Key Technological Issues in Constructing an Ecology and Environment-friendly Hydropower Project Development System

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1 Foreword

The goal of constructing a well-off society on all fronts as put forward by the 16th Congress of the Party involves four targets, one of which is continuous enhancement of sustainability, improvement of the ecology and the environment, remarkable upgrading of resource efficiency, promotion of harmony between man and nature, and advancement of the entire society towards a civilized development path that features economic development, affluent livelihood and a sound ecology.

As China faces enormous pressure of population growth and rapid development of the national economy, the construction of infrastructure is crucial to supporting socioeconomic development in the future. Grandiose projects such as the Three Gorges Project, the South-to-North Water Transfer Project, the West-to-East Pipeline Project and the Qinghai-Tibet Railway Projects are all of great significance to the realization of a well-off society on all fronts. The conflict between growing economic development and ecological/environmental protection becomes increasingly acute.

In a fairly long time to come, the development of water resources and hydropower will remain important infrastructure industries for the national economy. As such, water and hydropower projects capable of flood prevention, water supply, irrigation and power generation will play a significant supporting role in socioeconomic development. However, impacts of such projects on the ecological environment have attracted growing concern from the whole society, thereby becoming a constraint on such projects.

The Chinese energy mix has long focused on coal. In particular, coal-generated power takes up 70% of total power generation. The resulting huge emission of CO^2 and SO^2 not only severely pollutes the atmosphere but also subjects such power generation to constraint of international conventions. Water-energy is a clean and renewable energy. Aggregate water-energy resources in China top the whole world. After several decades' development, hydropower installed capacity has taken the first place in the world while hydropower generation is ranked No. 4 worldwide. Nevertheless, compared with developed countries, China is still limited in hydropower development, which is incompatible with the important status of water-energy resources in the entire Chinese energy mix. Consequently, China faces an arduous task in hydropower development.

China is rich in water-energy resources. The latest exploration data indicates that China possesses 689 million KW of water-energy reserves in theory (the 1980 census result was 680 million KW), 493 million KW (the 1980 census result was 378 million KW) installed capacity available for technical development, and 395 million KW installed capacity available for economic development. In order to satisfy the requirements of socioeconomic development in the new era, China should stick to the path of sustainable development, realize optimum allocation of resources within the largest possible extent, promote "west-to-east power transmission", highlight structural adjustment, protect the environment, save resources and promote healthy development of the power industry. All these need further acceleration of hydropower development and prioritizing the development of renewable water-energy resources.

However, the development of water-energy resources with common concepts and technologies has countered new constraints, i.e., ecological and environmental issues, which mainly include the following: sustainable development of the resettled population, impacts of constructing areas for the resettled on the ecological environment, the relationship with the natural reserves, impacts of reservoir sedimentation on rivers, impact of reservoir area silting on soil salinization, land sliding and

earthquakes brought about by reservoirs, impacts of slope reclamation on vegetation and landscape, impacts of flood discharging scouring and atomization on bank slope, impacts of excavation spoils and concrete wastes on the environment, and impacts of dam inundation, blocking and run-off adjustment on biological resources, biological diversity and landscape diversification, especially on rare fishes. Hence, it is an imperative research task for China to coordinate water and hydropower development with protection of ecology and the environment along rivers or river basins.

The existing guiding principle of development is to consider ecological and environmental issues under the prerequisite of safety, technical feasibility and economic rationality. In order to realize the strategic objectives put forward by the 16th Congress, China needs to attach more importance to ecological issues, and establish an environment-friendly hydropower project development system under which priority will be given to ecological and environmental issues throughout the stages of planning, exploration/testing, designing, construction, operation and management, so that China will reach a win-win situation of resource development/utilization and ecological/environmental protection.

2 International Trends and Development

Developed countries have basically completed their infrastructure development. With an early start in hydropower generation, developed European and American countries reached 70% of water-energy resources development back in the 1950-60s. At the moment, developed countries basically refrain from large-scale development of the remaining 20-30% of water-energy resources. The situation in China, however, is different. At the moment, water-energy resources already developed and still under development only occupy 30% of the total quantity available for economic development. There is still 150-200 million KW of water-energy resources to be developed even if China is to reach the level of development that European and American countries achieved in the 1950-60s.

With growing awareness of environmental protection among the general public, some environmental issues resulting from the construction of hydropower projects have increasingly exhibited themselves. As such, how to take economic development and environmental protection into overall consideration has become a brand new task for developers of such projects. It is generally held that environmental issues possibly resulting from hydropower development include the following:

- After water impoundment of a reservoir, with the increase of industrial wastewater discharged into the reservoir, water flow of the reservoir area will slow down, diluting and diffusing capability of the water body will be reduced and concentration of pollutants in the water body will gradually increase, all of which will lead to decline of water quality in the reservoir;
- Dam construction will impact directly on water aquatic organism, especially on migrating fishes, and lead to the disappearance of spawning areas of some fishes;
- After impoundment, temperature mix of some reservoirs will change, which might cause cold damage on crops of the lower reaches.
- In addition, after impoundment, changes in flow pattern will exert potential impacts on ecological environment of the lower dam and river outlet areas, and result in the rise of ground water level in periphery reservoir areas and salinization of soil.

Since the 1970s, mankind has paid more attention to ecological and environmental issues caused by dam construction. Some scholars hold that the development value of clean, efficient, reliable and renewable hydropower resources is being reduced by its long-term and extensive potential negative impacts on ecological equilibrium. Inundation, blocking and change of run-off courses resulting from dam construction lead to fragmentation of the river ecological system, which will impact severely on the aquatic ecological system. Main expressions thereof include the following:

- Loss of the original natural run-off and hydrological conditions that the original species have been used to;
- Loss of functions of rivers as the communication corridor for organism and nutrients;
- Decline of the “filtering” function of the connected high land and water-area ecological systems along the rivers. The extent of impact depends on the scale and position of projects. Some large-scale water and hydropower projects may affect the ecological formation of the entire river basin, leading to

erosion and marine transgression at the lower-reach riverbanks and source reduction of nutrients in the outlet regions.

Research over the recent years focuses on the inclusion of ecological and environmental impacts into the whole process of project planning, designing and construction so as to mitigate the impact of water projects on the ecology and the environment. The US Department of Energy has developed the ecological turbine and established biological passes for protection of fishes.

3 Research Level and Technical Status Quo in China

Since implementation of the environmental assessment system, China has carried out considerable research on the impacts of large-scale project construction on the ecology and the environment, focusing on the Three Gorges and South-to-North Water Transfer Projects. Such research, however, is mainly confined to macroscopic qualitative statement rather than microscopic quantitative work, and is focused more on analysis of impact on the existing ecology and environment than on forecasting in terms of analyzing ecological and environmental effectiveness. For instance, at the moment, assessment of ecological and environmental effectiveness of large water projects in China is restricted to single-factor assessment, with very limited consideration given to functional changes of the ecology in the river basin after project implementation, structural and functional degradation of the ecological system in the basin and the corresponding recovery measures. At the same time, environmental assessment of strategies and plans and the research of the service functions of the ecological system are at the initial stage while research on recovery of damaged ecological system is still at the qualitative stage. In face with the fragile ecology and environment and rapid economic growth, how to coordinate the conflicts between rapid economic development and ecological/environmental protection is an important aspect of sustainable development. The current consensus is that emphasis should be placed on ecological and environmental protection throughout the process of policy-making, planning and construction. In addition, China is deficient in systematic research and consideration of the impact of dam construction on the survival and reproduction of fishes. With most rivers failing to consider the installation of passage facilities for fishes in dam construction, such deficiency is even more acute in the case of engineering measures. In particular, insufficient attention is paid to ecological and environmental protection and recovery, while more emphasis has been placed on returns on power generation, flood prevention and irrigation. Areas that require sufficient attention and substantial research include how to re-examine the objectives of developing water resources and hydropower in China from the perspective of sustainable development, how to give genuine consideration to intensive and practical attention to environmental and ecological protection and positive/effective engineering measures, and how to conduct salvage project research of issues that really impact the ecology and the environment.

4 Recommendations for Technological Development

In order to establish a large-scale environment-friendly system for hydropower project development, China needs to focus on the development of the following research areas.

4.1 Review and evaluation of environment assessment of built dams

4.1.1 Implications

It is of great significance to review and evaluate environment assessment of built dams, summarize the extent and degree of impact that project construction and operation exert on the ecology and the environment, and examine the effectiveness of measures that are adopted in project development for soothing out ecological impacts. Such researches are conducive to systematic understanding of multiple effects on habitat, biological diversity, water quality and society that result from inundation, blocking and run-off changes due to dam construction and understanding of the “real’ impacts of dam construction on the ecology and the environment. They are also of great significance for the production of pertinent measures for mitigating environmental impacts, and to the provision of systematic preliminary data for designing and constructing ecology-friendly dams in the future.

It is expected that the above research efforts will lead to the following results:

- Objective, fair and scientific assessment of the advantages and disadvantages that the dams will bring to the ecology and the environment after several years' operation;
- Production of recommendations and measures for improving the ecology and the environment, enhancing dam management and operation and reducing negative impacts;
- Summary of past experiences and lessons and establishment of future-oriented ideology, understandings and ways of thinking in pace with increasing economic, social and ecological requirements regarding project development such as dam construction.

4.1.2 Major research contents

Impact of dam construction on the ecology and the environment will be analyzed from planning and project development stages. Research work will be conducted on three levels, i.e.,

- Carry out systematic survey of dam construction and its impact on the ecology and the environment in China;
- Conduct analysis of sensitive issues in terms of the impact of dam construction on the ecology and the environment via case studies;
- Produce ecological standards for ecology-friendly dam construction and operation.

Specific research contents are described below.

Establish a case base for China's dam construction and its impacts on the ecology and the environment.

Efforts shall be made, under systematic survey, to select representative dams for overall consideration of elements such as dam size, development objectives, operation modes and ecological and environmental features of the rivers, analyze the impact of parameter portfolio on ecological functions and structure of rivers, so that a case base for dam construction and its impacts on the ecology and the environment will be set up.

Review and evaluation of dam construction and its impacts on the ecology and the environment

Typical cases shall be selected to systematically analyze dam construction and its impacts on the ecology and the environment. In view of existing topical issues, efforts shall be made to conduct priority analysis and review of plans for cascade development of hydropower stations from the layers of planning and project development, and positive/negative impacts of reservoir (power station) construction on the ecological environment. Systematic research shall also be carried out in terms of cumulative impacts of typical river-basin dam construction on the river-basin ecology and environment, while evaluation shall be made of the effectiveness of measures already adopted for mitigation of ecological impacts. Review and analysis study shall also be done for rationality of river-basin development plans in terms of their impact on the ecology and the environment.

Review and evaluation of changes in hydrological patterns resulting from dam construction and their impacts on the habitat and the environment

Through comparison of hydrological data before and after dam construction, summary shall be made of changes taken place in important ecological and hydrological indicators. In combination with species changes of indicative organism, efforts shall be made to analyze impacts of habitat changes on the growth history, species and quantity of organism. Alternatively, comparison of remote data series will be used to analyze habitat changes.

Research of ecological standards for ecology-friendly dam construction

On the basis of review and evaluation and in combination with domestic and overseas research achievements, basic ecological standards shall be established for dam construction and reservoir operation, including theories and methods for determining minimum quantity of undershot ecological flow quantity, ecological and hydrological scheduling for ecological recovery of river adaptability, and new-style reservoir scheduling standards that are based on the integration of ecological, hydrological and project scheduling.

4.2 Research of techniques related to environmental assessment of plans for developing water resources and hydropower.

4.2.1 Implications

It is required by both governance and river-basin development and utilization to carry out environment assessment of water resources and hydropower planning. Such assessment is basically a

blank space in China. With only some river basins or regions carrying out conceptual work, China lacks a complete system of assessment theories, techniques, methodologies and standards. At the same time, due to the increasing prominence of ecological and environmental problems in different regions over the recent years, environmental assessment of regions, plans and strategies have remained topical issues of environmental science and researches.

We shall also carry out analysis and assessment of environmental cost for development of water resources by observing the principle of sustainable development of river-basin environment, and in accordance with the natural conditions, functionality, multiple objectives, dynamics and uncertainty of the river-basin environment. Dynamic development modes should be used to analyze economic and environmental elements while environmental systematic planning and integrated management will be used as the main indicators for gradual establishment of a set of theories and methodologies for river-basin planning assessment that combines qualitative with quantitative elements, so as to improve and innovate dynamic development modes that are geared to sustainable development of the environment and set up an indicator system for environmental assessment of planning.

Active preliminary work in this regard shall be of great significance for providing water authorities with operable management basis for the latter's implementation of the *Environmental Assessment Law*, and for formulating water and hydropower plans and carrying out river-basin ecological and environmental protection in the new era.

4.2.2 Major research contents

4.2.2.1 Scope of environmental assessment concerning water resources and hydropower planning and analysis and research of key ecological and environmental issues

For determination of the scope and priorities of environmental assessment concerning water resources and hydropower planning, it is necessary to classify such planning activities, analyze their direct and indirect impacts on the ecology and the environment, investigate and analyze environmental problems caused by different planning, and analyze and study key ecological and environmental issues related to special water resources and hydropower planning under uniform total river-basin management of water quality and quantity.

4.2.2.2 Research of theories and methodologies concerning ecological and environmental carrying capacity of river basins (or regions)

As the prerequisite for rational planning of water resources and hydropower, the assessment and study of ecological and environmental carrying capacity include research of the establishment of an assessment indicator system and subsequent research of theories and methodologies concerning ecological and environmental carrying capacity.

4.2.2.3 Cumulative effect of river-basin cascade development and techniques/methodologies for assessing such effect

Relevant work in this regard includes systematic study of cumulative impact of dam construction on river-basin ecology, environment, natural environment and social/economic aggregates, as well as the exploration of key elements related to environmental impacts caused by river-basin development. One single plan might only exert very limited impact on the ecology and the environment. However, accumulation of different development activities usually results in summed effect or synthesis. Assessment of cumulative effect is an issue that must be considered at the stage of planning for river-basin development, which involves the study of techniques and methodologies for assessing such cumulative effect of river-basin development and utilization and the subsequent production of such techniques and methodologies.

4.2.2.4. Establishment of a system of criteria for environmental assessment of water resources and hydropower planning

The establishment of a system of criteria for environmental assessment of water resources and hydropower planning includes the collection of information related to techniques and criteria of such assessment, domestic and overseas comparative study of such techniques and criteria, as well as the establishment and improvement of a system of criteria for environmental assessment of water resources and hydropower planning.

4.2.2.5. Research of the integration of techniques related to environmental assessment of water resources and hydropower planning.

With regard to research of the integration of key techniques related to environmental assessment of water resources and hydropower planning, it is necessary to design a mode that integrates the techniques and methodologies with the system of technical criteria for environmental assessment of water resources and hydropower planning, integrate and establish river-basin spatial information data management technologies and the methodology base for such environmental assessment, and carry out research of key technologies.

4.3 Ecological and environmental effects of water and hydropower projects and the countermeasures thereof

4.3.1. Implications

In a fairly long time to come, development of water resources and hydropower will remain important infrastructure industries for the national economy. As such, water and hydropower projects capable of flood prevention, water supply, irrigation and power generation will play a significant supporting role for socioeconomic development. However, impacts of such projects on the ecology and the environment have attracted growing concern from the whole society, thereby becoming a constraint on such projects. Elements that water and hydropower projects cannot afford to ignore include impacts of dam inundation, blocking and run-off adjustment on biological resources, biological diversity and landscape diversification, the risk to biological safety as a result of inter-river-basin water transfer and impact on the lower-stream biology. Hence, it is an imperative research task for China to coordinate water and hydropower development with protection of the ecology and the environment along rivers or river basins. With the issue of project technologies already taking its preliminary shape (including the introduction of overseas technologies), ecological and environmental issues are major constraints on future project development.

4.3.2 Content of research

4.3.2.1 Research of mechanism concerning the impacts of changes in key hydrological elements on biological resources

From the macroscopic perspective, comparison will be made of long-term and extensive changes in key hydrological elements and the rules of death and growth of biological resources, so as to study the extent and ways of hydrological patterns that are caused by water and hydropower projects and their impacts on biological resources. From the microscopic perspective, efforts shall be made on the basis of different organism's attraction to and avoidance of different hydraulic conditions, so as to study the impact of different hydraulic environments (such as velocity, flow pattern and run-off adjustment below dam) formed as a result of the related water and hydropower projects on important biological resources and explore the functions of such projects and the biological and hydraulic mechanism of important biological resources.

4.3.2.2 Research of major compensations for negative impacts on important biological resources

Efforts should be focused on the mainly impacted species and the key sources of negative impacts, i.e.,

- Technologies for rebuilding the habitat for key biological resources (man-made habitats);
- Technologies for adjusting and compensating run-off on the basis of biological hydraulics (such as projects for man-made flood peak and undershot temperature adjustment and technologies for run-off adjustment);
- Technological development of eco-hydraulic engineering.

4.3.2.3 Research of biological standards concerning the operation of ecology-friendly water and hydropower projects (including bio-hydrology and bio-hydraulics)

In this regard, efforts shall be made to conduct further research and establish basic biological standards for dam construction and reservoir (power station) operation, including theories and methods for determining minimum undershot biological flow quantity, bio-hydrological scheduling for biological recovery of river adaptability, and new-style reservoir scheduling standards that integrate bio-hydraulics with project scheduling.

4.3.2.4 Exploration and research of ways for eco-friendly investment-oriented resettlement

Efforts shall be made to take advantage of the opportunity of water and hydropower development and further explore new-style resettlement policies for sustainable development. At the same time, modes of eco-friendly investment-oriented resettlement shall be studied according to the indicator and

principle that the ecology and the environment will be improved while the number of resettled population and area of inundated farmland per unit installed capacity or reservoir capacity will be reduced.

4.4 Research of new technologies for project exploration and testing based on 3S technologies and physical exploration technologies

4.4.1 Implications

At the moment, geological explorations such as tunnel, dent and pit explorations are frequently applied in exploration for water and hydropower projects, which, due to explosion, excavation, random placement of spoils and omission of backfill and sealing, has to some extent impacted on the ecology and the environment of the project area. As such, we should vigorously develop project exploration technologies that are of less impact on the ecology and the environment, such as the 3S (RS、GPS、GIS), as well as new physical exploration technologies that are represented by integrated well-testing technology, micro-earthquake technology, shallow reflection, shallow refraction, chromatography imaging technology, reflective imaging, magnetic-wave geological radar technology, VLF magnetic wave testing technology, etc.

4.4.2 Key research content

（1）Integrated technical research on the application of 3S system in exploration and testing of water and hydropower projects;

（2）Research into ways and methods for establishing GIS visualized 3D spatial data model for geological information in project exploration areas;

（3）Research on technologies for interchange of 2D and 3D geological information;

（4）Research on analytic techniques concerning 3D geological information models for specific geological bodies;

（5）Research of technologies for integrated utilization of 3S exploration and testing results (such as quality assessment of rock mass, analysis of slope stability and automatic imaging system of development project exploration and testing);

（6）Research of the adaptability, reliability and accuracy of various physical exploration technologies

4.5 Research of new technologies for careful design, excavation and consolidation

4.5.1. Implications

Since the 1970s, with the construction of a considerable group of large and medium-sized hydropower stations, excessive tunnel, dent and pit excavation and slope reclamation have overwhelmingly changed the original natural topography and land form, destroying and negatively affecting the ecology and the environment, which is incompatible with the requirements for building large ecology and environment-friendly power station projects. In order to minimize the impact of project development on the natural environment, it is imperative to carry out research of new technologies for careful design, construction and consolidation of projects.

4.5.2. Key research contents

（1） Research of key technologies for large-scale underground plants, including：Research of advance forecasting technologies concerning excavating geology of tunnels during the construction stage; research of new technologies for excavation of large underground tunnels under complicated geological conditions; research of new technologies for lining and support and tunnel formation of large underground tunnels under complicated geological conditions; research of new technologies for non-damage quality testing of lining and support construction for large underground tunnels; research of new technologies for feedback information and decision making concerning stability monitoring of adjoining rock of large underground tunnels; research of new technologies for excavation of large underground tunnels; research into methods for analysis and integrated assessment of the stability of adjoining rock of large underground tunnels under complicated geological conditions;

（2）Fine technologies for excavation of slopes, including: research of technologies for integrated control of high slopes; research of technologies for ecological restoration of high slopes as a result of certain projects; research of technologies for total utilization of materials used in high slope

excavation; research of new technologies for slope exploration and monitoring; integrated analysis of project slope stability.

（3）Research of explosion and excavation technologies under complicated environmental conditions, including: research of methodologies for controlled explosion of outline excavation under complicated environmental conditions; development of imitation systems aimed at underground project excavation and explosion; research of technologies of fine excavation and explosion for tunnel formation and outlet locking; research of technologies for total-utilization controlled explosion that integrates with explosion-resistant research and excavation materials that meet requirements of dam fillers; research of criteria for assessment and control of safety impact of explosions; analysis of technologies for controlled explosion in terms of their impact on high slope stability and dynamic stability.

4.6 Research of key technologies for preventing and controlling geological disasters caused by reservoirs

4.6.1. Implications

Reservoir impoundment constitutes certain destruction on the stability of the banks, which is mainly expressed in the rise and fall of reservoir water level and the impact of wave scouring on the banks. At the same time, reservoirs result in the rise of ground water along the banks and cause changes in the nature of stress and physical dynamics within the bank rock mass and cliff debris. Softening of rock soil and decline of intensity will lead to a series of geological disasters along slopes, such as slide of bank cliff debris, revival of ancient landslips and collapse of bank slopes. Such geological disasters have taken place to different extents in built water and hydropower projects, exerting certain impacts on the ecology and the environment of the reservoir areas. China began its forecasting and study of landslides and avalanche in the 1960s, and has since put forward a variety of slide forecasting methods including but not limited to the three categories of determinative forecasting model, non-determinative forecasting model, and comparative analysis. However, it remains unresolved in China as to what theories and theoretical models should be adopted in forecasting. China is still in the process of exploring for effective solution of and theoretical models for forecasting landslides and avalanches.

4.6.2. Key research content

（1）Preliminary theoretical research related to forecasting of landslide and avalanche disasters in reservoir areas;

（2）Automatic systems for early warning and 3D monitoring of GPS-based landslides (including regular monitoring, laser positioning 3D monitoring, photographic imaging analysis and monitoring, earthquake chromatography imaging 3D monitoring); Efforts shall be focused on practical GPS technologies; forecasting software for real-time receipt, disposal and analysis of monitoring data and data bases for such monitoring.

（3）Research of methods for analyzing landslides and slope stability;

（4）Research of optimum measures for integrated control of reservoir collapses and landslides

4.7 Utilization of abandoned excavation materials, filling and building criteria and technologies for reclaiming construction sites

4.7.1. Implications

In traditional hydropower development, large amount of earth-rock projects inevitably explode mountains and rocks with earth taken for filling and building purposes, which destroys the surrounding ecology and environment to some extent. At the moment, such extensive practice will undoubtedly be subject to the constraint of environmental protection. An urgent task for the new generation of engineers is how to build ecology-friendly hydropower projects.

With regard to the previous research results, China has done a series of studies concerning rational utilization of earth-rock materials in its hydropower development. The Chinese starting point, however, has been based on economic considerations or failed to consider environmental elements in a conscious manner due to the shortage of sources of materials. Consequently, the Chinese research

results are not comprehensive. Nevertheless, relevant research results have also laid a good foundation for further study in the future.

In face with huge area covered by construction sites of hydropower projects, China should pay attention to ways of reclaiming and utilizing the sites after project completion.

4.7.2. Key research content

（1）Research of the engineering mechanics of poor earth-rock materials, the feasibility of applying such materials in filling dam bodies and technologies for such dam building;

（2）Research of the impacts of different dam materials distribution areas on deformation of dam body stress, as well as the reasonable shape of dam structure when building excavation materials or other poor earth-rock materials are used to fill up the dam body;

（3）Design scheme as well as technical criteria for construction control in replacing clay with poor earth-rock materials to fill up the core wall of an earth-rock dam;

（4）Technologies for ecological restoration of material premises and reclamation/utilization of construction sites

4.8 Research of new technologies of energy dissipation for mitigation of scouring caused by flood discharging, rain and fog

4.8.1 Implications

In flood discharging, high dam projects usually apply surface holes, medium (deep) holes, spillways and spillway tunnels. For the purpose of enhancing efficiency of energy dissipation, nappe collusion of holes and medium (deep) holes is also adopted to dissipate energy. However, scouring caused by flood discharging, rain and fog remains a serious problem. From the perspective of protecting banks and meeting specific environmental requirements, it is necessary to research into new energy-dissipating technologies that are efficient in energy dissipation, minor in atomization impacts and economically viable.

4.8.2 Key research content

（1）Mechanism research of flood discharging rain and fog;

（2）Energy-dissipating technologies within flood-discharging holes;

（3）New energy-dissipating technologies that integrate the construction of flow-diverting holes with permanent flood-discharging holes

4.9 Technological research of high-dam fish passes or fish stairs

4.9.1 Implications

Amongst other impacts on the ecology and the environment, dam construction affects growth and reproduction of fishes, which was not taken into sufficient consideration in previous dam construction in China. While developing the Gezhou Ba Hydraulic Project, a huge amount of research was done to protect the Chinese sturgeons. At present, China has made some achievements by way of artificial reproduction of the sturgeons. In the overall sense, we have not paid sufficient attention to fish protection in dam construction, let alone the conduct of corresponding researches. As such, further efforts should be exerted in this regard.

4.9.2 Major research content

（1）Efforts should be made to survey the existing living situation of fishes in typical rivers (rivers with stair development of dams or basically without development), including investigation and analysis of fish distribution prior to development from the perspective of geographic distribution conditions, with focus placed upon changes of the water body environments at upper and lower reaches due to reservoir construction, elements that affect survival and reproduction of fishes and the degree of such effect and survey of hydraulic conditions required by different fishes in different localities for survival and reproduction.

（2）Survey and study the design, utilization, management and technical standardization of domestic and overseas buildings that help fishes pass dams (especially regarding high-dam construction), focusing on overseas stair-development projects along rivers. On the basis of overseas research and application experiences and lesson, efforts shall be made to define problems that exist in

protecting dam-passing fishes in China's dam construction and put forward the direction for future research.

（3）Carry out research of hydraulic conditions of buildings that are geared to the passage of fishes through dams (overflow turbines), including physical model experiment and numerical imitation research from the perspectives of streamlining structures, improving convenience of construction and management.

（4）Develop project measures for addressing living conditions of fishes in reservoir areas and impacts of dissolved oxygen from lower stream buildings on fishes.

（5）Select typical completed projects (at the moment medium or small projects would be better choices) to carry out applied research of trial projects and follow-up observation, including the input of fries, the growth, migration and reproduction of fishes, with elements considered covering water temperature, velocity, sedimentation content and physical/chemical parameters.