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The Yellow River Basin: Water Accounting, Water Accounts, and Current Issues

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Abstract*: There is increasing recognition of the problems facing China in meeting the growing water demand in the Yellow River basin, the "cradle of Chinese Civilization" and a critically important agricultural and industrial region. Meaningful debate on the range and relative costs of options available to policy-makers in addressing the problem depend fundamentally on an accurate understanding of basin water resources. Unfortunately, the ability of outsiders to participate in the debate and for Chinese, with their long history of water management, to contribute to similar discussions elsewhere in the world is hindered to some extent by a lack of understanding of differences in water accounting systems and concepts. This paper attempts to address this problem by describing the water accounting system used in the Yellow River basin and elsewhere in China. The paper shows that the primary difference between water accounting methodologies in the Yellow River and those typically applied elsewhere 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 the apparent declining trend in basin rainfall and runoff and the dramatic growth in industrial and domestic water use. Together declining supply and rising demand will increasingly cause policy-makers to face hard choices in assessing their water planning options. These choices will only become more difficult as managers in the Yellow River, as elsewhere in the world, try to incorporate ecological needs in the water accounting equation.*

Keywords*: Yellow River, water accounting, China, water management, environmental use*

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 4,500 m 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 nine provinces and autonomous regions and drains an area considerably larger than the area 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 Academy of Engineering, 2001; Qian, 2001; Wang, 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 forefront as major issues for basin administrators, residents, and the nation as a whole (Jing, undated; Geography Institute of the Chinese Academy of Sciences, 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? 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 largely 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.

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 percent 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 increases 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.

The middle reach, covering 46 percent of the basin area and providing an additional 43 percent 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 percent 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 the Yellow River's historically devastating floods.

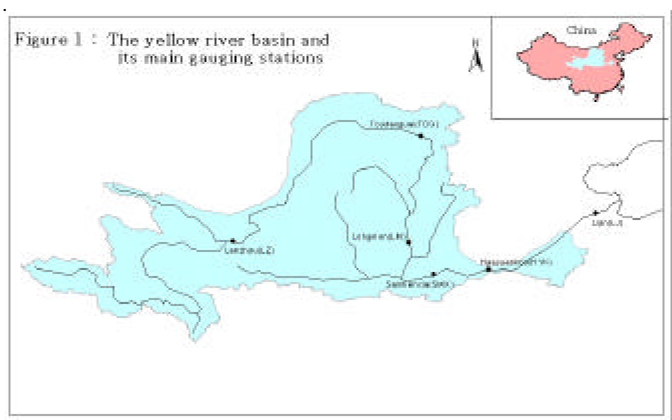

Figure 1. The Yellow River Basin and its main gauging stations

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, 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 rising 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 percent 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 the most fundamental elements in basin 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. We now explain some of those differences using the example of the Yellow River.

The basic water resources accounting framework used by the Yellow River Conservancy Commission (YRCC) is show 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 accounting error to arrive finally at a total water resource calculation. It is unclear to the authors how the two double accounting 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 and, as will be seen, in understanding the nature of current water management problems.

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/groundwater double 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 1. Yellow River Basin Water Resouces (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) and (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

Table 2. YRCC and IWMI Yellow River Basin Water Resouce 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 percent and most variation less than 4 percent. 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 appears to exist differentially across the Yellow River basin. 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 original rationale for the water accounting system in the Yellow River basin was 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 has been responsible for surface water, groundwater was until recently considered as a mineral resource and administered by what was known as the Ministry of Geology and Mineral Resources and other agencies. While the Ministry of Water Resources is now ostensibly responsible for both surface and groundwater, actual responsibility and management authority has yet to be firmly established and so any change in water accounting procedures may need to await further administrative reform.

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 possible changes in climatic conditions and changing relationships between rainfall and runoff yields (Geography Institute of the Chinese Academy of Sciences, 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.

It is immediately clear from Table 3 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 apparently less severe dry-spell occurred in the decade from 1922 to1932, 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; He, 2001; Chen, Zhikai, 2002; Liu, 2002), as shown in Table 3. The 1990s saw the rainfall/runoff ratio in the upper reach decline by an average of 16 percent from previous decades while in the middle reach the decline was by 34 percent (note that there is essentially no rainfall or runoff in the lower reach because of the "suspended" channel). In general, a 1 percent decrease in upper reach rainfall was associated with a 4 percent runoff decline, while in the middle reach a 1 percent decrease in rainfall was associated with a 2 percent decline in runoff.

Some suspect that the changing rainfall/runoff ratios are related to alterations in land use patterns including intensified agricultural and livestock production. While land use could clearly play a role, the fact that the change in ratios appears to have occurred only in the 1990s, though such land use changes began much 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 described above. As rainfall declined in the 1990s, farmers responded by increasing groundwater withdrawals an estimated 5.1 billion cubic meters, or 61 percent, 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, particularly the middle reach, increased abstraction would reduce the quantity of groundwater able to enter the channel and contribute to river flow. Both of 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

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

	Area (000 km²)		*1956-70*	*1971-80*	*1981-90*	*Time Period 1991-00*	*Average*	*1990s Change 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%
Basin	752	Rain (mm)	482	451	455	413	454	-9%
		Runoff (bcm)	65	56	61	43	57	-24%

Source: YRCC, 2002d

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 to 1998 (Geography Institute of the Chinese Academy of Sciences, 1998; Ma, 1999; Chinese Academy of Engineering, 2001; Chen, Zhikai, 2002). 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 nominally end absolute flow cut-off even though drought conditions continued in the ensuing years (Ma,1999; Li, undated; 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 by the Yellow River Conservancy Commission that 15 billion cubic meters of annual flow is required for sediment transport in the flooding season, a level not met in any of the recent drought years.

An additional implication of the changing runoff levels is related to basin water planning. Various Chinese documents and papers continue to cite 58 billion cubic meters as average annual runoff. However, as shown in Table 3, the average flow from 1956 to 2000 is already marginally below this level, and the figure from the 1990s, averaging only 43 billion cubic meters annually, is 25 percent lower. Even if some of this reported decline is due in part to a mis-accounting of basin resources as described above, 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.

As seen in Table 4, the average annual withdrawal from the Yellow River basin in recent years has been approximately 50 billion cubic meters of which approximately 74 percent was from surface water and 26 percent was from groundwater. Agriculture is by far the largest user of water, accounting for 80 percent of total withdrawal, with industrial, urban, and rural domestic sectors sharing the remaining 20 percent. In terms of current management issues, it is interesting to note that agricultural withdrawals decreased in 2000 by 2 billion cubic meters 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, probably largely as a result of greater groundwater abstraction.

In terms of depletion, Table 5 shows the rapid growth which has taken place over the past decade. While agricultural depletion increased, the growth in the industrial and domestic sectors was dramatic. Dealing with the likely continuation of that growth is going to be a key issue in future basin water management.

Basin Water Accounts

Putting the information on Yellow River water supply and demand together gives us the water accounts as shown in Table 6 for the year 2000. In total, approximately 76

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. Yellow River Depletion (bcm), 1998-2000 and 1988-1992

				Domestic	
	Total	*Agricultural*	*Industrial*	*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

percent of the river's total water resources were depleted by acknowledged human uses and an additional 14 percent was depleted through river/canal evaporation or as other unrecorded "losses." In total then, only 10 percent of the river's runoff entered the sea. These figures indicate: first, the scope for eliminating "waste," that is water depleted by non-beneficial uses is relatively small, and second, there is already very little water left in the system that can still be developed to meet growing human demands. This problem is only going to be further compounded when ecological water uses are further considered.

Ecological Water Use

There is now a growing recognition in China, as in other parts of the world, that water should be used to serve ecological and environmental functions in addition to direct human needs. 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.

In many western countries, environmental water requirements are determined not by some objective measure but rather by a combination of legislative, regulative, and legal procedures tempered by social values and only partly predicated on scientifically justified criteria. In addition, western definitions of ecological water requirements, and demands to recognize them, continue to evolve over time as new evidence emerges on the function of rivers within ecosystems and economies and public attitudes concerning the value of nature change. This multi-pronged determination of ecological water requirements and the evolving understanding of environmental water function and value are 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 maintenance of biodiversity and "natural" ecosystem function, as is emphasized in the West, but also maintenance of the landscape as a place for human habitation and livelihood.

Table 6. Yellow River 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 from outside the basin's topographic boundaries in the lower reach is calculated as actual abstraction.

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 devastating floods. At present, 1 billion tons of sediment is assumed to enter the Yellow River each year (MWR, 2002b). Of these, 400 million tons are calculated to be captured by two large reservoirs and various irrigation diversions, 100 million tons are believed acceptable to allow settling 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 billion cubic meters (3.5 billion cubic meters of water per 100 million tons of sand) (YRCC, 2002c), more than one quarter of recent flow, are estimated as currently necessary. As was the case with runoff, however, actual sediment loads in the 1990s were substantially below levels from which the 1 billion ton number was based, and the level in 2000 was only 5 percent of the 1956 to 1995 average (Figure 2). Whether or not the change is permanent and how it will eventually be reflected in Yellow River management plans remains to be seen. Nonetheless, it is still assumed that an ecological water requirement of some 15 billion cubic meters is needed for sand flushing but that the figure will decline as erosion control measures are successfully implemented. However, since these control measures are based in part on the establishment of new vegetative cover, they will also require water. At present, the YRCC estimates that the savings in water for sediment flushing through the use of control measures will be approximately offset by the additional water use.

In the more "traditional" sense of ecological use, Chinese scientists also recognize the value of maintaining dry-season flows for biodiversity protection and sustenance of grasslands, wetlands, and fisheries at the mouth of the river. To meet these needs, a 5 billion cubic meter minimum environmental flow requirement for the river mouth is also assumed necessary along with a minimum continuous flow of 50 meters^3/second 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

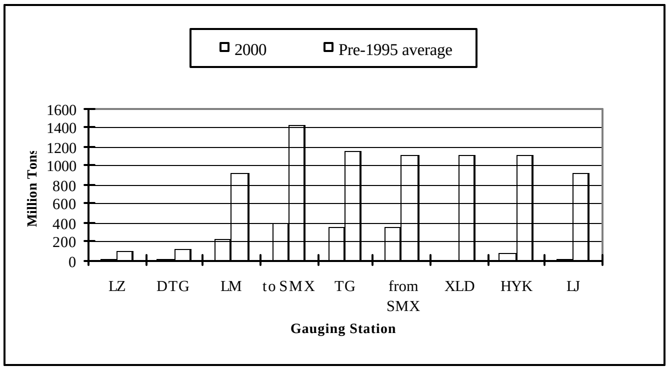

Figure 2. Sands Movement in the Yellow River at various gauging stations

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 over 20 billion cubic meters 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 will likely 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 billion cubic meters 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.

Conclusion

There is increasing recognition of the problems facing China in meeting the growing water demand in its Yellow River basin, the "cradle of Chinese Civilization" and a critically important agricultural and industrial region. Meaningful debate on the range and relative costs of options available to policy makers in addressing the problem depend fundamentally on an accurate understanding of basin water resources. Unfortunately, the ability of outsiders to participate in the debate and for Chinese, with their long history of water management, to contribute to similar discussions elsewhere in the world is hindered to some extent by a lack of understanding of differences in water accounting systems 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 in at least some parts of the Yellow River basin, 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 environmental 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 potential 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 highlight the need to fully understand concepts and perspectives when undertaking comparative work.

In addition to providing insights on Chinese water accounting systems, a basic 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 and accounting 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. The pressure to address those trade-offs is going to be substantially increased as environmental water requirements are recognized and additional efforts are made o ensure that they are at least partially included. Basin managers currently calculate a need of over 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.

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