Water Crisis in the Huang Ho (Yellow) River: Facts, Reasons, Impacts, and Countermeasures

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Abstract

The Huang Ho (Yellow) River or "Mother River of China" no longer flows into the sea these days because of extensive use of its limited water resources. This paper will present the remarkable story about water resources and its effect on the Yellow River, focusing on the phenomena of dry-up (zero-runoff) in recent years, its reasons, impacts, and possible counter-measures. The essential reasons for dry ups in the watershed are that the Yellow River basin is located in an arid and semi-arid region, its water resources are limited, and global warming and other vital human activities are adversely impacting the watershed hydrology. The dry up issue has resulted in many serious problems, from agriculture to industry, from domestic to environmental, and from water quantity to water quality. The main countermeasures proposed in this paper include: water savings, water management, increased regulation, water transfer, and rational and practical groundwater use.

Keywords

Dry up phenomena; water resources; Yellow river

INTRODUCTION

The Yellow River, the 6th longest river in the world and 2nd longest river in China, has long been regarded as the "Cradle of Ancient Chinese civilization" or as the "Mother River of China", because human inhabitants have existed in this region since prehistoric times (Wang et al, 2000). The headwaters of the Yellow River begin in the Bayankala Mountains and flow eastward, passing through several rural and urban regions before emptying into the Bo Hai Sea. According to survey results of 1973, the Yellow River is 5,464 km long with a basin area of 752,443 km^2. The watershed area is as large as 794,712 km^2 if the Erdos inner flow area is included. According to statistical data of 1997 (Yellow River Commission, 1999), there were 107 million residents and 12.6 million hectares of cultivated land within the watershed, representing 8.6% and 13.3% of the national total, respectively. The watershed's 1997 GDP (Gross Domestic Product) was about 484.2 billion *yuan*, which is equal to about 58.2 billion US Dollars. Industrial and agricultural output values were 601.5 and 150.9 billion *yuan*, respectively. In addition, the irrigation districts in the lower reach, which are located outside the watershed and channeled river water, have an irrigation area of 2.86 million hectares and a population of 54.73 million distributed throughout 80 counties of the Henan and Shandong Provinces.

The Yellow River basin consists of 4 distinct landforms: the Qinghai-Tibet Plateau, Inner Mongolia Plateau, Loess Plateau, and North China Plain. The terrain is high in the west and low in the east, and is divided into three ladders. The first ladder is the northeast portion of the Qinghai-Tibet Plateau, which is 3,000-5,000 m above sea level and famous as the "roof of the world". The second ladder includes the Hetao Plain, Erdos Plateau, Loess Plateau, and Fen-Wei Basin among others. The average height of this ladder is about 1,000-2,000 m. The third ladder moves east from Taihang Mountain towards the coast forming the great Yellow River alluvial plain, with an average height lower than 100m.

RIVER CHARACTERISTICS

The Yellow River is well known not only for its history and large drainage area, but also for its high sand content, frequent floods, unique channel characteristics in the lower reach (the riverbed is higher than the land outside of the banks), and limited water resources. The river is named the Yellow (Huang) River because of the resulting color caused by high sediment content. The Yellow River's average annual sedimentation and sediment concentration are 1.6 billion tons and 35 kg/m^3, respectively at San-Men-Xia station. An average of 400 million tons of sediment are deposited annually on the lower reach of the Yellow River, resulting in an annual riverbed increase of 10cm.

The Yellow River is also a river of frequent floods with the Chinese saying, "two breaks in three years and one channel change every hundred years" effectively expounding on the repetitiveness of this climatic challenge. According to 2,000 years of historical records through 1946, there were 1,500 dike breaches in the lower reach with its main course being changed 20 times within a 250,000 km^2 area of the Huang-Huai-Hai Plain. The flood of July 1958 was one of the most serious floods of the last century in the Yellow River. A 2,610 km^2 area suffered 200 mm of rainfall in a singe day. The peak discharge was 22,300 m^3/s on July 18 at Hua-Yuan-Kou station. The Beijing-Guangzhou railway, the most important North/South railway passing through China was halted for 19 days as a result. According to incomplete statistics, there were 1,788 submerged villages in Shandong and Henan provinces alone, with 740,000 casualties and 202,700 hectares of cropland destroyed (Wang et al, 2000). To ensure increased safety from the floods, the downstream dikes have been strengthened three different times since 1946 and the downstream river channel is 4-7 meters higher than the land outside the bank, with a maximum of up to 13 meters.

The prominent characteristic of the water resources of the Yellow River is "short of water". The average annual natural runoff is 58 billion m^3 in the Yellow River basin, representing only 2% of the national total. The annual average runoff depth is 77 mm in the basin, which is only 28% of the 276 mm average runoff depth for the whole country. The amount of water resources per capita is 593 m^3, which is about 23% of that of the national average and 1/16 of the world average. The average water per *mu* (1/15 hectare) of cultivated land is 324 m^3, which is equal to 18% of the country total.

The spatial distribution of the natural runoff varies by area. The watershed above the Lan-Zhou station, with an area of 222,551 km^2 (about 29.3% of the total basin area), is the main source of runoff to the Yellow River and produces about 55.6% of the total annual average runoff. The dry climate, the corresponding loss via evaporation, and riverbed leakage in the Lan-Zhou to He-Kou areas cause the runoff to decrease by one billion m^3 even though the basin area is larger by 163,000 km^2.

The temporal distribution of natural runoff in the Yellow River is also uneven. 60% of the year's average natural runoff at every station on the main stream occurs during the flood season from July to October. The peak discharge is large and rises and falls sharply during the flood season. Conversely, the discharge is very small in the dry season and variation is limited. For instance, the peak runoff measured at Lan-Zhou station in 1946 reached 5,900 m^3/s in the flood season while the minimum runoff was only 335 m^3/s or 17 times less in the dry season during the same year. Additionally, the peak runoff measured by Shan-Xian station in 1933 reached 22,000 m^3/s, but the minimum at the same year was only 240 m^3/s, or 91 times smaller.

The natural runoff also varies from year to year. The coefficients of variation of annual runoff are 0.20-0.25 for stations on the main stream and 0.40-0.50 for stations on tributaries. The maximum annual runoff at Hua-Yuan-Kou was 100.4 billion m^3 in 1964 while minimum annual runoff at the same station was only 28.4 billion m^3 in 1928.

With increases in population and regional economic development, the Yellow River runoff (both observed runoff and natural runoff) has decreased significantly during the last 50 years (Figure 1). A dry up phenomenon has taken place in the lower reaches of the Yellow River since 1972. The dry up phenomenon first occurred at the Li-Jin hydrological station, 104 km from the river mouth. The flow dry up phenomenon has occurred more and more often during the last 30 years (Figure 2). Also, as the onset time of flow dry-up advanced, the dry-up period prolonged, and the section of dried-up river extended. In the drought year 1997, the river dry up period lasted 227 days in Li-Jin station, and for 330 days there was no water discharged to the sea; producing a 687 km dry riverbed.

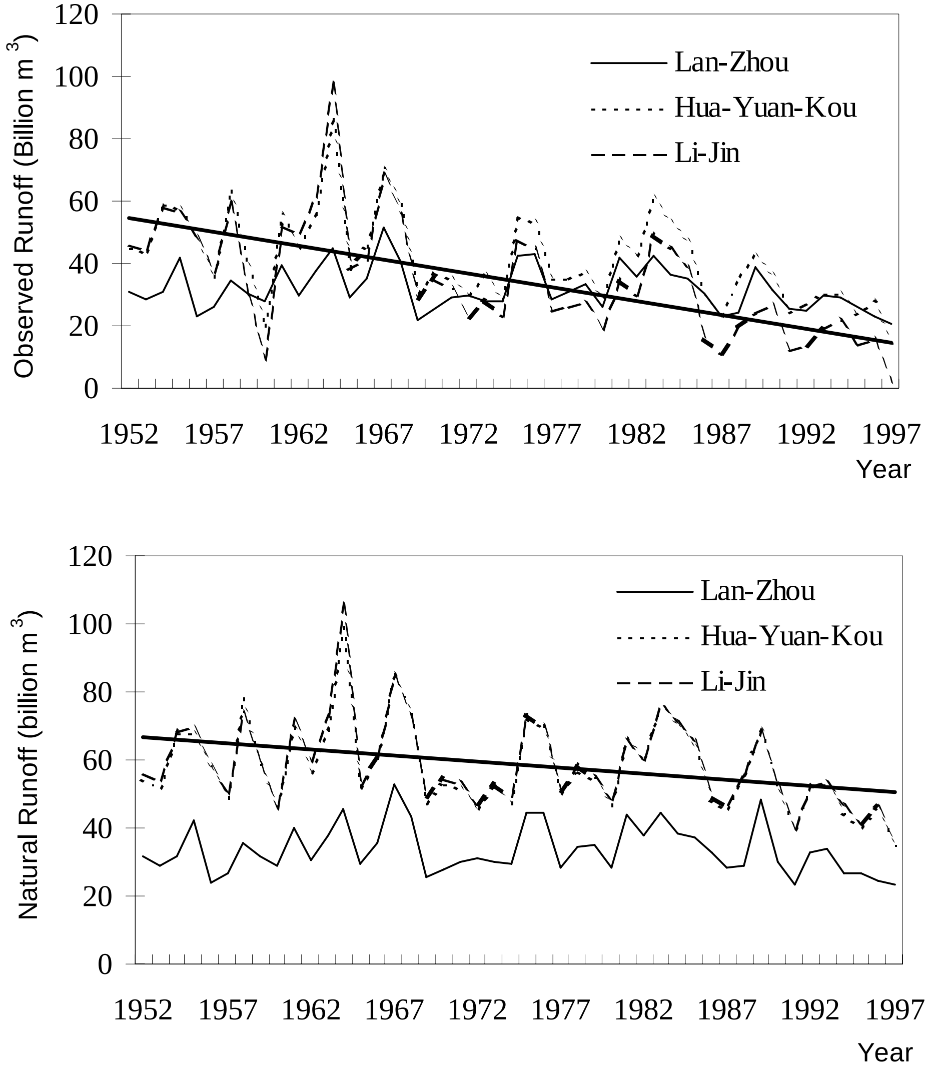

Figure 1 The observed and natural runoff of the Yellow River (1952-1997)

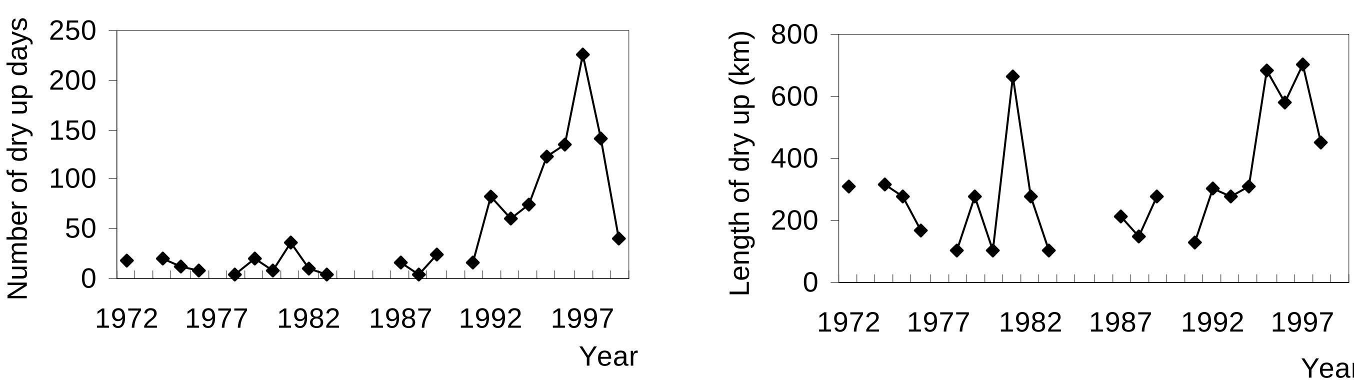

Figure 2 The number of days and lengths of dry up of the Yellow River at Li-Jin station (1972-1999)

The phenomena of dry up, resulting in water crisis in the Yellow River, has raised many critical problems for the watershed. This paper will try to analyze the reasons, impacts, and possible countermeasures.

REASONS

Natural reasons

The essential reason for the development and increased occurrence of the dry up phenomenon is that the Yellow River basin is located in an arid and semi-arid region and its precipitation and water resources are limited. Table 1 lists some characteristics of the six longest rivers in the world with the distinctive features of the Yellow River's water resources clearly noted.

Table 1. Comparison of important world rivers (Fu et al, 2003)

River	Length (km)	Drainage Area ($10^3 km^2$)	Annual Runoff (km^3)	Sediment Discharge (10^6ton/yr)	Runoff Depth (mm)	Silt content (kg/m^3)
Nile	6670	2960	30	0	10.1	0.00
Amazon	6570	6150	6300	900	1024.4	0.14
Yangtze	6300	1808	976	478	539.8	0.49
Mississippi	5970	3270	580	210	177.4	0.36
Yenisei	5870	2580	560	13	217.1	0.02
Yellow R.	5464	752	**49**	**1080**	**65.2**	**22.04**

The impact of global warming/climatic change on hydrology may be a partial reason for the resulting dry up in the Yellow River. Kendall's test was used to analyze the climatic trends of the Yellow River over the last half century (Fu et al, 2003) and the results show that the temperature of the basin has a significant increasing trend during the last 50 years, with a more significant increase in minimum temperature than in mean and maximum temperatures. The water issue in the Yellow River is likely to be more critical in the future according to the scenarios of global warming.

Land use/land cover change (LUCC) is also related to the decrease of runoff in the Yellow River during the last 30 years. Many agricultural activities, such as land use change from rangeland to agricultural land, land surface change from slope land to terrace, irrigation area expansion, and soil and water conservation have affected regional hydrology and river runoff.

Human activities

Human activities are the number one factor leading to the dry up phenomena in the Yellow River basin during the last three decades. Human activities are far ranging, but the following specific human activities are particularly relatable to the decrease of runoff during the last 30 years.

- Population of the Yellow River basin has increased markedly during the last 50 years. The population doubled from 41 million to 84 million during the 30 years between 1953 and 1982. The population growth rate has been reduced since 1982 when the "family planning" policy was adopted however the population has still greatly increased, climbing to about 107 million by 1997. The population growth is the major driving force for increase of water demand and water use.

- Irrigation area has dramatically expanded during the last 50 years. The majority of the irrigation facilities in the Yellow River basin were built during the last 50 years. An irrigation area of only 800 thousands hectares in 1949 increased to 7.51 million hectares by 1997. The dry up is due mainly to increasing irrigation water withdrawal, which is officially reported to be 91% of all surface water subtraction from the Yellow River (Chen et al, 2003).

• Twelve dams have been built or are in the process of being built in the main channel of the Yellow River. Combined, their theoretical storage volume is 56.32 billion m^3 with 35.56 billion m^3 of that effective storage. These dams produce not only 33.55 billion kW·h of power every year, but also hold partial runoff, change the yearly runoff distribution, and increase water surface evaporation.

• Besides dams in the main channel; 3,147 reservoirs with storage of 57.4 billion m^3, 4,500 diversion works with theoretical annual diversion potentials of 29.5 billion m^3 of water, 29,200 pump-sites capable of drawing 4.8 billion m^3 of water, and 875,000 wells drawing large quantities of ground water have all been built in the watershed. All these hydraulic facilities have increased water usage and evaporation and consequently decreased runoff in the channel.

Because of irrigation area expansion, population growth, and development of growth economies, the river runoff consumed by agriculture, industry, and domestic usage has increased during the last 50 years. The consumed runoff was 7.4 billion m^3 in 1949, 27.8 billion m^3 in 1990, and 30.8 billion m^3 in 1988-1992. After the serious dry up in 1997, the Chinese government limited the consumed runoff amount in an attempt to ensure at least a partial runoff needed to maintain ecological systems and the natural environment. Consequently, the consumed runoff was stable in 1998-2001 with a range of 26.5-29.9 billion m^3.

IMPACTS

Impact on society

The drying-up has produced serious impacts on agriculture production, industry, and residential life in the lower reaches. Agriculture within the two provinces of Shandong and Henan, in the lower reaches, is particularly vulnerable to spring drought, summer floods, and autumn drought. It is estimated that 4.7 million hectares of cropland were affected for the 19 years between 1972-1996, which resulted in cereal losses of 9.86 billion kg and an economic loss of 12.2 billion *yuan* ($1.5 billion). The effects have become even more pronounced as this period of time progressed. The economic loss was about 200 million *yuan* every year during the 1970's and 1980's, but increased sharply to 1.6 billion *yuan* in the 1990's. The percentage of agricultural loss due to drying-up to the total agricultural loss also changed from 10% in the 1970's and 1980's to 80% in the 1990's.

Industrial enterprises, particularly the oil industry through impact on its oilfields, suffered suspension of production and great losses from the dry-ups. It is estimated that industry losses have amounted to 40 billion *yuan*, with 200 million *yuan* per year in the 1970's and 1980's, and an astounding 4 billion *yuan* per year in the 1990's. These water shortage numbers represent 8%-11% of total industry losses during the 1970's and 1980's and 82% for the 1990's.

The drying-up also had significant influences on domestic water usage. There are ten cities in the lower reach of the Yellow River, which depend primarily on the Yellow River as their major municipal water source. In 1995, urban water supply in De-Zhou city was cut in half, from 120,000 tons/day to 50,000 tons/day. As a result, 139 plants and factories had to limit production or be totally suspended, causing a loss of 600 million *yuan*. Over 100,000 residents of Dong-Yin, Bin-Zhou, and De-Zhou cities could not get enough water and severe health concerns were only averted by severely limiting per capita and industrial water usage. All factories in Bin-Zhou were closed because of domestic water prioritization and even then the residents could only get half of their usual quota. Residents had to join long daily queues at appointed public water taps; seriously impairing normal living schedules and causing considerable social unrest.

Impact to the river course in the lower reaches

Runoff discharge reduction in the lower reaches decreased the sediment transport capacity. As a result of this change in sediment transport capacity, the location of sediment deposit changed from the river-beach to the main channel. 70% of all sediments were deposited at the river-beach during the 1950's while 85-90% of sediments have been deposited in the main channel in recent years. It is estimated that the sediment deposit at the lower reach was about 211 million tons per year during 1985-1995, which was about 15 million tons more than that during 1950-1985, even though the sediment yield in 1985-1995 was only 59% of that during 1950-1985. The increasing amount of sediment being deposited within the main channel of the Yellow River has produced and will produce higher water levels even for historically and comparatively smaller flood rates. For example, the water level at Hua-Yuan-Hou station from a flood of 7,680 m^3/s in August 1996 was 0.19 meters higher than that at the same station from a flood of 22,300 m^3/s in 1958. This ordinary flood resulted in disaster for the lower reach of the Yellow River. The peak discharge at Hua-Yuan-Kou in 1998 was 4,700 m^3/s, which was much less than the 22,300 m^3/s in 1958, but resulted in a water level that was 0.56 meters higher than that in 1958 and considerably higher than the flood height reached two years earlier at the same station. "Small water amount and heavy disaster" is the serious issue the Yellow River faces. This dry-up enduced situation is a big danger to a rather large flood passage. The hydrologists estimate that a flood of 7,000 m^3/s would overflow the river beach and riverbank and potentially change the main channel route as was the case in 1855.

Environmental deterioration

The environmental situation has been severely impaired because of dry ups on the Yellow River. The actual effect is more serious than it appears today, and is usually un-reversible. The eco-system is particularly vulnerable at the river mouth and is easily affected by silts and water shortages. The ecological resources in the estuaries are rich and productive. The plankton density is 10 million/m^2 and plankton biomass reaches 249 mg/m^2 during the spring, summer, and fall seasons. The river mouth and nearby sea area is a central region for young fish and commercial fish farms and is nicknamed "home of prawn". The river dry-ups have the potential to impact the nutrition input and therefore the biological resources and fish production within the Yellow River delta region.

The Yellow River delta is one of the most highly prized, largest, and youngest warm temperature wetland zones in the world. The dry-ups have affected many functions of the wetland, such as storage capacity, climate modification, soil erosion control, and water quality purification.

The river dry-ups have impaired, as well, many aspects of the agriculture ecological system in the lower reach of the Yellow River, such as impacts to the agriculture ecology through salinization and alkalinization of the soil.

Water quality

Industrialization has caused an increase in wastewater production, which is proving ecologically troublesome for the region. Wastewater production was 1.85 billion tons/year during the 1970's, 2.17 billion tons/year in the 1980's, and 3.26 billion tons/year during the 1990's. Additionally, the dry-ups have only worsened this trend, simply because not enough fresh water is available to dilute the solute in the water.

COUNTER-MEASURES

Water saving

Water use efficiency within China is lower than that for developed countries. For example, the GDP of China is only about one tenth that of US, but water usage amount in China is almost the same as in the US. The output for every cubic meter of water is only about one thirty-seventh that of Japan. The industrial water reuse ratio is less than 55% in China, which is smaller than the 75%-85% range for developed countries. Furthermore, the water usage efficiency in the Yellow River is still lower than the average level for all of China. The comprehensive water consumption ratio for the Yellow River watershed is only about 57% of the national average. The irrigation ratio is 50%-100% higher than that of regions in the same climate. Water savings and improvements in water use efficiency are the most effective ways to deal with the water crisis in the watershed. Shifting from conventional surface irrigation to drip irrigation in India has increased overall water productivity by 45-225% for crops as diverse as banana, cotton, sugar cane and sweet potato (Gleick, 2002). By using a new method to estimate water saving potential capacity, which is based on crop water requirements, we estimate the water saving potential capacity to be about 3.11×10^9 m^3 for the Ningxia and the Inner Mongol irrigation districts and about 2.4×10^9 m^3 for the Shandong and Henan irrigation districts of the Yellow River basin (Fu et al, 2002). However, this will not be easy to implement, as it requires enormous facilities investment, institutional change, new management tools and skills, and public conscientiousness.

Water management

The purpose of water resources management is to ensure the availability of water in sufficient quantity and quality at the right location and the right time to meet various uses, improve the ecological environment, and mitigate or prevent the adverse impact of excessive runoff or shortage of water (Xu et al, 2001). The management work in the Yellow River is both complex and broad in scope and requires work on multiple fronts including: sediment control in middle reaches, flood prevention in the lower reaches, reduction of water shortages and dry-ups in the lower reaches, and delta management. Moreover, different government agencies control their own engineering projects and facilities, and as such, control and management is not well coordinated and unified. Integrating water resources management, creating a framework for planning, organizing and controlling water systems to balance all relevant views and goals of stakeholders (Girgg, 1999), all have proven effective as ways to deal with water problems in the Yellow River. The dry up did not occur in year 2002 even though its natural runoff was only 43% that of its yearly average. This was for the most part due to the water management agency's ability to determine and control water discharge flow in the Yellow River from the first to the last reservoir.

Regulation ability

Although there are some dams in the main channel of the Yellow River, its regulatory ability, especial at the lower reaches, is still limited. Xiao-Lang-Di reservoir, which is under construction, has a total capacity of 12.65 billion m^3 and a valid adjusting capacity of 5.05 billion m^3. The main purposes for building Xiao-Lang-Di are flood and sediment deposit prevention in the lower reaches. It may have the function of regulating the runoff process in the middle and lower reaches, but as of now it cannot be proven.

The National Planning Commission of China has limited the maximum water usage to 37 billion m^3 leaving 21 billion m^3 to flow into the sea. The actual discharge into the sea was only 17 billion m^3 in the first six years of 1990's. This means that increase of regulation ability may supply water for agricultural, industry, and domestic usage, but its function of alleviating or solving the dry-up issue and water crisis are still limited.

Water transfer

The Water Transfer from South to North project aims to channel a portion of the water from Changjiang (Yangtze) River where water resources are relatively rich in south China to the Huang-Huai-Hai region where the water resources are very limited in north China. This project has been approved by the Chinese government and its first phase has already been initiated. We do believe that this water transfer project will mitigate the water crisis in North China. However, there are still a few questions about this water transfer project, such as the accuracy of the investment estimation and who will pay for the vast monetary and labor investment as well as who will buy the water.

Groundwater

Groundwater in the Yellow River is unevenly distributed. For example, groundwater exploit ratios in the Hetao Plain and Taiyuan Basin are 118% and 115%, respectively, while the same ratio is almost zero for the region east of Jinan city where diversion water from the Yellow River is more easily obtained and cheaper. Since the groundwater level at this region is only 2-4 meters deep, there is the potential for using the ground water to meet all industrial, agricultural, and public use; leaving more channel water. The unified and optimized use of both surface water and groundwater at this region is a necessary way to deal with the dry up and water crisis in the watershed.

CONCLUSIONS

Industrialization, population growth, and other associated human activities along with global warming and the unique water characteristics and arid and semi-arid climate zone of the Yellow River basin have caused a dry up phenomena in the Yellow River basin during the last three decades.

The dry-ups have had a large impact on the region's communities, industry, and agriculture as well as its environment, particularly in regards to water use and water quality. In order for changes to be made several countermeasures have been proposed. These include: water savings, water management, increased regulation, water transfer, and rational and practical groundwater use.

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