Chapter 6 Policy Framework Research on Improving Service Functions of Aquatic Ecosystems

6.1 Characteristics of China's Water Resources

China's water resource mainly exists in surface aquatic ecosystems including rivers, lakes, reservoirs and swamps, and in ground aquatic ecosystems. China's river systems consist chiefly of the Songhuajiang River, the Liaohe River, the Haihe River, the Yellow River, the Huaihe River, the Yangtze River and the Pearl River (Zhujiang River). The fresh lake ecosystems include the Poyanghu Lake, the Dongtinghu Lake, the Hongzehu Lake, the Chaohu Lake, the Honghu Lake, the Nansihu Lake, the Baiyangdian Lake, the Hulunhu Lake, the Changbaishantianchi Lake, the Jingpohu Lake, the Dianchi Lake, and the Bositenghu Lake, etc..

Various factors, such as climate conditions, geography, and socio-economic conditions of the large population, affect China's water resources. The following sections present the characteristics of China's water resources.

6.1.1 Rich Water Resources but a Low per-Capita Water Availability

The total volume of China's average annual precipitation is 6 085.4 billion m^3, which is equivalent to a rainfall depth of 643mm. China's annual average water resources totals 2 774.1 billion m^3, taking the sixth place in the world with a surface water resources volume of 2 669.1 billion m^3, which is equivalent to a runoff depth of 282mm and ground water resources volume of 808.7 billion m^3. With a vast territory and large population, China's volumes of water resources per capita and per *mu* (1 *mu*=666.6 m^2) are 2 200 m^3 and 1 440 m^3 respectively, accounting for only one quarter and 60% of the world average.

6.1.2 Uneven Spatial Distribution of Water Resources and a Mismatch between the Distribution of Water Resources and Production Resources

In China, there are rich water resources in the south but few in the north, and the gap is large. The six water resources areas (the Songhuajiang River Area, the Liaohe River Area, the Haihe River Area, the Huaihe River Area, the Yellow River Area and the Inland Rivers in Northwest China) take up large percentage of the total area, population, GDP and cultivated land in China (63.5%, 46.1%, 44.5%, 60.5%, respectively). However, the area of these six main water resources areas only account for 19.1% of the total Chinese water resources area.

The area, population, GDP and cultivated land of the four water resources areas in the south (the Yangtze River Area, the Pearl River Area, Southeast Areas and Southwest Areas) constitute 36.5%, 53.9%, 55.5%, respectively, of China's corresponding totals. Yet, the water resources account for 80.9% of its total. Figure 6-1 and Figure 6-2 show the first-tier zoning of China's water resources and their respective total water resources.

Figure 6-1 First Tier-Zoning of China's Water Resources

Data source: comprehensive planing for national water resources, 2010

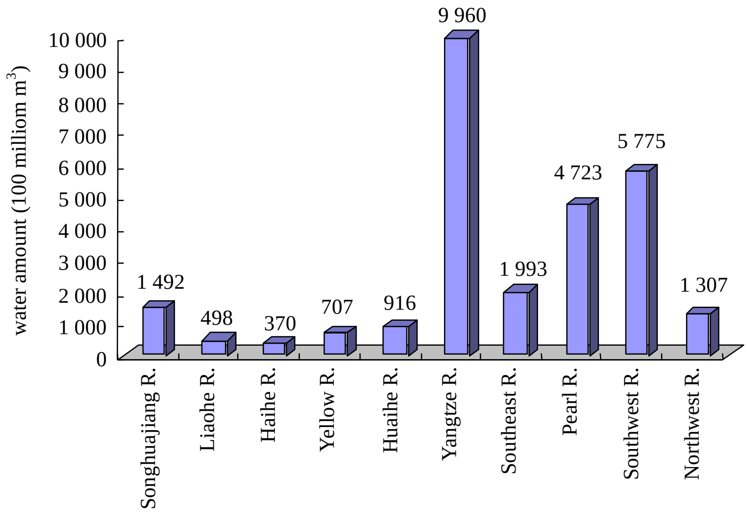

Figure 6-2 Total Water Resources in the First-Tier Zone of China's Water Resources

6.1.3 Uneven Distribution of Intra-Year and Inter-Year Water Resources, causing frequent Droughts and Water-logging Disasters

Due to influences from the southeast monsoon climate, the intra-year distribution of precipitation in China is extremely uneven. In most areas, the precipitation in four consecutive months accounts for 70% of the annual total. In the southern water resources areas, strong precipitation usually takes places from April to July. While strong precipitation occurs during June to September in the north. The large inter-annual variation in China's water resources leads to cyclical patterns, featuring consecutive plentiful or dry seasons in the seven river basins. The ratio of plentiful and dry seasons in southern water resource areas is 3.0 to 5.0, while it can be as high as 10.0 in the north.

The uneven temporary distribution of water resources has caused droughts in the northern water resources areas and frequent water-logging disasters. Seasonal droughts also cause water shortages in the southern areas.

6.1.4 High Sediment Content in some of China's Rivers

The Yellow River of China is the most sediment-concentrated river in the world, with an annual average sediment concentration as high as 35kg/m^3. In addition, the Liuhe River, one of the primary tributaries of the Liaohe River, is also laden with high sediment concentration. The sediment problems exert urgent pressures to improve service functions of river ecosystems and to achieve water and soil conservation.

China's large population and its limited water resources, its uneven spatial and temporary water resources distribution, and the distribution mismatch between its water resources and productive forces all generate present and long-term national challenges to China's water management efforts.

6.2 China's Actions to Improve Aquatic Ecosystem Service Functions

Since the early 1990s, under the guidance of such thoughts as sustainable development, harmonious coexistence between man and nature, scientific outlook on development and ecological conservation, and scientific research, comprehensive planning compilation on water resources, project construction and regulation implementation have been carried out to improve aquatic ecosystem service function actions in response to the drying up of rivers, water body pollution, water and soil losses, wetland shrinkage, land subsidence, sea water intrusion, vegetation degradation, and reduced biodiversity caused by inappropriate exploitation and ineffective protection of aquatic ecosystems.

6.2.1 Scientific Research Actions

From early 1990s to 2005, the Ministry of Science and Technology (MOST), the Ministry of Water Resources (MWR) and the Chinese Academy of Engineering (CAE) have organized experts to conduct research studies on rivers, lakes, vegetation and eco-oriented water demand for water and soil conservation. Some of these efforts are listed as follows: the Rational Water Resources Allocation and Its Carrying Capacity in Northwest Regions under National Key Scientific and Technological Project During the 9th Five Year Period Planning of Research on Rational Water Resources Development and Utilization and Its Eco-Environmental Conservation in Northwest Regions; the Water Use Standards for Ecological Purpose in Different Regions under National Key Scientific And Technological Project During the 10th Five Year Period Planning of the Research on Water Security Guarantee Technologies; the Eco-environmental Building and Water Resources Protection and Utilization under CAE's major consulting project of the Research on Water Resources Allocation, Eco-environmental Building and Sustainable Development in Northwest Regions.

6.2.2 Comprehensive Water Resources Planning Compilation Actions

From April 2002 to May 2009, a nationwide comprehensive water resources planning compilation was organized through the joint efforts of the National Development and Reform Commission (NDRC), the MWR, the Ministry of Land and Resources (MLR), the Ministry of Environmental Protection (MEP), the Ministry of Housing and Urban-Rural Development (MOHURD), the Ministry of Agriculture (MOA), the State Forestry Administration (SFA), and the China Meteorological Administration (CMA). Comprehensive water resources planning achievements were put forward at the national, seven-river-basin and provincial administrative (municipal and autonomous regional) levels. Control indexes of eco-environmental water consumption for major cross-sections of the Songhuajiang River, the Liaohe River, the Haihe River, the Yellow River, the Huaihe River, the Yangtze River, the Pearl River, and other rivers were proposed in the national comprehensive water resources plans. Such effort has provided an important basis for improving China's river ecosystem service functions in the upcoming period of time.

6.2.3 Project Implementing Actions

After the serious flood in 1998, large-scale projects of lake restoration from the fields in lakeside areas and displaced people resettlement in newly built towns were implemented in the Dongtinghu Lake and the Poyanghu Lake. These projects represented a historic transition from the thousands of years of lake reclamation for farmlands and competition between lakes and farmlands, to large-scale lake recovery of up to 2 900 km^2 in the Yangtze River Basin (13 billion m^3 of flood storage volume increase). Since 1999, unified regulation of water resources in the Yellow River contributes to the River's continuous water flow for 10 consecutive years. From 2001 to 2009, a total of nine water and sediment regulations were conducted via the adoption of an integrated regulation of Xiaolangdi Reservoir. All lines of river main channels in lower reaches were flushed with 356 million tons of sediment, leading to 575 million tons of sediment into seas and significantly improvements of the discharge capacity.

Eco-fragile rivers such as the Heihe River and the Tarim River were comprehensively treated and their water resources were managed and regulated through an integrated approach. As a result, the lower reaches of the Heihe River east to the seas have not dried out for five successive years, and the ecology in lower reaches of the Tarim River has been restored gradually. Eco-emergency response water compensation projects were implemented in some important water-short wetlands such as the Zhalong Wetland, the Nansihu Lake, the Xianghai Wetland and the Baiyangdian Wetland, greatly improving the eco-environment of the wetlands. The water diversion project in the Yangtze River, aims at improving the quality of water bodies and reducing losses caused by water pollution, diverted 14.7 billion m^3 of water into the Taihu Lake in eight successive years.

Substantial achievements have been obtained by setting up pilots for aquatic ecosystem protection and rehabilitation in cities of Guilin, Wuhan, Wuxi, Laizhou and Lishui City, etc.. Since 1992, five natural reserves have been built in Yichang City and estuaries of the Yangtze River to protect six kinds of rare aquatic animals, including the white dolphin, white sturgeon, Chinese sturgeon, Yangtze River sturgeon, finless porpoise and sucker fish, all of which were affected by the Three Gorges. To protect the Chinese sturgeon, artificial propagation and release have been conducted in China and a cumulative total of 5 million Chinese sturgeons have been released to the Yangtze River and the Pearl River. National projects for water and soil conservation were launched in the middle reaches of the Yellow River, upper reaches of the Yangtze River, warp land dams[1] in the Loess Plateau, Beijing-Tianjin dust storm source areas, black soil zones in Northeast, and the Karst rocky desertification areas. A grand total of 1.016 million km^2 of water and soil losses were treated, reducing the soil intrusion by an annual average of 1.5 billion tons and increasing water storage by over 25 billion m^3.

National ground water function areas and over-exploitation areas have been delimited, while water resources protection has been strengthened in priority water source areas of the South-to-North Water Diversion Project, water source areas of drinking water, and over-exploited areas of ground water. By means of shutting down wells and limiting exploitation and compensation, the continuous decreasing trend of ground water level in some parts of areas have stopped [2]. All the aforementioned projects have played a demonstrative and leading role in gradually improving China's aquatic ecosystem service functions.

6.2.4 System Implementing Actions

In accordance with the Law on Environmental Protection, the Law on Water and the Law on Water and Soil Conservation, China has implemented the EIA system on project construction, the water resources demonstration system, and the water and soil conservation plan compilation system, taking the overall water resources conditions, the carrying capacity, as well as the impacts of project construction on eco-environment into full consideration. It also adopted a guarantee system for eco-oriented water usage and basic flows in river cours-

[1] "Warping dam is a dam built on gully in soil and water loss area for the purpose of creating newly arable land by silt deposition in front of dam, decreasing gully slope, and mitigating gully erosion by gully bed raised step by step." http://unesdoc.unesco.org/images/0013/001381/138198e.pdf

[2] Chen Lei, Address on Congress of MWR Celebrating the 60th Anniversary of New Chinas Foundation, China Water Resources, 2009, (18): 21-30

es. The most stringent water resources management system has also been implemented, drawing three "red lines" on water resources management which are intended to clarify the bottom lines of water resources development and utilization in the following aspects: the first bottom line is to strictly control the total water consumption and the pollution sheltering in water functional zones; the second is to control the total pollutant discharge into rivers; and the third is to raise water use efficiency and to keep water wastage within limits. The implementation of all the aforementioned measures have served as a legal guarantee for gradually improving China's aquatic ecosystem service functions.

6.3 Analysis on Aquatic Ecosystem Service Functions

Aquatic ecosystem service functions, including socio-economic service functions and natural ecological service functions, refer to the aquatic ecosystem, the eco-environmental conditions, and the eco-processes that humans use, rely, and are sustained by [3, 4].

6.3.1 Socio-Economic Service Functions

Socio-economic service functions of aquatic ecosystem mainly consist of six items, including water supply, aquatic product supply, hydroelectricity, inland navigation, recreation, culture and aesthetics.

6.3.1.1 Water supply

Water supply is the most fundamental service function of rivers, lakes and ground ecosystems. It constitutes the major venues for fresh water storage and conservation and the main source of fresh water for man's existence. In the light of different water qualities in water bodies, water usages can be classified into waters for domestic, industrial, agricultural irrigation, and municipal eco-environmental purposes.

6.3.1.2 Aquatic product supply

One of the most distinct features of aquatic ecosystems is their forms of bio-productivity. By means of primary (higher plants and algae) and secondary production (animals, bacteria), aquatic ecosystems can produce an abundant supply of raw materials and foods for man's production and life, and forage for animals.

[3] Li Wenhua, Zhang Biao, Xie Gaodi. Research on ecosystem services in China: Progress and Perspectives, Journal of Natural Resources, 2009, 24 (1): 1-10

[4] Ouyang Zhiyun, Meng Qingyi, Ma Dongchun. Water ecosystem services and water management of Beijing. Beijing Water, 2010 (1): 9-11

6.3.1.3 Hydroelectric power

Potential energies are produced and stored as a result of water falling due to differences in terrains and landforms. Hydropower is considered to be a clean and renewable source of electrical energy with great development potential. Currently, 20% of the total power in the world comes from hydropower. There are 24 countries relying on hydropower for 90% of their energy usage, and 55 other countries for 40%. China's installed capacity has reached 117.2 billion kW, making it first in the world with an annual power generation of 600 billion kWh representing 20% of its total installed capacity and 15% of its total power generation.

6.3.1.4 Inland navigation

Rivers play an important role in transportation. Compared with other transportation methods such as railway, road, and air, inland navigation boasts advantages such as low cost and energy consumption, high efficiency, and large transportation volume. Therefore, men chose to build canals such as the Great Beijing-Hangzhou Canal in China to make full use of the natural rivers and to develop inland navigation. Such functions of the river ecosystem are of great significance to land resources conservation, environmental pollution reduction and sustainable development of regional economy and society.

By the end of 2008, there were 123 000 km of inland navigation ways in China, which are concentrated in the four major river systems of the Yangtze River, the Pearl River, the Huaihe River, and the Heilongjiang River. These systems span over 23 provinces, autonomous regions and municipalities, all directly regulated by the central government. The annual transportation volume of the Yangtze River arteries is over 1.1 billion tons, which is equivalent to the transportation capacity of 16 Beijing-Guangzhou Railways. The mileage of inland grade navigation pass amounts to 61 000 km, approximately 50% of the total navigation mileage in China. 7% of the inland grade navigation pass mileage is navigable by 1 000 tonne-class shipments (8 800 km), and 20% are navigable by 300 tonne-class shipments (24 600 km). However, China's navigation grade is still rather low, with only 11.3% of advanced level navigation pass above Grade 4. Consequently, further improvements are still required for its navigation capacity.

6.3.1.5 Recreation

Within the same river basin, rivers, lakes and wetlands are all interdependent. The unique landscapes of aquatic ecosystems provide important venues for recreation and nature experiences. From a vertical perspective, forests and grassland in the upper reaches and lakes, beaches and wetlands in the lower reaches are integrated into a diversified landscape; from the horizontal view, the inlaid pattern of highland, river bank, river surface and water body make the landscape features distinctive with a harmonious integration of river landscapes, exemplified by a sharp contrast between the dynamic flow and static river bank, swimming fishes and flying birds and forests and grasses at a standstill. Since 2001, the MWR approved 370 national water resources landscape areas of various types in the forms of reservoir, wetland, natural or municipal river and lake, irrigation area, water and soil conservation.

6.3.1.6 Culture and aesthetics

Cultural and aesthetic functions refer to the role of aquatic ecosystem and the cultural, aesthetic, educational and scientific research values it brings to human. Different aquatic ecosystems, especially different river ecosystems, give birth to different regional cultures and religious arts and diversified ethnic traditions and dispositions. Thus they directly influence scientific and educational, as well as civilization development. For example, the Nile gave birth to Egyptian culture, Euphrates and Tigris Rivers to the old Babylon culture, and the Yellow River and the Yangtze River to the Chinese civilization.

6.3.2 Natural Ecological Service Functions

Natural service functions of aquatic ecosystems mainly include five items: flood regulation and storage, biodiversity protection, environmental purification, substance transportation, and climate adjustment.

6.3.2.1 Flood regulation and storage

Lakes and wetland are capable of flood storage, adjustment for runoff from rivers and mountains, flood peak reduction, and flood process detention, thus aggregately reducing the economic losses caused by floods.

6.3.2.2 Biodiversity protection

Water is the source of life. Various bio-environments such as rivers, lakes, wetlands, and flood plains provide habitats for a great diversity of species and for their reproduction, conditions for bio-evolution and the emergence and formation of biodiversity, and a gene base for the protection of naturally superior species and the improvement of their economic qualities. Some aquatic ecosystems serve as places for wild animals to habitat, reproduce, migrate and live through the winter, others may serve as transfer stations for rare amphibians and special varieties of fishes.

6.3.2.3 Purification

Water provides and maintains an excellent metabolizing environment for physical and chemical pollutants, and improves the clarification ability of regional environments. By absorbing chemical substance from their surrounding areas, aquatic ecosystems have accomplished the process of pollutant transfer, transformation, dispersal and enrichment. During this process, the formation, chemical composition and attributes of the pollutant change, resulting in clarification effects. Moreover, as many water pollutants tend to absorb or adsorb on the surface of sediments, the slow streams of swamps and flood plains accelerate the deposition of floating substances. Meanwhile, pollutants (such as heavy metal) can attach to the floating materials, which will be deposited into water column, eventually forming polluted sediments that can slowly transform.

Water can increase air humidity through evaporation and transpiration, which can assist in the reduction of air pollutants. For instance, humidity may greatly shorten the remaining time of SO_2, speed up the deposition of air-borne particulates, and facilitate the decomposition and transformation of air pollutants.

6.3.2.4 Substance transportation

Rivers possess a series of ecological service functions such as sand and nutrient transportation and deposition. River currents may wash out the sand from the riverbed, so as to dredge the watercourse naturally. On the other hand, low currents may lead to mud sediments being deposited, with a rise in the riverbed and the infill of lakes. Moreover, the ability to store flood water and flood control will be dramatically decreased. Rivers transport large amounts of nutrients such as C, N, and P, which serve as important elements for global biogeochemical cycles and the main nutrition sources of the ocean ecosystems. This process plays a vital role in maintaining the high productivity of the receiving ecosystems. The bed-load of sediments carried by river are deposited at the river mouth and estuaries, gradually and consistently forming into small islands and deltas, leading to an increase of land area on one side and effectively protecting the seashore from storm erosion on the other. Related survey shows that the annual amount of sand transportation from rivers to the sea is about 3.35×10^8 t (Table 6-1).

Table 6-1 Sand Transportation Amount of the Main Sea Branches in China

(Unit：10^8 t)

Sea	Bohai sea				Yellow Sea	East China Sea				South China Sea	
Branch	Liaohe river	Luanhe river	Haihe river	Yellow river	Huaihe river	Yangtze River	Qiantangjiang	Oujiang	Minjiang	Zhujiang	Hanjiang
Sand amount	0.123	0.190	0.001 3	0.771	0.093	1.30	0.02	0.025	0.060 1	0.753	0.017 9

6.3.2.5 Climate adjustment

Aquatic plants and algae absorb CO_2 through photosynthesis and reserve the resultant organic substance as their own nutrients. Meanwhile, peat bogs cumulate and reserve large amounts of carbon as organic substance for soil, which also absorbs and stores carbon to a certain extent. Consequently, aquatic ecosystems help to decrease atmospheric CO_2 levels. In addition, aquatic ecosystems have significant effects in stabilizing regional weather and adjusting local climate by improving humidity, giving rise to rainfall, and influencing temperature, rainfall and wind. As a result, aquatic ecosystems may abate the negative influence of extreme weather events on human beings.

Water ecological service functions depend on the structure and ecological attributes of the ecosystems, and are fundamentally influenced by the water's natural characteristics. These characteristics include water quantity, water quality, water depth, speed of flow, and water temperature. Water quality and quantity deserve the most attention as they are the most prominent manifestation of human disturbances in water. These two elements are usually used to evaluate the freshwater ecological service functions (Table 6-2).

Table 6-2 Ecological Response to Flow and Water Quality Change

Hydrological elements	Change	Ecological response
Scale and frequency of flow	Flow changes frequently and on a big scale	Sensitive species disappear; algae increase; organic substance can be washed away; life cycle can be disturbed; energy flow changed
	Stable flow	Water transported to river floodplain abates, seeds cannot be dispersed efficiently
After seasonal flood peak	Gradually slow down	Fish are disturbed, when spawning, holding, or migrating; water plants change their net structure; vegetation grows slowly
Low flow	Slow flow prolongs	Physiognomy changes; water organic substance collects; aquatic diversity decrease; riverside vegetation decreases, species change
	Flood prolongs	Vegetation change its type; water plant living riffle fade away
Water quality	Worse	Eutrophication of water; fish die in large amounts
	Better	Clear water, nice sunlight, high biodiversity

Natural ecological service function of river, lake, swamp and groundwater system (Table 6-3).

Table 6-3 Aquatic Ecosystems Service Function and Its Evaluation Guide Line System

Type \ Service Function	Floodwater storage	Sand transportation	Clarification	C fix	Biodiversity maintenance
River	√	√	√	—	√
Lake	√	—	√	—	√
Swamp	√	—	√	√	√
Groundwater	√	—	—	—	√

Note: "√" possesses this kind of ecological function; "-" does not possess this kind of ecological function.

6.4 Current Situation and Evolution of China's Major Aquatic Ecosystems

China boasts the world's grandest and highest mountains and plateaus, and verges on the world's deepest and largest ocean. It nourishes various kinds of complex aquatic ecosystems, including long rivers, famous lakes, and swamps, and all kinds of land ecosystems. China's aquatic ecosystems functioned well and exhibited great resilience in the past. These ecosystems have protected a large number of rare species dating back to the ancient times during a number of global catastrophes and mass extinction, including the giant panda and the metasequoia. Since the 1970s, the integrity of our aquatic ecosystems has been compromised under the influences of climate change and human activities, resulting in scale shrinkage, simplified structure, decreased quality, regressive functions, and loss of biodiversity in some areas with intensive human activities.

6.4.1 Rivers

China boasts a large number of rivers, more than 50 000 of which cover 100 km^2 or more. Data from nearly 600 hydrological stations of major rivers shows that 76% recorded human activities that influenced the flow process, such as water withdrawal, with the measured flow evidently less than its natural run off. The change of hydrological situation is obvious, with the most prominent changes in the north. The proportion recorded from most hydrological stations in northern China since the 1980s is much lower compared to that before the 1980s. In Yellow River, Huaihe River, Haihe River and Liaohe River areas, the average measured flow is 50% to 80% of the natural flow, while in some parts 20% to 60% or even 10% have been recorded. Yet, years of complete drying-up has been recorded in other parts of river reaches. If 10% of the average annual natural flow is the criterion to maintain the basic ecological functions, the major function of the river ecosystems will be seriously destroyed with withered riverbed, exposed areas, and dried rivers when the natural flow fall below this criterion. Data of monthly flows between 1960s-1990s show increasing months of drying of major riverbeds in the Yellow River, the Huaihe River and the Haihe River. (Table 6-4)

Table 6-4 "Drying" Situation of First Class River
——the Yellow River, Huaihe River and Haihe River in different decades

First-class water resources	Name	Control station	Total Months of "Drying"			
			1961～1970	1971～1980	1981～1990	1991～2000
Haihe River areas	Luanhe River	Luanxian	0	1	24	34
	Xiatuohe River	Huangbizhuang	15	40	68	64
	Tanghe River	Xidayang	19	33	35	43
Yellow River areas	Yellow River	Lijin	4	13	19	56
	Fenhe River	Hejin	1	26	27	58
Huaihe River areas	Yihe River	Linyi	26	29	63	38
	Yinghe River	Fuyang	13	35	16	54

Data between 1956 and 2000 show slight differences in the total annual amount of water flow into the sea, but major differences are recorded when comparing the northern regions and southern regions. With the increase of the exploration and utilization of water resources, four first class water resources, including Yellow River, Huaihe River, Haihe River and Liaohe River has experienced downward trends in the amount of water flow into the sea (Figure 6-3), and such trends are particularly prominent in the Yellow River and the Haihe river. In the 1950s, the proportion of water flow into the sea to the surface water resources was 70%, while it has declined to less than 30% in the 1990s. Figure 6-4 describes the annual change of run off water in the Haihe River areas.

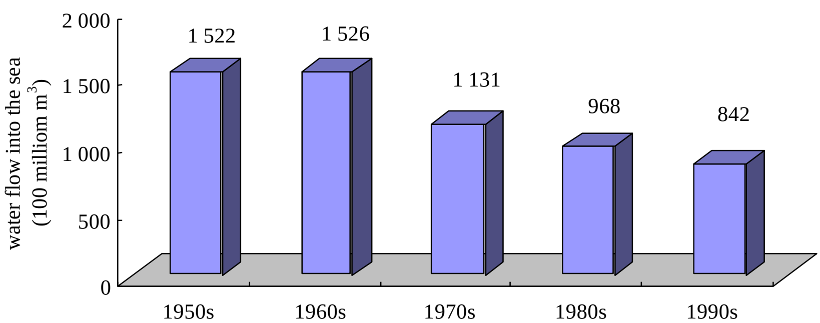

Figure 6-3 Annual Change of Water Flow into the Sea in North China 1950s to 1990s

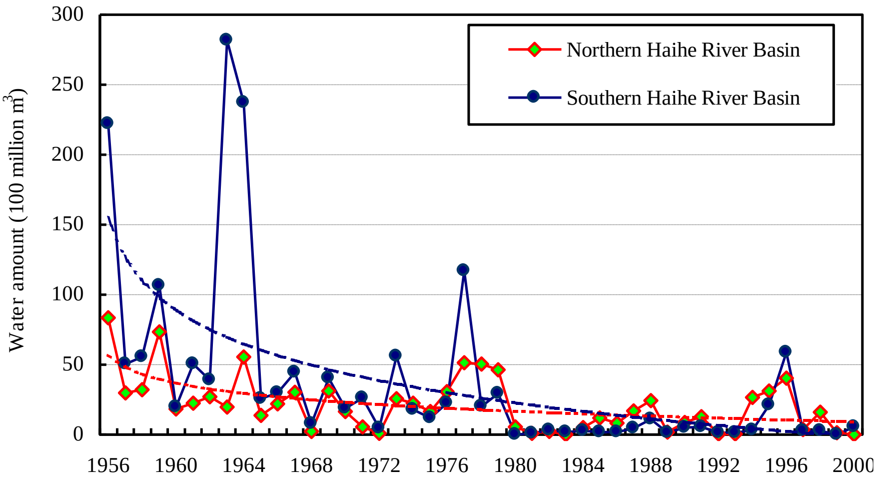

Figure 6-4 Annual Change of Water Flow into the Sea in Haihe River Areas

6.4.2 Lakes

China is dotted with a large number of lakes. In 2000, we have 2 941 natural lakes that are more than 1 km^2 in area, amounting up to an area of 85 000 km^2. These natural lakes are mainly dispersed in lake areas of the Qinghai-Tibet Plateau, eastern plains, and Mongolian Plateau. The total acreages of the northeast river areas and the Yangtze River areas account for 60% and 20% of the total river areas across the country, respectively. 27 lakes with an area of more than 500 km^2 spread across the country, amounting to a total of 36 000 km^2. Table 6-5 to check the classification of Chinese lakes.

Table 6-5 Classification of Lakes in China

Classification (km^2)	Number	Area (km^2)	Water storage (billion m^3)	Remarks
F[①]≥500	27	39 000	362	Water storage is related with the average water line for years. The total amount of water storage means that for lakes more than 10km^2.
100≤F<500	106	22 200	253.4	
10≤F<100	504	16 500	126.8	
1≤F<10	2 304	6 900		
Total amount	2 941	84 600	742.2	

Note: ① F represents the lake area.

Since the 1950s, the trend of lake shrinkage in China became increasingly obvious. Compared to the 1950s, the lake area had decreased by 14 767 km^2 by 2000, which is approximately 14% of lake area loss since the 1950s. 229 lakes among the lakes of more than 10 km^2 began to shrink, with a reduction in area of 13 776 km^2. 89 lakes dried up, amounting to a total of 4 289 km^2. The recessed area of freshwater lakes makes up 82% of the total amount of recession, while saltwater lakes account for 12% and saline for 6%. (Table 6-6).

Table 6-6 Recession Report for Lakes more than 10 km^2

First-class water resources areas	Recession lake number			Losing lake acreage			Decreasing amount of lake storage ability	
	Total number	Drying up number	%	Total km^2	Drying up km^2	%	Decreasing amount of storage ability (billion m^3)	%
Songhuajiang River areas	16	7	7.0	184	123	1.3	0.16	0.3
Liaohe River areas	3	3	1.3	69	69	0.5		
Haihe River areas	5		2.2	1 013		7.4	1.02	2.0
Yellow River areas	11		4.8	602		4.4	1.81	3.5
Huaihe River areas	10	3	4.4	816	113	5.9	1.11	2.1
Yangtze River areas	139	60	60.7	7 387	1 466	53.6	28.39	55.0
Pearl River areas	4		1.7	35		0.3	0.19	0.4
Rivers in NW China	41	16	17.9	3 670	2 518	26.6	18.98	36.7
Nationwide	229	89	100	13 776	4 289	100	51.66	100

Note: The decreasing amount of lake storage ability does not include the amount for drying up of areas.

6.4.3 Swamp wetlands

Results of the wetland investigation in China from 1995 to 2000 show that there are 2 895 swamp wetlands with an area of about 1 370×10^4 hm^2. The swamp wetlands are widely distributed in China, but generally develop centrally in the frigid-temperate zone and temperate zone humid regions, such as the Xing'an Mountains, the Changbai Mountain, the Sanjiang Plain, the Liao River Delta, the south of the Qinghai-Tibet plateau and the east Ruoergai Plateau, the river source area of the Yangtze and Yellow Rivers, the flood plains near rivers and lakes, the sea delta areas, and the seashores full of sand and mucky soil.

The Sanjiang Plain is China's most centralized swamp wetland area, with an area of about 534.5×10^4 hm^2 in the beginning of the 1950s, accounting for about 80.2% of the total area of the Sanjiang Plain. However, a long period excessive cultivation caused significant reduction in the swamp wetlands area by 74.76% since the 1950s, resulting to approximately 134.9×10^4 hm^2 of total swamp wetlands area in 2000. By the year 2008, the swamp wetlands area was reduced further to 100×10^4 hm^2, totaling 81.29% reduction since the 1950s. Declines of swamp wetland area greatly reduce their ecological service function and biodiversity, and further destroy the ecological systems.

6.4.4 Groundwater systems

China's shallow groundwater exploitation amount grew from 55.7 billion m^3 in 1980 to 108.1 billion m^3 in 2008, 90% of which arise from the northern parts of China. The exploitation quantity in many areas has surpassed the exploitable amount, leading to a continuous decline in groundwater levels, growth of regional groundwater over-exploitation areas, and increase of many environmental and geological problems. Groundwater over-exploitation is concentrated mainly in plains in the north of China. In 2000, the groundwater over-exploitation area in the Haihe Plains amounted to about 100 000 km^2, which represents 91% of plains in the Haihe River Basin and 55% of China's total over-exploitation areas. Groundwater over-exploitation in Grade Ⅰ water resources areas is indicated in Table 6-7.

Table 6-7 Groundwater Over-Exploitation in Water Resources Areas at Grade Ⅰ

Grade Ⅰ Water Resources Areas	Over-exploitation areas in Year 2000 (km^2)		Over-exploitation quantity in Year 2000 (100 million m^3)	Cumulative over-exploitation quantity (100 million m^3)
	Total area	Serious over-exploitation areas		
Songhuajiang River Areas	6 374	2 377	1.6	29.3
Liaohe River Areas	3 790	1 304	2.3	68.1
Haihe River Areas	102 353	41 528	61.6	975.3
Yellow River Areas	10 140	4 213	11.3	170.4
Huaihe River Areas	26 719	10 610	8.4	126.3
Yangtze River Areas	17 940	7 380	3.2	58.1
Rivers in SE China Areas	1 584	444	0.3	1.2
Pearl River Areas	2 134	635	0.3	10.6
Rivers in NW China Areas	14 424	4 835	10.6	92.1
Nationwide	**185 457**	**73 325**	**99.6**	**1 531.3**

Note: In terms of the total amount in Haihe River Basin, 14 890 km^2 of the overlying areas in over-exploited areas of shallow ground-water and deep artesian water and 11 000 km^2 of overlying areas in serious over-exploited areas have been deducted.

6.5 Analysis on Changes in Service Functions of China's Aquatic Ecosystems

Along with the evolution of natural aquatic ecosystems, China's ecological service functions also change accordingly. Overall, the provision of products from China's aquatic ecosystems has been greatly improved while its natural ecological and environmental service functions have degenerated dramatically due to the following aspects.

6.5.1 Water Regulatory Ability Declines

The decrease in the volume of China's major lakes, and the shrinkage of wetlands have caused a decline of natural storage capacity of aquatic systems. For example, over the past 50 years, the Dongtinghu Lake has shrunk 45% due to reclamation, resulting in reduced areas, and a decline in storage ability, and increased outlet volumes from the lake, which further caused a continuous rise of flood levels in the middle and lower reaches of the Yangtze River during the past decades. Due to farmland reclamation, the Sanjiang Plain Wetlands have also disappeared in large quantities, and the flood storage capacity and water conservation of aquatic ecosystems has declined sharply.

6.5.2 Substance Transportation Capability Degenerates

The increase in dam and reservoir construction, water withdrawal outside river courses, and changes in water volumes and dynamic conditions have impaired the river's capability in transporting sediments. This not only leads to the accumulation of nutrient salts, sedimentation, and eutrophication in reservoir bays, but also poses problems for maintaining the high production rates of the coastal ecosystems. For example, there are sedimentation problems in all 12 major estuaries in the Haihe River Basin. The total sediment volumes have reached 950 million m^3, reducing the flood discharge greatly. Meanwhile, since gates are constructed in succession to prevent saline water intrusion and store fresh water in estuaries, fish migration routes have been destroyed. The basin ecosystems were gradually transformed from open-type to enclose or inland-type, the ecology of estuaries were destroyed, and river species diversity has changed into lower grades.

6.5.3 Water Quality Purification Gradually Weakens

Large amounts of water diversion outside river courses and hydro projects hinder the self-purification of the water bodies in river courses. Added to the increase in pollutant discharges into rivers, prominent pollution takes place in water bodies in China. According to *State of the China Environment in 2009*, there is widespread organic pollution in China's seven key river systems, and only 57% of mainstream sections of all the river basins could satisfy Grade Ⅲ water quality requirements. Yellow River, Liaohe River and Haihe River are moderately or heavily polluted. In addition, there is severe eutrophication in China's major lakes. Among 26 major government-controlled lakes (reservoirs), those at Grade Ⅴ and worse than Grade Ⅴ add up to 14, accounting for 53.8% of the total. Major pollution indicators are total nitrogen and total phosphorus.

6.5.4 Service Functions of Providing Habitats Decrease

Rivers, lakes, and wetlands provide habitats for many species, but their decrease causes a similar decline in the usability of these habitats. Diversified vegetation communities in wetlands provide wild animals, some being rare and endangered species, with appropriate habitats for reproduction, migration, and winter refuge by birds and amphibians. According to latest research findings, China's wetland areas have decreased 11.46% during the past twenty years, from 366 000 km^2 in 1990 to 324 000 km^2 in 2008. Furthermore, of this 2008 figure, only 210 000 km^2 are stable, while most of the others are temporary wetlands formed by glacier snow and spring melt, resulting in damages to habitats needed by many migratory organisms.

6.5.5 Decline in Biodiversity

The degradation of aquatic ecology and pollution of water environment have resulted in the loss, fragmentation, and destruction of the environment for many living things. These factors have consequently caused a decline in the biodiversity of the ecosystem. Relevant findings suggest that the threatened species in China make up 20%-40% of all the existing species. In particular, the percentage of threatened plant species exceeds previous estimations with 4 000 to 5 000 advanced plants under threat, 15% to 20% of the total. The degradation of the aquatic ecosystem is the main contributing factor to this loss in biodiversity.

6.6 Major Contributing Factors to the Degradation of Service Functions of China's Aquatic Ecosystems

In addition to natural hydrological fluctuations and global climate change, other major contributing factors leading to the degradation of service functions on China's aquatic systems and the nature of this include the following five parts.

6.6.1 Fast Growth in Socioeconomic Water Consumption Robs the Available Water Needed for Ecological and Environmental Purposes

The water supply was 100 billion m^3 in the early 1950s, 400 billion m^3 in 1980, during which water was mainly used for agricultural purposes. Water supply in China surpassed 590 billion m^3 in 2008, during which water was primarily used for industrial and municipal purposes (Figure 6-5). Rapid increases in water use has led to a decrease in the water resource available for ecological and environmental purposes, especially in the north of China where basic level of ecological water use cannot be guaranteed, which has caused aquatic ecosystem degradation.

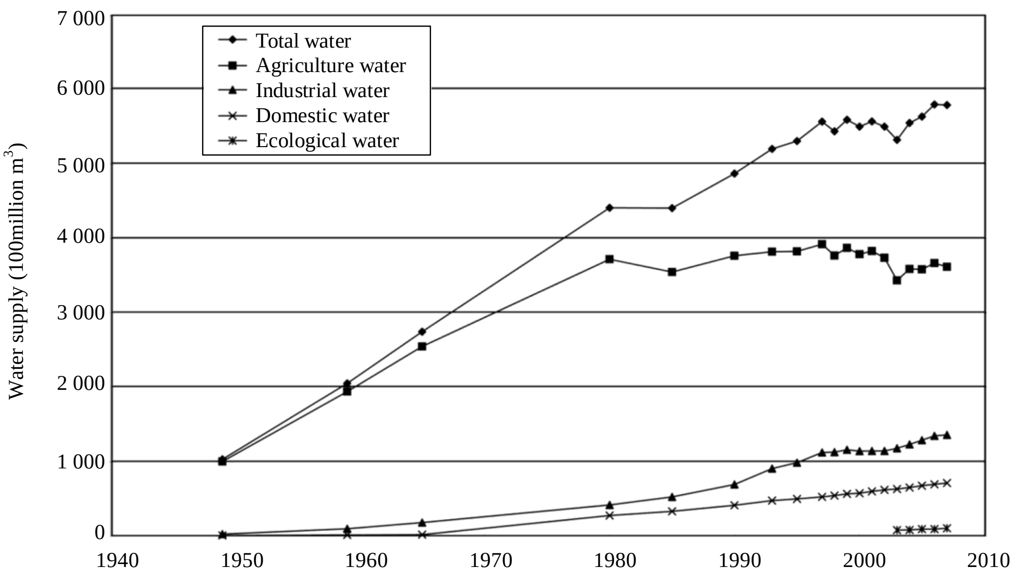

Figure 6-5 Water Supply Change Process of China's Water Supply Systems since 1949

6.6.2 Land Use Changes Leading to the Shrinkage of Natural Aquatic Ecosystems

Along with the agriculturalization around 1949 and urbanization and industrialization drive in the late 1980s, the increase in large-scale socio-economic land use resulted in reclamation from lake swamps, with some natural lakes, wetlands and swamps being replaced by farmlands and lands for construction, causing loss in area of aquatic ecosystems, or fragmentation and weakened service functions of aquatic systems. According to investigations, among all the lakes that have been reduced in size, sedimentation and reclamation make up 2/3 of the total.

6.6.3 Irrational Exploitation of Water Resources Exerts Influence on the Natural Aquatic Ecosystem Functions

Rivers and lakes consist of aquatic ecosystem resources, but some regions are driven by economic benefits to exploit other resources in water areas, causing the degradation of service functions of aquatic ecosystems. The most prominent problems are sand excavation in river courses and breeding in lakes. Disordered sand excavation in river courses causes excessive corrosion of river beds, damaging the living environment of river ecosystems, changing river course formation, lowering the ability for river courses to conserve water sources, and causing serious damage to river ecosystems.

6.6.4 Pollution Discharges into Rivers are Beyond Carrying Capacity of Water Environment

China's industrial and domestic sewage reached 75.8 billion t in 2008. Pollution discharges into rivers beyond the self-purification capacity of water bodies in many regions have caused environmental pollution and degradation of service functions of the aquatic environment. In Taihu Lake, the perennial average water amount was 17.7 billion m^3. However, water withdrawal in 2005 reached as high as 35.5 billion m^3. Sewage discharges from households, secondary and tertiary industries surpassed 6 billion m^3. The pollutant discharges have been beyond the bearing capacity of the water environment, which has led to the deterioration of water quality in the cycle processes.

6.6.5 Water and Hydro Project Construction has Exerted Negative Impacts on Ecological Environment

At present, there are over 86 000 reservoirs in China with a total capacity of nearly 700 billion m^3, and 44 000 gates of various types with a total installed capacity of over 170 million kW. While playing their roles of flood control, irrigation, water supply and power generation, various water and hydro projects will have negative influence on natural ecological environments such as river flow interception, changing hydraulic characteristics, and causing bio-environmental changes.

6.7 Impact of Reservoir and Dam Construction on River Ecosystem Service Functions in China

6.7.1 Impact on Socio-economic Service Functions of River Ecosystems

By the end of 2008, 86 000 reservoirs have been built in China with over 4 860 dams above 30m high. They have played an enormous and irreplaceable role in promoting socio-economic service functions of aquatic ecosystems. Since the 21st century, dams have been of great significance in the sustainable development of the nation's socio-economy[5].

6.7.1.1 Improve water supply capability to ensure water supply security

China's climate and topography have determined that China's water supply problems cannot be solved only by relying on natural adjustments and storage of river ecosystems. Thanks to the dam construction, the water supply capacity of river ecosystems has been improved, the irrigation area has been expanded, and imbalances between water resources and seasonal variation of river flows overcome and stability of water supply of river ecosystem maintained.

At present, various types of reservoirs with total of 86 000 have been built and have a total capacity of 692.4 billion m^3. Water diversion works, water raising projects, water diversion projects, and ground water source projects can supply a total of 591 billion m^3. This is sufficient to supply China's demands. China is a large country with a population of 1.3 billion. Its agricultural security mainly relies on irrigated agriculture and its annual irrigated area stands at 58.47 million hm^2, which is around 48% of the total cultivated lands. However, there are still 63.34 million hm^2 of cultivated lands that cannot be irrigated—with 20 million hm^2 of drought-stricken cultivated lands. China is in the process of accelerated urbanization and industrialization. There are over 400 cities in shortage of water. The conflicts between water supply and demand will be more serious by 2030 when China's population reaches a new record high of 1.5 billion. Therefore, dam construction, along with the increased capacity of river water supply, is an important remedy to ensure the safety of drinking water, food security, and socio-economic development.

6.7.1.2 Reduce natural aquatic product supply and increase artificial aquatic product supply

Eutrophication in reservoirs produces some aquatic plants such as poor quality algae which will affect aquatic forage supply. Changes in river beds, river courses and estuaries,

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[5] Dam reservoir and the coordinating development, Chinese exploration and practice. China Water Resources, 2009 (12): 1-3

and the shrinkage of wetlands, swamps, and flood plains have exerted an impact on the habitat, spawning reproduction and growth of many species of animals. These include fishes, amphibians, mollusks, insects, birds, and other riparian species that inhabit areas along beaches and rivers. This has led to a decrease in the supply of natural aquatic product. However, expanded waters due to reservoirs from dam construction provide immense space for breeding and promoting the existence and development of wildlife such as aquatic birds, thus increasing the artificial aquatic product supply.

6.7.1.3 Hydroelectricity to ensure energy security

Hydropower is the most important clean energy which can be developed on a large commercial scale in the world. Along with the sustained growth of energy demand and increasing impact of global climate change, countries all over the world consider hydropower development as a top priority for energy development and as a common response to climate change and sustainable development. At present, hydropower satisfies about 20% of the power demand. There are 55 countries relying on hydropower for half of their demand and other 24 countries for over 90% of their demand.

Due to a shortage of petroleum, China is increasingly relying on coals to provide the necessary energy. This will definitely lead to excessive CO_2 emissions. China should develop diversified renewable energy, including hydropower, wind, solar and biomass energy. China's total water energy take the first place in the world with a potential storage of 689 million kW and technical exploitation amount as 542 million kW only next to conventional energy such as coals. Currently, 172 million kW of water energy have been exploited in China, ranking first in the world, but only with a low exploitation rate of 30% compared to 65% in developed counties, including 82% in America, 84% in Japan, 65% in Canada, 73% in Germany, and over 80% in France, Norway, and Switzerland. Therefore, China still has a great potential for developing water energy as an alternative compared with developed countries.

As for now and in the long run, China is and will be at a critical juncture for fully building a moderately prosperous society in an all-round way and accelerating modernization drive, which requires a stable growth of power demand for socio-economic development. Hydropower, as a clean renewable energy, will be of more significance in national energy security strategies. Dam construction and development of water energy resources are in the interest of the international energy development and will play an important role in promoting low-carbon economic development.

6.7.1.4 Raise water level to increase inland navigation capacity

Dam construction increases navigation capacity of rivers by raising the river water level and expanding the area of the basin. The Three Gorges Dam, for example, has promoted further development of navigation of trunk lines and major tributaries in the Yangtze River. It is accessible to ten thousand tons of fleet navigating from Chongqing Municipality directly to Wuhan and Shanghai Municipality, navigation capacity of one-way launch from Wuhan to Chongqing Municipality up to 100 million tons, a 35% reduction in transportation costs in the Yangtze River.

6.7.1.5 Exert both positive and negative impacts on entertainment and recreation, culture and aesthetics

Dam construction on rivers and reservoirs will damage the environment of river ecosystems and exert an impact on entertainment and recreation, culture and aesthetics of rivers. However, the imposing dam and broad expanse of waters will both bring new perspectives of entertainment, recreation, aesthetics, and new cultures to the public. Currently, China has constructed over 60 national-level water landscape areas in the form of reservoirs.

6.7.2 Impact on A River's Ecosystem Services

The construction of dams and reservoirs will affect a river's ecosystem services – both in positive and negative ways. On the positive side, they will increase capabilities for flood regulation and storage, reduce greenhouse gas emissions, and improve regional climate. Negative impacts include damages to aquatic habitats, reduction in biodiversity, blockage to the channels of migratory fish fauna, and alterations to the balance of flushing and silting in river courses[6, 7].

6.7.2.1 Increased flood regulation, storag, and safety

With numerous rivers and under the effect of the Southeast Asia's monsoon climate, China has always been affected by frequent floods. There are more than 60 major floods since the early 20th century, with one occurrence in less than two years. China's floods are mainly caused by torrential rain episodes. Along the middle and lower reaches of the rivers are dense population, highly urbanized areas and developed industries and agriculture. These communities would suffer from tremendous losses from a major flood.

Since the founding of the People's Republic of China in 1949, massive construction of flood facilities including dams has greatly reduced flood-related fatalities, but economic losses have risen due to the growing economic size of flood-prone areas. Flood damages are estimated to be around 110 billion *yuan* since 1990 on a national annual basis. Considering

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[6] Peng Hui, Liu Defu, Value evaluation of the effects of a dam on river ecosystem services. J. Huazhong Univ. of Sci. & Tech (Natural Science Edition), 2010, 38 (1): 125-128

[7] Xiao Jianhong, Shi Guoqing, Mao Chunmei, Xing Zhenxiang, River ecosystem service function and dam-construction, Chinese Journal of Ecology, 2006, 25 (8): 969-973

the limited flood discharge capability of many river courses, the only way to reduce flood damage is to build a comprehensive system composed of reservoirs, levees and flood retarding basins, particularly large capacity reservoirs. The flood control reservoir of the Three Gorges Project, for instance, has a capacity of 22.15 billion m^3, which can reduce the occurrence of floods from once every ten years to once every 100 years.

By the end of 2008, China has constructed 86 000 reservoirs with a total capacity of 692.4 billion m^3. These reservoirs, together with other flood facilities such as levees, have provided China's major rivers with basic capabilities to prevent floods. Compared to developed countries, however, China's reservoirs and dams have a limited runoff control, which is 21.6%, while this figure is 33.7% for the United States and 27.0% for Russia.

6.7.2.2 Replacement of coal-fired power generation to reduce greenhouse gas emissions

The construction of dams for hydropower will replace coal burning and reduce greenhouse gas emissions such as CO_2 and SO_2. China currently has an installed hydropower capacity of 172 million kW, which is set to increase to 300 million kW by 2020 with an annual power generation capacity of 982.5 billion kWh. Hydropower will annually reduce coal consumption by 326 million tce, CO_2 emission by 820 million tons, SO_2 emissions by 5.7 million tons, NO_2 emissions by 2.52 million tons, and soot emissions by 2.27 million tons. Hydropower will play an important role in reducing greenhouse gas emissions and securing some forms of environmental safety.

The Three Gorges Project has an installed capacity of 18.2 million kW with an annual power capacity of 84.7 billion kWh, ranking first in the world. It has an equivalent effect of annually reducing 50 million tons of raw coal burning, 125 million tons of CO_2 emissions, two million tons of SO_2 emissions, 10 000 tons of CO emissions, and 370 000 tons of nitrogen oxides.

6.7.2.3 Increased surface area of water body in reservoirs and improved regional climate

The storage of water in reservoirs has greatly increased the surface area and evaporation of the water body. Evaporation will change air humidity, slightly increase rainfall in the river basin, and absorb the heat from solar radiation to avoid excessive increase in local temperature. It has the effect of regulating air temperature, and water vapor maintains humidity conditions that facilitate rainfall. On the whole, dam construction has a positive influence on the regional climate around the reservoir area and beyond, resulting in prolonged frost-free period, less variation of day and night temperatures, lower high temperatures, and higher low temperatures. In general, when air temperature around a reservoir drops by four to five degrees centigrade in a hot summer, relative humidity will rise by 10% to 15%. This has reduced the biological threat of environmental factors to some extent and facilitated biological growth and development.

6.7.2.4 Damaged aquatic habitat and less biodiversity

The construction of dams and reservoirs has greatly altered the hydrological and hydrodynamic conditions like flow regime, water temperature, water quality, substrate, and the terrains of existing rivers. This is damaging to the growth, spawning, and breeding habitats of aquatic organisms and hence, their diversity is reduced.

(1) **Altered flow regime.** After dam construction, the water level of a reservoir will rise, water surface will expand, flow rate in the reservoir will slow down, and the flow regime will stabilize. As a result, existing water channels will lose torrents, shoals, and bends. For cascading portions of rivers in particular, the torrent regime will be totally eliminated. Such changes to the aquatic habitat are good for calm water or still water fish, but devastating for torrential fish. As a result, there will be a smaller population of torrential fish fauna and a smaller population of calm water fish fauna.

(2) **Water discharge of dams will alter natural seasonal flow in the downstream.** Water storage during the flood season will reduce discharge flow, while water discharge in the dry season will normally increase flow. Less flood duration and amount in flood season will reduce spawning area, prevent favorable conditions for spawning, and cause fish eggs and brood fish to die in the spawning area. Moreover, hydropower plants need to discharge water during peak electricity demand. This sometimes causes river level to change by several meters, causing the destruction of fish habitats.

(3) **Altered water temperature.** For deeper storage of water in reservoirs, there is an obvious phenomenon of vertical distribution of temperatures. The deepest water in the reservoir perennially maintains a low temperature. Alteration to water temperature will negatively affect aquatic organisms in the river. For fish fauna in the lower stream, frequent discharge of low temperature water at the bottom of reservoirs will cause water temperature in the lower reaches to be lower than usual. This will affect the spawning of fish fauna in certain sections of a dam’s lower reaches. It will also delay the spawning period, and negatively affect irrigated crops and aquatic organisms. In addition, for diversion and mixed type hydropower plants, a certain length of the river will become dry or lose water for a particular season or for the whole year.

(4) **Altered water quality.** After a dam and reservoir are constructed, the flow rate will decrease and the water body’s self-purification capacity will decline due to deeper water storage. Not long after a reservoir begins to store water, due to limited sedimentation of silt and nutrients, there is a limited impact on water quality in the reservoir area and lower stream. But with the progression of time, pollutants in the upper stream will accumulate in

the reservoir area, which may deteriorate water quality in the reservoir area and lower stream. Eutrophication will occur gradually in reservoir bays with limited flow rate and shallow water, as well as reservoir tails of tributaries, causing fish to die of hypoxia. For the fish fauna in the lower stream, when a large dam discharges water from a high water level, the rapid water flow will develop a high permeation of oxygen in the surface, absorbing air into discharged water. As a result, the water body will have intense aeration and the gas dissolved in the water will become saturated. This may cause air bubbles in the blood of fish and even cause fish to die of air bubble disease.

(5) **Altered river bed substrate.** Due to silt in the reservoir, there will be less sand content in the discharged water after dam construction. This will increase the erosion of a river bed in the downstream, scouring away its silt and changing the composition of sand and stones in the substrate of a river bed. Fish spawn in different places in the water such as in the weeds, on the underwater ground or rocks. When a river bed's substrate changes, certain fish species will not be able to spawn, or their eggs will not survive. Less silt will cause massive deaths of organisms and slash fish population in the dam's lower reaches.

(6) **Altered river course terrains.** Complex and changing river course terrains form a complex habitat. The more complex the habitat, the greater the biodiversity there will be. After water is stored in a reservoir, the central shoals of a river course will be inundated, the cross-sectional of a river course will change from compound cross section into a single cross section, and the cross-head of backwater area and bend of river courses are reduced. If river course terrains are the same, there will not be much diversity in habitat and fish fauna as well.

6.7.2.5 Blocked migration channels and destroyed migratory fish fauna

Most of China's estuary brackish migratory fishes are distributed in the downstream river mouth waters of various river systems. Some of them are in the middle and upstream waters. Most of them are rare and valuable species, including anadromous migratory fish and catadromous migratory fish, as well as near-shore migration and offshore migration between oceans and inland rivers. The most direct impact of dam and reservoir construction is the blockage of migration channels, and this impact is destructive and irreversible. Millions of Chinese sturgeons crashed into the Gezhouba Dam during anadromous migration and died. A barrage at the inflow river of Qinghai Lake suffocated thousands of anadromous scale-less carp (*Gymnocypris przewalskii*). The barrage blocked the gene communication of fishes from both sides, which is unfavorable to the breeding of multiple fish varieties.

6.7.2.6 Altered flushing and fill balance of river courses

Once silt-containing rivers enter a reservoir, the sediment will gradually settle in the reservoir, which reduces the reservoir's capacity. Sedimentation greatly affects a reservoir's functions and may even disable the entire hydropower plant. If silt is stopped by the dam in the reservoir, it will reduce the normal quantity of silt in the lower stream. Clean water discharged by the dam will more fiercely scour the river beds and riverbanks in the lower stream to offset insufficient silt to reach a new balance. River beds of lower reaches are usually washed by a few meters within ten years after dam construction began, so that the river course in the lower stream will become deeper and narrower and the otherwise broad and compound river courses with many reefs and sand banks will become straight, flat, and simple. Intense scouring of discharged water to river beds and riverbanks in the lower stream will have an adverse impact on the levees and buildings in the lower stream.

6.7.3 Win-Win Strategies for Achieving Socio-Economic Service Functions and Natural Ecological Service Functions

6.7.3.1 Hydropower planning, design, operation, and management at a basin level geared to developing in green direction

The comprehensive planning of a whole river basin serves as a basis for standardizing various exploitation actions over the basin and a guidance for formulating hydropower development and planning. The relationship between hydropower development and integrated water resources utilization (including flood control, navigation, water supply and irrigation, etc), eco-environmental protection, and regional socio-economic development should be well coordinated. Orderly exploitation of water energies should be conducted following the principle of giving priority to eco-environmental protection.

In the development and planning of hydropower within a basin, we should fully discuss the negative impacts of eco-environmental cascade-hydropower development of the whole river, adopt the necessary ecological protection measures and green operation and management methods, and build eco-friendly hydro projects that minimize the negative impacts to the lowest degree.

According to the integrated eco-environmental characteristics and biodiversity distribution within the entire basin, river sections that require protection should be clearly delimited with a ban on dam construction so as to check the disorderly hydropower development now occurring in some regions. For those hydropower cascades with water diverting methods, necessary basic ecological flows should be guaranteed for the lower reaches. For endangered plants and animals, protection areas should be built according to their living distribution conditions. Dams that would block passages for rare and endangered migratory species and for aquatic plants and animals under national first-grade protection should be stopped. For dams blocking aquatic plants and animals under national second-grade and third-grade protection, it is necessary to build migratory channels, conduct artificial reproduction, and release work and to construct protection areas, etc.. For sediment deposit caused in reservoirs by dam construction and flushing problems in river beds in the lower reaches, it is important to set up silt orifices in hydro projects and adopt the operation method of "storing the clean water and discharging the sediment" (making use of flood discharge holes and silt orifices to release sediment in the flood season when there is much flow and sediment deposition, and reserving clean water within the reservoir at the end of the flood season) so as to reduce the silt in the reservoir.

6.7.3.2 Implementation of EIA on hydropower development and planning in a river basin

It is important to implement EIA on the planning level so as to avoid any negative impacts of dam construction on the environment at the source. EIA on basin planning should be carried out according to the Law on EIA for coordinated and sustainable development between hydropower development and eco-environmental protection before compiling new plans or revising previous editions of hydropower development at a river or basin level.

6.7.3.3 Development of green hydropower certification systems

The development of green hydropower certification systems is an effective way to solve eco-environmental constraints of dam construction. It should be a particular encouragement for the owner to take effective ecological protective measures to minimize the negative impacts of dam construction and management on the eco-environment in order to realize a win-win progress in economic development and eco-environmental protection.

6.8 Policy Recommendations for Improving China's Aquatic Ecosystem Services

In the light of the existing aquatic ecosystem problems in China and the underlying causes, policy recommendations for improving China's aquatic ecosystem services are proposed as follows.

6.8.1 Establish and Improve Water-Related Laws and Regulations and Enact Law on the Yangtze River and Law on the Yellow River

As the implementation of the basic strategy *Rule of Law* deepens, China has formulated a series of water-related laws and regulations with *Water Law* at the core and a complete set of others including *Flood Control Law*, *Water Pollution Prevention Law*, *Soil and Water Conservation Law*, *Environmental Impact Assessment (EIA) Law* as a guarantee for the protection and rehabilitation of aquatic ecosystems and the improvement of aquatic ecosystem services. The seven rivers of the Yangtze River, the Yellow River, the Haihe River, the Huaihe River, the Songhuajiang River, the Liaohe River and the Pearl River constitute China's most important aquatic ecological system, especially the Yangtze River and the Yellow River. The Yellow River is the mother river of the Chinese nation, which has played an irreplaceably vital role in sustaining China's socio-economic development.

However, there is no water resource protection law at a basin level in China so far while the current water-related regulations that are irrelevant, not systematic and operational cannot achieve stringent management and effective protection of the Yangtze River and the Yellow River. Therefore, it is urgent to promulgate *Law on the Yangtze River* and *Law on the Yellow River*, by drawing upon managerial approaches on river law formulation in other countries, and in line with the actualities of the Yangtze River and the Yellow River. These laws should emphasize strict management and effective protection so as to promote harmonious development between human use and ecological needs associated with the rivers.

6.8.2 Strengthen Current Enforcement and Management of Water Resources

For construction projects, the EIA system, water resources verification system, water resources demonstration system, soil and water conservation plan compilation system, drinking water source area protection system, planning environmental impact assessment (PEIA) system and others are being fully implemented in China. Ground water protection system, optimized water resources allocation system, aquatic function zone management system, sewage outlet management system, total inlet sewage volume control system, unified regulation system of water volume and quality, sewage discharge trading system, water body pollution accountability system and others are being widely adopted. System of eco-oriented water demand and basic flow guarantee in river course and ecological regulation system are initially applied. Moreover, the most stringent water resource management system is being strongly promoted by delimiting three bottom lines of: total volume of water withdrawal, aggregate sewage inlet volume, and water use efficiency. The bottom line of water resources development is clarified by a stringent control on total water use volume. The bottom line of accommodating pollution in water function zones is defined clearly by aggregate sewage input volume control. The bottom line of water use efficiency control is made clear by firm prevention of water waste. In addition, water quota-setting and water volume dispatch systems have been set in place in the Yellow River basin and the Heihe

River basin. However, some systems are not strictly enforced in practices, such as "three-simultaneity" in the EIA system, "three-simultaneity" in soil and water conservation plan compilation system, total sewage input control system, and the PEIA system, etc.. The enforcement of existing water-related laws and regulations should be further strengthened in a strict manner, and unlawful practices should be investigated and prosecuted.

6.8.3 Develop a Concept of Water Resources Management and Improve the Natural Ecological Aspects of Aquatic Ecosystems

Conventional water resource management, which focuses only on the socio-economic services of the aquatic system such as water supply, aquatic product supply, and hydroelectric generation, neglects its natural functions including flood regulation and storage, biodiversity maintenance, environmental purification, substance transportation, and climate regulation. As a result, the water resource is locked in a vicious cycle of relentless degradation due to the overexploitation of the resource. By extending aquatic ecosystems to a maximum degree without sacrificing natural ecological services of aquatic ecosystems such as flood regulation and storage, biodiversity maintenance, and substance transportation, water resources management should be optimized[8].

6.8.4 Enhance Theoretical Research and Accelerate the Establishment of Ecological Compensation Mechanisms for Aquatic Ecosystems

The establishment of ecological compensation mechanisms for aquatic ecosystems, in terms of economic theory, is the economic internalization and externalization of water resources and aquatic ecological service protection with the aims to make people who have put great efforts in protecting aquatic ecological services to enjoy economic returns brought by follow-up outcomes. It will also make the beneficiaries of aquatic ecological services pay for relevant expenses so that the justice of aquatic ecological function, a special "public good", between producers and users or consumers can be achieved through institutional design. And so that rational returns for investors in aquatic ecological products can stimulate the sustainable production of aquatic ecological services.

Currently, at the local level, ecological compensation mechanism of aquatic ecosystem has only been introduced initially in a few areas such as Huangshan City, Anhui Province, and Luoyang City, Henan Province. At a national level, The Ministry of Water Resources has issued guiding principles to direct theoretical research on ecological compensation mecha-

[8] Ouyang Zhiyun, Meng Qingyi, Ma Dongchun. Water ecosystem services and water management of Beijing. Beijing Water, 2010 (1): 9-11

nism of aquatic ecosystems. It will require further study to determine the compensation range, compensation body, compensated body, compensation standards and ways, ecological service values provided by compensation areas, and compensation fund raising and usage. According to the mechanism of aquatic ecosystem services and aquatic ecological system protection cost, administrative and market methods should be applied to regulate the relationship between stakeholders for aquatic ecosystem protection.

6.8.5 Develop Green-Oriented Watershed Hydropower Planning, Design, Operation, and Management and Build Eco-Friendly Hydro Projects

Integrated watershed planning, the basis of standardizing various watershed hydropower development planning, should be under the guidance of an overall watershed planning approach that coordinates hydropower development with unified watershed water resource utilization (flood control, navigation, water supply and irrigation); eco-environmental protection; and water energy exploitation under the principle of giving top priority to eco-environmental protection in an orderly manner. When developing watershed hydropower, *EIA Law* should be abided by, strategic environmental impact assessment (SEIA) must be conducted in a strict sense. The negative impacts of cascade development on eco-environment of the whole river should be fully revealed, necessary protection measures should be taken, and green operation and management should be implemented to build eco-friendly hydro projects. All of these measures will help to reduce the negative impacts to the lowest level.

In accordance with the overall eco-environmental characteristics and biodiversity distribution, rivers or river segments under protection from dam construction are clearly defined to prevent inappropriate development of hydropower in some areas. For those hydropower cascades of water withdrawal type, necessary ecological bases in lower reaches must be guaranteed. For rare and endangered species, natural reserves should be built according to their living environment and distribution conditions. Dams that block national first-grade rare or endangered migratory or special varieties of aquatic animals must be prevented. For dams that block national second-grade and third-grade migratory aquatic animals, migratory channels should be built or artificial reproduction release should be adopted or natural reserves should be built. For problems of dam-induced reservoir sedimentation and erosion on river beds in lower reaches, sediment flushing holes should be built on hydro projects. The method of “storing clean water and discharging muddy water” should be adopted (which aims at discharging sediment by sediment flushing holes or discharging flood water by flood-relief holes during flood seasons and when there are heavy loads of sediment, blocking clean water in reservoirs at the end of flood seasons) to reduce sedimentation in reservoirs.

The green hydropower accreditation system, an effective solution to eco-environmental constraints of dam construction should be established for hydro project construction. Owners of hydropower stations should be encouraged to take effective ecological protection measures to reduce the negative impacts of dam construction and management on eco-environment to a maximum extent. This will help to achieve a win-win progress between economic development and eco-environmental protection[9].

6.8.6 Increase Input and Fully Implement Protection and Rehabilitation of the Aquatic Ecosystem

Based on experiences from aquatic ecosystem protection by countries such as the USA, Japan, UK, Germany, Denmark, and Austria, some trials on aquatic ecosystem protection and rehabilitation have been set up in 14 cities including Guilin City in Guangxi Autonomous Region, Wuhan City in Hubei Province, Wuxi City in Jiangsu Province, Laizhou City in Shandong Province, Lishui City in Zhejiang Province, Songyuan City in Jilin Province, Xingtai City in Hebei Province and Xi'an City in Shaanxi Province. These examples have provided reliable support for comprehensive aquatic ecosystem protection and rehabilitation nationwide in terms of technology, management, institution, and financing channel. China should increase input for aquatic ecosystem protection and rehabilitation so as to change the general trend of aquatic ecosystem imbalances.

[9] Yu Xuezhong, Liao Wengen, Luo Huihuang, Discussion and Establishing Green Hydropower Certification in China. Water Power, 2007, 33 (7): 1-4