \beta_k X_{k,i} + \lambda_p + u_i \ , \qquad \text{(Eq 2.6.4)}$$

where y_i is per capita income (or consumption), z is the poverty line, $\sum_{k=1}^{K} \beta_k X_{k,i}$ is a set of explanatory variables—such as community and household characteristics—denoted by X and indexed by *k=1, …, K;* β is a *K x 1* vector of parameters; λ_p vector of parameters; is location fixed effect; and u_i is a random error term. The dependent variable y_i/z is in log form (natural logarithm), allowing for the log normality of the variable.

The second approach is a direct modeling of household-level poverty measures—to explain whether a household is poor or not—using a probit or logit regression. In this case the dependent variable is binary, taking on a value of 1 if the household is poor and zero otherwise, and the independent variables are as in first approach. This approach has often been used in the literature (see, for example, Bardhan 1984; Gaiha 1988; World Bank 1994, 1995a, 1995b, 1996; Grootaert 1997). Some of the information, however, is lost when the direct approach is used for modeling the determinants of poverty, because the information on the household living standards above the poverty line is censored—all nonpoor are treated alike. There are a few other reasons why modeling household income or consumption is preferable to modeling household poverty levels (see, for example, Datt and Jolliffe 1999).

In our analysis of poverty determinants in the rural YRB, we have used the first approach described above. For modeling income as in equation (2.6.4), we used the income data from the 2001 HIES. We converted the income data from RMB to international PPP dollar with 2005 as the base year, as we did for poverty analysis. The income model in equation (1) has been estimated using the ordinary least square (OLS) regression. The standard errors have been corrected for the sampling effects.

2.4.2 Results and Discussion

- *Results for water-related poverty profile in the Yellow River Basin*

In this section, we provide a profile of poverty in the YRB focusing on the empirical links between water and poverty in the basin. The profile assesses the magnitude of poverty and its distribution across geographic and socioeconomic domains, provides information on the characteristics of the poor, and examines the pattern of poverty to see how it varies by water availability and access.

Poverty and Inequality in the YRB

Table 2.4.1presents the poverty measures for the rural YRB region and by parts of the provinces belonging to the YRB. Using the PPP US$1.25 a day poverty line and per capita income levels, the table shows that 30.5 percent of the population in the rural YRB region were living in poverty in 2001.[1]

Table 2.4.1 Poverty in rural YRB: People living on less than US$1.25 a day in 2001

Location	Poverty headcount rate	Poverty gap	Squared poverty gap
	(percent)	(x100)	(x100)
YRB	30.5	8.9	3.7
Parts of the provinces belonging to YRB			
Shanxi	21.3	5.1	1.9
Inner Mongolia	8.1	2.0	0.7
Shandong	3.1	0.8	0.3
Henan	14.6	2.9	0.9
Sichuan	17.8	2.2	0.5
Shaanxi	42.1	13.4	5.9
Gansu	52.2	14.9	5.9
Qinghai	44.9	15.5	7.3
Ningxia	26.3	8.2	3.6

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Note: The international poverty line of US$1.25 a day is in 2005 purchasing power parity (PPP) term.

There are pronounced regional differences in poverty rates within the YRB. Parts of nine provinces of China belong to the YRB region. The incidence of poverty (headcount poverty rate) varies widely in different parts of the YRB, ranging from a low of 3.1 percent in Shandong province in the east to highs of 52.2 percent and 44.9 percent, respectively, in Gansu and Qinghai provinces in rural western China.[2] This pattern of poverty incidence corresponds quite well to that of the national level—poverty in China is mainly concentrated in the western part of the country.

Table 2.4.2 also shows the depth (poverty gap) and the severity (squared poverty gap) of poverty at the YRB level and by parts of provinces belonging to the basin. The measures of poverty depth and poverty severity provide complementary information on the incidence of poverty. While province-level poverty depth and severity followed the pattern of headcount poverty rates in most cases, there are a couple of differences. For example, the part of Gansu province in the YRB shows the highest headcount poverty rate, but it is in the second rank (after Qinghai) according to both the poverty depth and the severity indices. Compared to the people in the Qinghai part of the YRB, the people in the Gansu part of the YRB have a higher risk of being in absolute poverty, but their

[1] The poverty measures are based on the estimated population distributions of persons ranked by household income per person, where each person in a given household is assumed to have the same income. Sample households were multiplied by household size to calculate population.

[2] The province-level poverty results need to be treated cautiously because the samples of households in the portions of the provinces belonging to the YRB may not necessarily be statistically representative of those portions.

poverty tends to be less deep and less severe. Further, the YRB-part of Shaanxi province ranks the third in terms of both the poverty headcount and the depth indices, but it is in the second rank in terms of the severity of poverty—the same as Gansu. The types of interventions needed to help these groups of people would therefore likely be different.

Figure 2.4.1 illustrates the poverty incidences in the YRB region in a poverty map of the region. The poverty rate shown outside the YRB in a province represents the average rural poverty rate in that entire province. For instance, the overall PPP US$1.25 a day poverty rate in rural Gansu province was 37.6 percent, but the rate was 52.2 percent in the part of the province that belongs to the YRB. Similarly, the incidence of poverty was higher (17.8 percent) in the small part of Sichuan province belonging to the YRB than that of the average for Sichuan province (8.6 percent). On the other hand, the headcount poverty rate was lower in the YRB-part of Shanxi province (21.3 percent) than that in the entire Shanxi province (24.6 percent).

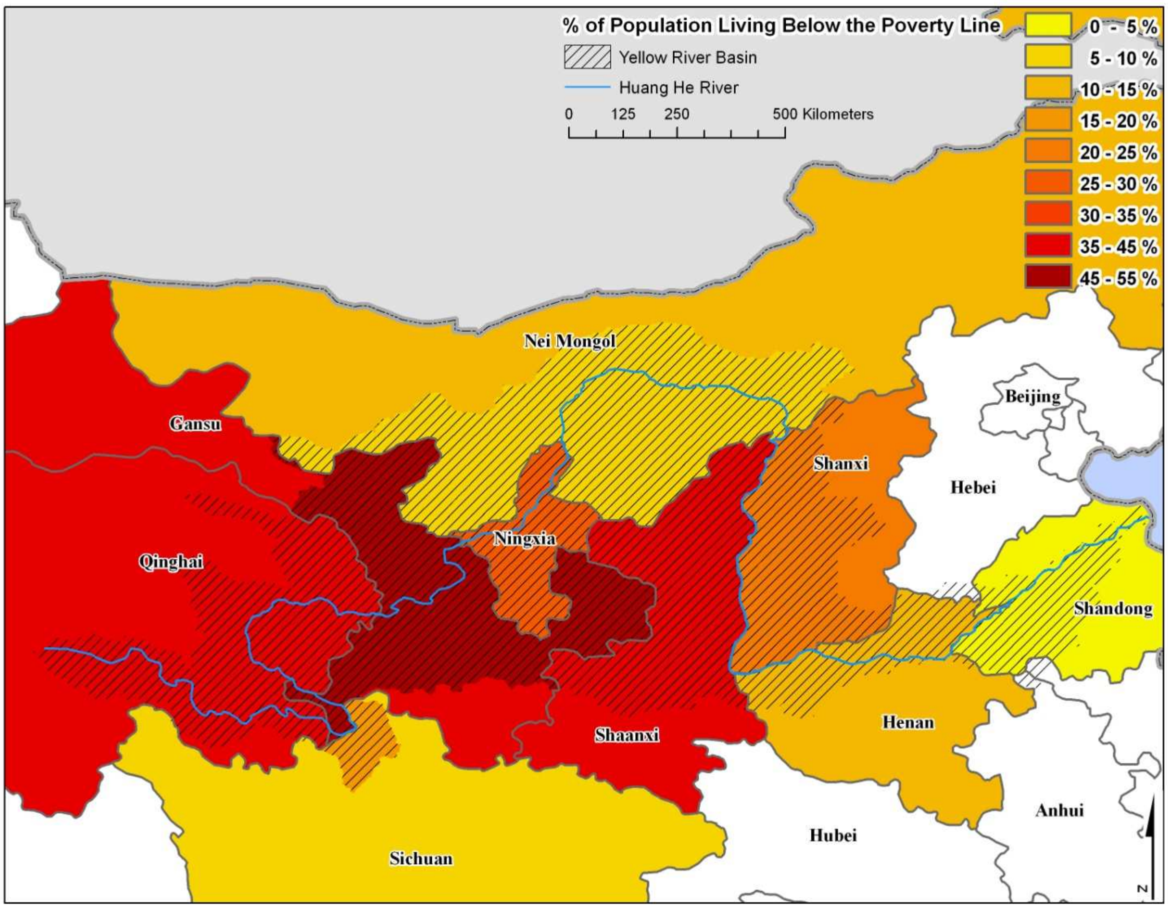

Figure 2.4.1.: Poverty map of the YRB by province: People living on less than $1.25 a day

Turning next to inequality measures, Tables 2.4.2 and 2.4.3 show, respectively, the patterns of income and land distributions in the YRB, the simplest way to measure inequality. In Table 5.2, the population in the YRB was divided into 10 equal groups (deciles) from poorest to richest, and the percentage of per capita total income that accrued to each decile group is reported. The figures in the table show that 7.1 percent of all income was earned by the poorest 20 percent of households and 27.5 percent by the richest 10 percent. The distribution of cultivated land in the YRB is more skewed than that of income: only 4 percent of all land under cultivation was cultivated by the smallest 20 percent landholders while the largest 10 percent landholders cultivated 34.8 percent.

Table 2.4.2 Distribution of per capita income by decile, YRB 2001

Per capita income decile	Average per capita income	Share of total income in each decile
	(yuan/person/year)	(percent)
1 (poorest)	775	2.8
2	1,181	4.3
3	1,473	5.4
4	1,749	6.4
5	2,019	7.4
6	2,348	8.6
7	2,757	10.1
8	3,302	12.1
9	4,196	15.4
10 (richest)	7,528	27.5
All households	2,732	100.0

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Table 2.4.3 Distribution of cultivated land by decile, YRB 2001

Cultivated land decile	Average cultivable land	Share of total cultivated land in each decile
	(hectare/household)	(percent)
1 (lowest)	0.08	1.1
2	0.21	2.9
3	0.28	3.9
4	0.34	4.8
5	0.43	6.0
6	0.52	7.3
7	0.67	9.3
8	0.88	12.3
9	1.26	17.6
10 (highest)	2.49	34.8
All households	0.71	100.0

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

The most widely used summary measure of inequality is the Gini coefficient, which is mainly used for comparing inequality over time and space. The estimated Gini indices are 40.5 percent for income distribution and 46.3 percent for cultivated land distribution in the YRB.

The Gini coefficient can be interpreted in the context of a Lorenz curve. Figure 2.4.2 presents the Lorenz curve for income distribution and Figure 2.4.3 provides the Lorenz curve for cultivated land distribution in the YRB. The interpretation of the Lorenz curve for income distribution in Figure 2.4.2 follows. After ranking all persons by per capita income, the Lorenz curve plots the cumulative percent of total income on the cumulative percent of population. From this graph, it is possible to determine what percent of total income is realized by, say, the poorest 25 percent of the population. The 45-degree line represents the line of perfect equality, where everyone has the same income. The area between the 45-degree line and the Lorenz curve gives a measure of the extent of inequality. The Gini coefficient is measured as the ratio of the area between the Lorenz curve and the 45-degree line of perfect equality and the area of the triangle underneath the 45-degree line. Similar interpretation holds for the Lorenz curve for land distribution in Figure 2.4.3.

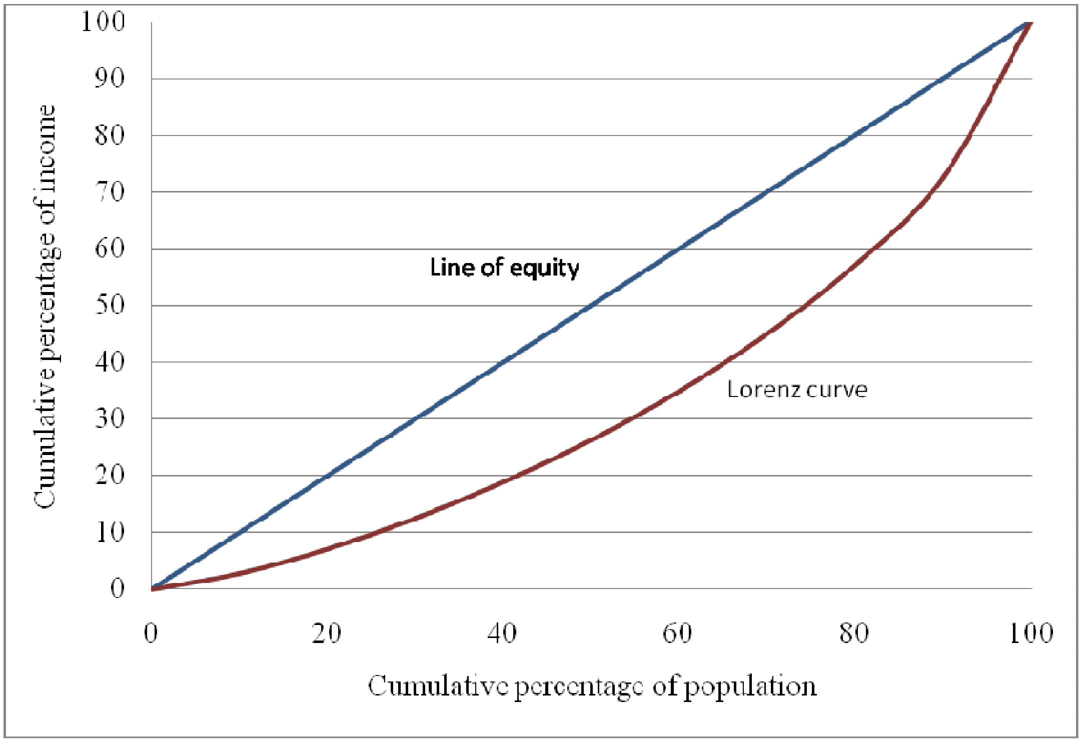

Figure 2.4.2.: Lorenz curve for income distribution in the YRB

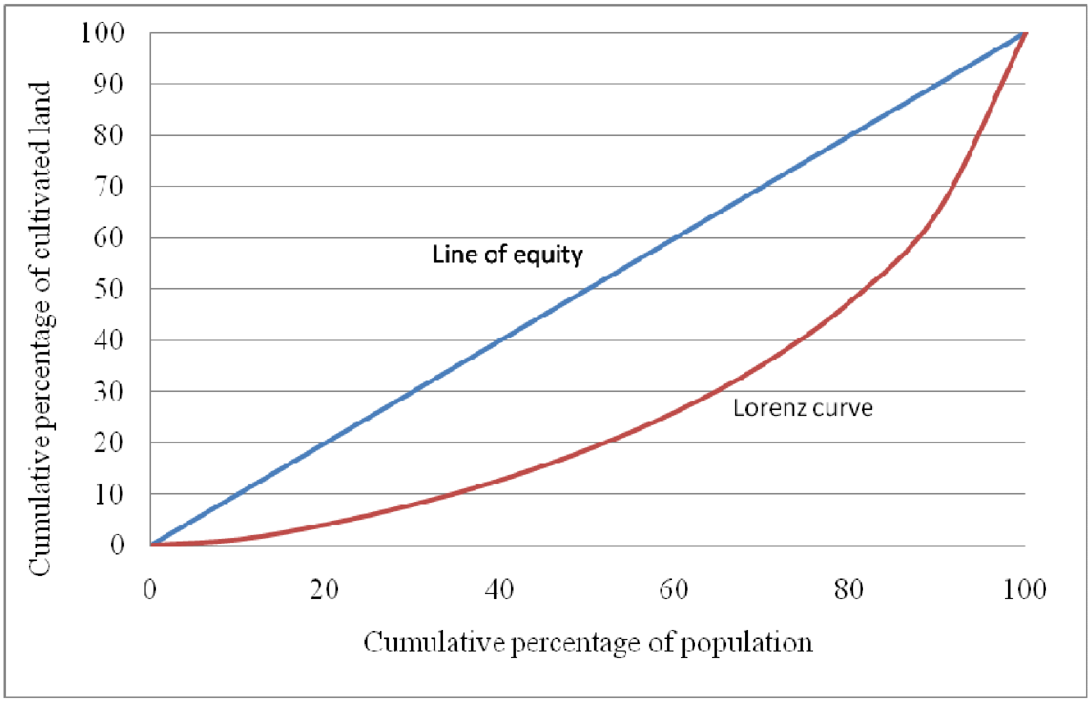

Figure 2.4.3: Lorenz curve for distribution of cultivated land in the YRB

Regional Dimensions of Poverty within the YRB

In general, the incidence of poverty is high in remote areas and in areas characterized by a low resource base, low rainfall, and other inhospitable climatic conditions (World Bank 2005).

In the YRB, 43 percent of the sample households live in plain land villages, 13 percent in live in hill villages, and 44 percent live in mountain villages. Figure 2.4.4 shows the distribution of sample households living in plain land, hill, and mountain villages by per capita income quintile. The results indicate that poverty is considerably higher in the mountain region compared to the other two regions of the YRB. Among all sample households in the poorest quintile group, 70 percent live in mountain villages, 17 percent live in plain land villages, and 13 percent live in hill villages. The mountain villages are home to a disproportionately large proportion of households belonging to the second lowest income quintile as well. On the other hand, while only 19 percent of all households belonging to the highest income quintile live in mountain villages, 74 percent of the households in that quintile live in plain land villages.

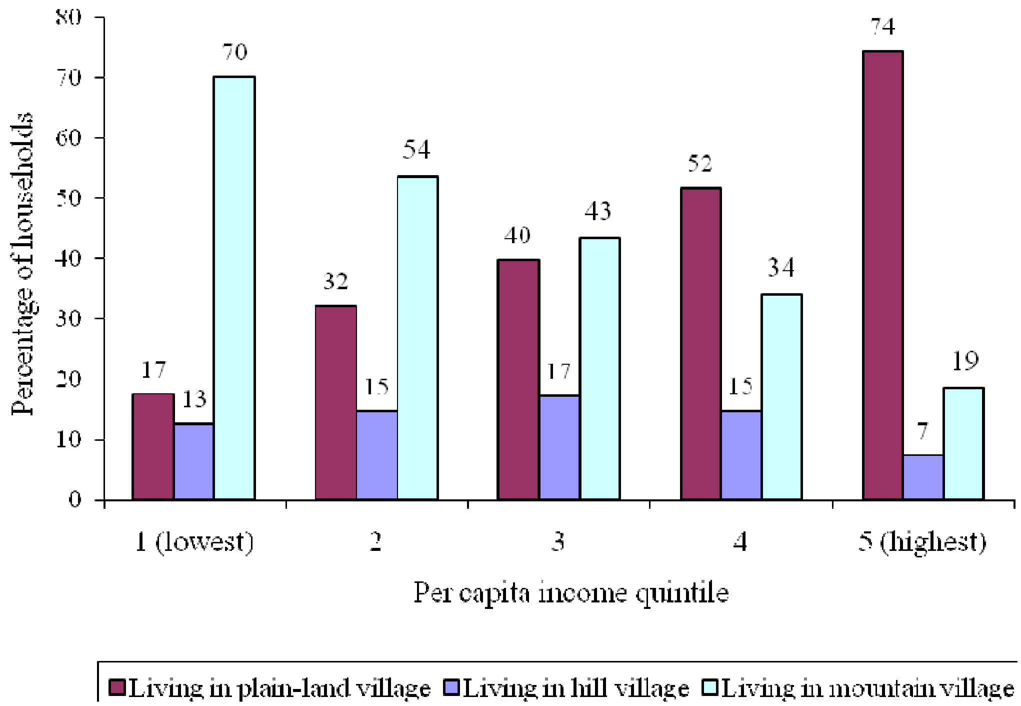

Figure 2.4.4: Regional distribution of households by per capita income quintile

Figure 2.4.5 shows the estimates of the PPP US$1.25 a day poverty headcount rates for the three geographical regions. The poverty rate is the highest in the mountain region and the lowest in the plain-land region. As shown above in Table 2.5.1, among the nine provinces that lie in the YRB, Gansu and Qinghai have the highest levels of poverty—52.2 percent and 44.9 percent, respectively. The Yellow River has its source in these mountainous provinces. These two provinces have low levels of rainfall. Further, Qinghai has inhospitable climate characterized by long and very cold winters. On the other hand, Shandong province has the lowest levels of rural poverty in the YRB and poverty in Henan province is also relatively low. These provinces lie in the lower reaches of the Yellow River where the climate is mostly wet and warm. Our analysis thus indicates that the poor in the YRB are highly concentrated in the mountain regions while households in the plain land regions along the lower reaches of the Yellow River are relatively well-off.

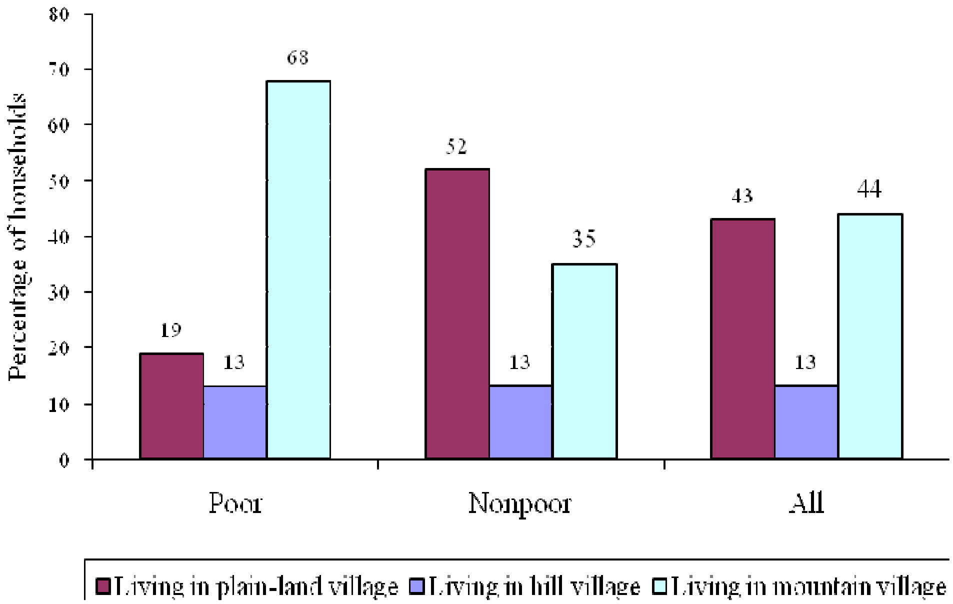

Figure 2.4.5: Regional distribution of households by poverty status

- Water-Related Poverty Profile of the YRB

Background

Shortage of water is one of the most prominent characteristics of the YRB. The river feeds 12 percent of China's population, accounts for 15 percent of the country's irrigation area, and contributes towards 9 percent of China's GDP. Yet, the average annual runoff of 58 billion cubic meters represents only 2 percent of China's annual runoff (Feng and Wu 2009). More recent estimates refer to total runoff of 53.5 BCM. The per capita water resource is approximately 590 cubic meters which is about one-fourth of the national average, and one-sixteenth of the world average. Moreover, even this limited runoff is highly variable in its spatial as well as temporal characteristics. The watershed above the Gansu province, which represents nearly 40 percent of the total basin area, produces nearly 56 percent of the annual average runoff. Thus, lack of discharge is not necessarily a sign for poverty. Sixty percent of the year's average natural runoff at every station on the main stream occurs during the flood season from July to October. The peak discharge is large and falls sharply during the flood season whereas the discharge is small during the dry season and variation is limited. Besides this seasonal dimension to the variation, there is also a large year-to-year variations in total runoff. Irrigated agriculture is the major consumer of water from the river, using up nearly 78 percent of the total water use (Jianzhong et al. 2009). Water is therefore a highly valuable resource and no analysis of poverty in the region can be complete without analyzing it in the context of the availability of water.

At the outset, it is important to note that we had serious data limitations in analyzing water-related poverty for the YRB. An analysis of water-related poverty would typically involve the use of data from a survey specially designed to collect water-related information from households and communities. However, the partial HIES data set provided to us had only three water-related variables: amount of land irrigated at the village level; access to safe drinking water; and amount of land irrigated by electric tubewell at the household level. We supplemented the household survey data with annual average rainfall data to assess water availability.

We proceed with an analysis of the relation between water and poverty in the YRB in the following sections. We used the variables on the level of surface water irrigation coverage in a village and the use of electric tubewells for irrigation by households living in the village to disaggregate the analysis by irrigated and non-irrigated villages. A village without any surface water irrigation coverage and without any use of electric tubewells for irrigation is considered a non-irrigated village. We also classified households by poor and nonpoor in irrigated and non-irrigated villages.

Water from the YRB is primarily used for irrigation purposes. Nearly 80 percent of the run-off is used for irrigation (Jianzhong et al. 2009). Yet, 65 percent of the surveyed households reported to be living in villages without any irrigation and the average irrigation coverage is only 24 percent. Agriculture is the primary source of livelihood for the majority of the rural households in the basin with crop production contributing to 43 percent of total household income. Water availability is therefore of critical importance from a livelihood perspective. Poverty in the YRB, therefore, is likely to be highly interlinked with water poverty (here, through lack of access to water for crop production). Water requirements for agriculture can either be met through rainfall or through irrigation or both. Our descriptive analyses of water-related poverty below take into account both irrigation and rainfall as water source.

Household Demography

Table 2.4.4 shows the average household size, composition, and dependency ratios for poor and nonpoor households living in irrigated and non-irrigated villages. The overall average household size in the YRB is 4.4 (not shown in the table). Poorer households tend to be relatively larger; and households in non-irrigated villages are slightly larger than those in irrigated villages. On average in the YRB (not shown in the table), households have 2.9 adults of working age (16–60 years), 0.3 children under age 6, 0.9 children between the ages of 7 and 14 years, and only 0.3 elderly persons above 60 years. The household composition has similar patterns across irrigated and non-irrigated villages.

Table 2.4.4 Household demography

Description	Households living in irrigated villages			Households living in Non-irrigated villages		
	Poor	**Nonpoor**	**All**	**Poor**	**Nonpoor**	**All**
Household size (number)	4.8	4.1	4.3	5.1	4.4	4.7
Less than 6 years (number)	0.4	0.2	0.3	0.4	0.3	0.3
7-15 years (number)	1.1	0.8	0.9	1.2	0.9	1.0
16-60 years (number)	3.0	2.8	2.9	3.1	2.9	3.0
More than 60 years (number)	0.3	0.2	0.3	0.4	0.3	0.3
Dependency ratio (percent)	71	57	59	80	60	69
Family Structure:			**(percent)**			
Bachelordom or couple only	2.2	5.8	5.1	1.3	4.4	3.1
Couple and one child	8.4	18.5	16.5	6.6	14.9	11.4
Couple and two children	28.0	35.2	33.8	24.4	27.5	26.2
Couple and three or more children	22.6	15.6	17.0	27.5	22.8	24.7
Single parent and children	2.5	1.6	1.8	1.5	1.9	1.8
Family with three generations	29.2	19.5	21.4	32.5	22.6	26.7
Other	6.9	3.7	4.3	6.3	5.9	6.1
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.
Note: Dependency ratio = Number of members aged below 15 and over 60 / Number of members aged 15-60.

The total dependency ratio is defined as the ratio of the number of members in the age groups 0–14 years and above 60 years to the number of members of working age (15–60 years). The ratio is expressed as a percentage. Poor households tend to have higher dependency ratios. This indicates that adult members of working age in poor households have more people to support than those in nonpoor households. Households living in non-irrigated areas have higher dependency ratios than households living in irrigated areas. The dependency ratio is 71 percent for the poor in irrigated villages and 80 percent for the poor in non-irrigated villages. The dependency ratios for nonpoor households are 57 percent and 60 percent, respectively, in irrigated and non-irrigated villages.

There are stark differences in family structures between the poor and the nonpoor. For example, 8.4 percent of the poor families in irrigated villages have their family composed of a couple with one child. The figure is 18.5 percent for the nonpoor families.

Education

Education is a prerequisite for poverty alleviation. Providing universal, high-quality education contributes significantly to poverty reduction and promotes economic growth in developing countries. At the individual level, every additional year of education increases a person’s potential for a better life in the future.

Figure 2.4.6 shows the net enrollment rates in school for children aged 7 to 15 years.[3] The results disaggregated by irrigated and non-irrigated villages suggest that enrollment rates are higher in irrigated villages than those in non-irrigated villages, and that the rates are lower for children from poor households than those from nonpoor households. However, the gap in school enrollment between the poor and the nonpoor is smaller in irrigated villages than that in non-irrigated villages. In non-irrigated villages, the net enrollment rate for children from nonpoor households is 4.4 percentage points higher than those from poor households. This difference is 2.0 percentage points in irrigated villages. However, the overall school enrollment rate in China (and in the YRB) is higher than in most developing countries.

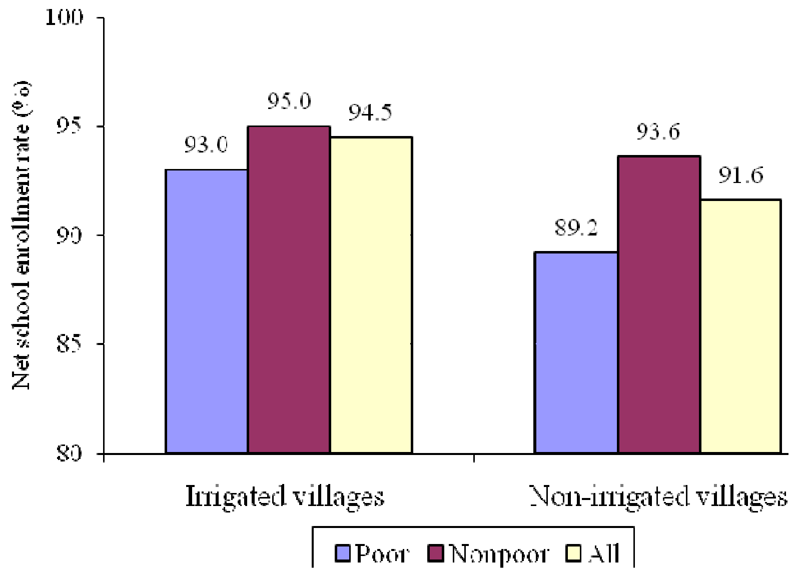

Figure 2.4.6: Net school enrollment rate, children aged 7-15

Table 2.4.5 reports the levels of illiteracy and education attainment of the labor force in the YRB, by poor and nonpoor and irrigated and non-irrigated villages. The rate of illiteracy is considerably higher for households living in non-irrigated villages than those living in irrigated villages. The gap in literacy between the poor and the nonpoor is also large, with poor households living in non-irrigated villages having the lowest literacy levels—about one-fourth of them are illiterate or semi-literate.

[3] Net enrollment rate (NER) = (All school-going children aged 7-15 years old / all children aged 7-15 years in the sample) * 100. The data set does not provide disaggregated information by primary and secondary school-going children.

Table 2.4.5. Education of labor force

Description	Households living in irrigated villages			Households living in non-irrigated villages		
	Poor	Nonpoor	All	Poor	Nonpoor	All
			(percent)			
Illiterate and semi-literate	13.7	7.2	8.4	25.8	13.1	18.4
Completed primary	25.0	24.2	24.3	32.5	27.7	29.7
Completed junior secondary	49.9	53.3	52.7	32.7	45.7	40.3
Completed senior secondary	10.4	13.2	12.6	8.1	11.3	9.9
Completed specialized secondary	0.9	1.8	1.6	0.6	1.8	1.3
College education of above 3 years	0.1	0.4	0.3	0.2	0.4	0.3

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

The patterns of schooling are very similar in nature. The differences in schooling between the irrigated and non-irrigated villages are quite remarkable. For example, while about half of the poor households in irrigated villages completed their junior secondary school, only one-third of the poor in non-irrigated villages attained that level of education.

<u>Employment</u>

Table 2.4.6 presents the employment status of sample households by various sectors in the YRB. Among the eight categories, considerable differences in employment are noticed in mining and manufacturing sectors— across irrigated and non-irrigated villages and also across the poor and the nonpoor. While only 1.7 percent of the sample households living in irrigated villages have mining workers as a household member, this rate is 6.4 percent in non-irrigated villages. By contrast, relatively more people work in the manufacturing sector in irrigated villages than in non-irrigated villages.

Table 2.4.6 Employment by sector

Description	Households living in irrigated villages			Households living in non-irrigated area villages		
	Poor	Nonpoor	All	Poor	Nonpoor	All
			(percent)			
Household has a farmer	96.3	94.4	94.7	96.6	94.5	95.4
Household has a mining worker	1.2	1.8	1.7	2.2	9.3	6.4
Household has a manufacturing worker	6.4	9.9	9.2	3.2	3.9	3.6
Household has a construction worker	7.5	8.4	8.2	11.3	8.3	9.6
Household has a wholesale trader	5.5	6.2	6.1	5.5	5.5	5.5
Household has a social service worker	3.7	5.3	5.0	4.6	5.6	5.2
Household has a government worker	1.3	1.2	1.2	0.3	1.7	1.1
Household has a worker of other occupation	17.7	17.9	17.9	11.5	17.5	15.0

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Budget Shares and Food Consumption

Table 2.4.7 shows that average monthly per capita consumption expenditure among households living in irrigated areas is 31 percent higher than that of households living in non-irrigated areas. While the average share of expenditure on food is higher in non-irrigated areas, the shares on other goods and services—clothing; housing; medical expenses; transport and communication; culture, education and recreation; and other services—are higher in irrigated villages.

Table 2.4.7 Household budget share

Description	Households living in irrigated villages			Households living in non-irrigated villages		
	Poor	Nonpoor	All	Poor	Nonpoor	All
Monthly per capita expenditure (yuan)	79	144	131	68	124	100
Budget share				(percent)		
Food	54.0	48.4	49.5	60.8	53.8	56.8
Clothing	7.4	7.9	7.8	6.2	8.1	7.3
Housing	10.1	12.7	12.1	10.3	11.2	10.8
Household facilities, articles and services	5.2	5.3	5.3	3.8	3.9	3.9
Medical	5.6	5.7	5.7	5.3	5.4	5.4
Transport and communication	4.1	6.0	5.6	2.8	4.5	3.8
Cultural, educational and recreational service	11.6	11.3	11.4	9.1	10.2	9.8
Other	2.1	2.8	2.6	1.7	2.8	2.3
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Table 2.4.8 shows the patterns of cash food expenditures in irrigated and non-irrigated areas by poor and nonpoor households. The monthly per capita cash food expenditure of households in irrigated areas is about 32 percent higher than that of households in non-irrigated areas. However, the share of expenditure on staple foods is higher for households in non-irrigated areas. The share of expenditure on most other food items is higher among the households in irrigated areas. Table 2.4.9 presents the information on the quantity of daily per capita food consumption, which is self-explanatory.

Ownership of Household Assets

Table 2.4.10 presents the ownership of some selected assets and equipment by the poor and nonpoor in irrigated and non-irrigated areas. In general, as expected, a greater proportion of households in irrigated areas own most of the assets and equipments. However, the only exceptions to this pattern are household ownership of draught animals, water heaters and heating equipment. The proportion of households that own a draught animal in non-irrigated villages is more than double than that in irrigated villages. This leads us to infer that crop production in irrigated areas is likely to be more mechanized and input intensive as compared to non-irrigated areas. Further, a considerably greater proportion of households in non-irrigated households own heating equipment and a similar proportion own water heaters while a much larger proportion of irrigated households, both poor and nonpoor, have fans in their homes. This pattern indicates that households in irrigated areas are mostly located in warmer regions while non-irrigated areas are more concentrated in the colder climatic zones.

Table 2.4.8 Cash food expenditure and food budget share

Description	Households living in irrigated villages			Households living in non-irrigated villages		
	Poor	**Nonpoor**	**All**	**Poor**	**Nonpoor**	**All**
Monthly per capita cash food expenditure (yuan)	18.5	35.4	32.1	15.6	30.7	24.4
Food budget share (cash only)			(percent)			
Staple foods	16.3	10.2	11.4	21.9	17.4	19.3
Vegetables	9.1	9.0	9.0	9.0	8.1	8.5
Pulses	1.3	1.2	1.2	1.3	1.3	1.3
Oils	7.8	6.8	7.0	5.0	4.5	4.7
Sugar	2.0	1.6	1.7	1.7	1.7	1.7
Meats and poultry	12.7	15.5	15.0	8.5	11.8	10.4
Eggs	2.8	3.8	3.6	1.1	1.7	1.4
Fish	0.5	1.5	1.3	0.2	0.6	0.5
Condiments	7.4	5.5	5.9	8.0	6.1	6.9
Tobacco	11.4	12.0	11.9	14.4	15.8	15.2
Wine	6.0	6.9	6.7	6.0	7.5	6.9
Other beverages	2.5	1.8	2.0	5.0	3.1	3.9
Dried fruits	3.6	4.6	4.4	3.3	3.4	3.4
Milk and milk products	1.1	1.0	1.0	1.1	1.0	1.0
Other prepared foods	15.4	18.5	17.9	13.3	16.0	14.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Table 2.4.9 Quantity of daily per capita consumption of food items

Description	Households living in irrigated villages			Households living in non-irrigated villages		
	Poor	**Nonpoor**	**All**	**Poor**	**Nonpoor**	**All**
				(grams/person/day)		
Wheat	443	510	497	464	508	489
Rice	38	53	50	17	41	31
Maize	38	54	51	28	49	40
Potatoes	29	25	26	44	47	46
Pulses	8	10	10	10	12	11
Vegetables	140	234	216	92	161	132
Condiment	3	7	6	3	5	4
Oils	19	18	18	16	21	19
Meats	21	38	35	19	31	26
Eggs	6	15	13	9	10	10
Milk	3	3	3	9	15	12
Fish	1	3	3	0	1	1
Sugar	3	4	4	2	3	3
Beverages	10	23	20	10	16	14
fruits	34	90	79	24	45	36
Other prepared food	3	6	5	2	4	3

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Poverty, Irrigation, and Access to Safe Drinking Water

Our estimates suggest that the PPP $1.25 a day headcount poverty rate is significantly lower in irrigated areas than that in non-irrigated areas of the YRB region: while 19.4 percent of all households living in irrigated villages are poor, the rate is more than double (41.4 percent) in non-irrigated villages.

Table 2.4.10 Ownership of selected assets and equipment

Asset	Households living in irrigated villages			Households living in non-irrigated villages		
	Poor	**Nonpoor**	**All**	**Poor**	**Nonpoor**	**All**
	(percent of households)					
Automobile	1.0	1.9	1.7	0.4	2.9	1.9
Small hand-held tractor	23.1	35.5	33.1	14.1	21.8	18.6
Water pump	14.1	24.3	22.3	6.6	8.3	7.6
Draught animal	26.5	22.1	22.9	60.5	50.0	54.4
Productive cattle	13.2	18.6	17.5	19.6	20.1	19.9
Sanitation equipment	83.5	88.9	87.8	86.3	84.5	85.2
Heating equipment	73.8	66.8	68.2	87.3	80.2	83.2
Washing machine	24.9	40.3	37.3	10.6	26.9	20.1
Electric fan	36.3	61.3	56.4	9.0	26.3	19.0
						(cont.)
Refrigerator	4.9	10.3	9.3	1.0	7.5	4.8
Air conditioner	0.4	0.4	0.4	0.0	0.0	0.0
Microwave oven	0.0	0.3	0.2	0.0	0.1	0.1
Water heater	0.7	2.5	2.2	1.0	3.3	2.3
Bicycle	79.8	89.7	87.8	63.2	64.9	64.2
Land-line phone	19.8	32.1	29.7	8.1	19.8	14.9
Mobile phone	1.6	4.0	3.5	0.6	2.5	1.7
Color television	46.9	59.0	56.7	30.7	53.8	44.1
Computer	0.0	0.1	0.1	0.0	0.3	0.2

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

When the poverty rate is disaggregated at the province level, we observe a strong and negative correlation between poverty and the share of population living in irrigated villages. Figure 2.4.7 shows this relationship—the nonpoor are more concentrated in irrigated villages. Shandong, Inner Mongolia and Henan, respectively, are the provinces where the proportion of population living in irrigated villages is the highest, second highest and third highest. These are also the provinces with the lowest, second lowest and third lowest levels of poverty, respectively. On the other hand, Gansu and Qinghai are provinces with the lowest share of population living in irrigated villages and also the highest levels of poverty among the nine provinces belonging to the YRB.

Irrigated villages have better access to safe drinking water in the YRB. Figure 5.8 shows that the difference in household access to safe drinking water is large between irrigated and non-irrigated villages. The figure also shows that nonpoor households have greater access to safe drinking water than poor households have, but the poor-nonpoor gap in access is larger in non-irrigated villages. While the difference in access to safe drinking water between poor and nonpoor is 15.5 percentage points in non-irrigated villages, it is only 3.1 percentage points in irrigated villages.

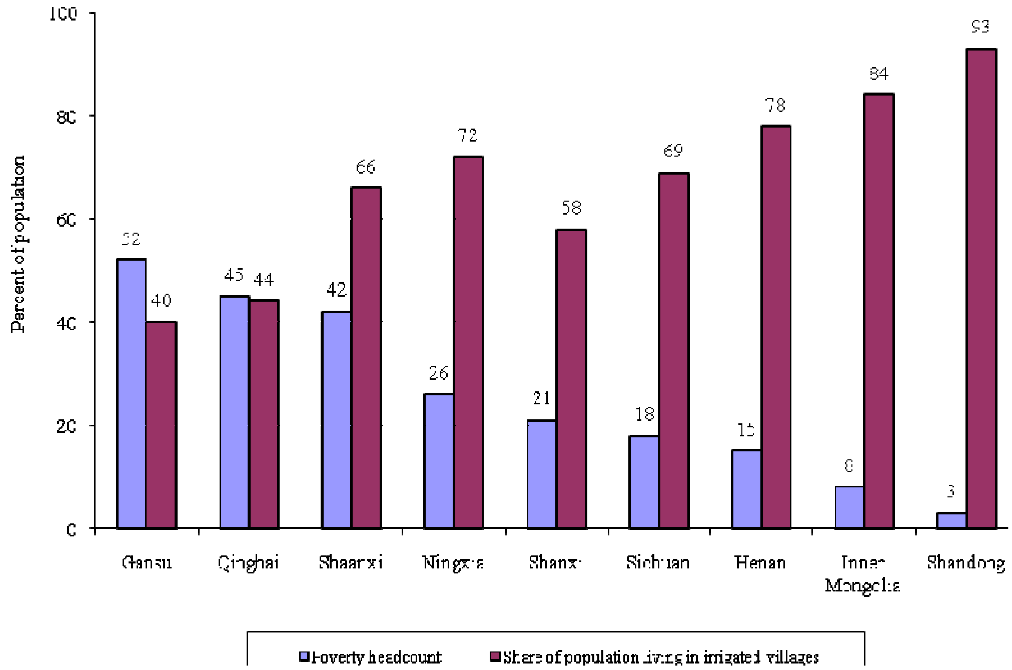

Figure 2.4.7: Headcount poverty and share of population living in irrigated villages

Figure 2.4.9 shows that poverty and proportion of population having access to safe drinking water are negatively correlated at the province level. However, the relationship is not as strong as it is between poverty and people living in irrigated villages as shown in Figure 5.7.

<u>Regional Dimensions of Water and Poverty</u>

Earlier, we had found that poverty is concentrated in the mountain region of the YRB, and that people living in the plain land region are better off. Here, we examine whether there is convergence between income poverty (lack of money) and water poverty (lack of water). We look at the regional distribution of rainfall and irrigation—the two sources of water for agricultural production.

Figure 2.4.10 shows that mountain regions in the YRB have the lowest annual average rainfall (454 mm) followed closely by hill villages (460 mm). Plain land villages receive considerably higher levels of rainfall (549 mm), 21 percent more rainfall than mountain villages.

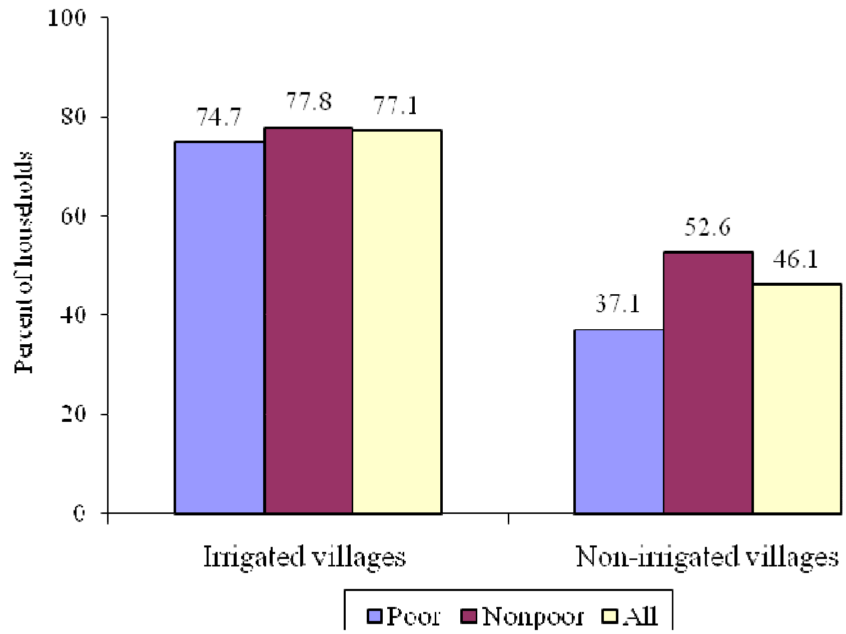

Figure 2.4.8: Access to safe drinking water

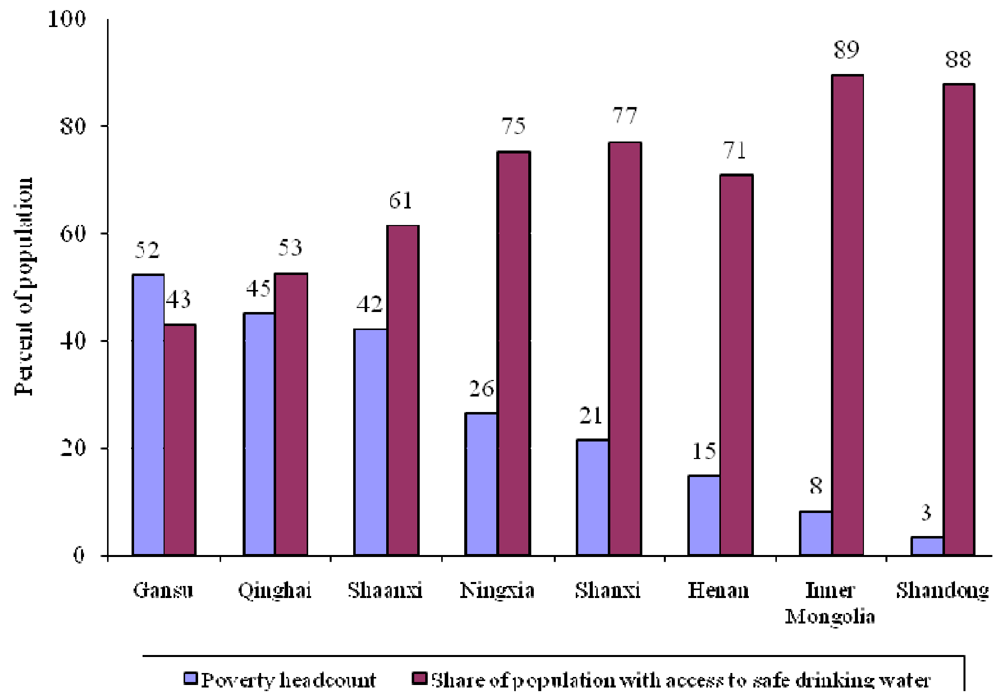

Figure 2.4.9: Headcount poverty and share of population with access to safe drinking water

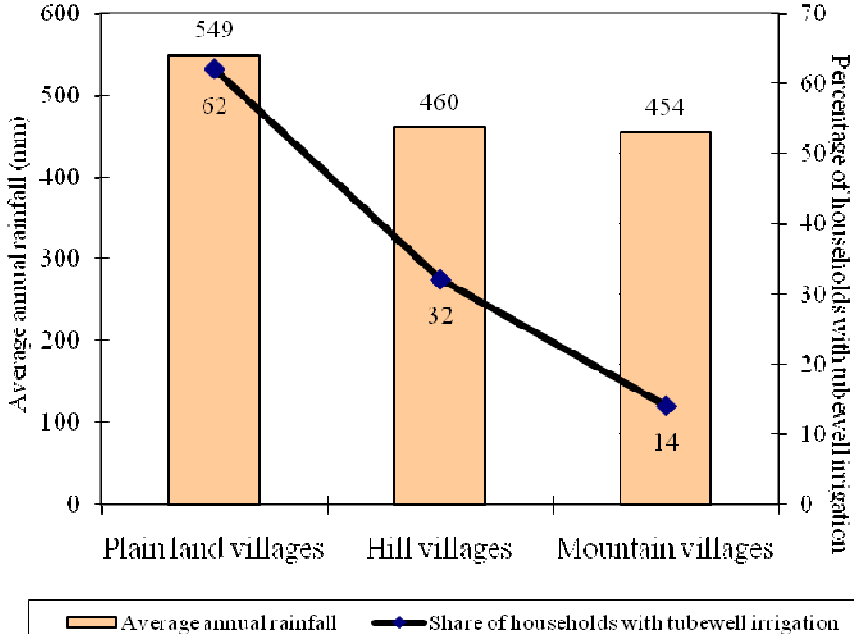

Figure 2.4.10: Regional patterns of rainfall and tubewell irrigation

The regional distribution of irrigation coverage, measured by percentage of households who used tubewell irrigation for cultivation, is even more skewed in favor of plain land villages. As Figure 2.4.10 shows, 62 percent of households in plain land villages had used electric tubewells for irrigation. By contrast, only 32 percent households in hill villages and 14 percent households in mountain villages had access to tubewells for irrigation.

These results, in combination *with earlier* findings, reveal a clear convergence of water poverty and economic poverty—both being concentrated in the mountain regions, less so in the hill regions and least in the plain land regions.

We now look at the interaction between poverty and levels of average rainfall within these three geographical regions. Figure 2.4.11 shows that, in the mountain region where the overall level of rainfall is low, the average annual rainfall experienced by poor and nonpoor households is somewhat similar. However, in the hill villages, there is a large difference in the amount of rainfall received by poor and nonpoor households—poor households are concentrated in low-rainfall villages. On the other hand, in the plain land region, poor households live in villages with relatively higher rainfall levels than nonpoor households do. These results indicate that higher levels of rainfall have beneficial effects in the hill region, but adverse economic effects in the plain land region.

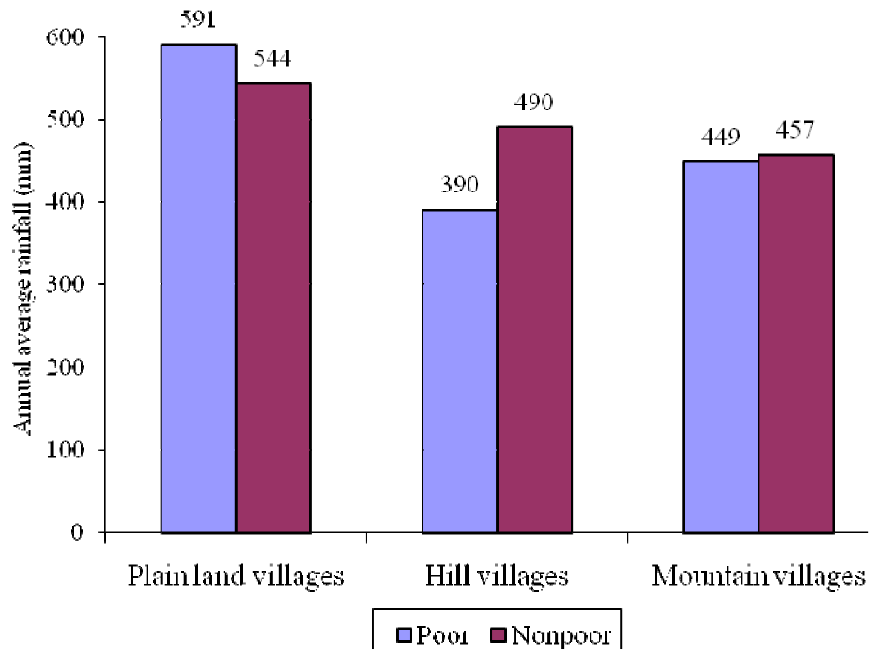

Figure 2.4.11: Regional variations in rainfall and poverty

Water Productivity

The productivity of water denotes the contribution water in improving crop yields (that is, amount of crop output per unit of sown land). We look at the effects of two sources of water on crop yields—rainfall and irrigation.

Rainfall and Crop Productivity

Wheat is the most common crop grown by farmers in the YRB, followed by maize. About 80 percent of the sample households grew wheat, and wheat cultivation accounted for 48 percent of crop land on average. Maize is the second most common crop, grown by 65 percent of the households in the YRB. However, very few farmers—only 8 percent of the YRB households—grew rice. Because of the dominance of wheat and maize in the YRB agricultural sector, we consider the yields of wheat and maize to examine the relationship between annual average rainfall and crop yields.

Figure 2.4.12 shows that crop yields are highest in the lowest rainfall quintile. The yields drop sharply for villages belonging to the second rainfall quintile and then rise with increases in rainfall. The highest crop productivity in the lowest rainfall area might appear counterintuitive.

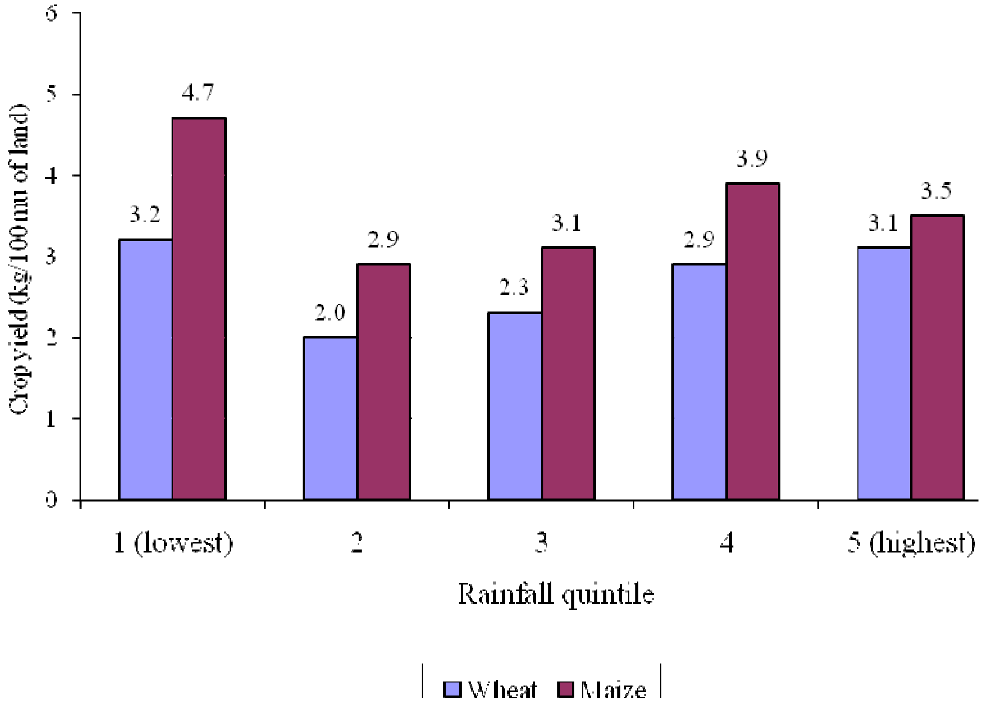

Figure 2.4.12: Crop yields by rainfall quintile

However, the apparent puzzle becomes clear when we look at irrigation coverage in conjunction with rainfall. Figure 2.4.13 shows the distribution of village-level irrigation coverage of total cultivated land by rainfall quintile. The pattern in Figure 2.4.13 matches the one in Figure 2.4.12—villages belonging to the lowest rainfall quintile also have the maximum irrigation coverage in the YRB. The results presented in the two figures indicate that the productivity of irrigation water is optimum in areas with the least amount of rainfall in the YRB region.

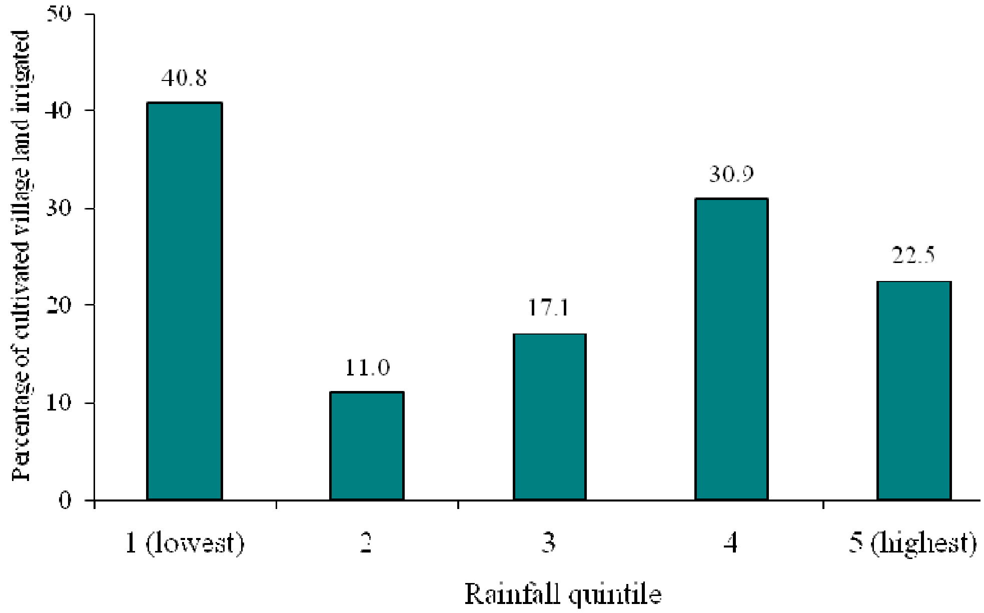

Figure 2.4.13: Distribution of irrigation coverage by rainfall quintile

Irrigation and Crop Productivity

The relationship between crop yields and irrigation coverage is direct and instantly recognizable. Higher irrigation coverage of cultivated land at the village level is associated with greater crop productivity (Figure 2.4.14). Wheat yield increases by 32 percent from the lowest to the highest irrigation quintiles. Maize yield appears to be even more responsive to irrigation—the yield increases from 4.2 kg/ha in the first irrigation quintile to 6.9 kg/ha in the fifth quintile—64 percent increase from the lowest to the highest quintiles. Figure 2.4.15 shows that yields of various crops grown in the YRB are substantially higher in irrigated villages than those in non-irrigated villages.

Irrigation induces technology adoption in crop production. Figure 2.4.16 shows that the shares of land under high-yielding varieties (HYVs) of wheat and maize crops increase significantly with increased coverage of irrigated land. For instance, the HYV share in wheat cultivation increases by 34 percentage points from 42 percent in the lowest irrigation quintile to 76 percent in the highest irrigation quintile.

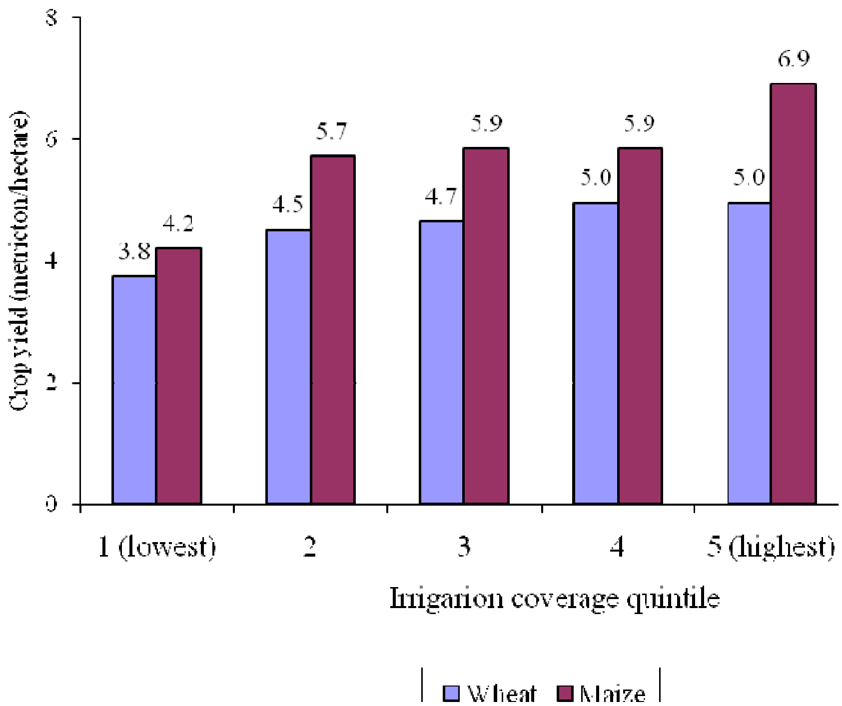

Figure 2.4.14: Crop yields by irrigation coverage quintile

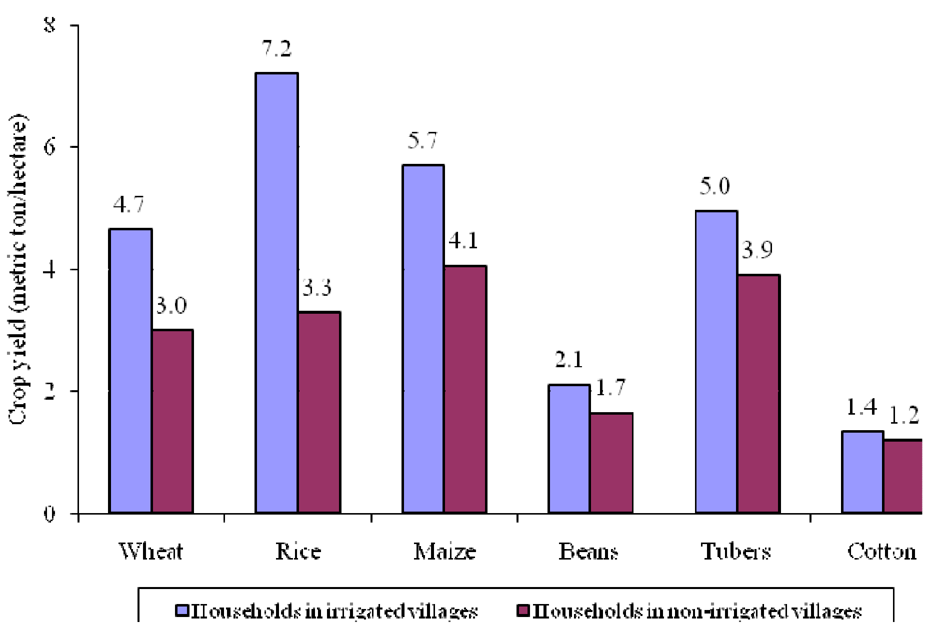

Figure 2.4.15: Crop yields by irrigated and non-irrigated villages

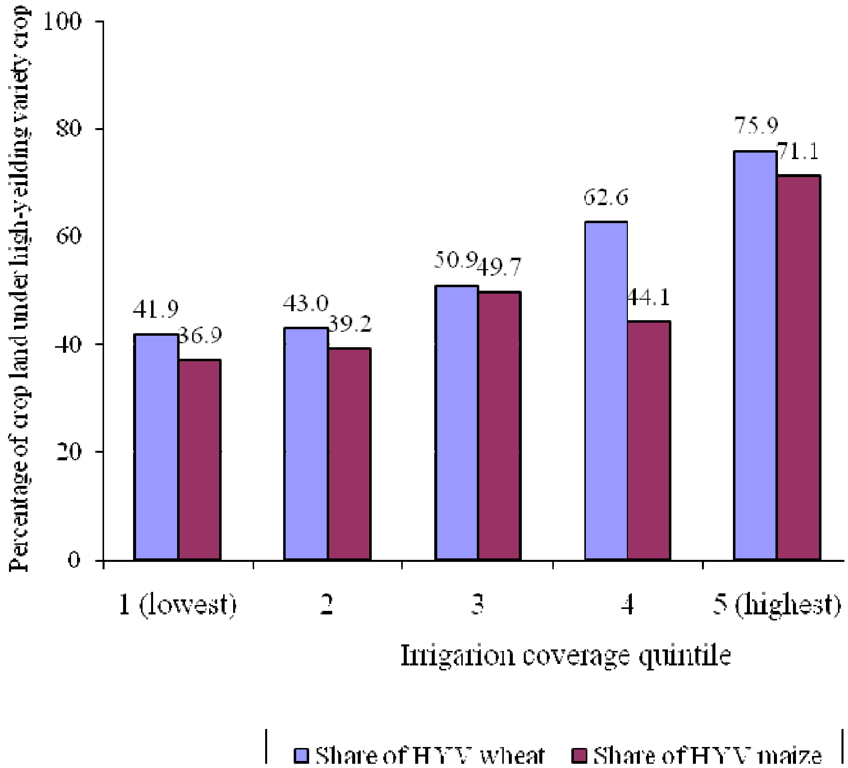

Figure 2.4.16: Adoption of high-yielding varieties by irrigation coverage quintile

Crop yields of poor households are however considerably less than those of nonpoor households. Figure 2.4.17 shows that, even within irrigated villages, there are large differences in crop yields between the poor and the nonpoor households. These differences arise mainly because the poor are less able to make the investments needed for yield improvement, such as investments on irrigation, fertilizers, high quality seeds, or improved pest management.

Variation in Crop Yields

Low level of yield variability encourages farmers to adopt improved technology in crop production. Figure 2.4.18 shows that the variation in crop yields across households living in irrigated villages is much less than that of households living in non-irrigated villages, except tubers. For instance, the coefficient of variation of wheat yields is 35.6 percent in irrigated areas versus 54.8 percent in non-irrigated areas. Thus, irrigation leads to more uniform crop yields across farms.

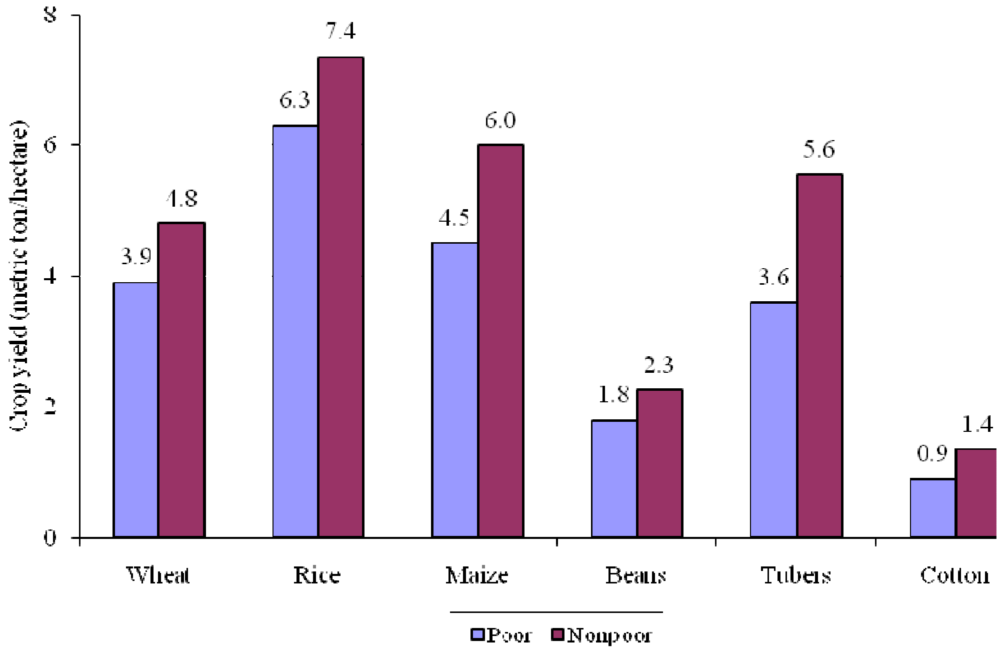

Figure 2.4.17: Crop yields among poor and nonpoor households in irrigated villages

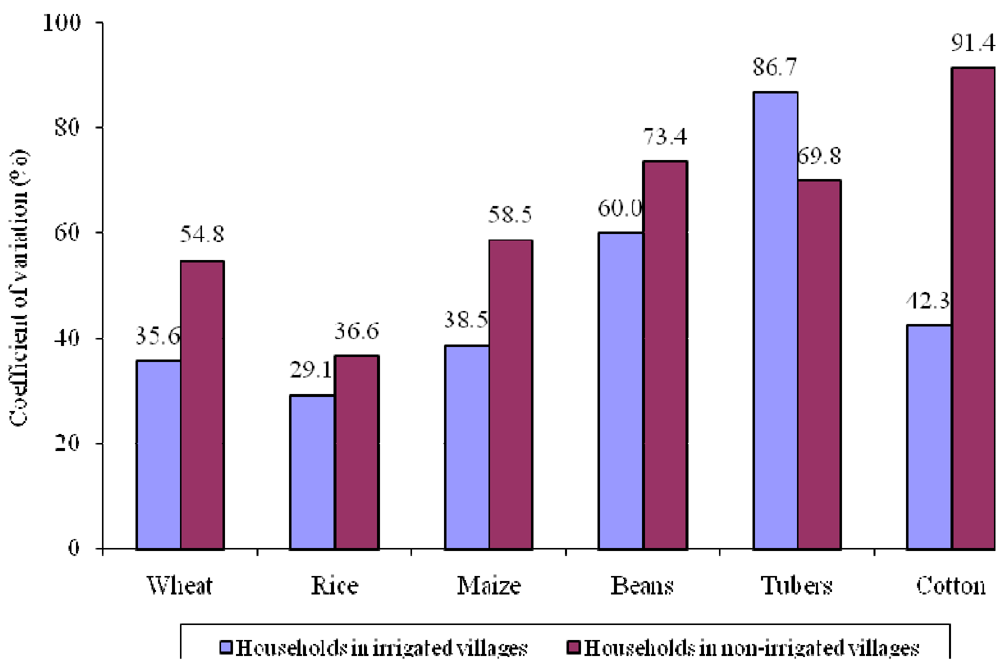

Figure 2.4.18: Variation in crop yields by irrigated and non-irrigated villages

Figure 2.4.19 suggests that, the variation in yields is less for poor households living in irrigated villages than that for poor households living in non-irrigated villages. A similar pattern holds for nonpoor households in irrigated and non-irrigated villages. However, within irrigated and non-irrigated villages, the variation in yields is higher for poor than nonpoor households. It is likely that many poor households living in irrigated villages may not have access to irrigation. However, data limitations do not allow us to confirm this assumption.

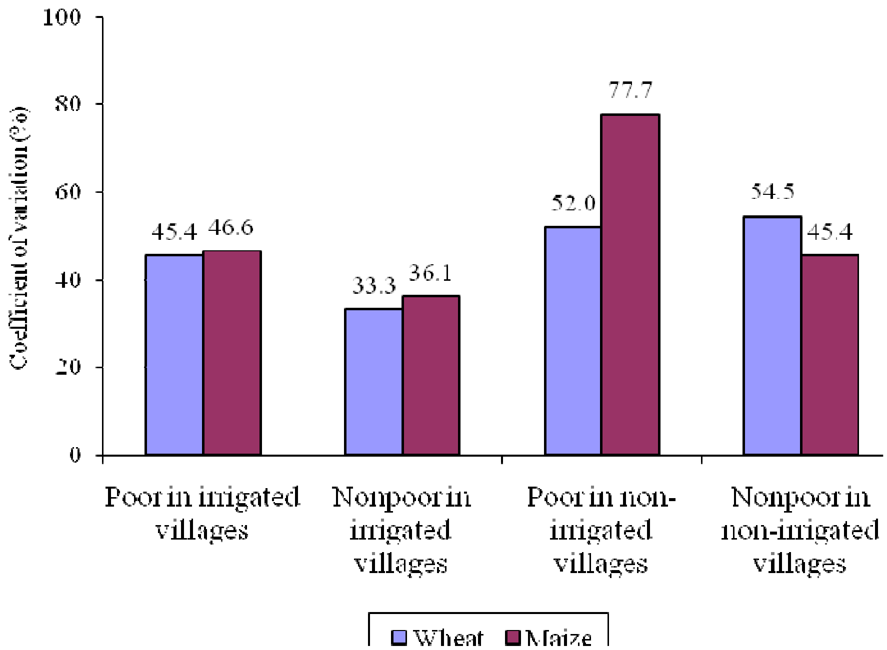

Figure 2.4.19: Variation in crop yields among poor and nonpoor households

<u>Water and Poverty in Upstream, Midstream, and Downstream Areas of the YRB</u>

Table 2.4.11 shows selected welfare indicators of households living in different segments of the Yellow river flow, that is, households belonging to 'upstream', 'midstream' and 'downstream' areas of the YRB. Households in the upstream area have, on average, the lowest levels of wellbeing followed by those in the midstream area. Households in the downstream area enjoy the highest level of economic attainments. This is true for most of the welfare indicators such as the incidence of poverty, per capita income, irrigation coverage, and crop yields.

Table 2.4.11 Profile of households in upstream, midstream, and downstream areas of the YRB

	Location of households			
	Upstream	**Midstream**	**Downstream**	**All**
Poverty headcount rate—living on less than $1.25 a day (%)	47.5	29.6	9.9	30.5
Average per capita income (yuan/person/year)	1,851	2,802	3,536	2,732
Village-level surface water irrigation coverage of cultivated land (%)	8.8	30.6	21.8	23.2
Percentage of households having land under tubewell irrigation	19.5	30.3	69.8	36.8
Average annual rainfall (mm)	447	480	663	507
Wheat yields (metric ton/hectare)	3.8	3.8	5.3	4.2
Variation in wheat yields (%)	42.7	50.7	25.1	43.4
Maize yields (metric ton/hectare)	5.0	5.2	5.8	5.3
Variation in maize yields (%)	55.0	48.8	30.3	44.6

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

The $1.25 a day poverty headcount ratio shows stark differences across the three areas. The poverty rate in the upstream area (47.5 percent) is nearly five times higher than that in the downstream area (only 9.9 percent), while the rate in the midstream area (29.6 percent) is three times higher. This pattern is quite similar to that observed in mountain, hill, and plain-land regions of the YRB.

The differences in per capita income, though considerable, are not as remarkable as the differences in the poverty rate. The average per capita income of households living in the downstream area is 91 percent and 26 percent higher than the average per capita incomes of those living in the upstream and the midstream areas, respectively.

Next, we look at the relationships between the availability and use of water for irrigation, and indicators of economic wellbeing in upstream, midstream and downstream areas. Water availability and use near the lower reaches of the Yellow river are much higher than those in the upper reaches as the average rainfall and irrigation data reflect.

Rainfall in the downstream area is 48 percent and 38 percent higher than that in the upstream and midstream areas, respectively. The differences in the use of electric tubewell irrigation are even larger between the three areas. The percentage of households using electric tubewells for irrigation increases considerably from upstream to midstream areas, and increases dramatically from midstream to downstream areas. While only 20 percent of the households use tubewell irrigation in the upstream area, the rate of use is 30 percent in the midstream area and as high as 70 percent in the downstream area. However, village level coverage of surface-water irrigation reveals a rather different pattern with the largest share of cultivated land being irrigated in the midstream area. The patterns of the surface water irrigation coverage and the use of electric tubewells for irrigation suggest that households living in the downstream area rely mostly on groundwater for irrigating their crops, probably due to the lack of surface water availability from the Yellow river.

The combination of higher rainfall and irrigation use—particularly, the extensive use of tubewell irrigation—seem to contribute to higher crop productivity, and hence, increased income of the households living in the downstream area. As evidenced from the data in Table 5.11, not only are the yields of wheat and maize (the two most important crops grown in the YRB region) much higher, but also the variability in the yields across households is significantly lower in the downstream area compared to the upstream and midstream areas.

However, the higher incidence of irrigation in the midstream area compared to the upstream area does not translate into higher crop productivity and lower yield variability. A possible explanation could be the fact that there is not much difference in rainfall between these two locations. The average rainfall in the upstream and the midstream areas is about 30 percent lower than the average rainfall in the downstream area. Topographical factors may also play a role in this regard.

- *Determinants of poverty*

The water-related poverty profile of the YRB in the previous section provided tabulated and graphical information on the levels of poverty and inequality, and the characteristics of the poor in the context of water availability and access. The findings of the descriptive analysis provide us with important clues to the underlying determinants of poverty. However, the bivariate nature of the informational content of the profile did not isolate the effect of a particular variable on poverty from other confounding factors. In this section, we have extended the descriptive analysis of the profile by modeling the determinants of poverty through multivariate analysis to addresses the question of what causes poverty in the rural YRB, with particular emphasis on water and agriculture.

Selecting Explanatory Variables

In selecting among potential determinants of poverty, we were careful in choosing the explanatory variables that are most likely to be exogenous to current income or poverty. For instance, we did not include household assets (except for land) and dwelling characteristics, because they are thought to be determined by household income or poverty status.

The selected variables can be classified into community- and household-level variables. Descriptive statistics of the dependent variable and the explanatory variables are provided in Table 2.4.12. In addition to these explanatory variables, we introduced province fixed effects in the model to control for potential omitted-variable bias. Since parts of 9 provinces belong to the YRB, we used a dummy variable for each of the 8 provinces, and one province was left out of the regression to serve as the point of reference.

Estimated Parameters of the Model

Table 2.4.13 presents the estimated parameters of the OLS regression model of the log of per capita income. The estimates show how closely each independent variable is related to per capita income (the dependent variable), holding all other influences constant. The interpretations of the key results are provided below.

Table 2.4.12 Descriptive statistics of dependent and explanatory variables

Variable name	Mean	Std. Dev.	Minimum	Maximum
Dependent variable				
Natural logarithm of per capita income in PPP dollar	4.00	0.628	0.56	6.81
Community (village) characteristics				
Share of total farm land under irrigation (percent)	23.18	31.052	0.00	100.00
Annual average rainfall (mm)	507.22	165.921	182.31	933.10
Dummy: Plain land village = 1	0.49	0.500	0.00	1.00
Dummy: Hilly village = 1	0.19	0.394	0.00	1.00
Dummy: Mountain village = 1	0.50	0.500	0.00	1.00
Dummy: Ethnic minority village = 1	0.12	0.326	0.00	1.00
Dummy: Village has paved road = 1	0.95	0.224	0.00	1.00
Distance to the nearest bus stop (km)	6.66	9.704	0.10	70.00
Distance to the nearest post office (km)	4.37	4.036	0.02	30.00
Household characteristics				
Household size	4.40	1.339	1.00	14.00
Household size, squared	21.18	13.728	1.00	196.00
Number of children below age 15	1.21	0.976	0.00	6.00
Number of persons above age 60	0.27	0.571	0.00	3.00
Dummy: Illiterate adult member = 1	0.25	0.434	0.00	1.00
Dummy: Adult with primary education = 1	0.51	0.500	0.00	1.00
Dummy: Adult with junior secondary education = 1	0.76	0.429	0.00	1.00
Dummy: Adult with senior secondary education = 1	0.24	0.429	0.00	1.00
Dummy: Adult with specialized secondary education = 1	0.04	0.198	0.00	1.00
Dummy: Adult with 3 years college education = 1	0.01	0.090	0.00	1.00
Share of non-farm income in total income (percent)	40.98	27.869	0.00	99.82
Owned cultivated land (ha)	0.73	0.789	0.00	10.00
Percentage of wheat land under HYV wheat	49.66	49.124	0.00	100.00
Dummy: Household has land under electric tubewell irrigation = 1	0.36	0.480	0.00	1.00
Percentage of total expenditure for food	33.41	13.285	2.90	85.00
Distance to primary school (km)	1.19	1.652	0.02	30.00
Distance to junior high school (km)	4.42	5.187	0.25	80.00

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Table 2.4.13 Determinants of income, OLS regression estimates

Description of variables	Coefficient	t-statistic	P>t
Community (village) characteristics			
Share of total farm land under irrigation (percent)	0.00733	4.31***	0.000
Annual average rainfall (mm)	-0.00334	-4.06***	0.000
Annual average rainfall, squared	0.000003	4.24***	0.000
Interaction effect: % irrigated land * average rainfall	-0.00001	-3.93***	0.000
Dummy: Plain land village = 1	0.11246	1.93*	0.056
Dummy: Hilly village = 1	-0.03105	-0.66	0.507
Dummy: Mountain village = 1	0.01552	0.25	0.800
Dummy: Ethnic minority village = 1	-0.19774	-3.06***	0.002
Dummy: Village has paved road = 1	0.11730	2.20**	0.029
Distance to the nearest bus stop (km)	-0.00124	-0.69	0.492
Distance to the nearest post office (km)	0.00397	0.84	0.403
Household characteristics			
Household size	-0.23999	-6.54***	0.000
Household size, squared	0.01451	3.90***	0.000
Number of children below age 15	-0.05217	-5.01***	0.000
Number of persons above age 60	0.00704	0.56	0.579
Dummy: Illiterate adult member = 1	-0.06266	-2.53**	0.012
Dummy: Adult with primary education = 1	0.00898	0.51	0.609
Dummy: Adult with junior secondary education = 1	0.05695	2.83***	0.005
Dummy: Adult with senior secondary education = 1	0.09483	4.75***	0.000
Dummy: Adult with specialized secondary education = 1	0.05739	1.45	0.150
Dummy: Adult with 3 years college education = 1	0.08001	1.12	0.266
Share of non-farm income in total income (percent)	0.00364	6.74***	0.000
Owned cultivated land (ha)	0.05016	2.01**	0.046
Percentage of wheat land under HYV wheat	0.00015	0.45	0.654
Dummy: Household has land under tubewell irrigation = 1	0.05906	1.73*	0.086
Percentage of total expenditure for food	-0.01600	-17.56***	0.000
Distance to primary school (km)	0.04012	1.60	0.112
Distance to Junior high school (km)	0.00013	0.03	0.974
Location (province) dummy	Yes		
Constant	5.62833	20.28***	0.000
Number of observations	3,646		
F-statistic	42.43***		
Adjusted R-squared	0.56		

Source: Calculated by authors using data from the 2001 Household Income and Expenditure Survey, National Bureau of Statistics, Peoples Republic of China.

Notes: Dependent variable is natural logarithm of per capita PPP dollar per month. The standard errors are corrected for sampling effects by estimating the equation using the 'svyreg' command of the Stata statistical software. Significance levels: * significant at the 10 percent level; ** significant at the 5 percent level; *** significant at the 1 percent level.

Community-Level Irrigation and Rainfall

As mentioned earlier, the 2001 HIES data used for our analysis came from rural areas of the YRB. From the village-level data, we calculated the share of irrigated land in a village as the area under effective irrigation divided by total cultivated land area in that village.

The coefficient of this variable has the expected positive sign and is statistically significant at the 99 percent level.

The income elasticity with respect to the share of irrigated land in total cultivated land area in a village is 0.17 at sample mean. Thus, a 10-percent increase in the village-level irrigation coverage increases per capita income of households living in that village by 1.7 percent on average. The effect of village-level irrigation coverage on poverty is provided in the simulation analysis below.

Besides irrigation, rainfall is a critical source of water for agricultural production in a rural community, affecting income of the households living in the community. Rainfall may also have effects on living standards of people through other ways. In our model, the annual rainfall variable denotes 50-year average rainfall (in millimeter) at the community level. We have also added an interaction term to the model to incorporate the joint effect of the two water-related variables (rainfall and irrigation) on income, over and above their separate effects.

The coefficient estimates of both the linear and the squared rainfall variables are statistically significant. The linear term has a negative coefficient while the squared rainfall variable has a positive sign, yielding a U-shaped relationship between rainfall and income. This relationship implies that a marginal increase in rainfall actually decreases household income in low-rainfall villages, and the marginal effect becomes positive beyond a critical level of rainfall. This critical level of rainfall is 492 mm per year—about 3 percent lower than the average annual rainfall of 507 mm in the YRB region.[4] These results might appear counterintuitive if interpreted without taking into account the moderator effects of the interaction between rainfall and irrigation.

The interpretation of the interaction term in conjunction with the net effects of rainfall greatly expands the understanding of the relationships between rainfall, irrigation and income. The interaction term between irrigation coverage and average annual rainfall is statistically significant and has a negative sign, suggesting that the combined effect of interaction between the two sources of water dampens their individual effects. This result, in combination with the negative linear term and the quadratic positive term of the rainfall variable suggest that irrigation yields a higher return at the margin in relatively low-rainfall communities. However, the marginal return to irrigation is lower in relatively high-rainfall communities of the YRB, above a certain level (that is, communities with annual rainfall greater than 492 mm).

<u>Other Community-Level Characteristics</u>

Among the community-level variables, living in plain-land villages and villages with paved roads in the YRB boost per capita income, as the statistically significant coefficients of these variables suggests. However, the effects of living in hilly or mountain villages on income turn out to be statistically insignificant. The coefficient of the ethnic minority village is statistically significant at the 99 percent level with a negative sign. This result indicates that the ethnic minority group is relatively poorer than the general population in the YRB.

<u>Household-Level Characteristics</u>

Demographic Factors

Household size and composition have poverty implications. Household size has a significant negative effect on its living standards—as household size increases, per capita income decreases. This inverse relationship implies that poorer households tend to be larger, which is a common finding in other developing countries. However, the quadratic

[4] Differentiating the income function with respect to rainfall amount (R), setting it to zero, and solving for R gives the critical value of 453 mm of annual rainfall.

term is significant and positive, which implies that, the relationship between household size and per capita income turns positive when the household size crosses a critical number. This turning point is estimated at 8 persons. These results are an indication of economies of household size in living standards.

The poor also tend to live in younger households. The number of children under 15 has a significant negative effect on household income.

Education

Literacy and schooling are important determinants of people's ability to take advantage of income-earning opportunities. A household with an illiterate adult member has a statistically significant negative effect on income per capita.[5] Households with an adult member who completed junior secondary education or senior secondary education both have significant positive effects on household living standards, as measured by household income per person.

Non-Farm Income

We find that non-farm income as percentage of total household income has a statistically significant positive effect on household living standards. The income elasticity of non-farm income share at sample mean is 0.15. This estimate suggests that a 10 percent increase in the non-farm income share of rural households living in the YRB region leads to an increase in per capita household income by 1.5 percent on average. This largely reflects the underlying lower rate of return to agriculture compared to other sectors.

Agriculture

Cultivable land is a vital asset base of households living in rural areas. We find that owned cultivated land has a significant positive effect on per capita household income.

The household survey data set has information on farm land irrigated by electric tubewells. However, we could not construct a variable representing the share of cultivated land under tubewell irrigation, because the cropping intensity with tubewell irrigation was way above 100 percent as many farmers grew double or triple crops in a year on the same plot of land using tubewell irrigation. As an alternative, we used a dummy variable that takes the value of 1 if a household had any land under tubewell irrigation, zero otherwise. The coefficient of the tubewell irrigation variable is positive and statistically significant, suggesting that the use of tubewell irrigation increases per capita household income.

Wheat is the most common crop grown by farmers in the YRB. About 80 percent of the sample households grew wheat, half of all wheat land was under high-yielding variety (HYV), and wheat cultivation accounted for 48 percent of crop land on average. In our model, we used the share of HYV wheat in total land under wheat cultivation as an explanatory variable. Although the coefficient of the variable has a positive sign, it is not a statistically significant determinant of per capita household income.

Food Expenditure

We find that the share of food consumption expenditure in total household expenditure is negatively related to per capita income, and the relationship is statistically significant. As household income rises the share spent on food falls conforming to the Engelian relationships.

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[5] Our construction of the literacy and education variables was constrained by the type of data provided to us in the partial household survey data set. The only information available on literacy and education is "education of labor force." We used this information to create dummy variables that take the value of 1 if at least one adult person (that is, the labor force age of 16-60) in the household belonged to one of the literacy and education categories, zero otherwise. Thus, for example, if a household had one illiterate adult member and one adult member who completed primary education, then that household was considered twice in the model. However, such cases were quite small in number.

Poverty Simulations

We generated predictions of poverty from the estimated parameters of the income model for a set of selected determinant variables. Using the estimated parameters, we first predicted per capita income in PPP dollar for every household in the sample. Next, based on the predicted per capita income, we calculated the PPP $1.25 a day headcount poverty rate for the YRB as the base simulation. Finally, we re-estimated the headcount poverty rate separately for each of the four determinant variables by increasing the level of the variable by 10 percent.[6]

Table 2.4.14 presents the simulation results. Among the three determinant variables considered for simulations, the simulated impact of community-level irrigation coverage generates the largest reduction in poverty in the YRB—increasing irrigation coverage by 10 percent reduces the predicted value of poverty by 5.11 percent.

Non-farm incomes are an important determinant of poverty in the YRB. Simulation 2 suggests that, the headcount poverty rate is expected to decline by 4.52 percent if the share of non-farm income in total per capita household income increases by 10 percent.

In simulation 3, we examine the effect of increasing cultivated land area of households, a measure of expanding physical capital. The predicted result of this simulation is relatively modest—the percentage of rural population living in poverty would decline by 1.03 percent if cultivated landholdings were increased by 10 percent.

[6] The simulations assume that the considered changes in the determinant variables do not affect the model parameters of other explanatory variables, which is a plausible assumption for small changes.

Table 2.4.14 Poverty simulations

Description of simulation	Percentage change in	
	Per capita income	**$1.25 a day poverty headcount over base simulation**
1. Increase irrigation coverage at the village level (share of cultivated land irrigated) by 10 percent	1.69	-5.11
2. Increase the share of non-farm income in total per capita household income by 10 percent	1.49	-4.52
3. Increase cultivated land area of households by 10 percent	0.31	-1.03

Source: Calculated by authors using predicted values from the base model presented in Table 6.2.

2.4.3 Conclusion

In this study, we analyzed water-related poverty in the Yellow River Basin. The YRB is home to around 9 percent of China's population and accounts for 15 percent of the country's irrigated area. Shortage of water in this region is a major challenge for the livelihoods of many and for the economic development of the region as a whole.

We illustrated various approaches to study "water poverty" and "water-related poverty." The livelihoods approach offers ways to determine who the "water poor" are and how this state affects them. An alternative approach is to measure the relationship between water and income poverty. We followed the second approach, which involves a two-step analysis of poverty for the YRB—constructing a water-related poverty profile and assessing water and non-water determinants of income poverty.

The poverty situation in the YRB needs to be seen in the context of China's remarkable performance in poverty reduction. We looked into China's performance toward achieving the Millennium Development Goal (MDG) of poverty reduction; and analyzed poverty trends and how they relate to growth and inequality.

Economic reforms in China, begun after 1978, have generated significant and steady growth in investment, consumption and standards of living in the country. China has been the fastest-growing major economy in the world for the past 30 years with an average annual GDP growth rate of 9.7 percent from 1978 to 2007. China's impressive growth performance has been associated with dramatic reduction in poverty: the $1.25 a day headcount poverty rate fell from 84 percent in 1981 to only 16 percent in 2005. During this period, 538 million people have been lifted out of poverty, mainly benefiting from liberalization of agriculture and rural industries. The first MDG target is to reduce by half between 1990 and 2015 the proportion of people living in poverty and suffering from hunger. Indeed, China has over achieved the poverty MDG—in 2005, the $1.25 a day poverty rate in the country was only about one-fourth the rate in 1990.

During the 1999-2005 period, the elasticity of poverty reduction with respect to per capita GDP growth is estimated at -1.1; that is, 1 percent growth of GDP per capita resulted in 1.1 percent reduction in the number of the poor. The estimate for the growth-poverty elasticity for the 2002-2005 period is -1.6, indicating that for every 1 percent increase in GDP per capita, poverty reduced by 1.6 percent on average in the more recent years in China.

China's growth rates were high, but inequality also increased. The trends of increasing income inequalities overshadow China's impressive performance in economic growth and poverty reduction.

Having analyzed the trends in growth, poverty and inequality at the national level, we moved to the task of constructing a water-related poverty profile for the YRB. Most of the data for our analysis came from the 2001 Household Income and Expenditure Survey conducted by the National Bureau of Statistics of China. Therefore, the findings of our analyses represent the situation in 2001.

Using the purchasing power parity (PPP) $1.25 a day poverty line and per capita income levels, we estimated that 30.5 percent of the population in the rural YRB region were living in poverty in 2001. The poverty rate was highest in the mountain region and lowest in the plain land region. Parts of nine provinces of China belong to the YRB region. The incidence of poverty (headcount poverty rate) varied widely in different parts of the rural YRB, ranging from a low of only 3.1 percent in the YRB part of Shandong province in the east to as high as 52.2 percent in the YRB part of Gansu province in western China. This pattern of poverty incidence corresponds quite well to that of the national level—poverty in China is mainly concentrated in the western part of the country.

Income distribution in the YRB is rather skewed—only 7.1 percent of all income is earned by the poorest 20 percent of households and 27.5 percent by the richest 10 percent. The estimated Gini index is 40.5 percent for income distribution in rural YRB. The Gini at the national level was 38.0 percent for rural China in 2002.

The profile of poverty in the YRB focused on the empirical links between water and poverty in the basin. The PPP $1.25 a day headcount poverty rate is significantly lower in irrigated areas than in non-irrigated areas of the YRB region: while 19.4 percent of all households living in irrigated villages are poor, the rate is more than double (41.4 percent) in non-irrigated villages.

Education is a prerequisite for poverty alleviation. The net school enrollment rates disaggregated by irrigated and non-irrigated villages suggest that enrollment rates are higher in irrigated villages than those in non-irrigated villages, and that the rates are lower for children from poor households than those from nonpoor households. However, the gap in the school enrollment rate between the poor and the nonpoor is smaller in irrigated villages than that in non-irrigated villages. These results indicate that the availability of irrigation at the community level is not only associated with increased school enrollment in the community, but this improvement also seems to benefit the poor more than the nonpoor.

Irrigated villages have better access to safe drinking water in the YRB. The difference in household access to safe drinking water is large between irrigated and non-irrigated villages—78 percent of households in irrigated villages have access to safe water compared to only 47 percent in non-irrigated communities. The results also show that nonpoor households have greater access to safe water compared to poor households, but the poor-nonpoor gap in the access is much smaller in irrigated villages. While the difference in access to safe water between poor and nonpoor is 16 percentage points in non-irrigated villages, it is only 3 percentage points in irrigated villages. Thus, irrigation appears to provide the poor with higher access to safe water. These findings have important policy implications, as access to safe water is critical for improved health and nutrition, particularly for children. This calls for further research in China and elsewhere on the links between irrigation, poverty and access to safe water.

Crop yields are highest in the villages that receive the lowest average annual rainfall. The yields drop sharply for villages belonging to the second rainfall quintile and then rise with increases in rainfall. The highest crop productivity in the lowest rainfall area might appear counterintuitive. Further analysis however shows that, villages belonging to the lowest rainfall quintile also have the maximum irrigation coverage in the YRB. These results suggest that the productivity of irrigation water is optimum in areas with least amount of rainfall in the YRB region.

Irrigation induces technology adoption in crop production. The shares of land under high-yielding varieties (HYVs) of wheat and maize—the two main crops grown in the YRB—increase considerably with increased coverage of irrigated land. Cultivation of HYVs of crops is more capital-intensive than that of traditional varieties of crops. Irrigation takes much of the risks out of crop production as the dependence on rainfall is reduced. Thus, the access to irrigation encourages farmers to invest more on seed-fertilizer technology in agriculture.

The variation in crop yields across households living in irrigated villages is much less than that of households living in non-irrigated villages. Low level of yield variability also motivates farmers to adopt improved technology in crop production.

The $1.25 a day poverty headcount ratio shows stark differences across upstream, midstream, and downstream areas of the YRB. The poverty rate in the upstream area (47.5 percent) is nearly five times higher than that in the downstream area (only 9.9 percent), while the rate in the midstream area (29.6 percent) is three times higher. The percentage of households using electric tubewells for irrigation increases considerably from upstream to midstream areas, and increases dramatically from midstream to downstream areas. However, village level coverage of surface-water irrigation reveals a rather different pattern with the largest share of cultivated land being irrigated in the midstream area. The patterns of the surface water irrigation coverage and the use of tubewells for irrigation suggest that households living in the downstream area rely mostly on groundwater for irrigating their crops, probably due to the lack of surface water availability from the Yellow River.

The findings of the descriptive analysis of poverty profile provided us with important clues to the underlying determinants of poverty. However, the bivariate nature of the informational content of the profile did not isolate the effect of a particular factor on poverty from other confounding factors. Therefore, we extended the descriptive analysis of the profile by modeling income to identify the determinants of poverty in the rural YRB, with particular focus on water and agriculture.

Access to irrigation leads to increased agricultural productivity, and hence, incomes of farmers. Irrigation coverage (that is, the percentage of cultivated land under irrigation in a village) is a statistically significant determinant of per capita income of households. The estimated income elasticity with respect to irrigation coverage suggests that, a 10-percent increase in the village-level irrigation coverage increases per capita income of households living in that village by 1.7 percent on average. Further, poverty simulations using the estimated parameters of the income model suggest that, increasing irrigation coverage by 10 percent reduces the incidence of poverty by 5.11 percent.

Irrigation yields a higher return at the margin in relatively low-rainfall communities. The marginal return to irrigation is lower in relatively high-rainfall communities of the YRB above a certain level (to be precise, communities with annual average rainfall greater than 492 mm).

While the impact of irrigation expansion on poverty reduction is large, we also find fairly large and positive effect from expanding off-farm income opportunities in rural YRB. The headcount poverty rate is expected to decline by 4.52 percent if the share of non-farm income in total per capita household income increases by 10 percent.

In sum, expanding irrigation in the YRB will help boost crop yields, which in turn will increase incomes of the poor and reduce poverty. However, there are limits to expanding irrigation coverage, and labor productivity is known to be lowest in agriculture. Therefore, accelerating a shift of rural labor force out of agriculture by creating off-farm employment opportunities in higher productivity sectors in rural areas is arguably even more important for the poor. That said, rapid agricultural growth must be pursued for poverty reduction. The World Development Report 2008 shows that growth in agriculture is two to four times more poverty alleviating than growth in other sectors. Both China and India offer concrete evidence of this finding. Therefore, faster agricultural growth accompanied by a speedy shift of rural labor force out of agriculture is a key for poverty reduction in the YRB.

2.5 High-Impact Interventions

To assess high-impact interventions, we implemented a review on past, current and planned interventions by the Chinese Government. We also held discussions with stakeholders in the upstream, midstream, and downstream part of the basin, and the researchers in the project developed their own priority list of interventions. Finally, we designed and implemented a multi-agent system (MAS) modeling framework to simulate the YRB. The model draws on the YRCC water simulation model described in Annex B and is also described there.

The following sections provide a brief overview of the methodologies used followed by a presentation of results.

2.5.1 Methods

We used a literature review to assess high-impact interventions. We also convened stakeholder workshops in the upstream, mid-stream, and downstream part of the basin. Finally, we used quantitative simulation analysis. The last methodology is described further in the following.

The theory of MAS has emerged from computer science theories associated with distributed artificial intelligence (Sycara, 1998). An agent is defined as an autonomous unit within a system that interacts with others and characterized by behavioral rules. Agents in a watershed MAS can be defined as water users that utilized water for its own benefits. The behavior in water use decisions for a single agent is affected by the behaviors of its neighbors and also limited by physical conditions and management regulations. The MAS model depict the water management institution more realistically than a conventional centralized model which assumes a “super hand” controlling not only system-level decisions but also the decisions of individual water users or stakeholders.

Traditionally, to address these water resources allocation issues, the entire watershed has been modeled as a single system and water use of individual water users (agents) is a decision variable in a consistent mathematical programming model that optimize system-level objectives. However, if the number of decision variables is too large, the model may become unsolvable. The situation is even more complex if the format of the utility function is nonlinear. Using the MAS modeling framework to formulate the water allocation problem is supposed to avoid the computational difficulty by decomposing the large model into a number of connected smaller models. To implement the MAS model, we define 52 water use agents, 5 reservoir agents and 3 ecosystem agents for the YRB following the setting in Zhao et al (2009). The map of the agents corresponding to the definitions is given in Figure 2.5.1.

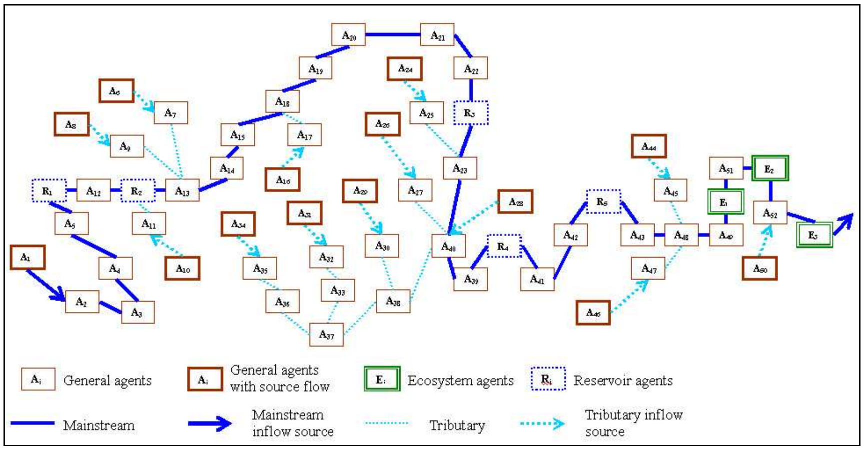


Figure 2.5.1: Agent map of the Yellow River Basin- 52 general agents, 5 reservoir agents and 3 ecosystem agents.

The following criteria are set up to ensure that water prices converge at a reasonable level: 1) total water consumption equals to total water permits; 2) whenever the outflow from agent *i* becomes negative, the water trading with agent *i* will stop, which means that additional trade is physically impossible although it is desired by agents; 3) a criterion that prevents an agent to buy water from downstream agents (negative outflow) by controlling the water prices; 4) only the water consumption for agricultural water use is allowed to be traded, and the M&I water use is treated as the basic water use for all agents and cannot be relocated; 5) the minimum flow requirements are set for ecosystem agents using UWFR results. See also Appendix B3.

2.5.2 Results

- *Results from the Basin Diagnostic Tour*

The Basin Diagnostic Tour, implemented in January, 2008 visited the irrigation system of Victory Canal in Henan, the Farm Irrigation Research Institute (FIRI) – Henan, the flood retention scheme and eastern route of the SNWT project in Shandong, an irrigation canal in Shandong, and the Shandong Academy of Agricultural Sciences Crop Research Institute.

Key results from discussion with various stakeholders during the tour included:

- Water scarcity is considered the largest problem for irrigation
- Water fees and water quality are also important issues constraining agricultural productivity.
- Irrigators are weary of increased competition with urban-industrial and environmental water uses.
- Zero tillage [a companion CPWF project that we visited] is considered as one strategy to save water and labor, adoption for maize and wheat.
- Most farmers have off-farm jobs [small land area, many non-farm employment opportunities]
- Climate change is recognized as a potential future threat – experience of more extreme cold events during the winter and reduced runoff despite stable rainfall
- Relatively low poverty in Henan and Shandong provinces [downstream basin area]

- *Results from Stakeholder Workshops*

In order to further understand water management institution, policies and related pro-poor issues, we organized several stakeholder workshops (or focus group discussion) in three provinces in the Yellow River Basin (YRB). These three provinces are Ningxia, Shaanxi and Henan Provinces. In Ningxia Province, four focus group discussions were organized, two with the management bureau of Ningxia Province and the management bureau of Qingtongxia Irrigation District, and two with groups of farmers. In Shaanxi Province, we also conducted two focus group discussions, the first with the management bureau of Jinghui Irrigation District, and the second with farmers. In Henan Province, we organized two focus groups discussions, one with the management bureau of People's Victory Irrigation District, and the other one with farmers.

During the stakeholder workshop, we have tried to understand two major issues. First, what kind of water resources the stakeholders have access to, and second who decides on water access. Based on the discussion, it appears that in the Ningxia Province, local people mainly have access to four kinds of water resources: gravity irrigation, pump irrigation for surface and groundwater, and domestic tap water. Rainfall is the major water source for some stakeholders in Ningxia Province. In Shaanxi and Henan Province, except for pump irrigation of surface water resources, local people can easily access four other water resources: gravity irrigation, pump irrigation for groundwater, domestic tap water and rainfall.

Regarding the question on who regulates access to water resources, it seems that there are no differences among provinces. For example, managers of irrigation districts regulate the water access of farmers. For rural domestic and industrial water use, the decision makers are always village committee and local water resources bureaus. For urban domestic water use, water supply companies decide on water access. For urban industrial and environmental water use, both water resources bureaus and local government decide on water access.

It is interesting to note that in all provinces, the factors contributing to pro-poor poverty alleviation are similar and local people in various regions also gave them a similar significance. The first important factor that can help farmers increase their income is non-farm employment. If the non-farm employment is higher, farmers' income will also be higher. The second important income source for farmers is profit from agricultural production. This is dependent on many factors, such as irrigation availability, the quality of marketing of agricultural products and output/input ratio. In addition, education and local transportation conditions are also considered as two important factors influencing poverty.

In the stakeholder workshops, we also discussed the issue of water allocation priority. The priority seems different between upstream regions (such as Ningxia Province) and downstream regions (such as Shaanxi and Henan Province). In the upstream regions, industry is less developed compared to downstream regions. Domestic water use has been given the first priority in water allocation in all regions, but the second allocation priority in Ningxia is agricultural water use, whereas in both Shaanxi and Henan Provinces it is for industry. For all provinces, environmental water use has been given the last priority in water allocation.

In the YRB, several measures have been adopted to increase water productivity and deal with water shortages. The first measure is to reform irrigation management institutions through changing management from collective to either WUAs or contracting management (with or without incentives). Second, the water price has been reformed to give certain incentives to water users. Third, water rights transfer pilot projects have been implemented; these have moved part of the water from the agricultural sector to industry with the purpose of increasing agricultural water use efficiency. Finally, water saving technologies has been adopted along with agricultural technologies that can increase crop productivity.

Based on the discussion, we also could highlight some challenges facing local water managers. First, although reforms have been implemented for irrigation management institutions, it is still difficult to operate WUAs effectively. Second, the irrigation infrastructure is poor, not only for main and branch canals, but also in the field canals at the village level. Third, there are no incentives for local water managers (WUA managers) to increase water use efficiency. The wages of IDs managers depend on water fee collection, hence, if water use is reduced so will their wages. Therefore, there are conflicts between increasing water use efficiency on the one hand, and raising water revenues on the other. Besides, ID managers still face difficulties to collect water fees, particularly in Henan.

Wages for ID managers are closely linked with water fee collection, and as such they are extremely unpredictable, due to variable water supply and to the difficulty in collecting water fees. Under such management mechanism, ID managers have no incentive to increase water use efficiency. They are afraid to increase water prices since they think farmers will reduce water use (or turn to groundwater use), resulting in income shortfalls for them. Most ID managers suggested for the government to subsidize water fees, so that farmers can use more water and the fee could be collected more easily. Due to financial constraints of the local government, the revenue situations of most IDs are hard to be improved in the short term.

There are some additional challenges. In the past 15 years, water prices have been increased in most IDs. However, this has potential negative impacts on farmers' income and agricultural production. On the other hand, without increases in prices farmers have no incentive to increase water use efficiency. Discussions also revealed that the upstream regions use more water than the water quota allocated by the YRCC, while the downstream regions use less water than the water quota (of 1987). As a result most of these regions are considering reservoirs to store water that they cannot use. Perhaps the allocation system could be improved then.

Other problems have to do with the water rights transfer projects. Although the projects have facilitated innovation and increased water use efficiency in agriculture, there are no real water rights transfer between industrial and agricultural water users; all the transfer projects have been managed by the local governments and the managers of the irrigation districts, while local managers and farmers were not really involved, which makes the water rights transfers ineffective . Moreover, if the transfer should for any reason affect negatively local managers and farmers, they have no instrument to ask for compensation. Finally, we found that in the Henan Province after the implementation of the new water project infrastructures were not able anymore to withdraw water from the Yellow River. Before the project, the river bed of the Yellow River was high and local infrastructures for water abstraction were designed accordingly. After the implementation of the Xiaolangdi project, the river bed decreased and water intakes became too high to abstract water. Financial and engineering problems are presently hindering solutions to this problem.

- *Results from Researcher Consultation*

Results from the researcher consultation are shown in Figure 2.5.2. Researchers agreed on three best-bet options: The first best bet option is continued investments in yield improvement, including for drought stress. The Chinese Government is already pursuing this avenue and is the developing-country government with highest research expenditures on agricultural R&D, including for water savings in agriculture. The second option identified is further advances in water management, with a focus on irrigation management reform—a focus of WP4 and water rights and water markets, which are analyzed with the MAS model developed for WP5. A final area for high-impact interventions identified are continued irrigation infrastructure investments to make structures perform in real-time for both drought and flood management and to increase overall water use efficiency in agriculture.

Table 2.5.1: High impact interventions according to researcher consultation

	Low cost	Reach	Environmental impact	Poverty impact	Food security
Water pollution control	☹		✔		✔
Yield improvement, including for drought stress		✔		✔	✔
Water management	✔	✔	✔	✔	✔
---in particular Water rights and markets		✔ /?	✔	✔	✔
----ID management support		✔ /?	✔	✔	✔
----Water pricing		✔ /?	✔		✔
Water monitoring system	☹	✔	✔	✔	✔
Resettlement	☹	☹		✔	✔
Off-farm opportunity development		☹		✔	?
South-to-North transfer	☹ ☹	✔	?	☹	✔
Irrigation infrastructure investment (Canals, etc.)	☹		✔ / ?		
On-farm irrigation technology investment		✔	✔ / ?		
Virtual water			✔		
Education/Family planning	✔	✔	✔	✔	✔

- *Selected results from literature reviews and engineering analyses*

Given the size of the YRB, no single intervention could possibly do justice to the extreme diversity of water-related challenges found in the basin, which ranges from the upstream mountainous areas dominated by livestock herders, to the hilly/mountainous Loess Plateau with severe erosion challenges, the semi-arid to arid irrigated plains in Inner Mongolia/Ningxia with rapidly growing industries, to the key urban-industrial centers interspersed with highly productive irrigation downstream. Many interventions have been implemented in the past to increase water supply and enhance flood control. Key among these are the construction of the Xiaolangdi reservoir, completed in 1999, which has increased the designed flood-control period from 60 years to over 1000 years; the construction of several thousand silt-trap dams across the Loess Plateau; and two large watershed rehabilitation projects implemented by the government of China and the World Bank. Additional interventions in recent years to address growing water shortages and the need for food include the conversion of hillside production into terraces (this was also done as part of the watershed rehabilitation project); rainwater harvesting schemes in the western upland areas; the use of plastic sheeting to contain soil moisture and reduce evaporation in the arid parts of Inner Mongolia and Ningxia; and the resettlement of people out of extremely dry areas.

<u>Technical interventions:</u>

While many technical or engineering interventions have been already implemented in the basin, a series of additional measures could increase water supply or reduce demand. The possibly most important one is the south-to-north water transfer (SNWT) project. If fully implemented, it could transfer up to 50 km^3 (comparable to total Yellow River runoff) from the Yangtze River in southern China to the North China Plain. However, among the three routes (western, middle and eastern routes) only the western route would directly affect water resources in the YRB. It could transfer 20 km^3 to irrigate an additional 1.3 million ha and provide water for economic development in Qinghai, Gansu, Shanxi and Shanxi provinces, as well as Ningxia and Inner Mongolia, all in the YRB. However, economic, engineering, and ecological side effects prevent this route from development in the foreseeable future.

Even without the SNWT, engineers at YRCC still see some potential for water savings in the basin, amounting to 5.7 km^3 by 2020 and 7.6 km^3 by 2030, mostly in the agriculture sector (but allowing for continued agricultural and economic growth and small increases in irrigated area). During the last two decades, the water utilization level and water use efficiency in the YRB have been improved greatly; but there is still considerable room for improvement when comparing the YRB with Australia or the United States, for example. According to statistics, the water withdrawal quota per ten thousand Yuan GDP in the YRB decreased from 876 m^3 in 1980 to 104 m^3 in 2006, a decline of 88 percent. Furthermore, the water recycling rate is 61%. However, in the developed world, the water withdrawal quota per ten thousand Yuan GDP is below 50 m^3, and the industrial water recycling rate reaches 80% to 85%. In the YRB, the farm real-irrigation quota dropped from 542 m^3/mu in 1980 to 420 m^3/mu in 2006. The irrigation water use efficiency is 0.49, compared to 0.7~0.8 in developed countries.

Through adjustments in planting dates and crop varieties, technological advances in agriculture, and various engineering measures, we expect additional water savings in irrigation in the range of 54.72 million mu by 2020 and 30.39 million mu by 2030, resulting in total irrigation water savings of 4.04 BCM and 5.42 BCM. The industrial water-saving measures mainly include the adjustment of the industrial structure, the use of advanced technologies and advanced equipment, and improved water recycling rates. Through these water-saving measures, the water withdrawal quota per ten thousand Yuan GDP is expected to decline to 52.9 m^3 by 2020, the water reuse rate is projected to increase to 72.3%, resulting in total water savings of 1.53 BCM in the industrial sector, by 2020. By 2030, the water reuse rate in the industrial sector will increase to 83.5%, the water withdrawal quota per ten thousand Yuan GDP will be decreased to 30.4 m^3, and the water-savings amount will be 2.05 BCM. In the urban-domestic sector, water savings will be achieved through engineering measures, new technologies and management techniques to reduce water losses, including disconnecting invalid water connections and increasing the efficiency of water uses. The expected volume of water savings is 0.12 BCM by 2020, and 0.17 BCM by 2030. Combined water savings across all three sectors will reach 5.69 BCM and 7.64 BCM in 2020 and 2030. The summary of proposed water savings is shown in Table 2.1.6.

Table 2.5.2: Proposed water savings in the YRB (BCM)

Level year	Industrial water-savings	Agricultural water-savings	Urban water-savings	Total
2020	1.53	4.04	0.12	5.69
2030	2.05	5.42	0.17	7.64

However, these savings will not be sufficient to turn around trends of growing water deficits in the basin, particularly in dry years. Thus, even more investment in agricultural research and development will be needed to achieve even more rapid improvements in crop yields without use of more irrigation water.

An assessment of crop water productivity across the YRB showed that while there is still scope for increased water-use efficiency in irrigated agriculture in the YRB, the scope is limited and further declines in allocation of water to irrigation will eventually result in reduced food production with serious implications for local food security and farmer incomes, as well as potential impacts on global food prices and trade.

<u>Reform of governance:</u>

Despite high levels of water scarcity in the country and in the YRB, integrated water management in China remains elusive as a result of fragmented management and conflicts among water users at the national, provincial, and local levels. Key challenges in Chinese water legislation and administration relate to the lack of regulations supporting implementation of the 2002 water law; and poor incentives for water conservation at the level of the irrigation system. To address growing water scarcity, in addition to water supply/engineering measures, the government has started to support reform of irrigation management. Our studies found that significant scope for governance and institutional reforms remain in the following areas: 1) Reforming irrigation management institutions; 2) Reforming water pricing; 3) Implementing water rights transfer projects; and 4) Support for water reallocation across provinces.

Economic solutions: Role of water pricing and water markets

Market mechanisms and water pricing measures are also adopted to promote water savings. Although China does not currently have formal water markets that are supported by clearly and universally assigned water property rights, China is slowly reforming its water policies in an attempt to reallocate water (Heaney, et al., 2005). Effective pricing mechanisms focus on incentives for farmers to value water resources and to use water carefully (Liang, 2005). Water was always free to farmers until 1978, when the government started charging for the use of water. Current water prices do not reflect the actual cost of water, since the government subsidizes prices (He, et al. 2005). Farmers pay for the water based on the amount of irrigated land, not based on how much they use. Water pricing for irrigation does not reflect the actual costs of water because farmers remain poor, and raising water prices would raise the costs of production for farmers. Water pricing mechanisms are more important than the pricing itself (Li and Zhang). Water prices have increased more than fivefold for industrial withdrawals and agricultural irrigation since the 1990s. Increasing water prices are intended to encourage farmers to conserve valuable water resources and reduce water use instead of increasing agricultural products prices and punishing farmers. Therefore, care should be taken for designing water pricing systems for agriculture, and a pricing scheme that pays farmers for reducing water use is preferred to a direct water price (Cai and Rosegrant, 2004).

A crop irrigation water quota is another form of water pricing. The user would be charged much higher prices (than the standard price) for water use that exceeds the quota amount. For example, in the water rights experimental City of Zhangye, users pay an additional 50 percent charge for exceeding their quota by 30%, a 100% charge for the use of an extra 31 to 50 percent of water, and a 200 percent charge for an excess water use of 51 percent or more (He, et al. 2005).

The third part of water pricing is the water tax. An increase in water prices by a tax would encourage farmers to adopt improved irrigation technology. However, this may result increased agricultural product prices, leading to reduced competitiveness in the world market.

Although water prices have been steadily raised over the past several decades in China, and particularly since the latest round of water-pricing reforms started in 1997, agricultural water is still thought to be much under-priced. As a result, water charges remain a limited instrument to increase water use efficiency and productivity further. oreover, given the growing rural-urban income divide, it is unlikely that the government will raise irrigation fees to levels high enough to reduce irrigation water use seriously. Furthermore, in the YRB, the UWFR has led to income shortfalls of districts in parts of the basin where irrigation water supplies were cut considerably, particularly in midstream provinces.

Since 2000, YRCC has promoted the establishment of water-right systems by conducting demonstration projects aimed at reducing water competition among sectors. The purpose of these demonstration sites is to reallocate water from agriculture to industry through increasing irrigation efficiency, generally through engineering measures, such as canal lining. One transfer pilot project operates in Ningxia Province and 16 projects signed transfer contracts in Inner Mongolia, with a value of US$100 million. Under these projects, irrigation districts transfer part of their water use rights to industrial enterprises for a period of 25 years. However, analyses showed that water users in the irrigation districts are generally not aware of the water rights transfer; transfers are determined by the administration, not markets; and there are no adjustments based on market signals or economic measures. Thus, major challenges remain until a true market for water rights can be established.

Importantly, the intra-provincial irrigation-to-agriculture transfers in the YRB provide important inputs for the potential development of inter-provincial water trading, which has been discussed by both policymakers and water allocation managers at the MWR and YRCC for several years.

- *Selected results from modeling analysis*

The MAS model is populated with aggregated data from the water-simulation model of the Yellow River Conservancy Commission (YRCC). A total of 52 water-use agents are defined: nine for the provinces sharing Yellow River flows, three to reflect downstream ecological needs, five to represent key reservoirs, and the remainder to represent key tributaries and inflows. The model is calibrated to 2000 data.

Using this modeling framework, we compare two scenarios to evaluate the consequences of changes from the current scheme of water allocation (that is, business-as-usual under the current UWFR based on the 1987 allocation agreement): (1) water allocation across provinces without quotas, and (2) water trading among agents using irrigation water. For the lower three ecosystem agents, we also assess the impact of using environmental flow requirements (as established by several Chinese studies) on the potential for water trading.

The scenario without regulation mimics the situation before the UWFR was implemented, so the only constraint affecting water users would be the physical limit of water availability. An obvious result from this scenario is that upstream water users will take advantage of available water while downstream water users can only utilize whatever is left from upstream. The water-trading scenario is implemented through a price bargaining process, where local water prices are adjusted to ensure that the systemwide total water consumption matches the total value of water permits.

The environmental flow scenario establishes stream-flow requirements for the three downstream ecosystem agents (Huayuankou, Gaochun, and Lijin). Requirements are differentiated for a normal flow period (from November to March), a fish nursery period (from April to June), and a flooding period (from July to October).

Impact of the UWFR on Water Use and GDP

As expected, annual water consumption under the scenario without regulation is higher—by 11 percent (38.3 billion cubic meters (m^3) compared with 34.5 billion m^3 under the UWFR). At the same time, the basin-wide GDP—at 1123.26 billion RMB under the scenario without regulation—is 10 percent lower than the 1246.68 billion RMB achieved under the UWFR scenario (see also Figure 2.5.2). As a result of increased water consumption without the UWFR, flows to downstream ecosystems are reduced and flow cutoff events occur from February to June.

Flow impacts are even stronger for the ecosystem agent that is farthest downstream, where cutoff periods start in February and continue through December. These results reflect the period from 1972 to 1998, before the UWFR was enforced, and show the benefit of the UWFR for downstream ecosystem flows. Moreover, basin-water consumption under the UWFR scenario is lower and GDP higher as compared with the unmanaged scenario. Although some upstream agents experience declines in GDP (by about 2.5 billion RMB annually), total basin GDP is higher.

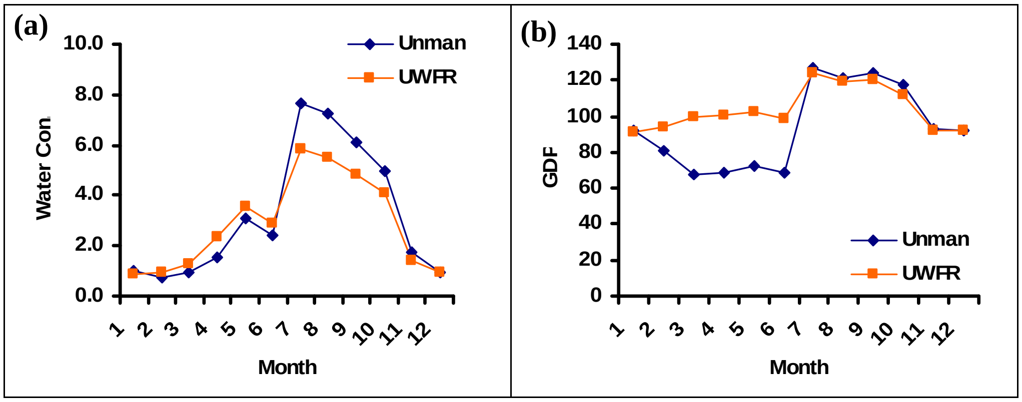


Figure 2.5.2: System-wide comparison between UWFR scenario (baseline) and the scenario without UWFR: (a) monthly water consumption (billion m^3); (b) monthly GDP (billion RMB)

Impact of Water Trading on Water Use and GDP

The water trading scenario starts from an initial water price of 27 RMB/m^3 based on trial-and-error. If the local water price is above this value, all agents would only use water for M&I use and sell the rest of their water entitlement. This implies that the maximum marginal benefit of agriculture water use over the whole basin is 27 RMB/m^3. Starting from this initial water price, the model ends with equilibrium water prices for each agent and month. Results for selected months are shown in Figure 2.5.3.

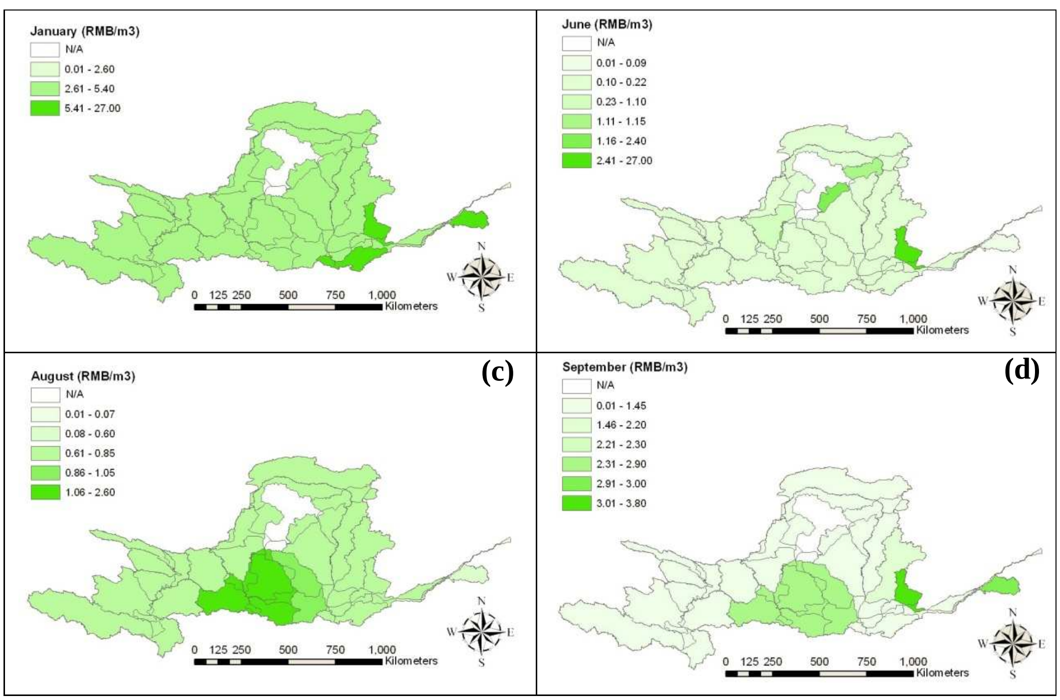
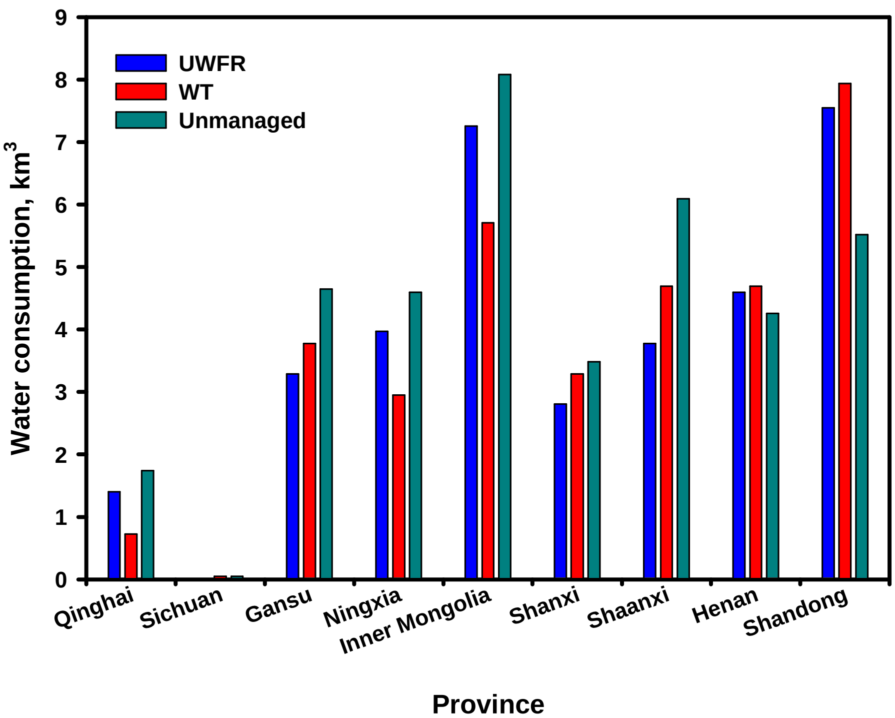


Figure 2.5.3. Equilibrium water prices for different agents in different months. (a) January; (b) June; (c) August; (d) September

Generally, water prices are higher in tributaries than in the mainstream because much less water is available and can be transferred. January is an example of a month with relatively uniform water prices for agents along the mainstream and the major tributaries. Only a few agents located at smaller tributaries in the downstream area have higher water prices. Moreover, since January is usually the month with lowest flow, the average water price for the entire system is relatively higher compared to other months. In general, water prices are lower in high-flow months. However spatial heterogeneity in water prices exist in the high-flow season. Moreover, water prices in tributaries, particularly the source areas of tributaries, are higher than those in other places. This is because water transactions from mainstream toward tributaries or from downstream toward upstream are physically impossible without engineering works. The marginal benefit of water in those areas will therefore be higher in these areas under the water trade scenario.

The annual water consumption under the water-trading scenario is slightly lower at 33.8 billion m^3 than the annual water consumption under the UWFR scenario while total GDP is higher at 1270.1 billion RMB in the former scenario. As expected, water-use agents upstream use less water under the water-trading scenario compared to the UWFR scenario (a decline of about 3.27 billion m^3), while midstream and downstream agents use more (2.55 billion m^3). Thus, upstream agents tend to sell water to gain revenue, while downstream agents buy water for greater water-use benefit. The GDP increase is 5.64 billion RMB for upstream agents and 17.8 billion RMB for midstream and downstream agents, with a total GDP increase of 23.45 billion RMB.



Note: Provinces are shown from upstream to downstream.
Figure 2.5.4: Water consumption in the YRB under alternative allocation scenarios

Figure 2.5.4 presents the results for water consumption by province (from upstream to downstream) under the unmanaged, UWFR, and water-trading scenarios. The water-trading scenario follows prescribed withdrawals downstream to support the ecosystem agents, but also reallocates water from Inner Mongolia and Ningxia to Shanxi, Shaanxi, and Gansu provinces.

For all months evaluated, the quantity of water sold exceeds the quantity of water purchased. The additional water is assumed to be purchased by the Government to fulfill ecosystem flow requirements. The total value of water transactions of 2.95 billion RMB is actually quite low compared with the total additional basin-wide GDP increase (Table 2.5.3). As such, water trading increases the basin economy by more than 20 billion RMB, and the implementation is economically efficient. The results of the water-trading scenario demonstrate that basin-wide water-related GDP can increase under water trading despite strict flow control measures for the downstream ecosystem.

Table 2.5.3. Water trading and the economic benefit of water trading (BCM)

Month	Upstream water buying	Mid-stream/ downstream water buying	Upstream water selling	Mid-stream/ downstream water selling	Total water buying	Total water selling	Difference	Transaction value (billion RMB)
1	0.0004	0.0001	0.0674	0.0405	0.0005	0.11	0.11	0.56
2	0.01	0.02	0.03	0.05	0.03	0.08	0.05	0.02
3	0.01	0.05	0.07	0.05	0.06	0.12	0.06	0.06
4	0.01	0.02	0.14	0.05	0.03	0.19	0.16	0.06
5	0.09	0.09	0.47	0.04	0.18	0.51	0.32	0.06
6	0.04	0.07	0.19	0.06	0.12	0.24	0.13	0.02
7	0.08	0.79	0.93	0.66	0.88	1.58	0.71	0.81
8	0.12	0.44	0.99	0.42	0.56	1.41	0.86	0.54
9	0.09	1.41	1.54	0.44	1.50	1.98	0.48	0.42
10	0.06	0.69	0.87	0.09	0.75	0.96	0.21	0.28
11	0.01	0.04	0.15	0.07	0.06	0.21	0.15	0.07
12	0.0005	0.0908	0.0564	0.0610	0.0914	0.12	0.03	0.05
Sum	**0.53**	**3.72**	**5.50**	**2.01**	**4.25**	**7.51**	**3.26**	**2.95**

Can the YRB Economy accommodate full environmental flow requirements?

The UWFR was implemented mainly to restore downstream flows in the YRB and to preserve the ecosystem in the delta area. However, studies on environmental flow requirements for the YRB delta suggest that flows should be greater than those listed in the UWFR, particularly to preserve deltaic fish nurseries from April to June.

Under the environmental flow scenario as specified above, water purchases decline to zero for the months of January, April, and June. Thus, no one is buying water in the basin during those months; instead agents consume water equivalent to municipal and industrial needs, which receive highest priority. At the same time, agents sell large amounts of water to support the high ecosystem demands. Despite these sales, instream flow requirements cannot be met fully in the months of January, April, and June. Thus, it is physically impossible to satisfy both human and ecosystem requirements in those months unless additional measures, such as reservoir re-operation or new infrastructure development, are undertaken. As water scarcity increases under the environmental flow scenario, water-trading prices on the mainstream also rise by 30 percent compared with the UWFR scenario, where they rise from 1.16 RMB/m^3 to 1.62 RMB/m^3.

2.5.3 Conclusion

The government of China has recognized the severe water constraints in the YRB. To address growing water scarcity, the government has started to change its approaches from management of water supply toward improved management of water demand. Signs of the new approaches are the 2002 water law, the increased number of regulations on water prices and a series of water trading pilots implemented in the YRB. However, most organizations concerned with water management are still headed and staffed by engineers, and traditional water-engineering measures, as exemplified by the SNWT, still dominate interventions in terms of funding.

There is no panacea for addressing the severe water scarcity challenges in the YRB. Based on an assessment of options available, we believe that the government should continue to reform the institutions responsible for irrigation management and water pricing across all water-using sectors; but current users need to be compensated for ceding water resources to users with higher-valued uses. Projects that transfer enhanced water rights that follow market mechanisms, and include the establishment of water rights and related responsibilities would be a first step in that direction. Reform is also required at all the administrative levels from the central to the local government to support fully integrated land and water management at the basin level and to avoid large inefficiencies caused by conflicting objectives of the various agencies involved in water supply and food production in the YRB.

Expanding irrigation in the YRB will help boost crop yields, which in turn will increase incomes of the poor and reduce poverty. However, the potential for expanding irrigation is limited, and labor productivity is known to be lowest in agriculture. Therefore, accelerating a shift of the rural labor force out of agriculture by creating off-farm employment opportunities in higher-productivity sectors in rural areas is arguably even more important for future rural economic development.

Other ancillary measures that need to be continued include further adoption of water-saving technologies, and continued support to agricultural research and development to increase crop productivity for both irrigated and rainfed crops. Continued productive investment is needed, rather than subsidies, in the rural non-farm sector to ensure that the urban-rural poverty gap does not widen even further. There is still scope for savings of agricultural water through improved water productivity. But continued transfers of water out of agriculture will eventually result in declining production, with implications for national food production as well as global food prices and trade.

2.6 Knowledge Base and Evaluation Platform

2.6.1 Methods

The methods used for the knowledge base is principally GIS maps of key parameters of importance for agricultural water use in the Yellow River Basin. Several GIS-based databases have been connected to the MAS model for dynamic updating of the data sets. Data and output indicators from this project have been incorporated into the CD-Rom titled Digital Water and Food Atlas for the Yellow River Basin.

2.6.2 Results

The Knowledge base WP has generated the following datasets that are made available on a CD-Rom "Yellow River Water and Food for Poverty Alleviation Atlas:"

1. Physiography: Digital elevation data to provide more accurate basin/watershed boundaries, river networks. The elevation datasets are also crucial for surface water modeling and management.
2. Land cover and land cover change: Land cover maps for the Yellow River Basin.
3. Climatic and hydrologic data, time series of precipitation and temperature. Monthly data at the resolution of 50km (from IPCC (http://www.ipcc.ch/).
4. Water supply and irrigation infrastructure data, including reservoirs and dams, water lift projects and water diversion projects.
5. Crop distribution data - Spatial distribution of major crops split by irrigated and rainfed portions. The method provided by Cai et al. (2006a) was used to retrieve irrigated and rainfed crop area and yield at the level of irrigation district.
6. Socio-economic data - Rural/urban population density distribution; poverty and water maps generated from this project.

The GIS-maps and databases generated can be directly linked to the current Digital Yellow River framework. However, the Digital Yellow River framework is not one coherent system—instead pieces are scattered across various YRCC organizations.

The project has also generated a website http://www.ccapwater.com/river/index.html that is directly linked to the CCAP website to achieve wide policy impact. A first policy brief has been drafted and is currently being reviewed. A total of 5 policy briefs will be produced at the end of the project. All briefs will be available on the website for downloading in English and Chinese.

2.6.3 Discussion

We had hoped to achieve a larger exchange and integration of data with our Chinese partners. However, there is still considerable reluctance on their side regarding data sharing. It took us almost 2 full years to obtain data for water simulation modeling. Researchers outside China were not allowed to handle the Chinese household data set.

2.6.4 Conclusion

Access to agreed upon GIS layers remains fundamental to achieving enhanced food and water security in the YRB. Thanks to our collaborators at YRCC, CCAP, BNU, and Tsinghua University, we have been able to use the latest available data for our analyses. However, such data is not available for other researchers to per-use and many researchers will therefore continue to need to rely on secondary/internationally available data to do their analyses for this river basin and other basins in China.

3. OUTCOMES AND IMPACTS

This portion of the study focuses on outcomes and impacts.

3.1 Proforma

Summary Description of the Project's Main Impact Pathways

Actor or actors who have changed at least partly due to project activities	What is their change in practice? I.e., what are they now doing differently?	What are the changes in knowledge, attitude and skills that helped bring this change about?	What were the project strategies that contributed to the change? What research outputs were involved (if any)?	Please quantify the change(s) as far as possible
All collaborators involved in the project	Improved collaboration over time, working in teams, sharing data, developing modeling tools, and joint papers and policy briefs	Understanding the benefits from collaboration	Work package teams including staff from different organizations	
YRCC	Enhanced appreciation of linkage of water use with poverty alleviation Enhanced information on the impact of climate change on river flows	Knowledge that alternative water allocation policies at YRCC do influence poverty outcomes in the basin Research activity that was added during the project as a result of demand	Presentation by A. Ahmed to YRCC staff Research papers on the topic	
CPWF	Better appreciation of the contribution that research in the YRB can provide for other river basins that are less developed	Research papers, presentations, policy briefs	Preparation of research papers, policy briefs, and workshops	
Irrigation districts (IDs)	IDs will consider to use incentives instead of name change	Selected irrigation districts in the basin are aware of research results—particularly the benefit of	Research papers and policy briefs	

		incentives for water allocation institutions in conserving water		
Researchers (particularly engineers)	Better appreciation of water rights trading benefits	New insights on impact of water rights trading in the YRB, particularly on the basin GDP, winners and losers	Research papers and policy briefs	

Of the changes listed above, which have the greatest potential to be adopted and have impact? What might the potential be on the ultimate beneficiaries?

The research results generated, including the water-poverty analysis and the MAS modeling, including the ecosystem flow assessment, will likely have the largest impact for enhanced basin water allocation. We hope to disseminate these results widely through a series of policy briefs that we have produced both in English and Chinese.

The insights from the irrigation water reform research will help shape Chinese irrigation policy in the future, as results are being used in subsequence water pricing and irrigation reform studies.

What still needs to be done to achieve this potential? Are measures in place (e.g., a new project, on-going commitments) to achieve this potential? Please describe what will happen when the project ends.

More work is being done on assessing ecosystem flow requirements and the values of ecosystems. We hope that some of this work can build on our project.

Each row of the table above is an impact pathway describing how the project contributed to outcomes in a particular actor or actors.
Which of these impact pathways were unexpected (compared to expectations at the beginning of the project?)

It took a long time to realize the benefits of collaboration, including data sharing. In fact, the project was inactive for the larger part of a full year as a result. However, in the end, most planned outputs could be achieved.

What would you do differently next time to better achieve outcomes (i.e. changes in stakeholder knowledge, attitudes, skills and practice)?

Clarify expectations of all collaborators early on in the project; present preliminary results not only at the medium- and final workshops in Beijing, but improve communication during project duration with other stakeholders in China, particularly the provincial leadership in charge of provincial water allocation.

Establish a panel that includes officials from both the Ministry of Agriculture and Ministry of Water Resources to discuss current water policies that adversely affect agriculture and current agricultural policies that adversely affect water resources in the YRB and to identify mutually beneficial policies.

3.2 International Public Goods

3.2.1 Tools and Methodology

We used a variety of research methods, ranging from stakeholder consultations, workshops with researchers, to descriptive qualitative analysis, and quantitative, modeling analysis. Quantitative analysis methods included a) econometric analyses to relate agricultural water with poverty outcomes and to relate water-related institutions with water savings; b) hydrologic and water supply and demand simulation modeling, including SWAT modeling to assess the impact of climate change on Yellow River Basin water resources; water supply and demand modeling (YRCC-led) to assess water availability and use in the basin; and MAS modeling to assess the impact of alternative high-impact interventions; and c) GIS-based analysis of water productivity to assess the spatial variation of water productivity across the basin.

The most innovative components of our research were the water-poverty analysis and the MAS modeling that empirically showed the benefits from water rights trading taking hydrologic constraints and ecosystem requirements into account in the YRB.

3.2.2 Project Insights

Key project insights include:

- Most of the poor are concentrated in the western part of the YRB, where irrigation options are costly and limited.
- Irrigation has been a significant contributor to poverty alleviation in the YRB. Thus, limited further expansion should continue.
- Under business as usual, the water deficit in the YRB will continue to increase; the deficit will also continue to widen as a result of climate change; and will be particularly high in dry years.
- Engineering measures in the water sector, including the SNWT, will not be sufficient to reverse growing water shortages.
- While there is still scope for improving water productivity in the basin, and rainfed and irrigated soybean and maize achieve similar yields in the downstream part of the basin, further increases in crop water productivity will soon reach limits.
- Once yields decline in the YRB as a result of growing water shortages and transfers out of irrigation agriculture, net food imports in China and food prices globally will be affected.
- To address growing shortages, the establishment of water use rights below the province level—and particularly for irrigators or organizations representing groups of irrigators will be crucial.
- We show empirically that water rights trading by irrigators alone will reduce water shortages and increase overall basin GDP.
- We show that some government policies in the agriculture arena have adverse impacts for the water sector and vice versa. Examples include high input subsidies instituted by the Ministry of Agriculture that adversely affect water quality in the YRB and elsewhere in China. While many subsidies have been decoupled, in practice, monetary transfers are still used for fertilizers. The long-term cost of this policy is not only a wastage of productive resources that could

be invested in crop yield improvement, extension, transportation and agricultural marketing, but also the long-term costs to water availability and quality, with adverse health impacts for everybody, but particularly for those who cannot afford bottled water. Another policy in the agriculture arena that has adversely impacted the irrigation sector is the removal of the agricultural land tax that has increased the difficult to collect the water service fee as both fees used to be collected together (logistical/cost factor). Moreover, farmers feel that the elimination of the land tax should also lead to an elimination of the water fee. On the water side, the new policy in the YRB to flush silt out of the lower basin through large reservoir spills is highly effective, but it has led to irrigation channel intakes along the river to be too high up the river bed for actually accessing water. Thus, irrigation looses out to river safety. Another policy in the water sector has been to increase irrigation service fees to conserve water resources. However, unless incentives are changed, irrigation district managers are hurt through this policy as their income depends on the volume of water delivered. Thus, if conservation is the key, the incentives for ID managers need to be changed towards merit payments keyed to water conservation and not keyed to overall irrigation water volume delivered.

3.2.3 Partnership Achievements

With project collaborators

The development of various modeling tools required new partnerships between project partners. For example, the development of the climate change impact analysis water supply and demand in the YRB required a linkage between BNU and YRCC; and the development of the MAS model required a linkage between YRCC, Tsinghua University, and UIUC. This model development was facilitated by staff from China visiting the ARI collaborator at Illinois.

Second, the water-poverty analysis would not have been possible without the close collaboration between CCAP who has a copy of the 2001 HIES and IFPRI, which has implemented many poverty analyses in the past.

With the CPWF BFP

The exchange of information on modeling tools and work package progress was helpful, not only for the project leader, but also for collaborators who were more removed from the CPWF

Learning across large-scale basins is highly innovative and will be helpful to gain new insights for future individual basin case studies.

4. Recommendations

For the YRB

We found that the exchange of researchers has been highly fruitful for both parties. One student from Beijing National University and one associate professor from Tsinghua University spent one year each at the University of Illinois at Urbana-Champaign. This has helped enhance data exchange, and has increased mutual learning and collaboration and helps ensure future collaboration. We suggest that future research projects should consider such exchanges as well.

In terms of research, we believe that more research is needed on ecosystem service impacts from upstream water usage, on water quality impacts from poor agricultural policies, including the cost of water quality deterioration to the overall basin economy.

For basin-level research

Additional research should be undertaken on the linkage between water and poverty and water and food security in a river basin context, for example, as they are affected over time by climate change and, even more importantly, by the reallocation of water out of agriculture. We have shown for the Yellow River Basin that irrigators have progressively lost access to water. A threshold where water has adversely impacted overall food production, has not yet been reached, but will likely be reached in the coming decade. We already show declines in wheat yield as a result of reduced irrigation water availability in based on village survey data for Ningxia and Henan provinces.

Additional research should be undertaken on the adverse impacts on water and food from poor agricultural policies and on food from poor water policies. This research should be combined with identifying win-win strategies that support both water and food. We have identified, for the YRB, a series of agricultural policies that harm water (quantity and quality), and a series of water policies that adverse affect agriculture. Both types of policies increase the costs to government and the economy overall.

Given the positive effects of water rights trading, further discussions should be held with the Ministry of Water Resources and senior YRCC staff on these results.

5. Publications

Publications are listed in Appendix A.

REFERENCES

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998) Crop evapotranspiration: Guidelines for computing crop requirements. *Irrigation and Drainage Paper No. 56*, FAO, Rome, Italy.

Arnold, J.G., Fohrer, N., 2005. SWAT2000: current capabilities and research opportunities in applied watershed modelling. *Hydrological Processes* 19 (3), 563–572.

Bardhan, P.K. 1984. Land, labour, and rural poverty. Essays in development economics. New Delhi: Oxford University Press.

Brown, L., 1995. Who Will Feed China? Wake-Up Call for a Small Planet. New York: W. W.Norton/ Worldwatch Institute, 160 pp.

Brown, L. and B. Halweil. 1998. China's water shortage could shake world food security. Worldwatch, No. 7/8, Online

Cai, X. and Rosegrant, M., 2004. Optional water development strategies for the Yellow River basin: Balancing agricultural and ecological water demands. Water Resources Research, 40, W08S04, doi:10.1029/2003WR002488.

Cai, X., De Fraiture, C. and Hejazi. M. I. 2007. Retrieve irrigated and rainfed crop data using general maximum entropy approach, *Irrigation Science*, 25-325-338.

Cheng L, Xu Z X, Luo R, et al. 2009. SWAT Application in arid and semi-arid regions: a case study in Kuye River basin. Geographical Research, 2009, 28(1): 65-74. (in Chinese)

Cui, B., Tang, N., Zhao, X. and Bai, J. 2009. A management-oriented valuation method to determine ecological water requirement for wetlands in the Yellow River Delta of China. *Journal for Nature Conservation*, 17:129—141.

Datt, G., and D. Jolliffe. 1999. Determinants of poverty in Egypt: 1997. FCND Discussion Paper No. 75. Washington, D.C.: International Food Policy Research Institute.

Dibike, Y.B., Coulibaly, P., 2005. Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. *Journal of Hydrology* 307, 145–163.

Doorenbos J. and Pruitt, W. O. 1977. Guidelines for predicting crop water requirements. FAO, Rome, *Irrigation and Drainage Paper No. 24*, p 144

Doorenbos J. and Kassam A.H. 1979. Yield response to water. *FAO Irrigation Drainage Paper 33*, United Nations, Rome, pp. 193.

Foster, J.E., J. Greer, E. Thorbecke. 1984. A class of decomposable poverty indices. Econometrica 52: 761-766.

Gaiha, R. 1988. Income mobility in rural India. Economic Development and Cultural Change 36(2).

Grootaert, C. 1997. Determinants of poverty in Côte d'Ivoire in the 1980s. Journal of African Economies 6.

Huntingford, G., Gash, J., Giacomello, A.M., 2006. Climate change and hydrology:next steps for climate models. *Hydrological Processes* 20, 2085–2087.

İnalhan, G., Stipanović, D. M. and Tomlin, C. J. 2002. Decentralized optimization, with application to multiple aircraft coordination, *Proceedings of the 41st IEEE Conference on Decision and Control*, December 2002, Las Vegas, NV, USA.

Ke, S. and Zhou, K., 2007. Integrated water resources management in the Yellow River basin. People's Yellow River No. 1, 18-22.

Jin, L., and W. Young. 2001. "Water use in agriculture in China: Importance, challenges, and implications for policy." *Water Policy* 3: 215-228.

Liu, X., Lian, Y. and Ke. S. 2009. The ecological water requirement analysis for the Yellow River Delta. Journal of Hydraulic Engineering, 40(8): 956-961. (in Chinese)

Ma, X, J. Han and Y. Chang. 2007. Research on Evolution of Water Rights Transfer in the Yellow River Basin, Research of China's Economic History, No. 1:41-47.

Ma X. 1996. The Flood and Drought Disaster of the Yellow River Basin. Zhenzhou, China: Yellow River Press.

Ministry of Water Resources, 2006. *Water Resources Bulletin*, Ministry of Water Resources, Beijing, China.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2005. Soil andWater Assessment Tool Theoretical Documentation Version 2005. Temple, Texas, USA.

Ni, J., Jin, L., Zhao, Y. and Liu, X. 2002. Minimum water demand for ecosystem protection in the Lower Yellow River. Journal of Hydraulic Engineering, 10:1-7. (in Chinese)

Nyberg AJ and S Rozelle. Accelerating China's Rural Transformation. Published by the World Bank, 1999.

Pang J P, Xu Z X, Liu C M. 2007. Research progresses of SWAT model application. Journal of Soil and Water Conservation. 14(3): 31~35. (in Chinese)

Prudhomme, C., Reynard, N., Crooks, S., 2002. Downscaling of global climate models for flood frequency analysis: where are we now? Hydrological Processes 16, 1137–1150.

Rosegrant, M.W., Cai, X., Cline, S., 2002. World Water and Food to 2025: Dealing with Scarcity. The International Food Policy Research Institute, Washington, DC.

Rosegrant, M.W. and Cai, X., 2003. Rice and water: An examination from China to the world. In T.W. Mew, et al., eds., Rice Science: Innovations and Impact for Livelihoods. Manila, the Philippines: International Rice Research Institute. 847–867.

Sycara, K. 1998. Multi-Agent Systems. AI Magazine, 19(2): 79-92.

U.S.D.A. Soil conservation service, 1967. Irrigation water requirement. Tech. Release No 21, Engl. Div. SCS. 83 pp.

Wang, J., and J. Huang. 2000. Water Institutional Analysis in China and Fuyang River Basin, Report Submitted to International Water Management Institute.

Wang, J., Z. Xu, J. Huang and S. Rozelle, 2003. Pro-poor Intervention Strategies in Irrigated Agriculture in China, Report Submitted to International Water Management Institute and Asian Development Bank.

Wang, J and L. Zhang. 2009. Water Policy, Management and Institutions: Role in Pro-Poor Water Allocation in the Yellow River Basin. Report prepared for the Challenge Program on Water and Food.

World Bank. 1994. Poverty in Columbia. World Bank Country Study. Washington, D.C.: World Bank.

World Bank. 1995a. Ecuador poverty report. World Bank Country Study. Washington, D.C.: World Bank.

World Bank. 1995b. Understanding poverty in Poland. World Bank Country Study. Washington, D.C.: World Bank.

World Bank. 1996. Hungary: Poverty and social transfers. World Bank Country Study. Washington, D.C.: World Bank.

World Bank. 2005. Introduction to poverty analysis. Washington, D.C.: World Bank.

Yang, Y. C. E., Cai, X. and Stipanović, D. M. 2009. A decentralized optimization algorithm for multi-agent system based watershed Management. Water Resources Research. 45, W08430, doi:10.1029/2008WR007634.

Yang, H., Zhang, X., and Zehnder, A.J.B., 2003. Water scarcity, pricing mechanism and institutional reform in northern China irrigated agriculture. Agricultural Water Management, 61, 143-161.

Yang, Z. F., Sun, T. Cui, B.S., Chen, B. and Chen, G.Q. 2009. Environmental flow requirements for integrated water resources allocation in the Yellow River Basin, China. Communications in Nonlinear Science and Numerical Simulation, 14: 2469–2481.

Yang Y.C.E., Zhao, J. and Cai, X. 2010. A multi-agent system model for water allocation management in the Yellow River Basin, Environmental Modeling and Software, under review.

Yellow River Conservancy Commission (YRCC). 2003. The Yellow River Water Resources Bulletin (in Chinese). http://www.hwswj.gov.cn.

Zhao, J., Wang, Z., Wang, D and Wang D. 2009. Evaluation of economic and hydrologic impact of Unified Water Flow Regulation in the Yellow River Basin. *Water Resources Management*, 23:1381-1401.

Zwart, S. J. and Bastiaanssen, G. M. (2004) Review of measured crop water productivity values for irrigated wheat, rice cotton and maize, *Agricultural Water Management*, 69: 115-133.

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Appendix A: Abstracts of publications

1) Abstracts of published papers

Streamflow response to climate variability and human activities in the upper catchment of the Yellow River Basin

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Both sensitivity-based method and simulation method are used to analyze the streamflow response to climate variability and human activities in the upper catchment of the Yellow River Basin (UYRB) in this study. The separation regime of effects from climate variability and human activities is investigated. Results show that the effect on streamflow is more sensitive to precipitation than potential evapotranspiration (PET). Effect of climate variability on streamflow estimated using the sensitivity-based method is weak in the upper catchment of Jimai station, and strong in the upper catchment of Lanzhou station, where the climate effects accounted for about 50% of total streamflow changes. Effects of human activities on streamflow accounted for about 40% in the UYRB, with weaker effects in the upper catchment of Tangnaihai station than those in the upper catchment of Lanzhou station. Both climate variability and human activities are main factors to affect the changes of streamflow in the UYRB.

Zongxue Xu, F.F. Zhao, and J.Y. Li. 2008. Impact of climate change on streamflow in the Yellow River Basin. In Fighting Poverty Through Sustainable Water Use: Volumes I. Proceedings of the CGIAR Challenge Program on Water and Food 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, November 10—14, pp. 167-169.

To assess how streamflow in the headwater catchment of the Yellow River Basin will be affected by climate change in the future, the HadCM3 model, developed at the Hadley Centre in the United Kingdom, was used to generate low emission scenarios (B2) in this study. The statistical method was used to generate future possible local meteorological variables in the study area. The down-scaled data were then used as input to the Soil and Water Assessment Tool (SWAT) model to simulate the corresponding future streamflow regime in the headwater catchment of the Yellow River Basin. Three benchmark periods simulated were 2010–2039 (2020s), 2040–2069 (2050s), and 2070–2099 (2080s). The time series generated by HadCM3 and statistical downscaling method indicate a significant increasing trend in both maximum and minimum temperature values, and a slight increasing trend in precipitation. The hydrologic impact analysis made with the downscaled temperature and precipitation time series as input to the SWAT model suggested an overall decreasing trend in annual streamflow in the headwater catchment of the Yellow River Basin, in three benchmark periods in the future. This should be considered by policymakers of water resources planning and management.

Yang, Y.C.E., Cai, X. and Stipanović, D. M. 2009. A decentralized optimization algorithm for multi-agent system-based watershed management. Water Resources Research. 45, W08430, doi:10.1029/2008WR007634

A watershed can be simulated as a multiagent system (MAS) composed of spatially distributed land and water users (agents) within a common defined environment. The watershed system is characterized by distributed decision processes at the agent level with a coordination mechanism organizing the interactions among individual decision processes at the system level. This paper presents a decentralized (distributed) optimization method known as constraint-based reasoning, which allows individual agents in an MAS to optimize their behaviors over various alternatives. The method incorporates the optimization of all agents' objectives through an interaction scheme, in which the ith agent optimizes its objective with a selected priority for collaboration and forwards the solution and consequences to all agents that interact with it. Agents are allowed to determine how important their own objectives are in comparison with the constraints, using a local interest factor (bi). A large bi value indicates a selfish agent who puts high priority on its own benefit and ignores collaboration requirements. This bottom-up problem-solving approach mimics real-world watershed management problems better than conventional ‘‘top-down’’ optimization methods in which it is assumed that individual agents will completely comply with any recommendations that the coordinator makes. The method is applied to a steady state hypothetical watershed with three off-stream human agents, one in-stream human agent (reservoir), and two ecological agents.

Also as Yang, Y.E., J. Zhao and X. Cai (2010), A Multi-Agent System Based Model for Water Allocation Management in the Yellow River Basin, proceedings of World Water Congress, Environmental and Water Resources Institute (EWRI), Am. Society of Civil Engineers, Providence, RI, 2010.

2) Abstracts of papers submitted to journals

Yi-Chen Ethan Yang, Jianshi Zhao, and Ximing Cai. Under review. A Multi-Agent System Model for Water Allocation Management in the Yellow River Basin

The management of large river basins, such as the Yellow River Basin (YRB) in China, is complicated by distributed, local decision processes, as well as mechanisms that coordinate individual decisions and manage basin-level issues. Since 1998, the Yellow River Conservancy Commission (YRCC) has used the Unified Water Flow Regulation (UWFR) water allocation management plan as a centralized controlling mechanism that enforces an upper limit of water withdrawals (water permits) for eight provinces located in the basin. The implementation of UWFR has maintained a prescribed minimum flow in the downstream channel and avoided the flow cutoff events that occurred every year between 1972 and1998. In the context of the regulation plan, this study attempts to explore the socioeconomic and environmental consequences of the regulation, understand the behaviors of the water users, and test alternative management plans to improve water allocation management in the basin. To address these objectives, a multi-agent system (MAS) based model is developed for the YRB in which water users, reservoirs and downstream ecological zones are defined as agents. The MAS model depicts agents' autonomy in water use decisions and interactions among the agents in the context of a water right and market system. A decentralized optimization algorithm was extended to determine local water prices as an incentive to influence agents' decision toward the basin-level policy targets. The proposed water market scenario shows possible improvements of the UWFR with respect to social (equity), economic and environmental objectives.

Claudia Ringler, Ximing Cai, Jinxia Wang, Akhter Ahmed, Yunpeng Xue, Zongxue Xue, Ethan Yang, Zhao Jianshi, Tingju Zhu, Lei Cheng, Fu Yongfeng, Fu Xinfeng, Gu Xiaowei, and Liang You. Yellow River basin: Living with scarcity. Under review, *Water International*.

The Yellow River Basin is a key food production center of global importance facing rapidly growing water scarcity. Water availability for agriculture in the basin is threatened by rapid growth in the demand for industrial and urban water, the need to flush sediment from the river's lower reaches, environmental demands, and growing water pollution. Climate change is already evident in the basin with long-term declines in river runoff, higher temperatures, and increasing frequency and intensity of drought. The Chinese Government has exhausted most options for improving water supply. The challenge will be to switch to improved water demand management, which is hampered by existing governance structures, and lack of integrated agriculture and water resource policies.

Ximing Cai, Yi-Chen E. Yang, Claudia Ringler, Jianshi Zhao, and Liangzhi You. Agricultural Water Productivity Assessment for the Yellow River Basin. Under review, *Agricultural Systems*.

Agricultural water productivity (WP) has been recognized as an important indicator of agricultural water management. This study assesses the WP for irrigated (WPI) and rainfed (WPR) crops in the Yellow River Basin (YRB) in China, using data from sixty counties throughout the basin. WPI and WPR are calculated for major crops (corn, wheat, rice, and soybean) using experimental, statistical and empirically estimated data. The spatial variability of WP is analyzed with regard to water and energy factors (i.e., the ratio of actual and potential evapotranspiration to precipitation, respectively), as well as agricultural practices (irrigation versus rainfed). Results show that although irrigated corn and soybean yields are significantly higher than rainfed yields in different regions of the YRB, WPI is slightly lower than WPR for these two crops. This can be explained by the seasonal coincidence of precipitation and solar energy patterns in the YRB, that is, high solar radiation and precipitation during the summer, which allows for the effective use of precipitation for crop growth, and relegates irrigation to a supplemental source in most parts of the basin. However, as expected, irrigation stabilizes crop production per unit of water consumption over space. WPI and WPR vary spatially from upstream to downstream in the YRB as a result of varying climate and water supply conditions. The water factor has stronger effects on both crop yield and WP than the energy factor in the upper and middle basin, whereas energy matters more in the lower basin.

3) Abstracts of online reports (http://www.ccapwater.com/river/index.html)

Ahmed, A.U., J. Wang, A. Bhaskar, and W. Quabili. 2009. Water and poverty in China's Yellow River Basin. Prepared for the CPWF YRB Focal project. (WP1)

In this report, we have carried out a water-related poverty analysis for the YRB. The purpose of the analysis is to determine to what extent irrigation or agricultural water management explains poverty in relation to other factors. This assessment is important for an understanding of the options for making interventions in the agricultural water sector so as to have the highest likelihood of reducing poverty. The profile of poverty in the YRB focused on the empirical links between water and poverty in the basin. The PPP $1.25 a day headcount poverty rate is significantly lower in irrigated areas than in non-irrigated areas of the YRB region: while 19.4 percent of all households living in irrigated villages are poor, the rate is more than double (41.4 percent) in non-irrigated villages. Access to irrigation leads to increased agricultural productivity, and hence, incomes of farmers. Irrigation coverage (that is, the percentage of cultivated land under irrigation in a village) is a statistically significant determinant of per capita income of households. The estimated income elasticity with respect to irrigation coverage suggests that, a 10-percent increase in the village-level irrigation coverage increases per capita income of households living in that village by 1.7 percent on average. Further, poverty simulations using the estimated parameters of the income model suggest that, increasing irrigation coverage by 10 percent reduces the incidence of poverty by 5.11 percent. Given the limits to expanding irrigation coverage and low labor productivity in agriculture, accelerating a shift of rural labor force out of agriculture by creating off-farm employment opportunities in higher productivity sectors in rural areas is arguably even more important for the poor.

Li Jingzong, Fu Yongfeng, Xu Zongxue, Cheng Lei, Sun Yongliang, and Zhu Tingju. 2010. Water Supply and Demand in the Yellow River Basin: Opportunities from Water Savings (WP2)

The YRB is a highly water-scarce basin. Much of the infrastructure on this highly controlled river has been built for flood control, but climate change and droughts will bring new challenges to a basin that has only been prepared for flood management. The report describes the current water supply and demand situation in the river, and reviews the impact of future supply and demand, as well as the potential impact of climate change on water resources. It continues with a combined analysis of demand increase and climate change impacts, and concludes with avenues for reform, focusing on technical and engineering methods.

Ximing Cai, Yi-Chen E. Yang, Claudia Ringler, Liangzhi You. 2009. Water Productivity Assessment for the Yellow River Basin. (WP3)

Agricultural water productivity (WP) has been recognized as an important indicator of agricultural water management. Using data from sixty counties from upstream, middle stream, and downstream sub-basins, this study assesses the WP for irrigated (WPI) and rainfed (WPR) crops in the Yellow River Basin (YRB) in China and extends the analysis to the entire basin. WPI and WPR are calculated for major crops (corn, wheat, rice, and soybean) with experimental, statistical, and empirically estimated data. The spatial variability of WP and the water and energy factors are analyzed with regard to climate, land cover, and agricultural practices. Results show that although irrigated yield is significantly higher than the rainfed yield for corn and soybean in different regions of the YRB, WPI is slightly lower than WPR for the these two crops. This can be explained by the synchronized pattern of precipitation and solar energy in the YRB, which allows effective use of precipitation for crop growth. As expected, irrigation stabilizes the crop production per unit of water consumption. WPI and WPR vary spatially from upstream to downstream, with both climate and water supply conditions linked to irrigation systems. The water factor has stronger effects on both crop yield and WP than the climate factor. Among the sub-basins, the midstream region faces more critical agricultural water management issues from the perspectives of both crop yield and WP.

Wang Jinxia and Lijuan Zhang. 2010. Water Policy, Management and Institutions: Role in Pro-Poor Water Allocation in the Yellow River Basin. (WP4)

The overall goal of this report is to examine water policy in the Yellow River Basin (YRB), the institutional arrangements that shape this policy and determine how water is managed, and understand their impacts on water use efficiency, water productivity, agricultural production and poverty. In order to realize this goal, we have pursued the following three objectives. First, we describe the legal framework for water administration and management in the Yellow River Basin. Second, water allocation principles and mechanisms at the national, basin and local levels that affect basin water allocation and use are described. Given the significant correlation between access to irrigation and wealth in villages in the Yellow River Basin, policies, institutions and economic incentives (such as water pricing policy, water management, water rights and transfer) affecting irrigated agriculture are examined in detail. Finally, we describe the major results from informal discussions with stakeholders in the upstream, midstream, and downstream parts of the basin. Data used in this report are based on literature reviews, government reports, as well as from empirical analyses and surveys conducted by the authors.

Xue Yunpeng, Yan Sun, and Claudia Ringler. A Review of Governance, Laws and Water Interventions in the Yellow River Basin over the last 60 Years. (WP5a)

As part of the Yellow River Basin (YRB) focal project of the CGIAR Challenge Program on Water and Food (CPWF), this paper presents a literature review of the history and impacts of intervention policies on water-related poverty in rainfed and irrigation regions of the YRB. In addition, high-potential interventions that increase water and food security for the poor while maintaining environmental sustainability have been identified. In irrigated regions, the policy has shifted from expanding irrigated areas to reducing total irrigation water use and increasing irrigation water use efficiency and productivity, with the goal of providing more water for industry, urban areas, and the environment. However, since many irrigation systems have been poorly constructed and/or maintenance has been postponed over the years, and financial difficulties have prevented both irrigation districts and farmers from applying water-efficient techniques, policies that increase investment in water-saving practices and promote better water and finance management are essential. Additionally, the side effects of raising irrigation water prices and water rights transfers from agriculture to industry must be studied carefully. For much poorer rainfed regions with problems related to water accessibility and soil erosion, past policies of building high lifting pump stations and long-distance water transfer projects are effective, but the costs are too high to continue these into the future. Comprehensive soil and water conservation approaches including terracing, rainwater harvesting, re-vegetation and small sediment trap dams, cash cropping, and fence grazing are promising new approaches for these areas.

Ximing Cai and Yi-Chen E. Yang. A Multi-Agent Based System Model for Water Allocation Management in the Yellow River Basin. (WP5b)

Several administrative water reallocation schemes have been implemented in the Yellow River Basin. The most successful, administrative water transfer to date in the basin was the enforcement of the quota-based Water Allocation Agreement of 1987 through Unified Water Flow Regulation (UWFR) in 1999 that ensured that flow to the Yellow river mouth was not cut off after 2000. This policy was in line with the refocus, over the last decade, on sustainable water use and keeping the Yellow River 'healthy' promoted by the Government of China. However, the enforcement of the UWFR policy did not compensate those provinces and water users that had to give up water as a result. This led to significant income declines for both irrigation districts and irrigating farmers. Given the key importance of compensating irrigation for giving up water for both flows at the river mouth and rapid urban-industrial development downstream, we analyze the potential impact on GDP of water rights trading using a Multi-Agent System (MAS) modeling framework for the Yellow River Basin.

4) Titles of online policy briefs (available in English and Chinese) (at http://www.ccapwater.com/river/index.html)

1) **Water and Poverty in China's Yellow River Basin** --By Akhter U. Ahmed, Jinxia Wang, Anjor Bhaskar, and Wahid Quabili

2) **Water Supply and Demand in the Yellow River Basin: Opportunities from Water Savings** --By Xu Zongxue, Fu Yongfeng, Cheng Lei, Sun Yongliang, Zhu Tingju, and Li Jingzong

3) **Water Productivity Assessment for China's Yellow River Basin**--By Ximing Cai, Yi-Chen E. Yang, Claudia Ringler, and Liangzhi You

4) **Water Policy, Management, and Institutions: The Role of Pro-Poor Water Allocation in the Yellow River Basin** --By Jinxia Wang and Lijuan Zhang

5) **Water Rights and Water Rights Trading: Option for the Yellow River Basin?** --By Nicola Cenacchi, Yunpeng Xue, Fu Xinfeng, and Claudia Ringler

6) **Governance, Laws, and Water Interventions in the Yellow River Basin Over the Past 60 Years: From Supply- to Demand- Side Management**--By Xue Yunpeng, Yan Sun, and Claudia Ringler

7) **Water Allocation Management in the Yellow River Basin: Potential for Water Trading?**--By Ximing Cai, Yi-Chen E. Yang, Jianshi Zhao, and Claudia Ringler

5) Abstracts of papers that will be submitted as working papers or journal articles

Ximing Cai, Yi-Chen E. Yang, Jianshi Zhao, and Claudia Ringler. Water Allocation Management in the Yellow River Basin: Results from a Multi-Agent System Model. Under Review, IFPRI Discussion Paper.

Several administrative water reallocation schemes have been implemented in the Yellow River Basin. The most successful, administrative water transfer to date in the basin was the enforcement of the cross-provincial, quota-based Water Allocation Agreement of 1987 through Unified Water Flow Regulation (UWFR) in 1999 that ensured that flow to the Yellow River mouth was not cut off after 2000. This policy was in line with the refocus, over the last decade, on sustainable water use and keeping the Yellow River 'healthy' promoted by the Government of China. However, the UWFR did not take into account the value of water in various uses and water users who had to give up water resources, chiefly irrigators in the upstream and midstream provinces, were not compensated. We analyze the potential impact on GDP of irrigation water rights trading using a Multi-Agent System (MAS) modeling framework for the Yellow River Basin. Compared to the baseline scenario simulating the UWFR, the water trading scenario results in a small decline in water consumption, combined with a significant increase in agricultural GDP. Total basin GDP increases by 1.9% and would be much higher if domestic and industrial uses would become active water trading sectors.

Zhu, Tingju. Dry Season Water Management in the Lower Yellow River. For submission to journal (TBD).

The lower Yellow River irrigates more than three million hectares of cropland and supplies water for municipalities and major industries along the river downstream. The vast irrigated areas along the lower river constitute the central piece of the Huanghe-Huai-Haihe plain, the breadbasket of China, producing more than 20 million metric tons of grain annually as well as cotton and oil crops. Despite its obvious socioeconomic importance, water supply shortages have been rather common for the downstream, due to natural hydroclimatic variability, overuse in the upstream reaches, and imperfect management of water infrastructures. The last two storage reservoirs on the main stem of the Yellow River, Sanmenxia and Xiaolangdi, play a key role in supplying water to the downstream, especially during the dry season. Effective management of conjunctive operation of these two reservoirs is essential for ensuring timely and reliable water supply to the downstream irrigated areas and non-agricultural users. Besides conventional purposes of irrigation, water supply and hydropower, the reservoirs have to undertake flood control and ice-flood control tasks, facilitating sediment-flushing in summer and forming of ice cap with sufficient flow capacity underneath it in winter. These functions pose additional complexity in modeling irrigation and water supply management in the downstream with these two reservoirs, essentially excluding the application of linear or non-linear program models. We formulate the water management problem using a dimensional dynamic programming model, with reservoir storages as state variables and water release from reservoirs as decision variables. The Discrete

Differential Dynamic Programming (DDDP) algorithm is applied to refine model solutions and speed up model solving. Based on the dynamic programming results, a linear operating function is estimated for each ten-day period during the dry season and used to operate the reservoirs, in order to remove the ‘perfect hydrological foresight’ assumption in the optimization model. Simulation results indicate that the estimated empirical operating functions can manage the water resource system reasonably well, yet at acceptable cost of reduced water supply and hydropower performance. The overall analysis implies that water shortage occurs frequently in the lower Yellow River, due to insufficient water resource and high water demand. The shortage can be much higher during a major, indicating dramatic damages for irrigated agricultural and industries that depend on water from the lower Yellow River. Conjunctive use of surface and ground waters in the lower Yellow River irrigated areas and improved flexibility in operating upstream major storage reservoirs can provide promising solution for high water supply reliability in the lower Yellow River, however demand side management such as water saving irrigation technologies and improved industrial water use efficiency may greatly enhance water use sustainability in the lower Yellow River.

Appendix B: Model Descriptions

B1 YRCC Water Simulation Model

- *General structure*

The water supply and demand equilibrium model system includes three main parts: pre-processing, solution and post-processing. The basic function of the pre-processing program is to input a large number of basic data for the actual water resources system to reflect the physical and economic characteristics and system rules of operation. A standard river flow network was constructed based on the node map and basic data. The basic solution function program implements a long series of simulations across successive periods. The main parameters and their relationships are then exported from the pre-processing program. The simulated results on successive periods could be exported from the simulation program. Post-processing program is made up of a group of independent processes. In order to analyze the results and evaluate the program, the results are processed into different forms, including visual and easily readable charts.

- *Model design: Node-link system*

Nodes are the basic calculation unit of the model, as shown in Figure B1.1. To calculate the water balance in one node, requires: runoff in previous node, interval inflow, return flows from other nodes, water diversion into and out of the basin, domestic water (urban and rural) use, industrial water use (urban and rural), ecological water requirement (urban and rural), change in reservoir storage, reservoir water loss, and discharge from the node (including power generation). A (monthly) water balance equation for node i +1 could be written as:

$$W_i + W_{in} + W_{re} + W_{dii} + S_{t0} - W_{dou} - W_{mi} - W_{ecu} - W_{dor} - W_{ag} - W_{ecr} - W_{dio} - S_t - W_{lo} - W_d = 0 \quad \text{(Eq. B1.1)}$$

Where: W_i: runoff of the previous node in the period; W_{in}: inflow to the node in this period; W_{re}: return flow from other nodes in this period: W_{dii}: water transfers into the node in this period; S_{t0}: water storage capacity of reservoirs at the beginning of this period; W_{dou}: the urban domestic water volume diverted from this node in this period; W_{dor}: rural domestic water volume diverted from this node in this period; W_{mi} the industrial water volume diverted from this node in this period; W_{ag}: the agricultural water volume diverted water volume from this node in this period; W_{ecu}: the urban ecological water volume diverted from this node in this period; W_{ecr}: the rural ecological water volume diverted from this node in this period; W_{dio}: water volume transfer from this node outside the basin in this period; S_t: the reservoir water storage capacity at the end of this period; W_{lo}: the water loss of reservoirs in this period; and W_d: the water discharged from this node in this period.

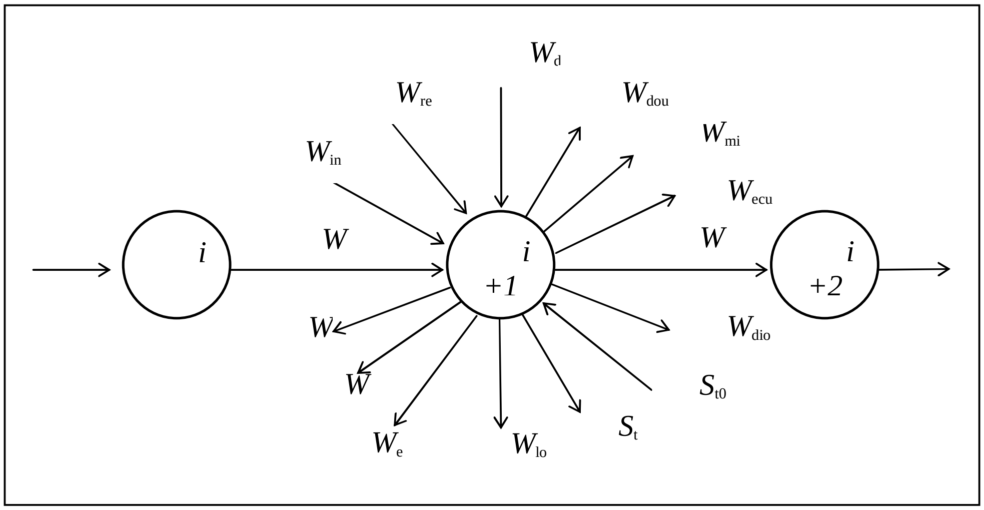

Figure B.1.1: Schematic diagram of water balance for nodes

- *Model design: Irrigation water requirement*

To reflect the impact of annual precipitation on irrigation water requirement, the annual irrigation water quota is calculated based on crop water requirements and annual precipitation, which varies across time. Therefore, a variable quota is adopted to calculate irrigation water requirement in the model.

- *Model design: Water supply priority*

The water distribution policy is one of the most important factors and must be considered for the rational utilization and the optimal distribution of water resources. The water distribution policy and operating rules are embodied as water priority orders in the simulation model. The priority order refers to the priorities of water supply and storage; it is reflected as a set of values that can be arbitrarily set in the model. The key of ranking water uses is to reflect the relative relationship between the water distribution policy and operating rules.

The simulation model is a network model, where costs of water flows are minimized. There is a separate file for cost of water transportation in the model. In addition, costs for domestic, industrial, and ecological water needs and reservoir storage are subject to the water supply priority. For different regions, sectors and time, water supply priorities are assigned through careful analysis and research. In the process of calculation, the model meets the needs of various kinds of water users according to the different priorities determined. The smaller the cost of the user's priority, the higher the priority to receive water in the allocation of water resources. Through changing the priority order, a variety of water distribution policies and operating rules can be tested.

- *Model design: Reservoir operation rule simulation*

In the model, the task of regulating reservoirs is to meet the demand of various water users as much as possible. These include flood control, ice prevention, water supply, power generation, among others. According to the operating rules, the water volume for storage and reservoir discharge of reservoirs can be determined. Moreover, the guiding idea of the reservoir operation rules is that the reservoir water storage capacity is divided into several layers (in this model 11 layers are included). Storage below the dead storage is considered the first impoundment layer. The highest priority order is to ensure the dead storage, followed by different water demands for every layer, with different priorities, to guide the reservoir storage and discharge.

- *Model design: Combined surface and groundwater simulation*

Since the Yellow River Basin is a large area, which involves many provinces and districts, is highly complex, has differences in hydrogeological conditions and groundwater depth, the basis of information varies greatly; therefore, in this study, the combined use of surface and ground water in different regions is calculated with the direct deduction method or the water balance method.

- *Model Solution*

(1) The year for water supply and demand analysis is 2020, considering entry into force of the Guxian Hydro-Junction Project.
(2) According to the administrative divisions and the distribution of the drainage system, and considering the main sections and engineering conditions, the whole basin is divided into a total of 40 nodes for which a water resource supply and demand balance has been calculated is shown in Figure B.1.2. The names corresponding to the second-level districts and provinces for each node are shown in Table B.1.1.
(3) There are two scenarios for water supply and demand analysis, one that takes into account climate change and one that does not. The natural water resource availability is 51.979 BMC for the first scenario (result of "the Yellow River Basin Integrated Water Resources Planning"); for the second scenario, water availability is provided by Beijing Normal University.
(4) In the calculation of the water supply and demand balance, the priority of tributaries, surface water and groundwater unified deployment, the water release requirements for Lijin control section are considered.
(5) For the water supply order we gave priority for domestic water, followed by all other uses, including irrigation, industrial, ecology, and environmental uses.

Table B.1.1 Nodes and corresponding locations

Nodes	Provinces (regions)	The second grade district	Calculational nodes	Provinces (regions)	The second grade district
A1	Qinghai	Upper longyangxia	A18	Shanxi	From Hekouzhen to Longmen
A2	Sichuan	Upper longyangxia	A19	Shanxi	From Longmen to Sanmenxia
A3	Gansu	Upper longyangxia	A20	Gansu	From Longmen to Sanmenxia
A4	Qinghai	Upper longyangxia	A21	Shaanxi	From Longmen to Sanmenxia
A5	Qinghai	From Longyangxia to Lanzhou	A22	Ningxia	From Longmen to Sanmenxia
A6	Gansu	From Longyangxia to Lanzhou	A23	Gansu	From Longmen to Sanmenxia
A7	Qinghai	From Longyangxia to Lanzhou	A24	Shaanxi	From Longmen to Sanmenxia
A8	Gansu	From Longyangxia to Lanzhou	A25	Shaanxi	From Longmen to Sanmenxia
A9	Qinghai	From Longyangxia to Lanzhou	A26	Shanxi	From Longmen to Sanmenxia
A10	Gansu	From Longyangxia to Lanzhou	A27	Henan	From Longmen to Sanmenxia
A11	Gansu	From Lanzhou to Hekouzhen	A28	Shanxi	From Sanmenxia to HuaYuankou
A12	Gansu	From Lanzhou to Hekouzhen	A29	Shanxi	From Sanmenxia to HuaYuankou
A13	Ningxia	From Lanzhou to Hekouzhen	A30	Shaanxi	From Sanmenxia to HuaYuankou
A14	Inner Mongolia	From Lanzhou to Hekouzhen	A31	Henan	From Sanmenxia to HuaYuankou
A15	Inner Mongolia	From Hekouzhen to Longmen	A32	Henan	Underside HuaYuankou
A16	Inner Mongolia	From Hekouzhen to Longmen	A33	Shandong	Underside HuaYuankou
A17	Shaanxi	From Hekouzhen to Longmen			

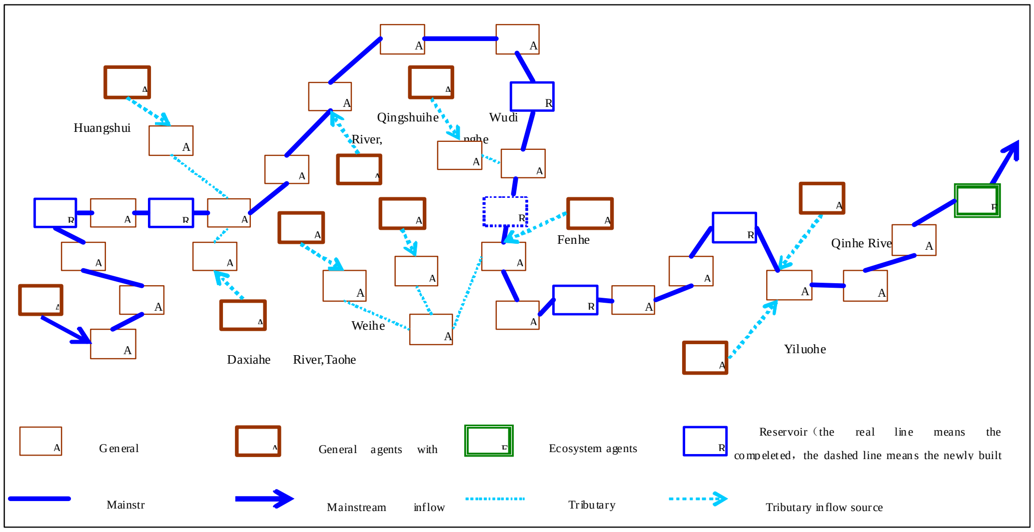

Figure B.1.2: Node-link network, YRCC water supply demand simulation model

B2 Beijing Normal University SWAT Model

For climate change impact studies, hydrologic models are required to simulate sub-grid scale phenomenon, and such hydrologic models require input data at similar sub-grid scale, which has to be provided by converting the GCM outputs into a reliable regional hydrologic time series at the selected watershed scale. The methods used to convert GCM outputs into local meteorological variables required for reliable hydrologic modeling are usually referred to as 'downscaling' techniques (Dibike and Coulibaly, 2005; Huntingford et al. 2006).

In this study, the statistically downscaled GCM output, and the atmospheric circulation indices as well as humidity variables derived from the HadCM3 model developed at the Hadley Centre in UK were used to downscale daily precipitation and temperature series at headwater catchment of the Yellow River basin. The climate scenarios generated were then used to drive the distributed Soil and Water Assessment Tool (SWAT) model. Changes in the modeled daily flow regime between current and future climate scenarios were compared and analyzed.

- *Study Area and Data Descriptions*

The headwater catchment of the Yellow River basin from source of the river to Tangnaihai station with an area of 122,000 km^2, known as the 'water tank' of the basin, contributes on average 35% of total runoff in the Yellow River basin. In terms of climate, the catchments are described as a semi-humid region of the Tibetan Plateau. The annual average precipitation is about 450 mm. More than 70% of the total annual precipitation falls in the flood season from July to October. During the past several decades, the streamflow regime in the headwater catchment of the YRB has changed significantly, which resulted in degradation of the ecosystem. Changes in hydrologic regime include decrease in streamflow and, more significantly, occurrence of drying-up, i.e. periods with zero flow. Understanding the relationships among the hydrologic regime, climate factors, and anthropogenic effects is important for the sustainable management of water resources not only for the study area but also for the entire YRB.

Spatial data used in this study include a digital elevation model (DEM), land use/cover, soil type, and climatic data. A digital elevation model with a scale of 1:250,000 was provided by the Data Center for Resources and Environmental Sciences (RESDC), Chinese Academy of Sciences. Land use data with a scale of 1:1,000,000 and soil data with a scale of 1:4,000,000 were also obtained from same organization. The baseline used in this study is 1961–1990, the standard World Meteorological Organization period. It has been selected because it incorporates some of the natural variability of the climate, including both dry (1970s) and wet (1980s) periods (Prudhomme et al., 2002). Daily streamflow data at the Tangnaihai station was available. Daily maximum and minimum temperatures (TMAX and TMIN) from 7 stations in and around headwater catchment of the Yellow River basin were compiled and daily precipitation (PRCP) from 16 gauging stations is available in this study.

- *Methodology Descriptions*

The method used in this study is focused on the most widely used downscaling method which has been recently suggested by the Canadian Climate Impact Scenarios (CCIS) project for climate change impact studies (Dibike and Coulibaly, 2005). A well recognized statistical downscaling tool is made available to the broader climate change impact study community via the Canadian Climate Impacts and Scenarios project (http://www.cics.uvic.ca/scenarios/). It implements a regression based method and is referred to as Statistical DownScaling Model (SDSM) (Dibike and Coulibaly, 2005). From the 30 years of data representing current climate (1961-1990), the first 15 years are used for calibrating the regression model while the remaining 15 years of data are used to validate the model. In this study, the SWAT model is used. It is a physically-based model being able to estimate the impact of land uses on water, sediment and agricultural chemicals on a subcatchment and land use unit scale over long periods of time (Sun and Cornish, 2005). In which, the surface runoff is estimated using a modified SCS curve number method based on moisture content. Compared with the original SCS method, which describes moisture condition as a function of antecedent rainfall, the modified curve number method may cause calibration problems relating to soil structure, profile depth and plants grown. The Nash-Sutcliffe coefficient of efficiency (ENS), the coefficient of determination (r2) and the percentage volume difference DV (%) are used to measure the model performance. In every simulation for calibration, only one parameter was adjusted while others were kept unchanged. Reiterations of optimization were done until satisfactory results were met, which was based on graphical comparison and numeric evaluation of the simulated discharge against the measurements.

B3 YRB MAS model

A modified penalty-based decentralized method (İnalhan et al., 2002; Yang et al., 2009) is applied in this study to solve the formulated MAS mathematical problem. This algorithm allows each agent to have its own decision context that captures the local benefits and the interconnected constraints associated with these benefits. The method achieves optimization among agents under a bargaining scheme, in which the i^{th} agent optimizes its objective with a selected priority for collaboration and sends the solution back to all other agents with which it interacts. The method uses a two-step approach – first finding out a solution based on the choices of all individual agents, allowing the violation of some constraints defined with the optimization models for individual agents, and then trying to reduce the constraint violation at the system level.

We apply the algorithm to the YRB. We also introduce a management mechanism that based on the free market concept. The mathematical expression for each water user (agent) is:

$$\max F_i(x_i, p_i | w_i) = \max\{f_i(x_i) - p_i(x_i - w_i)\} \qquad \text{(B3.1)}$$

where x_i is the water consumption from agent i, $f_i(x_i)$ is the benefit corresponding to x_i consumption, $p_i > 0$ is the local water price applied to agent i and w_i is water right or water permit for agent i. Under this setting, $x_i - w_i \neq 0$ can be viewed as the amount of water trading for agent i. When $x_i < w_i$, "- p_i $(x_i - w_i)$" is positive, which means agent i uses less water than it is entitled. Therefore, "- p_i $(x_i - w_i)$," is the benefit of water selling and works as an incentive to the agent. When $x_i > w_i$, "- p_i (x_i-w_i)," is negative and can be interpolated as the cost of water buying for agent *i*. Applying the first-order condition to equation 2.1, we can have:

$$\frac{\partial F_i}{\partial x_i} = 0 \Rightarrow f_i'(x_i) - p_i = 0 \qquad \text{(B3.2)}$$

We assume that each agent will adjust its p_i to satisfy equation B3.2, which means that the marginal benefit will equal to local water price and the ideal converge criteria at the system level matches when the condition in equation B3.2 is satisfied for all agents.

The attributes that characterize the agents are the water availability, water use and their benefit functions. The total available water for a unit includes three components: local surface water, groundwater (which was treated as a local "reservoir") and upstream inflow.

According to the above definition, the decision variable of each province-level water use agent is the monthly water consumption for agriculture and M&I purpose. Meanwhile, a utility function that uses GDP as the dependent variable and monthly water consumption as the independent variable is developed for each agent, at the monthly scale. Several assumptions are involved in the construction of the utility functions:

1) All the utility functions take a concave, quadratic form.
2) Annual $GDP_{M\&I}$, that is GDP generated by the urban-industrial sector, is evenly distributed across 12 months and the annual GDP_{AG} is distributed into each month based on the monthly distribution of agricultural water use.
3) M&I water use is given a higher priority than agricultural water use, which follows the general water use regulation in China.
4) A time variable (T) is incorporated into the M&I utility function to reflect the technology change over years (Cai and Rosegrant, 2002).
5) Monthly precipitation (P) is an input in the agricultural utility function.
6) Groundwater will be used when surface available water (local surface plus upstream inflow) is insufficient to supply M&I water consumption; groundwater recharge will occur when surface available water is larger than the M&I water consumption.

   The format of M&I utility function and the constraints for agent *i* is given as:

$$GDP_{M\&I} = A_{1i} \times x_i^2 + B_{1i} \times x_i + C_{1i} \times T + D_{1i} \qquad \text{(B3.3)}$$

$$\text{st.} \begin{cases} x_i - L_i - I_j \pm G_i \le 0 \\ x_i - MI_{\max} \le 0 \end{cases}$$

where x_i is the water consumption, L_i is local surface inflow, I_j is the inflow from upstream agent *j* and G_i is available groundwater. The plus and minus sign means it could be pumped from or recharged to groundwater. *T* is the technology index and year 2000 is set as the baseline year with T=100, MI_{max} is the maximal M&I water consumption and A_{1i}, B_{1i}, C_{1i}, and D_{1i} are the coefficients for the quadratic format. The non-linear regression method - least squares error method is used to estimate these four coefficients. Since only seven years of water consumption and GDP data (1997 to 2003) are available for each agent, a calibration procedure is undertaken to adjust the value of A_{1i}, B_{1i}, C_{1i}, and D_{1i} to match the result of baseline year.

The following equation represents the agricultural utility function of agent *i* and the constraints to which it is subject:

$$GDP_{AG} = A_{2i} \times [(x_i - MI_{\max}) + P_i]^2 + B_{2i} \times [(x_i - MI_{\max}) + P_i] \qquad \text{(B3.4)}$$

$$\text{st.} \begin{cases} x_i - L_i - I_j \pm G_i \le 0 \\ x_i - MI_{\max} + P_i \le AG_{\max} \end{cases}$$

where AG_{max} is the maximal agriculture water consumption (i.e., water demand), x_i-MI_{max} is the surplus M&I water that can be used for agriculture, P_i is the rainfall available for agriculture, and A_{2i} and B_{2i} are the coefficients which are also subject to calibration. There is no constant in equation 8 which means that we assume if no water (either irrigation or rainfall) is available, then GDP_{AG}=0.

The total benefit of a water use agent is the sum of $GDP_{M\&I}$ and GDP_{AG}. These utility functions remain unchanged for all scenarios. If not otherwise specified, the term “agent” means “water use agent” in the following sections.

The Definition of Reservoir Agents

There are more than three thousand reservoirs located in the Yellow River Basin. Their total storage is approximately 70 km^3, which exceeds the total annual runoff of the river, 58 km^3 (Cai and Rosegrant, 2004). It is impossible and not necessary to identify all the reservoirs as agents in this study, because most of them are small and their capacity is not sufficient to carry over water across the minimum time period of the model (i.e. a month). Five key reservoirs from upstream to downstream: Longyangxia, Liujiaxia, Wanjiazhai, Sanmenxia and Xiaolangdi are selected as reservoir agents. The combined storage for these reservoirs is about 51 km^3. All these reservoirs have multiple purposes such as water supply, flooding control and hydropower generation. The actual operation rules for all of the reservoirs are very complex. To incorporate the real operation rule of each reservoir into the modeling is time consuming and behind the scope of this study. To simplify the model without misrepresenting this complex system, the reservoir agents are defined based on two behavior rules, 1) following their pre-determined operation curve to regulate the streamflow, and 2) maximizing hydropower generation. Two objectives are defined for the reservoir agents:

$$\min_{x_i} f_i(x_i) = (x_i - Y_i)^2 \qquad \text{(B3.5)}$$

$$\max_{x_i} f_i(x_i) = x_i \times \Delta H(x_i) \qquad \text{(B3.6)}$$

$$\text{st.} \begin{cases} x_i - x_{Max} \le 0 \\ S_i - S_{Max} \le 0 \\ S_i^m = S_i^{m-1} + I_j - x_i - E_i \end{cases} \qquad \text{(B3.7)}$$

where x_i is the water released from reservoir agent *i*, and Y_i is the targeted water release specified by the basin management agency. $\Delta H(x_i)$ is the difference of water head during a given month, which is also affected by the water release, and change in storage. x_{Max} is the water release capacity, S_{Max} is the storage capacity, I_j is the inflow from upstream, and E_i is the evaporation from the reservoir. The two objectives expressed by Equations 5 and 6, respectively, may not be consistent. Following the current reservoir operation practices, the reservoir agent tries to match the pre-determined operation curve by minimizing the objective function (Equation B3.5). When no regulation exists, the reservoir agents maximize the objective for hydropower generation (Equation B3.6). The detailed use of different objectives will be explained in the scenario section.

The Definition of Ecosystem Agents

Three ecosystem agents are defined near the delta area to address the ecological and environmental concerns. Ecological and environmental flow requirements have been assessed by local scientists (e.g., Ni et al, 2002, Yang et al, 2009, Cui et al, 2009 and

Liu et al, 2009). They considered different environmental functions of the streamflow and defined the requirement of environmental streamflow for flooding (July to October) and non-flooding period (November to June). Yang et al (2009) estimated the baseflow of different regions for these two periods. The results of Ni et al. (2002) and Yang et al (2009) are used to set up the targeting flow for two ecosystem agents: Huayuankou and Gaocun. For one additional ecosystem agent, Lijin, at the delta of Yellow River, the target flows are assessed following the studies of Cui et al. (2009) and Liu et al. (2009). Cui et al (2009) separated a "fish breeding period" (April to June) from the rest of the non-flooding period. Liu et al. (2009) defined total ecological water requirement with consideration of wetland plants, freshwater fish community and bayou ecosystem. The targeting flow for the most downstream ecosystem agent is adapted from Cui et al (2009). The targeting flows for all ecosystem agents in different time periods are provided in Table B.1.2.

Table B.1.2 Targeting instream flow for ecosystem agents at different periods (without / with sediment flash consideration)

Agents	Normal flow period (November-March)	Fish breeding period (April-June)	Flooding period (July-October)
EA_1(Huayuankou)	0.341/0.605	0.341/0.605	0.455/5.111
EA_2 (Gaocun)	0.277/0.612	0.277/0.612	0.397/6.016
EA_3 (Lijin)	0.363/0.363	2.581/2.581	0.850/15.85

* unit: BCM/month

The utility function and the constraint for ecosystem agents are given by equation B3.8.

$$\min_{x_i} f_i(x_i) = (x_i - EcoT_i)^2 \qquad \text{(B3.8)}$$

$$\text{st. } x_i - I_j = 0$$

where x_i is the streamflow for agent *i*, $EcoT_i$ is ecological targeting flow and I_j is upstream agent *j* water release. The constraint is set as a hard constraint. Thus ecosystem agents under this formulation will act like reactive agents in the system (Yang et al., 2009).