WORKING PAPER 57

Yellow River Comprehensive Assessment

Basin Features and Issues

Collaborative Research between
International Water Management Institute (IWMI)
and Yellow River Conservancy Commission (YRCC)

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Zhongping Zhu, Mark Giordano, Ximing Cai (IFPRI-IWMI)
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International Water Management Institute

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COMPREHENSIVE Assessment of water management in agriculture

YRCC

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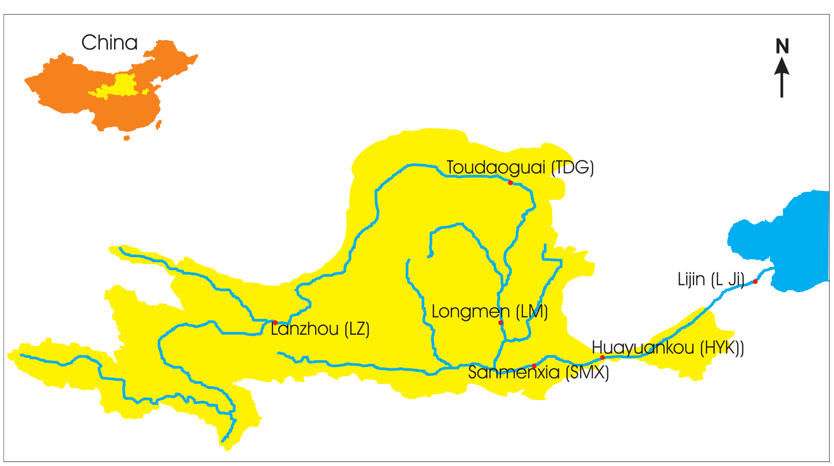
1. Introduction

The Yellow River has played a key role in China's long history as the "cradle of Chinese civilization." Ironically, the river has also been called "China's Sorrow" because the alluvial deposits, which have fostered human development on the North China Plain, are associated with frequent, sometimes catastrophic, floods. The devastation brought by these floods, often at scales unimaginable in the West, made successive Chinese administrations from the legendary Xia Dynasty through to the twentieth century to treat "harnessing the Yellow River" as a number one priority civilian affair. While the possibility of flooding is ever present, major achievements have been made in flood control and prevention since the founding of the People's Republic of China in 1949 (Wang 2001; Chen 2002; Jin 2002). As a result of this success and the rapid economic and social changes taking place in the recent decades, new issues such as water scarcity, overuse of resources and environmental degradation are now rising to the top of the basin water management agenda. A transition in river management is now taking place, in which focus is shifting from prevention of the river doing harm to people, to a focus on preventing people from doing harm to the river.

To bring about such a fundamental transition in a river management system that has evolved over two millennia requires significant institutional, policy and legal reforms. As importantly, it requires the application of new forms of knowledge and science as well as perceptual changes in basin residents, managers and the nation as a whole. The Yellow River Conservancy Commission (YRCC), as the primary water management institution in the Yellow River basin, must be, and is, at the forefront of these changes.

To help facilitate these changes, the YRCC and the International Water Management Institute (IWMI) decided to join hands in producing this Comprehensive Assessment of the Yellow River basin. Through this assessment, the YRCC brings an in-depth knowledge of the conditions of the Yellow River basin, while IWMI brings experience on water management from throughout the world. Together, the two organizations are able to develop new ideas to address the critical water issues facing the basin while at the same time share the Chinese experience with the rest of the world.

The Yellow River basin



2. Basin Characteristics

The Yellow River is the second longest river in China. It flows through 9 provinces and autonomous regions over a length of 5,400 km and has a basin area of 795,000 km^2. The basin contains 9% of China's population and 17% its agricultural land (YRCC 2002a), and is at the center of China's political, economic and social development.

The Yellow River originates in the Bayangela Mountains in western China. It 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. The river can be divided into three reaches for analysis.

The Three River Reaches

In the upper reach, which drains 51% of the basin area, the river begins in a high moisture plateau and provides 56% of total basin runoff (based on pre-1990s averages). As it moves northward into the desert plain, however, evaporation rises to a level several times that of precipitation, resulting in a largely reduced river flow.

The middle reach covers 46% of the basin area and provides 43% of basin runoff on average. In its southward route, the river cuts through the Loess Plateau, the world's most erodible land surface. Massive amounts of loess soil enters the main stem and tributaries, providing 90% of the river's total sediment, and resulting in sediment loads unprecedented amongst the world's major waterways. Unpredictable and intensive summer storms in the reach exacerbate the sedimentation problem, and cause devastating floods in the basin.

The lower reach is one of the most unique river segments in the world. Here the sediment transported from the middle reach begin to settle as the river spills onto the flat North China Plain, producing a consistently aggrading, meandering riverbed. 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 silts constantly elevate the channel. Over time, the process has created a "suspended" river, in which the channel bottom is above ground level, sometimes by as much as 10 meters (Liu 2002). The "suspended" river channel brings in severe flood threats if the levees break. In addition, rainfall on surrounding lands cannot drain into the river nor can tributaries enter the it. In the lower reach, the "basin" becomes a narrow corridor no wider than the few kilometers breadth of the channel. With almost no inflow, the contribution of the lower reach accounts for only 3% of basin total runoff.

The table below shows characteristic parameters of the three river reaches.

River reach parameters of the Yellow River

	Drain area (km^2)	River length (km)	Elevation drop (m)	Channel slope 1/1,000	No. of tributaries
Reaches					
Upper	428,235	3,472	3,496	10	43
Middle	343,751	1,206	890	7	30
Lower	22,726	786	94	1	3
Basin total	794,712	5,464	4,480	8	76

Source: YRCC 2002a

Climate and Rainfall

The basin has different types of climates: an arid and semi-arid continental monsoon climate in the northwest, and a semi-humid climate in the southeast. The basin average annual temperature is 4-14° C. As shown in the table below, average rainfall during 1956-2000 was 372 mm in the upper reach, 523 mm in the middle reach, 671 mm in the lower reach, and 454 mm over the entire basin (YRCC 2002d). However, the decade of the 1990s has seen less precipitation compared to the previous decades. More than 60% of the annual precipitation arrives during the June-September period. The basin receives a large part of its solar energy in the same period, providing a favorable condition of coincident rain-heat for agricultural crop production.

Average annual rainfall in the Yellow River basin

	Time period				
	1956-70	1971-80	1981-90	1991-00	Average
Upper	380	374	373	360	372
Middle	570	515	529	456	523
Lower	733	689	616	614	671
Basin total	482	451	455	413	454

Source: YRCC 2002d

Water Resources

During 1956-2000, the average annual basin runoff was 57 bcm (billion cubic meters) (YRCC 2002b), while the figure in the 1990s was only 43 bcm, a drop of 24% in the drought decade. Groundwater has been extensively utilized in the basin since tubewell usage began in the late 1950s. In year 2000 groundwater extraction reached 10.7 bcm within the basin and 2.7 bcm outside the “basin” corridor along the lower reach.

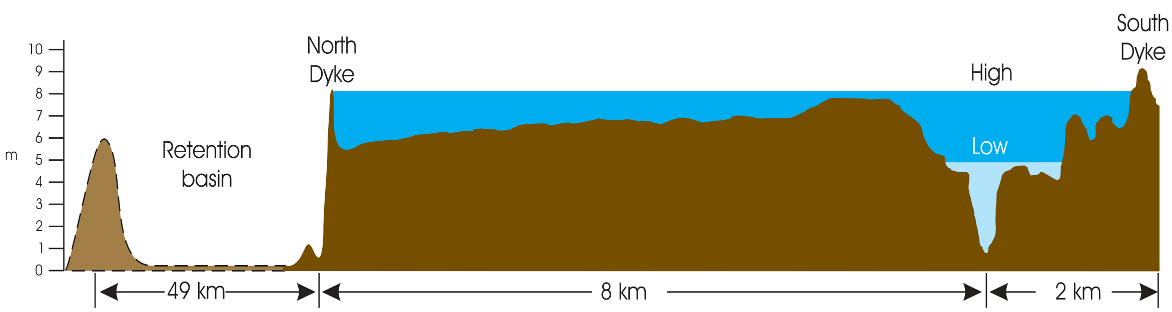
Water is poor in the Yellow River basin. The average per capita share of water resources is 553 m^3, only 7.5% of the world average and 22% of China’s average (YRCC 2002d).

Sediments

The Yellow River flows through the Loess Plateau, a 640,000 km^2 area, with a thick loess soil layer dozens to hundreds of meters deep. Seventy percent of the area is classified as an "active" erosion area, and the region as a whole is considered to be the largest erodible area on earth (MWR 2002c). The soil of the Loess Plateau is washed down into the Yellow River and its tributaries in massive quantities, in particular during the concentrated rainstorms of the summer months.

As a result, the Yellow River carried an average 1.6 billion tons of sediment each year in the wet decades 1950 and 1960 and has, by far, the highest silt concentration of any major river in the world. If made into a square belt with one meter-wide sides, the quantity of sediment moved annually by the river would be sufficient to loop around the earth at its equator 27 times. Of the total sediment, only about 25 percent is carried through to the sea, and the remainder is deposited in the riverbed, forming a "suspended" channel on the downstream plain. The riverbed has risen at an average rate of 5-10 centimeters per year and flood control embankments have been periodically raised in response. It is this sediment and its impact on channel dynamics that has made governance of the river in its lower reaches so difficult.

Schematic representation of a cross-section of the Yellow River just above the railway bridge linking modern Zhengzhou with Xinxiang, i.e., just west of the old Bian Canal.



Lands and Minerals

Approximately 75% of the basin lands are covered with mountains and hills, while plain areas account for only 17%. The basin has 12 million ha of arable land, 10 million ha of forests, and 28 million ha of pastoral lands. The average per capita arable land is 0.12 ha, a low figure compared to many international river basins but still 1.5 times China's national average (YRCC 2002d).

The basin has rich mineral resources, including 37 of China's 45 listed minerals. In particular, 45% or more of China's coal and aluminum ores are located in the basin. The hydro-energy potential in the upper reach, the coal mines in the middle reach and the petroleum and natural gas in the lower reach, have made the basin an energy base in China.

Population and Economics

In year 2000 the population within the basin boundary was 110 million or 8.7% of China's total population. The figure would be 189 million or 14.9% of China's total if the flood area surrounding the lower reach were included. (Li 2002a). The level of urbanization in the basin is 26.4%, a lower level than China's national average of 29% for the year 2000.

The basin's gross output value was 77.1 billion US dollars in 2000, representing 6.8% of China's GDP. If the downstream flood zone is included the figures increase to 131.3 billion US dollars and 11.8% respectively (YRCC 2002d). The grain production in the basin and its flooding area reached 76.2 million tons or 16.2% of China's national total in 2000. While the absolute values of these statistics are large, the basin remains an economically backward region in China. The basin population is projected to continue growing to 121 million by year 2010, and similarly, to 121 billion US dollars of GDP by that time.

Production scales in the Yellow River basin

	Agriculture (10^6 tons)			Gross output value (10^9 US$)
	Grains	Cotton	Oil	
1) Within basin	36.2	0.1	2.4	77.1
2) Downstream flood area	44.6	1.3	4.0	61.3
3) Total	76.2	1.4	5.9	131.3
1) over national (%)	7.8	3.1	8.2	6.8
3) over national (%)	16.2	24.8	19.8	11.8

Source: YRCC 2002d

Floods and Droughts

Flood and drought have been the twin major disasters in the long history of the Yellow River basin. As shown in historic records, before 1949 there were, on average, two river breaches every 3 years and one river course change every 100 years, caused by the lower reach floods. The flat North China Plain, which was created by the alluvial deposits of the Yellow River, was always prone to flood threats.

Embankment along downstream areas of the Yellow River

Droughts also frequently hit the basin, probably more than 1,000 times in history before 1949 (YRCC 2001). Even in more recent times, 34 million Chinese people were struggling on the verge of death in the decade-long drought during the 1920-1930 period. The Yellow River is known as "China's sorrow."

Cultural Links

The Yellow River basin has played a key role not only in China's economic development but also in the historical cultural identity of the Chinese people. Chinese culture in the Yellow River basin probably began to emerge about 12,000 years ago. The nutrient-rich soils carried from the Loess Plateau and deposited in the lower reach, along with a favorable coincidence of precipitation and solar energy, would have been the major factors behind the origin of early agriculture in the basin. These agricultural origins and human habitation, as exemplified by the Yangshao, Majiayao and Dawenkou cultures, provided the basis for Chinese culture.

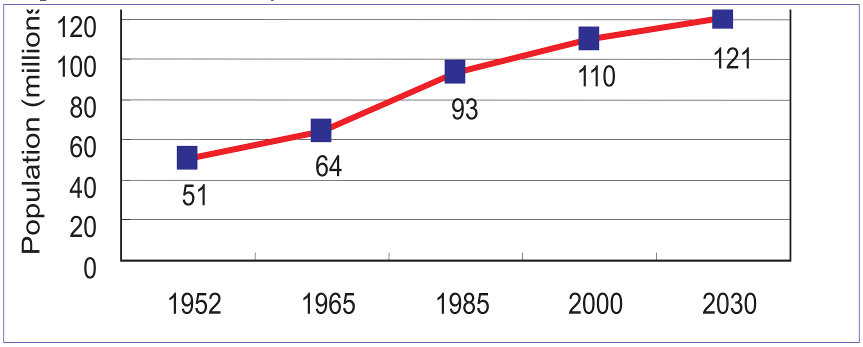
The connection between Chinese culture and the Yellow River is recorded in the Legend of Yu. Considered one of three early, probably mythical, leaders of China from 4,000 years ago, he is known for taming the Yellow River floods. Repairing river dikes damaged by floods and feeding people during droughts in the Yellow River basin was a major responsibility of every Chinese dynasty. Many Chinese philosophers built their philosophic theories and views around how to harness the Yellow River. The rich experience of mass mobilization of labor for the Yellow River dike constructions might explain why China has had long-lasting centralized governments for thousands of years.

3. Basin Development Since 1949

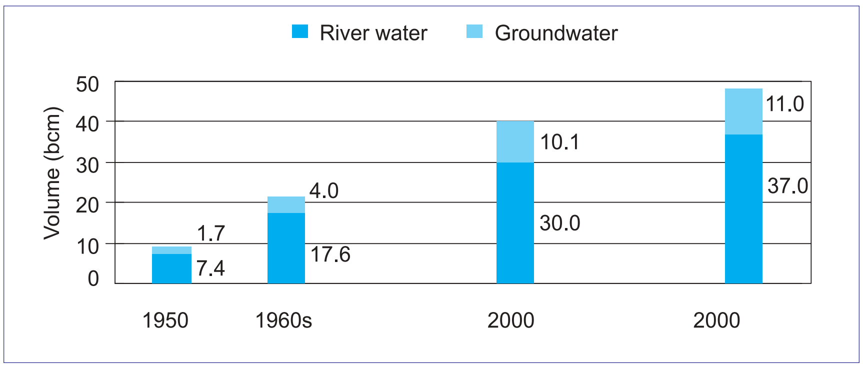
The establishment of the New China in 1949 ushered in fundamental changes for China socially, politically, and also in terms of the development of the Yellow River basin. The basin witnessed a large array of infrastructure development on flood control, hydropower, and irrigation during the past 5 decades. In 2000 the basin had 10,100 reservoirs of different sizes in operation, among which 22 are large reservoirs with a total storage capacity of 62 bcm, a figure exceeding the basin's total annual runoff. There are 9,860 diversion gates, 23,600 lifting stations, and 380,000 tubewells. Equipped hydropower capacity is 11.1 million KW, providing 40 billion KWH of electricity per year. More impressively, the irrigated agricultural area expanded from 5% to 46% of the basin's arable lands since 1950, accompanied by a 440% increase in human river-water consumption. The river also supplies the domestic and industrial water demands of 50 cities and 420 counties in the basin, and has periodically diverted water to the Tianjin, Qingdao, and Jinan cities, thousands of kilometers away from the basin.

As shown in the following two figures, the basin population (excluding the downstream flood-prone area) in 2000 almost doubled that of 1950. Human water use (including both river water and groundwater) jumped 4.4 times from 9.1 bcm to 40.1 bcm in the past 5 decades, and is projected to reach 48 bcm by 2030 (YRCC 2002d).

Population statistics of the Yellow River basin



Human use of water in the Yellow River basin



Clearly, water is highly developed and utilized in the Yellow River basin. The trend will likely to continue in the course of the next decades, given China's demographic and economic growth pattern. It is not an exaggeration that the Yellow River has served China so much that every drop of water it has is exhausted.

The basin experienced several stages in its water development. In the 1950s when the New China emerged, an ambitious plan was made to "conquer" the river by building more than 40 large dams to control sediment and increase hydropower and irrigation. Large-scale river engineering constructions were carried out in the decade with a conviction in human power to overcome nature.

In the 1960s the difficulties of the Sanmenxia Project—a reservoir constructed on Russian aid, without sediments flushing design which lost its storage capacity to sand in the first two years of operation—woke up the people and the government. The fact that sands is routinely carried in the river, as well as the crux of river management, received recognition as a lesson of this failure. The "big diversion, big irrigation" policy in the Great Leap Forward of 1958 left severe water-logging, salinization, and crop yield drops in irrigated lands. This decade cooled down the enthusiasm for pure engineering solutions to basin development and was followed by a slow but sustained revision of river plan, drainage development, and irrigation system rehabilitation.

In the 1970s, large dam construction continued in the basin's upper reach, soil conservation campaigns brought in new terraced croplands on the Loess Plateau along the middle reach, and irrigation diversions were substantially expanded in the lower reach provinces. A wide-ranging set of reforms swept through China in the 1980s. The commune system was abolished and a rural household responsibility system moved production decisions and power towards individual farmers. Government control became less centralized, and also, investment in the water sector declined. During this decade, public environmental awareness started to grow, particularly related to water quality and the flow-cut events in the lower reach.

The 1990s saw a new water era in the basin and throughout China. The booming economy of the nation demanded an accompanying growth in the water sector. However, water resource shortages began to emerge, undermining the continuous economic growth. In addition, the 1990s was a drought decade on the North China Plain. The conflicts between reduced water supplies, but constantly rising demands on water made water scarcity a more acute challenge than the flood threat. A shift away from a singular emphasis on flood control toward a comprehensive basin management strategy began evolving in the basin. In addition, an increasing awareness of the ecological value of water developed, coinciding with the downstream flow cutoffs, which started in the 1970s but became acute in the mid-1990s.

Partially in response, the Chinese government strengthened, and adjusted, its intervention and investment in the water sector during the 1990s, particularly through legislation. Water-related laws, such as the Water Law of 1998, the Soil and Water Conservation Law, the Flood Control Law, the Environmental Protection Law, the Fishery Law, the Forestry Law, and the Mineral Resources Law were passed in the 1990s. Many administrative rules and regulations for water management were also promulgated. In 2002 China issued a new Water Law, calling for a transition from an engineering-dominated to a resource-oriented water development strategy.

The large-scale exploitation of water has driven the Yellow River basin to its water resource limit and resulted in series of water problems and even crises. This study has identified the following four major challenges in the basin:

- Increasing water scarcity
- Constant flood threats
- Massive soil conservation work
- Degrading environment

4. Increasing Water Scarcity

Water stress represents the most pressing issue in basin water management in the Yellow River basin (Li 2002b; Liu Changming et al. 2003). The stress is caused by an expansion of human use—particularly for agriculture, a period of drought since the 1990s, and a growing awareness of environmental water needs after the flow cutoff events in the lower reach.

Supply and Use

The table below gives the YRCC estimate of the water resources at the two major river gauging stations, LZ (Lanzhou) and HYK (Huayuankou). The HYK station is the virtual end of the basin, and its figure represents the total basin water resources.

Year 2000 water resources in the Yellow River basin (bcm)

	Gauging station	
	LZ	HYK
Surface runoff		
a) River flow measurement	26	16.5
b) Depleted by human intake1[1]	2.7	18.4
c) Reservoir storage changes	-3.3	0.1
1. Surface runoff = a)+b)+c)	25.4	35
Groundwater		
e) In hilly area	12.6	22.6
f) In plain area	1.6	15.4
g) Double counting in e) and f)	0.7	4.1
2. Groundwater = e)+f)-g)	13.5	33.9
3. Double counting in 1 and 2	12.8	24.7
Total resources = 1+2-3	26.0	44.1

Source: YRCC 2002b

[1]According to the YRCC, water depletion means the portion of human withdrawal without returning to the river or groundwater.

The following table shows the water uses in the basin. The average annual human use has been around 50 bcm in recent years. Agriculture is by far the largest user of water, accounting for 81% of total withdrawal, with industrial and domestic sectors sharing the remaining 19%. Ecological water is not budgeted as a water use in practice. Note that the human use figures are larger than total basin resources because of groundwater pumping outside the basin in the lower reach region and the effect of recycling.

Water use in the Yellow River basin (bcm)

	By sector				
Year	Agricultural	Industrial	Domestic		Total
			Urban	Rural	
1998	40.5	6.1	1.6	1.5	49.7
1999	42.6	5.7	1.8	1.5	51.7
2000	38.1	6.3	2.1	1.6	48.1
Average	40.4	6	1.8	1.5	49.8
share	81%	12%	4%	3%	100%

Source: Data from YRCC 2002b

As shown in the table below, the basin had 48.4 bcm of utilizable water in year 2000, of which 35.0 bcm was river water and 10.7 bcm was groundwater generated by the rainfall within the basin boundary. Another 2.7 bcm was from well abstraction outside the basin. Depletion from human withdrawal accounted for 36.6 bcm or 76% of the utilizable basin resources. Only 4.9 bcm (10%) entered the sea as outflow, leaving 6.9 bcm (14%) as unaccounted depletion from surface evaporation or other unrecorded losses.

Yellow river basin water accounts, 2000

	(bcm)	Percentage
Utilizable	48.4	100%
1) River water	35.0	
2) Groundwater	10.7	
3) Groundwater outside the basin	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%

Human use has also constantly increased in the basin (Chen Zhikai 2002; Ma 1999). As shown in the table below, the total depletion from human use has grown by 21% over the past 10- year period. Sectorally, the increase consists of a moderate increase in agricultural depletion and dramatic growth from the industrial and domestic sectors.

Human use depletion in 1988-1992 and 1998-2000 (bcm)

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

Source: Data from Chen Zhikai 2002 and YRCC 2002b

Partially in response to declining supplies and increasing demand, groundwater pumping has also increased dramatically by 5.1 bcm over the past 20 years (MWR 2002b). In many cases groundwater overdraft has caused land subsidence and an extension of aquifer funnels.

Drought Decade

The 1990s was a drought decade in the Yellow River basin as well as on the entire North China Plain (Chinese Academy of Engineering 2001; MWR 2002a; He 2001). The river carried extremely low channel flows during the decade. The table below shows river flow in 2000. Compared to the averages of 1956-1999, the flow in the main stem dropped by 18% at LZ, 59% at HYK, and 86% at LJ (Lijin station), while flows in Weihe and Fenghe, the two main tributaries, were trickles compared to normal years.

Yellow River flows in year 2000 (bcm)

Gauging stations	Annual flow 2000	Annual flow Average	Difference from average
Main River			
LZ	26.0	31.7	-18%
HYK	16.5	40.5	-59%
LJ	4.9	33.7	-86%
Major tributaries			
Weihe	3.6	7.3	-51%
Fenghe	0.2	1.2	-87%

Source: YRCC 2002b

Seasonal desiccations have appeared in the lower reach. During 1995-1998 there was no flow in the lower reach for some 120 days, each year (Geography Institute of China Science Academy 1998). The affected river section extended to Kaifeng, a city 700 kilometers distant from the river end. This cutoff in flow has serious repercussions to basin function in terms of accessibility of river water to downstream provinces, sediment transportation to the sea, the river delta's ecologic sustainability, and costal fisheries. With the enforcement of the 1987 Water Allocation Scheme, the YRCC has since 1999 managed to nominally end absolute flow cutoff, though the flow levels are sometimes so low as to be largely symbolic.

Irrigation Development

A large part of the Yellow River basin is located in an arid and semi-arid geographic region. Irrigation is important for crop production. While irrigation has been part of the basin for thousands of years, it has rapidly expanded since 1949. Currently the basin has a total irrigated area of 7.5 million ha, accounting for 46% of the arable lands. Large-scale schemes of 20,000 ha or more are located in four major irrigation districts: Ningmeng, Fenwei, Henan, and Shandong (YRCC 2002d). The spatial distributions of these irrigation lands along the river reaches are given in the following table.

Yellow River basin irrigation areas in year 2000 (in million hectare)

River sections	Arable areas (mh)	Irrigation areas: Large (mh)	Small (mh)	Total (mh)	Irrigation (%)
Upper LZ	1.01	0	0.31	0.31	31%
LZ-LM	2.42	0.71	0.83	1.55	64%
TDG-LM	1.58	0	0.19	0.19	12%
LM-SMX	5.42	0.44	1.23	1.67	31%
SMX-HYK	0.86	0.31	0.23	0.54	63%
Down HYK	4.79	3.13	0	3.13	65%
Total	16.09	4.59	2.8	7.38	46%

Source: Data based on YRCC 2002d

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

Irrigation withdrawal rates vary with locations, and are higher in upstream and lower downstream because of the differences in rainfall. The average basin withdrawal rate in 2000 was 5,164 m^3/ha (Zhu et al 2003). Compared to many irrigation systems in the world, the Yellow River basin shows a lower rate of irrigation water intake, indicating a pressing competition for water use, and a probable high water use efficiency in the basin irrigation systems.

The Ningxia irrigation district

Water scarcity is now the number one priority in Yellow River water management. Given the growing supply and demand imbalance in the basin, it is difficult, if not impossible, to meet new water demands from one sector without decreasing supplies to another. There will be hard choices in allocation of water between sectors and locations (Giordano et al. 2003). Since agriculture is by far the largest consumer of water, a reduction of water supply to agriculture would be unavoidable in the future. Given the importance of agriculture to the Chinese economy, its role in rural livelihoods, and the long-standing policy of self-sufficiency in food production, reduction may seem disruptive and radical. However, as reflected in China's rural reform history in the late 1970s, when few foresaw what the massive success the Household Responsibility System policy would bring, changes in water policies will indeed be adopted in the basin and lead to real water savings in agriculture. A key issue is how to practice the reallocation with minimum disruption to the livelihoods of farmers and agricultural output. China's recent ascension to the World Trade Organization, and the expected changes in the nation's agricultural product market may help provide an opportunity to begin considering options. As the Chinese saying goes, "*zhi nan er jin:"* "though it may be difficult, it is necessary to proceed."

Environmental Water Requirements

A further complication are the environmental water requirements in the basin. With the river's unique nature of heavy sediment load, according to the YRCC, the number one consideration of environmental water is the river flow needed for flushing the sediments. The average sediment load in the river was approximately 1,000 million tons during 1956-1995, as will be further explained in the next section. The YRCC plans the following four strategies to move the sediment load (YRCC 2002d):

- 400 million tons to be captured by the Xiaolangdi reservoir and irrigation diversions
- 100 million tons allowed to deposit in the lower reach channel
- 100 million tons to be moved out by non-flood season river flow
- the remaining 400 million tons to be flushed by an environmental flow of 14 bcm (3.5 m^3 of water per ton of sand)

The planned environmental flow needs of 14 bcm were equivalent to a quarter of the basin runoff in 2000. Whether or not the situation of 2000 is permanent and how environmental water requirements will eventually be reflected in the basin water allocation plan remains to be seen.

In the more "traditional" sense of ecological use, YRCC scientists also recognize the value of maintaining dry-season flows for bio-diversity protection and sustenance of grass, wetlands and fisheries at the mouth of the river. To meet these needs, a minimum flow requirement of 5 bcm or a continuous flow of 50 m^3/s at Lijin gauging station in the non-flood season is required. This minimum flow is also expected to be sufficient for diluting and degrading human-introduced pollutants in the river. Together then, the environmental water requirements for the Yellow River basin are currently estimated by the YRCC at 20 bcm per year, a figure predicted to remain relatively constant as reductions in sediment-flushing requirements are offset by increases in erosion control requirements.

A fundamental issue is how the environmental requirements will be met. The requirements of 20 bcm represent approximately one third of the average annual flow over the past 4 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, urbanization and agricultural demand further claiming water resources, the challenge to balance human demand with ecological needs will be vitally serious and difficult to meet.

5. Constant Flood Threats

Over the millennia, Yellow River floods have caused the deaths of literally millions of people and sometimes portended dynastic change, and it is therefore not surprising that until recently, flooding was considered to be the primary management issue in the Yellow River basin. During the 2,500 years from the beginning of the Qin Dynasty to the establishment of the People's Republic of China, records indicate over 1,500 dike breaches and 26 significant course changes in the Yellow River. On average, that is two breaches every 3 years and one course change every 100 years (Chinese National Committee on Irrigation and Drainage 1991). These course changes have been substantial with the mouth of the river shifting back and forth at various times from the Tianjin city in the north to the Huai and Yangtze rivers in the south. The most recent "natural" shift occurred in 1855 when the channel mouth moved from the southern to the northern side of the Shandong peninsula, a change of a 1000 km. The channel also shifted in 1938 when the dikes near Huayaunkou were purposefully breached to stop advancing Japanese troops. The breach, which left some 800,000 Chinese struggling on the verge of death, was plugged and the river returned to its current channel in 1947.

Since 1949 the Chinese government's efforts in huge river dam construction and dike repairs has greatly reduced the risk of flooding. However, flood threats are reduced but have not disappeared. Damming has reduced probability of big floods, but the river channel has become more constricted by sediments and vulnerable to even small floods. For example, the flow of 7,600 m^3/s passing Huayuankou gauging station in 1996 caused a rise in the river 1 meter higher than the rise caused by a flow rate three times greater in 1958 at the same station. In addition, some tributaries remain unregulated, and therefore, a threat to flooding.

Sediments in the lower reach became more severe in the 1990s. As shown in the following table, the sand load passing Lijin gauging station (LJ) in 2000 was 24 million tons or only 3% of the average prior to 1995. However, deposited sands between Sanmenxia (SMX) and LJ accounted for 380 million tons or 73% of the level prior to 1995. The drought moved little sand to the sea but left comparably large amounts of sand in the river channel. The continuously raising lower reach channel is now some 13 meters higher at Kaifeng City and 5 meters higher at Jinan City, aggravating the impact of a possible flood.

Sediments in the Yellow River basin (million tons)

	Passing		Deposited	
	Prior to 1995	2000	Prior to 1995	2000
SMX	1,122	342	316	62
XLD	1,125	4	-3	337
HYK	1,109	82	16	-78
LJ	921	24	189	58
Total	0	0	518	380

Source: Data based on YRCC 2002d

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

The downstream flood-prone area is densely populated with 90 million residents. If the flood area were a country, it would have the twelfth largest population in the world. In addition, the area is amongst the most economically developed in China, with numerous cities, national transportation arteries providing key North-South and East-West linkages. More importantly, the area is one of China's breadbaskets. Ensuring the safety of the areas presents a priority consideration for the Chinese government.

A form of flood, known as ice flood, occurs in the early spring in the middle reach near the Ningxia/Inner Mongolia area and in the lower reach near Kaifeng city. In winter, higher latitude but further downstream reaches could be the first to freeze, blocking the passage of flow from lower latitude but more upstream regions and causing floods. Similarly, higher latitude but downstream reaches could stay frozen longer into the spring than upstream reaches, again blocking flow and causing floods. The ice floods have been responsible for about 1/3 of all floods in the basin. Ice floods are notoriously difficult to control, so much so that there was a saying in the Qing Dynasty that a river official could not be found guilty of causing such a flood.

Dike construction in the Yellow River basin

The Yellow River flood control policy since 1950 is to "retain water in the upper and middle reaches, drain water at the lower reach, and divert and detain water on both sides of the river," following the notion of "keeping wide river sections and strengthening embankments". The government has spent vast sums of money and devoted massive amounts of human resources to Yellow River flood control. In total an estimated 1.4 billion m^3 of earth and rock works have been constructed, which is a volume equivalent required to build 13 Great Walls.

Because of efforts by the government and people, there has been no major dike breach in the basin over the past 50 years, an achievement almost unprecedented in the history of China. However, reservoirs lose storage capacities to silt at rates faster than planned and sediment deposits in the lower reach requires continual heightening of the dikes. Each time the dikes are raised, the potential consequences of a break increases. As former minister Qian Zhengying suggested (Qian 2001), dike raising will not be a sustainable solution. A reduction in sediment flows would increase the life-span of reservoirs and postpone the limit of dike raising. But given the nature of the physical landscape and climatic conditions, it is unlikely that such an outcome will be possible in the near future, if ever. The dream of "letting the river run clear" is probably just that, a dream.

Thus the job of flood control, in the sort-term, is to continue protecting the lower reach from flooding by improved reservoir operation, dike maintenance, regulation of the Sanhuajian tributaries, flood pre-warning systems, and other technical measures as the YRCC is doing now. In the long-term, however, it is important to think back to the earlier Chinese river philosophies, not in specific methods but more in general concepts. Both the Taoists and Confucians prefer "using the river to manage itself," which is quite consistent within the context of integrated water management to improve both flood management and address other issues such as water scarcity. For example, emptying the flood detention areas such as Dongping Lake from human residence can provide both a means to dissipate flood water and recharge groundwater aquifers—a way to make it possible not only to stop the destructive power of floods but also to actually produce benefits from the floods. It is up to the government to balance the costs and benefits of such strategies. Examples of attempts to create such win-win strategies might be sought from the U.S. Army Corps of Engineers in the management of the floods in the Mississippi, where the Corps' strategy is, instead of continuous embankment construction, to move people out of the flood plain so that the area can serve its natural function.

6. Massive Soil Conservation Work

Soil conservation on the Loess Plateau as a policy began in the mid-1950s, primarily as a means to increase food production rather than ecological preservation, as indicated in the early policy slogan “let bald hills become green fields.” After the difficult experience in handling sediments in the Sanmenxia reservoir in the 1960s, the role of sediment control in Yellow River has been recognized. From that time on, the Chinese government has taken a “two-birds with-one-stone” approach to use soil conservation as a means to both increase local grain production and control sand eroded in to the Yellow River.

The main thrust of soil conservation policy on the Loess Plateau has been technical treatment of the erodible soils. Over the last 40 years, about 3,000 km^2 have been treated per year. At present, 166,000 km^2 or 36.6% of the farmland in the erosion area is considered to have been brought under control through the use of terracing, strip farming, sediment retention dams (swamping dams), and the planting of trees and grasses among other measures. According to one analysis, the average annual reduction of sediment deposition from such measures has been about 300 million tons since the 1970s, resulting in accrued benefits of 200 billion Yuan and an annual increase in grain production of 4 million tons. As stated in YRCC research, the achievements of the effort could be further improved if focus is placed on the coarse-sand areas in the upper portions of the middle reach, where the majority of the sediments silted in the downstream channel originate.

Terraced agricultural fields in the middle reach

However, the challenge in soil conservation on the Loess Plateau will still obviously be huge. At current rates, it would take 100 years or more to fully "treat" all the erosion areas, assuming the current treatment is in fact as successful as claimed. As a matter of fact, current treatment structures such as swamping dams do not survive for long in practice, and repeated construction of these dams every 5-8 years has been the experience on treated sites. Adding to the problem, erosion control efforts have been offset by other non-agricultural activities in recent decades. For example, small-scale coal and non-ferrous metal mining in the "black triangle" of Shaanxi, Shanxi and Inner Mongolia has created severe erosion. Mining activities are still under the unofficial permission, even support, of local county governments for developing their economies.

Within the context of current technical treatment efforts, improvements may be made, though the improvements can only have marginal impacts on the rate of control. An alternative is a change in erosion control paradigms. Soil erosion control could be viewed from a broad perspective in which conservation efforts are placed within a overall economic planning and policy reform framework (Giordano et al. 2003). For example, soil conservation strategies could consider activities such as the mining previously mentioned. In addition to direct impacts, mining indirectly aggravates soil erosion, for example by encouraging the cutting of trees which has contributed to continued loss of forest area and thereby erosion-controlling vegetative cover. For soil conservation strategies to focus on technical solutions in the agricultural sector may cause one to overlook such basic opportunities. More fundamentally, the choice between alternative conservation strategies should be better placed within a comprehensive analysis of short-term costs, long-term benefits, and the distribution of those costs and benefits. For example, while the energy resources of the Loess Plateau are being developed, the main economic and employment benefits of that energy are enjoyed by other regions of China in the form of cheap energy and raw materials. Thus the Loess Plateau receives much of the environmental damage from coal mining but little of the benefits of the down-stream industries that could provide alternatives to farming marginal, highly sloping and erodible lands on the Plateau.

From a water use perspective, the basic strategy behind current soil conservation efforts also needs to be more closely examined. Qian (2001) argued that while soil conservation may help block erosion it also depletes water through increased vegetation. A policy question is whether the increasing agriculture upstream by building swamping dams as part of soil erosion control sufficiently justifies the reduction in downstream runoff where economic development and demand on additional water continues to expand.

It is promising that the YRCC has launched a chain of pilot actions to explore additional measures for reducing the pressure of sediments in the river. In July 2002, the YRCC organized a man-made pick-flow using the reservoir release of Xiaolangdi to flush sediments in the lower reach (YRCC 2002c). An amount of 2.6 bcm of water was purposely released at an average flow rate of 2,740 m^3/s from July 4-15. The release carried 66.4 million tons of sand to the sea (or 39 m^3 of water per ton of sand) during the 11-day pilot project—an unprecedented reservoir operation for river sediment movement in the basin as well as, probably, in the world. In this way, the basin's 22 large dams as giant, modern river engineering structures may hopefully find a different functioning role than hydropower generation, which is no longer in big demand in North China. New research studies have also been started by YRCC to search sediment depository pocket sites along the middle reach before the river enters the downstream plain area. Those pockets could shorten the travel distance of sediments and reduce the silt accumulation in the Xiaolangdi reservoir.

7. Degrading Environment

The Yellow River is now the second-most polluted large river in China. Rapid degradation of river quality is becoming an increasing challenge in the basin (Li 2002a and 2002b).

Pollution control efforts in fields

The deteriorating river quality is exemplified in the following table (YRCC 2002d). According to the classifications in the *Surface Water Quality Standards* by China's National Environmental Protection Agency, classes I and II are good drinking water sources, class III represents potentially potable water after appropriate treatment, and classes IV and V signify low water quality appropriate only for industrial and agricultural uses. In 2000, less than 40% of the water courses in the basin were in class I, II and III, and 24% were unfit for human use (class V or worse).

Water quality in river reach lengths

	Classes				
	I & II	Class III	Class IV	Class V	Worse
Main stem	6%	49%	20%	20%	5%
Tributaries	0%	23%	20%	14%	43%
Total	3%	36%	20%	17%	24%

Source: Data based on YRCC 2002d

Wastewater discharge is the main pollution source. In year 1998 the basin had a wastewater load of 4.7 bcm (3.7 bcm industrial and 1.3 bcm domestic), equivalent to 10% of the total river runoff in the year.

Non-point source pollution from agricultural lands is another important factor in water quality decline. From the early 1980s to the middle 1990s, farmers substantially increased the use of fertilizer and pesticides with the result that a considerable fraction of residues now enter the river with return flow from irrigation. In the upper reach, large quantities of agricultural return flow drains directly to the main river while in the middle reach most of the return flow goes to tributaries such as Weihe, Fenhe and Qinhe. In the flooding season, pollutants are taken up from the large flood plain and enter the river, providing a second non-point pollution source.

Another type of environmental disruption is the shrinking wetlands along the lower reaches and in the river delta (Liu 2003). These wetlands used to hold a rich array of aquatic species, provide habitats for migrating birds, and serve as the basis for valuable fisheries. Historically, floods played an important function in cultivating the ecology of these wetlands. The success in flood control in the past 5 decades meant an end to natural flooding, and caused a retreat in the shore-line in the delta, caused saltwater intrusion, and increased salinity and lowered sea water temperature in the Bohai estuary. Further complicating matters, the Shengli Petroleum field, the second largest petroleum base in China, is located in the delta and competes for the trickling river flow for environmental needs.

The water quality in many parts of the Yellow River is already approaching or at crisis levels, and the current trend is likely to be a worsening of the situation, rather than an improvement. It also appears that there is little hope for the construction of new wastewater facilities to keep pace with rapid economic growth and urbanization. Discharge of untreated sewage into the river is likely to continue into the future. Thus efforts at improving water quality must take a realistic approach in determining water quality protection and pollution abatement plans.

Using river flow to flush the pollutants in the basin has been discussed (YRCC 2002d). The idea, however, may have limited scope for success when flow is abundant but is unfeasible under the water scarcity conditions that are likely to continue in the future. In addition, dilution won't be the solution for toxic materials. Many industrialized nations used similar dilution strategies in the 1960s but have changed plans as environmental awareness grew and additional knowledge of the costs of pollution became known. By studying these experiences, the YRCC has an opportunity to learn from the lessons of others and may be able to skip over an environmental development stage in its efforts to satisfactorily solve the pollution problem.

An immediate step may be to begin considering legal and institutional reform. At present, the situation is one of "local environmental agencies standing on the bank while the YRCC stands in the river." In other words, YRCC has the control over the river but not of the pollutants being discharged in to the river. With the promulgation of the 2002 Water Law, this may be a good time to integrate the management and responsibility for pollution control and work towards having "all parties with one foot on the bank and one in the river." How this will work out in practice should be a matter for discussion by parties from multiple sectors and points of view. For example, the state of California in the United States uses a committee composed of one political appointee, two lawyers, two biologists and two engineers to, guide environmental water policy.

Secondly, it may also be useful for the YRCC to investigate the use of semi-market mechanisms in pollution control. For example, the Commission could set annual pollution discharge levels and issue permits to polluters up to that level. Over time, the limits could be reduced. Dischargers who can more cheaply reduce effluents could then sell their permits to those whose reduction is more costly. In this way, pollution loads could be reduced with the least harm to the overall economy.

As a third option, the YRCC may wish to build from China's National Environmental Protection Bureau's policy on regulating the river by function. A central point is to reserve good quality river reaches from damaging discharge by properly utilizing the river's self-purification capacity. In other words, some river reaches can be designated as discharge reaches, some reaches as intake reaches, and some as recovery reaches. The effort may involve investments for relocating river intake points, but in the end, this may still be more economically viable than the treatment of more polluted water intakes that would otherwise be required.

8. Future Research Issues

Additional focus on the following research topics is likely to especially contribute to improved water management in the Yellow River basin:

Inter-sectoral Allocation

With increasing water stress in the basin, one key question is how to meet the growing demand from industrial and domestic sectors. One possibility is to cut agricultural water. However, agriculture in China holds an important status in high politics. Meanwhile, the rural sector is the most impoverished, and shifting water away from the rural sector has implications on equity and, perhaps, social stability. On the other hand, it is industrial growth that has been the driving force in powering China's transformation to a world-class economy, and growing urban/ industrial water demand will continue. A better understanding of the trade-off between equity and efficiency in water resource allocation and the range of possibilities for institutionalizing water allocation decisions would serve to better inform future critical water allocation decisions.

Water Savings in Irrigation

The agricultural sector is now by far the largest consumer of the Yellow River's water and pressure is growing to decrease irrigation water. Increasing irrigation efficiency is one of the ways to reduce agricultural water use. However, while there are areas in the upper basin where this may be possible, there is also evidence that overall irrigation efficiency from the whole basin perspective is already quite high. Another option is to shift thinking away from irrigation efficiency and focus instead on crop water productivity. That is, increasing the value of irrigation output by shifting water to those crops or regions which can produce a higher value of agricultural output per unit of water input or by rationalizing agricultural input and output prices to provide economic incentives for more efficient water use. Key areas worthy of additional analysis include examinations of the true scope of potential irrigation water savings, the costs and benefits of alternative water saving farming systems, the potential role of agricultural and other policy changes in changing irrigation water use decisions, and the institutional frameworks which are best suited to realizing the decided options.

Pollution Control and Treatment

Water pollution levels in the Yellow River, and especially some of its major tributaries, are exceptionally high. In addition to its direct environmental and health costs, pollution exacerbates the water scarcity problem by discounting water usability. The key question is what measures can be taken to improve the situation in the short term while addressing the true nature of the problem in the long term without inflicting undue harm to economic growth. The problem with pollution control is not, fundamentally, technical know-how. Rather, it is in devising ways to finance and enforce existing anti-pollution regulations and effectively integrate the interests and authority of various organizations and agencies responsible for pollution creation and control. Analysis of these issues will be critical in changing the trend in the Yellow River's water quality.

Environmental Water Needs

There is now growing recognition in the basin that water should be used to serve ecological and environmental functions in addition to direct human use. Currently, ecological water requirements are not an explicit category in water budgeting or allocation in the Yellow River. The definition of environmental water use in the basin includes not only maintenance of biodiversity and "natural" ecosystem function, as is emphasized in the West, but also sediment flushing to control potentially devastating floods. Three issues related to environmental water use in the basin would benefit from additional work. The first is ensuring that definitions of environmental use by policymakers and researchers, both within and outside of China, are consistent or at least understood. The second is developing better methodologies for determining the value of various environmental flow levels on annual or shorter time scales so that the costs of particular environmental flow choices can be evaluated and debated. The final issue is the development of mechanisms for ensuring that any environmental flow requirements are actually met. Since the present YRCC estimate of environmental water requirements are between one third and one half the total annual river runoff, this final issue is clearly going to be the most challenging for basin managers to address.

Data Issues

A problem facing researchers, not only those outside China but also those within, in attempting to understand the Yellow River basin is data access and attribution. In some cases, data is collected but functionally unavailable. While unwillingness to make data available can occur for legitimate state reasons, it is probably more typically a result of lack of clear dissemination rules and desire for control by decentralized collection agencies. In other cases, data is made available but collection methodologies and key parameters necessary for understanding its context are missing. For example, many papers discuss average Yellow River runoff of 58 bcm, sediment loads of 1.6 billion tons, and an expanding river delta. In fact over the last 10 years runoff has averaged less than 50 bcm, sediment loads have been closer to 1 billion tons, and the Yellow River delta is retreating rather than expanding. While data problems are not unique to the Yellow River basin, they can perhaps still be improved within the Yellow River basin context if users and collectors become precise in their data use and attribution, and consider more openness in data availability and dissemination.

Institutional Gaps

Water management is an inherently complex issue in part because the "natural" unit for administration is the river basin while the actual institutional governance may have other boundaries. In the case of the Yellow River, the Yellow River Conservancy Commission (YRCC) does not have the power to act as a true basin authority in basin water allocation and other water policy decisions. While the new water law of 2002 has partially addressed the issue by positioning river basin authorities at higher institutional status, the authoritative scope of the YRCC and how it can and should interact with the 9 Province Governments over key issues such as upstream-downstream river flow conflicts and groundwater administration, remains ambiguous. The YRCC, like all government organizations in China, must now operate in a different economic and social environment than before. The basin authority was primarily functioning as an engineering agency for flood threats. While it has had much success in this regard, the problems today are much broader with less easily definable solutions. This shift in the nature of the problems is well reflected in official Chinese water management focus from "engineering water utilization" to "resource oriented" water development. However, the question remains as to what institutional arrangements can best turn the change in thinking to a change in practice.

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This report was prepared as a joint venture of the Yellow River Conservancy Commission (YRCC) and the International Water Management Institute (IWMI). Much of the data and information in this report came directly from YRCC or other Chinese sources, which have not been documented in the "international" sense, but are invaluable to gaining an understanding of the Yellow River basin and the critical issues it now faces. The literature cited in this report is given below.

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