Long Term Trends in Agricultural Water Productivity and Intersectoral Water Allocations in Zhanghe, Hubei, China and in Kaifeng, Henan, China

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ABSTRACT

Faced with growing demand for water for non agricultural uses – industry, domestic, and hydropower – China has been adopting a range of water saving irrigation practices. A study has been undertaken in two sites in China to identify the water saving practices and policies and determine the impact on water productivity at farm, system, and district level. The sites are the Zhanghe Irrigation System in the Yangtze River Basin approximately 200 km west of Wuhan and the Kaifeng City Prefecture located just south of the Yellow River in Henan Province. The study is being conducted by scientists from Wuhan University, the International Water Management Institute, and the International Rice Research Institute.

A first step in this study has been to examine the long term trends in water allocations between agricultural and non-agricultural uses and in crop and water productivity. In both sites there have been substantial gains in crop and water productivity although with a slowing down or modest decline in crop production. In this paper we describe briefly trends in water use and water productivity from the late 1960s until 2000. We describe the range of factors that may have contributed to water savings and gains in water productivity, and understand how these factors play role in different contexts (Yangtze River and Yellow River basins). As our study proceeds we hope to identify more clearly the relative importance of the various factors and some management strategies can be presented to the water managers to improve irrigation efficiency in their districts.
KEYWORDS: Long term trend, water allocation, competition, water productivity, water saving, Zhanghe Irrigation System, Liuyuankou Irrigation System, Kaifeng City, China.

1. INTRODUCTION

Competition for freshwater increases rapidly in Asia, with a growing demand for freshwater for industrialization and domestic urban needs. Less water will be available for agriculture, but more food is needed to feed a growing population. The per capita freshwater availability in China is amongst the lowest in Asia, and only one-third of the world's average (Wang, 2000). China has been facing an intense competition for limited water supplies for various uses during the last decade and it is becoming increasingly difficult to develop new fresh water sources. Much of the water will have to come from water savings. Rice, the staple food of China and a water intensive

crop is a major target for such savings. Growing more rice with less water is one of the major challenges of the 21st century and crucial for food security.

Major efforts have already been made to save water in irrigated rice areas and there is much to learn from previous efforts, particularly in China, where researchers and practitioners have already pioneered and developed many practices for farmers to deliver less water to their fields. These methods are collectively known as *water-saving irrigation* (WSI) practices and many success stories are reported (Li et al., 1998; Li, 1999; Li and Cui, 1996; Mao, 1993; Peng et al., 1997; Wang, 1992; Wu, 1998), such as *alternate wet and dry irrigation* (AWDI), which has spread in South China (Li et al., 1999). Li (2001) gives an extensive overview of the developments in WSI research in China.

This paper describes the analyzes the changes in water allocation and crop production in Zhanghe Irrigation System (ZIS) in the Yangtze River Basin, Hubei Province and in Kaifeng City Prefecture, along the Yellow River in Henan Province (Figure 1).

First the research locations are described in more detail, after which the sources of data and the rationale for dividing and averaging the data across three separate time periods are discussed. The change over time in water allocation among alternative uses will be described followed by a description of the changes in area irrigated and crop production over time. Finally the factors that may have contributed to increases in crop production and water productivity over time will be discussed.

2. SITE DESCRIPTION AND METHODOLOGY

This section describes briefly the two site locations in the Yangtze and Yellow River Basins and the procedures for analysis of data by trend and time period.

2.1 Zhanghe Irrigation System

Zhanghe Irrigation District (ZID) is situated in the Hubei Province in central China, north of the Yangtze river about 200 km west of Wuhan (Figure 1). The area of the Zhanghe basin is 7,740 km^2 including a catchment area of 2,200 km^2. Zhanghe Irrigation System accounts for most of the irrigated area within the irrigation district with an irrigated area of 160,000 hectares. The Zhanghe reservoir supplies most of the ZIS irrigation water, however there are tens of thousands of medium- or small-size reservoirs, small basins and pump stations in the area partly incorporated into the system but sometimes operating independently. Main grain crops are rice and winter wheat. The upland crops are beans, sesame oil and sweet potatoes. Paddy cultivation accounts for about 80 percent of the total irrigated area. Loeve et al. (2001) describe in detail the layout and operation of ZIS.

2.2 Kaifeng City Prefecture

Kaifeng City Prefecture is located on the south bank of the Yellow River, 70 km east of Zhengzhou the capital of Henan Province (Figure 1). It has a total area of 6,644 km^2 of which 363,300 ha are cultivated land. There are four irrigation districts located within Kaifeng City Prefecture, of which Liuyuankou Irrigation System is studied in more detail. Loeve et al. (2003)

gives an overview of the history and physical characteristics of Kaifeng City Prefecture, Liuyuankou Irrigation District and System. By the end of the year 2000 the actual irrigated area of Kaifeng City Prefecture was 327,000 ha, accounting for 90% of the cultivated land in Kaifeng City Prefecture. About 133,000 ha (40% of the actual irrigated area) is directly irrigated by Yellow River water. The main crops are rice, soybean, corn and peanuts, and in the winter season wheat.

Figure 1. Location of Zhanghe Irrigation District and Kaifeng City Prefecture in China.

2.3 Analysis of data by trend and time period

The time series on which this paper is based was compiled by ZIS for the period 1966 to 2001 and by Kaifeng City Prefecture for the period 1968 to 2000. The figures in the text show the trends over time. In the text tables, however, mean values are shown for three separate time periods, 1966 (or 1968)–78, 1979–88 and 1989–98 (or 2000). This division was made to reflect the very sharp changes that occurred at the end of the first and second time periods (according to Hong et al., 2001).

Following the end of the Cultural Revolution in the late 1970s, significant reforms took place that affected both irrigation and agricultural production. Introduction of improved varieties and increased use of chemical fertilizers led to a sharp increase in rice yields. In ZIS volumetric pricing was introduced. New pumping stations were built. Medium- and small-size reservoirs were restored or expanded. In Kaifeng Prefecture the Yellow River diversions dropped dramatically.

The end of the 1980s saw further changes. Industrial and municipal demand rose, resulting in an increased competition between water for agriculture and other uses. The introduction of hybrid rice in ZIS gave a further boost to rice yields. In ZIS the installation of two new hydropower plants greatly increased the hydropower capacity. The pressure to save water led to an expansion of AWDI practices at the farm level and to other water-saving practices.

3. LONG TERM TRENDS

This section presents the analysis of long term trends in water use, crop production, and irrigation water productivity first for the Zhanghe Irrigation District and then for the Kaifeng City Prefecture. The section concludes with a discussion of the factors contributing to the increase in crop production and water productivity in the two sites.

3.1 Water allocation among alternative uses in Zhanghe Irrigation District

Over the past three decades, with the increase in population and industry, the water demand from municipal, industry, and power generation has increased (Figure 2). Jinmen City, a few kilometers from the Zhanghe main reservoir, is a new industrial city and has developed quickly in recent years.

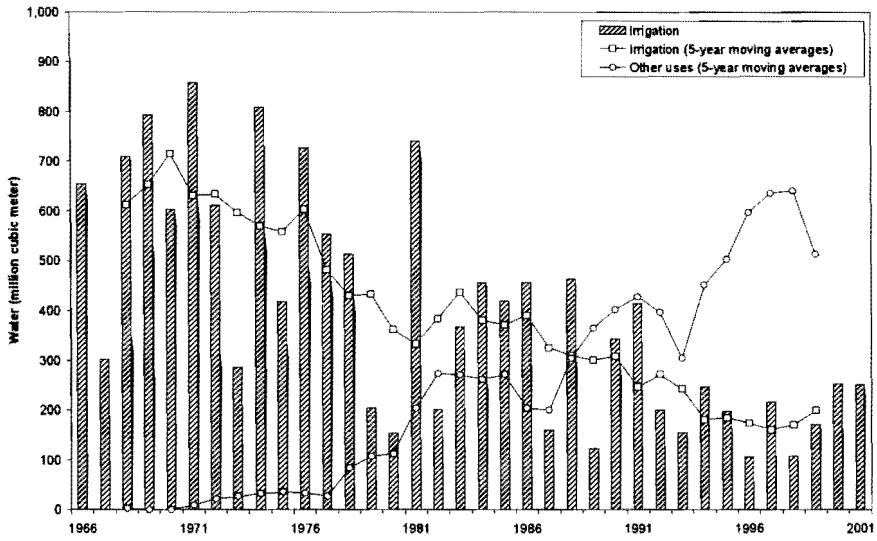

Figure 2. Zhanghe Reservoir, Hubei, China. Allocation for irrigation and other uses, 1966-2001. (adjusted from Hong et al., 2001).

* Other uses include: municipal, industry, hydropower and flood releases.

In ZIS most of the irrigation water supply comes from the Zhanghe Reservoir supported by medium and small size reservoirs and supplemented by pumping stations. A large (partly) interconnected irrigation network including storing, diverting, and withdrawing water has been established.

In the 1960s the main reservoir supplied three quarters of the irrigation water, but in the last decade it supplies only half of the total water for irrigation (Table 1). The water supply for irrigation from the main reservoir has dropped sharply since the mid-1980s. Despite the sharp drop in the water supply from the reservoir in the 1979-88 period, the total water supply for irrigation declined only slightly. In the 1980s a number of medium size reservoirs and ponds were restored or constructed to increase water-storing capacity, which evened out farm-level water availability from year to year and provided greater water control during the cropping season, facilitating water saving through alternate wetting and drying irrigation techniques on field level. However from the mid-1980s onward the water supply from small reservoirs and other source

declined. This seems to be due to the fact that many of the medium and small sized reservoirs were required to support themselves and were technically no longer a part of ZIS.

Table 1. Water supplied for irrigation in ZIS, by source.

	million cubic meter x 100			
Period	Main Reservoir	Small Reservoirs	Other sources	Total
1966-1978	6.03	1.50	0.96	8.50
1979-1988	3.62	2.47	1.65	7.74
1989-2001	2.14	1.12	0.70	3.96

The water supply for other uses (Figure 2) has increased rapidly from the 90ties. The largest increase in water allocation has been for hydropower, followed by industry and municipal water (Table 2). In contrast to most irrigation systems, the water flowing through the generators cannot be diverted back to irrigation.

The water allocated to hydropower in the 1989-2001 period exceeded the water allocated to irrigation. As a result of the growth in demand by hydropower and other sectors, the amount of water from the Zhanghe main reservoir allocated to irrigation in the past decade has declined to one third of its 1966-78 level (603 to 214 million m^3).

Table 2. Water releases and inflow Zhanghe reservoir.

	Average water use in million cubic meter x 100							Rainfall
Period	Irrigation	Industry	Municipal	Hydropower	Flood control	Evaporation	Inflow	(mm)
1966-1978	6.03	0.17		0.25	0.15	1.24	6.94	952
1979-1988	3.62	0.37	0.09	0.53	2.27	1.19	7.53	968
1989-2001	2.14	0.48	0.16	2.76	1.98	1.22	8.82	945

3.2 Changes in cropped area in Zhanghe Irrigation District and System

Table 3 shows the crop area irrigated in ZID and by ZIS for three time periods. Most of the irrigation is for rice. In the 1966–78 period, the area irrigated in ZID and by ZIS approximated the command area. However, in the beginning of the 21st century, the irrigated rice area had declined substantially compared to the 1979-88 period.

In the 1998–2001 period, irrigated rice area declined by 32 percent in ZIS and by 34 percent in ZID compared to the 1985–88 period. While this decline is large, it is much less than the 59 percent decline in total irrigation water supplied over the same period. Hong et al. (2001) describe in more detail the development over time of the irrigated rice area in ZIS and ZID.

Table 3. Command area and area irrigated in ZID and ZIS.

	Area in 1000 ha					
	ZID command area		ZID irrigated area		ZIS irrigated area (directly by reservoir)	
Period	Total	Rice	Total	Rice	Total	Rice
1966-1978	150	138	143	138	134	130
1979-1988	156	142	140	134	105	100
1989-2001	143	125	126	112	82	76

3.3 Changes in crop production in Zhanghe Irrigation District

Table 4 presents rice production, planted area, and rice yield per hectare for ZID. Rice production rose sharply in the period 1979–88 compared to the previous period despite a decline of 14 percent in planted area. This can be attributed due to the sharp increase in rice yields, due to the spread of modern varieties and increased use of chemical fertilizers following the change in agricultural policies at the end of the Cultural Revolution. Over the three time periods the yield per hectare of rice doubled. When the rice area began to decline substantially by the second half of the 1990s, rice production followed suit as yield growth had slowed to almost nothing. Comparing the 1998–2001 period with the 1985–88 period, rice area planted declined 31 percent while average yields rose by 9 percent. The net effect was a 25 percent fall in rice production. To some extent, this was compensated for by increased production of upland crops.

Table 4. Changes in rice irrigated area, plated area, production and yield in ZID.

Period	Irrigated area ha x 1000	Planted area ha x 1000	Rice ton x1000	Yield ton/ha	Water supplied MCM	$WP_{irrigation}$ kg/m^3
1966-1978	138	173	698	4.04	8.50	0.82
1979-1988	134	149	1,001	6.72	7.74	1.29
1989-2001	112	118	934	7.98	3.96	2.36

The total water supply for irrigation in ZID is unknown, except for the data on water supply in ZIS. However, it can be assumed that the main supply of water to areas in ZID not served by ZIS is the ZIS drainage water, with this information it is possible to estimate the change in water productivity over time. This assumption seems reasonable since in the period 1966–78 the area irrigated by ZIS and ZID was almost identical (Table 3). However, to the degree that this assumption does not hold, the water productivity values shown in table 4 represent an overestimate (Hong et al., 2001).

3.4 Water allocation among alternative uses in Kaifeng City Prefecture

During the past 30 years, municipal, industrial and livestock sectors have captured a larger share of total water use in Kaifeng City Prefecture (Figure 3), with their share rising from 13% in 1968 to 37% in 2000 (Table 5). The biggest increase came from industries, which in 1968 only used about 6% of the total water, but in 2000 had increased their share to 27%. The percentage of water use for agriculture correspondingly decreased from 87% in 1968 to 63% in 2000.

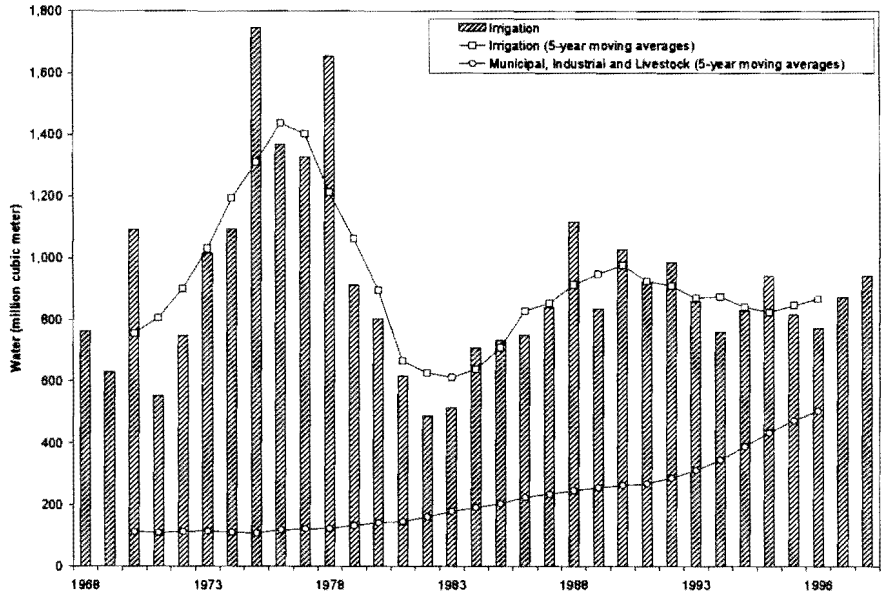

Figure 3. Water allocation for irrigation and other uses in Kaifeng City Prefecture, Henan, China, 1968-2000

The end of the 70ties show a sharp decline in agricultural water use (Figure 3), which is mainly due to a reduction in Yellow River diversions. A similar trend, although less obvious can be seen for the Yellow River diversion for Henan Province as presented by Dong et al. (2003) and in Liuyuankou Irrigation System (Loeve et al., 2003).

Table 5. Water use by sector Kaifeng City Prefecture (1968-2000).

	Average water use in million cubic meters				
	Irrigation	Municipal	Industry	Livestock	Total other uses
1968-1978	1,090	44	52	18	114
1979-1988	749	54	109	22	186
1989-2000	881	68	273	44	384

Groundwater extraction by all sectors has increased from 151 million m^3 in 1968 to 1,153 million m^3 in 2000 (Table 6). In the last 5 years more than 75% of the total water use in Kaifeng City Prefecture came from groundwater. This increase in groundwater use has allowed municipal and industrial demand to be met without cuts in supplies for agriculture. The share of total groundwater extraction used for the municipal and industrial sector increased from less than 5% in the first two periods to 35% in 2000 and picked up rapidly in the 1990ties (Table 6). It is not clear how much longer this trend is sustainable. Current research shows already a deep cone of depression in groundwater levels under Kaifeng City urban area, which might affect groundwater levels in rural areas.

The average total water use in the last decade is at the same level as in the period 1968-78, however looking within these periods the total water use increased from 876 million m^3 in 1968

to 1500 million m^3 in 2000, an increase of more than 70%. At the same time the Yellow River diversions dropped from 943 million m^3 in the 1968-1978 period to 392 million m^3 in the last decade, with a continuing downward trend resulting in a diversion of only 346 million m^3 in 2000. Whereas in the 1968-1978 period 77% of the total water use came directly from the Yellow River, in the 1989-2000 period this was reduced to less than one-third.

Table 6. Water use by source Kaifeng City Prefecture (1968-2000).

	Average water use in million cubic meters					
	Total	Total YRWD	Total groundwater	Groundwater for industry	Total for M&I	YRWD for M&I
1968-1978	1,205	943	262	10	96	42
1979-1988	935	505	430	31	164	79
1989-2000	1,265	392	873	208	341	64

YRWD = Yellow River Water diversion
M&I = Municipal and Industry

3.5 Changes in cropped area in Kaifeng City Prefecture

Table 7 shows the planted area of major crops on Kaifeng City Prefecture and average annual growth rates (3-years moving average). Among the summer crops corn was historically the most important. Since the economic reforms, however, the area planted to cotton and peanut has expanded at the expense of food crops like corn and soybean. The planted wheat area in Kaifeng City Prefecture increased rapidly after the reforms, most of the expansion occurred by 1985. The reduction in planted area rice in the period 1979-88 coincides with the reduced Yellow River water diversions in this period. The same trend is observed in Liuyuankou Irrigation System and is explained by deteriorated structures and lack of canal maintenance which forced the system management to reduce diversions to avoid further damage to canals and danger of breaches (Loeve et al., 2003). Heavy investments in infrastructure improved the water availability and around 1988 the trend reversed and the planted rice area increased again.

Table 7. Area of major crops, 1968-98, Kaifeng City Prefecture, with annual average growth rates in selected periods.

	Area in 1000 ha					
	Wheat	Corn	Soybean	Cotton	Peanut	Rice
1968-1978	193	54	41	26	20	7
1979-1988	240	82	55	70	47	6
1989-1998	289	75	30	97	78	7
Annual growth 1968-78 (%)[1]	1.3	21.0	-5.0	3.8	-3.5	0.8
Annual growth 1979-88 (%)[1]	3.7	-3.1	0.4	13.0	10.7	-7.5
Annual growth 1989-98 (%)[1]	0.6	-0.7	-4.6	0.0	1.4	9.1

[1] Annual average growth rates (3-years moving average).

3.6 Changes in crop production in Kaifeng City Prefecture

Table 8 shows the production of major crops on Kaifeng City Prefecture and average annual growth rates (3-years moving average) (Loeve et al., 2003). As in China in general, yields have

increased rapidly in the past 20 years. Most of the yield growth occurred in the first few years after the reforms, but yields have continued to increase after 1985.
The increase in production of wheat, corn and soybean in the period 1989-98 can be attributed to the increase in yield. For peanuts both the increase in planted area and higher yields resulted in an tremendous increase in crop production. The increase in production of all crops, except rice, in the period 1989-98 can be attributed to the increase in yield. For rice the increase in planted area was the main factor for higher production.

Table 8. Production, 1968-98, Kaifeng City Prefecture, with annual average growth rates in selected periods.

	Production in 1000 tons					
	Wheat	Corn	Soybean	Cotton	Peanut	Rice
1968-1978	231	86	34	8	11	21
1979-1988	754	241	65	51	67	21
1989-1998	1,139	386	55	87	208	42
Annual growth 1968-78 (%)[1]	11.3	21.8	-3.2	0.1	-0.8	12.1
Annual growth 1979-88 (%)[1]	10.2	3.3	2.8	30.0	19.4	-3.4
Annual growth 1989-98 (%)[1]	4.8	3.9	1.8	3.8	6.8	9.8

[1] Annual average growth rates (3-years moving average).

Without detailed information about water use per crop in Kaifeng City Prefecture it is impossible to calculate the water productivity per crop. However a more general idea about the water productivity trend over time can be established.
At the end of the 70ties agricultural water use declined sharply, primarily due to reduced diversions from the Yellow River. One major reason for this decline in water use was that large amounts of Yellow River water (and its associated sediment) were diverted for land reclamation from 1973-1978. Once this strategy ended, water use declined sharply. This suggests that there were improvements in water productivity (in terms of planted area per unit water utilized) in the first few years after reforms. In the period 1989-1998 agricultural water use has been essentially constant in Kaifeng City Prefecture, as has agricultural crop area. Agricultural production has increased, but can be attributed entirely to increased yields per unit area. Thus, any gains in water productivity in this period are most likely due to improved varieties and increased use of inputs such as fertilizer, not improved water management techniques. Table 9 shows the agricultural production value of all crops in Chinese Yuan in Kaifeng City Prefecture. It clearly confirms that the agricultural production value increased tremendously over time and most of the gains came from the increased value per hectare. The increase in water productivity is, however, impressive, although most of it cannot be attributed to improved water management techniques.

Table 9. Agricultural production value in Chinese Yuan and water productivity, 1968-98, Kaifeng City Prefecture, with annual average growth rates in selected periods.

	Agricultural Production Value		$WP_{irrigation}$
	Million RMB[2]	RMB/ha	RMB/m^3
1968-1978	307	537	0.31
1979-1988	1,015	1,610	1.41
1989-1998	4,165	6,169	4.91
Annual growth 1968-78 (%)[1]	4.2	3.6	-0.4
Annual growth 1979-88 (%)[1]	15.1	13.5	16.0
Annual growth 1989-98 (%)[1]	18.1	15.3	18.0

[1] Annual average growth rates (3-years moving average).
[2] Not indexed.

Further analysis is needed to establish detailed trends over time and explain the reason for these trends.

3.7 Factors Contributing to the Increase in Crop Production and Water Productivity

In Zhanghe Irrigation District long term trends in water allocation across sectors and in yield per hectare and per cubic meter of irrigation water supplied show that there have been water savings and a considerable increase in water productivity over time (Hong et al., 2001). Despite the decline in water for irrigation from the reservoir and in the area irrigated in ZID, rice production has declined only slightly over the averaged period but has declined by about 25 percent from the peak reached in the mid to late 1980s. Hong et al. (2001) describe several factors that may have contributed to sustained rice production including:

i) economic and institutional reforms initiated in 1978,
ii) a shift in cropping pattern from two to one crop of rice,
iii) on-farm and system WSI practices, such as ADWI,
iv) volumetric pricing of water,
v) development of alternate sources of water such as small reservoirs and groundwater,
vi) recapture and reuse of return flows through the network of reservoirs.

The various changes that occurred are not independent of each other, and more research is needed to identify more precisely the contribution of each of these factors. According to Hong et al. (2001) more than half of the increase in water productivity in ZID can be explained by the increase in yield per hectare. But a substantial amount of the gain in water productivity remains to be explained by other factors. AWDI practices may be one of the reasons behind the increase in water productivity in ZIS over time. Many farmers have adopted some form of AWDI practices in ZIS (Moya et al., 2001) and the adoption of AWDI practices had no effect on yields and reduced the water use at least at the farm scale (Cabangon et al., 2001 and Moya et al., 2001).

In Kaifeng City Prefecture long term trends in water allocation across sectors and in yield per hectare and per cubic meter of irrigation water supplied show a considerable increase in water productivity over time. However the data indicate that these gains have come from increased yields per unit area, not from reductions in water use due to water saving irrigation techniques. The reduction in Yellow River diversions over time is compensated for by an increase in

groundwater extraction in Kaifeng City Prefecture. It is not clear how much longer this trend is sustainable.
A further reduction in Yellow River diversions to the different irrigation districts in Kaifeng City Prefecture will most likely affect the cropping pattern and might have a negative impact on the agricultural output. Different actions are already undertaken at irrigation district level to make the best possible use of the currently available water. In Liuyuankou Irrigation System drainage water flowing out of the rice growing areas is redirected to so called *"recharge ditches"*, where it is used either to recharge the groundwater or pumped to the fields directly for irrigation. These kinds of practices will have a positive impact on the water productivity in the system and will influence the total water productivity in Kaifeng City Prefecture as a whole.

4. CONCLUSIONS

This paper examined the trends in water allocation among sectors, water use by source, cropped area and crop production and water productivity. In both study areas the water demand for purposes other than irrigation has grown. In Zhanghe Irrigation District this resulted in a sharp reduction of the water availability for irrigation. In Kaifeng City Prefecture the increased demand from other uses could be met by an increase in groundwater extraction without the dramatic cuts in supplies for agriculture as in ZID. However it is not clear how much longer this trend is sustainable.

In Zhanghe Irrigation District several water saving practices have been adopted to maintain crop production. The yield per unit area doubled, but production per unit irrigation water supplied almost tripled between the periods 1966-78 and 1989-2001. There are many different factors that may have contributed to the increase in water productivity, including ADWI practices, a changing cropping pattern, development of alternate water sources, volumetric pricing of water and the recapture and reuse of return flows through the network of reservoirs. The relative importance of the different factors contributing to increasing water productivity has yet to be determined and is a major scope for future research. A major objective of this research will be to identify those practices that could be successfully extended to other regions, both inside and outside China.

In Kaifeng City Prefecture agricultural production increased substantially since the economic reforms. At the end of the 1970ties agricultural water use declined sharply, primarily due to reduced diversions from the Yellow River, which indicates increased water productivity per unit of land. In the last decade agricultural water use has been essentially constant as has agricultural crop area, but agricultural production has increased substantially. Data indicate that these gains have come from increased yields per unit area. Gains in water productivity in this period are most likely due to improved varieties and increased use of inputs such as fertilizer, not improved water management techniques. The increase in water productivity is, however, impressive, although most of it does not result from reductions in water use due to water saving irrigation techniques.

This study illustrates the different stages a basin will experiences under pressure of increased competition of water. In Zhanghe Irrigation District new fresh water sources, i.e. small reservoirs were already exploited and the scope for developing new water sources was limited, resulting in the introduction of water saving policies and practices. But there appears to be little scope for

additional water savings and hence any further increase in allocation to non-agricultural uses is likely to result in further reduction in crop production. In Kaifeng City Prefecture there was still an opportunity to exploit new water sources, i.e. groundwater, and till now most of the water productivity increase comes from increased yields. However with an ever increasing competition for water and a limit to the exploitation of groundwater, water saving policies and practices will be needed in the future.

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