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The Three Gorges Project: Development and Environmental Issues

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I. Introduction

The Three Gorges Dam was a dream of many Chinese people, but today it has become a reality. The dam, 2309 m in length and 181 m in height, is the largest ever built in China (Figure 1). The reservoir behind the dam occupies the Three Gorges, one of the most spectacular sites of natural beauty in China, to form an elongated lake of more than 600 km in length, with a water surface area of 1,084 km^2. It has a water storage capacity of 39.3 billion m^3, equivalent to about 4% of the annual freshwater discharge of the Changjiang River. The dam has a catchment area of one million km^2 (i.e., 56% of the total catchment area of the river system). The budget of the project, including construction of the dam, the ship lock, power plant, and compensation for the migration of 1.2 million people from the reservoir area, reaches the astronomical figure of CNY 253.9 billion (USD 31.8 billion).

Because of its large scale, from the outset the project has been highly controversial, both within the country and worldwide. The benefits of the project, without a doubt, are large, but uncertainties exist with regard to the long-term impact on the environment. The major concern is the extremely large change that will inevitably cause significant modifications to the environment of the catchment region, against a background of global changes in climate, sea level, landforms, and ecosystems. Thus, a synthesis of the available scientific information, together with an analysis of the future trends in catchment changes following the completion of the project, will enable us to understand the

Figure 1: A bird's eye view of the Three Gorges Dam, currently under construction (photograph courtesy of Mr Bin-cheng Zhu, taken in August 2005).

project better and gain insights into possible solutions to the various problems.

Hence, the objectives of the present contribution are: (1) to review the decision-making process for the Three Gorges Project, with a short account of its history; (2) to summarize the social and economic benefits of the project in terms of hydraulic power generation, flood control, waterway transport, and urbanization, for both the catchment region and the entire country; (3) to identify the modifications to the environment and the resultant management problems, including river channel and river delta geomorphological readjustment in response to the dam construction, the impact on the freshwater and marine ecosystems, resettlement issues, and the protection of Chinese cultural heritage and tourism; and (4) to identify future requirements for the management of the catchment changes.

The methodology adopted for the present study includes the collation of relevant data and information from the literature and other published sources, together with my own measurements and observations. These data sets are then interpreted with a holistic view for the entire river coast system.

II. Regional Settings

A. Geology and Geomorphology Background

The Changjiang River, with a catchment area of 1.8 million km^2, is the largest river system in China (Figure 2). It is ranked the third longest river in the world, at 6,300 km. The river is often called the "Yangtze," which actually refers only to its lower reaches; the whole river should be called "Changjiang," meaning "Long River." The river originates in the snow-capped Gladandong Mountain (maximum elevation 6,621 m above sea level) on the Qinghai-Tibet Plateau, flowing through the Sichuan Basin, the Three Gorges, the Jianghan Plain, and the Middle-Lower Reach Plain, and meeting the sea in Shanghai (Figure 2). Generally, the catchment basin is characterized by mountainous and hilly areas.

In the catchment basin, rock strata formed during the pre-Cambrian to Quaternary periods. In the upper reaches above the Sichuan Basin, Paleozoic to Cenozoic strata are present. On the Qinghai-Tibet Plateau, Paleozoic and Mesozoic sedimentary rocks dominate.[1] The Sichuan Basin (or Chengdu Plain) is characterized by Quaternary sequences.[2] Pre-Cambrian and Paleozoic rock formations are exposed in the Three Gorges region.[3] Over the Jianghan and Middle-Lower Reach Plains, thick Quaternary sedimentary layers have been formed, with Paleozoic to Tertiary strata exposed in many places. Away from the river valley plains, Paleozoic to Cenozoic strata are present in the middle-lower reach regions,[4] characterized by the lower Changjiang River metallogenic belt,[5] which forms unique constituents in the Changjiang water and sediment that are discharged into the sea.

Over the upper reaches, some three million years ago the river flowed westward; then, at a late stage of the crust uplifting of the Qinghai-Tibet Plateau, the overall slope reversed and the river flowed to the east. The waters cut through the Three Gorges in the eastern Sichuan Basin, where the rock consisted of relatively weak limestone and mudstone. Subsequently, the huge depression over central China, in the form of lakes and wetlands, were filled with Changjiang sediments to form the present-day Jianghan and the Middle Reach Plains. The large lakes of today, such as the Dongting and Boyang, together with minor ones, represent relic features of the depression. Further to the east, following the rise in sea level that took place 7,000 years ago, the sediment carried by the river accumulated in the estuarine waters,

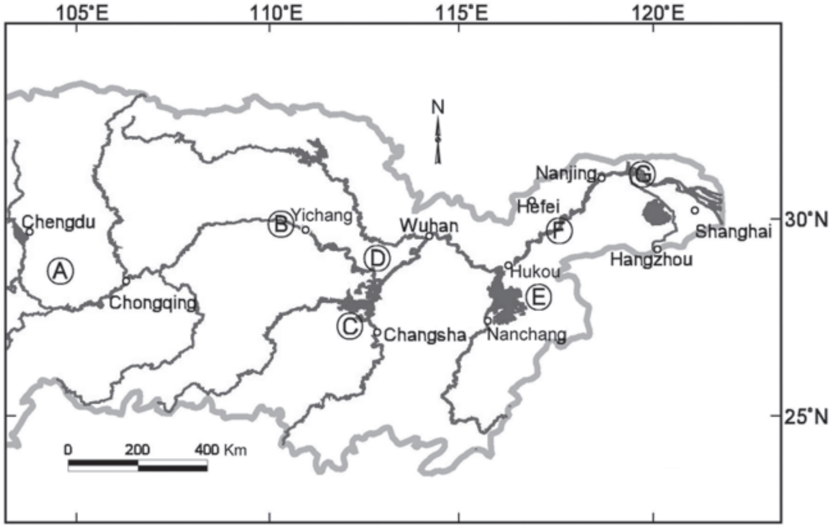

Figure 2: Location map of the Changjiang River catchment (A—Chengdu plain (Sichuan basin); B—the Three Gorges; C—Dongting Lake; D—the Jianghan Plain; E—Boyang Lake; F – the Datong Hydrological Station).

forming the present-day Changjiang River Delta (about 25,000 km^2 in area). These plains, with a total area of 203,400 km^2, account for 11.3% of the catchment area.

B. The River System

The Changjiang River can be divided into upper, middle, and lower reaches. The upper reach (4,500 km long, one million km^2 in catchment area) is above the city of Yichang, where the Three Gorges Dam was built. The middle reach extends from Yichang to Hukou (950 km long, 0.68 million km^2 in catchment area). The lower reach is from Hukou to the river mouth (930 km long, 0.12 million km^2 in catchment area) (for locations, see Figure 2). In the upper reach, the river channels are characterized by V-shaped incised valleys. In the middle reach, over the fluvial plains, the slope gradient of the riverbed is small (0.003% on average) and a meandering river channel system has been well developed. Finally, in the lower reach, the bed slope is further reduced, and the river flow is influenced by the tidal action at the river mouth.

Located in a mid-latitude region with a monsoon climate (annual precipitation exceeding 1,000 mm on average), the freshwater discharge is large.[6] According to statistical analysis of the gauge record

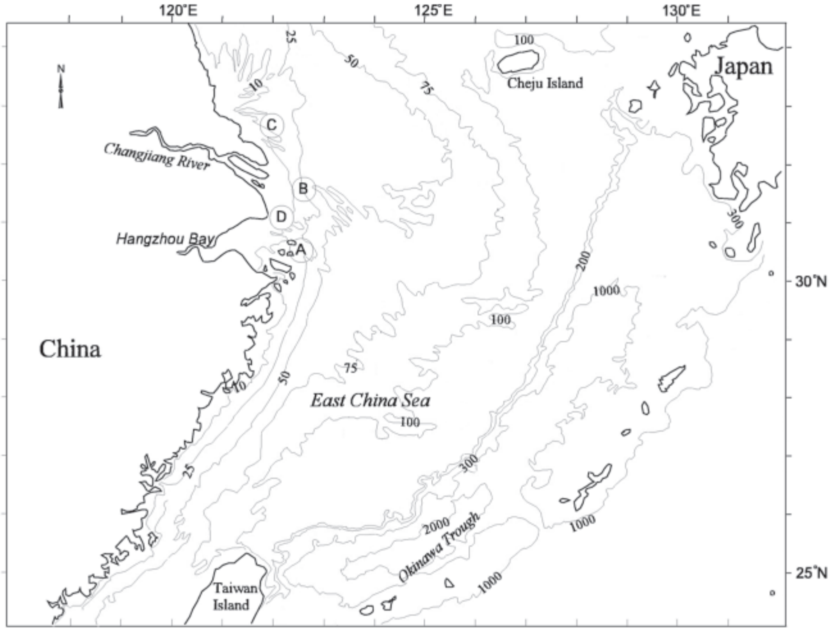

Figure 3: The Changjiang River discharges into the East China Sea (A—the Zhoushan Fishing Ground; B—the Changjiang River Mouth Fishing Ground; C—the Luisi Fishing Ground; D—the Yangshan Harbour off Shanghai). Bathymetry in meters.

at the Datong Hydrological Station, which is located 624 km to the west of the Changjiang River mouth, the long-term average water discharge of the river is approximately 900 billion m^3 yr^{-1}. Maximum discharge occurs in summer and is minimal in winter. Soil erosion is mild because of the dense vegetation cover in the watershed, but the sediment discharge still reached 500-million t yr^{-1} before the 1980s because of the large catchment area.

The river discharges into the wide epi-continental East China Sea (Figure 3), which consists of a continental shelf and the Okinawa Trough, with a shelf width of about 500 km. The continental shelf (water depth to 200 m) has a vast area[7] of 530,000 km^2. The East China Sea water is slightly diluted by freshwater discharges from land, with an average salinity value of 33.8 for the bottom layers and 32.9 for the surface layers.[8] Near the Changjiang River mouth, there are three well-known fishing grounds: the Zhoushan, Luisi, and River Mouth fishing grounds (marked A, B, and C, respectively, in Figure 3), with many brackish-water fish species.[9]

C. Social and Economic Development in the Catchment

With a population of approximately 430 million, human activities represent the most important factor in environmental changes for the Changjiang River catchment. Natural factors, such as climate change, play only a secondary role. For instance, since 1950, more than 48,000 dams have been built in the catchment, according to the Ministry of Hydraulic Engineering of China, for the purposes of irrigation, water storage for industrial and domestic uses, power generation, and canalization/navigation.[10]

The driving force for the large-scale dam building is the rapid urbanization within the catchment region. Today, there are ten large cities (i.e., population >1 million), with Shanghai, Nanjing, Wuhan, Chongqing, and Chengdu being the largest; 72 middle-sized cities (population 0.2 to 1 million); and 103 small cities (population <0.2 million).[11] Most of the cities are located on the fluvial plains and the river delta. Energy resources in China have been a problem for a long time because the country can only produce a small amount of oil and gas; hence, the potential of the hydrological power of the Changjiang catchment (estimated to be 676,050 mw in total) becomes highly attractive. Another problem is river flooding. Historically, flood disasters frequently occurred in the Changjiang catchment. Some of these floods caused heavy loss of human life and property.

At the same time, in order to solve the water shortage problem in northern China, it has been planned to transport up to 10% of the annual discharge from the river to the north. It is hoped that this will supply sufficient water for urban, industrial, and agricultural uses in this region. There are three optional routes for transport, located in the upper, middle, and lower reaches of the river basin, respectively. The lower reach route (between Shanghai and Nanjing) has been under construction, and the upper reach route is associated with the Three Gorges Project. With regard to large coastal engineering schemes near the river mouth, the construction of Yangshan Harbour[12] off the Shanghai coast (Figure 3), with a huge bridge (32 km in length) linking the harbor to the land, is indicative of their scale and socioeconomic influences on the catchment regions.

The social and economic development results in modifications to the catchment at an accelerating rate. In addition to changes to the physical environment, industrial and agricultural development increased the nutrient load (N and P) to an order of magnitude of 10^6 million t yr^{-1}.[13]

III. The Three Gorges Project: A Short History

A. Initial Ideas

The idea of a Three Gorges Dam goes back to the early 20th century. In 1918, Dr. Sun Yat-sen, the founder of the Republic of China, wrote an article in English entitled, "The International Development of China." This was later translated into Chinese and included in his well-known book, *An Outline for the Reconstruction of the Republic of China*.[14] In this article, he proposed that a barrage be built at the Three Gorges section of the Changjiang River so that the navigation channel linking Wuhan and Chongqing could be improved, and it would also be beneficial for flood control for the middle reach of the river. In 1924, in an article entitled, "On Democracy," Dr. Sun Yat-sen described the potential of utilizing the hydraulic power capacity of the region. His idea was perhaps the earliest proposal for a "Three Gorges" project. During the 1930s and 1940s, the Chinese government organized several *in situ* investigations. Overseas engineers were invited to participate in these activities in order to evaluate the feasibility of the scheme. Several reports on these studies were written, which eventually led to a serious design stage on which the Chinese and American engineers had collaborated, as is indicated by the "Preliminary Report on the Three Gorges Project on the Yangtze River," written in the 1930s at the request of the Chinese Government by an American engineer named Dr. John Lucian Sovage.

After the 1949 revolution, the construction of the dam was put on the agenda again by the government. In the 1950s, Mao Ze-dong wrote his well-known poem about the blueprint of the Three Gorges Dam: "A stone wall to be erected, to cut-off the cloud and rain from the Wushan Mountain; a lake with flat water surface is thus created in the high gorges." However, due to the complexity of the engineering project and the insufficient economic conditions, the dam was not built during Mao's time. More than thirty years later, in 1992, the Fifth Session of the Seventh National People's Congress passed "The Resolution on the Three Gorges Project of the Changjiang River," in which the plan was approved.[15]

B. Feasibility Studies and Environmental Impact Assessment

In the early 1950s, the Chinese government established an administrative body called the Committee of the Changjiang Catchment Management to coordinate the development activities of the river valley. The committee started to prepare the basic data sets with regard to the hydrology, geology, and ecology of the region for the Three Gorges project.

Since then large-scale investigations were organized as part of the engineering feasibility and environmental impact studies. These activities can be divided into three phases. The first phase was during the late 1950s, when research associated with the selection of suitable sites for the dam was carried out, focusing upon the geological conditions for two regions containing 14 of the potential sites (the Three Gorges Dam and the Gezhouba Dam are included in these potential sites). From 1956–1958, geological surveys covered an area of around 2,640 km^2, and several suitable sites were identified.[16] In addition, biological resources and fishery conditions were investigated in collaboration with Russian scientists.[17]

The second phase was from the early 1970s to the early 1980s, lasting for more than ten years. Extensive investigations were undertaken, focusing on hydrology, geology, ecology, regional economy, sociology, and archaeology.[18] During this period, it was recognized that the project was complicated and, therefore, it was necessary to build a dam on a smaller scale to test the engineering feasibility. As a result, the Gezhouba Dam, some 38 km downstream of the Three Gorges Dam site and 5 km upstream of the city of Yichang, was built in 1981.

The third phase began in 1984, after an important national conference was held in the city of Chengdu to identify further research required for the Three Gorges Project.[19] Following this meeting, eight research projects were implemented, with regard to sedimentation in the reservoir, migration of the local residents, navigation channel design, flood control and defense, power generation, architecture and dam structure, large equipment, and impact of the project on ecology and environment. The results of these studies were later published as reports, articles, and monographs.[20]

It should be noted that the last project, Assessment of the Impact of the Three Gorges Project on Ecology and Environment, was not included at the beginning. The idea was initially proposed by the Sichuan Province Government in 1982, when the Chengdu Branch of the

Chinese Academy of Sciences was requested to undertake the study. At the same time, the Administration of Water Resource Protection for the Changjiang River organized studies on the impact of the Three Gorges Project on tourism, landforms, and cultural relics. This study was completed in December 1986, producing a series of articles and reports, among which 80 research papers were published in a book.[21] These papers cover a very wide range of concerns, including the fishing industry, ecosystem protection, land resources, river channel geomorphology, environmental geology, oceanographic conditions at the estuarine waters, and resettlement of the local residents. It turned out that these topics are extremely important and have had extensive social ramifications.

C. Construction of the Dam

The project started in 1993 and will be completed in 17 years, by 2009.[22] The construction, according to the plan, consists of three phases: Phase I, 1993–1997, for river closure; Phase II, 1998–2003, for water storage at the preliminary stage; and Phase III, 2004–2009, completion of the whole project. So far, construction has been conducted according to plan. The channel at the dam site was closed in 1997, and the first power generator unit started to supply electricity in 2005. Around 70% of the investment has been used.

IV. Social and Economic Benefits

A. Power Generation

In China, the construction of large hydraulic power stations essentially began in the 1980s, and so far the Three Gorges Power Plant is the biggest (Table 1). With a total capacity of 18,200 mw, the electricity that can be generated will be approximately 85 billion kwh every year,[23] after the power plant is in full operation in 2009. The power plant started to generate power in late 2003. By the end of 2005, some 9.4 billion kwh of electricity had been produced. In 2005, the power generated by all the power plants in mainland China was around 2,470 billion kwh[24]; hence, the electricity provided by the Three Gorges Dam will account for about 3.4% of the total figure. This is a significant contribution, especially for the Changjiang River basin.

Table 1: Some other Large-Scale Hydraulic Power Stations in Use or Under Construction in China, in addition to the Three Gorges Power Plant.

Name of Hydraulic Power Stations	Total Capacity (Mw)	Name of the Catchment Basin	Time of Completion
Xiluodu	12600	Changjiang River	2015
Longtan	5400	Pearl River	2009
Laxiwa	4200	Yellow River	2008
Xiaowan	4200	Mekong River	2012
Ertan	3300	Changjiang River	2000
Pitan	3000	Changjiang River	2011
Gezhouba	271.5	Changjiang River	1981
Lijiaxia	200	Yellow River	1999
Longyangxia	128	Yellow River	2001
Liujiaxia	122.5	Yellow River	1974

B. Flood Control

In the Changjiang River basin, flood disasters have been devastating the area since the earliest civilizations. Historical records show that large flood disasters occurred 214 times during the 2117-year period between 206 BC and 1911 AD.[25] During each of the floods, the loss of human life and property was enormous. Records in the Qing Dynasty show that for most of the years between 1735 and 1910, a large number of counties were affected by flooding events. At that time levee dikes on the riverbanks were the only measure to fight flood hazards.[26] In the 20th century, following the rapid development and population growth of the period, disasters have become increasingly severe.[27] Some representative flood disasters with severe damage to the society are listed in Table 2.

Although many hydraulic engineering projects have been completed, large flooding disasters still occur today, indicating that flood control for the Changjiang catchment is a complicated task. The total amount of water that can be stored in the 48,000 reservoirs in the catchment accounts for only about 15% of the annual water discharge of the river. The Three Gorges reservoir, the largest of these reservoirs, holds a flood defense capacity of 22 billion m^3 or 2% of the annual discharge. Thus, when extreme flooding takes place, the reservoirs alone are not able to prevent it. Nevertheless, the Three Gorges reservoir can play a significant role in reducing the flooding, as indicated by the following estimate for the flooding event of 1954. For eleven days (August 7–16,

Table 2: Some Examples of Flood Disasters Related to the Changjiang River since 1870.

Year	General Descriptions	Literature sources (see Bibliography)
1870	Maximum flow discharge 105,000 m3/s (at Yichang Hydrological Station),	Hong, 1998
1896	Maximum flow discharge 70,600 m3/s (at Yichang Hydrological Station)	Hong, 1998
1931	More than 34 000 km2 of farmland inundated, around 142,000 people died.	Hong, 1998
1935	More than 890,000 km2 of land inundated, around 142,000 people died.	Hong, 1998
1949	Around 18,100 km2 of farmland inundated, with 5,699 deaths.	Hong, 1998
1954	Maximum flow discharge 92,600 m3/s (at Datong Hydrological Station), around 32,000 km2 of farmland inundated, and 33,169 people died.	Hong, 1998; ACRHE, 2004
1981	Maximum flow discharge 85,700 m3/s (at Chongqing Hydrological Station). The disaster occurred in the Sichuan Basin, with around 8,700 km2 of farmland being inundated and 888 deaths.	Hong, 1998
1998	Maximum flow discharge 82,300 m3/s (at Datong Hydrological Station), with 1,562 deaths	ACRHE, 2000

1954) the water level was above the critical level, with a total water discharge of 58 billion m^3.[28] Since the Three Gorges reservoir capacity for flood defense was around 38% of the discharge, the floodwater level could have been reduced by 1 m or more for the middle reach areas, if the reservoir were operating.

At the present time, the strategy adopted for flood defense is to build a system of strengthened dikes and water diversion areas, in addition to the reservoirs. By the early 1990s, some 36,600 km of riverbank dikes had been built along the main channel and the major tributary channels.[29] Water is diverted to the low-lying areas in the middle reach region, which is allowed to be flooded during extremely large flooding events. These areas have a total flood defense capacity of 50 billion m^3.[30] With the completion of the entire system, it can be anticipated that flood disasters will occur much less frequently in the catchment basin.

C. Waterway Transport

Changjiang River is a busy navigation channel for waterway transport. However, the navigation channels feature a number of shoals and reefs, especially in the upper reaches. Through the years, improvements to the navigation conditions have been made, but the river channels in the Sichuan section remain dangerous. After the water level rises to 175 m above sea level, the navigation conditions will be improved significantly, which means that larger cargo ships can be used and the capacity of waterway transport will be increased. Since the ship lock at the Three Gorges Dam was opened in June 2003, there has been an increase in the number and size of cargo and passenger ships. It has been estimated that in the near future, the one-way transport capacity for goods will increase from 10 million tons before the dam construction to 50 million tons.[31]

D. Urbanization

The degree of urbanization in the Changjiang catchment has been relatively high since the mid-19th century.[32] However, urban development is unbalanced between the upper, middle, and lower reaches in terms of the percentage of nonagricultural populations in urban areas.[33] Generally, in the middle and lower reaches there is more advanced urbanization than the national average, but in the upper reaches it is below average. In the Three Gorges region, the major cities include Chongqing and Yichang (for location, see Figure 2). The economic development here is relatively backward, with a much lower GDP than that of the middle and lower reaches.

An important reason for the situation is that in this region the transport facility is poorer; as a result, a large percentage of the population is involved in traditional agriculture. They grow rice and oranges but make very little profit because of inadequate market scale. Many people have continued to live in poverty, with insufficient food and clothes.

Thus, a large project like the Three Gorges Dam represents a trigger mechanism for regional development and urbanization. For instance, after the beginning of the Three Gorges Project, the city of Chongqing became a "Special City under the Central Government," significantly enhancing its status. In the city of Yichang, a small town in the mid-20th century, a transport system consisting of railway, motorway, and the Three Gorges Airport has been established. The Three Gorges Dam has created a large number of jobs for the region. When the Water Diverting Project (to provide water to northern China) is implemented, it can be anticipated that more labor will be required. Further, the energy supplied by the Three Gorges power plant and the improvement to the waterway will be highly beneficial to regional economic development. Today, the Yichang area has been turned into a large urban area, with a booming economy (especially in power generation and tourism).

V. Environmental and Management Issues

A. Modifications to Physical Environments

Construction of any large-scale dam will inevitably cause modifications to the physical environment, both locally and basin-wide. Within the reservoir proper, the excessive water loading after the dam begins to store river water may induce earthquakes. This has been observed in other countries and within China.[34] An earthquake with a Richter scale rating of 6.1 has been recorded at a reservoir on a small river in Guangdong Province. Consequently, at the stage of environmental impact assessment for the Three Gorges Project, geophysical and geological studies were carried out to evaluate the risk of having reservoir-induced earthquakes. Across the region, nearly 400 earthquakes have been recorded since 143 BC, of which 21 caused damage.[35] Analysis indicates that although there were three disastrous earthquakes (i.e., Richter scale of 6.5, occurring in 46 AD, 788 AD, and 1631 AD), generally this region is characterized by weak seismic activities. Based upon an analysis of the stratum and the water loading percolation conditions that determine the intensity of this type of earthquake, it has been surmised that the artificially induced earthquakes will be no more destructive than the natural events of the region.[36]

On the local scale, landslides may occur along the shoreline of the reservoir due to landmass instability after submergence below the water. They may also be triggered by reservoir earthquakes. The reservoir areas have a steep ground slope, which enhances the frequency of landslides. In the feasibility studies, Peng argues that because the rocks here consist mainly of limestone, mudstone, and sandstone, landslides will be present on a local scale but generally their influence on navigation and the reservoir environment as a whole will be minor.[37] However, the actual effect of the landslides should be monitored and evaluated on the basis of *in situ* measurements and observations.

On a basin-wide scale, the engineering project affects the river channel geomorphology. Physical model output has shown that the construction of the Three Gorges Dam will disturb the original morphological equilibrium of the river channel. The reduced sediment discharge (a part of the sediment will be trapped in the reservoir) results in reduction of the suspended sediment concentration and, therefore, contributes to the erosion of the river bed.[38] Thus, channel erosion will take place in the immediate downstream sections. At the same time, the water surface level will be lowered in response to the deepening of the channel. Mr. You and colleagues have argued that such effects will not be significant in the lower reaches.[39] However, in terms of geomorphology, the equilibrium state of a river system is determined by the magnitude and seasonal distribution pattern of the flow and sediment carried by the flow; any changes will result in modifications to the entire system. Therefore, the morphological adjustment following the closure of the dam should be monitored and investigated.

Furthermore, changes in the patterns of freshwater and sediment discharges following the construction of the 48,000 dams will affect the river mouth areas. Records of the suspended sediment discharge from the Changjiang River, measured at the Datong Hydrological Station, show a decreasing trend. Over the last ten years (for the period of 1995–2004), the average value was 2.9×10^8 t/yr, much lower than the long-term average of around 500 million t/yr.[40] This is due to the trapping effect of the reservoirs, in which the Three Gorges reservoir plays an important role. Before the Three Gorges Dam came into effect in 2003, it was estimated that more than 15% of the sediment discharge was trapped in the reservoirs. Today, perhaps more than 40% of the sediment discharge is left behind the dams.[41] As a result of this decrease, the mean suspended sediment concentration of the freshwater from the Changjiang River is also reduced (Figure 4).

Field observations[42] and numerical modeling studies[43] have revealed several consequences of the decrease in sediment output, including modifications to the seabed accretion/erosion and river delta growth patterns. The present Changjiang River delta is a result of sediment accumulation over the last several thousand years. The increase in

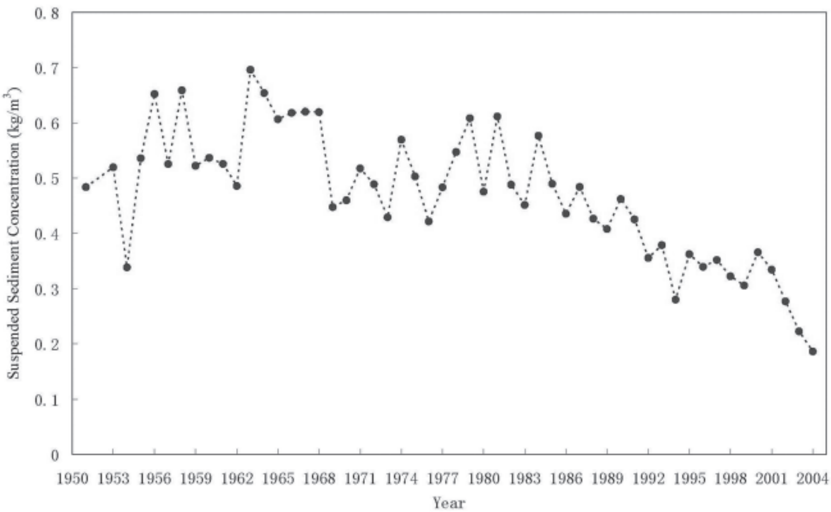

Figure 4: Annually averaged suspended sediment concentrations of the Changjiang freshwater, between 1951 and 2004, calculated on the basis of water and sediment discharge data in Gao and Wang (2006).

land is very important for the region and, therefore, reclamation of land from the sea has been an intensive human activity here for many years. However, the sediment from a catchment basin does not deposit entirely in the deltaic areas; oceanic forces transport some materials offshore.[44] This implies that if the sediment discharge is reduced to a certain level, then accretion will not continue. In fact, in recent years on the Changjiang deltaic coast, erosion has intensified and the shoreline has retreated.[45] Calculations on the basis of a lumped delta growth model show that if the sediment supply of 500 million t yr^{-1} can be maintained, then the delta will continue to grow for another 5–10 km (with influences of regional subsidence and sea level rise), but at a lower rate than before; however, if the sediment discharge decreases to a level of 300 million t yr^{-1}, then the growth will stop.[46] The sediment output is now below this critical value, indicating that the delta will not grow further and the seabed in the estuarine waters will be subject to erosion.

The end of net sediment accumulation will change the carbon burial patterns, influencing nutrient cycling in the marine environment and affecting the primary production in the estuarine and coastal waters. Before the 1980s, every year around 200 million t yr^{-1} of sediment was accumulated near the river mouth, causing a deposition rate of 1–6 cm yr^{-1} over the subaqueous delta.[47] The sediment contained on average 0.53% organic carbon,[48] which was partly from the catchment and partly from the marine environment. Thus, every year around one million tons of carbon would be buried with the sediment in the deltaic areas. Because the seabed accumulation has ceased, the carbon burial will approach zero. This means that the estuarine region will no longer work as a sink for carbon.

B. Influences on the River and Marine Ecosystems

The project has significant influences on both the freshwater and the marine (i.e., estuarine and continental shelf) ecosystems, which has been a big issue for discussion within the country and internationally. In this respect, the protection of precious fishes of the river system is a key point. In the Changjiang River there are more than 300 species of fish.[49] In the waters upstream of the Three Gorges Dam, 196 species have been found, among which about half are migratory species.[50] The dam will interfere with migration routes. Actually, the problem had occurred before the closure of the Three Gorges Dam. The Gezhouba Dam, which was a small-scale structure to test the various hypotheses about the ecological and environmental consequences of the Three Gorges Project, had already prevented the fish from their normal migration. There are three freshwater fishes in the Changjiang River that are protected by law: Chinese paddle fish (*Acipenser sinensis* Gray), paddle fish (*Psephurus ladius*, Martens), and longnose surker (*Myxocyprinus asiaticus*, Bleeker). They are all migrating species and use the upper stream as their spawning grounds. However, since the completion of the Gezhouba Dam, the fish living in the upper steam have remained there, and those living in the downstream sections have had to find spawning places near the dam. It has been found that these fish managed to spawn below the dam, with lower success rates. Techniques of artificial breeding were studied, and so far the technique for Chinese paddle fish and longnose surker has been established. For the fish living in the middle-lower reaches, changes in the hydrological conditions have had some consequences. For example, the flow discharge from the main stream to the lakes influences the number of young fish that move from the river into the lakes.

For other animals in the river, the white-flag dolphin is a representative species, also protected by law. This animal lives in the middle and lower reaches of the river. Because the hydrological and geomorphological conditions have been modified, their habitat is affected.[51] Compared with the situation before the construction of the Gezhouba Dam, the habitat area has been reduced by 200 km. At present, natural reserves have been established to protect the animals.

In terms of the marine ecosystems, the modifications to the oceanographic conditions induced by the dam construction (including the Three Gorges Project) will affect the composition of primary production patterns. This impacts the fishery industry.

The changes in the timing of freshwater discharges are causing longer flushing times in summer but shorter flushing times in winter.[52] In the future, if 10% of the Changjiang River water is transported to northern China, then the average flushing time will increase by around 10% for the shelf waters, with a salinity decrease of around 1 ppt.[53] Furthermore, a combination of salinity changes and increases in the nutrient load in the river water and/or reduction of freshwater discharge result in an enhanced nutrient concentration in the shelf waters. Between 1968 and 1998, the dissolved inorganic nitrogen (DIN) discharge in the Changjiang River increased from 0.2 million t yr^{-1} to 1.4 million t yr^{-1}.[54] Similar changes have taken place for phosphorous. There is a trend of further increase in nutrient input. Thus, with the enhanced salinity (this means the river flow will be confined within an area closer to the coast) and the increasing nutrient load, harmful algal blooms or red tides may occur more frequently than before.

Under normal conditions, there is a positive correlation between the Changjiang River discharge and the fish catch, because large discharge carries with it a large quantity of nutrients, which leads to high primary production and a high biomass of fish.[55] However, because the red tides consume the nutrients before the river plume reaches the open sea, the general pattern described above may be modified. In particular, in response to the reduction in suspended sediment concentrations of the river water (Figure 4), photosynthesis in the shallow waters near the river mouth will be enhanced, intensifying the red tides. The exact impact of such a change on the fishery catch in the estuarine and coastal waters is unclear, and further research is required to assess this ecological impact.

C. Resettlement of the Local Residents from Inundated Areas

According to an analysis of the conditions of the mid-1980s, around 632 km^2 of land (including 300 km^2 of farmland) would be inundated and 0.8 million people would have to move from their home for the Three Gorges Project.[56] The number of migrants increased to 1.1 million in the mid-1990s[57] and now it is clear that 1.2 million have to be resettled. So far, 0.87 million people who lived below the 135 m level (the inundation line for the first phase of the project) have already moved from their homes.

Several suggestions have been proposed for the migration of the local residents. The first suggestion is that the towns and villages should retreat from the waterline to higher places, where the settlements are rebuilt and new land is cultivated for agriculture. This solution is targeted at some of the farmers. So far, this has been carried out and, at the same time, before the inundation the fertile farm soil is being transported to new land. Because of the limitations of the potential land for these uses, this is not considered a satisfactory solution. Only a part of the people could be resettled and absorbed by the modification of the existing towns and villages.[58] Further, if the people have to depend upon the slope areas for their survival, then severe damage to the local eco-environment can be expected. In fact, if the slope land were suitable for cultivation, the local people would have done this long before the project since this area has been under population pressure for a long time.

A second suggestion is that some of the people should move out of their original residence to settle in towns and cities all over the Three Gorges region. Wang and his team analyzed the potential of the city of Yichang to absorb the migrants and concluded that around 150,000 people might be settled in this city. However, it would be problematic for the people, who largely belong to agricultural populations of the region. In order to make a living in the new environment, it would be necessary for them to learn new skills so that they can find a job.[59] In addition to their future economic activities, they will face social and psychological difficulties. It would take some time for them to settle into their new homes.

A third idea is that some of the farmers would still live within the reservoir areas, but they would be transferred to other businesses with help from the state government, rather than continue their farm labor.[60] For instance, the newly created resources for tourism by the reservoir itself may be utilized by the migrants, and environmental/engineering maintenance work on the dam and reservoir also requires workers.

Finally, one proposal suggested that some of the 1.2 million people who have been willing to move to the eastern part of the country would be resettled in other provinces (e.g., Anhui, Jiangsu, and Guangdong Provinces). This represents a support to the project, but they would have to face the problems of making a living and settling into places that are unknown to them. It would take time for them to overcome the difficulties in establishing their new homes.

So far, it has been determined that around 80% of the people will retreat to higher slopes and the remaining 20% will move to new settlements. The total budget for the payment from the state government to the migrants is CNY 18.5 billion (around USD 2.25 billion). This means an average of 15,000 yuan for each of the migrants. Apparently, this amount is too small for them to establish their new settlements. Because of the rapid economic growth triggered by the Three Gorges Project, in the near future more financial support to the migrants should be provided by the parties who have benefited from the project. Recently, the state government announced a new regulation, effective September 1, 2006, emphasizing that additional financial support will be provided for the resettlement associated with large-scale projects like the Three Gorges Project.[61]

D. Cultural Heritage and Tourism

Although the area between the mountains and the water is small within the Three Gorges region, there is a rich historical heritage as well as cultural relic wealth. Archaeological investigations have revealed 1,087 important relic sites so far. From the Old Stone Age to the present time, the historical record of the region is continuous. Hence, the value of the heritage is very great.

Acknowledging this situation, a large archaeological team, consisting of more than 1,000 experts from 110 institutions all over the country, was formed to speed up the collection of cultural relics from these sites.[62] The first stage of the work was concentrated upon the low-lying areas where inundation would take place in 2003, when the water level would rise to 135 m above sea level. During this period, some 1.3 million m^2 of the sites were excavated.[63] Although urgent measures were taken, many historical sites will eventually be buried in the reservoir. The loss in terms of archaeological and cultural value cannot be estimated at the present time. Nevertheless, there is a hope that in the future advanced technology can be applied to undertake underwater archaeological investigations.

Another important issue is the protection of the natural heritage of the region. The natural beauty of the Three Gorges has been well known to the Chinese people since ancient times. It has also attracted travelers from all over the world, ever since the early 20th century.[64] In 2009, when the dam is completed, the reservoir water level will reach 175 m above sea level. What will the influence be on the landforms, and what will happen to the tourism industry? Some of the natural beauty will remain, but the fast-moving turbid water flow, reefs along the waterline, and turbulent eddies will be replaced by a calm, flat water surface. It will be interesting for the tourist to compare the modified landforms with those recorded in historical poems, prose, photographs, and books. Niu has pointed out that some new tourist attractions will be created by the artificial lake.[65] For instance, the rise in water level will inundate a number of tributary channels, revealing sites that were unknown when the water level was low. The dam itself can become an attractive place for tourists. According to this view, although there will be modifications to the landscape, the tourism industry will not be affected.

VI. The Future of the Three Gorges Region

For a complex system like the Changjiang River, it is difficult to give a simple answer to the question of whether or not the Three Gorges Project is good or bad. It depends upon the angle at which we view the general picture, and how we plan for the future. At the present stage of social and economic development, it appears that the project is beneficial to the region in terms of hydraulic power production, waterway transport, flood control, and urbanization, but the project also causes a number of environmental, ecological, and management problems.

In the future, solutions to the environmental and ecological problems will be sought with advanced science and technology. Societal issues regarding regional development, population, and social justice are more complicated. Appropriate and effective management of the region and the entire catchment basin is required, and a joint effort from the public, the government, and the science-technology community is necessary to solve the various problems. ◉

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Notes

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