

Identifying Water Saving Opportunities: Examples from Three Irrigation Districts in China's Yellow River and Yangtze Basins

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Abstract

In a context of increasing basin-level water scarcity, agricultural water savings are often called upon to free up substantial amounts of water to meet the demand of fast growing urban and industrial sectors, maintain the environment or support expanded agricultural activities. Due to complex relationships between the uses and reuses of water within basins, the means of achieving such savings are not always immediately apparent. This paper provides a methodology, based on water accounting, which can be used to identify real opportunities to save water and increase the productivity of water. This methodology is illustrated through contrasted examples from three major irrigated areas in China: Bojili Irrigation District (BID) and Huinong Canal Irrigation District (HCID), in the lower and upper reaches of the Yellow River basin, respectively, and Zhanghe Irrigation District (ZID) in the middle reaches of the Yangtze basin. In each case, the salient characteristics of the district water use patterns are highlighted and opportunities to save water are discussed accordingly. The initial analysis undertaken shows that there is probably significant scope to reduce non-beneficial uses of water in the upper reaches of the Yellow River, as illustrated in the HCID example. For both BID and ZIS, evidence, however, suggests very little remaining scope for water saving gains, because effective water saving actions have already been taken. In all three locations, there remains scope for enhancing the productivity of water, especially by shifting from lower to higher valued uses. This paper suggests the need for a comprehensive program that would carefully study water use patterns at several scales and locations in the Yellow River basin, and consequently identify places where real water saving opportunities exist along with the means to achieve those savings.

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1. Introduction

How can limited water supplies meet the growing demands for food security and urban and industrial growth while maintaining a sound environment? As available water resources are fully or near fully utilized in several major river basins, this is one of the most burning questions for both users and managers of scarce water resources. A very frequent response is to look for water savings in agriculture, the largest user of water in the world. Agricultural savings are thus often expected to free up substantial amounts of water that can be used for more agriculture, to maintain the environment or to meet the needs of other, higher valued uses.

But how can such savings be achieved? Because of a common lack of understanding of the uses and reuses of water, there are numerous examples of expensive agricultural water conservation efforts (for example introducing canal lining or efficient, modern irrigation technologies) that have not yielded the expected savings in the past. The present paper provides a methodology which can be used to identify real opportunities to save water. This methodology relies on a water accounting framework giving explicit and simple information on the status of water use and productivity.

Essential water accounting concepts are discussed and illustrated through contrasted examples from three major irrigated areas in China's Yellow River and Yangtze basins. Drawing on these examples, this paper aims to throw more light on how water conservation efforts should be oriented under widely different conditions of water use. Ultimately, it intends to bring general guidance for assessing how and to what extent water savings can be achieved in the water-short Yellow River basin.

2. A framework to identify water saving opportunities

There are three basic approaches to address the need for increased food production:

1. Expanding water supplies: develop infrastructure to supply more water for more agriculture;
2. Conserving water: reduce wastage and loss of water by agriculture;
3. Increasing the unit productivity of water: deriving more output from each drop of water consumed by agriculture.

The focus of this paper is on the second approach – identifying means of saving water within agriculture. Here we speak of “real” water savings (Seckler 1996; Keller *et al.*

1996) where water can be freed up from an agriculture use without jeopardizing production levels. This same water can be transferred to other domestic, industrial, agricultural or environmental use.

IWMI has developed a water accounting framework to help identify opportunities for real water savings and increasing the productivity of water (Molden 1997; Molden and Sakthivadivel 1999; Sakthivadivel *et al.* 1997; Molden *et al.* 1997). The procedure uses a water balance approach and classifies different outflow components or flow paths into water accounting categories (Figure 1 and Box 1). As a first step to water accounting, it is necessary to identify the spatial domain and time period of interest. We may for example wish to consider the entire Yellow River basin over several years, or we could consider an irrigated area bounded by its areal extent, the crop canopy and the bottom of the aquifer system over a shorter period of time. In any case, a clear specification of the spatial and temporal domain of interest is essential for the success of any water accounting exercise.

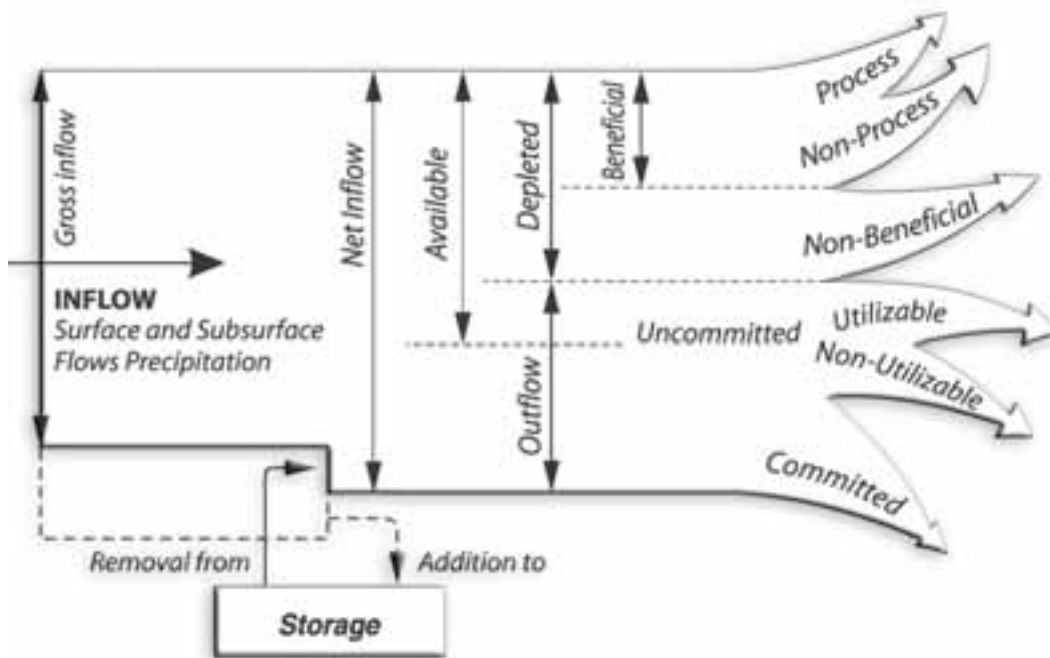


Figure 1. Water accounting categories

Box 1. Water Accounting Definitions

- *Gross inflow* is the total amount of water flowing into the water balance domain from precipitation, and surface and subsurface sources.
- *Net inflow* is the gross inflow plus any changes in storage.
- *Water depletion* is a use or removal of water from a water basin that renders it unavailable for further use. Water depletion is a key concept for water accounting, as interest is focused mostly on the productivity and the derived benefits per unit of water depleted. It is extremely important to distinguish water depletion from water diverted to a service or use as not all water diverted to a use is depleted. Water is depleted by four generic processes:
 - * *Evaporation*: water is vaporized from surfaces or transpired by plants.
 - * *Flows to sinks*: water flows into a sea, saline groundwater, or other location where it is not readily or economically recovered for reuse.
 - * *Pollution*: water quality gets degraded to an extent that it is unfit for certain uses.
 - * *Incorporation into a product*: through an industrial or agricultural process, such as bottling water, or incorporation of water into plant tissues.
- *Process depletion* is that amount of water diverted and depleted to produce a human-intended product.
- *Non-process depletion* occurs when water is depleted, but not by the process for which it was intended. Non-process depletion can be either *beneficial*, or *non-beneficial*
- *Committed water* is that part of outflow from the water balance domain that is committed to other uses, such as downstream environmental requirements or downstream water rights.
- *Uncommitted outflow* is water that is not depleted, nor committed and is, therefore, available for a use within the domain, but flows out of the basin due to lack of storage or sufficient operational measures. Uncommitted outflow can be classified as *utilizable* or *non-utilizable*. Outflow is utilizable if by improved management of existing facilities it could be consumptively used. Non-utilizable uncommitted outflow exists when the facilities are not sufficient to capture the otherwise utilizable outflow.
- *Available water* is the net inflow minus both the amount of water set aside for committed uses and the non-utilizable uncommitted outflow. It represents the amount of water available for use at the basin, service, or use levels. Available water includes process and non-process depletion plus utilizable outflows.
- A *closed basin* is one where all available water is depleted.
- An *open basin* is one where there is still some uncommitted utilizable outflow.
- In a *fully committed basin*, there are no uncommitted outflows. All inflowing water is committed to various uses.

Following the categories of water accounting defined above, it is possible to find general means of saving water. These are:

1. Reduce negative, non-beneficial, and low-beneficial depletion;
2. Reduce uncommitted outflows, either through improved management of existing facilities or through the construction of additional facilities.

When the saved water is transferred to a beneficial use such as more agriculture, protection of the environment, or urban use, an increase in water productivity will be achieved. Box 2 lists more detailed strategies to save water and increase the productivity of water. Reallocating water to higher valued uses and increasing the productivity per unit of water consumed by crops or another process use are means of enhancing productivity without water-saving measures. In places where major water conservation actions have already been taken (i.e. there remains no scope or practical ways to further

tap uncommitted outflows or reduce non-beneficial depletion), these are the only options to squeeze more outputs from water.

Box 2. Means of Saving Water and Increasing Productivity of Water

(taken from Molden *et al.* 2001)

Reducing non-beneficial depletion:

- *Lessening of non-beneficial evaporation* by reducing:
 - * evaporation from water applied to irrigated fields through specific irrigation technologies such as drip irrigation, or agronomic practices such as mulching, or changing crop planting dates to match periods of less evaporative demand
 - * evaporation from fallow land, by decreasing area of free water surfaces, decreasing non-beneficial or less-beneficial vegetation, and controlling weeds
- *Reducing water flows to sinks*—by interventions that reduce irrecoverable deep percolation and surface runoff.
- *Minimizing salinization of return flows*—by minimizing flows through saline soils or through saline groundwater to reduce pollution caused by the movement of salts into recoverable irrigation return flows.
- *Shunting polluted water to sinks*—to avoid the need to dilute with freshwater, saline or otherwise polluted water should be shunted directly to sinks.
- *Reusing return flows.*

Tapping uncommitted outflows:

- *Improving management of existing facilities*—to obtain more beneficial use from existing water supplies. A number of policy, design, management, and institutional interventions may allow for an expansion of irrigated area, increased cropping intensity, or increased yields within the service areas. Possible interventions are reducing delivery requirements by improved application efficiency, water pricing, and improved allocation and distribution practices.
- *Reusing return flows*—through gravity and pump diversions to increase irrigated area.
- *Adding storage facilities*—so that more water is available for release during drier periods. Storage takes many forms, including reservoir impoundments, groundwater aquifers, small tanks, and ponds on farmers' fields.

Increasing the productivity per unit of water consumed:

- *Changing crop varieties*—to new crop varieties that can provide increased yields for each unit of water consumed, or the same yields with fewer units of water consumed.
- *Crop substitution*—by switching from high water-consuming crops to less water-consuming crops, or switching to crops with higher economic or physical productivity per unit of water consumed.
- *Deficit, supplemental, or precision irrigation*—with sufficient water control, higher productivity can be achieved using irrigation strategies that increase the returns per unit of water consumed.
- *Improved water management*—to provide better timing of supplies to reduce stress at critical crop growth stages, leading to increased yields or, by increasing water supply reliability so farmers invest more in other agricultural inputs, leading to higher output per unit of water.
- *Improving non-water inputs*—in association with irrigation strategies that increase the yield per unit of water consumed; agronomic practices such as land preparation and fertilization can increase the return per unit of water.

Reallocating water among uses:

- *Reallocating water from lower-value to higher-value uses*—reallocation will generally not result in any direct water savings, but it can dramatically increase the economic productivity of water. Because downstream commitments may change, reallocation of water can have serious legal, equity, and other social considerations that must be addressed.

The specific strategy chosen will be guided by physical, economic and social factors. Existing water rights will often constrain choices, especially when there are options for reallocation of supplies. Among various aspects, cost-effectiveness and other social goals must be considered. In certain situations, the societal preference may be to a use that produces less agricultural output, but benefits disadvantaged groups. As a further example, it may be more cost-effective to reuse water through pumping from drains or groundwater than to modernize existing infrastructure to increase the beneficial depletion of water. Beyond impacts on costs or water conservation, such choices might have large implications on the operation of an irrigation system (e.g., as related to the accountability of water), and these should also receive adequate attention.

3. Case studies

Three examples from major irrigated areas in China were selected to illustrate water accounting concepts and discuss the opportunities to save water in contrasted situations. The selected areas differ widely in terms of their physical and managerial features that influence water use. While we do not yet have sufficient information for an accurate water accounting analysis, we have enough information to illustrate the process, and give direction for future work in these areas. A more qualitative approach was taken, which focuses on the relative importance of terms, particularly in a cross-system comparison perspective. With this respect, we believe that the estimates available are sufficient to develop a meaningful picture of the main contrasts across systems. Before taking specific actions, a more detailed analysis is however required.

Main features of the case-study areas

Two of the three selected irrigated areas, namely Bojili Irrigation District (BID) and Huinong Canal Irrigation District (HCID), are located in the water-short Yellow River basin (Figure 2). The third area, Zhanghe Irrigation District (ZID), is located in the more humid Yangtze basin. Important characteristics of these three areas are summarized in Table 1.

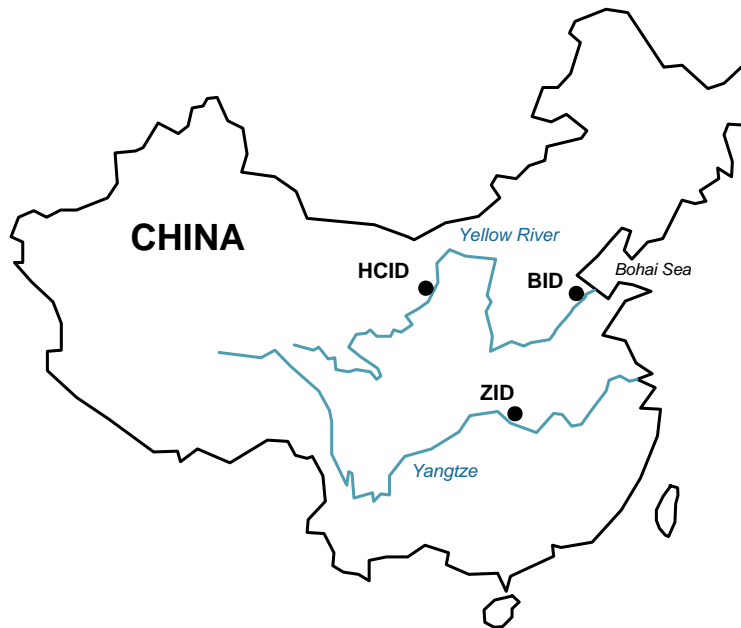


Figure 2. Location of the case-study areas in China’s Yellow River and Yangtze basins

Table 1. Salient features of the three case-study irrigation districts

	BID	HCID	ZID
Basin	Yellow River	Yellow River	Yangtze
Type of basin	closed	closed	open
Location within basin	lower reaches	upper reaches	middle reaches
Annual rainfall (mm)	550	190	970
Annual reference ET (mm)	1140	1300	1010
Nominal irrigated area (1000 ha)	110	75	160
Main crops	winter wheat, maize	wheat intercropped with maize, rice	rice, winter wheat
Main sources of irrigation water	river diversion, groundwater	river diversion	reservoirs

BID is located in the downstream part of the Yellow River basin, in proximity to the Bohai Sea. This region is characterized by substantial but highly variable (both intra and inter-annually) rainfall. Irrigation in the district is largely supplemental during the summer season, but still plays an essential role to secure and boost crop production. In response to a scarce and highly unreliable river supply, storage and recycling have been widely developed in BID. In particular, the shallow aquifer, which captures abundant

canal seepage and field percolation fluxes, is extensively exploited, through thousands of wells spread over the district area, to supplement canal supply. Among the essential features of the BID system is its high degree of hydrological closure: water is conserved in drainage canals using gates and earth dams, and regional groundwater flows are not significant. During the rainfall season only, the drainage system is kept open to prevent floods and significant amounts of water (mostly rainfall-generated runoff) leave the district area.

In HCID, where annual rainfall is less than 200 mm, irrigation is a prerequisite for crop production. Being situated on the upper reaches of the Yellow River, the irrigation district benefits from an abundant and reliable river supply. As supply is plentiful, high application rates of water are almost systematic in the area. Combined with insufficient drainage, these result in waterlogging and acute salinity problems. Two salient features of the HCID system are:

- The substantial amount of evaporation from (saline) wastelands, sustained by the very shallow groundwater and sometimes amplified by the disposal of excess surface water;
- The abundant canal spills, mostly produced during the rice growing season.

Non-process evaporation fluxes are obviously difficult to quantify, but most probably represent a very significant sink of water in the irrigation district. Canal spills, primarily due to the physical constraints of the water conveyance system (the main canal needs to be over-supplied to reach the high offtakes along its upstream sections, where rice is grown), were estimated to represent up to one third of the district water intake (Roost *et al.* 2003).

ZID is located in the Yangtze basin, in the more humid central China. In this region, where the mean annual rainfall approaches 1000 mm, irrigation is mostly a seasonal supplement to a largely rainfed agriculture. ZID is a typical melon-on-the-vine scheme, with a complex system of reservoirs that capture rainfall runoff and drainage water, and provide flexible irrigation supplies. In addition to the fact that ZID does not rely on river water diversion, a major contrast with BID and HCID is the much larger proportion of non-agricultural land surfaces in this district. For example, less than 30% of the total area downstream of the Zhanghe main reservoir consists of irrigated land (Loeve *et al.* 2003). Non-agricultural land surfaces, including large forest areas, obviously have an important influence on the district water use, depletion and productivity.

Water accounting and water saving strategies

Although often limited, the information available about each of the three case-study areas allows us to characterize the important contrasts, in terms of water use patterns and water saving opportunities, between these areas. For BID and HCID, this paper draws on data produced by the EU-funded project '*Policies for water savings in the Yellow River basin: a DSS applied to Ningxia and Shandong*' (Pereira *et al.* 2000). For ZID, estimates are based on information produced by the ACIAR-funded project '*Impact of water saving irrigation techniques in China*' and a district-scale water balance study carried out over a rice growing season (Loeve *et al.* 2003). Figure 3 presents the water accounting diagrams of the three selected irrigation districts.

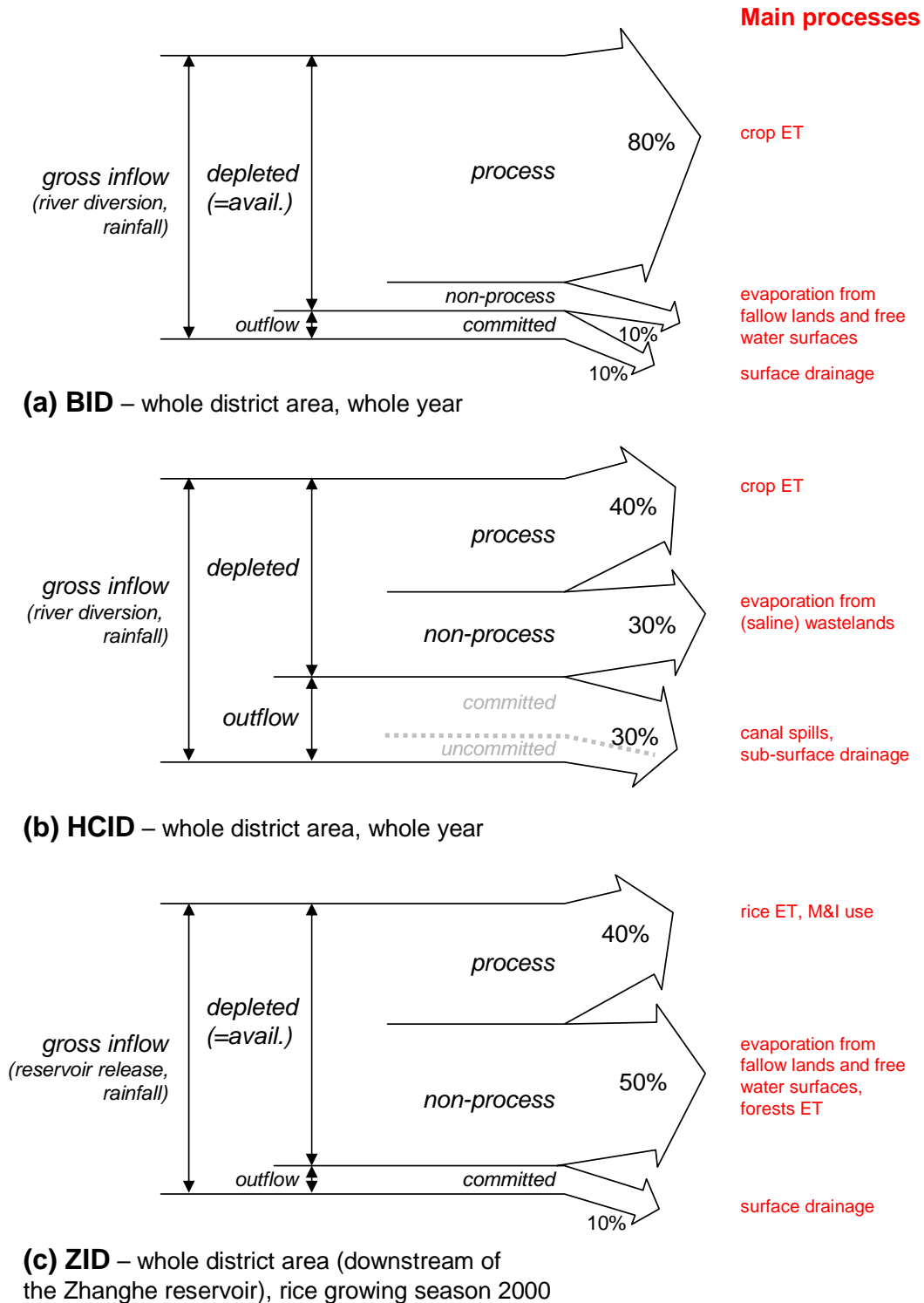


Figure 3. Water accounting diagrams of the BID, HCID and ZID study areas. The relative values presented are approximates based on present estimates. More detailed investigations are recommended for future action.

For both BID and ZID, these diagrams show that outflow is very limited and that the vast majority of the available water is depleted within the district boundary. This is the direct consequence of the successful implementation of structures and practices to save water, mainly: 1) the closing, using gates and earth dams, of the drainage system in BID; and 2) the complex system of reservoirs, which provides an efficient way to capture and reuse rainfall runoff and irrigation return flows in ZID¹. For both BID and ZID, there is most probably no uncommitted outflow to tap in most years, and thus no opportunity to deplete more water within the district boundary. In BID, the limited drainage outflow, concentrated during the rainfall season, is certainly important to remove the salts accumulated in the area during the drier season (when the system is virtually 'closed'). In ZID, outflow has another important function, since it contributes to maintain fisheries and meet possible downstream environmental needs. As is most generally the case, the precise amount of outflow committed to evacuate pollutants and satisfy downstream requirements however awaits additional research.

In contrast to BID and ZID, outflow is proportionally large in HCID. This observation deserves additional comments. First, it is essential to realize that a large fraction of HCID outflow readily finds its way back to the Yellow River. It is thus available for downstream use. From the perspective of the HCID system, this outflow is, at least to some extent, uncommitted – provided improved infrastructure and management procedures, it would for example be utilizable to irrigate more land in the district. It is however not clear to what extent this outflow is uncommitted from a basin perspective: the return flow of upstream irrigation systems indeed constitutes an important element of the already-short supply of users on more downstream reaches. Thoughts are obviously different regarding an open basin such as the Yangtze basin. For example, outflows in excess to environmental and fisheries needs in ZID would very unlikely be recovered by downstream users before the river enters the sea. In that particular case, and although ZID is situated several hundreds of km from the sea, uncommitted outflows might be considered a depletive use of water.

Related to this problem of categorizing water as committed or uncommitted is the important question of water rights specification. Defined in terms of *diversion* amounts, water rights are not completely supportive to integrated basin water management, as they do not properly represent the reality of water availability and use. In the Yellow River basin, where water resources are already fully (or even over-) committed, specification of *depletion* rights would add clarity, giving precise entitlements to users of water, and thus support more effective water management. For example, at HCID, it is the amount of depletion that ultimately impacts the Yellow River flow.

Understanding the nature of water depletion is essential to assess water saving opportunities. The three selected areas exhibit important contrasts in the way water is depleted. As mentioned above, BID and ZID are similar in that the vast majority of the available water is depleted within the district boundary. There are however major differences in the uses depleting water. In BID, the large majority of the water depletion occurs as crop ET (a process use). The remaining fraction consists in non-process

¹ Interesting to note is that while capture of irrigation return flows is mainly *lateral* in ZID, it primarily occurs in the *vertical* direction (involving the aquifer system instead of surface reservoirs), in BID.

evaporation from fallow lands and free water surfaces, and also includes a small amount of process depletion by domestic and industrial uses. By contrast, process depletion, which mostly accounts for rice ET² and some urban use, is not dominant in ZID. In this irrigation district, a large fraction of the available water is indeed depleted by three important non-process uses: evaporation from free water surfaces, evaporation from fallow lands and forests ET. A beneficial value may be associated with forests ET, as forests can carry important ecological and socio-economic functions. This may to some extent also apply to evaporation from reservoirs, which provide important fisheries. The coexistence of substantial process depletion and beneficial, non-process depletion highlights the more multifunctional use of water in ZID. In terms of water saving opportunities, this multifunctionality involves tradeoffs that only marginally appear in the other study areas. For example, reduction of the forest area would allow saving water that could be used for more rice production but would at the same time have a significant cost as benefits are derived from trees.

Since the main water conservation actions have already been taken in BID and ZID, the scope for saving water in these two areas appears very limited. In particular, conventional water conservation strategies that target higher conveyance and application efficiencies would most probably not yield any real water saving due to the already very extensive capture and recycling of irrigation return flows. Nevertheless, there probably remains significant scope for increasing water productivity, for instance by shifting to less water-consuming crops, or crops which yield higher (physical or economic) output per unit of water consumed. For HCID, the picture looks quite different: we hypothesize that there is a significant fraction of non-process, non-beneficial depletion that can be converted to process use. This can primarily be achieved through a better groundwater level control. In addition to saving water, this would allow more effective salinity control and higher water productivity – also because yields are affected by waterlogging under present conditions. Main options for improvement include reducing application depths, controlling canal seepage (by either engineering or managerial measures) and improving drainage. Because of acute salinity problems in the district, particular care should nevertheless be taken that irrigation duties remain compatible with leaching requirements.

4. What are the opportunities to save water in the Yellow River basin?

From initial water accounting studies such as those provided by Zhu *et al.* (2003) in this conference, we can make some inferences about the scope for saving water and increasing the productivity of water in the Yellow River basin. This discussion follows the guidelines given in Box 2.

Very aggressive water conservation strategies would be targeted at reducing non-beneficial or low beneficial uses to the maximum possible extent. A program to develop water saving strategies would first identify the scope for reducing the related volumes. There is evidence in the upper reaches of the Yellow River, as illustrated by the HCID

² Rice occupies about 80% of the total irrigated area in summer.

case, that irrigation directs flows to salt sinks that could be reduced. This must be done with some care as what may look like a wasteful use from an agricultural perspective, may be beneficial from another perspective. A wetland receiving irrigation drainage for example may provide important fisheries.

There is obviously no scope for tapping further uncommitted outflows from the Yellow River. In fact it could be argued that environmental flows, especially for sediment flushing, need to be increased. As illustrated in the HCID example though, to prevent unintended reallocation of water, it would be worthwhile to quantify how much outflow is committed for downstream uses.

There remains scope for increasing the productivity of water, especially by shifting from lower to higher valued uses, and to some extent increasing (already high) yield levels. There is already pressure to release water from lower valued agricultural and environmental uses to domestic and industrial uses. Counteracting existing pressures to increase unit productivity of water are threats of pollution, salinization and groundwater depletion.

We are suggesting a strategy that is quite different from traditional approaches. Traditional approaches would consider efficiencies of on-farm application and conveyance systems. Unfortunately, especially in closed basins like the Yellow River, these classical approaches do not yield real water savings. Here we do not focus on application or conveyance efficiency, but rather identify categories and places where water could be saved. The next step is to identify practices that would make the savings possible. Implementing changes are of course the next difficult step and requires changes in operations, infrastructure and incentives.

In conclusion, we suggest a comprehensive approach to identifying water savings in the Yellow River basin. This would include identification of means to save water and increase productivity. The program would carefully study water use patterns at different scales – farm, irrigated area, sub-basin and basin – to identify locations where water could be saved. The program would devise strategies to realize the savings.

5. Concluding remarks

Addressing the need to achieve real water savings in agriculture requires that actual uses, reuses and depletions of water be better understood. This paper presented a water accounting framework that provides a conceptual and practical basis for identifying means of saving water and increasing its productivity. A comparative analysis from three major irrigated areas in China was developed to illustrate essential water accounting concepts and highlight the important implications that different water use patterns can have in terms of water saving opportunities.

An evident scope for saving water by decreasing non-beneficial evaporation was highlighted for the HCID area, in the upper part of the Yellow River basin. For the BID area, located in proximity to the river delta, evidence was however shown of the very little remaining scope for water saving gains. The main reason is that effective water saving actions have already been taken. Similar conclusions were arrived at for the ZID area, in the Yangtze basin. ZID provided a valuable illustration of multiple uses of water,

with tradeoffs between important beneficial consumptive users such as forests and agriculture. In all places, there remains scope for improving unit productivity of water. Yet, it is absolutely essential that threats of pollution, salinization and groundwater depletion be properly addressed.

This paper suggests the need for a comprehensive program that would study water use patterns at several scales and locations in the Yellow River basin, and consequently identify places where real water saving opportunities exist and the means to achieve those savings.

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