A PRELIMINARY APPROACH ON IMPACTS OF HYDROPOWER DEVELOPMENT IN UPPER YANGTZE RIVER ON ECOLOGICAL ENVIRONMENT

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Abstract: There are abundant hydro-energy resources in the Yangtze River (also called Changjiang River), and the hydro-energy reserves in the upper reaches occupy nearly 90% of the whole valley. In future 20 years, a great amount of hydroelectric projects will be constructed in the upper reaches of Yangtze River, and a large scale of cascade hydropower stations will be formed in the main channel and branches in the upper reaches at that time. After construction and operation of these power stations and reservoirs, some important impacts will be produced on the ecology and environment in the upper areas and even the whole valley. In the paper, distribution of cascade power stations in the upper reaches is forecasted according to completed plans; some restricting factors of ecology and environment on hydropower station constructions in upstream are discussed; the impacts of cascade reservoirs on the habitat and Aquatic Life (such as fishes) in the valley ecosystem are discussed; and finally, some countermeasures for mitigating the impacts arisen from the cascade reservoirs are put forward.

1 Introduction

The Yangtze River is rich in water resource, big in water head and abundant in hydropower resources. According to recent general investigation, for the theoretical reserves of hydropower in the whole valley, the average power is 27781×10^8kw, and annual electricity output is 24336×10^8kwh, accounting for about 40% of the total China; 90% of the hydropower resources in the Yangtze River are distributed in upper areas. Undoubtedly, the development of renewable hydropower resources has vital significance for energy development strategy of China, but the construction and operation of large scale reservoirs will make the flow process, water-sediment proportion and ecosystem habitat change greatly, and the change of habitat will affect the natural ecosystem and environment significantly. If the planned hydroelectric projects are carried out completely, the main stems and quite a few branches of the upper and middle Yangtze River will be channelized partially or completely and the natural rivers will be transformed into semi-natural or artificial controlling rivers, which will result in long-term impacts on natural ecosystem and environment of Yangtze River. Healthy Yangtze River should not only serve the human beings, but also provide good environment for the natural ecosystem of valley, and the natural hydrologic cycle and ecosystem maintenance also need the Yangtze River. Therefore, in the development and utilization of hydropower, it should be fully realized that the Yangtze River is originally the product of hydrologic cycle, it need participate in and maintain the natural hydrologic cycle; the basic features of river hydrologic cycle include connectivity, flow dynamic characteristics and periodicity. In the paper, in view

of the present situations and the plan of future hydropower stations in the upper Yangtze River, the layout of cascade power stations of the upper reaches is analyzed; the changes of environmental factors such as water and sediment process etc. produced by the construction of cascade reservoirs are discussed; the impacts on aquatic life, such as fish ,since habitat changes are discussed; and finally, the countermeasures for mitigating the impacts arisen from cascade reservoirs are proposed.

2Construction of Hydropower Stations and Reservoirs in the Yangtze River

Shilong Dam, the first hydropower station in the Yangtze River Basin was built in 1910; and up to 1949, 31 dams had been built in the whole valley and all of them are of small ones, with the total installed capacity of 134mw. After 1949, hydropower stations and reservoirs were developed rapidly in 1950s ~1960s, and the hydropower development was located in the middle and lower areas with convenient traffic and developed economy; from 1960s to 1980s, the construction of hydropower stations in the upper, middle and lower reaches were in full swing; up to the late 20th century and the early 21st century, in order to meet the requirements of West Development strategies and "West-to-East Power Transmission", the stress of hydropower development was transferred to the upper Yangtze and the rivers of Southwest China, and up to December of 2001, 2441 hydropower stations had been built or are under construction, with installed capacity of 69727.1mw, and annual electricity output of 2924.96×10^8 kwh, accounting for about 70% of the total installed hydropower capacity in China. The installed capacity and annual electricity output of power stations having been built or under construction made up 30.5% and 27.9% of the economically developable reserves respectively. From the distribution in region, more than 50% of the hydropower in the middle and lower Yangtze have been developed and utilized, while only less than 20% for the upper areas, and for the stretch from headwaters to Yibin, less than 5% of economically developable reserves have been utilized for hydropower development. Therefore, in the future 20 years, the hydropower development of the Yangtze River will be carried out mainly in the upper reaches.

Viewed from reservoir construction, up to 2000, 44000 reservoirs had been constructed in the Yangtze River Basin with total storage capacity of 1373.37×10^8 m^3, including 109 large-scale reservoirs with total storage capacity of 667.42×10^8 m^3, 997 medium-sized reservoirs with total storage capacity of 242.00×10^8 m^3, and the total storage capacity would exceed 2113×10^8 m^3 inclusive of the large and medium scale reservoirs under construction. Table 1 shows the statistics of storage capacity of existing and planned large and medium reservoirs in main stems and branches of the upper Yangtze River, it can be seen that the degree of hydropower development in Wujiang River and main stems in upper Yangtze River is quite high, while it is lower in other valleys, but there are more reservoirs in planning for each reach, especially in Jinsha River, the total storage capacity in planning will reach 83% of river runoff. With gradual implementation of the planning reservoirs, the total reservoirs storage capacity of upper Yangtze River will reach 61% of river runoff. If a large amount of small scale reservoirs are considered, the surface runoff controlled by reservoirs will exceed more than 70% of annual runoff; and except a few branches such as Chishui River, cascade reservoirs will be arranged in most of reaches in upper Yangtze River, and quite a few natural

rivers will be transferred to artificially controlled river.

Table1 Large and Medium Scale Reservoirs in Upper Yangtze River (up to 2001)

River	Annual runoff (10^8m^3)	Storage capacity of existing reservoirs (10^8m^3)	Storage capacity of reservoirs under construction (10^8m^3)	Storage capacity of reservoir in planning (total storage capacity) (10^8m^3)	Percentage of total storage capacity to annual runoff (%)
Jinsha River	1565.2	0	0	1300（1300）	83
Mintuo River	1065.0	5.9	70.0	260（335.9）	32
Jialing River	698.8	37.1	25.3	171.6（234.0）	33
Wujiang River	551.1	30.5	166.0	73.5（270.0）	49
Yibin to Yichang	634.8	42.9	479.6	83.3（605.9）	95
Total of upper Yangtze River	4514.9	116.4	740.9	1887.6（2745）	61

3Some restricting factors on hydropower development of Upper Yangtze River

The upper Yangtze River Basin covers the area of 100×10^4 km^2 approximately, with abundant hydropower resources, as well as forest, mineral and tourist resources. In addition, it is located in the first and second topographic cascades of China, with steep terrain, high mountain and deep valley, shallow and thin soil layer, intense geological activity, serious external dynamic geologic disaster such as mud-rock flow, landslide, and landfall, and frail ecology and environment.

The upper Yangtze River, with extremely rich forest resources is the second forested area in China, next only to northeast China, and also an important barrier for water and soil conservation of the Yangtze River. The forest is mainly distributed in upper Yangtze River such as Jinsha River, Minjiang River, Dadu River, and Jialing River and so on. However, the forest has reduced sharply due to unreasonable development, over-cutting and neglect of forestation for many years. Once the forest is destroyed, it is very difficult to restore, and as succession, grass & shrub degradation will occur quickly, the self-adjustment ability of ecosystem decreases greatly, and land degeneration area expands continuously.

The mineral resources are also abundant in the upper Yangtze River, including copper, lead, zinc, stibium, tungsten, cobalt, tin, iron, manganese and aluminum, approximately making up 30%~50% of the total China; the reserves of magnesium, vanadium, titanium and mercury account for about 80% of the total China, and all phosphate rock distributes in the

Yangtze River Basin nearly; only in Panxi, with the area accounting for 0.7% of the total area in China, possesses titanium, vanadium and iron respectively accounting for 95%, 54% and 20% of the total China.

In the Yangtze River, there are 370 kinds of fish belonging to 17 orders, 52 families and 178 genera separately, including 294 kinds of pure freshwater fish, 22 kinds of salt freshwater fish, 9 kinds of sea freshwater migratory fish, and 45 kinds of marine fish. There are many kinds of fish in upper Yangtze River, totaling 230, 103 kinds are found only in upper reaches due to the influence of special natural conditions, and a dominant population is formed in upper reaches, such as Chinese sschizothoracin, David' sschizothoracin, Hucho bleekeri and so on.

The upper Yangtze River is a synthesis of river system, mountain chain, biology and human culture, it possesses numerous sceneries and historic sites, and it is valuable in natural heritage, sightsee and scientific research, such as the natural marvelous spectacles like Three Gorges, Jiuzaigou, Huangguoshu, Three Parallel Rivers, the habitat of giant panda and other protected areas. Up to 2003, 32 national natural protected areas had been established, with the protected area of two million hm^2, accounting for about 1/5 of the upstream area. Each river of upper Yangtze River is different in landscape due to different geographic position; therefore, the natural scenery is unique. Long before one million years human activity has existed in the upper Yangtze. There are many important legacies and incalculable cultural relic spots. The cultural relic spots only influenced by the Three Gorges reservoir reach 1087.

Therefore, When planning and construction of cascade reservoirs, especially the large-scale reservoirs, the sensitive points of ecology and environment should be thoroughly understood, the restricting factors of river ecology, resources, environment and human culture should be taken full consideration, and the impacts of hydropower development on ecology and environment should be avoided or mitigated.

4Changes of Habitat Caused by Cascade Reservoirs

The ecosystem consists of abiotic factor (namely habitat) and biotic factor, the impacts of cascade reservoirs on ecology and environment are represented by the change of habitat first, including water and sediment transportation process; river continuity, flow pattern, flow velocity, water temperature, dissolved oxygen and transparency of water body, the main impacts involve following aspects:

(1) The most direct impact of cascade reservoirs is that continuity of river is breached. The upper Yangtze River is an important habitat of many migratory fishes, and migratory fish need three fields and one pass (breeding field, fattening field, spawning field, and migration pass). But the construction of cascade reservoirs will make the life channel of aquatic life(like migratory fish) obstruct, quite a few migratory fishes may become extinct. Up to now, no any consideration has been given to the ecological pass, such as fish-way, for the dams having been constructed and under construction because fish-way construction make the construction cost and technical difficulties increase, and also it is difficult to appraise its effect. On the other hand, the runoff river plant without consideration of ecological pass will give the aquatic organism a devastating damage. For example, in Minjiang River, water diversion method is used for many hydropower stations, resulting in flow separation of partial river

stretches and whole river flow passing through penstock although there are no high dams and big reservoirs, which will bring migratory fish a crushing blow, Hucho bleekeri, a kind of rare fish has already vanished. Migratory fish is one of the key index species in aquatic ecosystem. Their vanishing will affect the structure and integrity of entire ecosystem.

(2) Although artificial adjustment of large and middle scale reservoirs make the guarantee efficiency of water utilization enhance remarkably, at the same time, the flood and low-flow process of natural river is weakened, even vanishes, resulting in great change of habitat for aquatic organism. Flood is a natural phenomenon. It is necessary for the formation of river system and river channel. There will be no river without flood. As a result, the river channel will whither, and the function of river will deteriorate. The change of flood and lower- flow will cause the changes in water level, water temperature, runoff, sediment content and falling zone, etc.. The biological diversity always has a direct bearing on the complexity of habitat. These phenomena are the representation of river habitat and the natural environment needed by biological diversity. Certainly, the catastrophic flood has great destruction to the human beings and natural ecology, but ordinary flood is necessary for natural ecology, many aquatic fauna and amphibious fauna spawn on alluvial plain. If the river does not flood onto the alluvial flat throughout the year, the habitats for Flora and fauna will be reduced largely. Researches show that, since the changes of rainfall and runoff with time are the main driving forces of lifecycle for plant, invertebrate and fish of river and marsh, the loss of seasonal peak flow will make the excitation conditions for fish spawning, incubating and migrating interrupt. Due to the weakening of flood process, it is more difficult for fish to enter into marsh or return water zone, as a result, the structure of food web for aquatic life is changed, the restoring ability of shore vegetation reduces or vanishes, and the growth rate of vegetation slows down.

(3) The construction of large-scale reservoirs will produce obvious impacts on the habitat since reservoir impoundment. Since flow speed in reservoir area slows down, the water receiving sewage ability and self-purification capacity will reduce, especially for the branches of reservoir, it is very difficult for pollutant to diffuse in reservoir. A lot of floodplain is submerged by reservoir; the habitat for fish and amphibian reduces. Due to the deep waters of reservoir, stratification of water temperature will occur; the low temperature water discharging from dam will produce adverse impacts on downriver aquatic life and farm irrigation. In addition, the sediment accumulation will affect the service life of reservoir, and the silting-up of reservoir tail will affect navigation and wharf.

(4) The construction and operation of cascade reservoirs will make the sediment discharge and sediment content in middle and lower river channel decrease over a long time. It is necessary for a normal river to keep sediment discharge balance, and a certain amount of sediment discharge is needed for bank stability, estuary evolution, nutrient transportation, water's purification and ecology maintenance. For example, when clear water discharges from the Three Gorges reservoir, scouring will happen in the downstream in a long distance for a long time, the river bed will descent and the inshore ground water level also will lower, as a result, the habitat of inshore marsh is influenced. In the lake area of plain, the flood entering into Dongting Lake will reduce due to the lowering of water level of the Yangtze River, which will accelerate the degeneration of Dongting Lake and change the relations between river and lake. Due to the discharging of clear water, the riverbank will be eroded and the safety of both

embankments will be threatened possibly. Because of lacking sediment supply in estuary of the Yangtze River for a long period, the bank line will be eroded by tide, the natural evolution rule and habitat of estuary will change, and at the same time, adverse impact will be produced on the utilization of estuary bank line. For the Nile Delta, after the construction of Aswan reservoir, the sediment entering the estuary reduced, resulting in unceasing retrogression and corrosion of coastline. Therefore, over high or low sediment content is not suitable. The problems caused by the reduction of sediment content shall be paid more attention.

(5) A large-scale reservoir constructions have certain impacts on regional climate, hydrologic cycle and environmental change. The construction of reservoir will make the water evaporation and seepage loss increase, which will result discharging runoff reduce. Such as Hanjiang River, after Danjiangkou Reservoir was constructed, the upstream inflow has reduced by more than 10% since 1990s because of the influence of regional climatic change, as well as the water evaporation and seepage. For example, Aswan Reservoir, the annual evaporation and seepage loss reach 210×10^8 m^3, accounting for above 10% of the total storage capacity. With a large-scale the construction of hydropower stations on in upper Yangtze River, some reservoirs begin worried about the problem of water storage in dry season. The Yangtze River is rich in water resources, but in fact, most of them come from flood, the water volume is not ample in non-flood season, and the majority of reservoirs begin impoundment after flood, which will intensify the contradiction between water for human being and water for ecology in dry season. In addition, the construction of reservoir, submergence of a large amount of land and resettlement will alter the land use method in reservoir area, make the ground water level rise, and cause the temperature, climate, regional hydrologic cycle and habitat change. Moreover, reservoir may induce geological disasters such as earthquake and landslide, etc.

5Impacts of Cascade Reservoirs on Aquatic Life

The impacts of cascade reservoirs on aquatic life are long time and complicated. With the damage of natural habitat and the appearance of artificial environment, some organisms can adapt to the new circumstances gradually through their own adjustment to survive and develop continuously, while others will degenerate or die out. In ecosystem, any organism possesses its own specific status, and different organisms are inter-dependent, the extinct of one organism will affect the living or death of others and the integrity of whole ecosystem. Therefore, the impacts of dam and reservoir on organism and the response of organism to dam and reservoir are extremely complicated, only through long-term observation and research; the quantitative achievement will be obtained. Taking fishes for instance, the situation of organism influenced by reservoir can be explained as follows:

In the Yangtze River Basin, there are 321 kinds of phytoplankton , 330 kinds of zooplankton including common types of 130, 220 kinds of zoobenthos, 214 kinds of higher aquatic plant, and in large-scale aquatic animals there are some precious and rare animals such as the beasts--Baiji Dolphin and Finless porpoise, the reptiles--alligator sinesis, and the amphibians--Big grass carp and so on, including the state-first-level protected animals like Baiji Dolphin, Chinese sturgeon, Acipenser dabryanus Dumeril and Psephurus gladius; the state-second-level protected animals like Finless porpoise, Myxocyprinus asiaticus, Sichuan

faimen, Brachymystax lenok tsinlingensis, Roughskin sculpin and so on. The impact of cascade reservoirs on fish can be illustrated from following aspects:

(1) With the construction of the Gezhouba Dam and the Three Gorges Project in main stem, and the large-scale embankment and floodgate along rivers, the migratory fishes such as Sturgeons and Richardson between river and sea have reduced greatly. For Chinese sturgeon, the state-first-level protected animal, there were 16 spawning fields originally distributing from Hejiang to Pingshang with the length of 800km. However, after the completion of Gezhouba power station, the artificial spawning fields were formed, but only confined within the range of 5km, and the area of spawning fields is only 1~2% of original one. For Psephurus gladius, the state-first-level protected animal, its spawning fields distribute in the lower Jinsha River and the upper main stem of Chongqing, spawning from March to May among gravel of beach. For Myxocyprinus asiaticus, the state-second-level protected animal, its spawning fields distribute in Minjiang River and Jialing River of the upper Yangtze River, its spawn is slightly viscous and distributes in the crack of stone to develop, and the young fish can drift to the middle and lower reaches and lakes connecting with rivers. If reservoirs are constructed in these rivers, the overflow land will be submerged, which will affect the habitats and migration routes of these precious and rare fishes inevitably.

(2) The most unique fishes of the upper Yangtze River live in running water for all life, their structures, physiological characteristics and ecologic habits adapt to flowing water, river bed material and benthos of habitat, such as Rock carp and Largemouth bronze gudgeon, etc. fond of the waters with fast flowing velocity, large contact surface with atmospheric and high oxygen content. After the completion of reservoir, they will die of scarcity of dissolved oxygen in still water.

(3) For the main economical fishes in the Yangtze River—four kinds of Chinese carp (Blak carp, Chub, Bighead, and Chinese ide), the spawning depend on environmental factors like water temperature and water level rise, etc. to a great extent, in the breeding season from the end of April to the beginning of May, if the water temperature does not reach 18℃, no spawn will be produced even if the river swells; while appropriate water temperature and sudden rise of river water level caused by rainfall will stimulate the spawn of Chinese carp, and the spawning scale is just relevant to the amplitude of water level rise. The fish spawn develops and incubates in the process of drifting, with drifting length of 300~400km, and the flow velocity shall be more than 0.2m/s, otherwise the spawn and young fish will sink so as not to develop normally. There are 20 kinds of fish with drifting spawn in the main channel of Yangtze River. In reservoir, it is difficult for spawn to incubate in drifting due to the submersion of overflow land in reservoir area and the reduction of spawning field.

(4) In cascade hydropower stations of the upper Yangtze River, most of them are runoff ones with low water head, not large reservoirs like high dams, but the utilization ratio of flow is very high, 90% of them flow across turbines or penstocks, so it is difficult for aquatic organisms such as fish to survive. In addition, for most of runoff power stations, daily regulation is performed, or zero-flow occurs in the river without regulation capacity every day, therefore, fish cannot survive. Moreover, a lot of high dam discharge water through aeration to dissipate energy, which result in supersaturated gas in water in a considerable length of river channel (several hundred kilometers), a great amount of young fish will die of bubble disease.

6 Counter measures

The impacts of cascade power stations on ecology and environment are very complicated, therefore, comprehensive and objective analysis shall be performed on the basis of scientific and pragmatic approach, relationships between ecological environment conservation and hydropower development shall be handled correctly. We cannot stop developing hydropower resources due to these impacts, but do not make blind development without consideration of them. All plan, design, construction and management of hydropower development shall widely heed the opinions of all stakeholders, encourage the public's participation, and try to take measures to reduce the impacts of hydropower engineering on valley ecology and environment. The recommended measures are as follows.

(1) The governments, departments, basin managers, reservoir managers and stakeholders shall possess the idea of ecological and environmental conservation, and realize the complexity and importance of problems in ecology and environment arisen from the construction and operation of hydropower stations.

(2) Strengthening integrated water resource management. In the water resources comprehensive planning of main stem and tributaries of the Yangtze River, the base flow standard for river ecology shall be worked out as the basis of hydropower station planning, design, construction and management, from the angle of the whole basin and in accordance with the characteristics of each river basin. The construction of power station shall be carried out under the conditions of ensuring the necessary ecologic base flow and considering the ecological operation from the angle of the whole basin.

(3) Taking river basin as a unit, routine ecological and environmental monitoring shall be carried out so as to perform long-term scientific observation and research; not only forecast and assessment of environmental impacts shall be conducted, but also the observation and analysis of ecological and environmental changes of post-project shall be paid more attention.

(4) In the planning of hydropower station, the economic index of hydro-energy utilization, as well as the impacts of power station and reservoir on every kind of natural reserve and ecological & environmental sensitive areas shall be considered, and the avoidance and reduction measures of the impact shall be taken as an important task in planning. For the impacts having been produced, necessary engineering measures and non-engineering measures shall be taken for remedy.

(5) A long-term ecological compensation mechanism shall be established in law to recover and protect the ecology and environment of impacted areas.

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