Implications of environment and institutions for water productivity and water savings: lessons from two research sites in China

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Abstract

This paper is based on research conducted at two irrigation systems in China situated in strikingly different environments. The Zhanghe Irrigation System (ZIS) is located just north of the Yangtze River approximately 200 km west of Wuhan. The Liuyuankou Irrigation System (LIS) lies south of the Yellow River, just to the east of Kaifeng City. ZIS is situated in hilly terrain with clay loam soil and relatively abundant water resources but increasing competition for water for other uses. LIS is situated in flat terrain with loam soil and good groundwater resources in the physically water-scarce Yellow River Basin. What can be learned by contrasting these cases? The lessons about water productivity and savings form part of a changing trend in thinking about irrigation that considers the analysis of scales, multiple uses, and practices of irrigation in the context of water scarcity.

The paper presents institutional and management arrangements and contrasts water management strategies at farm, system and sub-basin level and shows how these have led to water savings and increases in water productivity. In the water-rich environment of ZIS, farm and canal management of water is much more precise than in the water-scarce environment of LIS. Yet both systems are close to their water-saving potential. Both systems have experienced remarkable increases in irrigation water productivity over time, largely from increases in crop yields, but in the case of ZIS also from changes in management. Controlling supplies and reallocating as much as possible to non-agricultural uses while assuring an adequate supply for agriculture is extremely important in ZIS where water productivity per unit of irrigation supply is the key measurement. At LIS, because of water resource scarcity, there is evidently scope for reducing evaporation from raised watertables. Thus, water productivity per unit of evapotranspiration is the key measurement. We suggest that design improvements at LIS be targeted to reduce any non-beneficial evaporation, a recommendation that holds across many water-scarce environments globally.

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环境和体制对水分生产率和节水的影响
一从中国两处试验研究获得的启示

摘要：这篇论文基于在中国两个环境完全不同的灌溉系统开展的研究工作。漳河灌溉系统（ZIS）位于长江以北，大约在武汉市以西200公里的地方。柳园口灌溉系统（LIS）坐落在黄河以南，东临开封市。漳河灌区的地形为山地梯田，土壤为粘壤土，水资源相对丰富，但其他用水户的用水竞争与日俱增。柳园口灌溉系统坐落在平原地区，土壤为壤土，在地下水资源条件良好但缺水的黄河流域。对比这两个相反的例子会得到什么结果呢？水分生产效率和节水的启示引发了思考灌溉变化趋势，包括考虑分析尺度，多目标应用和在缺水条件下的灌溉实践 。论文介绍了体制和管理方面的安排以及在农田、灌溉系统和子流域上相互对比的水管理策略，展示了这些因素如何促进实现节水和增加水分生产效率。在水资源丰富的漳河灌溉系统，农田和渠道的水管理要比缺水的柳园口灌溉系统精确的多。这两个灌溉系统还具有节水潜力。这两个灌溉系统都经历了灌溉用水生产效率随时间的显著提高，大部分来源于作物产量的增加，但对于漳河灌区水分生产效率的提高还来源于在管理方面的改善。在漳河灌区，控制供水并尽可能将更多的水重新分配给非农业用户，同时保障为农业提供充足的水源是极其重要的。在漳河灌区，单位灌溉水量的水分生产率是主要的衡量指标。由于缺水，在柳园口灌溉系统通过减少由于地下水位升高而产生的蒸发是显而易见的事。因此，单位蒸腾量水分生产效率是主要的衡量指标。我们建议，在柳园口灌溉系统改善设计的目标是减少所有的无效蒸发，这一建议对全世界许多缺水的环境条件都实用。

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1 Introduction

Between 1999 and 2005, detailed studies of two irrigation systems were carried out in China.[2] The Zhanghe Irrigation System (ZIS) is located just north of the Yangtze River near the city of Jinmen, about 200 km west of Wuhan (Figure 1). The Liuyuankou Irrigation System (LIS) lies south of the Yellow River, just to the east of Kaifeng City.

Figure 1. Locations of study sites: Zhanghe Irrigation System (ZIS) and Liuyuankou Irrigation System (LIS)

The different physical and institutional contexts for each system provided an excellent opportunity to gain valuable insights into water savings, water productivity, institutions and incentives, irrigation operations and infrastructure. Studies were carried out at different scales — field, farm, household, canal level, system and sub-basin level — providing different perspectives on each of these issues. This paper compares and contrasts the two systems to draw out important lessons for stakeholders of the systems and, more widely, for all those involved in improving irrigation for enhanced water productivity.

The paper is organised as follows. Sections 2 and 3 describe the physical and the institutional context and settings for the two research sites. Section 4 discusses the incentives to save or reallocate water, and the sixth through eighth sections the scope for water saving and gains in water productivity. Section 9 is concerned with scale issues in water-resource management. Section 10 presents strategies for improved water-resource management in ZIS and LIS. The final section, Rethinking irrigation, draws some general conclusions about irrigation that emerge from this study.

2 Comparing ZIS and LIS: the physical context

ZIS lies in the Yangtze River Basin which, from an annual, basin-wide perspective, has ample water, but locally and in certain seasons physical scarcity may be an issue. The basin is ‘open’[3] in that not all water is allocated across uses, one of the reasons that China is considering a project for south–north water transfer. Downstream users will not readily notice whether or not ZIS depletes more water. On the other hand, the ZIS storage systems are important in protecting the basin from floods.

LIS is situated within the Yellow River Basin, a chronically stressed river. This basin is ‘closed’, in the sense that all water is allocated across uses, and there is arguably not enough water to meet environmental-flow requirements. If LIS depletes more water, other users within the basin will be affected, and it will be a contentious issue in river basin management.

ZIS is situated in hilly terrain that gradually flattens to the floodplains of the Yangtze. At ZIS, most drainage water readily finds its way back to the natural drainages and river system where it can be captured and used or reused, and is classified as a natural recapture zone.[4] The soil is clay loam with a relatively low percolation rate. Farmers acting on their own and the irrigation authorities in the area have taken advantage of this situation and built thousands of reservoirs and ponds of various sizes to capture drainage flows. Floods far overshadow water scarcity as an issue in the area. For safety, reservoirs are often drawn down to low levels in the flood season, a practice that at times stresses the agricultural system. Although not a topic of this study, water

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[2] This paper is based on the results of the project ‘More rice less water’ supported by the Australian Centre for International Agricultural Research (ACIAR).

[3] Open basins are those where useable outflow exists (in excess of acceptable environmental-flow levels) at the end of the basin and there is additional water for allocation across uses. Closed basins are those where all water is already allocated to human and environmental uses (Seckler 1996).

[4] Using the hydronomic zone classification system (Molden and Sakthivadivel 2000) in which a zone is an area where similar strategies can be developed. A natural recapture zone is an area where drainage flows by gravity to a river drainage, and can be reused from the river.

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quality is of increasing concern, especially pollution from agro-chemicals.

On the flat floodplains of the Yellow River, loamy soil with high percolation rates dominates LIS. There are two quite distinct zones within LIS — a natural recapture zone upstream of the railway line, and a regulated recapture zone[5] downstream of the line (Figure 2). Land use upstream of the line is dominated by paddy cultivation, with water in excess of crop evapotranspiration (ET) either finding its way to drains or percolating to groundwater. The drains eventually flow to the regulated recapture zone downstream of the railway line. Farmers use drainage canals and groundwater as primary sources of water. As in ZIS, reuse is prevalent, except that LIS relies more on pumping from drains and groundwater, while ZIS uses gravity and surface storage to capture flows.

The role of groundwater is quite different in the two areas. At LIS it is a main source of water below the railway line through pumping. At ZIS it is a significant, but indirect source, with high watertables contributing directly to crop ET. Much of the groundwater at LIS emanates from recharge from the Yellow River and rainfall. Much of the Yellow River recharge is induced by pumping. This underground withdrawal of water apparently goes officially unrecognised in Yellow River Basin water allocations. At ZIS, groundwater levels are influenced by topography and paddy irrigation practices, but it appears that these are not actively managed to control groundwater levels. Fortunately for both areas, salinity is not a major concern. Before large-scale pumping at LIS in the 1960s, watertable rise and waterlogging led to salinity build-up because of little surface or subsurface drainage at the larger system scale. Because of installation of pumps, the drainage at LIS is now adequate. Table 1 give a summary comparison of ZIS and LIS.

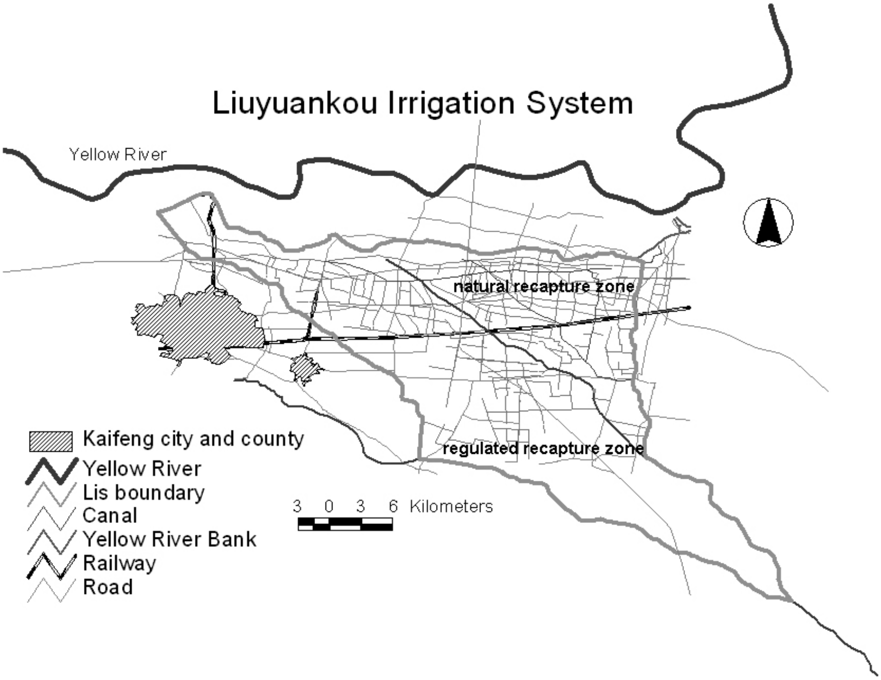

Figure 2. Layout of the Liuyuankou Irrigation System (LIS). The rice area served by canals is north of the railway line, while the diversified cropping system supported by groundwater lies south of the line.

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[5] A regulated recapture zone is where drainage water flows to drains or groundwater, and its reuse can be regulated by pumps or other hydraulic structures.

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Table 1. Comparing the Zhanghe Irrigation System (ZIS) and the Liuyuankou Irrigation System (LIS): the physical context

ZIS	LIS
Yangtze Basin – ‘open’ – abundant water	Yellow River Basin – ‘closed’ – physically water scarce
Natural recapture zone	Regulated recapture zone
Hilly	Flat
Clay loam, low percolation rate	Loam, high percolation rate
Drainage readily (re)captured for reuse – little salinity	Groundwater pumps recharged by water from rain and other sources
Uses surface water storage	Groundwater main storage mechanism
Surface storage prominent	Irrigation and drainage channels used for recharge
Large, medium, small reservoirs	Pumping from groundwater prevalent, especially in downstream areas
Groundwater contributes directly to crops	Groundwater pumped, and contributes directly to crops
Mainly paddy rice in summer, winter wheat and rapeseeds in winter	Less paddy rice and a variety of upland crops in summer, mainly winter wheat in winter

3 Comparing ZIS and LIS: the institutional context

The institutional context has evolved differently in both situations. The multi-tiered organisation of irrigation at ZIS is striking, with several actors — the provincial authority, the Zhanghe Irrigation Administrative Bureau, the canal management authority (three of the four main canals are managed by ZIS, but one is managed by Jingmen City Water Resources Bureau), and village and farmer groups.

The irrigated area of LIS is smaller than that of ZIS, so the LIS is under the direct control of the Kaifeng county and city-level authorities. The irrigation department of LIS is the main service provider to farmers at LIS, delivering bulk supplies of water to village groups upstream of the railway line.

ZIS tends to function as a demand system because of its built-in flexibility to store water in ponds and reservoirs close to the water users (Loeve et al. 2001). While farmers order water through their water user groups or village heads, many of the decisions about when to release water from the ZIS reservoir come from higher up in the canal operation hierarchy. Thus, there is a strong element of supply approach in which the reservoir operators make decisions based on the available storage, rainfall and an overall view of when the crop needs water. Our research tends to show, for example, that the decline in irrigation releases from ZIS over time (Figure 3) has put pressure on farmers to adopt alternate wetting and drying (AWD) irrigation (Cabangon et al. 2004; Moya et. al. 2004), to expand ponds (Mushtaq 2004) and to recycle water (Loeve et al. 2004a). Furthermore, volumetric pricing at the village or farmer group level, adopted in the late 1980s, has provided a further incentive to save water at the village and farm level (Mao Zhi and Li 1999).

The contrast with LIS is sharp. LIS falls under the local administrative jurisdiction, outside of the command system of the Yellow River Conservancy Committee (YRCC), which controls all the division gates along the river. Though the LIS has a share of the river water, when and how much water can be diverted to the LIS depends on the availability of water in the river and the allocation plan drawn up by YRCC and the Provincial Water Resources Bureau. Despite the fact that the Yellow River Basin is short of water, the institutional structure at LIS, coupled with a rather poorly developed infrastructure, provides no incentive and facilities for rice farmers north of the railway line (Figure 4) to save water. Because of the high watertable and high seepage from irrigation canals, practising AWD in rice cultivation is currently out of the question. Below the railway line, the picture is different, as farmers rely on pumping to grow crops other than rice.

At ZIS, there are multiple needs from the water sector for agriculture, cities and hydropower, and there are growing environmental concern. Water resources, initially developed to serve agricultural purposes, are being shifted to other uses. Allocating enough water to these uses, yet meeting agricultural needs, is a primary objective of system managers. ZIS reservoir managers actively manage the allocation of water to different uses. They receive more income from cities and hydropower than from farmers (Table

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3). There is a direct incentive to deliver less to agriculture (in 2000 water fees per sector were CNY 0.0371 for irrigation, 0.068 for cities, and 0.105 for industry). Counteracting this incentive is the role of the Provincial Water Resources Bureau which steps into negotiations about water allocations and try to ensure that enough goes to agriculturalists.

At LIS too there is growing competition for limited supplies. Similarly, it is important to use water to support agriculture, but also to meet other needs. LIS irrigation operators regulate the distribution of their share of Yellow River water only after the river water has passed through the Yellow River diversion gate. In contrast to ZIS, LIS delivers water primarily to farmers. LIS operators are charged a flat, area-based fee, and thus have an incentive to irrigate more area. On the other hand, more releases from the Yellow River would allow the maintenance of a high groundwater table in the rice area through seepage and infiltration. Moreover, the hydraulic infrastructure at LIS affords such poor water control that more precise delivery measures are difficult without an overhaul of the physical system, something which system managers have often pointed out.

4 Water savings and reallocation — why save water?

The numerous participants in both systems have different reasons to save water. One of the findings of the study that was clearly brought home is that the term *water savings* is potentially misleading because of these different perspectives. It is would be better to understand how the flow path of water within the basin or system changes, and evaluate the trade-offs for various stakeholders from the basin to the farmer level, than to say whether or not an intervention saves water. To demonstrate this, we discuss the concept of water savings from various perspectives.

We have already noted that there is a surplus of water in the Yangtze River Basin. Although there has been much debate about the benefits and costs, there are already plans to move water north from the Yangtze River Basin, with the first priority to meet rising non-agricultural demands. At a smaller scale within the study area, the Zhanghe Irrigation Administrative Bureau tends to allocate as much of the reservoir water as possible to higher-value, non-agricultural uses and therefore benefits from prac-

Table 2. Comparing the Zhanghe (ZIS) and Liuyuankou (LIS) irrigation systems: the institutional context

ZIS	LIS
Multi-tiered organisational structure	Under the local government system, not the command system of the Yellow River Conservancy Committee
ZIS reservoir authority serves agriculture, cities, hydropower uses	Irrigation department serves primarily farmers
Financially autonomous reservoir operating authority receives revenue from farm and non-farm sources — financially well-off	Finances collected from farmers are insufficient for irrigation department
Volumetric pricing	Flat rate pricing — lack of incentives to promote farm water savings practice for paddy rice
Good infrastructure, with adequate controlling structures	Inadequate controlling structures
Alternate wetting and drying irrigation promoted	Alternate wetting and drying currently not possible
Farm ponds expanded over time	Heavy groundwater pumping by individuals
The *fee gai shue* (FGS) policy promotes payment directly to irrigation authority	

Table 3. Sources of income (10^4 yuan) for Zhanghe Irrigation System ZIS reservoir operation

	Appropriation funds from the provincial government	Gross income from agricultural irrigation water supply	Net income from the city and industry water supply	Net income from power generation	Other mixed businesses	Total
Average value (1998~2002)	293	315	246	193	23	1070

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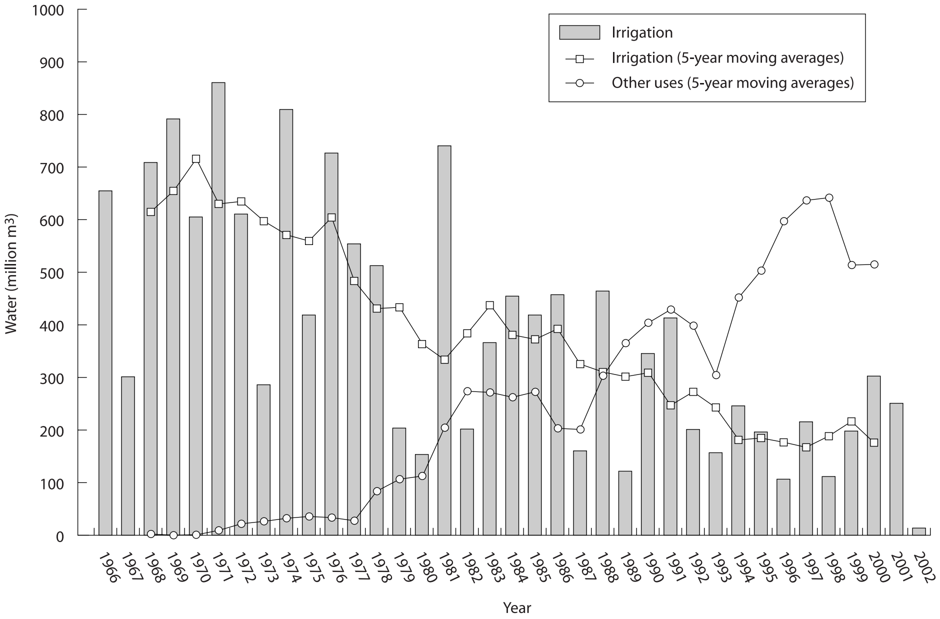

Figure 3. Changes in water released to agriculture and other uses over time in the Zhanghe Irrigation System

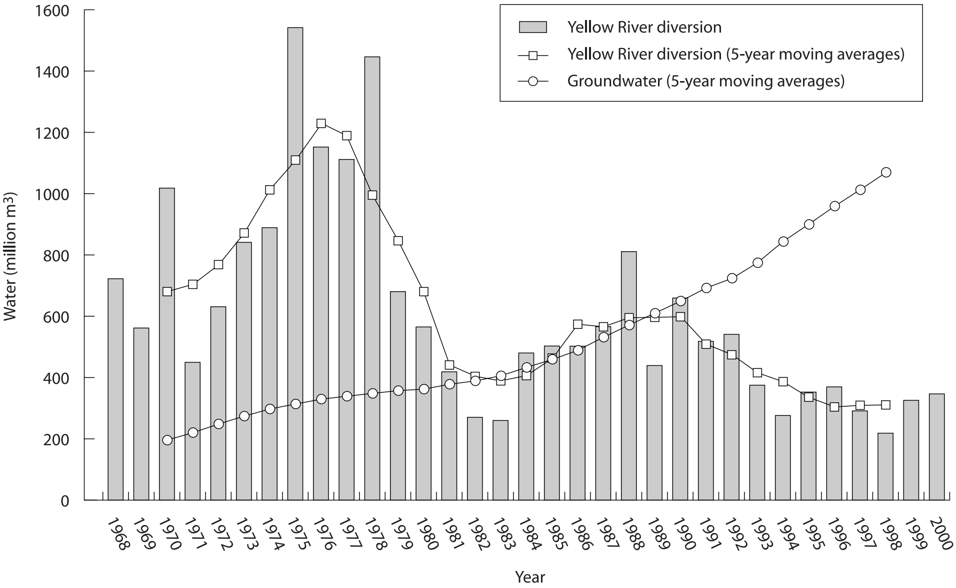

Figure 4. Trends in water use in the Liuyuankou Irrigation System. While Yellow River diversions have fallen, pumping from groundwater has increased.

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tices such as AWD, volumetric pricing, canal lining and pond development that enable them to reduce their allocations to agriculture without loss in agricultural production. The canal managers face a different problem. For operating and maintaining the canals, they rely on payments from water users.

During the years 2002 through 2004, a major policy change took place that affected the way water was delivered to farmers from the main reservoir. The policy of *fee gai shue* (FGS) required that farmers get organised to request water from the irrigation system and make payments directly to the irrigation authority, when previously their requests went through the village. Water deliveries, and hence income from water fees, were sharply down and canal managers faced a severe budget constraint. In response, farmers relied more on their small storage ponds for water supply, and practices such as AWD helped them to adapt to this policy shift. The farmers have faced both incentives (volumetric pricing) and pressures (reduced deliveries and FGS). As water deliveries to irrigation from ZIS have declined

Table 4. Incentives and pressures to save or reallocate water

Group	Zhanghe Irrigation System	Liuyuankou Irrigation System
Farmer perspective	Farmers acting out of necessity in light of decreasing agricultural water supplies	Understanding the condition of water shortage in the basin and having pressure from water resource managers to 'use' less water
Action	Apply less water through alternate wetting and drying strategy, and increase water fees	Apply less water
Rationale	Response to decreasing supplies	No good reason for farmers, but there is a view that rice is highly water consuming and a long term habit
Incentives	Necessity — get enough water to crops Volumetric pricing to village or farmer groups, cost savings pro-rated to farmers	No great incentive for paddy rice water savings at present
Irrigation operators	No external pressure but incentive to deliver more water within the system	Great external pressure but little internal incentive
Action	Reduce 'losses' from delivery system	Reduce 'losses' from delivery system and deliver less water to rice growers
Rationale	Deliver more water to customers Deliver more water to cities and industries	Deliver more water to more customers
Incentives	More fee collection from farmers, and higher payments from cities and industries.	Expansion of effective irrigation area by canal water
Water resource managers, society	Obtain higher value from water by responding to increasing demand from other uses, yet keeping agriculture healthy	Reduce water for rice to release water for other uses, yet maintain food production.
Action	Reduce withdrawals from reservoir for agriculture	Reduce withdrawals from Yellow River and reduce overall evapotranspiration.
Rationale	Maximising the benefits from the reservoir water	Maximising the benefits from the Yellow River Conservancy Committee allocation, better equity above and below the railway line
Incentives	More value from water	More value from water (increase water productivity) and better equity

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(Figure 3) they have adopted AWD, increased the number of ponds and recycled water.

The Yellow River Basin is short of water and there is considerable pressure to reallocate water, especially to the lower reaches of the Basin (Henan and Shandung provinces). Water releases from the Yellow River to LIS have gradually declined and this trend might be expected to continue. Meanwhile, pumping of groundwater for both agricultural and non-agricultural purposes (in nearby Kaifeng City) has increased (Figure 4). Given this situation, the irrigation operators would benefit by reducing seepage from the canal system and delivering less water to the rice producers, and delivering more water downstream of the railway line. A reduction in water to rice could lead to a fall in groundwater levels and a reduction in evaporation losses. Farmers might be encouraged to adopt AWD if convinced that there would be no sacrifice in yield. Reallocation of water could benefit farmers below the railway line.

One of the important and surprising contrasts between ZIS and LIS is the physical context and motivation for saving water. ZIS is located in a physically water-abundant area, while LIS is in a physically scarce area. Yet at ZIS there are more water-saving activities at farm and irrigation-system scale with farmers practising AWD, and managers and extension agents actively promoting means of water savings. At LIS, there is no great incentive for farmers to practice water savings for paddy rice, and the amount of water delivered to fields in relation to ET is high when compared with circumstances in ZIS (Table 5). Again unlike in ZIS, LIS system managers also have no great incentive to be stricter on water deliveries. From a basin perspective, the place that needs to practise water savings (LIS) does not pay attention to it, while the place where scarcity is not an issue (ZIS) is actively practising water savings. What is the reason for this contradiction?

Rice farmers above the railway line at LIS do not seem to have a compelling economic reason to refuse high rates of water delivery to their fields. At ZIS on the other hand, farmers feel compelled to adopt water-saving practices. Yield levels with AWD are about the same as those from traditional practices, and costs are also about the same (Cabangon et al. 2004; Moya et al. 2004). The main reason that farmers practise AWD at ZIS is apparently a response to a declining supply of water to irrigation. The farmer motivation is one of survival — the necessity to cope with falling water supplies. AWD helps farmers to adapt to a condition of lower supply and obtain at least the same output for a lower water input. At LIS, water deliveries remain high. Farmers have no real reason to practise AWD, and in fact do not.

Table 5. On-farm water application for paddy growth season[a] in the Zhanghe (ZIS) and Liuyuankou (LIS) irrigation systems

	ZIS (1999–2000)	LIS (2001–2003)
Irrigation application (mm)	417–470	512–590
Rainfall (mm)	407–310	462–360
Total inflow (mm)	824–780	974–950
Rice evapotranspiration (mm)	613	525
Yield (kg/ha)	7925–6500	7636

[a] The growth season for paddy is from about 20 May to 10 September at ZIS, and from 20 June to 20 October at LIS. The data are from Lu et al. (2003) and Dong et al. (2004)

We can explore the role of pricing in both cases. There is a flat, area-based pricing scheme at LIS, so there is no incentive from rice farmers to reduce deliveries. Downstream of the railway line, farmers pay the electrical costs of pumping, and employ water-saving practices and technologies (for example, they use a flexible pipe called a ‘white dragon’ to carefully deliver water to fields with minimum seepage). At ZIS, in contrast, volumetric pricing at the village or farmer group level was introduced in the 1980s (Mao Zhi and Li 1999). Cost savings are pro-rated to individual farmers, providing an incentive to adopt water-saving practices. One could argue, however, that reduced deliveries from the reservoir provided the primary incentive for adoption of water-saving practices.

5 Basin and system level outcomes

As already noted, there is pressure for water savings along the Yellow River. Any wasted water in agriculture would readily be used to serve environmental, industrial or urban needs or, for that matter, to better serve agriculture. There is intense societal pressure to save water.

At ZIS, in contrast, there is a need to make sure that various sectors are allocated sufficient water. This process of allocation and re-allocation is done at the sub-basin level by reservoir managers at ZIS. In con-

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trast to the Yellow River, along the Yangtze River there is evidently no great pressure to make sure more water flows in the river.

At both systems, an important way to reallocate water is to ‘save’ water that is perceived to be wasted (down the drain), and reallocate it to other uses. This already takes place at both systems. The depletion fraction measured at the scale of ZIS shows that about 90% of water is depleted by various uses and that there is therefore little remaining scope for additional savings. In fact, of concern is the need to meet downstream commitments for human or environmental needs. These should be considered before trying to recapture further water before it leaves the system boundaries.

Table 6. A summary of incentives to save water among the different stakeholders in the Zhanghe (ZIS) and Liuyuankou (LIS) irrigation systems

	ZIS	LIS
Farmers –		
reduce application	Medium	Low
reduce E or ET	None	None
Irrigation managers –		
reduce delivery to agriculture	High	Low
Basin resource management		
reallocation	High	High
reduce E	Low	High

Reducing evaporation or transpiration fluxes is another way to ‘save’ water. Evaporation is targeted first, because transpiration is directly related to the marketable yield of crops. At LIS, there are evidently high rates of non-productive evaporation from areas of shallow groundwater. It seems that no attention is being given to this at present. A reduction in this would free-up water that could be reallocated. At ZIS, crop ET is only 36% of total ET in the area. Major shifts in land use could change ET. A reduction in ET from the area would, however, mean more flows reaching the Yangtze River, which is potentially detrimental given the river’s propensity to flooding, and not necessarily beneficial from the overall basin perspective. The past strategy has been to limit drainage flows out of the ZIS area, and convert these into more ET.

Table 6 summarises incentives by different actors to change water use. At ZIS, the incentive is one of survival in light of reduced supplies, and for system managers, there is a strong financial incentive. There is little incentive for farmers or system managers to target evaporation losses.

6 The role of secondary storage and rain

Irrigation studies have traditionally considered the role of delivering water from the main sources — reservoirs or canals. An important reason for this is that initial investments are made in dams, reservoirs, diversion structures and canal systems, and their operation is given due importance. In some cases, secondary storage is built within irrigation to help operations. In other cases, the importance of secondary storage such as small dams or reservoirs evolves over time.

At ZIS, there are literally thousands of small and medium reservoirs within the system, some of which are from the original design in the 1950s, and others which have been added by farmers or local authorities. Most farmers receive water from the main irrigation canals originating from ZIS. In addition, many farmers receive water from small reservoirs or ponds, and some farmers from a third surface source — pumping from drainage canals, or simply using gravity-driven drainage flows from upstream. The combined management of these ultimately determines water productivity. As part of the response to declining water releases from the main reservoir to agriculture, farmers have relied increasingly on these alternative sources.

Over time, farmers have increased the number of ponds (Mushtaq 2004). The temporary introduction of FGS (2002–2004) forced farmers to rely much less on the main reservoir at ZIS. Table 7 shows that. even though reservoir releases to agriculture fell sharply during 2002 and 2003, the overall area and yield did not suffer, apart from a slight reduction in average yield in 2002. Farmers were able to rely on rain and farm ponds for their main water supply. The question arises as to the significance of these ponds and their relation to water-saving irrigation practices such as AWD in enabling the reduction of releases from ZIS. It is generally accepted that the ponds, by providing farmers with a source of water on demand, have facilitated the adoption of AWD. Another question is whether agriculture needs any water from the main reservoir if local sources can provide the supply. Modelling by N. Roost (formerly IWMI, unpub-

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lished data) shows that in normal years this may be possible, but in dry years, the reservoir provides a life-saving water source of water.

7 Response to reduced supplies

A response at LIS to reduced deliveries from the Yellow River has been to increase pumping from groundwater. It is doubtful whether the overall supply of water to crops has fallen significantly over time, and whether the overall ET has changed. Groundwater, much of which emanates from the Yellow River itself, has simply replaced surface water diversions into the system. Thus, the groundwater plays a very big role in sustaining agricultural practices and productivity at LIS (Table 8).

Management of rain, both at farm and sub-basin scales plays an important role in overall water management at ZIS. At the farm level, again in response to reduced deliveries, farmers capture as much rain as possible by building high bunds and practising AWD. The latter maintains low water levels within the fields and storage volume to capture rain.

The ZIS system configuration is very effective at capturing and using rain at larger scales. Internal catchments in the system provide water to small and medium reservoirs that ultimately serve farmers. Many small ponds capture excess flows resulting from off-field drainage of rain and irrigation water. At larger scales this capture and recapture of run-off and drainage flows ultimately keeps water within the system to meet the needs of various uses.

At LIS, the rain serves as an important source of recharge. At large scales at ZIS, almost all rain is effectively utilised by agriculture, either directly by crops, or indirectly by providing recharge to groundwater, which is then pumped again for agriculture.

8 What is the scope for water savings and water productivity gains?

Looking at sub-basin scale at ZIS and LIS, the *depleted fraction* is already quite high in both systems, and reducing outflow could have adverse consequences for downstream uses. (The *depleted fraction* of gross inflow is the evaporation and transpiration by all uses divided by the rain plus irrigation inflow.) At both systems, the *process fraction* of depleted water is not extremely high. (The *process fraction* of gross inflow is the rice ET divided by rain plus irrigation inflow and indicates the amount of inflow that is depleted by ET rice.) At ZIS, much

Table 7. The introduction of the *fee gai shue* (FGS) policy resulted in less water being released from the Zhanghe Irrigation System (ZIS) reservoir, but the overall area under paddy and yields were not greatly affected, demonstrating the role of secondary storage in overall water management

Year	Water release from the Zhanghe Reservoir (100 million m^3)	Rainfall (mm)	Area irrigated by water from Zhanghe Reservoir ('000 ha)	Planted area with paddy in whole ZIS ('000 ha)	Yield (t/ha)
2002	0.14	568	9.64	105	8.73
2003	0.38	590	47.44	102	7.52
2004	1.35	703	63.00	113	8.76

Note: farmers reported that the paddy yield in 2002 fell about 20~30%, but the yield data available from ZIS records show that the average yield decline was small. Rainfall figures are from Tuanlin Research Station and other data from ZIS records.

Table 8. Responses to reduction in supplies of water to irrigation in the Zhanghe (ZIS) and Liuyuankou (LIS) irrigation systems

ZIS	LIS
Alternate wetting and drying irrigation	More pumps
Increased ponds and secondary storage	Controlled recharge of groundwater through irrigation and drainage systems
Effective use of rain	Rain important to recharge groundwater
More precise delivery	Reduction of outflow to downstream areas
Cropping pattern change (from two to one rice crop; from paddy to upland crops)	Reduction of paddy area

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non-process depletion provides water for non-crop vegetation. At LIS, however, there is a large amount of non-productive evaporation and apparently scope for reducing evaporation.

The concept of water productivity incorporates water savings as well as gains in mass or value. If less water is applied or depleted, this is related to savings. The numerator of the water productivity equation increases when more mass or value is achieved. So even if there is little scope for savings, there could be possibilities for gains in value through improving yield or value of output (reducing input costs or changing crops) for the same amount of water, by reallocating irrigation water to higher-value uses within agriculture (higher-value crops) or between sectors, or by reducing negative externalities. Yield levels are already quite high in both systems. But in both systems there already is a reallocation across sectors that increases the benefit per unit of water. The challenge is to manage this reallocation to ensure that agriculture is able to maintain productivity. The biggest productivity gains may be in reducing externalities such as pollution or damage to other users, but we did not study this aspect in great detail.

9 Scale and water resources management

The studies have amply demonstrated the importance of considering scale in agricultural water management. Considering actions at only the field scale and simply extrapolating up to system or basin level is highly likely to lead to misunderstanding. Many other factors come into play when considering water productivity at larger scales (Table 9).

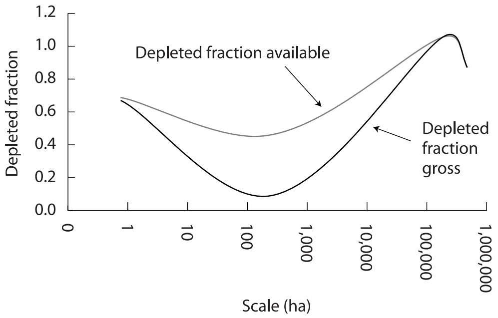

Figure 5. Depleted fraction [ET/(inflow + rain)] estimated at different scales in the Zhanghe Irrigation System (Loeve et al. 2004). The depleted fraction (DF) available adjusts for canal inflow minus outflow across the study domain. Differences in DF across scale are due to farmer practices, influences of other land use, capture of internal run-off and reuse of drainage flows.

At ZIS, our research was aimed at understanding these cross-scale interactions. Figure 5 shows the depleted fraction [ET/(surface and subsurface inflow plus rain)] at different scales. At field scale, the depleted fraction is quite high, because farmers carefully manage limited supplies including rain. But at a meso scale the depleted fraction drops at the study area, because the area contains forests which act as a catchment for downstream areas. Yet at larger scales,

Table 9. Factors that influence water resource use and productivity at various scales in the Zhanghe (ZIS) and Liuyuankou (LIS) irrigation areas

	ZIS	LIS
Micro (field) scale	On-farm water management practices Local influences of groundwater	On-farm water management practices
Meso scale	Run-off and capture in small ponds from other land uses	Reuse of drainage flows originating upstream of railway line Groundwater recharge and reuse
System scale	Influence of non-agricultural uses Water delivery practices Use of water from internal storage Policies – *fee gai shue* (FGS)	Pumping or recharge of drainage water originating from upstream areas
Sub-basin	Influence of multiple uses Consideration of downstream needs	Groundwater interaction with nearby cities Induced recharge from Yellow River Basin

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the depleted fraction increases again because of capture and use of run-off, and recapture and reuse of drainage flows. Ultimately, at system level the depleted fraction is quite high, showing that the scope for additional saving in the area is limited.

10 Strategies for water management at ZIS and LIS

Not surprisingly, the strategies employed at ZIS and LIS differ markedly due to the difference in context discussed above. At ZIS the basic approach is to:

- Keep as much water as possible in upstream storage (considering too the need for flood control, which requires low water levels in reservoirs at certain times of the year)
  - Reduce releases to agriculture
  - This promotes the development of internal secondary storage
- Use stored water to control reallocation to different uses
  - Water in the reservoir can be better targeted for city or hydropower use
- Promote gains in water productivity per unit of irrigation supply
  - Because farmers receive an increasingly smaller supply, AWD is a means to adapt. The same yield can be achieved with less water input from the reservoir.
  - Reduce seepage from conveyance structures to allow a higher proportion of canal water to reach farms.

An alternative strategy would be to release ample water from storage, and rely on recycling and reuse of drainage flows. A major disadvantage of this strategy is that it is more difficult, or even impossible, for system managers to control water once it leaves their management domain. For example, if water seeps from canals, farmers are able to reuse it, but system managers cannot capture this water for delivery to other uses.

At LIS, the prevailing strategy is one of conjunctive use. Groundwater provides an important buffer in case Yellow River supplies are further reduced. The results of this strategy have been impressive in terms of low water wastage and high water productivity.

The common view at LIS is that, because rice is a heavy user of water, deliveries to rice farmers should be reduced, or the area under the crop should be reduced. An alternative strategy to the prevailing one is to reduce deliveries to rice, and promote surface water deliveries below the railway line (Figure 2). This could be done by providing better canal control and promoting AWD practices. However, we question whether this will lead to net gains or just a redistribution of water, lessening the need to pump groundwater.

Instead, we propose a shift away from thinking about reducing deliveries to reducing any non-productive evaporation. The strategy is to identify where evaporation is occurring and control water to reduce this. Evaporation occurs from shallow water-tables, especially before and after the rice season. This could be reduced by introducing drainage or reducing deep percolation. Applying AWD may also lower the groundwater depth and therefore reduce the non-beneficial evaporation from fallow land within the rice area. Crop ET of rice is higher than from other potential crops such as maize which has an average ET value of about 420 mm compared with about 525 mm for rice.

There is often confusion and debate about whether we should be thinking in terms of depletion (ET) or deliveries of water. Obviously, both are important, but they carry different levels of importance in different contexts. In the highly stressed Yellow River Basin, which is closed and over-committed, water productivity analysis is better focused on ET. Only by reducing ET will more water be made available, yet maintaining levels of transpiration is important for crop production. In fact, efforts should first be focused on decreasing non-productive evaporation. Manipulating deliveries is a means to achieve this, and reducing deliveries is not the end in itself.

In contrast, in the water-abundant Zhanghe Basin, deliveries are far more important than ET from a water resource perspective (from a service perspective ET is important because it defines crop water demand). More or less ET will not be noticeable in the basin context. On the other hand, water control, keeping water in storage in the upstream areas of the system, and delivering less water, are all means of reallocating water to different uses and of reducing outflows from the system. Thus, considering water productivity in terms of deliveries is entirely appropriate.

11 Rethinking irrigation

In this final section we attempt to identify the general lessons from our research in China. How can the

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lessons learned from our two sites be interpreted on a broader scale? The prevailing notion that guides many decisions is that irrigation, especially irrigation for rice, wastes a lot of water. Thus, the focus has been on reducing deliveries and losses from deliveries by lining canals and introducing drip and sprinkler irrigation. The focus is on irrigation supply, and the classical concept of irrigation efficiency (typically estimated at 40% in many Asian systems) doesn't consider return flows and leaves rain out of the analysis. There is also the notion that farmers are the only customers and that irrigation managers are serving farmer needs. It is commonly felt that interventions at the system level (more control infrastructure, better organisation and management) are the main means to change practices. Therefore, if farmers would pay the real cost (full cost) of water, saving water would take place. In light of scarcity and competition, an expanded view is required when in comes to developing a strategy for increasing the productivity of water.

Everyone will agree on the importance of water savings to make most effective use of water. But we have shown that there can be several perspectives (farmer, irrigation manager and society), with different and competing objectives (save water so that more area can be irrigated, save water to save money, save water so that it can be reallocated to cities). Rather than using water savings as an operational term, it would be better to follow paths of water from source, to delivery to a use, to evaporation, run-off and deep percolation flows, then to the fate of these flows including reuse. Changes in management strategies will affect flow paths, incurring costs for some, and producing benefits for others. Decisions should be guided based on these changes in flow paths, and an understanding of who gains, and who bears the cost.

Quite often, farmers rely on *multiple sources* of water including both ground- and surface-water storage, yet much effort by irrigation authorities is placed on managing reservoir and canal water. Rain represents a significant source that is often overlooked. A challenge is managing rain by capture in the field and harnessing run-off generated within irrigation systems as is done in ZIS. Strategies should better take into account that farmer investments in constructing sources and tapping sources, such as we have seen in ponds at ZIS, can mitigate problems of scarcity and affect what happens at a larger scale.

Irrigation must be a responsible user of water in a basin context, as demands for non-irrigation uses of water grow. In spite of calls for integration, irrigation is still dealt with in isolation. In reality, irrigators often have no choice but to adapt to decreasing supplies due to reallocation to other uses, as happened in both case studies here. Not only is it important to understand these cross-sectoral interactions, but also to engage in negotiations across sectors.

An understanding of context and scale considerations will help to identify opportunities and avoid pitfalls. It is vital to consider the system- and basin-level consequences of actions taken at farm and field scale. Similarly, basin actions such as reallocation affect farm actions. The concept of open and closed basins provides an initial insight on context. Strategies appropriate for open basins — managing deliveries for high-value productivity while sustaining agricultural production — may have to shift when basins close due to increased development and competition for water resources. In closed basins, typically found in the semi-arid regions, there appears to be an opportunity for water productivity gains through reduced evaporation. This has not yet been a focus of many water-savings activities. With increasing population and demands on water, basins will become more closed, and there will be a need to shift our thinking to the use (evaporation and transpiration) side of the equation, rather than the supply side.

Especially in closed basins, it is important to recognise that a change in use will affect other uses of water. Strategies to enhance water productivity should first target flow paths where the use of water is generating negative or low values (recognising the values generated by other ecosystems) — for example, evaporation from shallow watertables. If a change is suggested, it is important to evaluate what happens to the water flow paths, then consider the trade-offs, who wins, and who loses. For example, a reduction in drainage flow may affect a downstream user. Is or should the downstream user be compensated?

Following this logic, reducing evaporation in closed basins such as the Yellow River Basin brings an opportunity to free-up water with minimal impact on other uses. This is a much different approach and requires different analysis than approaches that target reducing deliveries (e.g. sprinkler irrigation) or seepage (canal lining). The approach is to identify and quantify non-productive evaporation fluxes, then develop strategies on how to reduce these.

Our studies and experience have clearly demonstrated that there are multiple actors (farmers, irrigation managers, basin managers, broader society) who

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influence effective use of water, yet who typically have quite different outlooks and objectives on water use. Policies and strategies for changed water use and management must aim at aligning these objectives and incentives for all actors to obtain wider goals of improved water use.

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