The Environmental Impact of the Three Gorges Project and the Countermeasures

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Abstract The Three Gorges Project (TGP) is a landmark Chinese hydroelectric project with the goal of harnessing the Yangtze River and developing its water resources. Because of its enormous size and far-reaching influence, the project’s impact on the Yangtze River’s original ecological environment has been a concern to many people. This article examines the environmental effects of TGP with regard to reservoir-induced seismicity and bank stability, climate changes, sedimentation and bank erosion, the protection of aquatic species and water quality, and resettlement. Based on the operation monitoring data of TGP in 10 years (2003—2012), this article analyzes the tendency of reservoir-induced seismicity and bank stability, developing trend of sedimentation and bank erosion, the interplay between climate change and TGP, the distribution and cause of water contamination, the situation of aquatic species’ protection and living situation of resettled residents. At the same time, this article lists the comprehensive benefits of TGP in flood control, power generation, shipping, water supply, etc. In the end, the authors deem that there is a dynamic and harmonious relationship between humankind and nature. The cognition about TGP will be progressed in practice, and harmonious relationship between the environment and TGP will be achieved through more practice.

Keywords: the Three Gorges Project, ecosystem, aquatic species, water quality, flood control, disaster alleviation, energy saving, emission reduction

1 Overview

The Three Gorges Project (TGP) is a significant example of mankind’s impact on the natural world, and is a credit to mankind’s ingenuity with regard to social production and development. It is also a manifestation of mankind’s efforts in survival and ensuring sustainable development. With over 70 years of surveying, planning, design, demonstration and decision-making, plus an additional 17 years of construction, TGP has now fully realized its primary benefits in flood control, power generation, shipping, water supply, etc.

1.1 The Yangtze River

The Yangtze River (“Changjiang” in Chinese, literally, the “long river”), originated from “the roof of the world”, lying on the southwest of Geladandong Peak in the Tanggula Mountain range on the eastern part of the Qinghai-Tibet Plateau. The river runs for 6,363 kilometers and is the third longest both in terms of length and runoff capacity, with 956 billion cubic meters of water flowing annually into the sea on an average yearly basis. There are numerous tributaries along the river, resulting in a huge drainage area of 1.8 million square kilometers which covers one fifth of the total land area of China, which is also the habitat of a third of the population, generating as much as 40% of China’s gross domestic product (GDP) (China Renewable Energy Engineering Institute, 2004) (see Figure 1).

The river runs eastwards, with the city of Yichang dividing it into the upstream in the west and the lower reaches in its east. The upstream stretches for 4,510 kilometers, where there is mainly mountainous terrain with a water drop of up to 5,360 meters. Whereas, the middle and lower reaches are dominated by hilly plains, with the horizontal distance as long as 1,850 kilometers and an elevation drop of just under 68 meters during the flood season, which poses a great challenge in terms of flood control, particularly in the middle course area, which is referred to as the Jingjiang River area (stretching from Zhicheng in Hubei Province to the Chenglingji River Reach in Hunan Province, an area which features a typical winding river route). Due to sedimentation in the Yangtze River, the river bed of Jingjiang River is gradually rising, and has outgrown the north bank ground by over 10 meters. It relies solely on the Jingjiang Levee’s flood control so much that if the dam breaks, both banks will be flooded, causing severe damage to the properties and endangering the lives of its inhabitants. In this sense, the Yangtze...
The Environmental Impact of the Three Gorges Project and the Countermeasures

is not only a river that is rich in water resources but also a river that brings frequent flood disasters.

1.2 The flood history of the Yangtze

According to historical documents, there were over 200 severe floods from the Han Dynasty to the late Qing Dynasty, with one occurring every 10 years. In the 20th century, the Yangtze River flooded in the following years: 1931, 1935, 1949, 1954, 1982, 1996 and 1998. The 1954 Yangtze River floods witnessed a total of 3.174 hectares of land flooded, affecting 18.88 million people and causing 33,000 casualties. Wuhan City was besieged by floods for a long period and the Beijing—Guangzhou railway stopped functioning for 100 days.

The floods of 1998 are still fresh memories in the minds of the Chinese people (TGP construction had begun, but the reservoir had not yet been finished). The Datong hydrological station in Anhui recorded a maximum peak flow of 82,300 cubic meters per second. Although the efforts of nearly 200,000 Chinese soldiers fighting the floods on the front line ensured that the damage from this flood is less than any other in the 20th century, an area of 4,003 hectares was still devastated by the flood, leading to the collapse of 812,000 houses and a direct economic loss of nearly RMB 145 billion (Lu, 2007, pp.266-284). In some ways, floods make the biggest threat to the ecosystem of the Yangtze River.

1.3 The origin of Three Gorges Dam

The idea of the Three Gorges Dam was firstly proposed by Dr. Sun Yat-sen, a pioneer of the Republic of China, in his article entitled A Plan for the Development of Industry in 1919. At that time, American civil engineer J.L. Savage was invited by the Republic of China to carry out survey for the water resources development of the Three Gorges area, after which he put forward the well-known “Savage Plan”. After the founding of the People’s Republic of China, the new government set up a bureau for Yangtze River Planning and proposed the Opinions on the Three Gorges Project Planning of the Yangtze River (Anonymous, 1997) in March 1958. The Committee of The Yangtze Hydropower Development officially put forward A Report on Planning Issues on Comprehensive Utilization of the Yangtze River Basin in 1959 (Editorial department,1989), creating an overall strategy for harnessing the Yangtze River and developing its hydropower, and the leading role that TGP will play in these regard. In 1986, a panel of 412 experts from various fields was organized by the Chinese Ministry of Water Resources and Electric Power, to further demonstrate the feasibility of the project, which lasted for three years and covered 14 topics. The experts firstly confirmed that the primary role of the dam was to control floods and concluded that the project was technically feasible and economically reasonable. They also concluded that the benefits of the construction of the dam outweighed the disadvantages and the sooner the dam was built, the more benefits would be seen. Furthermore, 175 m was decided to be the normal impoundment level (Lu & Cao, 2010).

On April 3, 1992, the construction of the project was officially approved in the Fifth Session of the Seventh People’s Congress (Office of the TGP Review Committee of the State Council, 1992). After 70 years of surveying, planning, design and demonstrating, the decision to construct was made.

1.4 Overview of the project

TGP is a landmark hydroelectric project, bringing comprehensive benefits in flood control, power generation, shipping and water supply. The construction of the project used a continuous plan, featuring “first-class development, one-time completion, impoundment by stages, and continuous immigration”. The whole building process lasted for 17 years, and was in three phases. The pre-construction preparation commenced in 1993, followed by official construction starting in December 1994, with electricity to be firstly generated in
2003. In 2009, the construction of the main structures was completed and the project demonstrated its comprehensive benefits. The total length and area of the Three Gorges reservoir are 663 km and 1,084 square kilometers respectively, with a normal impoundment level of 175 meters, a flood season limited water level of 145 meters, and a total capacity of 39.3 billion cubic meters, of which the flood control capacity is 22.15 billion cubic meters. TGP is composed of three parts, namely the dam, powerhouse and navigation structures (see Figure 2). The dam is a concrete gravity dam with the spillway dam sections in the middle and the powerhouse and non-overflow dam sections on both sides. The total length of the axis is 2,309.47 meters; the crest elevation is 185 meters, while the maximum dam height is 181 meters. The Three Gorges Power Station, consisting of a left-bank power station, a right-bank power station, a right-bank underground power station and a power source station, has a total installed capacity of 22,500 MW with an average annual generating capacity of 88.2 TWh. It has 32 hydroelectric generating units with an installed capacity of 700 MW each plus two generating units of 50 MW each for backup, which makes it the world’s largest hydropower station. The navigation structures include ship locks and ship lift. The ship locks are double-way successive five-tier ship locks, built in the deep rock grooves by deep excavation of the left-bank mountain, with a total length of 6,442 meters and a maximum design water head of 113 meters, which make it an internal river ship lock with the most tiers and a highest water head in the world. Using the operation method of one line upward and one line downward, it can allow 1,000-ton-level ship fleets made up of 3,000-tonnage ships to pass through with a designed navigation capacity of 100 million tons/year. The ship lift is single-line one-tier vertical ship lift using full balanced gear-rack climbing type with a maximum tonnage of 3,000 tons and a maximum lifting height of 113 meters, which is mainly used for passenger ships and various special vessels to quickly pass through (Questions on Three Gorges Editorial Board, 2012).

2 The environmental impacts of TGP and the countermeasures

The TGP has changed the original ecological environment along the Yangtze River Basin, which caused two different voices about its advantages and disadvantages. In this regard, we must follow the laws of nature, analyze in a scientific manner, and ensure that the Three Gorges Project benefit the healthy and sustainable economic and social development of the mankind.

2.1 Reservoir-induced seismicity and bank stability

The Three Gorges dam site is located in Huangling block of the northern Upper Yangtze platform fold belt, and is also the core of quaquaversal anticline in Huangling, where the bedrock is mainly pre-Sinian flash cloud plagiogranite with uniform and complete lithology, high strength of rock mass mechanics and weak water permeability. The dam area has small faults and well-cemented tectonite. There are no regional active faults within 15 km of the dam site. Huangling crystalline basement area, with neither regional faults nor seismogenic structures which can lead to moderately strong earthquakes, is a rigid block with favorable geological con-
ditions and a high degree of stability. The China Earthquake Administration identifies the basic seismic intensity of the Three Gorges dam site as VI, and takes the ground motion parameter of annual exceedance probability of 0.0001 as the dam’s seismic fortification criterion considering the size and importance of TGP, with its fortification intensity of VII and the bedrock’s peak horizontal acceleration of 125 gal, the overall building features a high shock strength.

Since the impoundment of the reservoir raises the original water level of the river and the water pressure imposed on the riverbed rock face is liable to change, there will be small deformations in the geological structure during the adjustment process of rock stress, thus leading to reservoir-induced seismicity. According to the International Commission on Large Dams, the probability of the world’s large reservoir-induced seismicity is 0.2%. China is an earthquake-intensive country, and its probability of large reservoir (with a capacity of 100 million cubic meters or above) – induced seismicity is 5% based on statistics. According to the data of TGP induced seismicity monitoring system, 3,592 earthquakes have been recorded from June 1, 2003 when the Three Gorges reservoir began storing water until the end of 2012, including 3,589 microseisms below M3 (all belonging to non-inductive earthquakes), 2 of M3-3.9 and 1 of M4 -4.9, namely the M4.1 earthquake at the initial stage of 175-meter experimental impoundment (November 2008), which was far less than the predicted value of “M5.5” set out in the preliminary design report (China Three Gorges Corporation, 2014). Statistics from monitoring indicated that the reservoir’s impoundment has indeed induced seismicity, and there has obviously been some correlation between seismicity and changes in water level; reservoir-induced seismicity is mainly microseisms and ultra-microseisms, all less than the predicted value in the preliminary design report; with the gradual stabilization of the geological structure, reservoir-induced seismicity presents a gradually mild trend showing a convergent nature.

Hydro-fluctuation belt of the Three Gorges Reservoir Area is a geological disaster-prone zone featuring landslides and ground collapse. At the underground water level of both banks has changed with the rise and fall of the reservoir water level, gradually resulting in the looseness of its rock mass under the action of tectonic stress and a decline in its mechanical strength and stability, coupled with the combined effects of wave erosion, softening, penetration and water pressure, a variety of geological disasters. However, with the completion of banks reconstruction, the mountain’s inner stress at both banks has been on a tendency towards stability. Statistics from monitoring have indicated that since the normal impoundment level of 175 meters, the reconstructing of the banks of the Three Gorges Reservoir has induced some 400 landslides and other geo-disasters. In the first year, new geo disasters had obvious relationship with water impounding; but in the second year, the geo disaster rate dramatically reduced and leveled off.

With regard to seismic and geological disasters that might occur in the area, the reservoir area has established a high-precision digital telemetry seismic network, 24-hour geological disaster monitoring to strengthen the warning and preparation work for seismic and geological disasters. Besides the budget for the project, the Chinese government added another RMB 11.3 billion special funds for the comprehensive management of geological disasters in the reservoir area (when the construction was still underway). There are also further arrangements concerning the prevention of geological hazards in the subsequent planning for TGP, which were enacted by the Chinese government in 2011.

2.2 The impacts on the climate of the surrounding area

Analysis of meteorological monitoring data before and after the impoundment indicated that there were significant decadal variations in temperature changes in the area where TGP was situated. Furthermore, the pattern of changes was consistent with the warm-cold-warm periodic variations in the Yangtze waterway. The annual variations in precipitation and water level in the reservoir area have been fairly consistent with those of the eastern part of the upper reaches of the river in a nearly 10-year period and the overall fluctuation range was within the normal year on year climate change. Analysis of the monitoring data after the impoundment indicated that the Three Gorges Reservoir could exert subtle influences on the local temperature and there have been no significant impacts on other climate elements such as rainfall. As a result of the widened waterway, the water of the reservoir has warming effect in the winter and slight cooling effect in the summer. However, the influence on temperature by impoundment was less than that of by climate change. The climate model simulation analysis showed that TGP project would affect local weather and climate, particularly causing an obvious decrease in temperature above the reservoir, yet it could not result in kinds of extreme catastrophic climate change (National Climate Center of China, 2011).

Global warming has been the general trend of climate change over the past century and can lead to some further concerns such as accelerating the melting of glaciers, extreme weather and changes in the distribution of water resources. These issues could impact TGP in some way, for example, the reduction of inbound runoff and frequent extreme heavy rains. Nevertheless, climate change caused by global warming is a gradual process, so is its impact on TGP. Meanwhile, the Three Gorges Standards (with a normal impoundment level of 175 meters) are enough to withstand floods of 1,000 years reoccurrence, as the water level was raised to 185 meters, 10 meters higher than that of the normal level, floods of 10,000 years reoccurrence could be withstood. Under these circumstances, the main building of the dam structure will remain intact without damage. In other words, Global warming will not impact on TGP greatly either at present or in a long term.
2.3 Sedimentation and river bank erosion

Sedimentation in each river on the planet is the result of the erosion of rocks on the terrain, which is brought to rivers by fluxes of rainfalls on the ground from the upstream and is silted in the down reaches, leading to the formation of alluvial plains in the estuary. The construction of the dam on the upper reaches of the rivers will surely deposit sediment in the reservoir and alter the movement of the flow of sediment. In the early planning and design stages of the project, a large-scale model test on sediment was conducted by using reservoir simulation methods, working out the sediment deposition magnitude analysis in order to design a reservoir which can store clear water and discharge muddy water. This “storing clear water and discharging muddy water” operation mode is consistent with the flood control regulations of the reservoir. Ever since its impoundment (from 2003 to 2011), the annual inbound sediment to the Three Gorges Reservoir is 205 million tons, which is 39% of the quantity formulated in the phase of investigation and design (China Three Gorges Corporation, 2014).

Research indicates that the significant reduction of inbound sediment is mainly due to the construction of reservoirs on the upper reaches and projects for soil and water conservation. In the future, the sediment flowing into the Three Gorges Reservoir will be further reduced as large reservoirs in the Jinsha River, the Jialing River and the Wujiang River are used. According to the frequency of hydrological floods, a great deal of analysis of reservoir simulation tests have indicated that the Three Gorges Reservoir could eventually keep more than 80% of the capacity for long-term use and could operate for 70–80 years before erosion reaches a basic equilibrium. Hydrologic and sediment monitoring will be consistently conducted in a meticulous way for a long term on the upper and lower reaches of the Yangtze River, so as to understand the movement of sedimentation and guide the scientific and optimized regulation of TGP.

Due to the reduction of sediment from the upper reaches and the sediment deposited in the Three Gorges Reservoir, water discharged from TGP is clearer than the Yangtze River water. Water discharged downwards will cause erosion on river banks, deepening the riverbed thus improving the flood carrying ability on one hand, but triggering river bank collapse and water level lowering on the other hand. In this regard, the banks of the reservoir should be strengthened through treatment in the reservoir area and the lower stream of the reservoir. The inter-connection of the rivers and lakes could be improved through the construction of dam projects at the entrances of the Yangtze River, the Dongting Lake, and in the Poyang Lake. Through implementing appropriate engineering and regulation, sedimentation problems will not cause irreversible adverse consequences.

2.4 Protection of aquatic species and the development of fisheries

TGP has blocked the river course, changed the natural flowing state of the river and widened the watershed as wide as 1,084 square kilometers. The project has also raised the depth of reservoir (with an average depth of 70 meters) and altered the temperature. During the flood season, flood discharge and dissipation would lead to water aeration and super saturation, a decline in sewage discharge capacity of the backwater zone, deterioration of the water quality, and interference with the increasingly busy Yangtze River waterway, all of which have changed the original ecological environment of fish and other aquatic organisms. The construction and impoundment of TGP have had an impact on aquatic species in the Yangtze River. The number and spawning scale of Chinese sturgeon are both at a low level, with its spawning period now later than before. In the main stream of the upper Yangtze River, endemic fish species have reduced, and the spatial distribution of the fish has changed, as well as the fish population. It should be noted that these effects have been caused by a number of factors, with TGP as one of them; moreover, excessive fishing, increased water pollution and the growth of the shipping industry have also affected the survival of aquatic organisms (Project Team of Chinese Academy of Engineering for Periodic Assessment on Three Gorges Project, 2010).

Therefore, first of all, we must enhance artificial reproduction of fish to guarantee the quantity of fish in the Yangtze River. In August 2011, Chongqing Reproduction and Releasing Station of National Nature Reserve of Rare and Endemic Fish in Yangtze River Upstream Area was built in the back area of the Three Gorges Reservoir area, and was committed to the protection of rare and endemic fish in the Chongqing section of the Yangtze River as well as to the ecological restoration of the Three Gorges Reservoir area. In the same year, the Research Institute of Chinese sturgeon, based in Yichang, successfully bred approximately 50,000 “second artificially bred generation” sturgeons all through artificial propagation, marking full maturity of China’s artificial propagation technology for Chinese sturgeon. Secondly, we must strengthen ecological regulation and improve the natural reproductive capacity of the four major Chinese carps in the Yangtze River (black carp, grass carp, silver carp and bighead carp). Since the first impoundment of 175-meter water level in 2010, ecological regulation of the four major Chinese carps’ natural reproductive capacity has been carried out by generating artificial flood peaks and simulating the natural environment in order to adapt to the needs of the carps’ habitat, contributing to the gradual recovery of fishery resources for these four major Chinese carp species. Thirdly, we must prepare the Three Gorges Reservoir for the devel-
2.5 Water quality protection

After the impoundment of TGP, the reservoir water in the main stream remains at the II—III level: The concentration of main pollutants is stable with slight decline; heavy metal contaminants haven’t increased; density of fecal coliform continues to decline; total phosphorus and total nitrogen are over the standard level. The monitoring project of 38 major tributaries to the reservoir area showed increase in pollution, with the total phosphorus and total nitrogen pollution continuing to increase while fecal coliform contamination turning better. The backdrop areas of the main stream and tributaries have a slow water flow with cases of eutrophication, and algal bloom sometimes occurring in parts of the water. The possibility of eutrophication and algal bloom in the whole reservoir area is low (China Three Gorges Corporation, 2014). There is no distinct change in water quality while looking at a cross section of water along the major cities along the middle and lower parts of the Yangtze River.

With comprehensive management in Three Gorges Reservoir area and improvement in people’s living standards, industrial emissions in the Three Gorges area have decreased to some extent, while domestic emissions have increased rapidly with the total emissions exceeding industrial emissions, and being the main contributor to the water pollution in main streams and tributaries. Moreover, the treatment capacity for urban sewage is lagged far behind the pace of urbanization, and the pollution from domestic sewage in the upstream area and the affected area of the tributaries is especially prominent compared to the pollution of the main stream in the reservoir area, causing the water pollution in the tributaries more severe than in the main stream.

In May 2011, the Chinese government formulated the Plan on Water Pollution Prevention in the Middle and Lower Yangtze River Basin, with an investment of 46 billion RMB yuan, which comprehensively employed engineering, technical and ecological methods to strengthen ecological protection and construction, enhance water pollution controls and environmental regulatory standards of the Yangtze River Basin and offshore areas, ensure water quality and safety of drinking water sources, resolve outstanding water environment issues, so as to promote sustainable economic and social development in the Yangtze River Basin.

2.6 Resettlement, living and development

Impoundment of the Three Gorges Reservoir submerged part of the land in the upper Yangtze River, thus inevitably resulting in the relocation and resettlement of people as well as causing large change in the ecological environment. Before TGP, the Three Gorges Reservoir area including 20 counties and cities in Chongqing and Hubei Provinces was one of the 18 concentrated poverty areas. Ten of the fifteen counties in the Chongqing reservoir area are listed in state-level key counties for poverty alleviation and development, with an absolute poverty population of 644,000, and farmers’ annual per capita income was only RMB 576 before the construction of TGP (in 1992). The Three Gorges Reservoir Area has a steep terrain with no adjoining plains. The arable land is hilly, and almost all the towns and counties are concentrated in the river canyon slopes. With a dense population and an extremely limited environmental capacity, it is very difficult for this area to attract foreign capital and keep up with the pace of economic development nationwide. Nevertheless, the biggest advantage is that it has abundant water resources and is an important Yangtze River waterway section. The construction of TGP is unique chance for development for this area, and the reconstruction of resettled area and the adjustment of industrial structure are the only way to eliminate poverty and improve standards of living.

From 1993 to 2009, the resettlement of 1,296,400 people (1,119,600 from Chongqing and 176,800 from Hubei) was completed, of which 557,700 were from rural areas. TGP has completed the relocation of 12 counties (including cities) with 579,100 people, 106 towns with 159,600 people and 1,632 industrial and mining enterprises. A total resettlement arrangement of RMB 85.653 billion was finished. Some of the Three Gorges migrants were relocated outside of the reservoir area under the guidance of the government, moved to the economically developed flat areas along the southeast coast and became accustomed to the local communities, thus alleviating the shortage of land resources in the reservoir area. Post relocation living conditions, infrastructure and public service have been significantly improved. Urban and rural migrants have per capita house space of 33.1 m² and 42.12 m² respectively, higher than those before their relocation and at the average level of Hubei Province and Chongqing City; this area has basically improved infrastructure including water, power and roads, and enhanced public service facilities such as schools, healthcare facilities and cultural centers; resettlement production support measures have achieved initial success and migrants’ incomes have increased gradually. In 2011, the per capita net income of rural migrants was 6,429 Yuan, and the per capita disposable income of urban migrants (residents) was 18,700 Yuan, with average annual growth rates of 12.8% and 6.83% respectively from 2008 to 2011; the economy in the reservoir area has achieved rapid development, and the communities are stable.

There are also unsatisfactory parts of the Three Gorges Project Resettlement, such as migrants’ integration into the local areas and their stability and growing well-off, the impact on their production and living due to the reservoir banks rebuilding, delayed garbage and sewage treatment in parts of some towns and lagged behind infrastructure. On the basis of resettlement investment, the Chinese government set out
the *Three Gorges Follow-up Plan* in 2011 to invest RMB 123.8 billion to resettlement and environmental issues and strive, through 10 years of efforts to ensure that prior to 2020 the migrants’ standard of living and quality of life will reach the average level of Hubei and Chongqing. According to the plan, a social welfare and assurance system covering urban and rural residents will be established, the strategic adjustment of an economic structure in the reservoir area will make significant progress, infrastructure such as transportation, water conservancy and towns will be further improved, social public service in the resettlement area will become more equal, environmental degradation trends will be effectively curbed, the long-term mechanism for geological disaster prevention and control will be further improved, and a basic disaster prevention and mitigation system will be established. While reservoir induced migration is mandatory, their relocation has created more conducive conditions for their survival and development, which is consistent with China’s ongoing efforts in the direction of building a new socialist countryside. Through external input and efforts of migrants themselves, environmental and ecological change caused by resettlement could develop positively.

From the perspective of sustainable development, the essential problem of reservoir resettlement is water efficiency, and more specifically the distribution of benefits which come from it. Water resources are developed through the construction of dams; water, electricity and other social wealth are mainly enjoyed by the water/electricity-covered region; but as contributors to hydropower projects, reservoir induced migrants have not enjoyed any continuous benefit distribution. If the reservoir migrants hold expropriated land as their share of dam construction investment, they would have a reasonable dividend from the dam benefits, which could be a long-term mechanism to solve the reservoir induced resettlement issue.

### Operation of TGP

Since the impoundment of TGP in 2003, after 10 years of safe and stable operation, it has demonstrated comprehensive benefits in flood control, power generate-on, shipping, water supply, drought alleviation, as well as energy conservation and emission reduction (see Figure 3).

#### 3.1 Flood control and disaster reduction

TGP is a backbone hydroelectric project as part of a comprehensive flood control system of the Yangtze River. In order to control the one-million-square-kilometer drainage area in the upstream of TGP, to regulate and store the flood discharge of the Yangtze River, and to reduce flooding in the downstream of the river, the normal water level was designed to be 175 meters with a total storage capacity of 39.3 billion cubic meters, of which 22.15 billion cubic meters are for flood control and detention. The Three Gorges Reservoir can control more than 95% of the floods from the Jingjiang River, about 2/3 of the upstream of Wuhan, and is particularly able to effectively control flooding in the 300,000 km² rain-reduced-floods area which stretches from tributary reservoirs in the upstream to the Three Gorges dam site, which can enhance the capacity of the downstream Jingjiang Levee to withstand a 100-year recurrence flood up from a 10-year recurrence flood without using flood-diversion zones, directly protecting a 1.5-million-hectare area of arable land in the middle and lower Yangtze River, 15 million population and dozens of major cities along the Yangtze River (Lu, 2007, pp.266–284). In case of a 1,000 year recurrence flood or more, using downstream flood diversion and storage works, occurrence of devastating disasters, such as the main dike bursting along both sides of the Jingjiang River, could be prevented. Therefore, it is a critical measure to
guarantee the economy and society along the river as well as people’s life and property. During 2008—2012, there were medium and small floods in the Yangtze River, of which the inbound water peak to the Three Gorges Reservoir exceeded 70,000 m$^3$/s in both 2010 and 2012. Through scientific regulation, TGP uses its flood control capacity to retain small floods, and fully plays its role in reducing flooding with a total flood retention volume of 72.48 billion cubic meters and the annual maximum flood peak clipping rate up to 27.3%—54.6% (China Three Gorges Corporation, 2014), effectively reducing the water level of the main streams in middle and lower Yangtze River. It controls the water level in Shashi along the Jingjiang River, keeping it below the warning water level and ensuring the water level of the Chenglingji station below the safe level, effectively alleviating the flood control pressure in the middle and lower reaches. It prevents flood diversion with out putting land and houses at expense, reduces the number of patrollers on the dikes thus saving time and money, resolves the potential disasters caused by floods, and provides security for people’s life and economic development in the middle and lower reaches, all of which fully reflect TGP’s benefits flood control. Today, we can see that the role of TGP in flood control is irreplaceable.

3.2 Power generation, energy conservation and emission reduction

The Three Gorges Hydropower Station has 32 water-turbine generating units with installed capacity of 700 MW each and a total installed capacity of 22,500 MW (including two back up generating units with 50 MW installed capacity each) and has a designed annual generating capacity of 88.2 TWh. In years of high water flow, through reasonable regulation of small floods during the flood season, the yearly hydroelectricity production could reach 100 TWh. Compared to coal thermal power generation, the Three Gorges Hydropower Station can replace 27.74 million tons of standard coal consumption, reducing emissions of carbon dioxide by 70.56 million tons, sulfur dioxide by 760,000 tons and nitrous oxides by 210,000 tons on a yearly basis, and can also reduce inevitable pollution such as a large amounts of wastewater, other waste from coal production and floating dust. In the ten years of impoundment since 2003, TGP has produced total electric energy of 700 billion kWh, equivalent to a reduction of nearly 300 million tons of standard coal consumption, nearly 600 million tons of carbon dioxide emissions, and over 600 million tons of sulfur dioxide emissions, making significant contributions to China’s national economic development, energy conservation and emission reduction. Due to its great role in energy conservation and emission reduction, TGP was included in the world's top ten renewable energy projects by "Scientific American", a well-known popular science magazine.

3.3 Shipping

The Yangtze River is the main artery for China’s inland water transportation, as well as a tie linking the economies of Eastern, Central and Western China. After its impoundment, the Three Gorges Reservoir has greatly improved the waterway conditions in Three Gorges Reservoir area. The waterway rate from the Three Gorges Dam to Chongqing has been raised to Level Ⅰ from the former Level III before the construction of the reservoir. Its one-way shipping capacity has increased from 10 million tons to 50 million tons, and it has also realized all time navigation for all the line. Through water supply, the shipping conditions in the middle and lower Yangtze River have also improved, promoting the rapid growth of its transportation capacity as well as the development of shipping-related industries in the reservoir area. Meanwhile, TGP has facilitated ship standardization and upsizing, significantly improved the shipping safety, and greatly reduced the shipping costs and fuel consumption and contributed to energy conservation.

In the ten years since the Three Gorges ship locks were put into operation in 2003, they have been used more than 90,000 times, with 570 thousand ships passing through, and 10.01 million passengers and 600 million tons of goods transported (China Three Gorges Corporation, 2014). The annual cargo transportation volume is 5 times of that before impoundment. In 2011, the volume of shipments exceeded 100 million tons which is 5.6 times of the maximum volume before impoundment. The designed one-way cargo volume goal of 50 million tons prior to 2030 was achieved 19 years in advance. TGP’s shipping benefits have effectively promoted the rapid development of the Yangtze River shipping as well facilitated balanced and sustainable economic development along the river.

3.4 Ecological water supply

The Yangtze River has a large annual runoff, but is unevenly distributed in terms of year time with a large difference between runoff in the rainy season and in the dry season. The dry season in the middle and lower Yangtze River lasts from every December until the following March. Under natural conditions, its annual average runoff is 3,500 m$^3$/s and the minimum record in history is 2,700 m$^3$/s. When water is scarce, production and domestic water use along the river is constrained, shallow waterway navigation obstruction in the lower section of Jingjiang River appears, seawater intrudes from the Yangtze River estuary, thus severely impacting on people’s life and economic and social development along the river. During its design stages, TGP set the principle that discharged volume would not be less than 5,500 m$^3$/s, making its discharged volume about 2,000 m$^3$/s more than that under natural conditions. In case of drought in the middle and lower Yangtze River, it would increase the discharged volume,
thus effectively guaranteeing domestic water needs, industrial and agricultural production water, shipping water and ecological water in the dry season and under arid climate. In the first half of 2011, the middle and lower Yangtze River suffered persistent drought, and the Three Gorges Reservoir supplied more than 20 billion cubic meters of water to the downstream, raising the water level of main streams in the middle Yangtze River 0.7 to 1 meter. From the reservoir construction beginning until the end of 2013, the Three Gorges Reservoir has provided additional water amounting to over 60 billion cubic meters to the middle and lower Yangtze River, about three times that of TGP’s flood control capacity.

4 Conclusions

Ecology is the state of mutual survival and dependency among biological populations and among the same species in nature. This state is constantly changing in nature. The so-called ecological balance is relative, while imbalance is absolute. It is the imbalance that generates a natural impetus which constantly moves nature towards a new equilibrium, and promotes the biological principle of evolution i.e. “survival of the fittest” and “natural selection”, both of which provide the basis for Theory of Evolution written by Charles Darwin, the 19th century British scientist, and creates today’s global environment and human existence. As humankind is a part of nature, the artificial environment is also a part of the natural environment. But in such a mutually independent existence, only humankind has high production skills, thinking capabilities and a rich variety of emotion. Humankind is dominant in the natural environment, which is the result of natural selection rather than human will. With wisdom and emotions obtained from their own practice for survival, for better living and development, mankind not only continues to use both natural laws and natural resources in the transformation of the natural environment, but also curbs the unlimited pursuit of their own desires to prevent damaging the human right of survival and development in the future (Lu, 2007, pp.266–284). Nowadays, humans have become aware of global environmental degradation, a decrease in biological populations, and the crisis of sustainable human development. They are committed to ecological improvement and environmental protection. Its essence is for a better survival and development of mankind, based on “human-oriented” ecological and environmental concepts rather than the so called “nature-oriented” concept (Lu & Zhang, 2009).

TGP is the combined effort of time, history and human intelligence, as well as a scientific and reasonable creation. Epistemologically speaking, it has reflected and collected human knowledge and wisdom in natural sciences, social sciences, technical sciences, engineering sciences, engineering technology, engineering design, engineering management, engineering construction, engineering economics and other related fields in a concentrated and broad way; philosophically, we acknowledge that the nature and human society as objective existence are knowable, but “Knowability Theory” definitely doesn’t mean “Omniscient Theory”. We clearly recognize that human cognitive ability and level of understanding have limitations at any one “point-in-time”, and we will continue to break through these limitations with the progress of human practice. While TGP has basically been completed, people’s understanding and practice on TGP are far from over. The relationship between TGP and the environment, ecology and nature, as well as society will continue to move forward in a dynamic and harmonious way.

References


Overview of the Yangtze River basin and introduction of comprehensive utilization plan on the Yangtze River basin.