International Institute for Applied Systems Analysis
Schlossplatz 1 • A-2361 Laxenburg • Austria
Telephone: (+43 2236) 807 342 • Fax: (+43 2236) 71313
E-mail: publications@iiasa.ac.at • Internet: www.iiasa.ac.at

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Environmental challenges and impacts of land use conversion in the Yellow River basin

Anna Brismar (annbr@Tema.Liu.se)

Approved by

Günther Fischer
Leader, Land Use Change Project

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Contents

Abstract

While the Chinese population continues to grow, Chinese policymakers are faced with a seemingly insurmountable task of satisfying escalating demands for fresh water, electricity, agricultural products, etc. Not only is the irrigated land area presently shrinking, as previously cultivated land is converted to various non-agricultural purposes, but additionally, advancing pollution from expanding mining industries, urban centers, and upstream input-intensive farmlands, are causing a reduction in the usability of the Yellow River water. Unfavorable climatic, topographic, and geomorphic preconditions further constrain food production potentials. The exceptionally high silt load and sedimentation rate in the Yellow River constitute another major challenge for engineers. Dam construction and maintenance work are aggravated by rapid sedimentation in reservoirs, undermining potentials for water supply storage and electricity production. Likewise, flood prevention measures in the Lower Reaches are counteracted by sediment build-up in the canal. In the entire basin, freshwater constitutes an advancing challenge, with regard to its usability, storage, allocation, and absolute seasonal availability.

Based on a review of potential river ecological impacts of irrigation and multi-purpose dams, this report concludes that advancing intensification of agricultural practices and continuous construction of large dams may significantly alter riverine ecosystems with adverse implications for human livelihoods. The author argues that any larger intervention in the riverine landscape should by necessity be preceded by a comprehensive assessment of the river's various functions and values for its different user groups. Such an assessment should consider not only the physical, but also the water quality and biological aspects and their interrelations. Just as many scientists tend to focus on only a few research parameters, managerial strategies often tend to target only one or a few objectives at a time. Balancing the different interests at hand, based on a comprehensive but understandable environmental impact assessment, is identified as the key to successful integrated river basin management.

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About the Author

The author is a Ph.D. student at the Department of Water and Environmental Studies at the University of Linkoping, Sweden. In 1996, she graduated from the University of Stockholm with a “Master of Science with a major in biology” (Master Thesis in natural resources management). She has been working for the Stockholm Environment Institute (SEI) in Stockholm and York (UK). She is the author of “Freshwater and gender: a policy assessment” (1997), a background document for the Comprehensive Assessment of the Freshwater Resources of the World. Presently, she is involved in a multidisciplinary research project (directed by Prof. Lundqvist) that studies various aspects of the Southeastern Anatolia project (GAP) in southeast Turkey.

Glossary[1]

anadromous	= running upward; ascending rivers from the sea for breeding
benthic	= living on the bottom of the water body
lentic	= living in still water, e.g. lakes, ponds, swamps
lotic	= living in actively moving water
macroinvertebrates	= larger spineless animals

[1] Webster’s New Collegiate Dictionary, G. & C. Merriam Company, USA, 1973.

Environmental challenges and impacts of land use conversion in the Yellow River basin

Anna Brismar

1. Introduction

1.1 China faces growing food demands and decreasing land potentials

Of China's total area of 9.6 million km^2, about 14 percent are cultivated of which approximately 52 percent are irrigated (Fischer *et al*., 1998; China Statistical Yearbook, 1997). Hereby, China has more irrigated land than any other country (Elisabeth Economy, 1997). Yet, the per capita area of cultivated land is only 0.105 ha.

In order to provide food for the growing Chinese population, land reclamation for agricultural purposes increased in the last decades. In the less densely populated areas, large areas of non-agricultural land have been converted into rainfed and irrigated farmland, mainly in marginal zones between cropping and non-cropping areas (Sun and Li, 1997). During the 1950's, the area of cultivated land increased rapidly due to large-scale reclamation and economic development (Fischer *et al*., 1998). Due also partly to extended irrigation practices, between 1960 and 1984, the area of cultivated land expanded from the range of 104 to 111 million ha to around 135 to 142 million ha (Zheng, 1991). Based on recent data from China's State Land Administration, Fischer *et al.* (1998) have estimated that the total cultivated land in China at the end of 1995 amounted to 131 million ha.

In the last decades, China has experienced loss of productive farmland with favorable irrigation conditions. From 1988 to1995, 1.72 million ha was taken out of field crop cultivation[2], most of which was converted and lost in the northwestern provinces, Inner Mongolia and Shaanxi. Greatest losses occurred in 1995, when 800 000 ha was withdrawn from agriculture, mainly for the construction of state-owned units[3], according to the State Land Administration bureau. The Plateau region (including Tibet and Qinghai) is the only region where a net increase of cultivated land of 15,000 ha took

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[2] 1.72 million ha does not include abandonment of cultivated land.
[3] These include railways, highways, mining factory, water conservancy, and the expansion of cities and towns (Fischer *et al*., 1998).

place. Overall, the largest conversion of farmland during this eight-year period resulted from conversion to horticulture, construction, forestry and improved grassland, and natural disasters[4] (Fischer *et al*., 1998)

The scarcity of cultivated land is of great concern for China, not only because food self-sufficiency is high on the agenda, but also because of the population momentum and the aim for socioeconomic development. Despite strict measures from the government to slow down fertility rates, China's present population of about 1.23 billion continues to grow (China Statistical Yearbook, 1997). By year 2050 it will reach about 1.5 to 1.6 billion, according to most Chinese demographers and to the medium variant of UN projections (United Nations, 1997). This massive population increase will mainly strike eastern China, including the Yellow River basin's lower reach, an area which is already extremely densely populated and at the same time intensively cultivated (Heilig, 1996). As a result, in the future the per capita availability of arable land, particularly in these parts, will shrink further.

In the past, step-wise increases in productivity and total output enabled China to support its steadily growing population. However, the impressive growth in agricultural output was paid for in terms of soil erosion, water quality degradation, and water scarcity (Fischer *et al.*, 1996). The present decline in the area of arable land can only be counteracted by intensified use of agricultural inputs and technology (Sun and Li, 1997). This increases the risk for land degradation and water pollution. In the last four decades, the Chinese government, used to distort agricultural input and product markets to the point that unnecessary and costly environmental degradation undermines future food production. In fact, increased use of chemicals has lead to such high environmental pressure that it may wipe out expected increases in outputs, especially in the long term (Huang and Rozelle, 1995 in Spitzer, 1997).

In the light of decreasing land productivity and cultivated land area, China faces the immense challenge of feeding about 20 percent of the world's population using only 9 percent of the world's cultivated area (Spitzer, 1997). It is thus of great concern for the Chinese government and policy makers to identify those types of land use and management practices that make maximum use of the natural resources while causing the least harm to the natural environment, in the shorter and longer term (Fischer *et al.*, 1996). Such land use policies must be formulated in consideration to the nation's prevailing environmental challenges, not least those characterizing the Yellow River basin. In the basin, the main challenges are the ongoing expansion of water polluting and water demanding activities, which reduce the quality and flow of the Yellow River. Additionally, exceptionally high soil erosion rates on the Loess Plateau cause high silt loads and flood risks in the Middle and Lower Reaches.

This paper begins with an outline of the geographical conditions in the Yellow River basin, particularly in the Middle Reach and the Loess Plateau. It proceeds by a condensed presentation of the environmental problems in the region, i.e. the problems

[4] Natural disasters here refer to flooding, landslides, mud and sand drifts, sandy winds, etc. In the eight-year period these always exceeded 10 percent of the annual decrease in cultivated land, and amounted to more than one million ha for the period (Fischer *et al*., 1998).

of soil erosion and sedimentation, water scarcity, and water pollution. Thereafter, it discusses the potential ecological impacts of conversion from rainfed to irrigated agriculture, using multipurpose dams.

1. 2 Aim and scope of the study

The present study was carried out for the LUC project during three summer months in 1998, within the Young Scientists Summer Program 1998 at IIASA. The primary purpose of the study was to contribute to the LUC project's present work on land use conversion in the Yellow River basin. At the outset, the author recognized a need for an analysis of the *environmental* challenges and potential *ecological* impacts of ongoing and planned land conversions in the basin. Land conversions here refer to the shift from rainfed to irrigated agriculture, through the construction and use of multipurpose dams and irrigation practices.

Based on a perceived demand for such research, the study was divided into two main parts:

I) to assess the main environmental preconditions and challenges of the Yellow River basin

II) to identify the potential and evidenced environmental effects of conversion from rainfed to irrigated agriculture, specifically
   - i) the downstream river ecological impacts of irrigated agriculture
   - ii) the downstream river ecological impacts of multipurpose dams

The assessment of the main environmental preconditions and challenges for river basin management in the Yellow River basin (Part I) is based on a review of a number of scientific articles and books dealing with different aspects of the concerned topic. The results of the review is presented in Chapter 2 and in the system diagram of Appendix D. The literature review and the system diagram form the basis for the second part of the study. The aim of the second part (Part II) was to identify potential and evidenced ecological impacts of multipurpose dams and irrigation practices in the Yellow River basin, in the light of assessed basin characteristics and managerial challenges.

The Yellow River basin is normally divided into three reaches: the upper, middle and lower reaches. The present study focuses on the Middle and Lower Reaches of the Yellow River basin. This region was chosen because the main environmental challenges in the basin originate in the Middle Reaches and are hence transmitted downstream to the Lower Reaches. Additionally, most of the LUC data of use for my study concerns the Middle and Lower Reaches.

Despite the fact that much research has been done and numerous reports have been written on issues related to the environmental impacts of land use, not many attempts have been made to *synthesize* and *integrate* the different results in a systems analytical manner. This study is a first attempt by the author to create an integrated, systems analytical picture of the various key issues related to land use conversion in the Yellow River basin, both in view of prevailing environmental challenges and of potential ecological impacts.

2. Environmental preconditions and challenges in the Yellow River Basin

2. 1 The geography of the Yellow River basin

For a distance of 5,464 kilometers, the Yellow River (*Huanghe*) flows through the Chinese landscape, draining an area of 752,443 km^2 (China Statistical Yearbook, 1997). The river originates in the Yagmadagze Mountains. Here, at an altitude of approximately 5000 meters, precipitation gives rise to streams that join into a river – the Yellow River - at the foot of the Bayankala Mountains. From here the Yellow River flows eastward through eight provinces (and autonomous regions), Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, and Shandong, before it empties into the Bohai Sea from a man-made channel. (See map of China, Appendix A.)

As the second longest river in China, the Yellow River carries an annual flow of 66.1 billion cubic meters of water. This can be compared to the Yangtze River, which is 1.15 times longer but has a 14 times greater flow (China Statistical Yearbook, 1997). Due to the Bayankala Mountain ranges, which rest on the Tibetan Plateau (*Qing Zang Gaoyan*) in a northwest – southeast direction, the basin is sheltered from the moist air sweeping in during the monsoon season from the Indian Ocean and the South China Sea. As a result, the Yellow River basin is rather dry.

2.1.1 The three reaches of the Yellow River basin

The river basin is divided into three reaches, the Upper, Middle and the Lower Reach (see Figure 2.1). The *Upper Reach* is situated on the Tibetan Plateau at an altitude of more than 3,000 m above sea level (Shen *et al.*, 1989). It covers an area extending from the river source in the Yagradagze Mountains to the city Hekouzhen in Inner Mongolia, a length of 3,472 kilometers. The *Middle Reach* is mainly situated on the Loess Plateau at an altitude of 1,000 to 2,000 meters above sea level (Shen *et al.*, 1989). It stretches from Hekouzhen in Inner Mongolia, passing between the shared border of Shaanxi and Shanxi provinces to the city Zhengshou in Henan in the south, covering a distance of 1,206 kilometers. Its western tributary originates near Zhang Xian in Gansu. The *Lower Reach* is situated on the alluvial plains in Henan and Shandong provinces, where the river stretches over 786 kilometers from the town Zhengshou to the river mouth at the Bohai Sea. Here the Yellow River is no longer a river but a man-made channel in a dike system lined by levees for protection against flooding. Supported by the dike system, the riverbed rises 3 to 10 meters above the surrounding urban and agricultural areas (Ludwig *et al.*, 1996).

In profile, the three reaches can be described as three down-sloping staircases: the Tibetan Plateau, the Loess Plateau, and the alluvial flat land. The staircase descends from an altitude of approximately 5000 meters above sea level (asl) at the source to 1,000 meters asl at Hekouzhen and 400 meters asl at Zhengzhou. Within the reaches, the topography varies markedly. For example, the Upper Reach is composed of mountainous terrain, rangeland, farmland and grassland, including gorges, loess terrain, irrigation zones (e.g. in Ningxia), deserts, the Yinshan mountain range, and the inner

Mongolian Plain. Only 9 percent of the area are cultivable, but there are several well-irrigated sites as well as a number of hydropower stations along the gorge sections. The Middle Reach has a diverse landscape resting on thick layers of deposited unmodified aeolian loess (The Middle Reach will be further described in Section 2.2.1). The Lower Reach of the Yellow River is relatively more homogenous and made up of the alluvial floodplain of deposited sediment.

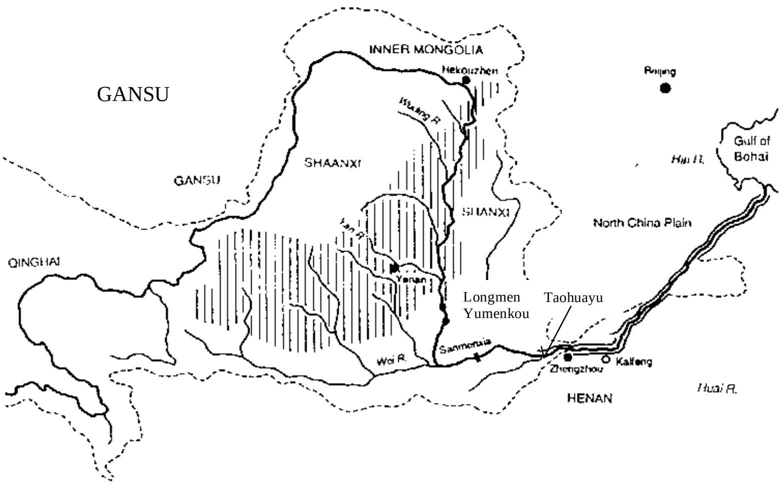


Figure 2.1 A general map of the Yellow River basin, the Loess Plateau, and some mentioned cities (shaded area). *Source*: Leung, 1996; Douglas, 1989.

2.1.2 Climatic conditions in the Yellow River Basin

Climatically, the river basin is characterized by a continental temperate climate, with two distinct seasons, a warm wet summer and a cold dry winter. Typically, drier, colder, continental winds enter the basin from the northwest, and warmer, wetter monsoonal winds sweep in from the southeast. Seasonal changes are significantly affected by the wind system. In the winter, the northerly winds move in with colder and drier air contributing only little rainfall, whereas the southerly winds in the summer bring a wetter and warmer climate with most of the annual rain. The continental climate conveys a wide range of temperatures and rainfall variations over the year and between years. Because of the Chinese wind systems, the winter temperature is much lower and the summer temperatures much higher than in other countries of the same latitude (Yang Dan, 1989).

2.1.3 Population density in the Yellow River basin

The Yellow River basin supports a population of 120 million people[5]. However, the population is not evenly distributed in the basin. As is shown in Table 2.1 below, the highest population numbers are found in the Henan and Shandong provinces; these are

[5] Brown and Halweil (1998) estimate 105 million people.

also the most densely populated in the basin. However, Qinghai province has the highest population growth rate in the basin and the second highest in China (China's Statistical Yearbook, 1997).

Table 2.1 Land area, population and population density in the basin provinces, 1996

Province	Total Area (in km^2)	Total Population 1996 (in million)	Population Density (People/km^2)	Natural Growth rate 1996 per thousand (%)
Qinghai	721,500	4.88	6	14.69
Ningxia	60,000	5.21	82	11.79
Gansu	454,000	24.67	51	9.66
Inner Mongolia	1,183,000	23.07	19	
Shaanxi	205,600	35.43	164	8.48
Shanxi	156,300	31.09	189	10.34
Henan	167,000	89.10	534	7.84
Shandong	153,300	87.38	562	3.84

Source: People's Republic of China, State Statistical Office, 1997

2.2 The Middle Reach and the Loess Plateau

2.2.1 The Middle Reach[6]

The Middle Reach encompasses an area of about 345 000 km^2 (Bai, 1989) and a population of about 35 million people (Douglas, 1989). The most important topographic feature of the Middle Reach is the Loess Plateau, which it partly covers (see Figure 2.1). About two-thirds down its length, the Middle Reach flows between a long stretch of narrow gorges extending from Hekouzhen in Inner Mongolia in the north to Yumenkou in the south. During this distance, the river drops through a set of cascades, witnessing a landscape of heavily eroded hills and gullies. At Yumenkou, the river emerges onto an open plain with loess tablelands, hills and rocky mountains, a semi-arid area practically devoid of vegetation cover. The last part of the journey goes between Tongguan and Tachuaya, a subhumid area to 87 percent covered by mountains and hills, and where the population density is higher than in the two previous segments (Douglas, 1989).

The Middle Reach is situated in a temperate region, characterized by two distinct seasons: a wet and humid summer with high precipitation and evaporation between June and October, and a dry cold season with low evaporation and precipitation from January to April. The rainy season contributes to about 50-80 percent of the annual precipitation (LUCa, 1998), partly due to intensive rainstorms. Annually, rainfall measures only around 400 mm, and the annual potential evaporation rate is three to four times as high.

[6] For an illustration of land use distribution within the Yellow River basin's Middle Reaches, see Appendix B: Land use in the Middle Reaches of the Yellow River basin. Source: Land Use Map, LUC project, IIASA.

However, in a wet year rainfall can be as high as 700 mm, while in a dry year only 50 mm (Shen *et al.*, 1989).

Due to significant temporal and spatial differences in precipitation, the amount of runoff varies markedly from month to month, year to year and between different localities. Figures 2.2-2.3 illustrate estimated monthly river flow at two stations in the Middle Reach. The distribution of vegetation and land use within the basin is depicted in the map of Appendix B. As shown by the map, the northwestern parts are dominated by desert areas and steppe land. The central part features hilly and mountainous grassland, non-irrigated fields, a few patches of irrigated land, tributaries of the Yellow Rivers, and some timber forest. To the south, irrigated and non-irrigated agricultural fields border the riversides along with some sparse wood, forest areas, and timber forest (LUCb, 1998).

The southeasterly parts of the reach comprise terrestrial plant communities of relatively high diversity and complexity. However many centuries of settlement and cultivation have diminished the diversity and abundance of both natural vegetation and wild animals in the area. Riverine aquatic habitats are also generally poor and aquatic communities are marginal because of the river's very high silt content. Habitat of significant fishery is mainly located in the tributaries. Fish do not form a significant part of the local diet, and in the lower basin, fish productivity, including aquaculture, represents only 0.2 percent of agricultural income (Ludwig *et al.*, 1996).

Fig. 2.2 Annual and monthly variations in the Yellow River flow at Gaojiachuan

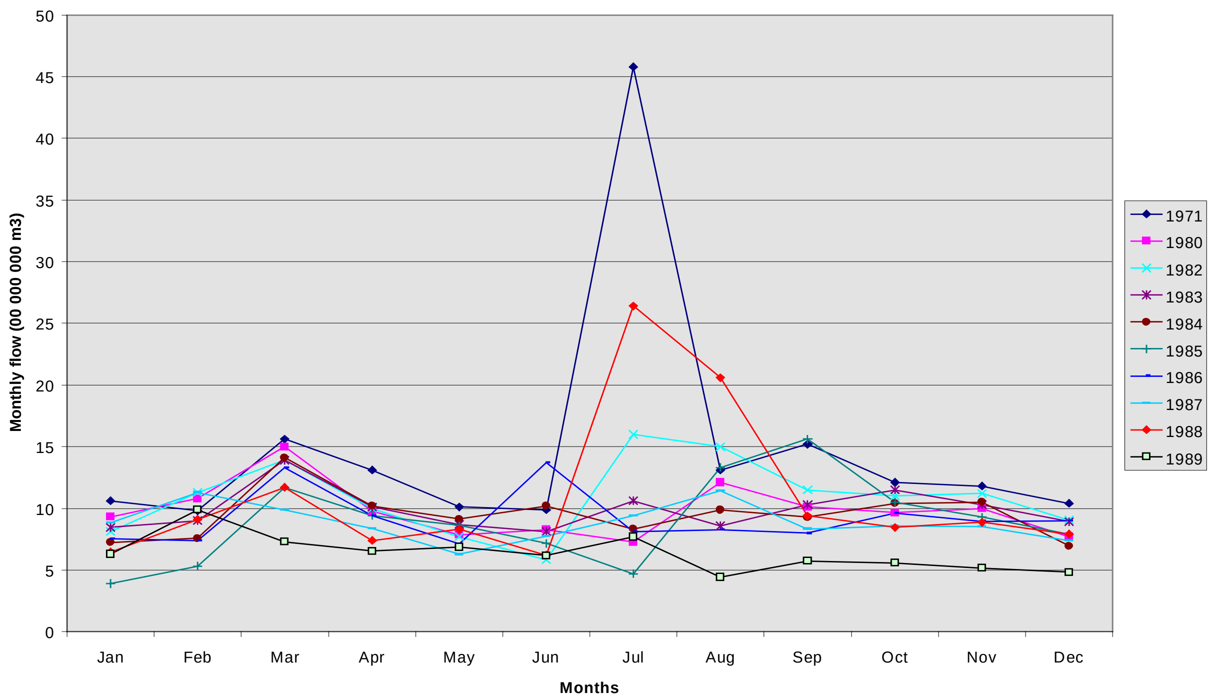
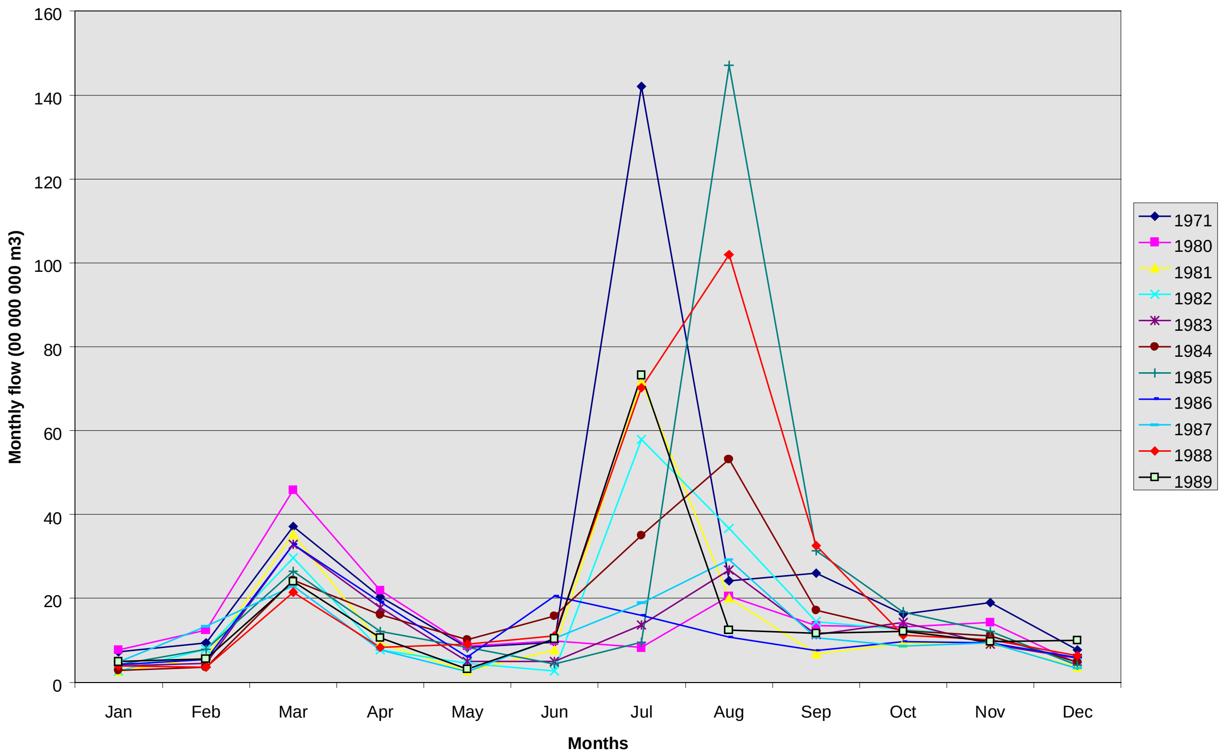


Fig. 2.3 Monthly and annual variations in the Yellow River flow at Wenjiachuan



The Middle Reach can be divided into three parts: (1) from Hekouzhen to Yumenkou, (2) from Yumenkou to Tongguan and (3) from Tongguan to Tachuaya (See Table 2.1). As the table shows, there is a north to south gradient of an increasingly humid climate with greater densities of vegetation, cultivated land, and human population.

Table 2.1 Three geographically different divisions of the Middle Reach

Divi-sions	**River length (km)**	**Drainage area (km^2)**	**Climate**	**Vegetation**	**% of culti-vated land**	**Popu-lation density per km^2**	**Mean annual runoff $t/km^2/y$**
1	725.1	111,591	Semi-arid to sub-humid, precipitation 400-600 mm	Degraded and largely depleted steppe and forest steppe	15.2	54.0	39.0
2	125.8	184,581	Semi-arid in NW but mainly sub-humid, 400-900 mm	Practically devoid of vegetation cover	29.9	129.0	51.0
3	374.0	17,909	Sub-humid 600-900 mm	Moderately good vegetation cover	23.9	248.0	No data

Notes: 1 = Hekouzhen to Yumenkou; 2 = Yumenkou to Tongguan; 3 =Tongguan to Tachuaya.

Source: Douglas (1989)

2.2.2 The Loess Plateau

The Loess Plateau covers parts of the Middle Reach, i.e., parts of Inner Mongolia, Gansu, Shaanxi, and Shanxi provinces. It has an area of 319,000 km^2 (Chen, 1989) or about three-fifths of the Yellow River watershed (Robinson, 1981) (See Fig. 2.1). The plateau rests on a thick layer of wind-blown (aeolian) deposit soils, 80 to 100 meters deep. The soils are highly calcareous and contain about 6 percent sand, 60 percent silt, and 34 percent clay and little organic matter (Robinson, 1981). The aeolian deposits were formed during the last ice age when precipitation was nearly absent and the land was flat. Although the loess can be amazingly cohesive when dry, it is very easily eroded by water. Especially where surface crusts are present and/or the soil is compacted, rainwater cannot infiltrate the soil and so creates runoff of high erosive potential. Therefore, as climatic conditions changed with time, precipitation gradually transformed the unique flat (originally partly forested) tableland on the plateau (*tai yuan*), through water erosion, into ridges (*liang*), mounds (*mao*) and gullies. Mature gullies can be between 200 to 300 meters deep (Leung, 1996). Three thousand years ago about 50 percent of the Loess Plateau were covered by forests, but after a long period of deforestation, in 1949, forests covered only 3 percent of the plateau. Forests are mainly found in the Ziwuling and Huanglong mountainous areas in the basins of the Beiluo River and Jing River (Liu and Wu, 1985).

Today, because most parts of the Loess Plateau are badly dissected by gullies due to wind and water erosion, the terrain is difficult to farm, especially in the absence of irrigation. Annual rainfall varies between 300-700 mm, of which most falls as high-intensity rain from July through September (Chen, 1989). Some areas of tableland - which can be ideal for cultivation - still prevail in parts of the western Wei River valley along the border between Shaanxi and Gansu.

2.3 The challenge of erosion and sedimentation control

2.3.1 Present sediment loads and their sources

While the inner parts of the Loess Plateau are slowly transformed into desert-like areas due to spreading sand dunes, the wetter areas are subjected to heavy rainfalls and water erosion. Intensive water erosion over an area of 430,000 km^2 (Leung, 1996) causes high volumes of silt to be discharged annually into the Yellow River and its tributaries. In average, the river carries 37.6 kg/m^3 suspended sediment per year. The maximum sediment concentration recorded for the Lower Reaches is 666 kg/ m^3, but values of 1700 kg/ m^3 have been measured in individual tributaries (Walling, 1981). The sediment load in the river equals an annual soil loss of about 3.0 kg/m^2 over the river’s entire watershed, resulting in an annual sediment yield of 2100 ton/km^2 (Douglas, 1989). On average, 1.6 billion tons of sediment enters the river channel at Zhengzhou annually, of which about 1.2 billion tons is carried out to sea (Leung, 1996).

As the most silt-laden river in the world (see Table 2.3), the Yellow River got its name from the muddiness of its water, which bears an ochre-yellow color (Leung, 1996). With silt contributing to 50 percent of the river’s weight, the flow is a liquid mud (Robinson, 1981). 90.6 percent of the sediment load in the river comes from the Loess Plateau region in the Middle Reach, and the remaining 9.4 percent is yielded from the Upper Reach (comprising 51 percent of the basin) (Douglas, 1989). Most of the sediment load comes from the northern parts of the Middle Reach, the distance between Hekouzhen and Longmen contributing 55 percent of the total load.

Table 2.3 Sediment yield of selected rives of the world.

River	Country	Total drainage area (1,000 km^2)	Average annual suspended load		Average discharge at mouth (m^3/sec)
			1,000 mt	t/km^2	
Yellow	China	680	1,890,000	2,800	1,500
Yangtze	China	1,950	499,000	256	21,900
Amazon	Brasil	5,800	363,000	63	182,000
Nile	Egypt	2,990	111,000	37	2,840

Source: Robinson, 1981

2.3.2 How does the sediment load vary in space?

The erosion rate varies considerably in space over the loess highlands and plateau, and likewise the sediment yields at different localities. Sediment loads at various stations along the Yellow River is shown in Table 2.4.

The Fenhe, Loehe and Weihe tributaries contribute considerable quantities of sediment to the Yellow River. However, the Wuding tributary in northern Shaanxi suffers from the highest sediment load on the Loess Plateau. Within a drainage area of only 36,000 km^2, 373 million tons of sediment is eroded and drained annually into the Yellow River, thereby producing 24.4 percent of the total annual load from less than 5 percent of the total basin area. (Douglas, 1989). Another heavily eroded area on the Loess plateau is a region by the northern bend of the Yellow River between Shanxi and Inner Mongolia. Here, the annual erosion rate reaches 60,000 tons/km^2 of land. Kuye tributary has had a maximum silt concentration as high as 1700 kg/m^3. Practically all the sediment eroded from slopes is transported out of the watershed and into the main river (Walling, 1981). At peak flows, the Yellow River can carry all the sediment it is capable of transporting (Douglas, 1989).

Table 2.4 Suspended sediment load of major stations along the Yellow River

Station	Drainage area		Suspended sediment load		Period of data
	km^2	% of total	10^6 ton/year	% of total	
Lanzhou	222,551	29.6	110.0	5.3	1947-83
Hekouzhen	367,898	48.1	146.4	9.4	1952-83
Longmen/Yumenkou	497,190	66.1	1030.8	66.1	1934-83
Shaanxian	667,941	88.8	1528.8	98.1	1919-85
Xiaolangdi	694,155	92.3	1558.8	100.0	1956-59, 1964-83
Huayuankou	730,036	97.1	1312.5	-15.8	1951-59, 1964-83
Lijin	751,871	100.0	978.8	-37.2	1956-59, 1964-83

Source: After Chen and Luk (1988) in Douglas (1989)

2.3.3 How does the sediment load vary in time?

The sediment load in the Yellow River basin is a result of heavy rainfall and eroding runoff. The intensity and length of the rainfall events vary annually, seasonally, and from one flood event to another, and therefore also the erosion rate and subsequent sediment load. (Ren, 1994). Douglas (1989) divides the record of suspended sediment load into three periods: 1919-53, 1954-70 and 1971-83, for which the middle period exhibits high and the last period decreasing sediment loads. However, other sources point at a gradual decline since the 1930's (Yuqian *et al.*, 1994).

Regarding seasonal variations, highest silt loads are recorded in the flood season, between July and September. 60 percent of the annual runoff and 85 percent of the annual sediment load have been accumulated during these months in the basin. As Figure 2.2 and 2.3 indicate, July and August typically have the highest monthly flow. Often, 75 to 95 percent of the annual sediment load in the river is discharged during these months. For example, in Yeyu river (at Heisunglin Reservoir), Shuimogou river (at Hunglingchin Reservoir), Hu river (at Chentzeliang Reservoir), and Wuding River, sediment yields for July and August together accounted for 93.9, 90.5, 81.0 and 79.4 percent of the annual yields, respectively. The explanation lies in the intensity of the rainfall. Individual extreme storms can account for a large part of the annual sediment load. For example, during one flood event from the 9-10 August, 1969, the Yeyu River contributed to 70 percent of the total sediment transport in that year (Douglas, 1989).

2.3.4 How is the sediment load enhanced?[7]

The sediment load in the river is a result of land use, soil type, landform, climate, vegetation cover, population density, and annual surface run off (Wolman, 1989). At present, population density on the Loess Plateau is about 50 to 200 persons per km^2 in most parts (Chen, 1989). With increased density, the impact of land use becomes a more important factor. Intensification of land use over the last hundred years has damaged the protective vegetative cover on the Loess plateau and increased its susceptibility to erosion. Vegetation cover today is less than 20 percent (Chen, 1989). In the period 1494-1855, the average sediment load was as high as 1330 million tons, with 78 million tons attributed to human induced erosion. During the period 1919-1949, the mean annual sediment load increased to 1680 million tons, of which 244 million tons are attributed to human induced erosion. The increase was caused by a substantial reduction in forest cover by 58 percent of the average in the former period, combined with improper land use practices, disorderly reclamation, and denudation (Mou, 1991).

In a study on smaller catchment areas in the gullied hilly loess area (Jiang *et al.*, 1981, in Douglas, 1989), farmlands caused splash, rill, and shallow gully erosion over 57 to 67 percent of the catchment area, and thereby contributed to 44 to 59 percent of the total erosion. Grazing and wasteland caused gully and sheet erosion over 25 to 87 percent of the area, contributing to 9 to 23 percent of the total erosion. On 13 to 21 per cent of the area, earth fall and landslide over steep slopes contributed to 20 to 25 percent of the

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[7] For a discussion on how sediment loads are controlled and/or reduced, see for example Liu, 1989; Mou, 1991; Leung, 1996; Walling, 1981; Wolman, 1989;

erosion. The remaining erosion was caused on roads, farmyards, and gully floors (Douglas, 1989). Furthermore, mining can cause large quantities of sediment to be discharged into streams and rivers, either through direct dumping or by erosion from waste piles, such as in the Shaanxi and Shanxi Provinces, and Inner Mongolia (Fang and Shi Mingli, 1992).

The combination of land use (that removes protective vegetation), erodible soils, and heavy rainstorms is the main cause of the high erosion rate on the Loess Plateau. As indicated above, the latter is a crucial factor. In fact, most of the sediment load is produced by a few major storms during the flood season, when the daily precipitation reaches 100-200 mm. In some areas, one storm event can contribute to more than 50 percent of the total annual sediment load. Very heavy storms can increase the annual sediment yield of small watersheds by a factor of two or more (Mou, 1991). In other words, the annual sediment load is not simply a factor of annual precipitation but depends on rainfall intensity and the geographical distribution of rainfall (Ren, 1994). Whereas water erosion takes place in the rainy season extending from June to September (and causing most of the soil loss), wind erosion (accompanied by sand storms) takes place in the dry season, extending from January to April (Fang and Shi Mingli, 1992).

The slope degree is also a significant determinant of soil erosion. It has been proposed that 15, 26 and 45 degrees are key threshold angles. For slopes greater than 15 degrees, surface runoff causes soil erosion; at 26 degrees, gravitational processes become more important; and at or above 45 degrees, erosion is most severe (Douglas, 1989; see also Yinzhen, 1983).

2.3.5 Risk for levee break and flooding

The swelling sediment load in the Yellow River is seen mainly as a problem in terms of the build up of the Lower Reach’s canal and the subsequent risk for levee breaks and devastating flooding of agricultural and settlement areas. Near the beginning of the alluvial delta, the riverbed builds up at a rate of about 5 to 30 centimeters per year (Robinson, 1981). Consequently the channel flow is now generally between 3 and 5 meters and in places 10 meters above the plain outside the dikes. Should the river break at its most dangerous locality, it would affect 150 million people (Scheuerlein and Obernach, 1987). The two provinces that have been most affected by flooding are evidently the Lower Reach’s Henan and Shandong. In 1997, 1,413.3 and 1,107.0 km^2 were covered and 709.3 and 685.0 km^2 hectares affected by floods, in respective province (China’s Statistical Yearbook, 1997).

Over the last 2000 years of recorded history, the dikes have broken 1,500 times (Shen *et al.*, 1989). Deposition of large amounts of sediment has caused numerous shifts in the main channel of the Lower Reach. Approximately 0.4 billion tons of silt are deposited in the channel every year. Silt is also deposited along the coast near the estuary. Horizontally, the delta grows by 0.42 km and adds 23.5 km^2 of land every year to the coast on average (Liu, 1989). The period between BC 602 and AD 1947 experienced at least 26 major shifts in the course of the Yellow River and more than 1,500 floods. Since 1949, the river has successfully been contained within the dike system, but aggradation between the dikes causes concern. The dikes and management strategy of 1989 were designed to cope with a peak flood of 22,000 m^3/s at Huayunkou, but in reality the flow could be as high as 45,000 m^3/s. In the last two hundred years, there have already been several flows exceeding 22,000 m^3/s, followed by devastating floods (Douglas, 1989).

Since 1971, sediment loads entering the Lower Reach have decreased. Twenty percent of the decrease is attributed to lower precipitation, and 27 percent to soil conservation practices and reservoir constructions. Ensuring an effective vegetation cover and eliminating soil surface cover to encourage infiltration can effectively reduce erosion. The possibility of a further reduction in the sediment load of the Yellow River depends much on how rapidly the control of grazing and deforestation can reestablish plant cover on the Loess Plateau. Additionally, reservoirs are also effective ways to reduce downstream sediment loads, although this diminishes water storage capacities. (This will be discussed more in Chapter 3) (Douglas, 1989). At present, over-withdrawal of water is reducing river flows and silt is deposited further and further up the river basin, in the dry periods as far up as the Middle Reach (personal comm. Sun, 1998).

2.4 Scarce water resources challenge growing demands

2.4.1 Experiences of water shortages

The natural availability of water in the basin is not enough to meet present demands in the surrounding areas (Liu, 1989). With only 2.6 percent of China’s water resources, the basin has to meet the needs of 8 percent of China’s total population (United Nations, 1997). The net precipitation is not only insufficient in absolute terms, but also it is unevenly distributed temporally and spatially within the basin (Bai, 1989), which is a major problem for efficient allocation (Liu and Wang, 1987). Of the annual precipitation (400-600 mm), about 80 percent fall in the rainy period extending from July to August (United Nations, 1997). The total average volume of precipitated water (1956-1979) makes up only 6.0 percent of China’s total (Bai, 1989). Due to the varied precipitation, the Yellow River has seasonal and annual flow fluctuations that are extreme compared to e.g. the Yangtze River (United Nations, 1997). The highest water level and strongest flow occur in the flood season, with observed maximum flow of 22,000 m^3/sec. The lowest observed flow is 250 m^3/sec, in the winter. During non-flood periods, water deficits become more acute. (United Nations, 1997)

Shortages of water are most prominent in the Lower Reach, due to high population densities and water intensive activities such as irrigation, and too high rates of withdrawal in the Upper and Middle Reaches, particularly for irrigation. The rate of water utilization in the Yellow River basin ranks highest among major Chinese rivers. Almost half of the total annual runoff is used in agriculture, industry and domestic activities, of which agriculture has the highest water consumption rate. The river provides irrigation water for about 5.87 million hectares of cultivated land, which consumes 27 billion m^3 of water annually. The Upper and Middle Reaches supply more than 2/3 of total irrigation water, while the Lower Reach accounts for 1/3. (Liu, 1989) Large amounts of water are presently diverted from the Upper Reach to irrigate cultivated land in Ningxia and Inner Mongolia. Further downstream, in Gansu and Ningxia, considerable amounts of water are pumped up several hundred meters from the river to the Loess Plateau for irrigation and water supply. The upper Yellow River water has even been diverted to irrigate land of the southern Tengger Desert, which forms part of northeastern Gansu and Luianjing in Inner Mongolia. (Ren, 1994)

The combination of low amounts of precipitation and high rates of water withdrawal causes the flow of the Yellow River to decline. Irrigation in the Upper and Middle Reaches has considerably reduced the discharge in the Lower Reach. (Liu, 1989). In March, the main channel of the Lower Reach often runs dry and during the summer months it has very low flow volume. In 1972, the water level fell so low that for the first time in China's history it dried up before reaching the Bohai Sea with no sea discharge on 15 days that year. Since 1985, the river has run dry each year, with the dry period becoming progressively longer. In 1996, the Lower Reach's canal was dry for 133 days, and in the drought year of 1997, it failed to reach the sea for 226 days. In some stretches it did not even reach Shandong Province (Leung, 1996).

2.4.2 Future expected water demands and supply shortages

Before 1950, only a very small amount of water was used in the basin. Since then, rapid development has occurred which has put increased pressure on the limited water resources (Bai, 1989) In the future, the demands on the limited freshwater resources in the basin will continue to grow as a result of unavoidable population growth and socioeconomic development. The demand for water is expected to increase in all sectors of society, not least in agriculture.

Present population growth in the basin along with rapid urbanization will boost residential water uses. As more and more Chinese people move into urban areas, the existence of indoor plumbing, showers and flush toilets encourage greater water use. According to China Statistical Yearbook of 1994, total urban water use increased from 21.59 million m^3 per day in 1978 to 123.34 m^3 per day in 1993 (United Nations, 1997). In rural areas, rising income levels enable increasing numbers of rural households to turn to piped systems, in the form of public standpipes or commonly as pipes to the house or courtyard. In the late 1980's, 26.7 percent of the rural population in China were served with water purified at treatment plants and supplied through distribution systems (United Nations, 1997). As the access to water improves for both urban and rural households, the residential water use is expected to rise from 31 billion tons in 1995 to 134 billion tons in 2030 in China (Brown and Halweil, 1998). In the Yellow River basin, the rural population is expected to reach 77.62 million in year 2000 and then decline to 76.00 million in year 2010. As a result, in the basin, rural water demand is expected to grow by 3.2 percent between 1993 and 2000 and 2.5 percent between 2000 and 2010, according to the Nanjing Institute of Hydrology and Water Resources. In the basin's urban areas, water demand is expected to grow from 1.83 billion m^3 in 1993 to 3.39 billion m^3 in 2010, as the population grows from 22.03 to 41.77 million. Although the expansion of municipal water infrastructure has so far not kept an even pace with the increasing overall urban demand in China, the basin's urban per capita water use will increase from 125 to 160 liter per day between 2000 and 2010. (United Nations, 1997)

Meanwhile, the industrial sector has developed rapidly over the last decades in the basin which has implied increased industrial water use (Bai, 1989). Between 1980 and 1993 the industrial water use increased from 2.79 to 4.86 billion m^3 in the basin (United Nations, 1997). China's planned economic shift from east to west implies that the Yellow River basin would become more important in the future as a source of water for growing industries (Bai, 1989). Water use for irrigation decreased slightly from 30.60 to 29.88 billion m^3 from 1980 to 1993, but is expected to increase to 35.32 and 38.59 billion m^3 in 2000 and 2010, respectively, in the basin. As in the rest of China, surface water constitutes the major source of irrigation water (groundwater accounts for only about 15.8 percent of the irrigation water in China) (United Nations, 1997). Competition over the limited water resources in the basin is thus likely to intensify in the next decades. Despite this, the total water consumption by agriculture at the end of this century may increase by 20 percent in the basin (Bai, 1989).

In order to supply more water for irrigation, industry and municipal uses, the construction of dams and reservoirs is expected to continue in China, although at a slower rate (United Nations, 1997). The rate of hydropower development along the Yellow River is higher than that of other rivers in China (Liu, 1989). As more dams are set up in the basin, water use and storage losses will increase, thus reducing the flow downstream. This is the case particularly in the warm flood season (July to September) when dams are filled to their rims for maximum electricity generation and the atmospheric evaporative demand is high. However, because of the high rate of reservoir siltation in the Middle Reach, storage capacities rapidly decline shortly after dam construction. Reservoir siltation reduces the storage capacity of the reservoir and thus the amount of withdrawable water. For example, between 1949 and 1975, the reservoirs in the provinces Shaanxi, Shanxi, Gansu and Inner Mongolia lost 1.15 percent of their total capacity of 3 billion m^3 every year due to dam siltation (Wang, 1998).

By the year 2000, the regional discrepancy between supply and demand will result in a 2.0 billion m^3 water shortage. The main areas to face water deficiencies are the Fehne and Weihe basins between Longmen and Sanmenxia, centers of economic development for Shanxi and Shaanxi provinces. (Bai, 1989)

Still, hundreds of projects to divert water from the Yellow River's Upper and Middle Reaches are planned for the coming years. The latest large dam/reservoir project is the Xiaolangdi multi-purpose project, located 40 km upstream of the city of Luoyang, Henan Province (close to the border between the Middle and Lower Reaches). This project consists of the dam, flood release, silt discharge, water diversion, and electricity generating structures. It is unique in the sense that it is designed to manage the high-level silt problem while at the same time supply electricity at a long-term annual average of 5.4 billion kWh, and provide water for irrigation of an area of over 2.2 million hectares in Henan and Shandong. It is this latter water use that will contribute most to changing the water flow, particularly initial monthly flow, compared to the diversions for urban and industrial uses (Ludwig *et al.*, 1996). Another project, to be finalized in 2003, will divert 146 million m^3 per year through a canal to Hohhot, the capital of Inner Mongolia (Brown and Halweil, 1998). These projects will have a substantial impact on the water flow of the Yellow River. As ground water tables and rivers are gradually being depleted, the ability to successfully meet the demands of water for increasing population numbers and water using sectors will become increasingly difficult in the future, particularly without jeopardizing the environment.

2.4.3 What can be done to alleviate future water shortages?

A water shortage around 2000 in the basin is thus unavoidable (if planned activities are realized), even if water is imported from outside the basin, e.g. from the Yangtze River. Effective water management in China, including the Yellow River basin, is of great urgency (United Nations, 1997). The shortage of water in the basin challenges Chinese policy makers on local and national levels. In order to combat declining water resources in the basin, present water utilization practices must be made more effective, particularly within the agricultural and industrial sectors. The additional demand expected from expanded population numbers can not be avoided but minimized to some extent by adopted measures for a more effective and rational use and allocation of the basin’s limited water resources.

2.5 Water pollution - an underestimated problem?

Few reports have been found that addresses the problem of water pollution in the Yellow River basin. Nevertheless, water pollution is likely to be of growing concern for the basin, as the basin becomes increasingly urbanized, industrialized, mined, irrigated and chemically fertilized, etc. Waste disposal, untreated water discharge, air pollution, and other effluents that are deposited in the landscape already impose potential threats to the health of humans, soils, rivers and various biota. Chinese experts have estimated China’s economic losses due to various kinds of pollution (see e.g., Xia, 1998). People can be affected either directly by water pollution by drinking polluted water, or indirectly by eating aquatic products or irrigated crops that have assimilated water pollutants. Xia (1998) estimates the economic losses in China resulting from the impact of water pollution on human health to approximately 20 billion yuan.

Excessive levels of chromium (in rice and cabbage), led (in rice) and arsenic (in water and food crops) have been detected in the Yellow River’s watershed. Toxic discharges from cities and upstream industries, such as mining enterprises, paper mills, tanneries, oil refineries, and chemical plants are responsible for high concentrations of heavy metals and other toxins in the river. Agricultural run-off and surface runoff constitute more diffuse sources of pollutants. Locally and along some parts of its route, the water is unfit for human consumption and even for irrigation, although some Chinese farmers are forced to use it anyway (Brown and Halweil, 1998).

Irrigated agriculture is typically input intensive with regard to agricultural chemicals, such as fertilizer, pesticides and insecticides. The concentrations of agricultural chemicals in the Yellow River (discharged as runoff from treated fields) were not available to the author, although such data most likely exist. What can be concluded for the basin is that Henan and Shandong provinces have the largest percentage of irrigated land of total farmland and also the highest amount of applied chemical fertilizer per hectare of irrigated farmland. According to the China Statistical Yearbook (1997), in

Henan and Shandong provinces the application level was higher than the national average of 292 kg per hectare of cultivated land (See Table 2.6). Agriculture is rapidly converting to chemical fertilizers as their availability increases. The increases in irrigation and chemical fertilizer application have gone hand in hand.

Table 2.6 Use of chemical fertilizers by province, 1996

Province	Consumption of chemical fertilizers (10 000 tons)	Total cultivated area (1 000 ha)	Consumption of chemical fertilizers per ha of Irrig. land (kg/ha)
Qinghai	6.6	630	105
Gansu	57.0	5164	110
Ningxia	28.3	1273	222
Inner Mongolia	61.9	8013	77
Shanxi	81.5	4712	173
Shaanxi	115.5	5337	216
Henan	345.3	8327	415
Shandong	373.3	7971	468
Total, China	3827.9	131113	292

Source: China Statistical Yearbook, 1997; Fischer *et al.*, 1998.

Table 2.7 shows that the use of chemical fertilizers increased markedly between 1993 and 1996, by 21 percent in the whole of China, and by as much as 118 percent in Ningxia province. The reason for the relatively lower increases in the other provinces is that agriculture here already is rather input intensive, particularly in Henan and Shandong provinces (see Table 2.6).

Table 2.7 Growth in application of chemical fertilizers, 1993 - 1996.

Province	Consumption of chemical fertilizers (10 000 tons)				
	1993	1994	1995	1996	% increase, 1993-6
Qinghai	6.1	6.1	6.5	6.6	8.2
Gansu	43.5	47.8	50.9	57.0	31.0
Ningxia	13.0	14.7	16.4	28.3	118
Inner Mongolia	46.0	44.7	53.7	61.9	34.6
Shanxi	67.4	71.4	77.1	81.5	20.9
Shaanxi	93.1	100.9	112.0	115.5	24.1
Henan	288.0	292.5	322.2	345.3	19.9
Shandong	355.0	326.6	362.3	373.3	5.2
Total, China	3151.9	3317.9	3593.7	3827.9	21.5

Source: China Statistical Yearbook, 1994-1997.

Evidently, without any major preventive measurements to reduced field runoff, the increased use of chemical fertilizers is expected to cause increased concentrations of chemicals in watercourses. Unfortunately, no such statistics were found for the present study.

Chapter 2 has described the overall environmental preconditions and challenges for land and water use in the Yellow River basin, particularly in the Middle and Lower Reaches. The next chapter will focus on how the conversion from rainfed to dam-dependent irrigated agriculture may potentially affect downstream river ecosystems, given the known environmental conditions of the Yellow River basin. By assessing potential impacts on the river ecosystem, the study brings into the picture possible effects on downstream ecology.

2.6 Summary

The underlying challenge in the Yellow River basin concerns how to satisfy growing human needs and demands while at the same time safeguard affected ecosystems from destruction, degradation or depletion. The question of how to supply food for a growing Chinese population is thus only one of the issues facing Chinese policy makers. Parallel to the growing food demand, and even as a consequence hereof, are other challenges that bear upon the environmental preconditions in the Yellow River basin. A summary of these is presented below.

Overall, the identified environmental challenges in the Middle and Lower reaches seem fundamentally to be related to the high erodibility of the Loess Plateau and the prevailing climatic conditions. The Loess Plateau is very demanding to cultivate, for topographic, geomorphic, and climatic reasons. Due to severe soil erosion, it is heavily dissected by gullies. Moreover, it has low soil productivity, due to low organic soil content. Additionally, the Plateau is subject to intensive summer rains, and poor rainfall and dry winds in the winter, which entail high susceptibility to water and wind erosion. Small-scale farming practices, such as terracing, are thus more endurable means to cultivate the Plateau. Additionally, dust winds from the North and subsequent soil erosion are spreading sand dunes on the Loess Plateau and slowly transforming it into a desert-like area. This process is very difficult to stop as it extends over such a vast region. However, soil conservation practices (involving control of grazing and deforestation) are being undertaken with varyingly positive results.

In the Lower Reaches, during the rainy summer months, the canal runs high risk of being flooded due to build-up of sediment in the furrow. Continuous maintenance work on the levees is required to keep the levees from bursting. Since 1971, lower precipitation and upstream soil conservation practices and sediment trapping reservoirs have helped to decrease sediment loads.

Whereas the above challenges are relatively “reaches-specific”, water supply needs, energy demands, and water pollution problems are to be found in the entire Yellow River basin. Water supply needs throughout the basin are difficult to satisfy, due to the highly variable net-precipitation, both temporally and spatially. *Water storage* problems prevail because the rains are concentrated in a few months and the flow is silt loaded. *Absolute water scarcity* occurs especially at some periods when the Lower Reaches’ canal runs dry for several weeks or months. How to obtain an *efficient water allocation* is yet another challenge that is likely to be given increased attention in the future, as a result of modernization and growth of urban areas.

Escalating *energy demands* have up till today been satisfied by the construction of new dams with turbines for hydroelectric power generation. In fact, China has one of the world's highest construction rates of large-dams. Dams have been built and more are planned in the Middle Reaches of the Yellow River, often combining power production with irrigation schemes. According to Liu (1989), the rate of dam construction along the Yellow River is higher than that of other rivers in China. As much as 2540 megawatts of hydropower capacity has been installed along the Yellow River, to generate 12 billion kwh each year (Liu, 1989). However, the heavy silt load and the low average flow rate constitute major challenges for engineers. Most suitable places for dams have already been used. At the same time, water and power demands continue to increase with ongoing population growth, urbanization and modernization processes. Already, water utilization is very high, particularly in the Upper and Middle Reaches, with agriculture having the highest water consumption rate of all sectors. *Water pollution* in the basin has been an underreported problem, but increased attention will have to be given to this serious problem, as the adverse effects of urbanization, industrialization, mining, and intensive irrigation practices will be made increasingly visible in the future.

3. Environmental impacts of land use conversion[8]

This chapter addresses the potential impacts on river ecology of conversion from rainfed to irrigated agriculture using a multipurpose dam. For clarity the impacts are distinguished in three general categories: changes in the *physical, water quality, and biological* conditions of downstream aquatic ecosystems, respectively. This chapter deals with a hypothetical case of irrigated agriculture and river impoundment, by addressing typical effects to be expected from multipurpose dams and irrigation. Because no water quality (except silt loads) and biological data was available for the Yellow River basin, the water quality and biological aspects are addressed with support of relevant findings for other basins. In fact, no articles on the ecological situation in the Yellow River basin were to be found.

3. 1 Downstream environmental effects of irrigated agriculture

This chapter is a short assessment of some key aspects of the physical, water quality and biological effects of irrigated agriculture. It is should be read with reference to the diagram in Appendix C, which gives a simplified overview of concerned cause-effect linkages.

3.1.1 Water quality changes due to pollution by agricultural chemicals

Irrigation practices serve to enhance agricultural productivity and are therefore commonly accompanied by intensified use of agricultural chemicals such as fertilizers and pesticides. These substances are not fully degraded on the field, but remain in the soil. Sooner or later they are flushed out by rainwater into streams as polluted surface

[8] Chapter 3 is complemented by Appendix C, which serves to illustrate graphically the cause-effect relationships here within discussed.

run off. Data on concentrations of various chemical compounds upstream and downstream an irrigation field in the basin would here have been useful information.

3.1.2 Increased salinity in return flow

As fields are irrigated, salts gradually accumulate in the soil due to soil water evaporation. In order to wash out excessive salts, irrigation water has to be applied in increasing amounts. As a result, the soil becomes waterlogged. Runoff from the fields contains salts and other minerals in sometimes rather high concentrations. When this water discharges into the river it can pose a threat to downstream riverine ecosystems (Leung, 1996). For practical assessments one would also have to know the sensitivity levels of different animal species to exceptional salt and mineral concentrations.

3.1.3 Changed silt load in downstream river

As discussed in Chapter 2, loess soils in the Middle Reach are sensitive to erosion caused by agriculture and other land uses. This means that if agriculture is not carried out by suitable practices such as terracing, tree planting, or cultivation in warping dams, soil erosion and subsequent river siltation are easily triggered. Excessive irrigation water runs off the fields, carrying organic matter that when discharged into streams and rivers add to the flowing silt load. However, in order to reduce the downstream silt load and deposition, tens of thousands of silt-trap dams have been set up, most after 1970, over the Loess Plateau to trap parts of the silt carried by tributaries of the Yellow River (Gong, 1987). In fact, high silt loads may have both desirable and undesirable consequences. Whereas silt in the river has the potential to increase soil fertility of the land on which it is deposited, it may also cause undesired effects on the biological life in (and off) the river, if it contains harmful substances. According to a study by Zhang et al (1994), ongoing erosion of high-arsenic sediment from the Loess Plateau in the lower parts of the Middle Reaches produces high concentrations of arsenic in the suspended sediments and water of the Lower Reaches. Based on a Chinese official report from 1977, about 16 000 tons of arsenic is transported on sediment in the Yellow River annually. Zhang et al (1994) also found a strong correlation between the concentration of arsenic in water and fish tissue, respectively. Significant residual arsenic concentrations were measured in harvested fish (including carp, crucian carp and catfish), particularly in the Lower Reaches. Extensive irrigation practices in the Ningxia Autonomous Region have proven to exacerbate erosion of arsenic soils and hence to increase the concentration of arsenic in the water, with elevated risks for arsenic accumulation in fish (Zhang et al, 1994). It would here be of interest to find out what arsenic levels in fish tissue could become a threat to human health.

3.1.4 Reduced river flow due to increased water withdrawal and consumption

Irrigation is the largest consumptive water use in most economies, and in particular in arid areas. In the Yellow River basin, irrigated agriculture accounts for 85 percent of the total water use (United Nations, 1997). Withdrawal of irrigation water for agriculture in

Upper and Middle Reaches may considerably reduce the flow in the Lower Reach. (See also Chapter 2.3.).

3. 2 Downstream environmental effects of multipurpose dams

Past impact analyses of various rivers provide evidence that dams alter downstream river ecology to various extents, through changes in prevailing physical, water quality and biological conditions. The downstream ecological effects of river impoundment result from three types of modifications: (1) *blockage* of the migratory path, mainly of migratory fish; (2) downstream *water quality* changes caused by water storage in a reservoir; and (3) changes in the *river flow regime* downstream of the reservoir (Brooker, 1981). Not only is there a transfer of changes from upstream to downstream areas. The change typically starts as an alteration in the physical conditions, which then causes a change in the water quality conditions, and finally a modification of the biological conditions. However, feedback mechanisms need to be considered. There is also a spatial gradient of change; some water quality changes typically originate in the reservoir and are transferred downstream with out-flowing waters, the distance depending on the turbidity and velocity of the water.

This section has been divided into four sub-sections corresponding to different types of modification (1) to (3) above, and a summary. Section 3.2.1 should be read in parallel with the diagram of Appendix C. The initial impacts caused by inundation will not be attended in this report (see instead e.g. Goldsmith *et al.*, 1984).

3.2.1 Changes in river flow regime and its downstream consequences

In the absence of major disturbances, the river ecosystem becomes adapted to the natural fluctuations of the river flow. A species composition evolves that can withstand the natural flow peaks and recessions caused by changes in surface runoff upstream. However, when a dam is installed across the river course, substantial changes in the river flow regime occur, particularly for dams designed for hydroelectric generation or for irrigation purposes, so as to suit the demand for electricity and/or irrigation supply (Brooker, 1981). Generally, the greater the alteration of natural flow, the greater the impact on the ecosystem (Soton, 1998).

Overall, typical expected changes in the river regime are lowered peak flows, heightened low flows, and rapid increases in the flow over short time periods (e.g. 3 to 12 hours) (Brooker, 1981). Some hydroelectric power dams are operated on a peak hour basis, which means that water is released on a daily or even hourly basis. Such extreme fluctuations can be detrimental to certain fish populations. Meanwhile, non-native vegetation species can become positively affected and as a consequence they proliferate and out-compete native species that have evolved and adapted to natural flow cycles and stream dynamics (Flug, 1998).

A study on the effects of river flow regulation by the Volgograd dam in the lower Volga River on the spawning efficiency of sturgeon showed that spawning efficiency is determined both by the total volume of water and by its distribution over time, i.e. the river flow regime. The higher the outflow volume in a flood period, the higher was the spawning efficiency. However, a smoothly fluctuating flow gave a higher spawning efficiency than a flow with sudden abatements. Since the maximum capacity of a hydropower dam is achieved at the expense of abnormally high water levels in winter, fish populations are affected by reduced water levels in spring and in summer. Also, the study showed that when the outflow is low, spawning areas and roe may dry out (Luckyanov *et al.*, 1983).

Altered flow regime may also cause degradation of the downstream riverbed. As the in-flowing water reaches the reservoir, its velocity decreases and a substantial fraction of its sediment load settles on the reservoir floor. Therefore, the silt load of out-flowing water has a lower silt concentration than upstream in-flowing water. If the out-flowing water has sufficient turbidity and a silt load less than its natural silt carrying capacity, degradation of the riverbed and its vegetation ensues. The channel morphology downstream changes so that sediment deposition is possible. The finer fractions of the bed material are transported downstream and the coarser material is deposited nearest to the dam wall. (Brooker, 1981; Flug, 1998). Because the reservoir permanently stores practically all the sediment load of the in-flowing water, it gradually loses more and more of its storage capacity (Brooker, 1981). Meanwhile, downstream areas typically experience fewer and smaller floods due to silt load reduction in the river downstream of the dam (Flug, 1998).

3.2.2 Blockage of the river flow

Perhaps the most obvious impact of a dam is caused by the construction itself. The physical presence of the dam wall hinders the natural movement of migratory fish, whose migratory path would otherwise be to swim passed this site. Essentially, the dam wall exerts a hinder for migratory fish species to swim upstream due to the huge height difference. However, the effects can be reduced to a certain extent by incorporating fish “ladders” for the fish to climb, although there is a limit to how much a fish can climb up heights. If a dam is built in a successive row of several dams, some specialists believe that certain stretches of fast flowing water can be conserved along the length of other river stretches to facilitate the growth of species and oxygenation in the basin. (Soton, 1998). Generally, dams on tributaries cause less impact than dams on the main stream.

3.2.3 Water quality changes

After inundation, the dam starts to develop characteristics very similar to those in a lake. Two of these are thermal and chemical stratification. Stratification in the dam is responsible for the majority of changes in downstream water quality (Brooker, 1981). Thermal stratification implies that the heavier water of 4^{o} C sinks to the bottom of the dam and the lighter water remains on top, creating three density layers of water: epilimnion (upper), thermocline (middle), and hypolimnion (bottom). Each of these layers displays rather particular water quality conditions.

Just like in a lake, dead organic matter falls to the dam floor, i.e. the hypolimnion layer, where it is decomposed by oxygen consuming microorganisms. Because oxygen is only produced in the epilimnion (through photosynthesis) and because there is little mixing in a stratified dam, the oxygen level in the hypolimnion gradually declines. If the oxygen level is sufficiently reduced, anaerobic conditions arise. Under anaerobic conditions, certain chemical reactions are triggered in the water and at the water/sediment interface (within the hypolimnion). These reactions increase the concentrations of iron, manganese and hydrogen sulfide in the hypolimnion layer. If the turbine outlets from the dam are located within the hypolimnion, the out-flowing water will have a much lower oxygen concentration than the upstream water (Ortalano, 1973). The depth from which the water is drawn is therefore crucial for determining the temperature, oxygen level and chemical concentrations of the water below the dam. In other words, if the wind or river turbidity does not mix the water, thermal stratification arises, with ensuing chemical stratification. In temperate areas, thermal stratification is made visible by creating a generally lower downstream water temperature in the summer, and higher temperatures in the winter than for unregulated rivers (Brooker, 1981). This may postpone or even eliminate ice formation for varying distances downstream a dam in the winter. The temperature stratification in the reservoir usually enhances the density and community of bottom-dwelling algae and generally favors cool-water species (Lowe, 1979).

Due to silt deposition in the reservoir, the transparency of the water in and downstream the reservoir increases. This increases light penetration, which in turn alters the rate of photosynthesis, the oxygen level, algal production, and the health of various species in the food chain, particularly fish (UNEP/GEMS Programme, 1998). Increased transparency in the water also reduces fish's ability to hide from predators (Flug, 1998). Changes in oxygen levels also affect aquatic biota. Aquatic species are dependent on sufficient oxygen concentrations in the water released from a stratified dam. Serious oxygen deficits can be detrimental, even life threatening, to the biota in or immediately below the dam.

Reservoirs greatly expand the surface area of the river and thus increase annual water loss through evaporation, particularly in more arid areas, such as in the Yellow River's Middle Reach. The higher the atmospheric evaporative demand and the larger the surface area, the more water is evaporated from the reservoir surface. Especially during the summer when high air temperatures prevail, large amounts of water evaporate from the reservoir's surfaces. This reduces the water in the reservoir and increases the concentrations of silt, salts, and chemicals, and if sufficiently high, toxicological effectson aquatic biota can ensue (Luckyanov *et al.*, 1983).

In summary, the water quality downstream of a dam results from the impact of water storage on water quality in the reservoir, dam design, and the dam location within the drainage basin, in addition to factors not related to the dam such as climate and upstream land use.

3.2.4 The creation of new aquatic ecosystems

As has been described above, dams affect biological life in a great number of ways. All biological life thriving in the downstream waters is at risk when a dam is impounded. Biotic effects may be expressed in terms of a variety of indicators such as changes in growth rates, reproduction rates, survivorship rates, mortality rates, age-structure, distribution, and habitat establishments (Hodson, 1990).

However, as the initial habitats and their species composition undergo changes, new habitats are created. As mentioned above, dams can create thriving habitat for non-native fish species. Changes in the water regime may thus cause certain fish stocks to decrease and other species to increase. Moreover, individual differences exist in the physiological constitutions within different populations, of e.g. fish. For example, some fish individuals have a stronger capacity to migrate upstream and will thus have access to the more favorable sites for rearing and spawning, where there is less competition between fish. Certain stages in the life cycle of fish are more sensitive to changes in water quality and living conditions than others. For example, salmonides are sensitive to changes in their spawning conditions and rearing areas. Such changes may include polluted waters, increased summer stream temperatures, low or intermittent stream flows, lack of habitat diversity, and lack of vegetation (Anonymous, 1997).

4. Discussion

4. 1 Comments on the reviewed literature

To start with I would like to comment on the literature that has been reviewed for the first part of the study. The majority of the scientific articles and books on the environmental preconditions and challenges of the Yellow River basin tend to focus on the *physical* conditions as opposed to the water *quality* (except for silt load) and *biological* characteristics of the Yellow River basin. Overall, “physical” variables such as climate, wind speed, soil types, river flow and topographic features are well attended in the reviewed literature, whereas the biological effects of land use changes in the river basin seem to have been little studied. No piece of literature (in either English or Chinese) was found that analyzed the physical, water quality, and biological impacts of dams and irrigation practices in the Yellow River basin. Such a study could significantly add to the understanding of how potential future land and water uses upstream may affect land and water resources downstream in the Yellow River basin.

Moreover, the literature review of the environmental challenges of the Yellow River basin indicates that the majority of the authors perceive the high erosion and sedimentation rate as the most urgent and challenging problems of the Yellow River basin. More attention has possibly therefore been given in the reviewed literature to these than to other pressing issues, e.g. the serious water pollution by agriculture or mining activities, or to the high rates of water withdrawal from the Yellow River. The lack of available literature and data on these topics for the concerned basin has therefore limited the results of the study (in Part I). As a consequence, the chapter on the environmental challenges in the Yellow River basin, particularly those of the Middle

Reaches, may possibly give a biased picture with an overemphasis on the challenges related to erosion, sedimentation and flood control. Nevertheless, the author has tried within the present limitations of time and data to present the reader with as comprehensive a picture as possible, aiming at an appropriate balance of scope and details.

Furthermore, the initial intention was to investigate possible river ecological effects of land conversion *in the light* of the environmental challenges first identified (Part II). However, because of the lack of biological and water quality data for the basin, this was not possible to the extent desired. As a consequence, in Chapter 3.2 (Part II), the author chose to focus instead on the key ecological parameters of a river ecosystem and on their interrelationships. These were identified on the basis of a literature review, and the results are depicted in the diagram of Appendix C. The main purpose of this diagram is to present the reader with an easy-to-grasp overview, that still is relatively comprehensive. Specifically, it serves to illustrate the connections between the physical, water quality, and biological parameters of the river ecosystems, and how a change in one parameter (initially caused by river impoundment and/or irrigation) may trigger a chain of effects throughout the river ecosystem.

4.2 Translating theory into practice

A common feature of the reviewed scientific articles on dams was to focus on only one or a few of the ecological effects hereby generated, without emphasizing how such an effect may cause changes in interconnected river parameters (or river functions). It is of course evident that within the field of scientific research, it is often necessary to limit the scope of the study and to focus on parts of the whole. However, if such a narrow picture was to be translated into management practices, by targeting one parameter (or river function) at a time, without due consideration to other key parameters involved, the risk for unwanted side-effects is high. For example, in the case of the Xiaolangdi dam project, the objective to regulate the river silt load by discharging high volumes of water from the dam not only reduced delta-build up but also threatened downstream-dwelling animal and plant species with sensitivity to abrupt changes in river flow. Such one-sided remedies typically focus on apparent water flow and water quality issues and not on the potential biological effects. Since these are inter-linked, single-objective approaches are not the safest or most efficient way to manage the river basin.

In fact, identification of the key functions of the river for human livelihoods and various interests are crucial for an integrated river basin management. In other words, every decision that requires resources utilization should preferably be preceded by some fundamental questions regarding the river's functions for different user groups. By way of exemplification, the questions could be expressed as follow: What are the *functions* of the river for human use? What will be the desired effects of the planned activity? *Who* will benefit from such changes? What river *functions* could be threatened and how? What *groups* of people are dependent on threatened functions and thus in the risk zone of becoming undesirably affected? Moreover, the linkages or interrelations between the physical, water quality and biological conditions of the river ecosystem should also preferably be considered (see e.g., USGS, 1998). A “multi-objective river basin management strategy” is here advocated, that attends to the multi-way interactions and interdependencies between not only the river basin and its users, but also the interactions between different parameters within (or functions of) the river ecosystem. These aspects should be considered before deciding upon the final managerial strategy, so as to attain a more comprehensive basis for river basin management.

The upstream-downstream *interconnectivity* of the upper, middle, and lower reaches within the basin should also form part of river basin management strategies. Within this context, the individual features of the respective reaches, and their respective spatial and temporal variability, must not be overlooked.

On the basis of a comprehensive assessment of potential threats of a river project to downstream river ecosystems, it may well be decided that the future gains in e.g. regulation of flow and silt loads are more important than expected biological losses. If this is the case, then the decision should still preferably be founded on an awareness of such possible losses and on the balancing of different interests (gains and losses). Hereby, unpleasant surprises can be minimized or avoided. In fact, no activity can be carried out without causing harm to a living organism, whether a plant, animal or human being, indirectly or directly. This fact should always be considered before taking any definite decisions. Balancing various interests successfully is therefore the ultimate challenge for river basin management.

An ensuing research question that deserves a future study is how to make integrative systems analytical diagrams more accessible and user friendly to policy makers, without compromising the essence of its message.

5. Conclusions

The Yellow River basin is yet another example of a region where increasing demands for freshwater, electricity, agricultural, and forestry products, etc, are challenged by difficulties to manage a dynamic, limited, and vulnerable riverine landscape. This study has concentrated on the challenges to cope with the high erosion rates of the Loess Plateau, the high sedimentation loads in the Middle and Lower Reaches, the risk for flooding of the Lower Reaches’ canal, and the increasing water pollution rate and relative freshwater shortages in the basin. Moreover, the author has attempted to illuminate how the conversion from rainfed to irrigated agriculture (in association to electricity production) – as a means to increase present supplies of food, freshwater, and electricity for the growing Chinese population, may pose various threats to downstream river ecological systems.

I here propose that, ongoing modernization of agricultural practices and the implementation of dam projects in the upper and middle reaches of the Yellow River may significantly change downstream ecosystems with long-term implications. However, more importantly, the Yellow River and its ecosystems (indirectly or directly) serve and govern the lives of more than 100 million Chinese inhabitants (United Nations, 1997). Changes in the functions of the river ecological systems may thus affect the livelihood preconditions of more than 8 percent of the Chinese population (United Nations, 1997).

To give fair consideration to the various features, functions, and interests within a basin, impose a great challenge for the decision-makers in concern. Just as many scientists tend to focus on only a few research parameters, managerial strategies often tend to target only one or a few objectives. As a result, representatives of different interests or societal sectors often plead for conflicting interests. At best, the conflicting interests lie on the table of the same group of decision-makers. Even such central management objectives as hydropower generation and flood prevention can become contradictory. For example, during the flood season, the reservoirs in the upper reaches of the Yellow River are regulated so as to maximize hydropower generation, but this entails reduced sediment transport capacity of the downstream reaches (Liu, 1989). Consequently, flood prevention of the lower reaches is jeopardized. In fact, risk minimization and benefit maximization of the same resource base can easily become opposing interests. However, instead of counteracting one or the other, conflicts of interests should be reviewed on the basis of the overall *balance* of gains and losses. Balancing the different interests at hand is in fact the key to a successful *integrated* river basin management approach.

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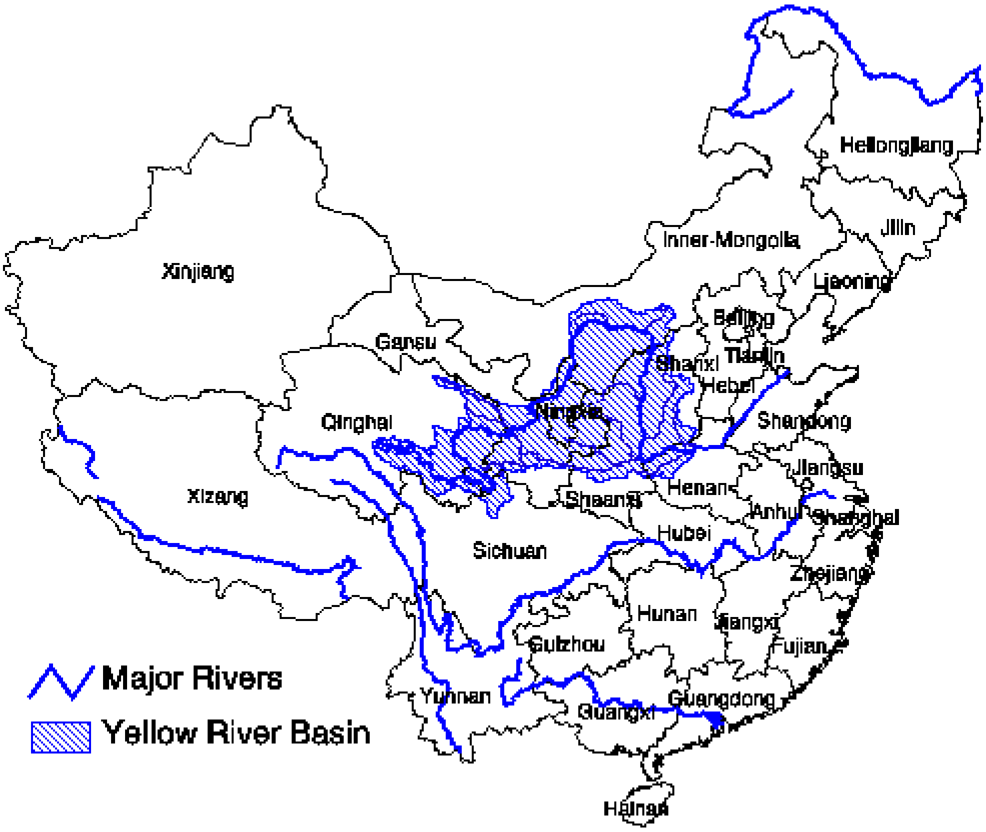
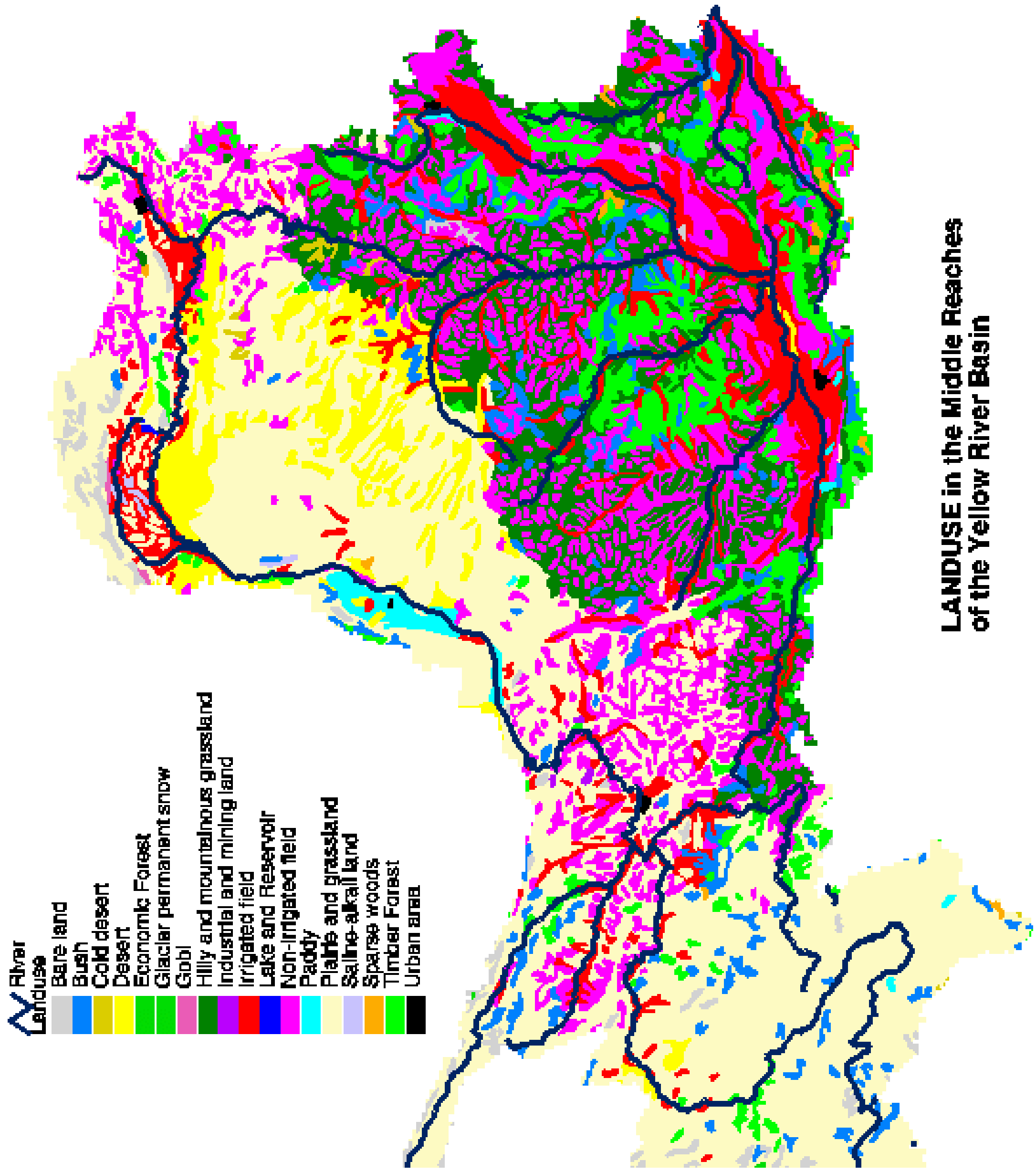
Appendix A. Map of provinces, major rivers and the Yellow River basin in China



Appendix B. Land use in the Middle Reach of the Yellow River basin



Appendix C. Impacts of conversion from rainfed to irrigated agriculture

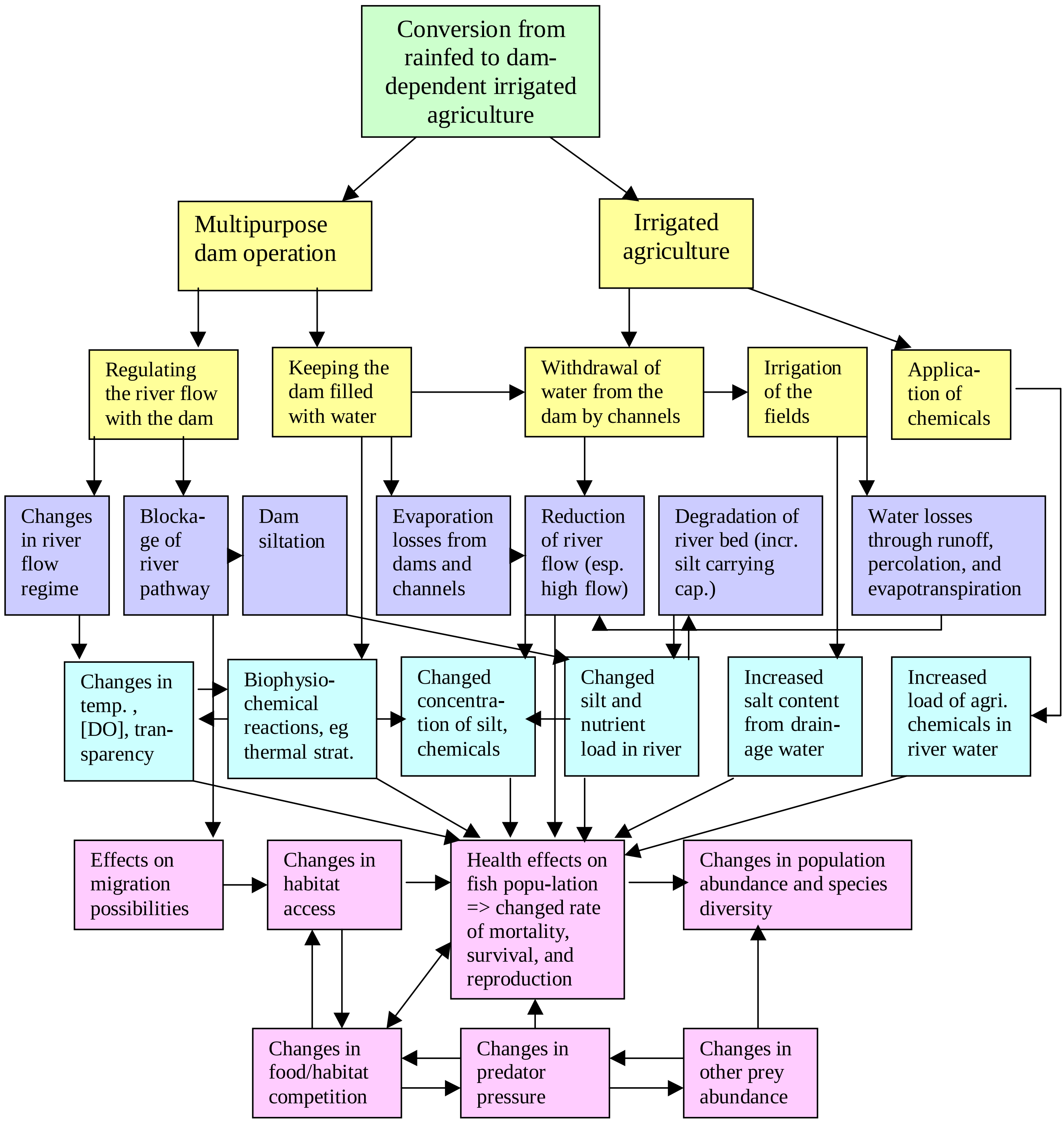


Figure C. A simplified overview showing expected changes in physical (purple), water quality (turquoise) and biological (pink) conditions of the downstream river ecosystems of the conversion from rainfed to dam-dependent irrigated agriculture

Appendix D. Environmental challenges in the Yellow River basin

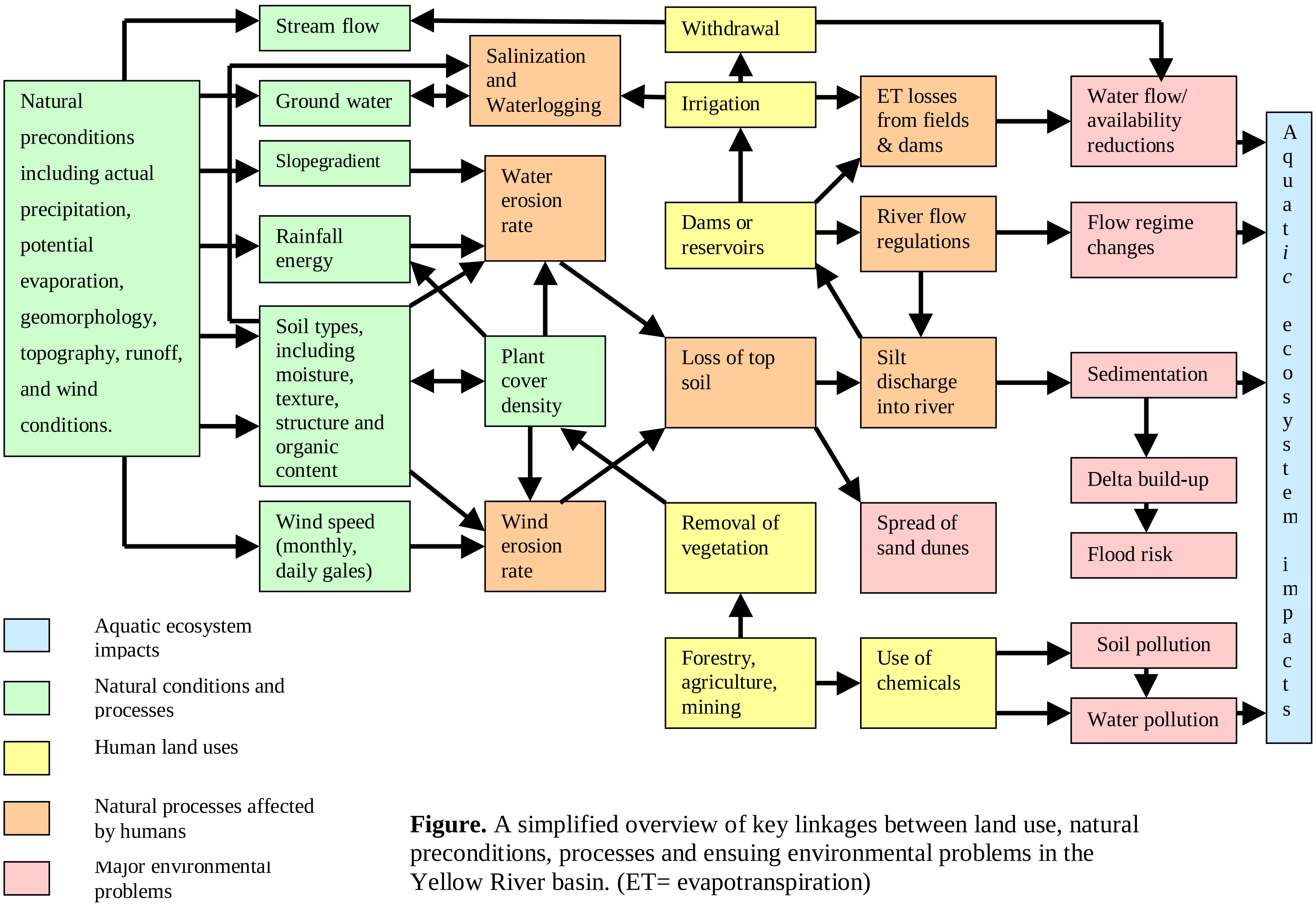


Figure. A simplified overview of key linkages between land use, natural preconditions, processes and ensuing environmental problems in the Yellow River basin. (ET= evapotranspiration)