Water

Impact of Water-Saving Irrigation Techniques in China:

Analysis of Changes in Water Allocations and Crop Production in the Zhanghe Irrigation System and District, 1966 to 1998

Hong, L., Li, Y.H., Deng, L., Chen, C.D., Dawe, D., Loeve, R., Barker, R.

In 1999, IWMI, in collaboration with the Wuhan University of Hydraulic and Electrical Engineering and the International Rice Research Institute, initiated a study on the impact of water-saving irrigation techniques in China. The initial focus was on *alternate wet and dry irrigation* (AWDI). As opposed to continuous flooding of paddy fields, AWDI allows for periods of field drying that reduce application requirements. The practice is widely adopted in the rice-growing areas of China and is said not only to save water but also to increase rice yields due to sturdier plants and the reduction of *black root.*

productivity in agriculture

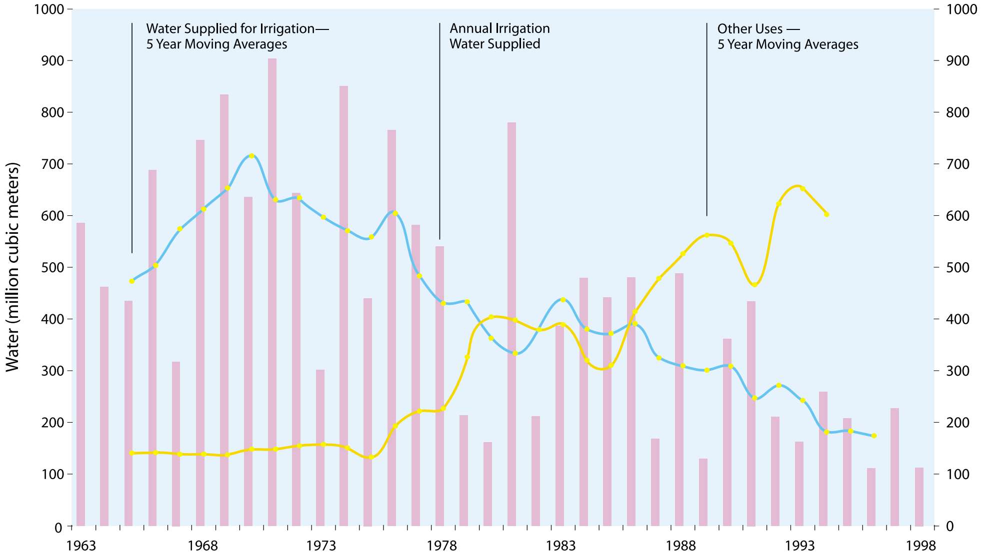
Our main research site is the Zhanghe Irrigation System (ZIS). The Zhanghe Irrigation District (ZID) is situated in the middle part of China north of Changjiang (Yangtze) river. ZID is an administrative unit consisting of all or parts of several county and city jurisdictions. The ZIS's water comes principally from the main reservoir although there are smaller reservoirs and other sources such as groundwater. The Zhanghe basin is 7,740 km^2 including a catchment area of 2,200 km^2. The ZIS accounts for most of the irrigated area within ZID. It is one of the typical large-size irrigation systems in China. Its designed irrigation area is about 160,000 ha. The Zhanghe reservoir, built between 1958 and 1966 on a tributary of the Chiangjiang river, supplies most of the irrigation water in ZIS. The reservoir was designed for multipurpose uses of irrigation, flood control, domestic water supply, industrial use, and power generation.

It is hypothesized that AWDI is one of the water-saving practices that has enabled Zhanghe to transfer water to other higher-valued uses without significant loss in crop production. We are conducting research at three levels to assess the extent of application and impact of AWDI. These include: (i) controlled experiments with and without AWDI and for different timing of fertilizer application, (ii) farm surveys to identify the degree of adoption of AWDI, and (iii) flow monitoring at various scales within ZIS to assess the farm up to the basin impact of AWDI.

Our ultimate goal in this research is to see whether water-saving technologies used successfully in China can be used in other rice-growing areas of the world. We feel that water-saving irrigation practices such as AWDI and recapture of return flows are suitable for monsoonal areas where there is considerable outflow that could be saved and put to productive use. In the more arid regions, especially where the water resources are fully committed to various uses, the scope for water saving by AWDI and related techniques may be limited.

Here we report on one of the initial steps in our research, an analysis of the historical records compiled by the Zhanghe system. This includes annual data compiled since 1966 on water inflows and allocation among alternative uses, area irrigated, and crop yields per hectare and per cubic meter of water. From the late 1970s to the late 1990s, water from the Zhanghe reservoir allocated to irrigation dropped from 600 mcm (million cubic meters) to about 200 mcm (fig. 1). The water allocated for other uses (municipal, industry, and hydropower) has increased steadily. However, the area irrigated and total grain production in ZID has declined only modestly. In analyzing the changes taking place, we identify those factors that seem to have contributed to sustained agricultural production despite a significant reallocation of water from irrigation to other uses.

Figure 1. Zhanghe Irrigation Reservoir, Hubei, China annual water allocations for irrigation and other uses, 1965–1998.



Analysis of Data from a Historical Perspective

The time series on which this report is based has been compiled by ZIS for the period 1966–1998. The values show the trends over time. In the tables, however, mean values are shown for three separate time periods—1966–78, 1979–88, and 1989–98. This division was made to reflect the very sharp changes that occurred at the end of the first and second time period.

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

The end of the 1980s saw further changes. The installation of two new hydropower plants greatly increased hydropower capacity but industrial and domestic demand also rose resulting in a still further decline in water available for irrigation. The pressure to save water led to an expansion of AWDI techniques at the farm level and to other water-saving practices such as canal lining. The introduction of hybrid rice gave a further boost to rice yields.

Regulation and Allocation of Water among Alternative Uses in the Zhanghe Reservoir

In ZIS, most of the irrigation comes from the Zhanghe reservoir supported by medium and small-size reservoirs and supplemented by a pumping station. Thus, a large irrigation network including storing, diverting, and withdrawing water has been established.

The water available for irrigation includes rainfall, water from main and minor reservoirs, river water, and groundwater. The annual rainfall is 960 mm with a standard deviation of approximately 20 percent. The inflow of water seems to have increased significantly over time. Also in more recent years, there have been significant releases of water for flood control. The flood year 1996 provides a clear example. The rainfall (1,354 mm) and inflow ($16.4 \times 10^8 m^3$) were abnormally high. Water released for flood control ($8.2 \times 10^8 m^3$) was the highest on record. Adjusting for water released for flood control, the available supply of water from the Zhanghe reservoir does not appear to have changed significantly over time. However, there are large year-to-year fluctuations which affect the annual releases for irrigation (fig. 1). When rainfall is low and the irrigation system needs more water for irrigation, the water yield from the catchment is small and vice versa.

Zhanghe is a multipurpose reservoir. While the primary purpose is irrigation other uses include flood control, hydropower, municipal and industrial water supply, navigation, and aquatic culture. The tasks of regulation are based on planning, design, and experience. The objectives of water supply are subordinate to flood control and the prerequisite reservoir safety. As much water as possible is stored to meet water demand for all users, but irrigation has the priority. In years of extreme shortage, such as the current year, water for hydropower is reduced.

In the 1966–78 period the main water use was for irrigation, but water was not managed well. The standard of flood control was low. There was excess water at the upper end of the canal but farmers at the lower end often did not receive water. In the period 1979–88 there were substantial improvements in regulation and management and volumetric pricing of water was initiated. In the most recent period, 1989–98, new management tools and information technologies were tested and implemented. These included multi-objective optimization modeling, real-time information feedback regulation management for forecasting weather and inflow into the reservoir, and remote sensing. Reservoir regulation and flood control were successfully linked with weather forecasting. In summary, improvements in regulation and management have improved the capacity of the Zhanghe reservoir in flood control and in satisfying demands for water among alternative users and uses.

Irrigation Performance Indicators

An emerging impact of IWMI's research over the past five years is a set of Irrigation Performance Indicators (water productivity in irrigated agriculture) which help water managers quantify the performance of a system from nine different perspectives.

Through more recent research, IWMI scientists have further refined these to four key indicators: agricultural output per cropped area; output per irrigation unit command; output per irrigation supply; and output per unit of water consumed. Agricultural systems have been studied in South America, Asia, North Africa, sub-Saharan Africa, the Middle East and the United States.

Since their introduction, the Indicators have been used to measure 40 irrigation systems in 15 countries. *IWMI Research Report 20*, available at www.iwmi.org presents this performance measurement data.

Others are starting to use this thinking and fine tune it to meet their own needs. The Indicators are core measurement criteria in the World Bank/IPTRID Irrigation Benchmarking System. Nepal, Sri Lanka and Mexico are at various stages of using the Indicators as agricultural policy tools.

Over the past three decades, with the increase in population and industry, the water demand from city, industry, and power generation has increased (fig. 1). Jinmen, a few kilometers from the Zhanghe main reservoir is a new industrial city with a population of 320,000. It has developed quickly in recent years. The central, provincial, and prefecture governments have established a number of factories in the city. Major industries include oil, chemicals, textiles, and leather. In addition to the Jinmen city other smaller cities and towns have developed rapidly placing a growing demand for water for industry and municipal use. The Zhanghe main reservoir supplies water to Jinmen, while domestic water for smaller cities and towns is supplied by medium and small reservoirs or groundwater.

Table 1: Water Inflow and Releases from Zhanghe Irrigation Reservoir.

Period	Average Water Uses (mcm x 100)							Rainflow
	Irrigation	Industrial	Municipal	Hydro-electric	Flood Control	Evapo-ration	Inflow	(mm)
1966–78	6.03	0.17	–	0.25	0.15	1.24	69387	952
1979–88	3.62	0.37	–	0.53	2.27	1.19	75275	967
1989–98	2.12	0.48	0.15	2.51	2.83	1.23	90273	967

1975–78 Average for industrial water use. 1973–78 Average for hydro-electric water use.

However, the largest increase in water allocation has been for hydropower, followed by industry and municipal use (table 1). The Zhanghe main reservoir was designed with one hydropower plant of 2 x 800 kw capacity utilizing, on average, a water supply of 0.84 x 10^8m^3. In contrast to most irrigation systems, the water flowing through the generators cannot be diverted back to irrigation. In 1989 and 1995, two new hydropower sets of 1 x 800 kw and 2 x 1,600 kw were installed. The water allocated to hydropower in the 1989–98 period exceeded the water allocated to irrigation—2.5 versus 2.1 10^8m^3 per annum (table 1). 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 (6.0 to 2.1 x 10^8m^3).

Change in Water Supplied for Irrigation by ZIS

Figure 2 compares the trend in water supply to irrigation by the Zhanghe main reservoir and by ZIS. In the 1960s and 70s the main reservoir supplied three-quarters of the water for irrigation, but now it supplies only half. The water supply for irrigation by ZIS 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 ZIS declined only slightly. This is because in the 1980s, a number of medium-size reservoirs and ponds were restored or constructed to increase the water-storing capacity. This 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 management of water in paddy fields. In the mid-1980s onward, however, the ZIS water supply from small reservoirs and other source declined. The apparent reason for this is that many of the medium and small-size reservoirs were required to support themselves and were technically no longer a part of ZIS.

Change in Rice-Irrigated Area and Paddy Rice Production and Yields in ZID

What impact has the reduced allocation of water for irrigation had on crop production, and on land and water productivity? The rice-irrigated area in ZID has declined, particularly during the 1990s (table 2). However, the area planted to upland or non-paddy crops has increased from 19,000 ha in 1966–78 to 63,000 ha in 1989–98. Since our focus is on irrigation, in this section we analyze the changes in production and yields only for rice.

The reported paddy rice grain production and yield per hectare are shown for ZID in table 2. No data are available on ZID water supply for irrigation. However, we assume that the main supply of water to areas in ZID not served by ZIS is the ZIS drainage water. Based on this assumption, we have estimated the yield per cubic meter of water. (This assumption seems reasonable since during the period 1966–78 the area irrigated by ZIS and ZID were almost identical).

Rice production rose sharply during the period 1979–88 compared to the previous period despite a decline of 13 percent in planted area. This is because rice yields rose sharply 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. Comparing the period 1989–98 with the previous period, rice planted area dropped by 19 percent and yields rose by 16 percent. Thus, rice production declined slightly. Over the three periods the yield per hectare of rice doubled, but the yield per cubic meter of water appears to have tripled. The increase in water productivity was greatest between the second and third period.

Factors Contributing to the Increase in Crop Production and Water Productivity

The long-term trend in water allocation across sectors and the trends 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. Despite the decline in water for irrigation from the reservoir (table 1) and in the area irrigated in ZID (table 2), crop production has been sustained.

Table 2: Changes in Paddy Rice Irrigated Area, Planted Area, Production and Yield in Zhanghe Irrigation District.

	Irrigated Area ha x 1000	Planted Area ha x 1000	Crop Production MT x 1000	Yield t/ha	Water Supplied Million mcm x 100	Yield* Kg/m^3 (irrigation)
1966–78	138	173	698	4.04	8.50	0.82
1979–88	134	151	1015	6.72	7.74	1.31
1989–98	118	122	952	7.80	4.10	2.32

*Upper limit, see Text for Discussion

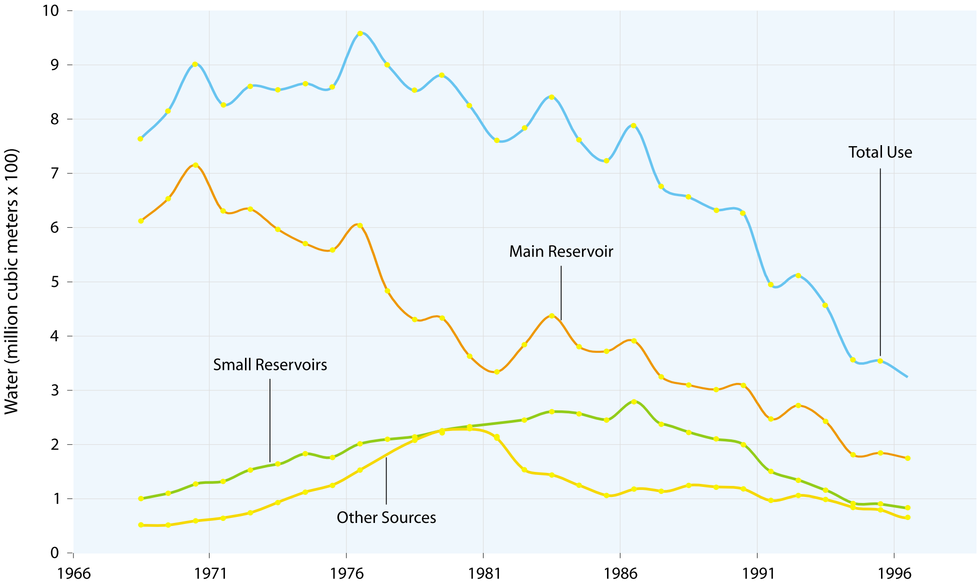
Several factors may have contributed to sustained rice crop production including: (i) economic and institutional reforms initiated in 1978, (ii) higher crop yields due to adoption of modern varieties and increased use of chemical fertilizer, (iii) a shift in the cropping pattern from two to one crop of rice, (iv) on- farm and system water-saving irrigation practices (e.g., AWDI of paddy fields), (v) volumetric pricing of water, which may have encouraged AWDI, (vi) development of alternate sources of water such as small reservoirs and groundwater, and (vii) recapture and reuse of return flows through the network of reservoirs. Of course, the various changes that occurred are not independent of each other, but we are attempting to identify more precisely the contribution of each of these factors.

Conclusions

The Zhanghe Irrigation System was initially designed as a multipurpose reservoir. Water was supplied initially only for irrigation. Gradually, the supply and management of water for other purposes has grown in importance. This includes flood control, hydropower, and municipal and industrial water needs. The reservoir also serves environmental needs, tourism, aquatic culture, and navigation.

In this report we have examined the trends in water allocation among sectors, in area irrigated, and in crop production and productivity. As water demand has grown for purposes other than irrigation, the water supplied to irrigation has fallen sharply. In order to maintain crop production, several water-saving practices have been adopted. While yield per hectare has doubled from the 1960s to the 90s, yield per cubic meter of water appears to have tripled.

Figure 2: Water use for irrigation from different sources.



There are a number of factors that may have contributed to the increase in water productivity. Research is being conducted to identify the impact of water-saving practices. The initial focus is on AWDI. A major objective is to identify those practices that could be successfully extended to other regions outside of China.

The Chinese authors of this paper are attached to the Wuhan University of Hydraulic and Electric Engineering, Wuhan and the Zhanghe Irrigation System, Hubei in China; D. Dawe is a researcher with the International Rice Research Institute (IRRI), Manila, Philippines. Ronald Loeve is a researcher with the Irrigation and Water Resources Program of IWMI, Randolph Barker is a senior scientist at IWMI.

This paper is part of a study entitled *Impact of Water Saving Irrigation in China* funded by the Asian Centre for International Agricultural Research (ACIAR). The research is being conducted by a team of scientists from the Wuhan University of Hydraulic and Electrical Engineering in China, the International Rice Research Institute in the Philippines, and the International Water Management Institute in Sri Lanka.