Hydroelectric Exploitations on the Upper Reach of the Yellow River in Gansu Province and Regional Economic Developments

Wenzhi Li: Gansu Provincial People's Government, 730030, China

Abstract: Ten cascade hydroelectric power stations have been planned to build on the Yellow River in Gansu province, of which four hydroelectric power stations as the Liujiaxia power station etc. have been built with the installed capacity of 2,404.5 MW and the total cost of $3{,}385\times10^6$ Yuan RMB, about 55% of its potential power have been exploited. By 2003, the four constructed power stations have generated the accumulative electric energy of 246.1×10^9 kWh, which delivered huge economic benefits that about 100×10^6 t of standard coal has been saved, 510×10^3 hm^2 irrigated area expanded and 3300×10^3 t farm products increased annually in three provinces of Gansu, Ningxia and Inner Mongolia. Especially under the control of the Liujiaxia reservoir, a flash flood such as happened in 1981 was avoided to form a catastrophic flood event as occurred in 1904, and also, the ice-jam flood disasters in the Ningxia-Inner Mongolia reach have decreased 80% of that before. Thus, the constructed reservoirs have protected the lives and properties of people lived in the riversides and promoted sustainable economic development in the areas along the Yellow River. Furthermore, a series successes, in designing, manufacturing, installing, running and managing the highest gravity dam, the largest single-machine capacity and installed capacity, and the extra-high voltage networks in China, and as well as in regulating the trans-province and multi-purpose water supply such as power generation, irrigation, flood and ice-jam flood control, municipal and industrial water uses, will provide many valuable experiences and lessons for the management, science and technology of the development of the Chinese hydroelectric industries.
Keywords: Yellow River; Hydroelectric exploitation; Economic development; Comprehensive utilization

1 Introduction to hydroelectric developing plans and exploitations on the Yellow River in Gansu Province

1.1 Introduction to the hydroelectric development plans

The Yellow River, the second largest river in China with a total length of 5,464 km, zigzags eastward through a gorge-filled reach of about 482.5 km from the Shigouxia to the XiaoGuanyin in Gansu province, China, where the natural fall is about 510 m and the theoretically estimated hydraulic energy storage is 4,664 MW, ten cascade hydroelectric power stations, including the Liujiaxia and Xiaoguanyin etc. have been designed to build with the total hydraulic head of 319.5 m and the overall installed capacity of 4,300 MW and the annual total electric generation of 19.233×10^9 kWh[1]. Their principal characteristics are referenced in Table 1.

Table 1. The characteristics of the ten cascade hydroelectric power stations on the Yellow River in Gansu Province

Power stations	Normal water level (m)	Storage capacity (10^6 m^3)	Designed hydraulic head (m)	Installed capacity (MW)	Annual electric generation (10^9 kWh)	Static investment (10^6 Yuan RMB)	Inundated farm lands (hm^2)	Resettlement of population	status
SHigouxia	1760	100	20	250	1.0	525	597	7609	Prepare to constructio
Liujiaxia	1735	5700	100	1225	5.7	638	5181	32639	constructed
Yanguoxia	1619	220	38	396	2.08	143	459	5925	constructed
Bapanxia	1578	49	18	180	1.05	149	73	201	constructed

Power stations	Normal water level (m)	Storage capacity (10^6 m^3)	Designed hydraulic head (m)	Installed capacity (MW)	Annual electric generation (10^9 kWh)	Static investment (10^6 Yuan RMB)	Inundated farm lands (hm^2)	Resettlement of population	status
Heikou	1558.5	9.6	5.6	81	0.449	360	0	0	To be built
Chaijiaxia	1550	15.8	6.3	96	0.519	354	0	0	Prepare to construction
Xiaoxia	1495	21	12	200	0.83	691	0	0	Being constructed
Daxia	1480	90	23	300	1.465	983	26.8	0	constructed
Wujinxia	1435	12	8.6	132	0.57	694	46.5	7310	Prepare to construction
Xiaoguanyin	1380	7020	88	1440	5.57	3050	3120	51869	planning
total		13237.4	319.5	4300	19.233	7587	9921.8	105553	

1.2 Introduction to the constructed hydroelectric power stations

According to the technological and economic report on the comprehensive exploitation and application of the resources of the Yellow River, the construction of Liujiaxia power station was the first-building project. In September1958, construction of both the Liujiaxia and Yanguoxia power stations were begun. Due to China suffering from the temporary economic difficulty later, the Liujiaxia power station's construction was forced to stop. Three years later, the Yanguoxia power station, the first power station on the Yellow River, was completed and its first hydroelectric generators began operation in November 1961. In November 1975 its eighth and final generator was installed and went into operation, by this time Yanguoxia power station's total installed capacity reached as high as 352 MW. The construction of the Liujiaxia power station restarted in 1964 and completed in 1968. Its five electric generators with the overall installed capacity of 1160 MW were installed completely and operated in December 1974. As for another two power stations: the Bapanxia station with the installed capacity of 160 MW and the Daxia station with the installed capacity of 324.5 MW, their constructions were begun in October 1969 and October 1991, completed in February 1980 and December 1996, respectively. Totally, the installed capacity of the four constructed power stations reaches 1996.5 MW nowadays.

The entire costs of constructing the Liujiaxia, Yanguoxia, Bapanxia and Daxia power stations were 638, 144, 149 and 2454×10^6 Yuan RMB, respectively, in which the installed capacity of the three power stations of Liujiaxia, Yanguoxia and Bapanxia, built before 1975 with the total investment of 931×10^6 Yuan RMB, was 1672 MW with the average cost of 557 Yuan RMB/kW, and the average cost of Daxia power station alone was higher and reached about 7562 Yuan RMB/kW. After China's reform and opening up, the installed capacity of the four power stations have been enlarged to about 2404.5 MW. The vital statistics about the constructions of the four power stations are listed in Table 2.

Table 2. Vital statistics about the construction of the four power stations

Power stations	Installed capacity at the station finished time (MW)	Installed capacity at present (MW)	Date of construction started	Beginning time for the first generator's operation	Duration for the first generator's operation (month)	Beginning time for all generators' running	Project work (10^3 m^3)		Total cost (10^6 Yuan RMB)
							Earthwork for excavation and filling	Concrete work	
Liujiaxia	1160	1390	Sep. 1958	Mar. 1969	90	Dec. 1974	18950	1820	638
Yanguoxia	352	470	Sep. 1958	Nov. 1961	38	Nov.1975	923	510	144
Bapanxia	160	220	Oct. 1969	Aug. 1975	70	Feb. 1980	1770	350	149
Daxia	342.5	324.5	Oct. 1991	Dec. 1996	62	Jun. 1998	4100	578.6	2454
Total	1996.5	2404.5							3385

1.3 Introduction to the operation and management of the constructed hydroelectric power stations

The most serious problem which Yanguoxia power station was facing to during its first operation period was the high sediment-laden stream of the Yellow River, which caused the generators broken down frequently. Although a sediment fence was used to filter, these problems were not solved completely until the constructions of the Liujiaxia and Longyangxia reservoirs.

The Liujiaxia power station's primary purpose is to generate electric power, additionally to meet other comprehensive requirements such as irrigation, flood control, municipal and industrial water uses. Liujiaxia power station is the principal power station acting as the amplitude and frequency modulator, and an accident standby in the electric network in the northwest China. The water stored behind the Liujiaxia power station can irrigate 860×10^3 hm^2 of farmlands in the three provinces of Gansu, Ningxia and Inner Mongolia. By regulating the Yellow River, Liujiaxia reservoir assures a steady flow of municipal and industrial water to Lanzhou, Shizuishan and Baotou cities etc., and also controls floods and ice-jam floods in the upper of the Yellow River. In order to better re-regulating water requirements for the agriculture, industry, flood control and ice-jam flood control in the three provinces of Gansu, Ningxia and Inner Mongolia, the Water Dispatching and Regulation Commission of the Upper and Middle of the Yellow River was established in August 1968 by approval of the State Council of P.R.China, in charge of water dispatching and regulation of Liujiaxia power station and the Upper and Middle of the Yellow River. The commission was constituted by the governments of Gansu, Ningxia, Inner Mongolia provinces, the Water Conservancy Commissions of the Yellow Rive of the Ministry of Water Conservancy of China, and the Bureau of Hydroelectric Management of Northwest China. The Commission Facilities Office is set in Lanzhou city, managed by Gansu Provincial People Government, and was in charge of the routine water regulations. After the construction of Longyangxia power station, Qinhai province was added to its members, and the commission director was acted by a staff of the Water Conservancy Commission of the Yellow Rive of the Ministry of Water Conservancy of China, and the association commission director and the office header were acted by staffs of the Bureau of Hydroelectric Management of Northwest China. Before 1969 when the Liujiaxia power station began operation, the Shanxi-Gansu-Qinhai-Ningxia Office was approved to establish in Lanzhou city by the former Ministry of Water Conservancy and Hydroelectric Power of China to dispatch the transported electric powers from the Liujiaxia power station to the three provinces of Shanxi, Gansu and Qinhai. Later in 1980, this office was replaced by the Bureau of Hydroelectric Management of Northwest China in Xian city, Shanxi province, which is in charge of the hydroelectric generation, and regulation in the four provinces of Shanxi, Gansu, Qinhai and Ningxia, of course, also in charge of the Liujiaxia power station's hydroelectric generation, dispatching and regulation.

2 The constructed hydroelectric power stations delivering huge economic benefits

2.1 Brief introduction to hydroelectric generations of the constructed hydroelectric power stations

The first generators of the Liujiaxia, Yanguoxia, Bapanxia and Daxia hydroelectric power stations began operations in 1969, 1961, 1975 and 1996, respectively. By 2003, their accumulative electric power were about 148.5, 66.9, 23.5 and 7.2×10^9 kWh, respectively. The total accumulative electric energy of the four power stations reached as high as 246.1×10^9 kWh.

2.2 Estimated economic benefits of the constructed hydroelectric power stations

The cascade exploitations on the Yellow River in Gansu province have delivered huge social and economic benefits. The constructed step is that the 'dragon head' **-** Liujiaxia power station was firstly constructed, then other cascade power stations continued to be built one by one in the gorge exits and preferable topographical and geological sites in its downstream. Thus, by the 'dragon head' regulating the discharge and flood peaks, it not only largely improved the benefits of the hydroelectric generations of the downstream Yanguoxia, Bapanxia and Daxia power stations, but also cut down their spillway capacities, shortened their constructing durations, reduced their inundated lands and a large amounts of investments. Therefore, the internal costs per electric unit of kW of these power stations were not larger and the constructing durations were shorter. For instant, the cost per electric unit of kW of Yanguoxia power station was less than that of the Xigu thermal electric power station and the duration of the first generator starting operation was also shorter at the same time. Furthermore, they repaid much more revenues than that of other power stations in China.

According to the calculations of reference [2], the three power stations of Liujiaxia, Yanguoxia and Bapanxia had produced the total economic value of 6.483×10^9 Yuan RMB by a calculated way of 65 Yuan RMB per 10^3 kWh electric power between the period from 1961, when the first generator of Yanguoxia power station began operation, to the end of 1984. Based on the data of 1980-1984 in Gansu province that 10^3 kWh electricity equaled to 53.8 Yuan RMB, including revenue of 8.81 Yuan RMB, sale cost of 4.99 Yuan RMB and power transmission cost of 5.97 Yuan RMB, the average profit of the three power stations was 28.4 Yuan RMB per 10^3 kWh electric powers for sale alone. According to the 7:3 ratio of fixed assets between electric generation and transmission, the average profits were about 23.84 Yuan RMB per 10^3 kWh electric powers. Based on this calculation, by 1984, the three power stations had generated the accumulative electric energy of 99.73×10^9 kWh, received the sale profit of 2.21×10^9 Yuan RMB which was 2.3 times of the total constructing cost of 0.961×10^9 Yuan RMB. At the same time, there had been 0.818×10^9 Yuan RMB of taxes repaid to the National Treasury, and 3.028×10^9 Yuan RMB of revenues received which was 3.2 times of the total constructing cost of three power stations.

After 1985, the three power stations have generated the average hydroelectric power of 8.07×10^9 kWh annually. If the sale profit of electric power in the years1980-1984 is still adopted in the calculation, about 0.18×10^9 Yuan RMB of profits at present would be received annually. Because the total construction costs of the three power stations have been already repaid completely and the electric price at present is raising largely that their economic profit will be huge, far more than 0.18×10^9 Yuan RMB annually in the future.

Daxia power station is the first to be built with the collecting money in Gansu province. Its installed capacity is 324.5 MW, and its construction was begun in November 1991, completed in 1996, and the first generator began operation in December of that year. By the end of 2003, it had generated the total hydroelectric power of 7.2×10^9 kWh and received 2.294×10^9 Yuan RMB of revenues for electricity sale, major portion of which is used to pay the loans, which is estimated to be repaid within a 15-year period.

3 Gansu hydroelectric exploitations promoting economic sustainable developments in the areas along the Yellow River

3.1 Gansu hydroelectric exploitations promoting national economic rapid growths in the five provinces of Shanxi, Gansu, Qinhai, Ningxia and Inner Mongolia

(1) Yanguoxia power station's operation relieving the electric power tensions in Gansu province and promoting its electrically-related industrial development

In the early period of 1960s, when China was suffering from the temporary economic difficulty period, the Xigu thermal electric power station was nearly broken down with only one generator's operation, mainly due to the coal shortage and non-repaired generators for a long time that induced serious electrical power restriction in Lanzhou power system. Yanguoxia power station's operation in November 1961 had a great contribution to relieving the electric power tensions in Gansu province. It not only alleviated the coal supply-demand contradiction and relieved the coal railway-transport tensions, but also created preferable conditions to repair the generators of the Xigu thermal electric power station.

(2) Low - cost hydroelectric power promoting electrically-related industrial and agricultural developments of Gansu province

In the period of 1980s, Gansu hydroelectric generation cost was 4.99 Yuan RMB per 10^3 kWh electric powers cheaper than 17% of the coal-fired electric generation cost of 28.4 Yuan RMB, its sale price was only 53.8 Yuan RMB per 10^3 kWh electric powers cheaper than 31% of the electric sale price in Shanxi province of 78 Yuan RMB. Low-cost hydroelectric powers have effectively promoted electrically-related industrial and agricultural developments of Gansu province, especially even for high-lifted irrigations, aluminium metallurgies, iron alloy productions benefiting from the preferable electric price policies. Generally, according to the lifted height, the electric sale price per 10^3 kWh electric power was ranked as follows: 10 Yuan RMB for the lifted height of 301-400 m, 20 Yuan RMB for the lifted height of 201-300 m, 30 Yuan RMB the lifted height of 101-200 Yuan RMB, 40 Yuan RMB for the lifted height of less than 100 m, cheaper than the average price of 53.8 Yuan RMB at those time of 13.8, 23.8, 33.8 and 43.8 Yuan RMB, respectively. Undoubtedly, if there are no low-cost hydroelectric prices, those electrically-related industrial and agricultural developments such as high-lifted irrigations, aluminium metallurgies, and iron alloy productions could not be advanced in such a greater scales.

(3) To lighten the atmospheric pollutions and to relieve tensions of the coal transport and coal supply

Hydroelectricity is a renewable clean energy resource. By 2003, the four constructed power stations have generated the accumulative electric energy of 246×10^9 kWh and saved about 98×10^9 t of standard coal, which have greatly lightened the atmospheric pollutions such as sulfur dioxide etc., bettered the ecological environments, relieved tensions of the coal transport and coal supply, and had a great contributions to the local social-economic development.

(4) To transmit the electric power to Shanxi and Qinhai assuring the safety running of the electric power system and the electric supply for the industrial and agricultural requirements of the two provinces.

In the periods of 1970s and 1980s, the electric powers of Shanxi and Qinhai were almost coal-fired. The electricity transmission from Liujiaxia power station to the two provinces through the 330 kv and 220kv lines, not only met their electric requirements, but also transmitted the reserve capacity to modulate the amplitude and to use as the accident standby. The maximum electric transmission amounted to 300 MW and 220 MW to Guanzhong of Shanxi province and Xining of Qinhai province, respectively, which assured the safety running of the Shanxi electric power system, especially at those times, the Qinling coal-fired electric power station showed high frequency of accidents.

(5) To meet adequately water needs in the Gansu, Ningxia and Inner Mongolia areas and to promote their industrial and agricultural development.

The areas along the Yellow River in Ningxia and Inner Mongolia are characterized by the flatness plain, abundant light and heat resources, little annual rainfall of about 200 mm, high annual evaporation of more than 3000 mm. Therefore, irrigation is the key assurance to the agricultures in these two areas. Although irrigation with aqueduct cannels began in the Qing and Han dynasty periods, their agricultures developed slowly due to no dams existing to regulate the Yellow River.

After the construction of the Liujiaxia Dam, about 800 – 1200×10^6 m^3 of water prearranged completely to assure spring irrigations in the two districts each year. In May, the average discharge in Lanzhou gauging station reached 994 m^3/s with a net increasing of 353 m^3/s from 641 m^3/s before the reservoirs' constructions, especially in its middle, the discharge could reach as high as 1090 m^3/s. Because a large amount of water was withdrawn for irrigation, the more irrigated lands and crop products were increased than ever. For examples, Ningxia had expanded its irrigation area from 233×10^3 hm^2 in 1968 to 280×10^3 hm^2 in1987, in which period its total crop product had increased from 400×10^3 t to 1100×10^3 t and its crop product per hm^2 also increased from 1500 kg to 5700 kg; Hetao irrigation region of the Inner Mongolia had an irrigation area of 48×10^3 hm^2 in1981 with the total crop product of about 400×10^3 t, while in 1984, its total crop product reached 1000×10^3 t. Besides the above-mentioned irrigation areas, several water-lifted irrigation regions were built in the areas along the Yellow River in Gansu, Ningxia and Inner Mongolia. By the end of 2003, there had been about 1370×10^3 hm^2 of irrigation area in the three provinces of Gansu, Ningxia and Inner Mongolia with increasing area of 510×10^3 hm^2 compared to that in 1968 and with annually average net crop product of 3300×10^3 t increased.

3.2 Effects of the Liujiaxia and Longyangxia power station's combined operation on the Yellow River cutoff and the agricultural developments in the two provinces of Henan and Shandong.

The Longyangxia reservoir is the only reservoir for the multiyear storage on the Yellow River. The primary purposes of Liujiaxia and Longyangxia reservoirs are to generate electric power, including other functions of irrigation, flood control, ice-jam flood control, municipal and industrial water uses. By regulating the Yellow River, these two reservoirs are operated conjunctly to bring water and power benefits to residents of the upper and lower Yellow River. In flood season, the two reservoirs store water and control flood by capturing and delaying flash floods, then smoothing the flow for the benefit of the downstream water users. While in non-flood season, the delivered water used for generating power from the two hydroelectric power stations can not only meet the agricultural and industrial much-needed water during May-July period in the upper Yellow River, but also assure the water-needed peak during March-June period in the lower Yellow River, in which the Yellow River cutoff happens frequently, by either directly withdrawing these water to irrigate lands, or storing them in plain reservoirs or underground reservoirs for irrigation later. The plain reservoirs and underground reservoirs in the lower river often store water in the period from November to February of the next year. According to the statistics results of references [3-4] on a near 11-year non-flood season data from November 1986 to October 1996, Liujiaxia and Longyangxia reservoirs had delivered about 14.97×10^9 m^3 of water to the lower Yellow River in about 11-year period, on average about 0.266 – 3.791×10^9 m^3 of water annually delivered. Especially in non-flood season, there is about 1.5×10^9 m^3 of water delivered annually, which can additionally irrigate the area of 383×10^3 hm^2. Furthermore, by regulating the Yellow River, Liujiaxia and Longyangxia reservoirs have shortened the frequency and duration of the Yellow River cutoff from about 3.1 months/year and 1-7 months before the two reservoirs' constructions to 1.66 months/year and 1.44 months after the two reservoirs' constructions, respectively.

3.3 The Liujiaxia reservoir putting down flood and ice-jam flood losses in the three provinces of Gansu, Ningxia and Inner Mongolia

Liujiaxia reservoir not only protects the Lanzhou city, but it also works in conjunction with Longyangxia reservoir, to prevent flooding along the downstream areas of Ningxia and Inner Mongolia of the upper Yellow River. It can smoothes the 100-year recurrence interval flood peak of 8080 m^3/s, ever recorded at Lanzhou gauging station, to the safe outflow of 6500 m^3/s. During the 17-year operation of Liujiaxia reservoir alone, the recorded six flash flood peaks were all regulated down to the safe discharge of 4000 m^3/s. Especially in September 1981, 7090 m^3/s of the flood peak on the upper Yellow River exceeded the previously recorded peak of record. Fortunately, Liujiaxia reservoir and Longyangxia reservoir's cofferdam had captured the flood peak and stored water long enough that the regulated 5600 m^3/s flood peak safely passed through Lanzhou and the maximum sluice outflow was delayed about 5-6 days. It is this valuable time that protected the lives and properties of people lived in the riversides in Gansu, Ningxia, and Inner Mongolia regions, ensured the security of the Baotou-Lanzhou railway, and avoided a catastrophic flood event as occurred in 1904.

Because the Yellow River flows from south to north in the Lanzhou-Baotou reach and its latitude difference is about 4.5 degree, characterized with large temperature differences and different thawing times, The Ningxia - Inner Mongolia reach of the Yellow River is subject to ice-jam frequently. These geographical characteristics result in earlier frozen, thicker ice cover, and later thawing in the Baotou reach than in the Lanzhou-Ningxia reach of the Yellow River. In the spring months, especially in March, with the rise in temperature, the ice cover melt in the upper reach begins firstly and causes the water in the river to rise – forcing the ice to break off and moved downstream in large chunks. As the ice moves downstream, Ice jams are most likely to form at any bends in a river. The Liujiaxia reservoir uses a regulated – discharge way to alleviate the ice jam losses. When the river begins to be frozen, the resrvoir delivers more water to force the ice cover surface of its downstream at a higher level that increases the water flow passage under the ice cover; during the frozen time, the outflow from Liujiaxia reservoir is controlled to be about 500 m^3/s; Till the thawing time arrives, the Liujiaxia, Yanguoxia and Bapanxia power stations decreases their power generation from the ration 1801×10^3 kW to 510×10^3 kW and delivers a stead and suitable downstream flow. Therefore, the ice cover thawing is only through the thermal process alone, which causes the melting ice water flow stead and that the ice-covered end time is delayed some days. The ice-jam disaster frequency is also decreased from once two years in the pre-reservoir years (1950-1967) to once per ten years at present.

According to the plan on the Yellow River's recent rehabilitation from the Ministry of Water Resource and Conversation, there are several basic types of floodproofing to be constructing and reconstructing to effectively defend floods and ice-jam floods in the reaches of Ningxia and Inner Mongolia of the Yellow River, these are: raising and building barrier construction about 688 km and other specific19 floodproofing.

4 Gansu hydroelectric exploitations promoting the developments of hydroelectric industry in China

4.1 Construction and operation of the Yanguoxia power station providing experiences for building of power stations on a heavy-sediment-load river in China

The Yanguoxia power station, constructed in 1961, was the first power station on a heavy-sediment-load river in China. Due to no adopted experiences, the power station was not equipped with a sediment flushing outlet, which caused many troubles and much works on examining and repairing in its operation: serious sediment siltation, woody and weed debris jam, turbines' ablation and gas erosion, etc. Based on summary of the construction experiences of the Yanguoxia power station, the Liujiaxia power station was equipped with a large-scale sediment flushing facility and a united and uniformed 20 cm spacing sediment fences, and at the same time, the material texture of its turbines was also improved. This process has provided valuable experiences for the building of power stations on other heavy-sediment-load rivers in China.

4.2 Construction and operation of the Liujiaxia power station promoting the developments of hydroelectric industry in China

The Liujiaxia reservoir is the concrete gravity dam. It is first designed, manufactured, and revised by the Chinese engineers alone, with a main dam's embankment 147 m high and the total installed capacity of 1160 MW. In addition, its maximum transmission voltage is 330 KV and maximum single machine capacity reaches as high as 300 MW. Therefore, the construction of Liujiaxia power station has provided experiences for the high dam building and hydroelectric industrial developments at home in China.

4.3 Construction and operation of the cascade hydroelectric power stations of the Liujiaxia, Yanguoxia and Bapanxia providing successful experiences for the constructions of the ‘ Dragon Head’ reservoir and its cascade power stations in Qinhai province and other regions in China.

The hydroelectric exploitation on the Yellow River in Gansu province follows the way of cascade power stations with the construction of the ‘Dragon Head’ Liujiaxia reservoir and other downstream run-of -the –river power stations as Yanguoxia station etc. Through this continue cascade exploitation way, the ‘Dragon Head’ Liujiaxia power station can fully carry out its runoff and flood-regulating function, and thereby enhances the hydroelectric generation capacity of the Yanguoxia power station and others, smoothes flood peak, decreases the inundated losses, reduces spillway work sizes, shortens the construction durations, and reduces project investments. The successful experiences obtained from the construction of the cascade power stations on the Yellow River have been adopted in the building of hydroelectric power stations in Qinhai province and other regions of China. For example, in Qinhai province, the ‘Dragon Head’ reservoir-Longyangxia power station was firstly constructed, then by taking advantage of its runoff and flood regulating function, the economic benefits of such run-of-the –river power stations as Lijiaxia, Gongboxia and Laxiwa stations, were greatly increased, and therefore, these power stations form the ‘high-grade ore’ of China’s hydroelectric resources.

4.4 The sediment removal methods of the Liujiaxia reservoir providing experiences for the sediment removal of other sediment-laden reservoirs of China.

The Taohe River flows into the Liujiaxia reservoir at 1.5 km ahead of the dam. Sediments and weed debris carried by the river pose a serious threat to the normal operation of the power stations. According to the density-current prone characteristic in the river, the Dam Administration worked out a series of schemes about the sediment removal. Hence, since 1974 a sediment removal project through a density-current way has been carried out on the Taohe River to deliver the inflow sediment out of the reservoir in time, thus greatly reduces amounts of sediment deposited in the reservoir and causes the time required to reach the dead storage of the reservoir delay by about 6 years later than the designed. By the end of 2003, the sediment removal operation by the density flow way had conducted about 207 times, in total, 287×10^6 t of sediment were flushed away, with a mean sediment sluicing ratio of density current of 62%.

In addition, a nonscheduled way was often used to solve the water blockage problem caused by the river sand step. According to the short-term forecast for the flood discharge, the stored water was quickly delivered through the sediment flushing tunnel enough before the flood entering into the reservoir that large amounts of pre -deposited sediments were flushed away by the inflowing flood. Then, the former water level of the reservoir was again refilled through the flood tail. During the period of 1981-1988, this sediment removal method was used four times, and about 33×10^6 t of sediment in the reservoir was flushed away. Besides this way, the sediment deposited close to the sluicing gate was always removed by opening it timely.

The successful application of the density current theory and other sediment removal methods in the Liujiaxia reservoir on the upper reach of the Yellow River effectively solve the reservoir sedimentation problem and obtain better economic benefits.

4.5 The successful operation of the Liujiaxia reservoir providing valuable experiences for the multi-purpose water regulation in the trans-province regions.

The water regulation of the Liujiaxia reservoir on one hand follows the principle of rational water uses but on the other hand also puts different stresses in different periods. In summer flood period and ice-jam flood period, the power generation should be subordinate to the flood control requirement; At the irrigation peak stage, the power generation should be adjusted according to irrigation water requirement; and in other period, the reservoir’s water is mainly used to generate power, additionally released for the industrial and agricultural uses. In order to rationally regulate the water amount of the Liujiaxia reservoir, the Water Dispatching and Regulation Commission of the Upper Yellow River holds one or two meetings every year to sum up the water regulation works in the current year and work out the water dispatching and regulation schemes of the Liujiaxia reservoir and its related regions in the non-flood season in the next year, coordinate the water contradiction between power production and agricultural use, and submit the reservoir's operation plan for the flood season (summer flood and ice-jam flood) to the National Flood Prevention Headquarters. Over the past thirty years, the Water Regulation Commission of the Upper Yellow River insisted on the principle as overall planning, proper arrangement, friendly negotiation and profit sharing, and overcame various difficulties to successfully perform the routine water regulation, thereby delivered great economic and social benefits: (1) In September 1981, the upper reach of the Yellow River experienced a largest flood, whose peak exceeded the previously recorded flood peak. Fortunately, Liujiaxia reservoir had captured the flood peak and stored water enough that its flood peak reaching at the Lanzhou Gauging station, was smoothed and cut down by 1500 m^3/s. Therefore a flood disaster as occurred in the 1904 was avoided; (2) In 1986, although Longyangxia reservoir impounded more water that caused the cutoff of the upper reach of the Yellow River lasting about four months, the 72×10^6 m^3 of more stored water in the Liujiaxia reservoir, due to a detailed regulation plan, adequately met the downstream industrial and agricultural water uses and reduced the electric power losses; 3) In 2000, the scheduled water was ordered to deliver to Tianjin province with an outflow discharge of 1050 m^3/s at the August. Later, the discharge and date were modified to be 900 m^3/s and 22th September, respectively, by the Water Regulation Office, according to the operation conditions of electric system at that time. This modification adopted by the administrations, resulted in avoiding the reservoir's water waste conditioning.

5 Ecological environment improvement in the regions of the constructed reservoirs and stable living conditions of migrants.

5.1 Reservoir inundation losses and compensation cost

In the four constructed reservoirs, Liujiaxia reservoir's inundation lands and migrants are larger than that of the other three reservoirs, especially it alone inundated a city's land as a patch of Yongjin County. Because Gansu is characterized as larger lands and sparse population, its economy is developing slowly that the migrants owned their properties as houses very few. Therefore, the migrants were resettled in the plentiful arable areas surrounding the reservoirs, which greatly reduced the reservoir compensation cost for the inundation lands. In total, the four reservoirs inundated 6031 hm^2 of farmland with 38,765 migrants and 119.47×10^6 Yuan RMB of the compensation cost[1], of which the Liujiaxia reservoir inundated 5181 hm^2 of farmland with migrants 32,639, and compensation cost 24.75×10^6 Yuan RMB. On an average, if the four reservoirs generate 10^3 kW power, it would need to inundate 3.02hm^2 of farmland, resettle 19.4 migrants and compensate 0.06×10^6 Yuan RMB. All these indexes are lower than those of other hydroelectric power stations constructed in the same period in the country, as can be seen in Table 3.

Table 3. Various indexes for the construction of hydroelectric power stations on the Yellow River in Gansu Province.

Item	Liujiaxia power station	Yanguoxia power station	Bapanxia power station	Daxia power station	total
Inundated farmland (hm^2)	5181	459	73	318	6031
Resettlement of population	32639	5925	201	0	38765
House rebuilding (room)	62665	12165	0	0	74830
Highway reconstruction (km)	25	0	7	2	34
Compensation cost (10^6 Yuan RMB)	24.75	1.5	7.22	86	119.47

5.2 Improvement of eco-environment and living condition of resettled population.

Because the resettlement areas are the mesas in the reservoir regions, whose irrigation and living water uses must be pumped from the river. In order to lighten the burden on farmers of the water lifted cost and to better their production, living conditions and ecological environment, the Reservoir Maintenance Fund was established by approval of the Ministry of Water Conservancy of China. According to the items of the fund, 1 Yuan RMB was extracted from per annual power supply amount of 10^3 kWh prior to 25 March 1997, of which 20% was used for afforestation in the reservoir regions, and remaining 80% was used as the lifting water cost and the farmers' living subsidy; From 25 March 1997 onwards the extracted money as the Reservoir Maintenance Fund was increased to 3 Yuan RMB per 10^3 kWh of power supply. Hence, the living conditions of migrants around the reservoir regions, although lower than that in the plain irrigation areas, are stable and will be improved gradually.

6 Future hydroelectric power development on the Yellow River in Gansu province.

6.1 A no determined 1400MWpowerdevelopment scheme on the Heishanxia reach on the upper of the Yellow River.

Up to now, four hydroelectric power stations have been constructed on the Yellow River in Gansu province, including the Liujiaxia, Yanguoxia, Bapanxia and Daxia power stations. The Xiaoxia hydroelectric power station is now constructing; Caijiaxia power station will begin to construct; another three power stations of Shigouxia, Hekou and Wujinxia will be prepared to construct; and the remaining power development scheme on the Heishanxia reach has not been determined till now.

With regard to the power development at the Heishanxia reach, there are two schemes, one is the two-stage scheme consisting of the Xiaoguanying high dam and the Daliushu low dam, another is the one-stage scheme of the Daliushu high dam. According to *the technological and economic reports on the comprehensive exploitation and application of the resources of the Yellow River* 1n 1955, the twostage scheme was adopted. Some years later, the one-stage scheme of the Daliushu high dam was also proposed. Therefore, there are considerable debates arisen about the power development scheme at the Heishanxia reach, although some Hydroelectric Design Institute has made much investigation and design works in the past 50 years.

6.2 The construction of Xiaoguanying high dam seems to be no necessary.

In the 1980s, China implemented the policies of planned economy, putting grain crop in the top priority. Hence it required reclaim large areas of wasteland to develop agriculture. According to the related planning at that time, by 2020, the irrigation area of the upper of the Yellow River will reach 1949×10^3 hm^2, industrial and agricultural water requirement will reach 17×10^9 m^3, the agricultural water uses is 15.5×10^9 m^3, with an increase of 649×10^3 hm^3, 4.3×10^9 m^3 and 3.6×10^9 m^3, respectively, compared to 2000. In order to regulate the stable water delivered from the power stations in the upper reach to meet the suitably industrial and agricultural water uses in Ningxia and Inner Mongolia, it needs a reservoir with a re-regulation storage capacity of 5×10^9 m^3. In such case, if the Heishanxia reservoir is not to be constructed, the Longyangxia and Liujiaxia reservoirs must be needed to burden this regulating work. Thus, the 13 cascade power stations will be restricted to operate only according to the water requirements and will reduce the hydroelectric generation by 900 MW. In other words, the construction of the Heishanxia reservoir will increase guaranteed power output of 900 MW. Hence, there is a need to construct a high dam on the Heishanxia reach[6].

With further deepening of the reform, in order to protect the ecological environment and to solve the issues of water shortage and cutoff of the lower Yellow River, the Ministry of Water Resource and Conversation worked out the *Recent Key Harness and Development Plan of the Yellow River* [5] in 2003 and stressed that great efforts should be made to save water in the upstream irrigation districts, but did not mention the development scheme of Daliushu irrigation district. According to the related planning, before implementation of the South-to-North Water Diversion Project in the West Line, the industrial and agricultural water consumption above the Hekou Town should be contained about 12.7×10^9 m^3, the minimum discharge at the Hekou gauging station should reach 250 m^3/s, hence, the re-regulating reservoir capacity for the industrial and agricultural water uses in Ningxia and Inner Mongolia will decrease by 60% or more as compared to that of the formerly planed, and is also lower than the present re-regulating reservoir capacity. At present, through the regulation of the Longyangxia and Liujiaxia reservoirs the flood and ice-jam flood damages in the Ningxia and Inner Mongolia reaches can be entirely brought under control, and the industrial and agricultural water use can be also guaranteed in time. Accordingly, in the present case, the construction of the Xiaoguanyin high dam with large reservoir shows to be no necessary. Because there is only 44MW guaranteed power output more than that in the 13 cascade hydroelectric power stations, which is only 5% of 900MW estimated in the past[6].

In addition, the construction of the Xiaoguanying high dam only uses 7.4 m higher hydraulic head than the three-stage development scheme and increases an annual energy yield of 0.41×10^9kwh. According to the estimated results from the reference literature[6], the construction of the Xiaoguanying high dam will increase a reservoir compensation cost of 11.8 Yuan RMB per unit energy output more than that of the three-stage development scheme. Therefore, the construction of Xiaoguanying high dam is infeasible due to lower power generation outputs and lower benefits but larger compensation cost for its inundating losses. Once the South-to-North Water Diversion Project in the West Line is completed, the discharge of the upper of the Yellow River will greatly and uniformly increase, of which 88.4-100% will be used in industrial, agricultural, ecological and domestic uses. Furthermore, the re-regulating reservoir capacity to ensure industrial and agricultural water uses in Ningxia and Inner Mongolia will decrease by 70% or more compared to the previously estimated[6]. Hence there is no more need to construct the Xiaoguanying high dam.

6.3 The Xiaoguanying high dam may cause great inundation losses and tremendous difficulties in the migrant resettlement.

According to the investigation by the Northwest Survey and Design institute in 1983, the twostage development scheme may inundate 3.2×10^3 hm^2 of farmland, 55.3×10^3 people will be resettled, and reservoir compensation cost will reach 325×10^6 Yuan RMB. Till 2003, about 6.7×10^3 hm^2 of farmland will be inundated, and by 2010, the inundating-related population may reach as high as 100×10^3.

According to the material price in the first season of 2002, the static investment of the twostage development project of the Heishanxia is 13.8×10^8 Yuan RMB, of which reservoir compensation cost for inundation and resettlement cost were about 6.5×10^9 Yuan RMB, with an increase of 107%, 81% and 19 times of the inundated farmlands, migrants and compensation cost for inundation, respectively, in 1983. In the previous scheme, the resettlement area was selected in the arid terrace with a lifting height of several hundred meters. Clearly, this resettled area is very difficult to be accepted by migrants nowadays.

6.4 A proposal on the threestage low dam scheme instead of the Xiaoguanying high dam scheme.

Owing to the water shortage, serious river cutoff, and fragile ecological environment in the areas of Ningxia and Inner Mongolia, the formerly planned Daliushu irrigation district cannot be constructed. In addition to these, the existing irrigation districts withdraw and wasted so much water that, the Ministry of Water Resources worked out a planning in 2003[5], which stated that the industrial and agricultural water uses in the upstream of the Yellow River above the Hekou Town will be greatly decreased than that in the formerly scheduled. The re-regulating reservoir capacity, assuring adequately and timely water supply, will be also decreased by 60% or more; At present, through the regulation of the Longyangxia and Liujiaxia reservoirs the flood and ice-jam flood damages in the Ningxia and Inner Mongolia reaches of the Yellow River can be entirely brought under control, and the industrial and agricultural water uses can be guaranteed in time. Accordingly, in the present case, the construction of the Xiaoguanyin high dam shows to be no value, because there is only 44MW guaranteed generation output more than that in the 13 cascade hydroelectric power stations, which is only 5% of 900MW estimated in the past. In order to carry out the “Three Reprehensive” thought, protect eco- environment and reduce reservoir inundation losses, Gansu Provincial People Government proposes a three-stage run-off low dam scheme consisting of the Hongshanxia, Wufo and Xiaoguanying low dams, instead of the previous Xiaoguanying high dam scheme.

7 Conclusion

(1) Over 40 years of the constructions and practices show that the hydroelectric development on the Yellow River in Gansu province is successful and has delivered great social and economic benefits, promoted the economic sustainable development in Shanxi, Gansu, Qinghai, Ningxia and Inner Mongolia regions , made great contribution to the agricultural irrigation in Henan and Shandong, and shortened the cutoff durations in the lower reach of the Yellow River. In addition, it also provides useful experiences for the dam construction and its equipment manufacturing, and for regulating and dispatching trans-province and multi-purpose comprehensive water uses, as well as for the management, science and technology of the development of the Chinese hydroelectric industries in China.

(2) Hydroelectric exploitations on the Yellow River in Gansu province have caused small inundating losses, their migrants were rationally resettled in the nearby regions. Additionally, the Reservoir maintenance fund is offered every year. Hence the resettled population living conditions are stable, and the eco-environment have been gradually improved due to afforestation in the reservoir regions.

(3) In the future, an important task is to exploit the hydroelectric resources in the Heishanxia reach of the upper of the Yellow River in Gansu province. Owing to lack of water resources and fragile eco-environment in Ningxia and Inner Mongolia, the exploitation project key has been changed from the previous wasteland reclamation and increasing farmland into today's restoring eco-environment, enhancing farm product yields per unit area and developing water-saving techniques. In such cases, the construction of Xiaoguanying high dam with large reservoir can only play a small role, and it has small economic benefit but large inundating losses. Hence, Gansu Provincial People's Government proposes a three-stage run-off low dam scheme instead of the previous Xiaoguanying high dam scheme.

8 References

[1] Editorial Board of Gansu Electric Power Industrial Chorography, Annals of Electric Power Industry in Gansu Province(M), Beijing, Modern China Press, 1996.

[2] Wan Jingwen, Wang Guofeng, Li Yunhong, Investigation and analysis of the economic benefits of the three hydroelectric power stations of Liujiaxia, yanguoxia and Bapanxia on the upper Yellow River,[J], Water Energy Techniques and Economies, 1985, suppl (1).

[3] Wan Jingwen, on the tremendous role of the Longyangxia and Liujiaxia reservoirs recharging water to relieve the contradiction between water supply and demand in the lower reaches of the Yellow River[J], Journal of Hydroelectric Engineering, 1996,(2):22-29.

[4] Northwest Survey and Design Institute of Electric Power Industrial Ministry, Summaries of key technical problems in the survey and design of the Longyangxia hydroelectric power station, Vol.1, Beijing, China Electric Power Press**,** 1998.

[5] The Ministry of Water Resource of China, Recent key harness and development planning of the Yellow River [M], Beijing, China WaterPower Press ,2004,(3):34-39.

[6] Wan Jingwen, A four-stage development scheme in the Heishanxia reach of the upper of the Yellow River [J], Northwest Water Power, 2004,(3):34-39.