COMPREHENSIVE Assessment of water management in agriculture

Research Report 3

Water Management in the Yellow River Basin: Background, Current Critical Issues and Future Research Needs

Mark Giordano, Zhongping Zhu, Ximing Cai, Shangqi Hong, Xuecheng Zhang and Yunpeng Xue

International Water Management Institute

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With support from the Yellow River Conservancy Commission

Comprehensive Assessment of Water Management in Agriculture

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Summary

Management of China's Yellow River basin is at a cross-roads. Decreasing water supplies, increasing demand and a rapidly growing economy have added new challenges to a management agenda and institutional infrastructure traditionally focused on flood control and irrigation development. As a result, basin managers must now contend with such issues as water scarcity, water allocation, and environmental degradation while still guarding against floods and contributing to China's food security goals. Because of the role of the Yellow River basin in China's overall economy, the success of its water managers in addressing these new issues will have implications for the entire country. At the same time, China's experience can provide lessons for other parts of the world facing similar challenges and change. The goal of this report is to provide an English language synthesis of information on water and water management in the Yellow River basin which will serve not only as a store of knowledge but also as a basis for informing and prioritizing future Yellow River basin water resources research. The report is divided into three parts. In the first, an overview of the Yellow River basin including its physical geography, its role in Chinese history, and the historic development of its water resources is presented, often utilizing information sources not typically accessed by water resources researchers. The report then discusses the key critical issues now being faced by basin residents and managers, breaking with conventional wisdom and placing water scarcity rather than flood control as the number one priority. The paper concludes with a discussion of promising areas for future research and analysis, including intersectoral water allocation, water savings, pollution abatement, data issues and institutional development.

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Introduction

The Yellow River basin has been part of China virtually since the inception of the Chinese nation. Designated as "the cradle of Chinese Civilization," the basin has played a key role not only in the country's economic development but also in the historic and cultural identity of the Chinese people. Perhaps, ironically, the Yellow River is also known as "China's Sorrow," because the soils which have fostered human development are also associated with frequent, sometimes catastrophic, floods. The devastation brought by these floods, often at scales unimaginable in the West, makes it easy to understand why successive Chinese administrations from the legendary Xia Dynasty (ca. 2000 B.C.) through the 20th century made flood control the number one priority of Yellow River management. While the possibility of flooding is ever present and remains a key issue in basin management, major achievements have been made in flood control since the founding of the People's Republic of China in 1949. As a result of this success and the rapid economic and social changes which have taken place over the past few decades, new issues such as water scarcity, overuse of resources and environmental degradation are now rising to the top position of the water management agenda. In essence, a transition in river management is now taking place in which focus is shifting from prevention of the river doing harm to people to preventing people from doing harm to the river.

Significant institutional, policy and legal reforms are required to successfully bring about such a fundamental transition in a river management system that has evolved over two millennia. This report has been produced as a background to assist researchers and policy makers in informing the debate surrounding that reform. The report is divided into three primary sections. The first discusses the background to the Yellow River basin and its management including the basic geography of the basin, the role of the basin in Chinese history, and the historic development of basin water resources management and water resources. The second discusses the key critical issues now being faced by basin residents and managers, including water scarcity, flood control, and land and other environmental degradation. The report concludes with some reflections on promising areas for future research and analysis, including intersectoral allocation, water saving, pollution abatement, data issues and institutional gaps.

General Basin Characteristics

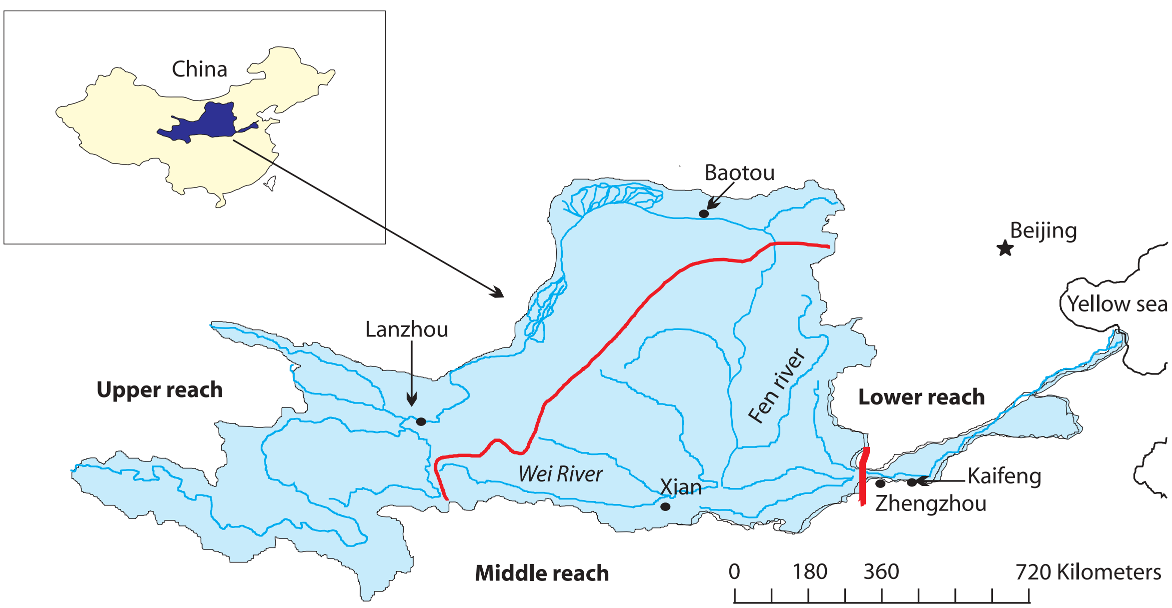
Physical Geography

Most descriptions of the Yellow River's geography commence with a recitation of facts. For example, the Yellow River begins in the Qinghai-Tibetan plateau of Qinghai province from whence it flows across 8 other provinces and autonomous regions before emptying into the Yellow Sea north of the Shandong peninsula (figure 1). With a length of over 5,400 km, the Yellow River is the second longest in China and the 10th longest in the world and drains an area larger than France. The basin contains approximately 9 percent of China's population and 17 percent of its agricultural area. While such static figures may be of passing interest, it is a deeper understanding of variation in the Yellow River basin's physical geography that is necessary if one wishes to understand the issues which both the Chinese government and basin residents face in their daily efforts to use, manage and protect the river. To accomplish this formidable task, the river is often divided into its three main reaches for analysis.[1]

The Upper Reach

The upper reach of the Yellow River drains just over half of the total basin area and extends from the river's origin in the Bayenkala mountains to the Hekouzhen gauging station downstream from the city of Baotou. While the upper reach provides approximately 54 percent of the river's total runoff, this contribution comes from two distinct geographic backdrops characterized by off-setting physical processes.

FIGURE 1.
The Yellow River Basin.



[1]By Chinese convention, the Yellow River is divided into the three reaches described here. However, other methods, such as that used by Greer (1979) may more closely reflect fundamental physical differences across basin space. This may be especially true in the Upper Reach.

On the Qinghai-Tibetan Plateau where the Yellow River begins, steep rock slopes, low evaporation and high moisture retention produce runoff coefficients estimated to range from 30 percent (World Bank 1993) to 50 percent (Greer 1979). This, combined with relatively high precipitation levels, results 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 (YRCC 2002a). As the river moves northward from there into the Ningxia/ Inner Mongolian plains and the Gobi Desert, evaporation rises to levels several times that of precipitation (World Bank 1993). As a result, this section of the river is a net consumer of runoff, and total flow is greatly reduced from the level which would otherwise exist if the river kept an eastward course. The spatial variation in flow contribution within the upper reach is further exacerbated by human usage patterns. In the most western regions of the upper reach, relatively low population densities, agricultural development and industrialization limit *in situ* usage. As the river moves northward from Lanzhou, the agricultural population, with its long history of irrigation, and a growing industrial base, substantially increase water withdrawals.

The Middle Reach

The middle reach, covering 46 percent of basin area and providing an additional 43 percent of the total runoff, begins at the Hekouzhen gauging station (YRCC 2002a). From there the river begins its "great bend" to the south into and through the Loess Plateau. The middle reach of the Yellow River plays a significant role in basin water balances and availability for human use for two reasons. First, the reach includes some of the Yellow River's major tributaries such as the Fen and the Wei, which contribute substantially to the total flow. Second, as the river turns southward, it cuts through the Loess Plateau and its potentially fertile but highly erodible loess soils. These soils enter the mainstem and its tributaries as massive quantities of silt, resulting in average sediment concentrations unprecedented amongst major waterways (Milliman and Meade 1983) and giving both the river and the sea into which it flows, their common "Yellow" names.

While sediment levels in the Yellow River are caused in part by such natural factors as the erodibility of the loess soils already mentioned, low average precipitation which retards the growth of soil stabilizing vegetation, and an increase in the gradient and power of the Yellow River as it passes through the most erodible zone, these levels are clearly exacerbated by anthropogenic factors, many of which have been in place for centuries or millennia (Ronan 1995). While there is debate on the degree to which the Loess Plateau was "naturally" forested, it seems clear that as early as the Qin and Han dynasties, large areas of land had been deforested for fuel wood and agricultural expansion, a factor which is believed to have contributed to increased erosion and, perhaps, regional desiccation (Menzies 1995).[2] Whatever the cause, the long standing nature of the sedimentation phenomenon can be seen in the Chinese use of the phrase "when the [Yellow] river runs clear" to mean "never." As will be described later, control of the potentially devastating Yellow River floods, which are greatly exacerbated by the high sediment loads generated in the middle reach, has formed a central theme in Chinese water management and politics for at least 3,000 years. In addition, control of sedimentation to reduce the severity and frequency of flooding,

[2]There is also evidence that the Loess Plateau, with the exception of riverine bottoms, higher mountains and some other areas has essentially been treeless at least since the Pleistocene (Ho 1998). Lowdermilk (1925, 1930) provides interesting observations and comments. The general debate is covered by Menzies (1995).

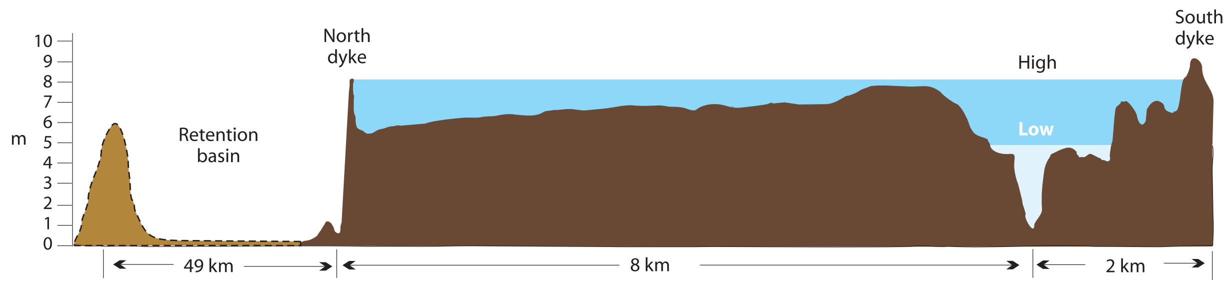
accomplished through flushing, is now estimated to require about 25 percent of the total Yellow River flow and so is a major factor in current utilization of basin water.

The Lower Reach

The lower reach of the Yellow River commences at Huayuankou near the city of Zhengzhou 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 (Ren and Walker 1998). This instability has in fact been so severe that the Yellow River has had 6 major channel changes over the past 3,500 years in which the outlet to the sea shifted the 400 km from one side of the Shandong Peninsula to the other (Greer 1979). These massive shifts in the river channel, as well as more frequent smaller movements, clearly cause problems for the millions of people who have attempted to farm the lower reach's fertile alluvial soils. In response, successive river managers down the millennia have constructed levees along the banks of the Yellow River in an attempt to stabilize the main channel. While such structures may hold the channel in the short term, their success depends on consistently raising levee walls as sediment elevates the level of the channel constrained within.

Over the time, the process of levee raising has contributed to a "suspended" river in which the channel bottom is above ground level, sometimes by more than 10 meters (Leung 1996) (figure 2). This raising of the channel above the level of the neighboring countryside has clear implications for the severity of flooding when the levees inevitability break but also alters the meaning of the Yellow River "basin." With the channel above ground level, the surrounding landscape 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 kilometer breadth of the diked channel. With almost no inflow, the contribution of the lower reach is limited to only 3 percent of the total runoff. While much of the sediment is deposited in the lower reach, approximately half has historically reached the river's outlet to the sea. These large deposits have, at least until recently, caused the river's delta to expand outward, creating substantial new farm land (see Ren and Walker 1998, for a discussion of the delta's dynamics).

FIGURE 2
Representative cross-section of the "suspended" Yellow River.



Source: After Ronan 1995.

Extra-basin Issues

While the above discussion focuses on the current geographic boundaries of the Yellow River basin, it is important to note that these boundaries, particularly in the lower reach, have changed, and may again change, over the time. As mentioned, the high sediment load of the Yellow River makes the channel highly unstable in the lower reach where the topography is extremely flat. When the Yellow River's channel shifts, typically after a flood event or through human intervention it connects hydrologically with either the Hai River system to the north or the Huai River system to the south, resulting in an expansion of basin boundaries across various portions of the North China Plain. The last time such a change occurred was in 1938 when the Yellow River's south dike was purposefully breached at Huayuankou to block an advance of the Japanese army. The river was returned to its present course by engineering means in 1947 (Todd 1949). The imposition of the Grand Canal, which runs perpendicular generally to the east to west flowing rivers of eastern China and essentially links all of the basins from Hangzhou north to Tianjin, further complicates strict definition of basin boundaries in the lower reach. The blur of basin boundaries and the challenge of the term "basin" across the North China Plain become more evident by an examination of the generally criss-crossing, highly engineered river systems of the region.

A second problem confusing the understanding of the Yellow River basin boundaries is the lack of congruence between the geographic extent of the basin as commonly delineated and the relevant hydrologic units. For example, in the lower reach of the basin, seepage from the suspended main stem of the river recharges groundwater aquifers in both the Hai and Huai basins where it is extracted for crop production. Additional water is also transferred out of the basin for industrial and domestic use, especially to the cities of Jinan, Qingdao and Tianjin. Of potentially greater significance for the future is the planned construction of the "South waters North" engineering schemes which may eventually transfer large amounts of water from the Changjiang basin into the Yellow River, further marring the relevance of the geographic definition of the Yellow River basin (Biswas et al. 1983; Liu 1998).

Human and Non-water Resource Geography

According to year 2000 statistics, the Yellow River basin is home to some 110 million people or around 9 percent of China's total population. If the flood zone in the surrounding lower reach were included, the figures would rise to around 190 million people or 15 percent of the total population. In general, population densities are highest in the lower reach and are lowest in the upper reach. While urbanization is increasing rapidly, about ¾ of the basin residents are still classified as rural and most of them depend on agriculture for their livelihood. Income levels in the basin are, on average, somewhat lower than national averages and the basin accounts for some 7 percent of national output (YRCC 2001). While its per capita share of total output is lower than average, the basin's agricultural output is higher with grain production within basin boundaries and on adjacent flood zones surpassing 75 million tons or 16 percent of China's national total in 2000 (table 1). The above average agricultural output is in part explained by the fact that the per capita arable land area in the basin, at 0.12 ha, is 1.5 times China's national average (Hong et al. 2002).

In addition to hydropower, the basin has important reserves of other energy resources and is known in China as the "energy resources basin." In total, the basin is estimated to contain

TABLE 1.
Agricultural production in the Yellow River basin.

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

Source: YRCC 2001.

almost half of the nation's coal and over 25 percent of its oil. The basin is also home to the "Victory Oilfield" (Shengli Youtian), located in Shandong province near the mouth of the Yellow River, which has significant symbolic value in addition to the value of its energy reserves. The verification of the high potential of this field by Chinese engineers in the early 1960s (and at the Daqing Oil field in Heilongjiang Province), after declarations by foreign petroleum engineers that China contained no oil, marked the modern era for Chinese achievement and self-reliance. In addition to energy supplies, the Yellow River basin is also a major source of minerals and contains nearly half of the nation's bauxite, as well as 4 of the 8 major Chinese aluminum plants, and significant quantities of zinc, lead, nickel, copper and gold.

The Yellow River basin is also at the nexus of important north-south and east-west trade axes. Historically Xian, Lanzhou and other cities in the basin served as important points on the famous silk road and the crossing of the Yellow River by the Grand Canal marked an important transport hub. In more recent times, an important north-south and east-west rail junction was sited at the city of Zhengzhou. The newly planned Eurasia Bridge, approximately 50 percent of which lies parallel to the Yellow River, will only further enhance the basin's role as a transport and trading center if it is completed according to plan.

Water Supply and Use[3]

On average, the Yellow River basin receives approximately 450 mm of rainfall per year, a quantity marginally sufficient for agricultural production (table 2). However, the average rainfall figures belie a great variation, both spatially and temporally, which has been a cause of the basin's two major natural hazards- drought and flood. Spatially, precipitation levels tend to be lowest in the north and west and highest in the south and east, with average levels of 120 mm in areas of Ningxia and Inner Mongolia and 800 mm in the hills of Shandong. Precipitation levels across much of the Loess Plateau, where soils are most erodible, average less than 500 mm.

Temporally, there is also a great variation in rainfall levels both within and across years. Intra-annually, most rainfall occurs between June and September with almost no precipitation between November and March. In addition, summer rainfall, especially in the Loess areas of the

[3]This section is based largely on Zhu et al. 2004.

TABLE 2.
Yellow River basin rainfall (millimeters).

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

Source: YRCC 2002c.

middle reach, often comes in quick cloudbursts which overcome the infiltration capacity of the soil and carry massive quantities of sediments into the Yellow River and its tributaries. It has been estimated that as much as 35 percent of precipitation comes in the form of these sudden cloud bursts (Greer 1979). Inter-year precipitation variability is also substantial and by some definitions drought is said to occur every 2-3 years.

This variation makes consistent agriculture production particularly difficult and has periodically led to massive drought and famine. For example, during the draught of the 1920s as much as half of the population in the basin has been estimated to have fled their homes in search of food. In addition to contributing to drought, the spatial and temporal concentration of rainfall has also been a major factor in flooding as discussed further below.

While the Yellow River basin has played and continues to play a critical role in China's social and economic development, it, in fact, has relatively limited water resources. For example, while the river is the second longest in China, it ranks fourth in terms of annual runoff and in total provides only 2 percent of China's water resources (YRCC 2002a). Basin residents have, on average, only about one quarter of the nation's 2, 200 m^3 annual average supply.

The water resources of the Yellow River basin for 2000 and the framework used for their accounting by the Yellow River Conservancy Commission (YRCC) are shown in table 3. 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 (discussed further below) and change in storage. Groundwater resources are then separately calculated for mountain and plain areas and the sum adjusted to compensate for a double counting error which occurs in the estimation process. The total surface and groundwater estimates are then further adjusted to account for a second, large, double counting error, to arrive finally at a total water resource calculation.

Water use in the Yellow River basin is currently considered to come from two sources, ground and surface, and serve three sectors: agriculture, industry and domestic. Data on use by source and sector for recent years is shown in table 4. As seen in the table, the average annual withdrawal from the Yellow River basin has been approximately 50 billion cubic meters (bcm), 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 the total withdrawal, with industrial, urban and rural domestic sectors sharing the remaining 20 percent.

TABLE 3.
Yellow River basin water resources (bcm), 2000.

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

Note: LZ = Lanshou; TDG = Toudaoguai; LM = Longmen; SMX = Sanmenxia; HYK = Huayuankou.

Source: YRCC 2002b.

In total, human depletion accounted for 36.6 bcm or 76 percent of total utilizable water resources in the basin in 2000 as shown in table 5. An additional 4.9 bcm entered the Bo Sea, leaving 6.6 bcm of the total 48.4 bcm of surface and groundwater supply to be accounted for as non-process depletion from evaporation, interaction between groundwater and deep aquifers, or other unrecorded "losses." Depletion at present levels means that theYellow River supplies are essentially fully allocated. Since the early 1970s, this has been reflected in the complete, or near complete desiccation of the lower reach at certain times each year.

TABLE 4.
Yellow River basin water withdrawal, 1998-2000 (bcm).

	By source			By sector				
	Surface	Ground	Total			Domestic		
Year	water	water		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: 1998, 1999, and 2000 YRCC water bulletins.

TABLE 5.
Yellow River water accounts, 2000.

		(bcm)	Percentage
Utilizable		48.4	100%
	1) River water	35.0	
	2) Groundwater	10.7	
	3) Groundwater outside 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	
Unaccounted Depletion		6.9	14%

*Groundwater from outside the basin's topographic boundaries in the lower reach is calculated as actual abstraction.

Source: YRCC 2002b.

Role of the Yellow River Basin in Chinese Culture and History

The Yellow River basin has been part of the Chinese nation essentially since its inception and has played a key role not only in country's economic development but also in the historic and cultural identity of the Chinese people. While the Yellow River Basin may have been inhabited for tens of thousands of years, its main cultural significance began to emerge less than 7,000 years ago with the development of agriculture (Ho 1998; Bray 1984). The availability of nutrient— rich and friable soils in the Loess Plateau region, along with a favorable coincidence of precipitation and solar energy in summer months, are believed to be major factors explaining the Yellow River's role in the early development of Chinese, and therefore world, agriculture (Lattimore 1988; Ho 1998). From these early agricultural origins developed one of the first known sites of human habitation in China (Banpo ca. 5000 BC) and complex social organizations, as exemplified by the Yangshao, Majiayao and Dawenkou cultures, which eventually provided at least one of the bases for Chinese culture (Hessler 2003).

Ironically, the Yellow River, the apparent "cradle of Chinese civilization," is also known as "China's Sorrow," because the loess deposits which have fostered human development are also associated with the frequent, often catastrophic, floods in downstream regions. While these floods and the climate extremes behind them have been linked with dynastic change (Bodde 1981), the devastation they bring, often at scales unimaginable in the west, makes it easy to understand why successive Chinese administrations have made flood control the number one priority of the Yellow River management. In fact, the control of Yellow River floods has been seen as a primary measure of good governance and is now ingrained in Chinese culture at a fundamental level.

This deep connection between Chinese culture, the Yellow River and flood control can be seen in the Legend of Yu. The Great Yu (c. 2,000 BC) was one of the three early, probably mythical, leaders of China and was known for taming the Yellow River floods using a strategy of channel clearing rather than dyke construction. While it is unlikely that Yu, or anyone else, successfully controlled Yellow River flooding by any strategy, the story continues to be told, in part because it carries with it the moral analogy that adverse human nature can be better corrected by guidance (clearing a path) than punishment (constructing a barrier).

More fundamentally, the channel-clearing versus dyke-construction can also be seen as a reflection of a general philosophical debate in river management which has continued in China for more than 2,000 years between Taoists, with their emphasis on letting nature, human or otherwise, follow its own path and Confucianists, with their desire to channel behavior through virtuous moral codes (Needham 1956).[4] The dichotomy of approach can still be seen in the modern debates on Yellow River management. In fact, both the historic and modern debates form part of a broader, and in many ways uniquely Chinese approach to river management predating Confucianism and Taoism of "using the river to tame itself."

Differences between ideals and practice not withstanding (Rhoades 1967; Tuan 1968; McNeill 1998), the value of recognizing the role of philosophy in Chinese water management, and the role of water management in Chinese philosophy and culture, is not simply for academic exercise. Rather it highlights a more historically robust and broadly defined concept of "integrated water management" than exists in the West in which concern is placed not only on basic science, engineering and appropriate management units, but also on a philosophical understanding of man and nature. For example, current Yellow River 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, if not the practice, of environmental water use in China can be considered to contain not only the maintenance of biodiversity and "natural" ecosystem function, as emphasized in the West, but also the maintenance of the landscape as a place for human habitation and livelihood.

Whatever the philosophical underpinning, Chinese water management practice has also been intricately connected both with the development of Chinese government as well as the modern perceptions of China by the outside world. For at least 2,000 years, major water engineering projects in China in general and the Yellow River basin in particular have used the mass mobilization of labor. For example, reports indicate that tens of thousands of workers were being mobilized for engineering projects by the 2nd century B.C. and that as many as 5 million laborers were used in canal construction by the 7th century A.D. (Greer 1979). While the number of people involved is amazing, even more impressive is the organizational skill which was needed to mobilize such numbers. Some have interpreted the development of mechanisms to successfully manage such large numbers of workers as a precursor to what would become a lasting centralized, autocratic government in China (Wittfogel 1957). While this contention, as well as the cause and effect relationship between water engineering and government development, has since been brought into question (Ho 1998), the idea of "oriental despotism" seems still to taint the view of many outsiders towards the Chinese political system in particular and Asian society in general.

[4] The actual debate on Yellow River management was more fundamentally over whether the river should be confined within narrow banks or dykes which would scour the channel or should be allowed to range widely in a flood plain constrained only by widely placed levees.

Basin Development and Management

From Earliest Times to the Founding of the People's Republic of China

Management of the Yellow River is recorded by the famous Han Dynasty (206 BC -220 AD) historian Sima Qian to have begun by the 20th century BC with the Great Yu and his flood control, and perhaps, irrigation work. While these earliest claims cannot be confirmed, an 8th century B.C. mention of an irrigation pond near modern Xian clearly suggests the early existence of water engineering programs in the Yellow River Basin (Chinese Hydraulic Engineering Society et al. 1991).[5] Y'ang K'uan (Greer 1979) also lists a number of flood control levees that had been built in the middle and lower reaches of the Yellow River and some of its tributaries by the 6th Century B.C. Further evidence is provided by a treaty signed in 651 B.C. banning the destructive use of flood control levees in warfare (Greer 1979).

The earliest significant irrigation project is reported to have been constructed between 424 and 296 B.C., in modern Henan Province (Ho 1998). The most famous early project, the Zhengguo Canal, was finished in 246 B.C. by the state of Qin and irrigated some 80,000 ha north of modern Xian (Greer 1979; Will 1998 for a history of the canal in the context of human ecology). The increased agricultural production from this project is believed to have contributed to the Qin state's ability to overpower the other warring kingdoms of the time, resulting eventually in the initial unification of China, again highlighting the central role of the Yellow River and its management in Chinese history (Greer 1979). Other early irrigation projects were developed in the great bend area of the river, perhaps also initially during the Qin dynasty but more likely during the Han Dynasty which followed (Chinese Hydraulic Engineering Society et al. 1991). Perkins (1968) provides estimates of the number of water control projects undertaken from the Han Dynasty forward to the 20th century and shows a cyclical construction pattern which he states is caused by a number of forces including settlement of new areas, population growth, severe weather and political stability.

The earliest known mention of Chinese water administration is said to come from the Zhou Li, or Rituals of the Zhou Dynasty (Caponera 1960), though its actual date is unclear. The Li-Ji (Record of Rites), believed to be written around 300 B.C., also includes passages on water administration including the collection of reasonable levels of water related revenues. The concepts from these early texts (water administration is the responsibility of the state; there is no private water ownership; duties but no rights related to water use) formed a basis for much of later codifications of the Chinese water law (Caponera 1960; Caponera 1992). In fact, the Han dynasty codifications, derived in part on the Zhou principles, established water management practices which have continued with modification into the 20th century and in some senses continue to date.

While regional, if not basin level, water planning may have begun as early as the late Spring and Autumn period (722-481 B.C.) (Chinese Hydraulic Engineering Society et al. 1991), pre-Han water management bureaucracies were relatively small in scale and scope in part because the kingdoms which controlled them were also small (Greer 1979). As a result, early construction and management programs were undertaken largely to serve local, narrowly defined purposes. During the Han Dyansty, a new office known as the Director of Water Conservancy (Tu-shui) was created under the

[5] Ho (1998) places the first mention of a possible irrigation ditch in the 6th century B.C.

Ministry of Public Works. Under such centralized offices, famous Chinese water managers emerged such as Chia Jang (fl. 6-2 B.C.), Wang Ching (fl. 58-76 A.D.), Chia Lu (1271-1386 A.D.) and Pan Jixun (1521-1595), all of whom devised relatively comprehensive strategies for flood control which, even if not at full basin scale, can be seen to have anticipated more modern River Basin Management concepts. In fact, as argued by Caponera (1960), integrated river development was already a "preoccupation" by the Tang times (618-907 A.D).

While the plans of the mangers just mentioned took a broad approach to water management, compressive basin planning was not undertaken, nor were the various functions of river management put under a single central authority, even nominally, until the 20th century. For example, the role of the Director of Water Conservancy was primarily one of planning while labor mobilization and construction was the responsibility of provincial and local agencies. Thus successful management of the Yellow River required coordination between the central and local levels (Dodgen 2002), a situation not dissimilar to that which exists today in the Yellow River basin and elsewhere in the world.

Modern efforts to comprehensively manage the Yellow River basin can be traced back to the Chihli River Commission, and later the Hua Bei River Commission, which began the first systematic monitoring of the Yellow River flow in 1922 (Todd and Eliassen 1940).[6] The monitoring work of the Chihli River Commission was taken over by the Yellow River Water Conservancy Commission (YRWCC) after its founding in 1933. The first commissioner of the YRWCC, Li Yi-chih, was perhaps the first person to advocate a basin level agency under central government control to manage the Yellow River that could avoid China's historically problematic inter-provincial tensions. Li Yi-chih, while a modern scholar, clearly placed his work within the context of ancient water management principals and Chinese philosophy and is considered one of the great managers in the long history of Yellow River Management. His influence and philosophy is still felt in the YRWCC's predecessor agency, the Yellow River Conservancy Commission (YRCC), which was founded in 1946 in the Communist controlled areas of Hebei, Henan and Shandong provinces. In June 1949, the responsibility for managing the whole basin was placed under YRCC and in November of the same year, the Commission was put under the leadership of the Ministry of Water Resources. In early 1950, the Yellow River Conservancy Commission was officially made a "basin management institution" under Order Number 1 of the State Council. Despite these changes and the ideas of Li Yi-chih, the YRCC was not given the autonomy to act even nominally as a true basin organization until the 1950s, though even then it served more as a mediating body, often without clear mandate, and frequently had conflicts with other ministries. (Greer 1979).

From the Founding of the People's Republic of China to the Present

The founding of the People's Republic of China in 1949 ushered in fundamental changes for China socially, politically and in terms of the water management and development. Despite the long history of water management projects just discussed, the entire country in fact contained only 6 large and 17 medium reservoirs in 1949 (Chinese Hydraulic Engineering Society et al.1991), and the total irrigated area was less than 18 million hectares (Perkins 1969).[7]

[6]The Chihli River Commission was primarily interested in the Hai River. However, the Yellow River sediment had a direct impact on the port of Tianjin over which it was concerned.

[7]Note that for a variety of reasons Chinese irrigation statistics (Nickum 1995; Nickum 2003), and statistics in general (Holz 2003), must be viewed with caution.

Furthermore, the Yellow River itself was still viewed primarily as a threat and even as late as 1940 two American engineers closely associated with the river stated that “There is probably no other river in the world which is of so little use to mankind as the Yellow River…The river is an enemy instead of a helpful agent” (Todd and Eliassen 1940). On coming to power, the government of New China set out almost immediately in a National Water Conservancy Conference and the first Five Year Plan (Chi 1965) to change this view of the Yellow River through projects to control flooding and utilize the river’s waters to increase agricultural and energy production as well as expand transportation opportunities.

The Ambitious 1950s

After the People’s Republic was founded and the focus of the nation shifted from war to reconstitution and progress, water resources development in general and the Yellow River basin in particular were given high priority. Early efforts were undertaken with support from the Soviet Union, and in 1952 alone 156 Sino-Soviet projects for harnessing the Yellow River were outlined. In 1953, a large-scale Yellow River basin survey was jointly conducted by Chinese and Soviet officers and professionals, and in October 1954 a Technical and Economic Plan for Yellow River Comprehensive Utilization was submitted to the State Council. This was probably the first ever comprehensive development plan for the basin and focused on power generation in the upper reach, flood control in the middle reach, and irrigation downstream. The ambitious plan, approved by First People’s Assembly in July 1955, envisioned, amongst other items, the construction of an astounding 46 large dams on the Yellow River’s main stem (Greer 1979). It is interesting to note that, probably because of the Soviet influence and aid, the water engineering efforts in the early 1950s were *relatively* capital rather than labor intensive as had traditionally been the case in Chinese water development (Chi 1965).

Behind the early People’s Republic of China plans for the development of the Yellow River basin was a strong belief in the ability of human ingenuity to overcome nature. This belief emanated from the tremendous pride and euphoria following the defeat of Japan, victory in the Chinese Civil War and the establishment of “New China,” and the success in stopping the advance of U.S. and U.N. forces in the Korean Peninsula. If the Chinese people could defeat feudalism and imperialism, why would not it also be possible to conquer the Yellow River? Why would it not be possible to use the will of the People to make the river “run clear” for the first time in history? The then Commissioner of the Yellow River Conservancy Commission, the successor agency to YRWCC, Wang Huayun presented such visions during a field trip to the Yellow River by Chairman Mao through a promise: The Yellow River would be made peaceful for at least three hundred years through the construction of the planned large dams. While Mao is attributed to have made a somewhat more realistic assessment of the potential to control the river in his suggestion that the Yellow River problems could be “well handled” though not necessarily fully resolved in this respect, the actions of the government were to follow the ambitious plans (Ma 1999).

An example of the resolve to develop the river is seen in the name of the first major irrigation project under the new development plans, the People’s Victory Canal, located in Henan province. This project, which still provides the name to a brand of cigarettes, was designed to divert Yellow River waters by gravity to irrigate almost 100,000 hectares of farmland (Zhang and Deng 1987). Signaling the symbolic and real significance of such undertakings, Chairmen Mao visited the project in October 1952 when he officially opened its diversion gates.

Irrigation and dam construction continued through the late 1950s under the slogan "big diversion, big irrigation." However, the primary means to complete projects shifted from capital to labor, probably in large part due to the withdrawal of Soviet aid. In fact, the decision, made in 1957, to "depend on the masses" and rely more on local capital in water construction projects can be seen in some ways as the beginning of the nationally disastrous great Leap Forward which began in 1958 (Chi 1965).

The Cooling-down 1960s

While the water engineering projects of the 1950s were built with great hope and optimism, they were not well designed or constructed. Project focus tended to be on basic infrastructure and ignored less visible, but critical, engineering and management aspects. As succinctly put by Perkins (1968), "Water-control developments in north China in the 1950s, both traditional and modern, were not so clearly beneficial." As an example, irrigation projects like the People's Victory Canal ignored drainage, and as a result, water logging and salinization occurred to such an extent that crop yields dropped below pre-project levels. The situation was so severe that farmers actually destroyed diversion canals and the irrigation scheme was essentially abandoned by 1961 (YRCC 2001). Comparable events took place in many other newly built schemes.

Similar failures in water engineering occurred in dam and reservoir projects, most notably in Sanmenxia. The Sanmenxia Reservoir was created behind the first significant dam in history to be built on the main stem of the Yellow River and, like the People's Victory Canal, was a symbol of the 1950s ambition to conquer the river. However, because of the failure of the Soviet Engineers to appreciate the nature of the sediment load in the river and the Chinese enthusiasm of the period to carry the project forward, the dam was woefully unsuited and the reservoir was silted within only a few years of construction. This in turn caused the waters of the Yellow River to back up into the Weihe basin where they inundated land and threatened the ancient city of Xian with flooding.

The huge engineering failure of Sanmenxia (Greer 1979, chapter 4), the similar failure of early irrigation projects, and the famine which occurred in the aftermath of the Great Leap Forward (Becker 1998) were shocks to the leadership of the People's Republic in Beijing as well as the Yellow River Conservancy Commission. Together, these events caused a new sense of realism in policy and dampened the enthusiasm for pure engineering solutions to development problems and programs. Better effort was made to understand the role of the sediment in reservoir operations, dam construction plans were modified and the number of new reservoirs to be constructed was reduced. Drainage development and irrigation system rehabilitation were also begun, and farmers were slowly re-convinced of the potential value of irrigation construction. Unfortunately the opportunity for a full review of the errors in the 1950s basin development blueprint was lost when the political chaos of the Cultural Revolution began in 1966 (Spence 1990; Meisner 1999).

The 1970s and 1980s

The Cultural Revolution, which lasted from 1966 to 1975, brought political chaos to China, including the Yellow River basin. Somewhat surprisingly, the moderately revised development plans of the 1950s and heavy government investment in the basin continued (Stone 1988, provides figures for irrigated area for China as a whole) despite the chaos, without substantial debate. Giant power generating reservoirs were constructed in the upper basin, a soil conservation campaign created new terraced fields on the Loess

Plateau of the middle reach, and irrigation diversions were substantially expanded in the lower reach, especially in Shangdong and Henan provinces. Meanwhile, village-based water management systems, including canal maintenance and water allocation between neighboring villages, were shaped in the basin although structured based on the political overtones of the time.

With the death of Mao Zedong in 1975, Deng Xiaoping came to power and helped to introduce a wide ranging set of reforms that swept through China in the 1980s (Meisner 1999; Naughton 2003). The commune system that had been established in villages was abolished and a rural household responsibility system moved production decisions and power towards individual farmers (Ash 1988). Government planning and control became more decentralized, and, as also occurred in the agricultural sector, government investment in the water sector declined. At the same time, environmental awareness started to grow and a more politically liberal atmosphere allowed people to review past basin strategies and lessons. In 1984, the State Council approved the Second Yellow River Basin Plan, which listed soil erosion control in the middle reach as the most important policy objective as opposed to power-generation and flood control as had been emphasized in the 1954 Plan.

The New Water Decade of the 1990s and into the New Millennium

The 1990s witnessed a new water era in China based on the reforms and their economic impacts, ushered in by Deng Xiaoping in the later 1970s and 1980s. The reforms have had two major impacts related to water management and use in the Yellow River. First, the rule of law was given added relevance. Second, economic growth placed increasing demand on water resources, both in quantitative and qualitative terms. Together, these and other factors caused fundamental changes in both perceptions of appropriate water policy and management, and increasingly, in water management practice.

While the impact of legal reform manifested itself most deeply in the 1990s, the new legal era in water management actually began with the introduction of a new Chinese constitution in 1982. In terms of water management, the constitution is significant because it caused a shift towards legal methods for guiding action and decision making and also because it reiterated the state ownership of water resources. After the promulgation of the new constitution, hundreds of laws were passed, institutions related to virtually all sectors of the economy, including the environment, changed, (Jahiel 1998; Palmer 1998), and continued efforts, especially in the1990s, to improve the operation and professionalism of the legal system were made. With regard to water, the major legal landmark was the 1988 water law which provided the basic framework and principles for water management in the 1990s. This was followed by related legislation including the Water Pollution Prevention and Control Law, the Soil and Water Conservation Law, and the Flood Control Law. A large body of additional administrative rules and ministerial regulations related to water was also passed along with a number of other laws at least indirectly related to water including The Environmental Protection Law, The Land Administration Law, the Fishery Law, the Forestry Law and the Mineral Resources Law.

This move towards legalism took place at a time of dynamic economic growth and structural change which began in the early 1980s. Increasing liberalization of markets and foreign investment helped to sustain rapid economic growth. Industrial output increased dramatically. Increasing agricultural labor productivity and *de facto* and *de juere* changes in residency rules freed people from the farms and allowed rapid urbanization. While population growth slowed, expansion continued, and, importantly, rising affluence caused dietary changes which favored meats and contributed to massive growth in feed grain use. Together, all these factors placed growing demands on water supplies for the industrial, domestic and agricultural sectors. At the same time, increased industrialization coupled with inadequate or poorly enforced pollution control regulations exacerbated water quality problems as did increased use of agricultural inputs. In the face of this massive demand growth and effective supply decrease caused by declining water quality, and a period of low rainfall, many places in China, in particular the north and the Yellow River basin, began to reach their water limits. Water policy and management needed to shift away from a singular emphasis on flood control and resource development, towards comprehensive basin management strategies.

Such a new direction in thinking was in fact reflected in Article 1 of the 1988 Water Law which stated that the law was "formulated for the rational development, utilization, economization and protection of water resources, for the prevention and control of water disasters and for the realization of sustainable utilization of water resources in order to meet the needs in national economic and social development." In other words, water management in China in the 1990s, harkening back to Tang Dynasty edicts, was officially going to take a more comprehensive approach which would include concepts of economic value and trade-offs, resource protection and sustainable development among other items. To carry out such changes in management, however, would require a movement in institutional structures towards integrated basin management.

While the Yellow River Conservancy Commission was already ostensibly serving as the river basin authority, in practice, its powers for basin management and planning were limited and unclear. However, the changes in thinking brought about in part by the 1988 water law slowly began to be reflected in the management mandate of the Yellow River Conservancy Commission. For example, in 1997, the State Council approved the Outline of Yellow River Harnessing and Development which, though still calling for the construction of 36 additional large dams, began addressing the issues of comprehensive utilization of the basin water resources. In 1998, the State Council, the Ministry of Water Resources and the National Planning Committee issued the "Yellow River Available Water Annual Allocation and Main Course Regulating Scheme" and the "Management Details of Yellow River Water Regulating," leading the way to the first basin-wide main course flow regulation which began the following year.

Part of the impetus for change to basin-wide flow regulation was derived from an increasing awareness of the ecological value of water. The flow cuts in the lower reach of the Yellow River, which began in the 1970s but which became acute in the early to mid-1990s, played a major role in shifting focus to ecological value. Recognition of the value of water in maintaining ecosystem functions in wetlands along the main stem and, in particular, in the Yellow River delta has also gained a prominent place in water management discussions as has the value of flows in diluting pollution levels and contributing to erosion prevention in the Loess Plateau region.

At the national level, other changes took place in the 1990s which began to impact Yellow River water management. In 1998, the Ministry of Water Resources brought forward ideas for the conceptual transformation of water resource development and management in China from engineering-dominated approaches to approaches based on demand management and the value of water resources (Boxer 2001). Following these ideas, concepts such as water prices, water rights and water markets were further discussed and tested and are now beginning to have profound impacts on water management across China including the Yellow River basin.

While the changes of the 1990s have pushed thinking on water management in the Yellow River basin towards an integrated concept, the actual situation there, as in most of the rest of the world, continues to be one of overlapping levels of authority, unclear responsibilities, and competing interests. A new water law passed in 2002 may give the Yellow River Conservancy Commission increased authority to act as a basin management organization, but the new goals of overall management will still need to be met through the combined efforts of national, basin, provincial and local governments with various interests in agricultural, mining, industrial development and other endeavors as well as domestic use. The challenge for the 21st century will be for Chinese society to devise acceptable water management systems in the midst of rapid change not only in water resources demand and supply but also in social structure, institutions and thinking on economics, politics, and openness to the outside world.

Current Critical Issues

Water Stress—Now the Number One Issue in the Basin

While flood control has historically been the primary issue in Yellow River management, water stress has now emerged as the number one issue for most basin authorities and residents. The rise of water stress as a critical issue has been caused by three factors: a recent decline in water supplies due to drought and other factors, an increase in demand, and a growing awareness of environmental water needs.

On the supply side, table 6 shows data on rainfall and runoff over the past 40 years. From the figures, it is immediately clear that recorded rainfall, runoff and rainfall/runoff ratios were all substantially lower in the 1990s than in previous decades. One question is whether the declines in the 1990s are part of a short-term climatic cycle or are caused by secular declines in long-term precipitation levels brought about, perhaps, by global climate change. As a similar but apparently less severe dry-spell occurred in the decade from 1922-1932, it is suspected by some Chinese hydrologists in particular 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.

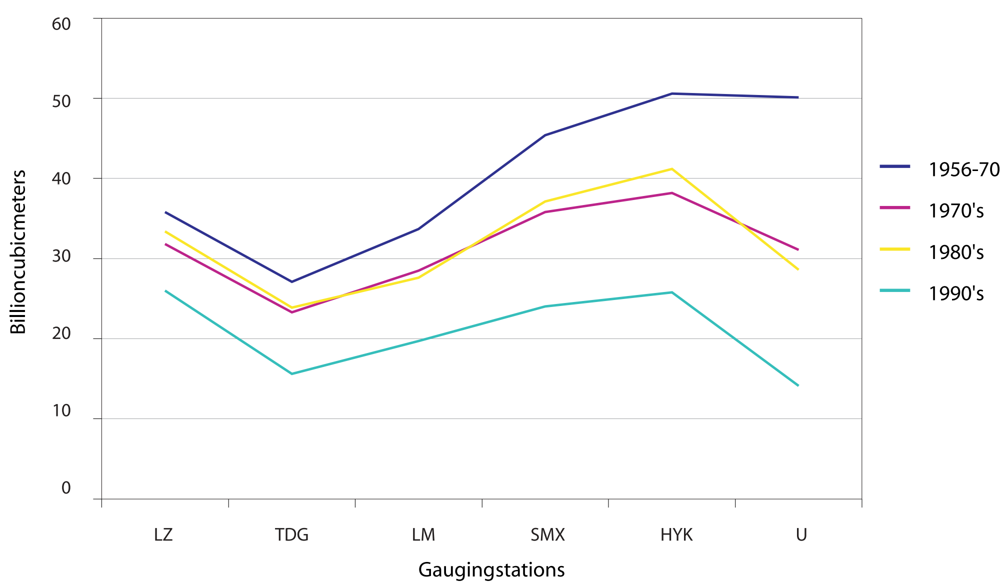
Clearly, rainfall in the 1990s has been low. However, as figure 3 graphically shows, the run-off decline is not only a phenomenon of the 1990s. Further, the fall in rainfall does not fully explain the decline in the rainfall/run-off ratio. In fact, the finding, as depicted in figure 3, that the relative decline in runoff seems to increase as one moves from upstream to downstream regions seems to support the idea that additional water detention and use in upstream regions are at least part of the explanation (see Ongley, 2000 citing Zhang et al. 1997). As such, it seems likely that some of the change in measured runoff and runoff yield may be related to accounting systems which have not been able to capture changes brought on by new water resource development patterns.

TABLE 6.
Rainfall and runoff in Yellow River basin, 1956-2000.

Area	(000 km^2)		1956-70	1971-80	1981-90	1991-00	Average	1990s Change from average
			Time period					
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%	-13%
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%	-25%
Lower	22	Rain (mm)	733	689	616	614	671	-8%
		Runoff (bcm)	1.5	1.1	0.6	0.0	0.8	-100%
		Runoff yield (%)						
Basin	752	Rain (mm)	482	451	455	413	454	-9%
		Runoff (bcm)	65	56	61	43	57	-24%

Source: YRCC 2002c.

FIGURE 3.
Yellow River Runoff, 1956–2000.



Note: LZ = Lanshou; TDG = Toudaoguai; LM = Longmen; SMX = Sanmenxia; HYK = Huayuankou; LJ = Lijin.

Source: YRCC 2002c.

On the demand side, total depletion has increased by a significant 21 percent over just a ten year period as shown in table 7. Geographically, this change can be decomposed into a reduction in lower reach depletion more than offset by increases in the upper and, especially, middle reaches. Sectorally, the change consists of a moderate increase in agricultural depletion and dramatic growth from the industrial and domestic sectors, again most notably in the middle reach.

Partially in response to declining supplies and increasing demand, groundwater pumping has also increased dramatically over the past 20 years. From 1980 to 2002, groundwater abstraction increased by 5.1 km^3 or 61 percent. In some regions of the basin, groundwater depletion is now a major problem. For example, in the Guanzhong plain located in the middle-reach of the basin in the vicinity of Xian, the area with a groundwater depth less than 4 meters has shrunk from 23 percent of the total land in 1981 to 8.5 percent in 2000 while the area with groundwater depth greater than 8 meters increased by 24 percent, from 10,700 km^2 in 1981 to 13,200 km^2 in 2000 (MWR 2002). Groundwater overdraft is now causing an extension of “funnels” and significant sinks. For example, in the city of Xian, average annual subsidence is now as high as 35 millimeters in some areas and the maximum accumulated decline has reached 1340 millimeters.

The outcome of declining supplies and increasing demand has already been the seasonal desiccation of portions of the Yellow River’s lower reach since the early 1970s. From 1995-1998 there was no flow in the lower reach for some 120 days each year and in some cases flow ended over 700 kilometers of the sea, failing even to reach Shandong province. This cut off in flow has important repercussions to basin function for three reasons. First, it limits the availability of surface water for human use. Second, it negates the competence of the river to carry its heavy sediment load to the sea, potentially resulting in a more rapidly aggrading

TABLE 7.
Yellow River depletion (bcm), 1988-92 and 1998-2000.

Years	Reach	Total	Agricultural	Industrial	Urban domestic	Rural domestic
1988-1992[a]	Upper	13.11	12.38	0.51	0.15	0.07
	Middle	5.44	4.77	0.38	0.17	0.11
	Lower	12.18	11.24	0.55	0.18	0.20
	Basin	30.72	28.39	1.45	0.51	0.38
1998-2000[b]	Upper	15.18	13.64	0.96	0.22	0.37
	Middle	10.59	7.69	1.47	0.54	0.89
	Lower	11.47	10.38	0.60	0.24	0.25
	Basin	37.24	31.72	3.02	1.00	1.51
Difference	Upper	16%	10%	88%	46%	430%
	Middle	95%	61%	286%	217%	711%
	Lower	-6%	-8%	9%	36%	23%
	Basin	21%	12%	109%	96%	297%

a) Data from Chen, 2002.

b) YRCC Water Resources Bulletins of 1998, 1999, and 2000.

and flood prone channel than would otherwise exist (though low flows also tend to be associated with lower sediment loads). Third, it has clear consequences for the ecology of the downstream areas and, in particular, the Yellow River delta and coastal fisheries. After the 1998 strengthening of the 1987 Water Allocation Scheme, the Yellow River Conservancy Commission has managed to nominally end absolute flow cut-off since 1999, though flow levels were still far below that considered necessary just for environmental needs.

With decreasing supplies and increasing demand, the Yellow River's waters are now essentially fully allocated, suggesting that reductions in allocations to some sectors must be found if additional new demand is to be accommodated. Further complicating matters, it is now clearly established that environmental water demands have not been adequately included in existing allocation schemes. The primary environmental water use in the Yellow River according to basin managers is for sediment flushing to control potentially devastating floods. At present, 1 trillion tons of sediment is believed to enter the Yellow River each year. Of these, 400 million tons are calculated to be captured by two large reservoirs and various irrigation diversions, 100 million tons are believed to settle within the lower reach, and an additional 100 million tons are flushed to the sea through dry-season minimum flow. To flush the remaining 400 million tons, an environmental water requirement of 14 bcm (3.5 bcm of water per 100 million tons of sand), which is more than one quarter of the recent flow, is currently estimated necessary. As was the case with runoff, however, actual sediment loads in the 1990s were substantially below the levels from which the 1 trillion ton figure was based, and the level in 2000 was only 5 percent of the 1956-95 average. 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 14 bcm is needed for sediment flushing but that the figure will decline as erosion control measures are successfully implemented. These control measures are to be based in part on the establishment of new vegetative cover which will also require water, and water for this purpose is also considered to be an environmental use. At present, the Yellow River Conservancy Commission estimates that this new use will approximately offset the savings from reduced sediment flushing, though with the clear advantage of increased agricultural output and an improved upland environment.

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 grass, wetlands and fisheries at the mouth of the river. To meet these needs, a 5 bcm minimum environmental flow requirement for the river mouth is also assumed along with a minimum continuous flow of 50 m^3/s at the Lijin gauging station. The minimum flow requirement is also expected to partly meet requirements for sand flushing. Similarly, both the overall sediment flushing and minimum flow requirements are currently seen as sufficient for the river to continue its function of diluting and degrading human introduced pollutants and so, no additional environmental requirement for this purpose is officially envisioned.

Together, then, the ecological water requirements for the Yellow River basin are currently estimated by the Yellow River Conservancy Commission 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. Nonetheless, the estimates may change over the 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, urbanization and agricultural demand further claiming water resources, the challenge in the Yellow River basin will be how to balance human demand with ecological needs.

Policy Discussion

Water resources management in the Yellow River basin is now no longer just an issue of flood control or the creation of new irrigation systems. It is a matter of making hard choices concerning the allocation of water between sectors and locations, and it is clear that these hard choices are going to become more critical in the coming decades. Even if rainfall and runoff patterns return to pre-1990 conditions, growing domestic and industrial water demand would likely fully exhaust expected additional supplies within a decade or so. Use of water for environmental purposes at levels recognized adequate by the Yellow River Conservancy Commission would mean that the river would be over-allocated even with increased flow and without any growth in demand. Hard choices must be made, and failure to act will likely only exacerbate the water-related difficulties already facing current users. Furthermore, a failure to create well-designed allocation plans and mechanisms almost ensures that valuable and scarce water supplies will not be put to their most productive, broadly defined uses. Addressing the problem of water scarcity is clearly the number one priority in Yellow River basin management now and will have impacts far outside basin boundaries (Compare Brown, 1995 and Brown and Halweil 1998 with Nickum 1998 for differing views on the role of Chinese water scarcity in global grain demand. See also Huang and Rozelle 1995).

In tackling the water scarcity problem in the Yellow River basin, it is imperative that management plans and policies be made based on sufficiently accurate figures and assumptions concerning supply. Various Chinese documents and papers continue to cite 58 bcm as average annual runoff for the basin. However, the average flow from 1956-2000 is already marginally below this level and the figure from the 1990s, averaging only 43 bcm annually, is 25 percent lower. As a result, it now seems apparent that traditional assumptions of Yellow River water availability need to be reassessed. Plans also need to consider strategies to deal with annual variation in whichever average is used so as to take into account the possibilities of low and high flow years as well as changes in availability by reach.

As importantly, the YRCC needs to reassess the system it uses to allocate water irregardless of flow conditions. The current system of basing allocations on a percentage of river flow, though similar to the strategy often still advocated in international river agreements, does not take into account differences in water productivity or its marginal value across economic sectors and locations. In addition, the current system does not fully take into account the critical value of the river's environmental services and so has not provided water to maintain river flow, resulting in painful flow cuts in the lower reach. Change from the current system may wish to focus on developing water allocation mechanisms to shift supplies to those sectors, including the environmental sector, and regions which use it most productively. In so doing, thinking would need to shift away from considering water as an absolute quantity to be allocated to water as an input whose value depends on differences in the manner and location in which it is used.

Given the growing supply/demand imbalance in the Yellow River basin, it will be increasingly difficult if not impossible to meet new water demands from one sector without decreasing supplies to another. Since agriculture is now by far the largest consumer of the Yellow River's water resources and appears to have relatively low water productivity levels, meeting growing industrial and domestic demands and environmental requirements is likely going to mean a reduction in supplies to the agricultural sector. Given the importance of agriculture to the Chinese economy, its role in rural livelihoods, and the long standing policy of maintaining near self-sufficiency in grain production, the talk of reducing agricultural water supplies may seem both highly disruptive and, even, radical. However, some choice must be made, and even if initially painful, it is clear that properly conceived policies executed correctly can bring tremendous long-term benefits. One need only reflect on the historic economic changes brought about by Deng Xiaoping's agricultural sector reforms in the late 1970s and early 1980s to be reminded of what is indeed possible. Few foresaw that the implementation of the Household Responsibility System would usher in a new era in Chinese agriculture and later the Chinese economy. The key questions to be addressed regarding water will be how to implement the new allocation policies which cause the least disruption to the livelihoods of farmers, in particular poor farmers, and agricultural output. China's recent ascension to the World Trade Organization may provide an opportunity to begin discussing options. As the Chinese saying goes, though it may be difficult, it is necessary to proceed (*zhi nan er jin*).

The Continued Threat of Floods

Yellow River floods over the millennia have likely caused the deaths of literally millions of people, sometimes portending dynastic change, and so it is not surprising that until recently, flooding was considered to be the primary management issue in the Yellow River basin. Since 600 B.C., records indicate over 1,600 dike breaches and 26 significant course changes of the Yellow River including 8 major shifts (5 "natural", and 3 human induced). On average, that is two breaches every three years and one course change every 100 years. These course changes have often been substantial with the mouth of the river shifting back and forth at various times from Tianjin 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 some 500 kilometers. The channel also shifted in 1938 when the dikes near Huayaunkou were purposefully breached to stop advancing Japanese troops (Todd 1949). This breach, which is estimated to have cost the lives of some 800,000 Chinese, was plugged and the river returned to its current channel in 1947.

Despite major engineering efforts, the historic records indicate that consistent flood control was rarely achieved for significant periods until the 20th century under the government of the Peoples' Republic of China. Since 1949, flood protection work has greatly reduced the incidence of flooding, and in fact there has been no major dike breach for over 50 years and only minor breaches during spring ice floods, a major accomplishment. However, while the threat of flooding has been reduced, it has not disappeared. Large scale dam and reservoir construction in the middle and upper reaches has reduced the probability of the large flows which have historically caused floods, but the channel in the lower reach is now more constricted by sediment, decreasing the flow levels required to cause flooding, and one major tributary, the Qing, is still un-harnessed and poses a substantial threat. Furthermore, the channel below Huayuankou continues to rise above the surrounding countryside as sediments are deposited and is now some 20 meters higher than the floodplain at Xinxiang City, 13 meters higher at Kaifeng City and 5 meters higher at Jinan City, aggravating the impact of a flood if it did occur (YRCC 2002c).

The potential costs of flooding have also increased as the basin has developed over the past 50 years. The areas subject to flooding cover approximately 250,000 km^2 from Tianjin in the north to Jianghuai in the south and include parts of the five provinces of Hebei, Shangdong, Henan, Anhui and Jiangsu. The flood prone area is the most densely populated in the basin and contains nearly 90 million people, a number which would rank the flood area number 12 in the world if an independent country. The region is also relatively well-developed economically, with numerous cities, national transportation facilities such as railways and highways providing key North-South and East-West linkages, and major telecommunication lines. In addition, the area is one of the breadbaskets of china and contains over 7 million ha of crop land. According to some estimates, if the river breaches at the north bank above Yuanyang or at south bank near Kaifeng, the direct economic loss would be hundreds of billion of yuan while the cost in loss of life and overall disruption of the national economy would be immeasurable, dealing a severe blow at the national economy and social stability. Thus ensuring safety from Yellow River floods and protecting what is considered the heartland of China continues to be a priority area for the national government and basin managers.

The flooding season of the Yellow River is normally from late June to late September, the period of the heaviest rainfall. About 40 percent of all precipitation falls in July and August and 70 percent falls between July and September. While more than a half of the runoff generated by rainfall comes from the upper reach, this flow is relatively consistent. In contrast, the watersheds between Hekouzhen and Huayuankou in the middle reach produce both substantial and highly variable runoff brought about by concentrated rainfall events, and it is the runoff from these events which is the primary factor in lower reach flooding. The storms are typically concentrated within a range of 10,000 km^2 and occur over a period of 6-20 hours during which time rainfall volumes can reach 2 – 6 $km.^3$ Massive floods, which are thought of as “1000 year floods” in contrast to the “100 year flood” standard used elsewhere, can also occur when these middle reach storms coincide with extreme rainfall events in the upper reach.

In addition to the “traditional” floods just discussed, a second form of flood, known as ice floods, occurs in the winter and early spring but for much different reasons than those just described. Ice floods occur when the river flows south to north as happens in the Ningxia-Inner Mongolia area and in the lower reach starting near Kaifeng. In the winter, higher latitude, but further downstream reaches are the first to freeze, blocking the passage of flow from lower latitude, more upstream regions and causing floods. Similarly, higher latitude downstream reaches stay frozen longer into the spring than upstream reaches, again blocking the flow and causing flooding. It has been estimated that 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. It is interesting to note that the ice flood phenomenon in the lower reach is a function of the particular course of the river. When the river’s mouth was below the Shandong Peninsula, as it was periodically before 1855 the probability of such floods was much lower.

The basic problem of flooding in the Yellow River is not simply one of large flood peaks but rather a combination of flow coupled with sediment transport and deposition. The middle reach of the river runs through the highly erodible

Loess Plateau which in some places produces 20,000 tons of sediment per square kilometer per year (YRCC 2002c). About 90 percent of the sediment comes from the reaches between Hekouzhen and Tongguan in the Loess area, and more than 80 percent comes in the flooding season as a result of only a few large storms. Over the last half century, the annual average sediment load reaching Huayuankou is generally estimated to have been 1.6 billion tons and the average sediment concentration 35 $kg/m,^3$ easily making the Yellow River waters the most sediment— dense of any major system in the world. The maximum sediment concentration measured at Sanmenxia was 920 $kg/m,^3$ essentially meaning that the river was a flow of mud rather than water. About one half of all sediment in the river is estimated to be deposited in the lower main channel and delta region. Deposition is in large measure a function of the volume of large particles within the sediment load as those are most prone to settle out before reaching the sea. Coarse sediment with particle sizes greater than 0.05 mm are believed by some to make up nearly 50 percent of the total deposition of the lower river channel. The primary source of large particles is the upper half of the middle reach, a fact which has implications for the focus of any erosion control policies.

The famous Qing dynasty emperor Kangxi, following the work of the Yellow River's great historic managers, once wrote that there are basically two strategies related to flood management, using flow to scour the channel or dividing the flow to dissipate its ability to do damage. However, the engineering skills brought to bear on the Yellow River in the 20^{th} century, especially after 1949 under the People's Republic of China, have expanded the range of possibilities for managing the river. The basic Yellow River flood control policy since 1950 has been 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". To accomplish its strategy, the People's Republic has spent vast sums of money and devoted massive amounts of human resources to Yellow River flood control. In total an estimated 1.4 bcm of earth and rock works have been constructed for flood control, a volume equivalent to that required in building thirteen 5,000 km Great Walls (Ma 1999).

The Chinese government has gradually adopted comprehensive approaches for flood control in the basin. Along with the primary embankment projects, detention basin projects, and reservoir storage built in the main river and its tributaries, soil conservation works in the upper and middle reaches have been undertaken. A system of flood control engineering works "retaining water at the upper stream and middle stream, discharging water at the downstream and retarding at detention basins on the both banks" has been formed. The current comprehensive flood management plan comprises a range of interrelated and delicately balanced strategies for the management of the natural resources base, following an assessment of the ADB (2001), including (i) extensive soil and water conservation programs in the upper and middle river reaches (particularly in the Loess Plateau); (ii) the construction of multipurpose reservoirs; (iii) the continuous adjustment and strengthening of flood control embankments in the lower river reach; (iv) the development and improvement of flood retention basins in the floodplain to store flood water when embankments are at risk of overtopping; (v) the implementation of development and building controls in flood-prone areas; and (vi) planning measures, such as the relocation of families presently living in areas of high flood risk such as the inner floodplain. These measures are complemented by flood prediction and warning systems.

Policy Discussions

Because of efforts by the Chinese government, the nature of flooding in the Yellow River basin has been changed over the last 50 years for, perhaps, the first time in human history. In particular, the construction of large dams on both the main stem and major tributaries has greatly reduced the probability of the major flows which have plagued the basin. At present, there is only one stretch of river which is still subject to historic flooding problems, the so-called "SanHuajian" area (the area between Sanmenxia and Huayuankou) which is affected by the still unregulated Qing River. However, despite the success in overall flow control, the nature of the river has also changed and the constricted channel capacity in the lower reach now means a flood can be generated with significantly less flow than before. In the post 1949 period, efforts to address the new nature of Yellow River flooding have focused mostly on reservoir construction and dike raising. However, neither of these approaches can be sustained in the long term. Reservoirs lose their storage capacity because of siltation, sometimes at rates much higher than originally anticipated. Even if they do function as planned, reservoir life-spans are relatively short. Similarly, continued sediment deposit 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 Chen has suggested (Qian 2001), dike raising is not a sustainable option, the question is how long the dike system can be maintained. Clearly, a reduction in sediment flows would increase the life span of reservoirs and post-pone the limit of dike raising and has potential benefits for agricultural production. However, given the nature of the physical landscape and climatic conditions, it is unlikely that such an outcome will be possible in near future, if ever. The dream of "letting the river run clear" is probably just that, a dream.

Thus the job of the Yellow River Conservancy Commission and other bodies is to develop measures to continue protecting the lower reach of the Yellow River from flooding in the short-term while developing long-term strategies for flood management. In the short term, the reservoir operation and dike maintenance and improvement are clearly necessary. In addition, focus must be placed on minimizing the risk of loss of life from the unregulated "SanHuajian"section, through river-harnessing efforts and/or improvement in flood prediction and evacuation.

In the long-term, it is important to think back on earlier river management philosophies, not necessarily in terms of specific concepts such as dividing the flow or letting it scour, but rather on the more general concept of "using the river to manage itself." Such ideas can be used within the context of integrated water management to improve both flood management and to address other issues such as water scarcity. For example, increased use of flood detention areas, such as Dongping Lake, can provide both a means to dissipate flood waters as well as recharge groundwater, freeing the highly developed agricultural area from sole reliance on rainfall for groundwater recharge. Such strategies make it possible not just to stop the destructive power of flooding, but to actually produce benefits from flooding. A key constraint in this strategy at present is the substantial human population, estimated at nearly ½ million in the case of Dongping Lake, which have moved into potential flood detention zones and flood plains. It will be up to the government to balance the costs and benefits of population and economic movement that such strategies would require and ensure that the gains from such a policy are shared with those whose lives would be disrupted. Examples of attempts to create such win-win strategies might be sought from the U.S. Army Corps of Engineers in its efforts to control the floods of the Mississippi. Instead, of continuing to build embankments on the river, a process it could physically accomplish, the Corps' current policy is to encourage the movement of people out of the flood plain in order to allow it to serve its natural function.

Soil Conservation

The Yellow River flows through the Loess Plateau, an area of about 640,000 km^2 covered with a thick loess 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 erodable area on earth (YRCC 2002c). The soil of the Loess Plateau is ripped down and into the Yellow River and its tributaries in massive quantities, in particular during the severe, concentrated rainstorms of the summer months. As a result, the Yellow River is estimated to have carried an average 1.6 billion tons of sediment each year in recent decades. If made into a square belt with sides of one meter, the quantity of sediment moved annually by the river would be sufficient to loop around the earth at its equator 27 times (YRCC 2001). Of the total sediment, only about 25 percent is carried through to the sea, and the remainder is deposited in the river bed and flood plains. As a result, the bed of the river 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.

The ultimate causes of soil erosion in the Loess Plateau are debated but generally associated with both human action and climate change. Much of the plateau region contains deep soils and temperature regimes favorable for crop growth, given sufficient water. Partly for these reasons, agriculture began very early in the region, probably 7-8,000 year ago (Ho 1998), and eventually allowed the early Chinese states to flourish. Agricultural expansion and associated activities, especially from the Qin Dynasty onwards, appears to have contributed to the loss of vegetative cover which exposed fragile soils to erosion. The problem seems to have expanded with population growth which eventually led to extensive land clearance and cultivation of highly sloping, and hence highly erodible, lands. It is believed that these trends in human related land degradation have been exacerbated by a long term secular decline in precipitation in the region. The result of the drying pattern is that the sustenance of erosion controlling vegetation, even on non-agricultural areas, is hindered. However, while human and recent climatic change may have greatly increased erosion on the plateau, the geologic record of the North China Plain makes clear that erosion processes in the Loess region are not limited to the historic era.

Soil conservation as a policy for the Loess Plateau began in the mid 1950s though primarily as a means to increase grain output rather than control sedimentation. The nature of the early policies is made clear in the slogan of the time which stated, "let bald hills become productive fields." After the problems from sedimentation of the Sanmenxia reservoir project in the 1960s, the critical role of sediment control in Yellow River management was also better recognized. From that time, erosion control was justified both on the grounds of increasing agricultural productivity as well as for flood control and river management. In essence, the Chinese government has followed a "two birds with one stone" approach by using soil conservation as a means both to reduce poverty and downstream sedimentation.

Policy Discussion

The main thrust of the soil conservation policy on the Loess Plateau since 1949 has been physical treatment of erodible areas. Over the last 40 years, about 3,000 km^2 have been treated per year, a figure which has expanded to around 6,000km^2 per year in the 1990s with the help of the World Bank. At the present time, 166,000 $km,^2$ or 36.6 percent of the farmland in the erodible area, is considered to have been brought basically under control through the use of terracing, strip farming, sediment retention dams, and planting of trees and grasses among other measures. According to one analysis, the annual average reduction of sediment deposition from such measures has been about 300 million tons since the1970's resulting in accrued benefits of 200 billion Yuan and an annual increase in grain production of 4 million tons.

The effective rate of erosion control, at least in terms of downstream deposition, might be further improved if focus is placed primarily on the coarse sand areas in the upper portions of the middle reach which contribute most to the sedimentation downstream. Even if such control is done, the coming challenge using conventional control strategies will still obviously be huge. In fact, at current rates, it will still take more than 100 years to fully bring Loess Plateau erosion under control even assuming that treatments are in fact as successful as claimed. Adding to the problem, erosion control efforts are being offset by other human activities, especially as related small scale coal and non-ferrous metal mining in the "black triangle" area of Shaanxi, Shanxi and Inner Mongolia, which are encouraged at the provincial level.

Within the context of current efforts and strategies, improvements can clearly be made in techniques applied to erosion control though these efforts can only hope to have marginal impacts on rates of control. Another alternative is a change in erosion control paradigms. Control of soil erosion should probably be viewed from a broad perspective in which conservation efforts are placed within the overall economic planning and policy reform frameworks. 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 hence the erosion-controlling vegetative cover. Focussing soil conservation strategies on technical solutions in the agricultural sector may cause one to overlook basic opportunities.

More fundamentally, the choice between alternative soil conservation strategies should clearly be better placed within a more 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 energy and raw materials for industry and manufacturing. Thus the Loess Plateau receives much of the environmental damage from coal mining, but little of the employment benefits of the down-stream industries that could provide alternatives to farming marginal, highly sloping and highly erodible lands.

From a water use perspective, the basic strategy behind current soil conservation efforts also needs to be more closely examined. Qian Zhengying, in her long career as China's water minister, argued that while soil conservation may help block erosion, it also depletes water— tree plantations make the land green but also consume water. A key policy question for the future will be whether or not the reduction in sediment flows and potentially increased agricultural activity upstream are sufficient to justify the reduction in runoff downstream. This question will become increasingly important as economic development in the lower reach and its demands for additional water continues to expand. The issue also leads to basic questions on water productivity and equity in use. It is likely that downstream areas have higher productivity in water use, especially in the industrial sectors. However, it is also downstream, eastern regions of China that are already economically most advanced. While the balance can be set by default, clear consideration of the issues based on empirical analysis can contribute to the possibility of generating positive sum solutions to this difficult problem.

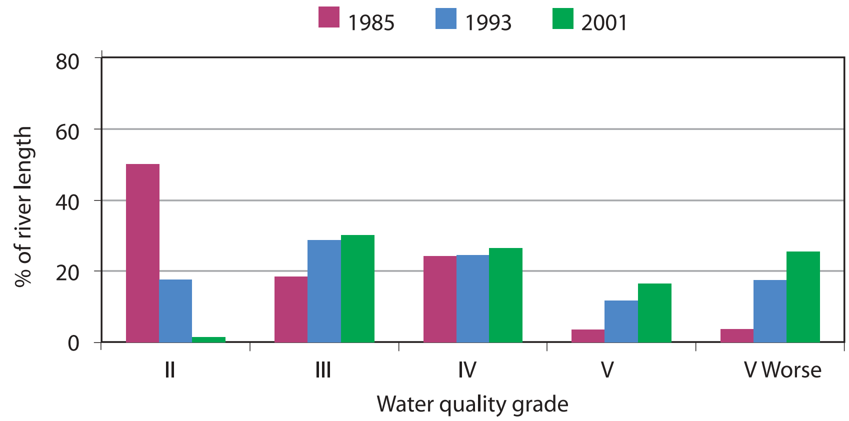
Water Quality and the Environment

While growing supply/demand imbalances and the threat of flooding— exacerbated by erosion— are still considered to be the primary issues facing Yellow River water managers, rapid degradation of water quality is increasingly becoming a key factor in basin water management. The expanded interest in water quality is not surprising, given the sharp increase in pollution levels over the past few decades and the fact that degraded water quality is aggravating water supply problems. In Shanxi Province, for example, return flow of water used in the mining industry is often so polluted that it has no value for other uses and severely degrades the quality and value of the "fresh" water with which it is mixed. Growing pollution levels along with changes in flow regimes are also having severe consequences for the ecology of the Yellow River delta and the coastal and marine environments of the Bo Sea as well as their commercial fisheries. For the Yellow River with its limited waters and growing demand, problems of water quality, water quantity, and sediment are interdependent, making basin management complex and calling for basin-wide, or even broader, approaches for their solution.

The declining state of Yellow River water quality is exemplified in figure 4. Data in the figure are classified using the system established in the *Surface Water Quality Standards* issued by the State Environmental Protection Agency (SEPA, GB3838-88 and revised as GHZB-1999 and GB3838-2002). Under the standards, Classes I & II represent acceptable drinking water quality, Class III represents potentially potable water if appropriate withdrawal and treatment measures are taken, and Classes IV and V represent quality levels appropriate only for industrial and agricultural use. At present, water in less than 40 percent of the reaches within the basin is suitable for direct human use, and in most of those places the water is in fact of only Class III quality. While the current figures are disturbing, more disconcerting is the fact that quality has been and continues to be declining at a rapid rate. As the figure shows, the percentage of the river length classified as Class II has declined from 50.1 percent to 1.5 percent from 1985 to 2001 while the percentage classified as "V— worse" has increased from 3.7 percent to 25.4 percent. This negative trend has continued to the present, with the percentage of river length classified as Class V or "V— worse" increasing from 33.8 percent to 41.9 percent in just 4 years from 1998-2001. The Yellow River is now the second most polluted major river in China after the Huai.

The worsening trend in Yellow River water quality, and the high absolute level of pollutants, are also illustrated in table 8 which shows the increases in two of the main measured pollutants. While the table only includes figures for the main stem, pollution levels tend to in fact be even worse in the Yellow River's main tributaries. For example in 2001, 66 percent of the total length of all measured tributaries was classified as Class V or "V— worse" whereas the figure for the main stem was "only" 15.8 percent. Over all, the most polluted section of the Yellow

FIGURE 4.
Yellow River water quality, 1985,1993 and 2001.



Source: YRCC 2002c.

River is near the inlet of the Weihe. Though not discussed further here, the problem of Yellow River basin water pollution extends to groundwater as well. As an example, 293 out of 500 domestic-use wells in Taiyuan city were found to have pollutant levels above allowed limits, and the area with damaged groundwater quality in Xian city has an extent of 200-300 km^2 (MWR 2002).

The pollution levels in the Yellow River are causing increasingly serious problems for water supply and the environment. These problems came to a head with the occurrence of the "black wave." In the beginning of 1999, a massive discharge of pollutants entered the main channel below Tongguan, causing the water to turn blackish-gray and produce bubbles and foam as high as several meters. Measured COD

TABLE 8.
$KMnO_4$ (potassium pemanganate) and NH_4-N (ammonia) concentrations in the Yellow River main stem, 1981 and 2002.

River stations	$KMnO_4$ (mg/l) 1981	$KMnO_4$ (mg/l) 2002	$KMnO_4$ % Increase	NH_4-N (mg/l) 1981	NH_4-N (mg/l) 2002	NH_4-N % Increase
Lanzhou	2.2	2.4	9%	0.37	0.56	51%
Toudaoguai	2.1	5.2	148%	0.06	1.2	1900%
Longmen	1.6	3.7	131%	0.07	1	1329%
Tongguan	1.7	5.6	229%	0.07	2.5	3471%
Smamenxia	1.8	5.4	200%	0.07	1.8	2471%
Huayuankou	1.4	5.3	279%	0.18	1.2	567%
Lijin	1.7	4.8	182%	0.08	0.8	900%
Average			168%			1527%

Source: Hong et al. 2002.

TABLE 9.
Provincial wastewater discharge, 1998.

Province		Industrial (MCM)	Domestic (MCM)	Sum (MCM)
1	Qinghai	248	45	293
2	Gangsu	658	114	772
3	Ningxia	496	74	570
4	Neimeng	162	80	242
5	Shanxi	416	161	577
6	Shaanxi	776	548	1324
7	Henan	423	228	651
8	Shandong	248	52	300
	Sum	3427	1302	4729

Source: Hong et al. 2002.

(Chemical Oxygen Demand) levels were as high as 64.7 mg/l in the main course and 125 mg/l at the entrance of tributary Weihe which are well above 25 mg/l required to be classed as Class "V— worse." The black wave, which continued for 20 days and resulted in the shut-off of many river intakes in areas further downstream, served as a wake-up call for the seriousness of the Yellow River's water quality problems.

The water quality problem in the Yellow River is caused by a combination of factors. Most fundamentally, large quantities of waste are discharged into the main stem and its tributaries as shown in table 9. While there is substantial discharge from all provinces, Shaanxi contributes over one quarter of the total and the Weihe tributary contributed the largest share, almost 30 percent of the basin total.

The overall load of COD and NH_4-N in the Yellow River's main stem and tributaries are shown in table 10 which indicates shockingly high levels. Total wastewater discharge in 1998 was estimated at about 5.1 bcm, of which about 80 percent is from industry and 20 percent is from domestic sources. The growth in discharge has been especially rapid in recent years (table 11). Over the last 8 years, total sewage discharge increased by 1.8 billion tons or more than 50 percent. While growth in industrial sewage outpaced that of domestic, the growth rates in both sectors were substantial. Already the average annual sewage discharge from 1998-2001 was about 12 percent of the average annual Yellow River runoff, with intra-annual ratios obviously much higher during the non-flooding season. Without timely and effective measures, the water quality of all the reaches in main stem and all significant tributaries will probably soon exceed Class V, an outcome which will seriously reduce the security of water supply in the basin and exacerbate environmental deterioration.

While the discharge numbers are shocking, they in fact account for only part of the problem of water quality degradation in the Yellow River. Two other important factors are the unmeasured wastewater discharge from industry in rural Township and Village Enterprises (TVEs) and non-point pollution sources from agriculture. Beginning in the 1980s, TVEs have developed rapidly throughout China and have often been allowed to remain out of compliance from wastewater laws and regulations because of their limited technology and financial levels, difficulty in monitoring their wastewater discharge, and the

TABLE 10.
Wastewater discharge in Yellow River basin, 1998.

		Pollution load	
	Flow (mcm)	COD (mil ton)	NH_4-N (mil ton)
Main stem	923	277	25
Tributaries	4134	1240	46
Basin sum	5057	1517	71

Note: Tributaries' wastewater flow estimated by proportioning the COD values in tributaries and main course.

Source: Hong et al. 2002.

TABLE 11.
Wastewater discharge (billion tons), 1993 and 1998-2001.

	Industrial sewage	Domestic sewage	Total sewage
1993	2.66	0.87	3.53
1998	3.25	0.95	4.20
1999	4.20	1.08	5.28
2000	3.07	1.15	4.22
2001	4.14	1.18	5.32

Source: Hong et al. 2002.

general trend in decentralization of economic control and management.

Non-point source pollution, also unmeasured, from agricultural lands is another important factor in water quality decline and plays a large role in the substantial increase of heavy metals in basin as well as BOD discharge. From the early 1980's to the mid 1990s, farmers substantially increased their 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 channel while in the middle stream, most of the return flow enters major tributaries such as the Weihe, Fenhe and Qinhe. In the flooding season, pollutants are taken up from the large flood plain and they enter the river, providing a second non-point pollution source.

The previous discussion has focused on the impact of pollution on river water quality. However, another source of environmental disruption is the change in Yellow River flow dynamics which has taken place over the past 50 years. The natural wetlands in the lower reach of the Yellow River and, in particular, the Yellow River delta, hold a rich array of aquatic species, provide habitats for migrating birds, and serve as the basis for economically valuable industries such as fisheries. Historically, floods played an important function in controlling the ecology of the delta as well as the wetlands along the river's banks. However, the success in flood control has meant an end to this natural function for the last five decades. The last three decades have also seen greatly reduced, and sometimes even stopped, flow. This, and the resultant lack of sediment output, has caused a retreat of the shore-line, saltwater intrusion, and increased salinity in the Bohai estuary amongst other changes. Together these factors have caused such changes as a lowering of seawater temperature during the fish breeding season from April to June and reduced nutrient levels which have contracted fish production and changed species composition. The cutting of the flows has also limited the ability of fish to return to the delta waters after breeding. Further complicating matters, the Shengli Petrolium field, the second largest oil source in China, is located in the Yellow River delta and requires increasing amounts of water for production as well as artificial changes in the river course.

Policy Discussion

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

At present, many officials and researchers suggest relying more heavily on using river flow to flush pollutants. Such a plan may have limited scope for success when the flow is abundant but is infeasible under the shortage conditions which are likely to continue, and probably worsen, in the future. Furthermore, the dilution approach does not address many fundamental environment problems which can be caused by high levels of pollution discharge. Many industrialized nations used similar dilution strategies, especially in the 1960s, but changed plans as environmental awareness in their countries increased and additional knowledge of the costs of pollution became known. By studying these experiences, the Yellow River Conservancy Commission has an opportunity to learn from the errors of others and may be able to skip over an environmental development stage in its efforts to satisfactorily solve the pollution problem.

A realistic immediate step in controlling the damage from pollution discharge may be to begin considering legal and institutional reform (Jahiel 1998). At present, the situation is one of "local agencies standing on the bank, YRCC standing in the river." In other words, YRCC has control over the water but not the pollutants which are discharged into it. With the promulgation of the 2002 Water Law, this may be a good time to try to further integrate 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 U.S. uses a committee composed of one political appointee, two lawyers, two biologists and two engineers to guide environmental water policy.

Also, building on the opportunity of the new water law and the possibility for institutional reform, it may also be useful for the Yellow River Conservancy Commission to investigate the use of semi-market measures to control pollution. 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 for whom reduction was more costly. In this way, pollution loads could be reduced with the least harm to the overall economy.

As a second realistic step in controlling the damage from pollution discharge, the YRCC may wish to build from China's State Environmental Protection Administration's recently issued policy on regulating the river by function. Within this framework, a central point is to identify key discharge and withdrawal points through study and monitoring in order to use the information to reduce the impact of discharge on withdrawal. In other words, some sections of the river can be designated as discharge reaches, some sections as withdrawal reaches and some as recovery reaches. By regulating the river in this way, the costs of pollution can be reduced. However, such an effort may involve large investments for relocating withdrawal points, but in the end it may still be more economic than the treatment of more polluted water withdrawals which would otherwise be required.

Key Issues for Future Research

This report has reviewed the geographic setting of the Yellow River basin, the role of the basin in Chinese history and culture, the trajectory of basin development and the issues considered to be most critical by current basin managers. These issues included water scarcity, the continued threat of flooding, erosion control and environmental water use. Based on the analysis we now outline particular issues for which additional research and policy review would likely contribute significantly to the future of Yellow River basin water management.

Inter-sectoral Allocation

With Yellow River basin supplies apparently declining in absolute and quality-adjusted terms and basin resources already over-allocated, one of the key questions facing basin managers and residents will be how to meet growing demand in the industrial and domestic sectors. One clear possibility is through changes in inter-sectoral allocations. In practice this would mean the transfer of water out of the agricultural sector. However, agriculture in China, as in many other countries, holds a special place and national food security is considered a matter of high politics. Furthermore, it is the rural sector which is most impoverished and has probably benefited least from recent economic growth. Shifting water away from those already relatively disadvantaged thus has clear implications for equity and, perhaps, social stability. At the same time, it is industrial growth, dependent on increasing water supplies, which is seen as the driving force in powering China's transformation to a modern, world class economy. It is also industrial growth, broadly defined, which has provided the relief valve for an overcrowded agricultural sector. A better understanding of the role of Yellow River basin water in economic growth, the trade-offs between equity and efficiency in sectoral water allocation, and the range of possibilities for institutionalizing water allocation decisions would serve to better inform coming critical decisions on inter-sectoral transfer.

Water Savings in Irrigation

The agricultural sector is now by far the largest consumer of the Yellow River's waters and, as mentioned above, pressure is growing to decrease agricultural water use. Already the Yellow River Conservancy Commission plans to cut agricultural consumption some 10 percent by 2010. One way to minimize the impact of any reductions is to improve the use of irrigation water in agriculture. There are a number of possible methods through which this could occur. Improvement in irrigation efficiency is one such method. However, while there are some areas where this may be possible such as the Ningxia/Inner Mongolia region, there is also evidence that overall irrigation efficiency from the river basin perspective is already quite high. A second option is the use of more water efficient plant varieties or cropping systems, methods which are already showing promise in some areas. Finally, there is the possibility of shifting thinking away from irrigation efficiency per se and focusing instead on improving irrigation water productivity. That is, increasing the value of output produced by irrigation, for example by shifting water to those crops or regions which can produce the highest 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. Drawing from this, key areas worthy of additional analysis include examination 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 change in changing irrigation water use decisions, and the institutional frameworks which are best suited to realizing the decided options.

Pollution Control and Treatment

In addition to its direct environmental and health costs, pollution in the Yellow River basin exacerbates water scarcity problems by reducing effective supplies. By any measure, including official Chinese government standards, water pollution levels in the Yellow River, and especially some of its major tributaries, are exceptionally high. The key question is what measures can be taken to improve the pollution situation in the short term while addressing the true nature of the problem in the long term while not inflicting undue harm to economic growth. To implement such measures it will be important to understand the evolving nature of pollution sources and to differentiate between pollution from "traditional" industries and urban zones, and that emanating from more decentralized Township and Village Enterprises (TVEs) and agriculture. The problem with pollution control is not, fundamentally, technical know-how. Rather, it is devising ways to finance and enforce existing anti-pollution regulations and effectively integrate the interests and authority of various organizations and agencies responsible for both pollution creation and control. Analysis of these issues will be critical in changing the trend in the Yellow River's water quality.

Environmental 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 water budgeting or allocation in the Yellow River. In addition, even if included, the Chinese definition of environmental water use would include 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. As such, Yellow River environmental use would include sediment flushing to control potentially devastating floods as well as more "traditional" concepts such as conservation and biodiversity. There are three primary issues related to environmental water use in the Yellow River basin which would benefit from additional work. The first is ensuring that the definitions of environmental use by policy makers 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 established environmental flow requirements are actually met. Since at present Yellow River basin managers estimate that requirements are between one third and one half of total annual flow, this final issue is clearly going to be the most challenging for basin managers to address.

Data Issues

One of the main problems facing researchers, especially those outside China but also those within, in attempting to understand key issues in the Yellow River basin is data access and attribution. In some cases, certain questions related to understanding the Yellow River's water management problems require the collection of additional data. In other cases, however, the data have already been collected but are functionally unavailable either because of lack of publicity or explicit control. While unwillingness to make existing data available can occur for legitimate reasons, it is probably more typically a result of lack of understanding of its potential value, unclear dissemination rules, and desire for control by decentralized collection agencies. Further complicating matters, the data made available do not carry with them the collection methodologies and key parameters necessary for understanding their context. For example, Chinese sources and outside papers often still discuss average Yellow River runoff figures of 58 bcm, average sediment loads of 1.6 billion tons, and an expanding river delta without stating the timeframe over which the information is based. Over the last 10 years runoff has averaged less than 50 billion cubic meters, sediment loads have been closer to 1 billion tons, and the Yellow River delta is retreating rather than expanding. Failure to understand data contexts can obviously lead to incorrect basic assumptions about the nature of the Yellow River phenomena. While the data problems just described are not unique to the Yellow River, they can perhaps still be resolved to some extent within the Yellow River basin context if all parties become more precise in their data use and attribution and more open in discussions on data availability and potential applications.

Institutional Gaps

Water management is an inherently complex issue in part because the "natural" unit for administration is usually considered to be the river basin while the actual units of governance have other boundaries. In the case of the Yellow River basin, efforts have been made to overcome this problem by creating the Yellow River Conservancy Commission (YRCC) as the river basin authority. However, from its founding to the present, the YRCC has not had power to act as a true basin authority, and, furthermore, the scope of its mandate has remained unclear. Instead, a wide range of environmental, agricultural, construction, and other agencies along with YRCC have had overlapping functions and authority while at the same time national, provincial and local agencies have been able to place varying claims and priorities on the river's resources and development. While the 2002 water law may have partially clarified roles, the authoritative scope of the many involved actors and the way they should interact over the key issues such as pollution control, groundwater management, resolution of upstream/downstream provincial conflicts and the myriad other issues is still ambiguous. With respect to YRCC itself, it, like most government organizations in China, now must operate in a much different economic and social environment than the one which existed at its creation. The YRCC was established primarily to defeat the threat of flooding and develop irrigation. While it has had much success in this regard, the problems today are much broader with less easily definable solutions or even preferred outcomes. This shift in the nature of the problems has already been reflected in official Chinese water management focus from *Shuili* to *Ziranshuli* (in essence a shift in emphasis from the "engineering benefits" of water to broader "resource" benefits). However, the question remains as to what institutional arrangements can best turn the change in thinking to a change in practice and which institutional frameworks can be used to handle the shift away from pure engineering problems to problems with a larger social dimension. In the end, clarifying institutional roles and establishing appropriate institutional arrangements may be the most significant challenge in ensuring the best long-term management of Yellow River basin resources.

Concluding Remarks

The Yellow River basin has played, and continues to play, a role in Chinese society disproportionate to either its land area or available water resources. The basin is considered the home to Chinese culture, provided the stepping stones to the creation of the Chinese nation and has been a source area for world agriculture and a breadbasket for the Chinese people. For thousands of years, the challenge in the Yellow River has been to control flooding and expand irrigated areas. Flooding is now largely under control, and irrigation growth coupled with rapid increases in industrial and household water use now leave the river a dry bed in some years. Because of these fundamental changes, the challenge in modern Yellow River management is no longer one of engineering, how to control the river, but one of management—how to allocate water between competing users while still maintaining ecosystem services. The government of the People’s Republic of China and the Yellow River Conservancy Commission recognize this challenge and the need to reform management institutions and mechanisms in order to meet it. However, it must be remembered that the fundamental changes which have taken place in basin issues occurred only in the past half century, and especially in the last 25 years, while the existing basin management institutions and philosophies have developed over the last few thousand years.

Clearly, implementing the institutional and management reforms needed to meet the new challenges will not be a simple task. However, the process can be made less painful by the careful study of the physical and social environment of the Yellow River basin itself, the pressures now facing basin managers, and the range of technical solutions that basin managers might apply in addressing current issues. Specifically, we have identified 6 areas in which researchers might focus their efforts, namely understanding the implications of intersectoral water transfer, assessing the potential for water savings in irrigation, studying options for pollution control and treatment, making clear the role of environmental flows and ensuring their provision, clarifying data issues, and assessing options and needs for institutional changes. A variety of methods can be used to address these issues. However, a promising avenue is to combine the broad water management knowledge base which already exists within the Yellow River Basin and elsewhere in China, with experience from elsewhere in the world. Such a combined effort not only offers new possibilities for developing meaningful solutions to water problems in the Yellow River basin, it also increases the potential of the Yellow River experience to contribute to the global knowledge.

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