Yellow River Basin Water Accounting

Zhongping Zhu, Mark Giordano, Ximing Cai[1], and David Molden
International Water Management Institute (IWMI), Colombo, Sri Lanka
Email contact: zp.zhu@cgiar.org

Abstract

Water accounting is a fundamental tool in river basin management and planning. Water accounting systems, however, are not universally consistent, complicating efforts to share information and research findings across nations. China, for example, utilizes a unique system that is not well understood by outside scientists. As China continues to emerge onto the global water management scene, it is becoming increasingly important for international researchers to understand Chinese water accounting frameworks and concepts. This paper uses data, largely provided by the Yellow River Conservancy Commission, to describe China's water accounting system and examine water balances in the Yellow River, one of China's most important water bodies. The paper shows that the primary difference between water accounting methodologies in the Yellow River basin and those familiar to most international researchers is related to supply accounting in general and groundwater accounting in particular. Although not currently included in its water accounting system, Chinese concepts of environmental water use, when included, will also differ substantially from those familiar to outside researchers. In terms of actual Yellow River balances, the paper highlights what could be a declining trend in both rainfall and runoff, which may require changes in current planning assumptions concerning average flow. In addition to declining supply, growing industrial and domestic demand are increasing pressure to reduce the use of water in agriculture, the basin's largest water consuming sector. As an initial guide for assessing possible agricultural policy responses, the paper provides estimates, for the first time, of Yellow River basin agricultural water productivity. Finally, the paper highlights the massive challenge managers in the Yellow River, as in other basins around the world, are facing as they seek to balance human water demand with increasingly understood ecological needs.

Key Words: Yellow River, Water Accounting, China, Water Management, Environmental Use

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[1] International Food Policy Research Institute (IFPRI), Washington DC

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Introduction

The Yellow River, or Huanghe, is the second longest river in China. Originating in the Bayangela Mountains in western China, the river drops a total of 4500m as it loops north into the Gobi Desert before turning south through the Loess Plateau and then east to its terminus in the Bohai Gulf. In total, the river flows over 5,400 km, passes through 9 provinces and autonomous regions and drains an area about the size of France. While the Yellow River basin has long been at the center of China's political, economic and social development, it is also prone to drought and flood, sometimes resulting in human misery at scales almost unheard of elsewhere in the world. The dual nature of the river in terms of human livelihoods has resulted in the simultaneous use of the phrases "the cradle of Chinese civilization" and "China's sorrow" to describe the Yellow River.

Since the founding of the People's Republic of China in 1949, major achievements have been made in both flood control and, through irrigation development, drought mitigation in the Yellow River basin (Chinese Engineering Academy, 2001; Qian, 2001; Wan, 2001; Chen Zhikai, 2002). While the possibility of flooding is ever present and remains a key issue in basin management, water scarcity and its economic and environmental consequences have moved to the fore as major issues for basin administrators, residents and the nation as a whole (Jin, no date; Geography Institute of China Science Academy, 1998; Chen Zhikai, 2002; Liu, 2002). Apparent declines in rainfall and runoff since the early 1990s, only now being understood and evaluated, have further complicated the job of allocating the Yellow River's scarce water resources amongst competing and changing uses.

How much water is available in the Yellow River basin and how is availability changing? How is basin water now used and how is demand changing? What is the efficiency and productivity of current water use? Where do ecological needs fit in? To begin answering these questions requires an understanding of Yellow River basin water accounts. Unfortunately, many outside scholars are unfamiliar with Chinese water accounting systems and concepts, making the sharing of information and ideas concerning Yellow River basin management difficult. To partially overcome this problem, the present paper uses information from the *Yellow River Water Resources Bulletins* of 1998-2000 provided by the Yellow River Conservancy Commission (YRCC), the primary agency responsible for Yellow River management, to both describe water accounting in the Yellow River basin and the current state of water supply and use.

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[2] International Food Policy Research Institute (IFPRI), Washington DC

Basin Geography

For analysis, the Yellow River is commonly divided into three reaches as indicated in Figure 1. The upper reach of the Yellow River drains over half of the total basin area and extends from the river's origin in the Bayangela Mountains to the Toudaoguai gauging station near city of Datong. While the upper reach provides a large part of the basin's surface runoff (YRCC, 2002a), the contribution comes from two distinct geographic backdrops characterized by counteracting physical processes. On the Tibetan Plateau where the Yellow River begins, steep rock slopes, low evaporation and high moisture retention produce high runoff coefficients. This, combined with relatively high precipitation levels, result in this western most region of the upper reach contributing 56% of the entire river's total runoff by the point of the Lanzhou gauging station (based on pre-1990s averages). As the river moves northward from there into the Ningxia / Inner Mongolian plains and the Gobi Desert, the evaporation rate rises to levels several times that of precipitation. As a result, the section from Lanzhou to Toudaoguai is a net consumer of runoff, and total flow is greatly reduced from the level which would otherwise exist had the river kept an eastward course.

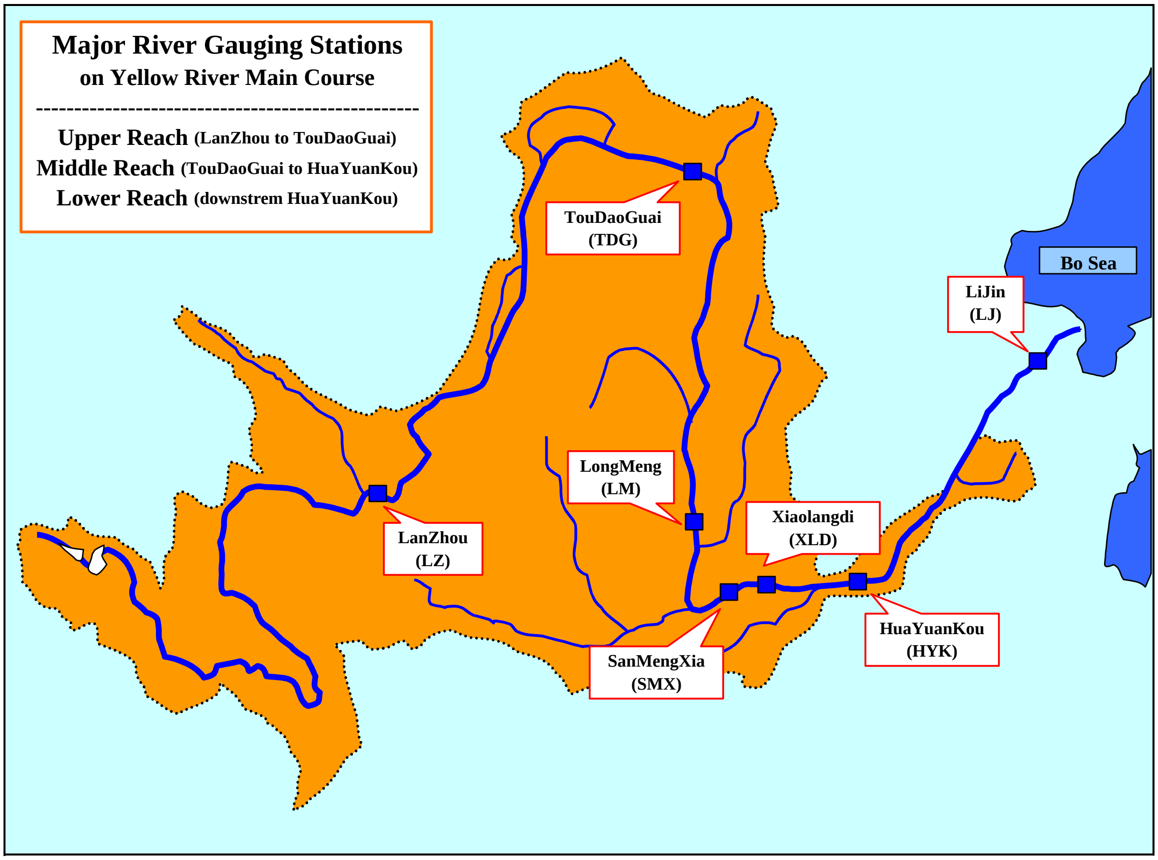

Figure 1. The Yellow River Basin and its main gauging stations

The middle reach, covering 46% of basin area and providing an additional 43% of total runoff (based on pre-1990s averages), sits between the Toudaoguai and Huayuankou gauging stations. From Toudaoguai, the river begins its "great bend" to the south into and through the Loess Plateau. The middle reach of the river plays a significant role in basin water balances and availability for human use for two reasons. First, the reach includes some of the river's major tributaries, such as the Fenhe and Weihe, which contribute substantially to total flow. Second, as the river turns southward, it cuts through the Loess Plateau and its highly erodible soils. These soils enter the main stem and its tributaries as massive quantities of silt, providing 90% of the river's total sediment, and resulting in average sediment loads unprecedented amongst major waterways (MWR 2002c). Unpredictable and intensive summer storms in the reach exacerbate the sedimentation problem and are the major cause of Yellow River's historically devastating floods.

The lower reach of the Yellow River commences at Huayuankou and forms one of the most unique river segments in the world. Here the sediment transported from the middle reach begins to settle as the river spills onto the flat North China Plain, producing a consistently aggrading bed and a naturally meandering and unstable channel. To stabilize the channel, millennia of successive river managers have constructed levees to hold the river. While such structures may succeed in the short term, their success depends on consistently raising levee walls as the sedimentation elevates the level of the channel constrained within. Over time, the process of levee raising has created a "suspended" river in which the channel bottom is above ground level, sometimes by as much as 10 meters. This raising of the channel above the level of the neighboring countryside has clear implications for the severity of flooding when levees break but also alters the meaning of the term "basin" in the Yellow River context. With the channel above ground level, rainfall on surrounding lands cannot drain into the river nor can tributaries enter. This essentially means that the river "basin" becomes a narrow corridor no wider than the few kilometers breadth of the diked channel. With almost no inflow, the contribution of the lower reach is limited to only 3% of total runoff.

Estimates of Basin Water Resources

Both China and the West have long, though differing, traditions of water management, and it is increasingly recognized that each side has information and insights valuable for the other. As a result, informational, scientific and policy exchanges in water management are becoming increasingly common. However, there are hurdles to the success of such exchanges. One such hurdle is language, a barrier which may be overcome with translation. The second, more formidable, hurdle is definition, a problem related to language but which requires translation as well as a deeper understanding of perspective and background if it is to be surmounted. The problem of definition appears immediately when comparative work is undertaken on one of most fundamental elements in basin water management, water accounting. At present there has been little research or reporting to clarify how water accounting differs between China and the West and how those differences may translate into varied images of basin scale water availability and use. The remainder of this paper attempts to partially remedy this shortfall using the example of the Yellow River basin.

The basic water resources accounting framework used by the Yellow River Conservancy Commission (YRCC) is shown in Table 1 (YRCC, 2002b). A similar system is used by the Ministry of Water Resources for North China's other two basins, the Haihe and Huaihe, as well as the Huanghe (MWR, 2002a). The YRCC framework divides water into its two primary components, surface and ground. Surface water is calculated as measured flow adjusted by estimates of human depletion (depletion is discussed further below) and change in storage. Groundwater resources are then separately calculated for mountain and plains areas and the sum adjusted to compensate for a double counting error which occurs in the estimation process. The total surface and groundwater estimates are then further adjusted to account for a second, large, double counting error to arrive finally at a total water resource calculation. It is unclear to the authors how the two double counting adjustments are made, but it appears that assumptions and empirically derived formulas may be the main tools. While the rationale for this system may be based on the well-recognized difficulty in groundwater measurement, the lack of procedural clarity is a hindrance to the utility and transferability of the figures.

Table 1. Yellow River Basin Water Resources (bcm), 2000

		Gauging Station				
		LZ	TDG	LM	SMX	HYK
(1) Surface runoff	(a) Measured river flow	26.0	14.0	15.7	16.3	16.5
	(b) Depletion	2.7	13.0	13.6	17.0	18.4
	(c) Change in storage	-3.3	-3.3	-3.3	-3.2	0.1
	Surface runoff = (a)+(b)+(c)	25.4	23.7	26.0	30.1	35.0
(2) Groundwater	(e) Hilly area	12.6	13.1	15.3	19.7	22.6
	(f) Plain area	1.6	7.6	9.5	14.6	15.4
	(g)Double counting in (e) & (f)	0.7	1.3	1.8	3.8	4.1
	Groundwater = (e)+(f)-(g)	13.5	19.5	23.0	30.4	33.9
(3) Double counting in (1) and (2)		12.8	17.2	18.6	22.4	24.7
(4) Total water resources = (1)+(2)-(3)		26.0	26.0	30.4	38.1	44.1

Lanzhou (LZ), Toudaoguai (TDG), Longmen (LM), Sanmenxia (SMX), Huayuankou (HYK)
Source: YRCC 2002b

To overcome similar measurement difficulties in other settings such as in Egypt (Zhu et al, 1995) and in the State of California in the USA (Department of Water Resources, 1998), ground water abstraction has been used as a proxy for groundwater resources. The primary danger in using abstraction is that it will overestimate groundwater resources if extraction is in excess of recharge. The primary advantage is that it is straightforward and avoids both the mountain/plain and surface/ground water doubling counting problems. In order to see how a change to the abstraction approach might impact YRCC estimates, a new set of Yellow River basin water resource estimates was produced by the International Water Management Institute (IWMI) as shown in Table 2**.** The IWMI estimates follow the abstraction approach of the Egypt/California convention using data reported by the YRCC.

Table 2. YRCC and IWMI Yellow River Basin Water Resource Estimates (bcm), 1998-2000

	Gauging Station				
	LZ	TDG	LM	SMX	HYK
Year 1998					
Surface water	28.1	28.6	33.7	39.1	44.8
Groundwater abstraction	0.4	2.8	3.3	8.7	10.2
IWMI estimate	28.5	31.5	37.0	47.9	55.0
YRCC bulletin	28.6	30.8	38.6	48.1	54.9
Difference	0%	2%	-4%	0%	0%
Year 1999					
Surface water	33.9	33.3	36.6	41.7	45.2
Groundwater abstraction	0.5	3.1	3.5	9.1	10.6
IWMI Estimate	34.4	36.4	40.1	50.7	55.8
YRCC Bulletin	36.8	40.5	43.0	53.9	56.3
Difference	-6%	-10%	-7%	-6%	-1%
Year 2000					
Surface water	25.4	23.7	26.0	30.1	35.0
Groundwater abstraction	0.5	3.2	3.6	9.2	10.7
IWMI Estimate	25.9	26.9	29.6	39.3	45.7
YRCC Bulletin	26.0	26.0	30.4	38.1	44.1
Difference	0%	3%	-3%	3%	4%

Lanzhou (LZ), Toudaoguai (TDG), Longmen (LM), Sanmenxia (SMX), Huayuankou (HYK)

Interestingly, the IWMI estimates are remarkably similar to the original YRCC figures, with no difference greater than 10% and most variation less than 4%. Assuming the data are accurate, a negative difference between the IWMI and YRCC estimates implies a horizontal groundwater flow into a reach from upstream and a positive difference implies either a horizontal outflow or groundwater overdraft.

It would be of great use to international researchers if the methodology behind the current double counting system were clarified or if estimates calculated using the abstraction methodology were published along with those using the current system. Publishing figures based on both methodologies would potentially have the added benefit of providing insights into the groundwater overdraft problem, which is believed to exist on the North China plain. However, the authors recognize that in China, as in other areas of the world, authority for water management is not delineated solely using basin boundaries and integrated water management concepts. It is quite possible that the rationale for the water accounting system in the Yellow River basin is based not only on the difficulty in measuring groundwater resources but also in part on the division of water management authority. For example, while the Ministry of Water Resources is responsible for surface water, groundwater is considered a mineral resource and has been administered by the Ministry of Mining and other agencies. Thus any change in water accounting procedures may need to be addressed through agreements brokered at relatively high levels of government.

Declining Water Resources in 1990s

A primary issue in basin water management planning is determining current and probable future basin water availability. As just described, even measurement of current availability is not straightforward, and in the case of the Yellow River, the task of estimating future supplies is further complicated by a possible change in climatic conditions and changing relationships between rainfall and runoff yields (Geography Institute of China Science Academy, 1998; Chen Lei, 2002). Table 3 shows the decade-average annual rainfall and runoff from 1956, the year in which full weather and flow gauging in the Yellow River commenced, to 2000. Following the Chinese convention, the runoff figures reflect river flow after adding back estimated human depletion and approach, but are not equal to, the natural runoff generated from rainwater. It is also important to bear in mind that in the lower reach, the channel is above the surrounding ground level so no tributaries enter and the reach does not contribute substantially to the basin runoff account.

Table 3. Rainfall and Runoff in Yellow River Basin, 1956-2000

	Area		Time Period					1990s Change
	(000 km^2)		1956-70	1971-80	1981-90	1991-00	Average	From Average
Upper	368	Rain (mm)	380	374	373	360	372	-3%
		Runoff (bcm)	35	34	37	28	34	-16%
		Runoff yield (%)	25%	25%	27%	21%	24%	
Middle	362	Rain (mm)	570	515	529	456	523	-13%
		Runoff (bcm)	29	21	23	15	23	-34%
		Runoff yield (%)	14%	11%	12%	9%	12%	
Lower	22	Rain (mm)	733	689	616	614	671	-8%
		Runoff (bcm)	1.5	1.1	0.6	0.0	0.8	-100%
		Runoff yield (%)						
Basin	752	Rain (mm)	482	451	455	413	454	-9%
		Runoff (bcm)	65	56	61	43	57	-24%

Source: YRCC, 2002d

It is immediately clear from the table that both reported rainfall and runoff were substantially lower in the 1990s than in previous decades. While no clear empirical measure has been defined, the low rainfall and runoff of the 1990s is interpreted by most observers as constituting a drought, at least in the middle reach and below. One question is whether this "drought" is part of a short-term climatic cycle or a secular decline in long-term precipitation levels brought on, perhaps, by global climate change. As a similar but somewhat less severe dry-spell occurred in the decade from 1922-1932, it is suspected by some Chinese hydrologists that the Yellow River is now at the tail end of a

70 year cycle and that rainfall levels and river flows will therefore begin climbing in the near future. While plausible, there is as yet insufficient evidence to confirm or refute this hypothesis and so the potential end to the dry conditions is unclear.

Adding to the problem of declining rainfall and runoff has been an apparent change in the rainfall/runoff ratio (Ma 1999, Chen Zhikai 2002; He 2002; Liu 2002), as shown in Table 3. The 1990s saw the runoff ratio in the upper reach decline by an average of 16% from previous decades while in the middle reach the decline was by 34% (note that there is essentially no rainfall or runoff in the lower reach because of the “suspended” channel). In general, a one percent decrease in upper reach rainfall was associated with a four percent runoff decline while in the middle reach a one percent decrease in rainfall was associated with a two percent decline in runoff.

Some suspect the changing rainfall/runoff ratios are related to alterations in land use patterns. While land use could clearly play a role, the fact that the change in ratios appears to have occurred only in the 1990s though land cover change was already taking place more than a decade earlier suggests that other forces may also be at work. One possible alternative to the land use hypothesis may be human response to declining rainfall coupled with the water resource accounting techniques currently in place. As rainfall declined in the 1990s, farmers responded by increasing groundwater withdrawals an estimated 5.1 billion cubic meters (bcm), or 61%, over the most recent 11 years (MWR, 2002b). In some parts of the basin, groundwater supplies emanate from channel seepage and the rate of this seepage out of the channel likely increased with increased abstraction. In other areas, increased abstraction would reduce the quantity of groundwater able to enter the channel and contribute to river flow. Both these factors, if not properly accounted for, could cause a decrease in measured runoff and give an appearance of a declining rainfall/runoff ratio when in fact rainfall and runoff dropped proportionally. The true origin of the changing ratios needs to be carefully examined, preferably with a longer data series than has currently been made available, since the appropriate policy response to the apparent change depends fundamentally on cause.

Whatever the reasons, the decline in rainfall and river levels has contributed to a desiccation of the river to the extent that that there was no flow in the lower reach’s main channel for some 120 days each year from 1995-1998 (Chinese Engineering Academy, 2001; Geography Institute of China Science Academy, 1998; Chen Zhikai, 2002; Ma, 1999). This cut off in flow has important repercussions to basin function for three reasons. First, it limits the availability of water for human use. Second, it negates the competence of the river to carry its heavy sediment load to the sea, resulting in a more rapidly aggrading and flood prone channel than would otherwise exist. Third, it has clear consequences for the ecology of the downstream areas and, in particular, the Yellow River delta. According to the 1998 Yellow River Bulletin, the Chinese central government strengthened the 1987 Water Allocation Scheme to address the desiccation issue by giving more authority to the YRCC for integrated demand management, including in-stream environmental and ecological requirements. Since 1998, the YRCC has managed to end absolute flow cut-off even though drought conditions continued in 1999 and 2000 (Ma 1999; Li, no date; Li 2002a). However, flow for environmental and ecological use, especially for sediment flushing, is still far below that required. For example, it has been estimated that 20 bcm of annual flow is required for sediment transport, a level not met in any of the recent drought years.

An additional implication of the changing runoff levels is related to basin water management. Various Chinese documents and papers continue to cite 58 bcm as average annual runoff. However, as shown in Table 3, the average flow from 1956-2000 is already marginally below this level and the figure from the 1990s, averaging only 43bcm annually, is 25% lower. Even if some of this reported decline is due in part to a mis-accounting of basin resources, it now seems apparent that traditional assumptions of Yellow River water availability need to be reassessed. In addition, planners in the YRCC and other agencies may wish to adopt both average and drought scenarios in their water resources assessment and planning which account for both changes in overall water availability and availability by reach.

Basin Water Uses

With a basic understanding of water supply accounting and current issues in supply assessment, we turn now to an examination of water demand accounting. Unlike supply, the water demand accounting system used in the Yellow River basin will generally be familiar to international researchers. The two main concepts of interest in Yellow River Conservancy Commission demand accounting are water withdrawal and water depletion. Water withdrawal is the water diverted, pumped or otherwise taken for human use, irrespective of whether it is returned to the system. Water depletion is defined as a use or removal of water from a basin that renders it unavailable for further use, for example that lost through evapotranspiration, flows directed to sinks such as evaporation ponds, or pollution (Molden, 1997). Because not all water withdrawn from the system is depleted, water withdrawal can be larger than total water resource availability. It should be kept in mind when using figures at the sub-basin scale that withdrawal from one reach may include return flow from an upstream reach. Also, the term “depletion” as used by the YRCC refers to both beneficial and non-beneficial uses and thus cannot be used as a traditional measure of efficiency.

As seen in Table 4, the average annual withdrawal from the Yellow River basin in recent years has been approximately 50 bcm, of which approximately 74% was from surface water and 26% was from groundwater. Agriculture is by far the largest user of water, accounting for 80% of total withdrawal, with industrial, urban and rural domestic sectors sharing the remaining 20%. In terms of current management issues, it is interesting to note that agricultural withdrawals decreased in 2000 by 2 bcm from 1998 levels, probably driven by difficulty in access to surface flow due to drier conditions. In contrast, industrial and domestic withdrawals expanded over this same time period as a result of greater groundwater abstraction. Also of note, ecological water uses are not included in the water demand accounts, an issue which will be discussed in further detail in later section.

Table 4. Yellow River Basin Water Withdrawal (bcm), 1998-2000

	By Source			By Sector				
						Domestic		
Year	Surface Water	Ground water	Total	Ag.	Ind.	Urban	Rural	Total
1998	37	12.7	49.7	40.5	6.1	1.6	1.5	49.7
1999	38.4	13.3	51.7	42.6	5.7	1.8	1.5	51.7
2000	34.6	13.5	48.1	38.1	6.3	2.1	1.6	48.1
Average	36.7	13.2	49.8	40.4	6	1.8	1.5	49.8
Share	74%	26%	100%	81%	12%	4%	3%	100%

Note: Groundwater withdrawal includes 2.7 bcm pumping in regions lower than Huayuankou
Source: YRCC, 2002b

Table 5 shows the water depletions in the basin during the periods 1988-1992 and 1998-2000. The total depletion increased by a significant 21% over the 10-year period. The increase of agricultural water depletion of 12% is offset by the dramatic growth from the industrial and domestic sectors.

Table 5. Yellow River Depletion (bcm), 1998-2000 and 1988-92

	Total	Agricultural	Industrial	Domestic	
				Urban	Rural
1988-1992[a]	30.7	28.4	1.5	0.5	0.4
1998-2000 [b]	37.2	31.7	3.0	1.0	1.5
Changes	21%	12%	108%	96%	297%

a) Chen Zhikai, 2002
b) YRCC, 2002b

As shown in Table 6, approximately 76% of total Yellow River withdrawal is depleted. However, for a variety of reasons, depletion ratios vary by reach and generally rise from the upper to the lower regions. Between Lanzhou (LZ) and Toudaoguai (TDG) the ratio is relatively low, perhaps suggesting excessive application of irrigation water and highlighting a promising area for water conservation efforts. However, high salt leaching requirements in the LZ-TDG reach may also justify the relatively high application rates. In the lower reach, the ratio approaches 100% because no return flow can enter the suspended river channel. However, some of the water "depleted" from the lower reach enters the groundwater system of the adjoining Hai and Huai Rivers where it can still be utilized.

Table 6. Yellow River Withdrawal and Depletion (bcm), 2000

Reach	Withdrawal	Depletion	Depletion / Withdrawal
Above LZ	4	2.9	73%
LZ-TDG	18.8	12.2	65%
TDG-LM	1	1	91%

LM-SMX	9.3	7.3	79%
SMX-HYK	3.2	2.4	75%
HYK-LJ	10.8	9.9	92%
Below LJ	0.7	0.7	100%
Inland basins	0.2	0.2	84%
Sum/Average	48.1	36.6	76%

Lanzhou (LZ), Toudaoguai (TDG), Longmen (LM), Sanmenxia (SMX), Huayuankou (HYK)
Source: YRCC 2002b

As shown in Table 7, the basin had 48.4 bcm of water as utilizable in year 2000, among which, 35.0 bcm river water and 10.7 bcm groundwater generated by the rainfall in the basin, and another 2.7 bcm groundwater abstracted outside the basin. Depletion from human withdrawal accounted for 36.6 bcm or 76% of the basin utilizable. An additional 4.9 bcm (10%) entered the Bo Sea, leaving 6.9 bcm (14%) as unaccounted depletion from river/canal surface evaporation or other unrecorded "losses."

Table 7. Yellow River Basin Water Accounts, 2000

	(bcm)	Percentage
Utilizable	**48.4**	100%
1) River water	35.0	
2) Groundwater	10.7	
3) Groundwater outside basin[1]	2.7	
Outflow	**4.9**	10%
Reported Depletion	**36.6**	76%
1) From agricultural use	30.6	
2) From industrial use	3.2	
3) From domestic use	2.8	
Uncounted Depletion	**6.9**	14%

[1] groundwater abstracted outside the basin along the lower river reach

The YRCC reported depletion from agricultural sector is a lump account, implying water depleted for growing crops (process depletion) as well as depletion from natural vegetation, and fallow land (non-process depletion). In addition, the direct rainwater on irrigation lands, a comparably large amount of water to crop growth in the lower reach area, is not addressed in the above table. A detail water balance study is desirable once information of the basin's crop ET and effective rainfall becomes available.

Basin Irrigation Water Use

As shown above, the agricultural sector dominates water use in the Yellow River basin, with agricultural withdrawals accounting for more than 80% of total withdrawals in 2000. As demand for industrial use increases, an appreciation of environmental water needs grows (see below), and supplies reach their limit, there is increasing pressure to reduce agricultural water depletion and increase its efficiency. In fact, the YRCC has instituted a plan to reduce basin agricultural water consumption 10% by 2010. With this in mind, we now turn to examination of agricultural water use in the basin.

The value of irrigation in Yellow River basin agriculture has long been recognized as evidenced by the number of pre-modern irrigation systems, some of which are thousands of years old. However, expansion of irrigated area has been especially rapid since the founding of the People's Republic, rising from 0.8 million hectares in year 1950 to 7.5 million hectares in 2000 (Li, no date). Table 8 shows the distribution of irrigated area by reach. The basin has 46% of its arable lands irrigated, and more than half of them are located within four large irrigation districts (Ningxia, Fenwei, Hanan, and Shandong).

Table 8. Cultivated and Irrigated Lands in Yellow River Basin

Reach Name	Arable Lands (mh)	Irrigation lands				
		Large -scale		Small-scale	Sum	Irrigation
		Name	(mh)	(mh)	(mh)	%
Upper LZ	1.01			0.31	0.31	30%
LZ-LM	2.42	NM	0.71	0.83	1.55	64%
TDG-LM	1.58			0.19	0.19	12%
LM-SMX	5.42		0.44	1.23	1.67	31%
SMX-HYK	0.86	FW & HN	0.31	0.23	0.54	63%
Down HYK	4.79	HN & SD	3.13		3.13	65%
Sum	16.09		4.59	2.80	7.38	46%

Lanzhou (LZ), Toudaoguai (TDG), Longmen (LM), Huayuankou (HYK), Sanmenxia (SMX), Lijin (LJ), Ning Meng (NM), Feng Wei (FW), He Nan (HN), Shan Dong (SD)
Source: YRCC 2002d

On a unit area basis, average irrigation withdrawal is 5,164 m^3/ha and depletion is 4142 m^3/ha (Table 9). In some Chinese papers, per hectare irrigation withdrawal figures as low as 1,500 m^3 per hectare are cited. However, those figures are based on total cultivated area rather than irrigated area and should, therefore be considered as indicators of general agricultural water use rather than irrigation application. Withdrawal rates vary substantially by reach but are highest in the upper regions, again in particular from LZ to TDG. Much of the difference in withdrawal rates is explained by differing rainfall levels, though the upstream/downstream conflict seen in other parts of the world may also be in play. Overall, irrigation application rates are relatively low since irrigation can generally be considered as a seasonal supplement to a largely rain-fed system.

Table 9. Unit-area Irrigation Withdrawal and Depletion, 2000

Reaches		Irrigated Water Use	
		(m^3/ha)	(m^3/mu)
	Withdrawal	8512	567
Upper LZ	Depletion	6596	440
LZ-TDW	Withdrawal	10982	732

	Depletion	7447	496
	Withdrawal	3972	265
TDW-LM	Depletion	3799	253
	Withdrawal	3575	238
LM-SMX	Depletion	3142	209
	Withdrawal	3637	242
SMX-HYK	Depletion	3178	212
	Withdrawal	3084	206
Down HYK	Depletion	2936	196
	Withdrawal	**5164**	344
Basin	Depletion	**4142**	276

Lanzhou (LZ), Toudaoguai (TDG), Longmen (LM), Sanmenxia (SMX), Huayuankou (HYK)

The substantial impact of irrigation on the yield of crops such as wheat, maize and soybeans is seen in Table 10**.** Rice would almost be impossible to grow in the basin without irrigation. Main crops such as wheat, maize and soybeans show 1.5 times or higher yields from irrigation. It is these increases in yield and production that have driven the expansion of irrigation in the basin since the 1950s. However, irrigation development is now widely believed to have reached its limit, given total water availability and increasing demand from other sectors. As a matter of fact, rain-fed crop production of 17.2 million tons accounts for 45% of the basin total crop production of 37.9 million tons. The role of rain-fed agriculture should be better played in the next course of the basin development when water becomes unavoidably scarce in the basin.

Table 10. Rain-fed and Irrigated Crop yields and Productions

	Rain-fed Yield		Irrigated Yield		Production		
	Summer (ton/ha)	Winter (ton/ha)	Summer (ton/ha)	Winter (ton/ha)	Rain-fed (mt)	Irrigated (mt)	Total (mt)
Cereals					17.2	20.7	38.0
Rice	0	0	7.17	0	0.0	1.2	1.2
Wheat	2.40	2.58	4.03	5.02	8.8	11.1	19.9
Maize	4.27	0	6.22	0	8.3	6.6	14.9
Other Cereals	1.14	0	1.91	0	0.1	1.8	2.0
Tuber	2.53	0	3.60	0	2.2	1.6	3.8
Soybean	1.05	0	1.91	0	0.5	0.6	1.1
Oil crops	1.47	1.37	2.00	2.20	1.4	1.3	2.6
Cotton	0.77	0	1.15	0	0.2	0.1	0.3
Others	5.00	0	8.00	0	0.2	2.2	2.4

Source: CCAP, 2002

An interesting but often overlooked factor in the physical landscape of the Yellow River basin is the synchronized pattern of rainfall and solar energy delivery (Qian, 2001). As shown in Figure 2, reference evaporation $ET_{0,}$ which indicates the solar heat flux in plant growth, moves in concert with rainfall, and some 60% of the total solar energy reaching the basin arrives during the rainy season. This coincidence of water and radiation provides conditions highly favorable to crop growth, and may help explain why the Yellow River basin has played such an important role in Chinese, and therefore world, agricultural development in what might otherwise appear to be a hostile cropping environment.

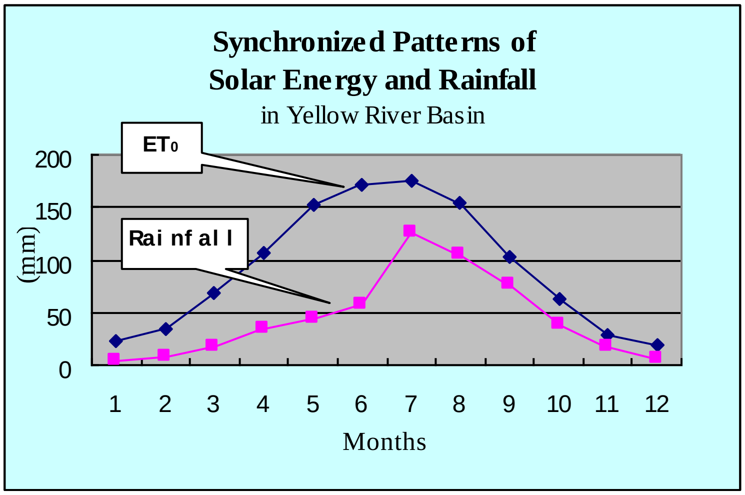

Figure 2. Solar Energy and Rainfall in Yellow River Basin

Agricultural Water Productivity

n the Yellow River, the scope for eliminating waste, that is water depleted by non-beneficial use, is already relatively small. The real gains within the Yellow River are to be made by increases in water productivity-the physical, economic and social benefits derived from the use of water (Rosegrant et al, 2002). In this paper, we make the first attempt to move from a focus on irrigation efficiency to a focus on agricultural water productivity in the Yellow River basin using two measures: agricultural output per unit of water and the value of agricultural output per unit of water.

Crop evapotranspiration (ET) and effective rainwater on irrigation lands are the two parameters of interest in water productivity calculation. Table 11 provides selected crop ET estimates from Chinese source. The basin had an average rainfall of 384 mm in year 2000, and the effective rainfall contribution to crop ET in the Yellow River basin was calculated by Cai (1999). By applying an assumed field irrigation efficiency of 50%, irrigation deliveries by crop for the basin are calculated, as shown in the table.

Table 11. Yellow River Basin Crop ET and Field Level Irrigation Requirements

	(1) [a]	(2) [b]		(3)=(1)-(2)	(4)=(3)/0.5 [c]	
	Crop ET	Effective Rain		Irrigation Requirement	Water Delivery	
Crops	(m3/ha)	(%)	(m3/ha)	(m3/ha)	(m3/ha)	(m3/mu)

Rice	9000	50	1920	7080	14160	944
Wheat	4950	20	768	4182	8364	558
Maize	3750	40	1536	2214	4428	295
Soybean	3750	40	1536	2214	4428	295
Cotton	5250	40	1536	3714	7428	495

a. "Chinese Rural Economic Statistics 1949-1996," Chinese Agricultural Publisher, 1997

b. Cai, 1999. The basin average rainfall in year 2000 was 384 mm

c. A gross irrigation delivery efficiency of 50% is assumed

By combining the water delivery estimates with measures of first yield and then price, water productivities can be calculated in terms of physical and economic output, as shown in Table 12. Be noted that the water deliveries in the table represent the actual irrigation deliveries to the fields. Crop water productivity values varied substantially by crop. For example, the same amount of water delivered for 1 kg rice produced 1.2 kg wheat and 2.8 kg of maize. In terms of economic output, water used for cotton had about twice the average value in output as water used for wheat or soybean.

Table 11. Yellow River Basin Crop ET and Field Level Irrigation Requirements

	(1) [a]	(2) [b]		(3)=(1)-(2)	(4)=(3)/0.5 [c]	
Crops	Crop ET (m3/ha)	Effective Rain (%)	(m3/ha)	Irrigation Requirement (m3/ha)	Water Delivery (m3/ha)	(m3/mu)
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c. A gross irrigation delivery efficiency of 50% is assumed

While these productivity estimates, like all similar estimates, are based on significant assumptions, they are useful as indicators to track performance over time and as an initial screening to investigate where irrigation problems may lie. For example, large spatial variation in estimates may suggest the utility of additional analysis to pinpoint underlying causes. Productivity estimates such as these can also provide a discussion point on the value of irrigation water from which options for designing irrigation and agricultural policy may be considered. Water productivity estimates should, however, be used with extreme caution and only in conjunction with other information. For example, the figures presented here should not be interpreted to suggest that all production in the Yellow River basin should shift to maize, with the highest physical water productivity, or cotton, with the highest economic water productivity since the estimates do not take into account production costs nor do they reflect the marginal value of water. Finally, in order to improve our understanding of how water productivity in the Yellow River basin might best be increased, it is important that better estimates of water withdrawals, effective precipitation, and the values of water at various spatial scales be created.

Ecological Water Needs

Because agriculture uses the majority of Yellow River water, it has been the focus in recent years of water savings efforts in order to free supplies to feed growing industrial and domestic demand. The task of reducing agricultural water consumption is now made more pressing by the growing recognition in China, as in other parts of the world, that water should also be used to serve ecological and environmental functions. Currently, ecological water requirements are not an explicit category in the sectoral water budgeting or allocation in the Yellow River. In addition, even if included, the Chinese concept of ecological water use would have substantially different meaning than that expected by those not familiar with Chinese considerations. With this in mind, we now turn to a description of environmental water accounting concepts and quantities as they may appear in future Yellow River water budgets.

In many western countries, environmental water requirements are determined not by some objective measure but rather by a combinition of legislative, regulative and legal procedures tempered by social values and only partly predicated on scientificly justified criteria. In addition, western definitions of ecological water requirements, and demands to recoginize them, continue to evolve over time as new evidence emerges on the function of rivers within ecosystems and economies and public additudes concernng the value of nature change. This multi-pronged determination of ecological water requirements and the evolving understanding of environmental water function and value is no different in China. However, Chinese water managers approach the problem of environmental requirements with a Chinese perspective of the interrelationship between man and the environment, and so define environmental water uses differently than may typically be the case elsewhere. In general, the concept of environmental water use in China can be considered to contain not only maintainance of biodiversty and “natural” ecosystem function, as is emphasized in the West, but also maintaince of the landscape as a place for human habitation and livlihood.

As a result, it is not surprising that the primary ecological use of Yellow River water is defined by basin managers to be the flushing of sediment to control potentially devestating floods. At present, 1 trillion tons of sediment are assumed to enter the Yellow River each year (MWR 2002b). Of these, 400 million tons are calculated to be captured by two large reseviors and various irrigation diversions, 100 million tons are believed acceptable to allow to settle within the lower reach, and an additional 100 million tons are flushed to the sea through dry-season minimum flow (see below). To flush the remaining 400 million tons, an environmental water requirement of 14 bcm (3.5 bcm of water per 100 million tons of sand) (YRCC 2002c), more than one quarter of recent flow, is currently estimated necessary. As was the case with runoff, however, actual sediment loads in the 1990s were substantially below levels from which the 1 trillion ton number was based and the level in 2000 was only 5% of the 1956-95 average (see Figure 3).

Whether or not the change is permanent and how it will eventually be reflected in Yellow River management plans remains to be seen.

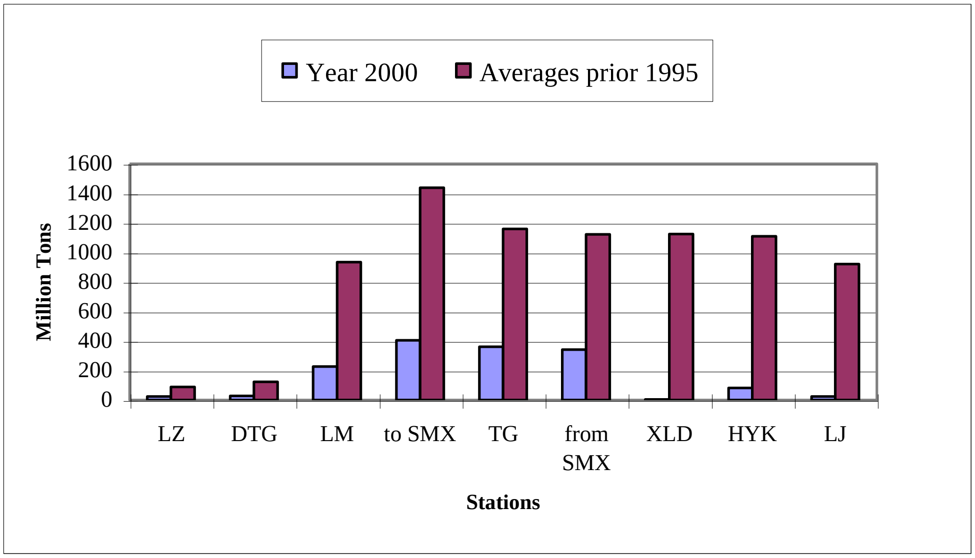

Figure 3. Sands Movement along the Yellow River in 2000

Nonetheless, it is still assumed that an ecological water requirement of 14 bcm is needed for sand flushing but that the figure will decline by approximately 1 bcm per year as erosion control measures are successfully implemented. These control measures are to be based in part on the establishment of new vegetative cover which will also require water. Water for this purpose is also considered to be an environmental use. At present, the YRCC estimates that this use is approximately 1 bcm per year but will climb by an additional 1 bcm per year in the near future as erosion control programs expand and new agricultural opportunities are thereby created.

In the more “traditional” sense of ecological use, Chinese scientists also recognize the value of maintaining dry-season flows for bio-diversity protection and sustanance of grass, wetlands and fisheries at the mouth of the river. To meet these needs, a 5 bcm minimum environmental flow requirement for the river mouth is also assumed along with a mimimum continuous flow of 50 m^3/s at the Lijin gauging station. The minimum flow requirement is also expected to partly meet requirements for sand flushing. Similarly, both the overall sediment flushing and minimum flow requirements are currently seen as sufficient for the river to continue its function of diluting and degrading human introduced pollutants and so no additional environmental requirement for this purpose is planned.

Together then, the ecological water requirements for the Yellow River basin are currently estimated by the YRCC at 20 bcm per year, a figure envisioned to remain relatively constant as reductions in sediment flushing requirements are offset by increases in erosion control requirements. Nonetheless, the estimates may change over time as managers improve their scientific understanding and economic growth alters perceptions, and perhaps definitions, of ecological value. More fundamentally, the question remains as to how these ecological "requirements" will be met. Twenty bcm represents approximately one third of the average annual flow over the past four decades and nearly one half of the flow during the dry decade of the 1990s. With the river almost fully utilized at present and with industrial growth and agricultural demand further claiming water resources, the challenge in the Yellow River basin will be how to balance human demand with ecological needs.

Concluding Remarks

As China continues to emerge onto the international scene, its millennia long experience with water management becomes increasingly available to outside scholars and managers. At the same time, Chinese water researchers now have more access to the large body of externally generated literature and knowledge on river basin management than probably ever before in history. Unfortunately, the ability of the international community to learn from Chinese water management experience, and vice versa, has been hindered to some extent by a failure to understand differences in basic water accounting frameworks and concepts. This paper attempted to partially address this problem by describing the water accounting system used by the Yellow River Conservancy Commission (YRCC), the primary body responsible for water management in the Yellow River basin. Though not explicitly discussed, similar water accounting systems are used by the Ministry of Water Resources for other basins in China.

The paper revealed that the primary difference between water accounting frameworks in the Yellow River basin and those familiar to most international researchers is related to supply accounting in general and groundwater accounting in particular. While there may be valid reasons for the use of the Chinese system, it lacks transparency and involves two complicated double counting adjustments, one between groundwater estimates in mountain and plains areas and a second between total surface and total groundwater estimates. We found that the use of groundwater abstraction as a proxy for groundwater resource availability produced estimates quite similar to those derived from the YRCC system while avoiding hidden assumptions and complicated calculations. As the abstraction approach also has limitations, especially since groundwater extraction appears to be taking place at unsustainable rates across much of China, the future supply of both estimates by basin authorities would be useful and may provide insights into the magnitude of groundwater overdraft. More fundamentally, understanding of the Yellow River basin accounting system by outside researchers would be greatly improved if the methodology behind the current structure were publicized.

The second area in which Chinese and outside water accounting substantially differ is in the concept of environmental requirements. While environmental water use is not currently included in Yellow River basin water balances, there is a clear understanding by Yellow River managers of environmental water requirements and the need for their eventual inclusion. Once included, it appears that the environmental water accounting system will be largely familiar to outside researchers, with environmental use simply becoming another category of demand. However, it is critical to understand that Chinese concepts of what should be included under the rubric of environment water use may not conform to outside, especially Western, ideas. For example, the primary environmental use of water in the Yellow River is considered to be sediment flushing to reduce the human costs of flooding. The fact that conceptual differences in the definition of environmental water use exist should not be taken to mean that one approach is necessary better than the other. Rather it should be taken to highlight the need to fully understand concepts and perspectives when undertaking comparative work.

In addition to providing insights on Chinese water accounting systems, an examination of Yellow River water balance data also provided a number of insights into current and probable future management issues. For example, it is clear that the 1990s saw a substantial reduction in the volume of Yellow River water resources. The reduction was caused in part by a decline in rainfall in much of the basin but also by an apparent decrease in the runoff levels generated by that rainfall. Some have suggested that the current drop in rainfall is part of a recurring 70-year cycle and is near its end. Even if true, data suggest that river flow may not return to the levels seen before the 1990s, because rainfall/runoff ratios have also declined. The extent to which the change in measured rainfall/runoff ratios is a result of actual change rather than an artifact of measurement procedures needs to be carefully explored, since it has serious implications for policy response.

Even without the decrease in rainfall and runoff, growing industrial and domestic demand is increasingly going to require difficult trade-offs in terms of Yellow River water allocation. This will only further increase pressure to reduce use in the basin’s main consuming sector, agriculture. There is already substantial work on technical and institutional mechanisms for reducing agricultural water consumption in the Yellow River basin. In this paper we attempted to supplement that work by presenting the first basin-wide estimates of Yellow River agricultural water productivity. The findings indicated that average productivity in terms of output volume was highest for maize and in terms of economic value was highest for cotton. While decision making should be based on marginal, rather than average, productivity, such numbers do provide some guidelines for water policy, especially in the context of China where government decision making still plays a major role in agricultural life.

The pressure to decrease water use in the agricultural sector is also going to be substantially increased by the growing recognition of environmental water requirements. Basin managers currently calculate a need of around 20 billion cubic meters per year for environmental purposes. This figure is about one third of historic flow and nearly one half the level experienced in the dry decade of the 1990s. How such a substantial need will be met, and how the balance between environmental and human use will be found, is going to be one of the major policy challenges for Yellow River managers as it is for water managers around the world. Clearly, however, this confluence of problems between Chinese and outside managers and researchers also provides opportunities for cooperation and exchange, opportunities which will best be utilized if each side has a thorough understanding of the other’s water management systems and perspectives.

Acknowledgements

The authors would like to thank the Yellow River Conservancy Commission and the Chinese Center for Agricultural Policy for their assistance with data and for providing useful dialogues on water resources issues in the Yellow River Basin.

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand. This research was supported in part through the Government of Netherlands support to the Comprehensive Assessment of Water Management in Agriculture.

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