
Comprehensive Assessment of the Ecological and Environmental Impact of the Three Gorges Project

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THE THREE GORGES Water Conservancy Project (TGP) is a colossal project that has caused public concern in China and attracted global attention in recent years. The Central Committee and the State Council have followed a positive and yet extremely prudent approach toward the final approval of the project. They have clearly stated that an updated report on the feasibility of the project should be prepared on the basis of detailed investigation and assessment. In the report, the assessment of ecological and environmental impacts is one of the most important components. Indeed, recent investigations conducted by the Bureau of Water Resources Protection, Changjiang River, and its associated research institute have been concerned with such major research topics as the selection of the normal water storage level for the reservoir and its impact on the ecological environment.

Wang Chaojun, "Changjiang sanxia gongcheng shengtai yu huanjing Yinxiang de zonghe lunzheng," in *Changjiang sanxia gongcheng shengtai yu huanjing yingxiang wenji* (Symposium on the ecological and environmental impact of the Three Gorges Project) (Shuilidianli chubanshe, 1988), pp. 3-17. The author is affiliated with the Institute of Water Resources Protection, Changjiang River. Translated by Jiaqing Gao and Ngan-chu Liu.

1. History of impact assessment

As early as the 1950s when the Planning Office of the Changjiang River Basin (POCRB) and other related institutions compiled a report on the general planning of the river basin and on the preliminary design of the TGP, several environmental factors relevant to the project were surveyed and investigated. These factors include the impact of backwaters, the effect of human activities on water discharge, reservoir slope stability, earthquakes, resettlement resulting from inundation, siltation, water quality, aquatic organisms, natural sources of virus [sic], and local infectious diseases. Some preliminary results were obtained and were included in the planning report. In 1979, the Institute of Water Resources Protection, Changjiang River (IWRPCR) was established as an associated institute of the Bureau of Water Resources Protection, Changjiang River (BWRPCR). The institute, in collaboration with more than forty institutions of higher education and research, organized research teams to investigate the environmental impact of the TGP. By 1980, a report on this subject was prepared for a normal pool level (NPL) of 200 m. In May 1983, a report on the feasibility of the NPL 150-m scheme was published. A chapter on "The Environmental Impact of Dam Construction at the Three Gorges" was contributed by the institute. During the period when the preliminary design of the TGP was conducted, two research reports, "The Impact of the Three Gorges on the Environment" and "Report on the Environmental Impact of the Three Gorges Water Conservancy Project," were completed. Other research reports on the impact of the project on water quality, climate, soils, vegetation, animals, and human health were also issued. In comparison with other major water resource projects around the world, all aspects of environmental impact of the TGP that should be considered have been evaluated. To ensure the quality of the evaluations, POCRB has secured the services of thirteen environmental scientists as consultants, who, together with other experts, were invited to attend and to present their opinions and recommendations in two symposia held in October 1984 and July 1985.

In May 1985 the State Science and Technology Commission (SSTC) convened a meeting in Chengdu to review the ecological and environmental impact of the TGP. During the meeting, members of BWRPCR presented a paper on "Evaluation of the Environmental Impact of the TGP at Different Water Storage Levels (150-m and 180-m schemes)." They have also participated in the review of ecological and environmental topics sponsored by the SSTC in June–July 1985.

In September 1986, a conference on the ecological and environmental evaluation of the TGP attended by invited experts was held in Nanjing, during which a document entitled "Outline and Schedule for the Evaluation of the Ecological and Environmental Issues of the TGP" was approved. Of the eighteen issues discussed, members of the IWRPCR have conducted research and presented assessments on the following five topics: (1) environmental conditions, assessment, and predictions in the areas affected by the TGP; (2) the impact of the TGP on the drainage of floodwaters in the plains and lake regions in the middle reaches of the Changjiang River; (3) the impact of the TGP on the ecological environment of the river estuary; (4) the capacity for resettlement in the reservoir area; and (5) the impact of the TGP on citrus production. The IWRPCR has also investigated the impact of the TGP on the white crane in Poyang Lake and the habitats of other rare migratory birds, the impact on the spread of schistosomiasis, and the methodology for the comprehensive assessment of the ecological and environmental impact of the TGP.

During two meetings on the ecological and environmental impact of the TGP sponsored by the SSTC in June 1985 and March 1987, it was generally agreed that the most important ecological and environmental problems affecting the feasibility of the project are inundation in the reservoir area and carrying capacity for resettlement. Subsequently, the BWRPCR responded by strengthening its research commitment on the issue of population carrying capacity of the environment. The problem for the reservoir area was analyzed and patterns predicted at the macro scale on the following assumptions: the entire project will be con-

structed in a single phase; water storage and resettlement will take place in stages; and a normal pool level of 175 m will be adopted. Research reports or interim reports on the above research were recently completed.

The TGP is a massive systems engineering project. Its ecological and environmental impact is also a very complex systems engineering problem. At present, evaluation is being conducted from the perspectives of ecology and environment, at several degrees of aggregation, and according to different scenarios, thereby providing scientific evidence for decision making at the macro level.

In evaluating the ecological and environmental impact of the TGP, the whole drainage basin, including the upper, middle, and lower reaches of the Changjiang River, is regarded as a megasystem. It comprises two subsystems, the biophysical and socioeconomic environments. After thorough survey and investigation, eight environmental components and thirty-two environmental factors were selected for study. By means of mathematical modeling, indices of special characteristics, simulation, and comparative analysis, the quantitative and qualitative changes in each factor caused by the construction of the project were studied. Based on the systems perspective and the need to evaluate environmental costs and benefits, evaluation of the total environmental impact of the project with and without remedial measures was attempted.

As the first stage of assessment has basically been done, evaluation work is divided at present into three different categories:

Category I. Issues that have been investigated and definite conclusions drawn. Only supplementary assessment is conducted. These issues include the impact on the local climate in the reservoir area, on water temperature and water quality, on aquatic organisms, on fisheries in the area, on terrestrial plants and animals, on soil conditions and agricultural ecology, on human health, on cultural and historic relics, and the environmental impact of the construction itself.

Category II. Complex and controversial issues such as the impact on the population carrying capacity of the environment, on the ground water in the lake and plains region in the middle

reaches of the river, and on the ecological environment at the estuary. Research is being strengthened both in depth and in breadth.

Category III. Issues that are closely related to other problems, such as the triggering of earthquakes and the stability of the reservoir shores. These are being investigated by research teams where work is clearly divided but properly coordinated. For other issues such as the settlement of migrants, the impact on upstream flood damage, the impact on flood prevention in the middle-lower reaches, and the problem of resettlement due to reservoir inundation, investigation is being done by other groups.

2. Environmental and ecological impact of the Three Gorges Project

In varying degrees, the TGP will have an impact on the ecological environment of the reservoir area, the middle and lower reaches, and even the estuary of the Changjiang River. The effects are both harmful and beneficial, short-term and long-term, present and potential, and revocable and irrevocable. Part of the harmful impact can be mitigated or eliminated by certain remedial measures.

2.1. Ecological impact in the reservoir area

2.1.1. Impact on local climate. The reservoir will have obvious ameliorative effects on the climate in the surrounding areas, with slight increases in average temperature. At present, the mean January and July temperature is 3.4–7.2°C and 28–30°C respectively. The absolute minimum temperature is –4°C in the west and –8.9°C in the east (Zigui County). In comparison, it has been estimated that after the construction of the reservoir, the winter and spring temperatures will increase by about 0.8°C, while in the summer, it will be lowered by about 1°C. The absolute minimum temperature in the reservoir area will likely be 3°C higher. The long-term average number of foggy days exceeds thirty in

the area west of Wanxian County, and in Chongqing it is sixty-nine. After construction, conditions affecting fog formation and thus its frequency of occurrence will not change to any significant degree. At present, wind is slight, with an annual mean speed of 1–1.5 m/s. This may increase by 15 to 40 percent after construction. Relative humidity will also increase by 2 to 8 percent over the current 65 to 85 percent. The annual precipitation will hardly be affected, but its spatial distribution in local areas around the reservoir will be somewhat altered.

The rise in winter temperature creates favorable growing conditions for citrus during the cold months. The increase in instantaneous wind velocity will adversely affect river navigation.

2.1.2. Impact on water temperature and water quality. Normally, temperature stratification occurs in the reservoir water in early April. It is estimated that the temperature of the water released between February and May will decrease by 2.8–4.4°C (4.1°C in April). The period during which the released water reaches a temperature of 18°C will lag by about twenty days, which may adversely affect the reproduction of the four well-known domestic fish species.

Overall, water quality may be expected to improve because of the filtering effect of the reservoir. However, as flow velocity is reduced the dispersion of pollutants is less effective. This, in conjunction with the concomitant industrialization and urbanization in the reservoir area, will lead to worsening of pollution along the shores. It is estimated that the maximum concentration of pollutants will increase by 20 to 30 percent. Therefore, control and management of waste disposal from towns, factories, and mines should be strengthened.

2.1.3. Impact on aquatic ecology, aquatic organisms, and fisheries. After construction of the dam, the structure and function of the aquatic ecosystem will be considerably altered. The species and quantity of zooplankton and phytoplankton will increase. Species composition will likely shift from riverine to lacustrine. The density of primary aquatic organisms may significantly increase. Because of the increase in water surface

area, development of fisheries in certain tributaries and estuaries in the reservoir area will become favorable if effective measures of fish culture are adopted. Between Chongqing and Zigui there are eight spawning sites for domestic fish. They will be completely or partially submerged after the reservoir is filled. Domestic fish will then have to migrate upstream to spawn in the upper sections of the reservoir or tributaries. Between Yichang and Chenglingji there are twelve spawning sites, accounting for 45 percent of the total along the main channel of the Changjiang River. After construction, the spawning environment will be adversely affected. At the Gezhouba (Gezhou Dam), natural reproduction of the Chinese sturgeon, which is a migratory fish species, was observed downstream of the dam. Artificial reproduction of the species has also shown some initial success. To prevent the extinction of the sturgeon, artificial reproduction should be expanded, and fishing should be properly controlled. Variations in water discharge and processes of scour and fill downstream of the dam may affect in varying degrees the habitat of the white flag dolphin.

2.1.4. Impact on terrestrial plants. In the proposed reservoir area, large forest areas do not exist below 200 m. Thus, if the 175-m scheme is adopted, natural vegetation communities will not be severely affected. However, orange groves (*Citrus reticula*) will be the major cash crop affected by inundation. Some 73,900 mu of orange groves will be inundated, most of which are located in western Hubei, and a disproportionately large area of 28,200 mu is in Zigui County. The impact on plants of economic value will be accentuated as such human activities as resettlement and construction begin. Preventive measures should be implemented to minimize such detrimental effects.

Most rare plant species in the reservoir area are found at higher altitudes. The extinction of lowland species can be avoided by transplantation or artificial cultivation.

2.1.5. Impact on the terrestrial animals. At present, the quantity and number of species of wild animals in the reservoir area are decreasing. After construction, the surface water area will be

enlarged, thus creating a favorable environment for such rare animals as the mandarin duck and the otter. This will also lead to an increase in the number of amphibious animals. Birds and wild animals will migrate to higher areas. However, the density of small animals, especially the rat, will soar in farming areas. This will affect people's lives and the production of crops.

2.1.6. *Impact on soil conditions and agricultural ecology.* The reservoir will inundate an enormous land area leading to increased pressure on arable land. Soil erosion will be exacerbated by the resettlement if the environment is not protected. The original agricultural ecosystem must be restructured and ultimately replaced by a new one.

2.1.7. *Impact on the geological environment.* The reservoir area has a tectonic structure characterized by weak earthquakes. Assuming the worst scenario of a continuous fault zone and maximum energy release, an induced earthquake along the Xiannushan-Jiuwanxi fault located close to the reservoir site may reach a magnitude of 5.5 on the Richter scale, which translates into an earthquake severity of 6.0 at the Sandouping dam site.

The Three Gorges is an area of frequent rockslides and landslides. Recently, landslides that severely affected navigation and caused great losses of life and property occurred at Jibazi in Yunyang County and in Xintan. According to recent systematic studies of the environmental geology of the area, it was established that the weakening of the Gorge walls caused by impoundment will not be significant enough to threaten navigation and the structures related to the project. However, in selecting the sites for resettlement, the hazards of slumping and landslides must be fully taken into consideration. Monitoring of the areas where potential landslides may affect navigation should be strengthened and warning systems should be installed.

The rocks in the reservoir area are impermeable and no problem of water seepage is expected.

2.1.8. *Impact on human health.* According to recent investigations, no oncomelania or schistosomiasis is currently found in the reservoir area. However, suitable habitats for oncomelania and

favorable conditions for the dispersion of schistosomiasis are found in some local areas. Thus, environmental changes in the area should be investigated, and the conditions for transmission should be controlled and monitored. After construction, the hazards of flooding and waterlogging in the middle and lower reaches of the Changjiang River will be mitigated. This would be helpful in preventing and controlling the dispersion of schistosomiasis in the Jiangnan and Dongtinghu plains.

Once the reservoir is impounded, breeding of *Anopheles* mosquitoes along the mainstream is unlikely, but breeding is favorable at the confluence of tributaries and local depressions. Appropriate measures are required to prevent the outbreak of malaria.

To prevent and control other diseases, especially haemorrhagic fever in the reservoir area, attention should be paid to mice known to be carrying the virus. After impoundment, they will migrate to the higher areas. This will pose a serious threat to human life, and preventive measures should be strengthened. Moreover, attention should be paid to other diseases with natural dissemination sources such as paragonimiasis and schistosomiasis to prevent their transmission.

2.1.9. *Impact on cultural relics and historic sites.* The Three Gorges is a key scenic area in China. After impoundment, the following cultural relics and natural features will be submerged: Zhangfei Temple in Yunyang County, the "stone fish" in Fuling, the karst landscape in the Xiling Gorge and on the banks of the Daning River (such as "ox's liver and horse's lung" and "military books and treasured swords"), the carved writings on the walls of the Qutang Gorge, the Dual Temple in Jiefang, Quyuan Temple in Zigui, the Qiujiang Pavilion in Badong, and other well-known historic buildings and rock formations along the river.

With a higher water level and a broader water surface, the attractiveness of the gorge will be diminished in sections where the relative relief is limited. In most sections where the relative relief is high, the aesthetic appeal of the gorges will remain intact.

2.1.10. Environmental impact of construction. The TGP involves massive construction work, a high degree of mechanization, and concentration of manpower. There are a great number of potential problems, such as shore pollution, air pollution, noise, and changes in the local landscape. Diseases such as malaria and hepatitis may occur. The sanitary condition of the construction site and the health of the construction workers should be monitored and protected.

2.2. Impact on ground water in the plains and lake region in the middle reaches of the Changjiang River

The section of the Changjiang River between Zhicheng and Chenglingji is called "Jingjiang." To the north of the river lies the Jiangnan Plain, which is characterized by fertile soil and abundant rainfall. It is one of the most important grain production bases in China. The four-lake region (Changhu Lake, Sanhu Lake, Bailu Lake, and Honghu Lake) is a low-lying hinterland of the Jiangnan Plain, criss-crossed by rivers and canals and known as the "land of plenty" in Hubei province.

At present, the bed of Jingjiang is 1–2 m higher than its surroundings. During floods, the water level is 6–13 m above the adjacent land. This imposes a flooding and waterlogging hazard in the area which is aggravated by the coincidence of the flood and rainy season. Traditionally, the lakes in the Jiangnan Plain have been important regulators of runoff, flooding, and waterlogging. However, the lake areas have been dramatically reduced due to years of alluviation and overreclamation. Their regulatory capacity has been depleted while the frequency of floods, droughts, and waterlogging has been greatly increased. The expansion of cultivated fields into low-lying lake areas has led to the deterioration of drainage conditions and the rise of the water table, causing waterlogging in fields of the lowland lake areas. To mitigate these problems, pumping stations have been constructed between Chenglingji and Xintankou.

The four-lake region is a broad alluvial plain, the level of

which is coincident with the elevation of the first fluvial terrace. It is underlain by Quaternary deposits. The region is surrounded by water bodies on three sides and by hilly areas on the remaining side. Its elevation decreases from northwest to southeast, ranging from 24–35 m at its highest point to 21 m at its lowest. At present, the elevation of areas along the Changjiang River is higher than that of the hinterland for a number of reasons, including previous breaching of embankments along the Changjiang and Hanjiang rivers and the problem of siltation. The hydrogeological characteristics of the region are closely related to the regional geology and geomorphology. According to the analysis of drilling logs, ground water in most parts of the region has two layers: an upper layer of phreatic water (or shallow ground water) and a lower layer of artesian water. They are separated by an impermeable layer which is 5–15 m thick. The phreatic zone, which occurs entirely in Holocene deposits that show complex changes in properties due to the shifting of river channels and lake locations, has a thickness that varies from 3 to 8 m. Its depth below the surface varies with both topographic conditions and season. Actual data indicate that its depth is not only controlled by rainfall but also related to irrigation methods and the capacity of the drainage system. During the flood season when rainfall is abundant, the depth of ground water in the alluvial plain along the Changjiang River is 1–3 m, and in the lowland lake region, 0.2–0.4 m. In winter, its depth within the lakeshore region is around 0.5 m. The relationships between the ground water level at the Qigenwa area, Jianli County, and both the water level at the Changjiang River and the total ten-day rainfall have been examined. With a small time lag, ground water level rises in response to rainfall, but it is not significantly affected by the fluctuation of the river water level.

The artesian zone occurs in Quaternary deposits of alluvial sand and gravel which are overlain by argillaceous material located 10–30 m below surface. However, because of the range of flow conditions under which these argillaceous deposits are formed, their thickness varies greatly, with a maximum of about

20 m. In comparison, the artesian zone is 90–110 m in thickness. The artesian zone is recharged either laterally or vertically by other aquifers. During the flood season, when the water level at the Changjiang River is higher than that of the artesian zone, recharge by river water occurs. In the dry season, due to the lower river level, reverse flow occurs. However, the aquifer only dips gently at a gradient of about 0.7 percent away from the river. Thus, the hydraulic gradient is small, flow velocity is low, and the level of river water has little influence on artesian water level. This is demonstrated by data from six observation wells located near the Guanyin Temple at the Jingjiang embankments where the river water level is considerably higher than the adjacent land. Continuous monitoring since the early 1970s shows that the influence of river water level decreases away from the river. Beyond 2,438 m, changes in the artesian water level are not in phase with the river water level.

In addition, through the analysis of the coefficient of soil permeability (K), it was found that the surface material in the embankment area which has a clay loam or sandy loam texture has an average K value of 1×10^{-5} to 4×10^{-5} cm/s. The subsurface material is fine sand whose K value has an average of 3×10^{-4} to 4×10^{-4} cm/s. This shows that the velocity of ground water flow is very slow. If the dry season lasts for at least 150 days, the distance affected coincides fairly well with the above observed range. In general, the water level of the Changjiang River has little impact on the groundwater level in the four-lake region.

After the construction of the TGP, the water in the four-lake region will be drained by the Xintankou pumping station. In years with moderate precipitation, the Changjiang River water level will rise by about 0.75–1.0 m during January–April. Elevation of the area near Xintankou ranges from 22 to 24 m. The river water level is about 0.5–5.4 m higher than that within the four-lake region. But the water level just beyond the pumping station is higher than the water level behind the embankment. Therefore, the construction will not substantially affect the drainage of flood water and ground water. In May, the actual and projected mean

water levels of the river are higher than those within the four-lake region both before and after construction. In October, because the reservoir is allowed to fill, the amount of regulated flow is less than the preconstruction discharge. This will require advancing the date for opening the sluice gate of the station and is conducive to the lowering of the water table. After construction, because the amount of displaced water will be reduced due to the rise in the water level of the river, the operating schedule of the Xintankou pumping station and small ports in Honghu County will have to be modified. In January and February when the water level of the river is the lowest, the capacity of the Xintankou pumping station should be utilized to the fullest so that the water levels of the major drainage canals in the four-lake region and of Honghu Lake can be lowered, thus expediting the rapid lowering of the water table in the cultivated areas. It is also possible to speed up the process by using the recently constructed Xintankou station and other electric pumping stations along the river. The additional cost will be minimal.

The above discussion shows that the construction of the TGP will not raise the water table in the four-lake region, and gleization and paludification will not be accentuated. On the other hand, the construction will alleviate the burden of local flood control and offer large quantities of inexpensive electricity. It will then be possible to increase drainage facilities, improve soil conditions, modify inappropriate irrigation and drainage methods, and reconvert some paddy fields back into lakes. In so doing, the hazards of flooding and waterlogging in the region can be mitigated.

2.3. Impact on the ecology and environment at the estuary

2.3.1. Impact on water discharge at the estuary. After construction of the TGP, the annual water discharge into the East China Sea in years of both moderate and low flow will remain unchanged. However, its seasonal distribution will be altered. For

instance, at the Datong hydrological station, located near the estuary and unaltered by tidal water, discharge will slightly decrease during October–November but will increase during January–May due to the regulation of the reservoir. No change is anticipated during the other months of the year.

If the 175-m scheme is adopted, the discharge in October will be reduced by 20 percent in the years with normal rainfall and by 17 percent in the years with heavy precipitation. However, runoff at the Datong station will still be greater than 33,000 to 40,000 m³/s. This discharge is still within the observed range for the same month prior to construction. In dry years, the reservoir stores water in October and November, thus reducing runoff at the station by 5,450 m³/s in October and 3,000 m³/s in November. This is equivalent to a discharge reduction of 32.4 percent and 18 percent in October and November, respectively. Statistical analysis of the daily discharge records from 1972 to 1984 suggests that, during October–November, the frequency of occurrence of a discharge less than 16,000 m³/s at the station will increase from 2.12 to 3 days per month. Therefore, even during dry years, flow reduction in October–November due to the presence of the reservoir will have little impact on water discharge in the estuary. However, the above discussion does not take into account the additional discharge resulting from the improved scheduling of the regulated flow and the compensatory effect of flow from tributaries and lakes downstream of the dam. Because the station is 640 km away from the estuary, which is one-third of the total distance from the Three Gorges to the estuary, the additional discharge from a drainage area of approximately 100,000 km² would certainly increase the discharge at the estuary.

During January–May, the estimated regulated flow will increase by 1,000–2,000 m³/s, and thus the dry season discharge at the estuary will be increased. By referring to data of the January–April period recorded from 1972 to 1984, it can be shown that discharge below 10,000 m³/s at the station during October–November will be reduced from 10.58 to 6.23 days per month.

Such a reduction is significant from the perspective of water quality because dilution will be effectively increased, the concentration of chlorides will be reduced, and the frequency of occurrence of pollution will be diminished.

2.3.2. Impact on sediment at the estuary. The impact of the Three Gorges reservoir on sediment transport and on water discharge in the lower reaches of the river is different. During the initial period after construction, inflow and outflow of sediment at the reservoir will not be balanced. About 70 percent of the sediment will be trapped and 30 percent will be exported. Because a discharge of less than 60,000 m³/s will flow through directly, and even for higher flows, only peak flow will be slightly reduced, changes in the sediment carrying capacity of the flow will be minimal. Thus, water issuing from the dam with a low sediment concentration will scour the downstream river channel. Eventually, farther downstream, sediment concentration will rise to a level compatible with the capacity of the flow. A similar tendency has been observed at a number of reservoirs both at home and abroad. For instance, at the Sanmenxia Reservoir, of the 6.76 billion tonnes of sediment reaching the reservoir from September 1960 to October 1964, 2.17 billion tonnes were trapped. But 2.31 billion tonnes were scoured from the channels below the dam, yielding a total of 4.48 billion tonnes at the estuary, which is approximately 66 percent of the sediment reaching the reservoir. Under natural conditions, the sediment delivery ratio at the channels of the lower Huanghe River is 0.75. Thus, without the dam, the total sediment discharged into the Bohai Sea would have been 5.07 billion tonnes during those four years. In comparison, sediment load at the estuary was still 88.4 percent of that discharged without the reservoir. Thus, as long as the amount of water discharged from the reservoir is not lowered, and peak flows are not excessively reduced, there will be minimal changes in the sediment load of the flow. In addition, a large portion of the middle and lower reaches of the Changjiang River is located in alluvial plains where sediment available for scouring is abundant. As a result, water issuing from the Three

Gorges reservoir during the initial period of operation will scour the 1,800-km-long channel downstream. Thus, the total sediment load discharged into the East China Sea will not be significantly reduced. Over a long period, say fifty years, it is expected that the sediment delivery ratio at the reservoir will reach 0.8. After eighty years, it will be higher than 0.9, by which time most sediment will be exported, a situation that is virtually the same as before construction. In general then, the Three Gorges Reservoir has a limited regulating effect, most of which is seasonal. It will have minimal effect on water discharge and sediment load in the middle and lower reaches of the Changjiang River and its estuary. Therefore, no major impact on the ecology and environment of the estuary is expected.

2.3.3. Impact on the incursion of sea water. The degree to which the incursion of sea water would occur depends on the discharge of the Changjiang River. The higher the discharge, the smaller the area affected by sea water and vice versa. Data on mean monthly salinity recorded from a ship-based marine hydrological station located 67 km downstream of Wusongkou show a high negative correlation with the mean monthly discharge measured at the Datong hydrological station. The period of high salinity tends to occur during December–April, with the peak in February. June–October is a low salinity period, with the minimum in July. After construction, because of the increase in regulated flow, the level of salinity at the marine observation station in February will decrease by 1.3 percent even during a dry year. In fact, the salinity level at the estuary of the river throughout January–May will be improved.

In Shanghai, the water for industrial, agricultural, and domestic uses is mainly derived from the Huangpu River, along which eight waterworks are located. Those waterworks affected by salt water incursion are Wusong, Zhabei, and Yangpu. They are respectively 1.7 km, 7.1 km, and 21.7 km away from Wusongkou. At present, the international and domestic water quality standard is 250 ppm of chloride for potable water. Usually, a figure of 100 ppm indicates that the water quality is affected by salt water

incursion. When the chloride level exceeds 500 ppm, the water becomes a serious hazard for irrigation and domestic uses. Data collected from 1972 to 1985 show that when the discharge at the Datong hydrological station exceeds 20,000 and 18,000 m³/s, the probability for the chloride level at the Wusong waterworks (which is closest to the estuary) to be >100 ppm and >250 ppm respectively is extremely low. Moreover, the mean discharge at the Datong observation station in October over the last forty years is 35,700 m³/s. After construction, the regulated flow will be reduced by about 8,400 m³/s during years with normal precipitation. Even so, the discharge at the station will exceed 20,000 m³/s for 89 percent of the time and the water quality standard at the Wusong waterworks can be met. However, in dry years when the discharge at the station in October is <18,000 m³/s, the salinity level in the Wusong waterworks will exceed 250 ppm. Statistical data show that during the October–November period when impoundment at the reservoir occurs, the frequency of occurrence of discharge >18,000 m³/s will be reduced by ten days per year. The exceedence probability will be reduced from 95 percent to 80 percent. Thus, the storage of water in the reservoir during dry years will have considerable impact on the water quality at Wusongkou. However, the probability for this to occur is not high, and such impact can be reduced in the future by adjusting the scheduling of water regulation at the reservoir.

After construction, the average regulated flow in January–April will be increased by 1,000–2,000 m³/s. During the same period, the mean monthly discharge at the Datong station is 8,900–20,700 m³/s in dry years. Thus, the effect of the increased discharge on reducing salinity is obvious. Apart from reducing the peak chloride concentration, the frequency of occurrence of chloride concentration at the Wusong waterworks >100 ppm and >250 ppm could also be reduced by approximately ten and fifteen days respectively.

2.3.4. Impact on the nutrient availability at the estuary and on fish resources of the adjacent seas. Due to its enormous drainage basin and extensive river network, the Changjiang River trans-

ports a tremendous amount of nutrients which are inputs into the water body for various physical, chemical, and biological processes that occur naturally, and for various human activities. A relatively large portion of the nutrients transported in tributaries and through lakes eventually enter the East China Sea. They become the major food sources for marine organisms there.

The effect of the reservoir on nutrients is to intercept them, resulting in local deposition. However, the effectiveness of interception is closely related to the water transit rate within the reservoir. Because the Three Gorges Reservoir is designed to regulate seasonal flow and thus will maintain a high transit rate, the impact on interception of nutrients especially during the flood season is insignificant. Moreover, only 20–30 percent of the nitrogen and phosphorous loadings are derived from upstream of the dam, and the bulk of nutrients entering the estuary originates from an extensive area in the middle and lower reaches of the river basin. Therefore, the construction of the dam will not have an obvious negative impact on the availability of nutrients at the estuary.

Because of the large volume of available nutrients, a favorable marine climate, and geographic location, the estuary and the adjacent seas of the Changjiang River are important fishing grounds in China. After construction of the reservoir, the regulated flow will be increased during January–May. Considering the life cycle of the fish species in the estuary, most will migrate to the outer seas during the winter months of January and February. At that time, marine organisms are inactive due to the low temperature, and their demand for nutrients is low. Thus, changes in water discharge and nutrient availability have little effect on the fishing grounds during this season. However, during March–May when the temperature ameliorates, the fish begin to migrate to the estuary and the adjacent seas to spawn and feed. An increase in discharge brings more nutrients and is favorable for the increased productivity of fish species in the estuary and the adjacent seas, as well as to the species that migrate upstream to spawn. Thus, on the whole, the impact of the increased regulated flow on fish-

eries at the estuary and adjacent seas is mainly positive. In October–November, the regulated flow is reduced, and so are the nutrients transported. But by this time, winter is approaching and the plankton population is dwindling. Many fish species are on the verge of migrating to the outer seas. The demand for nutrients is also reduced. Thus, the negative impact of the decreased discharge on fisheries in the estuary and the adjacent seas is minimal during this season.

In addition, the decreased discharge in October may cause the shifting of the convergence zone of the fresh and sea water by several kilometers, thus resulting in the displacement of the fishing ground as well. Such displacement will be greater in dry years but would not be sufficient to cause the complete disappearance of the fishing ground. The fish habitat in coastal areas is more strongly affected by the distribution and shifting of the injected bodies of fresh water. However, changes in the location of the injected fresh water bodies is mainly influenced by black tides, the warm current from Taiwan, and northern cold currents. The effect of water discharge from the Changjiang River is subsidiary.

From the above discussion, it can be concluded that the TGP will have a considerable impact on the ecology and the environment of the river estuary, but major changes are not anticipated.

3. Population carrying capacity of the environment for the resettlement area of Three Gorges Reservoir

After the Three Gorges Reservoir is impounded, vast areas of land will be flooded and the large number of people displaced will have to be resettled locally but at higher elevations. The population carrying capacity of the reservoir area plays an important role in determining whether the local economy will continue to develop, whether degradation of the ecological environment can be avoided, and whether the people displaced can be satisfactorily resettled. This is a crucial factor in determining the success of the project.

The population carrying capacity of a region refers to the size of population that can be maintained at specific production levels, living standards, and environmental quality. It is related to the natural environment, in particular the region's natural resources and socioeconomic bases.

The population carrying capacity of the environment is determined by its level of productivity. It reflects the extent and efficiency of the exploitation of natural resources. With increasing productivity, the human ability to transform and harness nature will improve and the population carrying capacity of the environment will gradually expand. However, such expansion has limits because it is constrained by conditions of natural resources, the total environment, and the ecosystem.

3.1. Present population carrying capacity of the Three Gorges area

The proposed Three Gorges Reservoir is located at the junction of Sichuan and Hubei provinces, bisecting the southern foothills of the Daba Mountains and the hilly area in western Hubei. The topography of the reservoir area is complex. It is characterized by high mountains, steep slopes, incised river valleys, and high relative relief. Mountains and hills account for over 90 percent of the area, while the remainder are river valleys and floodplains. With poor agricultural resources and weak industrial foundation, the area has long been the target for state support. The poor economic foundation and limited investment have led to slow economic development and widespread poverty. Most old cities and towns of the area have an irregular street pattern. The streets are narrow and the population densities high. At present, the reservoir area remains economically backward, with poor environmental conditions and a relatively small population carrying capacity.

In the nineteen counties and municipalities along the shores of the proposed Three Gorges Reservoir, there is a total population of 13.585 million, an area of 54,200 km², and a population den-

sity of 251 persons per km². This density is more than double that of the national average.

The total cultivated land in the reservoir area is 14.187 million mu, or 1.04 mu per person, which is about two-thirds of the national average. Of the existing cultivated land, 60 percent is slopeland under dry farming, one-quarter to one-half of which has a slope gradient exceeding 25°, and "hanging slopeland" in which "harvest is left at the mercy of God." In Wanxian County, for instance, slopeland steeper than 25° accounts for 25 percent of the total cultivated land area. It is 40 percent in Kaixian County, 47.9 percent in Yunyang, and 53 percent in Wushan. If the slopeland is converted into forest land, per capita acreage of cultivated land will be substantially reduced.

The level of grain output in the reservoir area is low, with yields averaging merely 208 kg per mu, which is 15 kg less than the national average and less than half of that in the lower and middle reaches of the Changjiang River.

The total grain output in the reservoir area was 5.18 billion kg. The per capita output was 327.5 kg in 1984, which is less than that in Hubei province by more than 135 kg, in Sichuan by more than 75 kg, and even the national average by over 50 kg. The area has been barely self-sufficient in recent years.

Present forest cover in the reservoir area is low. Apart from several counties in western Hubei which have forest cover exceeding 25 percent, Wanxian County in eastern Sichuan and the counties and municipalities located along the reservoir shores in Fuling Prefecture have only 5–10 percent cover. Soil erosion is serious, and the ecological environment is undergoing degradation that is self-perpetuating.

The gross value of industrial and agricultural output in the reservoir area was 7.4 billion yuan in 1984, of which 3.68 billion was industrial output and 3.72 billion agricultural output. The per capita output value of industry and agriculture was 545 yuan, which was 354 yuan less than the national average of 899 yuan. The per capita output value of industry was 271 yuan, which was 323 yuan less than the national average of 594 yuan.

The low level of productivity directly limits the population carrying capacity of the environment. The excess supply of urban and rural labor is related primarily to the production conditions of society.

Based on these conditions, it is clear that the major reasons for the relatively small population carrying capacity of the reservoir area at present are the low level of productivity, its backward economy, and the incompatibility of economic development and population increase.

3.2. Impact of reservoir impoundment on the carrying capacity of the environment for resettlement

According to the 175-m scheme, the TGP will inundate areas affecting nineteen counties and municipalities. The upper tail of backup waters would reach Mudong in Baxian County, 38 km downstream from Chaotian Gate in Chongqing. The reservoir will have a surface area of 1,028 km², a length of 600 km, and an inundated area of 604 km².

Of a population of 714,500 to be displaced, 54 percent are urban residents and 46 percent rural. Kaixian County will have to resettle 92,000 residents, the largest number compared to other localities. Four counties and municipalities will have to resettle 60,000–80,000 people each; five counties to resettle 40,000–60,000 people each; two counties to resettle 10,000–30,000 people each; and seven counties to resettle less than 10,000 people each. Of the population displaced by the reservoir, about 114,200 are already residing in the twenty-year flood zone. This is because the flood prevention standards in the riverine cities and towns were unduly low.

Though the absolute number of people displaced is considerable, they are distributed along the banks of the 600-km-long reservoir, averaging 595 persons per km of shoreline. In total, they account for 5.3 percent of the total population of the nineteen counties and municipalities. Moreover, the impact of resettlement on population density is small, with an expected increase of only two persons per km².

After impoundment, an area of 348,300 mu of cultivated land will be inundated, accounting for 2.46 percent of the total cultivated land of the nineteen counties and municipalities and including 1.4 percent of the total paddy field area. The per capita cultivated land area will be reduced from 1.04 to 0.97 mu. An area of 73,900 mu of citrus groves, or 6.7 percent of their total, will be inundated. Zigui County will be hardest hit with 56.5 percent of its existing citrus groves area inundated. In Badong, it is 24.5 percent.

Most cultivated land affected is largely in river valleys with favorable soil and water conditions, and high multiple-crop indices and yield. According to one estimate, the total loss of grain output caused by inundation will be about 150 million kg, or 2.8 percent of the total grain output of all counties affected. This is equivalent to a loss of 44 million yuan, or 2.1 percent of the agricultural output value in the reservoir area.

Local facilities inundated by the reservoir will also include 620 industrial and mining enterprises, with a total fixed asset of 804 million yuan. In addition, 957 km of roads, hydropower and thermal power installations with a capacity of 67,000 kW, and 1,133 km of high voltage power transmission lines will be flooded.

The major enterprises affected include those involved in food processing, textiles, machine-building, chemical, coal, electric power, and building material. Because their foundations are weak, production facilities poor, and technology primitive, the level of production of these industries is very low. If the monetary compensation resulting from inundation is to be invested in technical transformation and technological renewal, the productivity of the industries will expand considerably and the level of output will improve substantially.

In general, the construction of the reservoir will inundate part of the existing resources, causing considerable damage to production facilities and the life-support system. Because of the large number of people displaced and the weak economic foundation of the area, resettlement to higher elevations will exert

greater pressure on the land. If effective measures are not adopted, the ecological environment will be degraded, affecting, to a certain degree, the population carrying capacity of the environment. While the difficulty of resettlement is immense, the population to be displaced is scattered, and the proportion of the population to be displaced in the nineteen counties and municipalities is not excessive. These conditions are favorable for the organization of resettlement.

3.3. Approaches and measures of expanding the population carrying capacity of the reservoir area

Of the total population to be displaced, 54 percent are residents of cities and market towns. This nonagricultural population will be resettled en masse, according to the existing cities and work units. There will be no employment problem as they will retain their existing jobs, and the supply of commodity grain will be maintained. After several years of surveying, sites for relocation of most of the cities and market towns have been selected and relocation planning is underway. In the course of site selection, it was found that the available sites are higher than 182 m, and work involving large amount of land leveling and massive construction is required. These are not simple tasks given the constraints posed by existing topographic conditions. Nevertheless, suitable sites are available and construction in the resettlement area is planned according to the existing national standards. Housing and urban facilities will be substantially improved, residential population density will be reduced from 17,000 to 12,500 persons per km², and the built area will be increased by 50 percent. Also, the environmental conditions will be greatly improved.

Of the total population to be displaced, 46 percent is engaged in agriculture, primarily in farming. After inundation and resettlement, they may either continue as farmers or new jobs will have to be arranged. This is the crux of the problem when investigating the population carrying capacity of the Three Gorges

area. If the residents in the resettlement area could be assured of an income equivalent to or higher than the original level and of a prospect of continuous improvement, then the problem of resettlement capacity can be resolved.

The following section is a discussion of the preliminary analysis regarding the conditions for expanding the population carrying capacity of the reservoir area.

3.3.1. Abundant resources and high potential for economic development in the reservoir area. The Three Gorges reservoir area is one of the regions in China with relatively abundant natural resources. As far as its natural conditions are concerned, the reservoir area is a typical humid intermediate subtropical zone, where the maximum amount of sunlight, heat, and rainfall received occur in the same season. Besides, topographic variations are conspicuous. All these provide favorable conditions for the growth of various living organisms. According to statistics from local sources, there are 10 million mu of unused hill-land and grass slopes, which can serve as land reserves for the development of macro agriculture (*da nongye*). Granted that large portions of the relatively level and good-quality land will be used for establishing new cities, towns, and villages, part of the low-lying unused hill-land and grass slopes do have great potential to be exploited as farmland and economic forest land. However, land use must be determined according to local needs and conditions, and soil and water conservation and farmland capital construction work must be strengthened. This is to prevent the degradation of vegetation and the ecological environment, and the intensification of soil erosion. Also, there are 9.6 million mu of unforested land which can be used to develop forests and to make up for part of the losses caused by inundation.

The reservoir area is rich in various mineral resources worthy of exploitation. Preliminary surveys show that they include gold, copper, iron, rocksalt, natural gas, barium, mercury, phosphorous, aluminum, and so on. There are also large amounts of building material resources such as marble and limestone. The reserve of rocksalt is the largest, now estimated at 150 billion

tonnes, which can serve as an important material for salt-related industries. Coal is widely distributed over the area. At present, there are small coal mines in almost every county, with an average annual output of 200,000 to 500,000 tonnes each. The reserves of iron and phosphorous are abundant but are extracted only on a small scale. The reserves of natural gas are about 250 billion m³, while the proven reserves of other resources such as barium are 46 million tonnes, one of the largest ore bodies in China. It is both necessary and practicable to establish in a planned manner a group of industrial, mining, and township enterprises after the completion of dam construction. In particular, labor-intensive manufacturing industries should be established to absorb part of the resettled workers and to develop the local economy. Certainly the development of industrial and mining enterprises should not cause pollution.

The Three Gorges area, which is endowed with numerous charming mountains and rivers, scenic spots, and historic relics, is a world-renowned tourist area. While part of the area has been developed, many tourism resources have yet to be exploited because of limitations of transportation development. After the construction of the Three Gorges Dam, improvement in transportation and the emergence of new cities and towns will undoubtedly create favorable conditions for exploiting the area's tourism resources. Hence, the development of a comprehensive tertiary industry emphasizing tourism will be fostered. As tourism develops, construction, building material, and transportation industries will grow correspondingly, providing more employment opportunities for the resettled workers. Moreover, there are large amounts of hydropower and aquatic resources to be exploited.

Rational exploitation and utilization of different resources in the area can transform resource potential into economic gains. The existing population carrying capacity of the environment can thus be expanded, and the ecological environment will improve.

3.3.2. Develop the area's strong points, adjust the agricultural and industrial structures, and expand employment chan-

nels. Rural migrants in the reservoir area should continue as farmers. Based on the resource, topographic, and soil conditions of the area, we should adjust the geographical distribution of crops and the industrial structure; develop macro agriculture; diversify the rural economy by developing farming, forestry, and animal husbandry according to local conditions; develop a superior economy; and build up a base for producing agricultural commodities. According to surveys conducted by Chinese and foreign experts, the region bordering the 2,000-km-long river channel from Yibin in Sichuan to Jiujiang in Jiangxi has a mild climate, with abundant rainfall, a long frost-free period, and fertile soil. It is an ideal region for growing fruits such as *Citrus reticula*. In the Three Gorges area, which is located within this region, citrus groves are cultivated at present on 1.1 million mu of land. The total output amounted to 156,000 tonnes or 150 million yuan in 1985. In fact, growing citrus has become one of the economic pillars of the reservoir area. Moreover, the potential for further development remains high. Based on the development plans of various counties, the acreage of citrus will increase by 720,000 mu and 1.22 million mu in the years 1990 and 2000, respectively. The annual total output will reach 310,000 tonnes and 1.1 million tonnes, or 300 million yuan and 1 billion yuan, respectively. Auxiliary enterprises involved in preservation, processing, and transportation will be established correspondingly. Not only will they raise the income of the in-migrants, but they will also create jobs for a large number of in-migrants. This is the most promising measure in developing the local economy. Fuling in Sichuan has enjoyed a long history of producing preserved vegetables, the operation of which has been integrated from the stage of raw material production to research to processing and marketing. To enhance the advantages of producing preserved vegetables, we should strive to forge the links of commodity circulation and open up the international market. The production of tung oil in this area has already accounted for one-quarter of the country's total and ranks first in export. However, there is still room for further expansion in export of processed tung oil. Pre-

cious medicinal herbs produced in the area are another item that enjoys good prospects for expansion.

Relatively large areas of unused hill-land and grass slopes are found in each county of the reservoir area. Raising dairy cattle and other herbivores through the growing of pasture in this type of land and land on the edge of the reservoir can yield high economic returns. Certainly, effective measures should be adopted and farmland capital construction and scientific farming methods strengthened to increase yield. In short, measures adopted should be suited to the local conditions, bringing into full play the potential of the local resources. People displaced should be resettled through different methods. Lateral economic integration within the province and outside, in China and abroad, should be strengthened to activate economic development.

3.3.3. Implement special policies beneficial to the economic development of the reservoir area. The TGP, which involves massive resettlement, is a project that relates to many areas of policy making. The project has an important bearing not only on the welfare of the people to be displaced, but also on the area's future economic development and long-term stability. It is therefore necessary to adopt a resource-exploitative resettlement policy, which integrates the construction, resource exploitation, and economic development of the reservoir area with the task of resettlement, and which constitutes an organic component of the entire construction project. In so doing, greater economic, ecological, and environmental benefits will be obtained, and certain special policies beneficial to the economic development of the reservoir area can be implemented. For instance, the area inundated can be linked to the benefits of power generation of the TGP. That is, for a specified period, part of the revenue from power generation can be transferred to the reservoir area as construction funds (e.g., at 0.2 cent per kWh, a total of 60 million yuan can be transferred annually). Also, the inundation of large amounts of land will result in a decline in grain output and a change in industrial structure which will cause conversion of part of the agricultural population into nonagricultural population.

This will require a corresponding increase in the supply of commodity grain. It would be desirable to provide tax exemption or to apply other preferential policies to agricultural, industrial, and commercial sectors to support the local economy. The cultural standards of the residents resettled should be raised through investment in education.

3.3.4. Resettlement should be compatible with the area's economic development and ecological environment. With a relatively backward economy and fragile ecological environment, the reservoir area is facing a resettlement problem that is a very complex social and ecological issue. Therefore, the construction design of the project should also incorporate a comprehensive plan for resettlement. The issues of resettlement, economic development, land management, and ecological and environmental protection should all be taken into consideration in a unified and rational manner. In developing urban and township enterprises, pollution control should be carried out to maintain ecological balance. In the upper reaches of the Changjiang River and in the reservoir area, soil conservation programs should be properly implemented to prevent soil erosion. It is important to develop a new and improved system of human ecology, an agreeable, ever-improving environment which can meet the productive, domestic, and ecological requirement of the residents.

In general, resettlement can follow the principle of relocating existing administrative units (i.e., districts, townships) upslope. This does not mean, however, that all the people displaced will be "packed" into the narrow strips of land fringing the banks of the reservoir. To prevent overcrowding in the fringe area of the reservoir, and the consequence of a drastic decrease in per capita acreage of cultivated land, resettlement at some localities may be carried out according to regions. That is, within the same county, resettlement areas may expand longitudinally where appropriate, resettling people in planned districts or townships where larger areas of usable land and richer natural resources are found and where the population density is low. In so doing, the necessary resources available for a complete reconstruction of a production

and socioeconomic system with high potential for future development will increase. Therefore, resettlement will not adversely affect the current production, living standards, and ecological environment in the resettlement areas.

In short, the reservoir area possesses rich natural resources and high potential for further development. As long as there are appropriate and effective policies as well as sound resettlement plans for resource-exploitative migration, the carrying capacity of the resettlement areas may be considered acceptable from a macro viewpoint. Specific plans in different counties and some typical migration experiments have proven that this is viable.

4. Functions of the project and its major social and environmental effects

A project's ecological and environmental effects should be taken into consideration when carrying out a comprehensive environmental impact assessment of the project. This was recommended at an international conference on large dams and has been adopted by some developing countries.

The TGP serves multiple purposes, including flood prevention, power generation, navigation, aquaculture, and tourism. It will bring about enormous economic, social, and environmental benefits.

4.1. Effective reduction of flood hazard in the middle-lower Changjiang Plain; Improvements in production and living conditions

The middle and lower reaches of the Changjiang River are frequently ravaged by severe floods. Historical records show that there were more than 200 flood disasters of various severity during the two millennia from the Han to the Qing dynasty. This is equivalent to one flood disaster every ten years. In this century alone, severe floods occurred in 1931, 1935, 1949, and 1954. Floods destroyed farmland and houses, causing tremendous

losses to people's lives and property. The ecological environment of the ravaged areas was seriously damaged, and the subsequent spread of plague, oncomelania, and schistosomiasis caused numerous deaths and devastating emotional trauma. In the floods that occurred in 1931 and 1935, for instance, a death toll of over 100,000 people was reported each time. The 1954 flood, which was combated with great success under the party's and the government's leadership, still caused a death toll of over 30,000. When severe flooding occurred in the lower Changjiang River in 1983, the floodwater was diverted to Dengjia Lake. Because of the widespread occurrence of black rats (*heixian-jishu*), which caused the dispersion of haemorrhagic fever, in Maliang town alone, a district of merely 40,000 people, 3,600 contracted haemorrhagic fever, more than 210 died, and 21,500 suffered from dysentery, which also caused a significant number of deaths. The flood also led to widespread occurrence of oncomelania. After the 1983 flood, the area affected by oncomelania in Jiangtan, Nanjing Municipality, jumped from 2,000 *mu* to 30,000 *mu*, over ten times more than before the flood. Also, a large number of people were infected by exposure to floodwater during flood prevention and diversion, causing the incidence of acute schistosomiasis to reach 1,000 annually in recent years. In 1954 when the floodwater was diverted to the Jingjiang flood diversion region, the number of people transferred to un-flooded areas increased so dramatically that the resettlement areas had to accommodate 9,000 persons per km². Because of poor living conditions and widespread diseases, the death rate reached as high as 15 per 1,000. After the flood, people returned to their homes and suffered again from deteriorated living conditions and tremendous emotional trauma. A significant number died for this reason. It is evident that flood damage has a very serious impact on the ecological environment.

In the recent period of over three decades, embankments in the middle and lower reaches of the Changjiang River were heightened and reinforced. A total of 3 billion m³ of earthwork and 65 million m³ of stonework has been completed. Moreover, both

Pro: dam gives flood prevention. Past evidence of spread area.

flood diversion projects in Jingjiang and Dujiatai and large-scale reservoirs in Danjiangkou, Taxi, and Talin were constructed. However, the danger of floods in the middle and lower reaches of the Changjiang River remains serious. The embankments in various places can withstand floods that occur once every five to twenty years. Should a flood exceeding the above severity occur, diversion of floodwaters would be needed, but it would cause serious losses. The situation is most serious in the lowlands north and south of the Jingjiang section, which has an area of 40,000 km². During flood periods, therefore, the floodwater will often rise to a level more than 10 m higher than the surrounding level of the north bank. If an especially severe flood similar to the 1870 flood occurs, there will be no safe means of diverting the floodwater. The unstable parts of the embankments could breach, and it will cause a catastrophic number of casualties and huge economic losses. As well, navigation in the middle Changjiang River might be cut off, disrupting the economic development of the area. The recurrence of a flood like the one in 1954, even assuming that the floodwater is diverted as planned, will cause the inundation of 14 million mu of farmland, emergency displacement of 7 million people, the loss of 18 billion yuan for floodwater diversion and storage, and the loss of 3 billion yuan for flood prevention and industrial and transportation losses in cities. The total direct loss incurred is 21 billion yuan. This amount, however, does not include the negative impact on various sectors of the national economy and on the ecological environment, some of which cannot be evaluated in monetary terms. Once flooded, the lowlands in the middle and lower reaches will be inundated for a long duration. Often the damage inflicted by a single flood on the human ecosystem and the natural environment will take more than a few years to repair itself.

According to the TGP scheme, with a normal water storage level of 175 m, the flood prevention reservoir will have a capacity of 22.15 billion m³. The project will ensure that the Jingjiang embankments will be protected from the hundred-year flood, and thus a massive loss of life can be prevented. For floods of a

higher frequency, the project will reduce the risk of the Jingjiang and Chenglingji regions from being inundated, will maintain the water level in Shashi at 44.50 m, and will not require the diversion of floodwater into the Jingjiang flood diversion region. Meanwhile, the project will also create favorable conditions for constructing regulatory gates at three inflow sites of Lake Dongting, which will help develop the Dongting region. The TGP, in coordination with the construction of embankments as well as flood storage and diversion projects, will mitigate the threat of severe flooding in the middle and lower reaches and reduce the risks associated with breaching of the Jingjiang embankments during floods. This will also reduce the enormous labor and financial burden for embankment construction and flood prevention and the frequency of diverting floodwater into the flood diversion regions. The social and environmental problems created by flood prevention and diversion will thus be greatly alleviated. Moreover, the project will help control the widespread occurrence of schistosomiasis, reducing the loss of lives and property and the psychological threat created by flooding in the lower Changjiang valley. Hence, it will improve the region's production and living conditions as well as impart a sense of security to the people. Besides, siltation in Lake Dongting will be reduced, the lake's life span lengthened, the regulatory and storage capacities expanded, and the lacustrine ecology improved. It is evident that flood prevention can bring about enormous social and environmental benefits.

4.2. Large supplies of clean power as opposed to thermal power to avoid environmental pollution

Hydropower is a renewable and clean energy resource. The construction of dams for power generation is an important measure of utilizing water energy. The Changjiang River has an enormous flow volume and potential hydropower resource. Geographically well-situated, the proposed Three Gorges reservoir is located at the heartland of the river basin in Central China. According to

the 175-m scheme, the total generator capacity of the Three Gorges power station will be 17.68 million kW, and the annual average power output will be 84 billion kWh. Undoubtedly, the project, which will transmit a huge amount of hydropower to energy deficient yet needy regions such as Central and East China, will significantly contribute to the development of the national economy and improvement in the environmental quality of the regions. The use of hydropower will alleviate the environmental and social problems that might otherwise be created by the use of other forms of energy. A thermal power station with an equivalent power output will require the burning of 42 million tonnes of raw coal a year, discharging after combustion 2 million tonnes of carbon dioxide, 10,000 tonnes of carbon monoxide, 370,000 tonnes of nitrogen oxides, and over 12 million tonnes of ash. In addition to the environmental problems caused and capital investment required by the exploitation of coal mines, the construction of a transport system, and shipping arrangements, large amounts of water resources are consumed. The discharge of the water used for cooling also causes thermal pollution in part of the water body. All these poisonous, harmful substances, when discharged without treatment, will have severe adverse effects on the ecological environment. In contrast, the same amount of power can be generated at the Three Gorges without causing the pollution problems mentioned above because it is a source of clean energy.

4.3. Effective improvements to navigation in the reservoir area and downstream of the dam site

Navigation in the Changjiang River plays a vital role in China's inland navigation. Though Changjiang is the third largest river in the world, the development of its transport capacity has not lived up to the status it deserves. Its annual transport capacity is far smaller than comparable rivers in other parts of the world. This is because, except for the Gezhouba area, the river channels have remained unimproved, especially the Chuanjiang and Jingjiang sections, where navigability is extremely poor.

The section between Yichang and Chongqing is referred to as "Chuanjiang" and is 660 km in length. It passes through high mountains, hills, and deep gorges. The current is swift, with reefs and shoals appearing one after another. There are a total of 139 shoals and 46 stretches of one-way controlled navigation. Tourists, local and foreign alike, are carried away by the enchanting scenery of the Three Gorges on the Chuanjiang section. However, the reefs and shoals, roaring waves, and rapid currents have also made the Three Gorges a perilous course for shipping. Here, many shipwrecks occurred and people were drowned in recent history. The situation is especially serious in the upper reaches, where the transportation capacity is small, leading to long passage time and high costs. The transportation efficiency per unit power is merely one-tenth that of the middle and lower reaches, while the transportation cost is more than double. The Jingjiang section downstream of the dam site is a meandering channel with frequent formation and erosion of bars. Channel changes are highly unpredictable. During the dry season, exposure of bar deposits is frequent and unobstructed navigation is not ensured. All these have restricted the development of navigation and the tourism industry and fail to instill a sense of security.

After construction of the Three Gorges reservoir, the backwaters during the dry season will reach as far upstream as Chongqing, submerging all the rapids and shoals on the Chuanjiang section. Navigability in the reservoir area will be greatly improved. Meanwhile, the discharge in the middle and lower reaches downstream of the dam site will increase, channels will be deepened, and the Jingjiang waterway will be improved as well. In this way, the Changjiang River, a "golden waterway" traversing from east to west in China, will be of strategic importance in the continued economic development, social stability, and prosperity of the whole river basin.

4.4. Aquatic environment for fish species and marine organisms will be expanded in favor of fisheries

After construction of the dam, the ecological environment of the river channel in the reservoir area, which is characterized by

numerous shoals and rapids, will be changed. The water surface area will nearly triple. The reservoir waters will become more fertile and cleaner, because some of the organic matter and nutrients upstream will be trapped in the reservoir area. These new conditions will favor the reproduction and growth of fish species and organisms on which fish can feed. In winter, an increase in discharge downstream of the dam and in the water levels of the rivers and lakes will provide more favorable conditions for fish species to survive. However, the waters in the main river channel in the Three Gorges reservoir area will be too deep for the development of favorable fishing grounds. So emphasis should be given to the study and development of fishing grounds in sheltered bay areas as well as of new fish species adaptable to the new environmental conditions. In summary, the development of fisheries in the reservoir area and downstream of the dam is very promising.

4.5. A more charming environment for tourists will be created

The Three Gorges Reservoir area was the territory of the ancient Ba and Chu kingdoms for a very long time. The area abounds in scenic spots and historic relics, and the Three Gorges is especially famous worldwide for its imposing and precipitous, yet serene and charming scenery. After construction of the dam, "a peaceful lake will emerge at the deep gorges." The scenery of lakes and mountains, together with the grand reservoir project, will add luster to the wonderful scene at the Three Gorges, which will become a famous scenic spot. Also, the local people will be provided with more employment opportunities in the tertiary industry.

Moreover, the water quality and water supply in the middle and lower reaches will be improved during the dry season.

In short, the TGP will foster advantages and eliminate disadvantages. Its various functions will play an important role in promoting socioeconomic development and in improving the environment.

5. Comprehensive assessment and analysis of the environmental impact of the TGP

The TGP involves numerous factors that are interrelated in a complex way. Many of the environmental factors are difficult to quantify at present. To arrive at a comprehensive assessment, we have explored different methods and attempted to quantify and assess the impact of various complex environmental factors. The reliability of the results, however, depends in large part on the experience and perception of the participants in the assessment. The results, therefore, can hardly reflect reality in an objective and accurate manner.

In conducting the systematic project assessment, we consulted the method proposed by the International Committee on Dam Construction and Environment but with reference to the actual conditions of the TGP. In conducting the comprehensive analysis, we have followed several principles and methods: (1) A socioeconomic system was included, which took into account the environmental impact of important project functions such as flood prevention and power generation. (2) The whole basin was treated as a megasystem, and, where appropriate, quantitative and qualitative assessment at both the macro and micro scales were integrated. (3) For negative impacts, scenarios both with and without remedial measures were considered.

The following are the results of the comprehensive analysis of the ecological and environmental impact of the TGP:

1. The TGP has both positive and negative impacts on the environment. The overall impact is that the positive effects will outweigh the negative ones. The project will bring not only enormous economic benefits because of flood prevention and power generation, but also social and environmental benefits.

2. The TGP will affect in varying degrees the ecological environment of the reservoir area, the middle and lower Changjiang River, and the estuary. However, the impact will be most felt in the reservoir area, and among the many impacts, environmental problems created by flooding and resettlement will be the most

serious. By proper implementation of the tasks of comprehensive planning for the reservoir area, resource-exploitative migration, effective measures and policies, active development of productive forces, and establishment of a new human ecosystem, we believe, the population carrying capacity of the reservoir area will be acceptable.

The TGP will reduce flood disasters in the middle and lower reaches of the Changjiang River, save people's lives and property, and protect the ecological environment. Such positive impacts are highly significant.

The project has both positive and negative impacts on the ecological environment of the river estuary. The adverse effect occurs in October, when the reservoir is impounded, and the decrease in the regulated flow downstream will cause environmental problems. However, this will not lead to serious consequences.

3. In the reservoir area, the adverse effect of inundation caused by impoundment on the biophysical and the social environments will be the most serious. However, except for a few irrevocable and unrecoverable environmental components (for example, land, cultural relics, and landscape resources), most of the adverse effects can be avoided or alleviated through remedial measures. Some of them are as follows:

The life of the reservoir can be substantially lengthened if the siltation problem is controlled by following the principle of "retaining clear water and releasing turbid water" and by other auxiliary measures.

Though problems of environmental geology such as earthquakes, rockfalls, and landslides induced by the construction will not pose a threat to the safety of the dam, monitoring and forecasting work should be strengthened.

Cultural and historic relics should be saved by measures such as relocation, preservation, and reproduction.

Precious organic resources and rare animals and plants should be saved from extinction through transplanting, artificial breeding, and conservation.

Based on the principles of suiting measures to local conditions, utilizing favorable factors and averting harmful factors, and overcoming drawbacks and developing strong points, the pattern of land utilization should be adjusted, the potential of the mountain area and macro agriculture developed, and the agroecology improved.

Soil erosion should be prevented through reforestation in the reservoir area, and soil and water conservation.

In building new cities and towns and industrial and mining enterprises, and in exploring resources, pollution control should be incorporated into the planning, construction, and operation process of the projects.

The cleaning up of the reservoir, hygiene, and epidemic prevention should be strengthened to forestall infectious and epidemic diseases.

Many of the remedial measures are important components of the development plan in the reservoir area and are closely related to the resettlement project. If we work according to the natural and economic laws, and if we can coordinate the construction and development of the reservoir area with the protection of the ecological environment, we should be able to establish a new ecological balance that will ensure the maintenance of a benign cycle for the ecological environment of the reservoir area.